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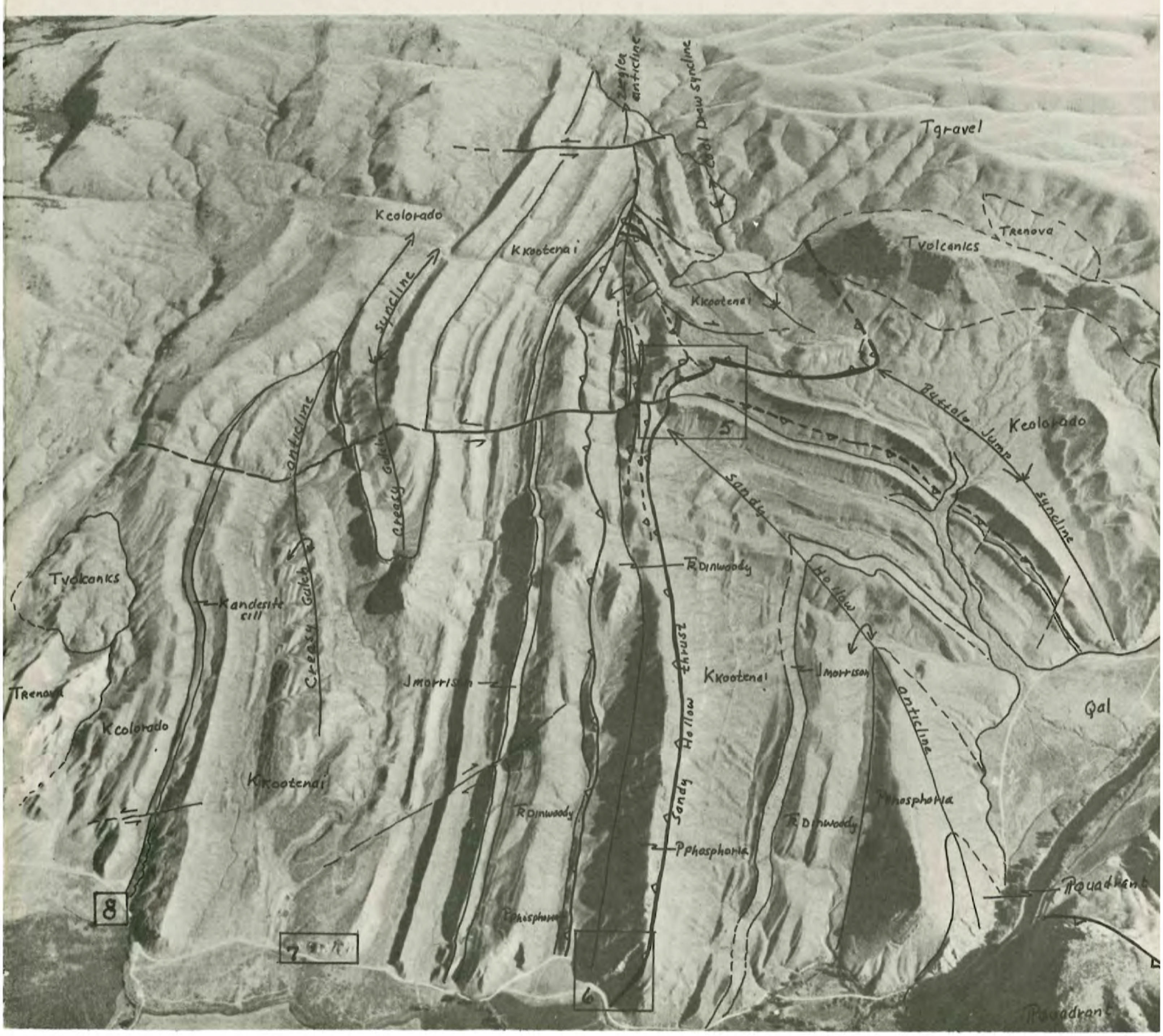
Tobacco Root Geological Society
14th Annual Field Conference—July 20-22, 1989

"Structure, Stratigraphy and Economic Geology of the Dillon Area."



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Cover: Oblique Air Photo of Sandy Hollow Thrust System. Photo by Hugh Dresser.

NORTHWEST GEOLOGY, V. 18, 1989

Tobacco Root Geological Society

14th Annual Field Conference

STRUCTURE, STRATIGRAPHY, AND ECONOMIC GEOLOGY OF THE DILLON AREA

July 20-22, 1989

Technical Co-Chairmen: John F. Childs and James W. Sears

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FIELD TRIP #1, JULY 20

A GEOLOGIC TRANSECT FROM THE HIGHLAND MOUNTAINS FORELAND BLOCK, THROUGH THE SOUTHWEST MONTANA THRUST BELT, TO THE PIONEER BATHOLITH

by

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Hugh W. Dresser, Department of Mining and Mineral Engineering, Montana College of Mineral Science and Technology, Butte,Montana

and

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Introduction

Southwest Montana's thrust belt challenges standard models for the development of foreland thrust systems for two reasons: 1) the basement is involved in the deformation, deflecting the regional detachment horizon, and 2) widespread batholiths invaded the thrust system as it was forming. On this field trip we will examine a transect of the thrust belt where the McCartney (or McCarty) Mountain salient is wedged between the Pioneer batholith on the west and the Archean-cored Highland Mountains on the east. Figure 1 shows the general geology of the field trip area.

Plate 1 shows the geology in more detail, after Brandon (1984) and presents a geologic cross-section of the field trip route. The Pioneer batholith shoulders the west end of the section, and the basement rises on the east. The batholith's intrusion accompanied thrust deformation in Late Cretaceous time (Brumbaugh, 1973), and some magma sheets appear to follow thrust planes (Eaton, 1983; Hyndman and others, 1988). The basement stood in a foreland uplift before thrusting, and interfered with normal thrust development (Brandon, 1984; Schmidt and others, 1988). Out-of-sequence thrusts appear in outcrops and on the geologic cross-section. Tertiary faults offset the older structures; intermontane volcanic rocks and sediments cover wide areas (Hanneman, 1989).

ROADLOG

Assemble in the southwest corner parking lot of Western Montana College.

0.0 Roadlog begins at corner of South Atlantic and East Poindexter streets. Turn right on Atlantic Street and proceed north on Business Loop I-15.

Hills to the left with the letters "B" and "M" are part of a large Tertiary volcanic field that overlaps late Cretaceous folds in the Frying Pan Basin five miles to the west. Tertiary gravel buries the volcanic rocks on the north edge of these hills. See the article by Fritz and others in this guidebook, for a summary discussion of the volcanic rocks.

0.7 Bear left on East Helena Street at Beaverhead County High School, and remain on Business Loop I-15.

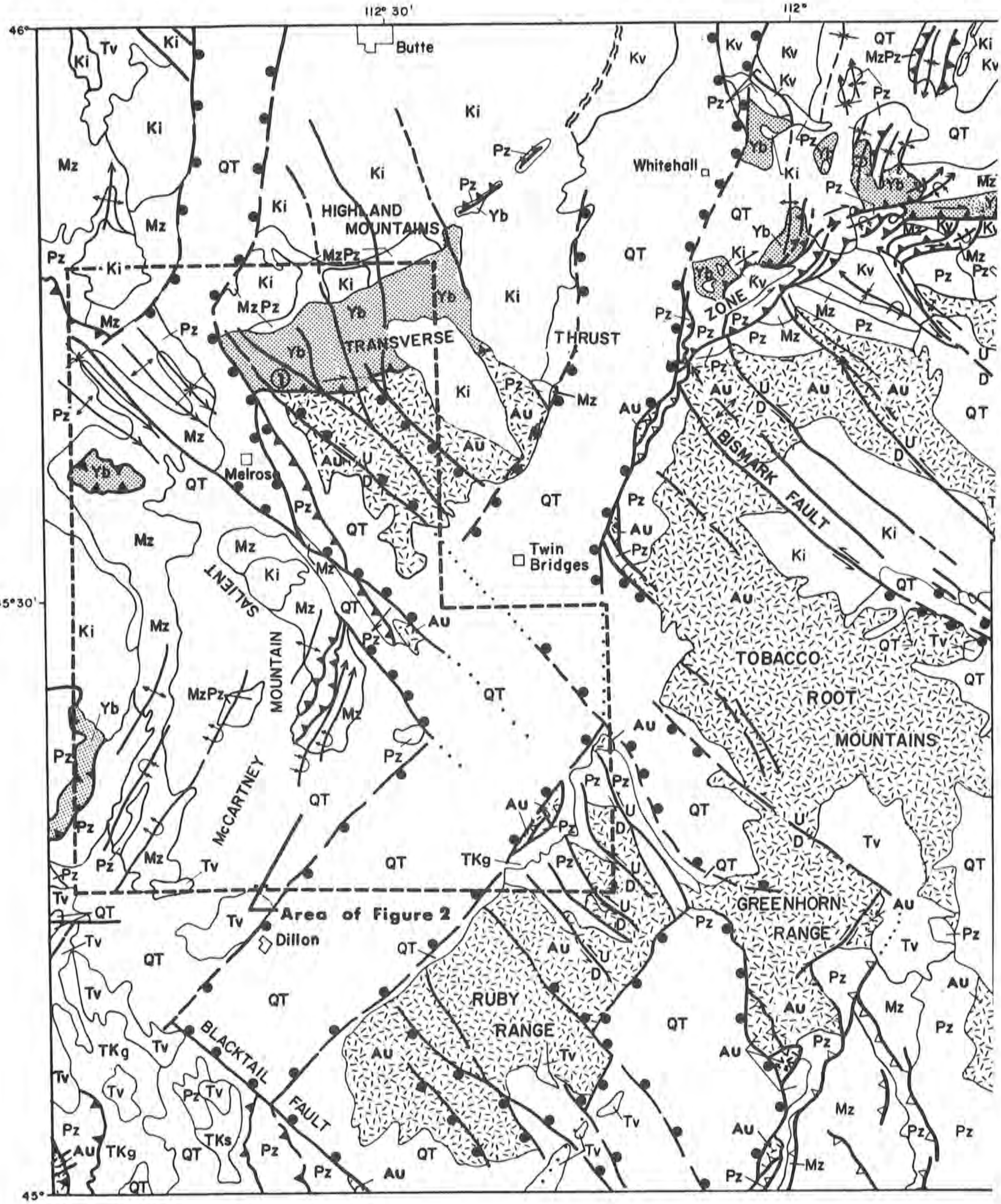
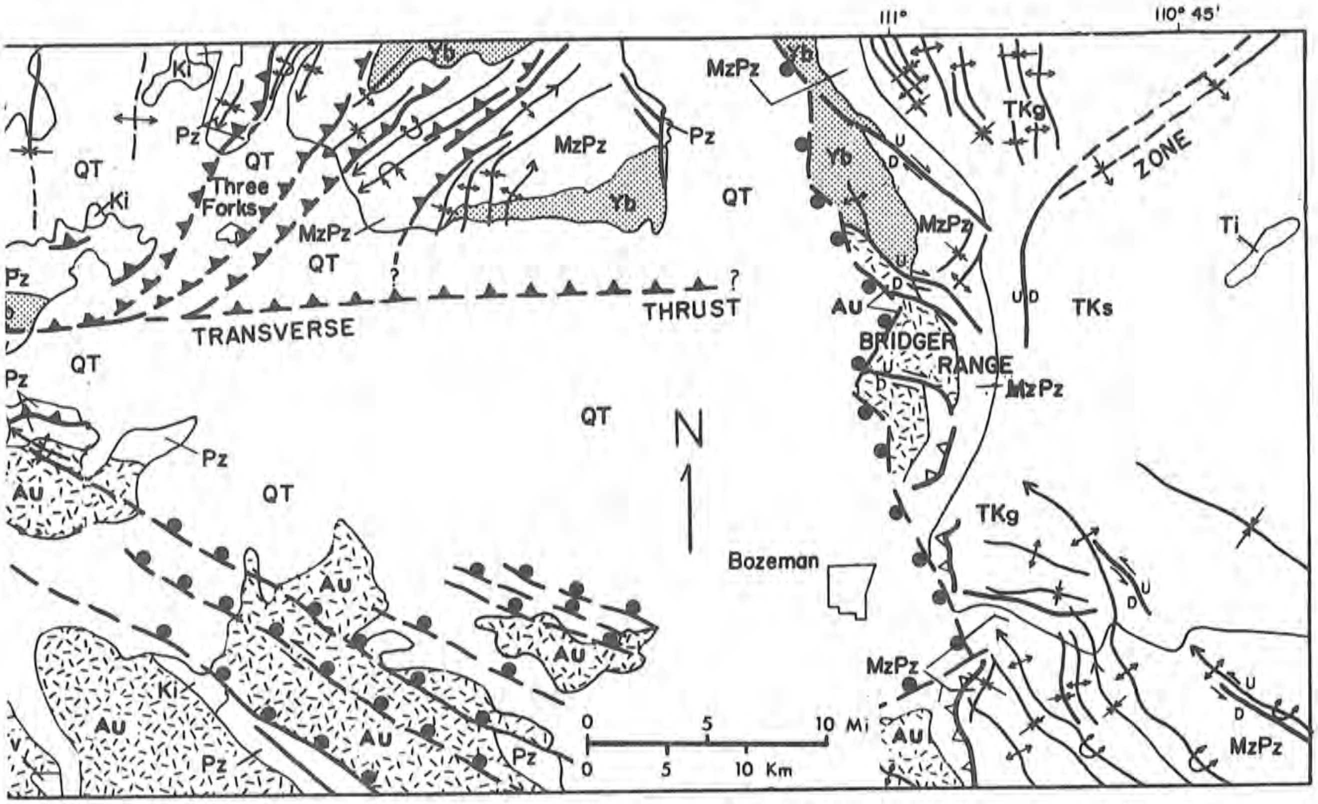


Figure 1. Tectonic map showing the McCartney Mountain salient, southwest Montana Transverse zone, and adjacent Rocky Mountain foreland. Location of Figure 2 is shown (after Schmidt and others, 1988).



EXPLANATION

QT	Quaternary–Tertiary basin deposits
Tv	Tertiary volcanic rocks
Ti	Tertiary intrusive rocks
TKg	Lower Tertiary and Upper Cretaceous Synorogenic sedimentary rocks
Kv	Cretaceous volcanic rocks
Ki	Cretaceous intrusive rocks
Mz	Mesozoic rocks
MzPz	Mesozoic and Paleozoic rocks
Pz	Paleozoic rocks
Yb	Middle Proterozoic Belt Supergroup metasedimentary rocks
Au	Archean metamorphic rocks

Major lithologic contact

Major normal fault (includes reactivated Laramide faults); bar on downthrown side

Major thrust fault (thrust belt)

Thrust fault with significant lateral movement (thrust belt)

Thrust faults (Rocky Mountain foreland)

U D High-angle reverse faults showing relative movement

Other faults

≈ ≈ ≈ Shear zone

Anticline

Syncline

Overturned Anticline

Overturned Syncline

Monocline

All structural features dashed where approximately located or inferred; dotted where concealed

Locations and location numbers

① Camp Creek thrust

Compiled by: C. Schmidt

Sources: Klepper (1950 and unpublished mapping), Mann (1954), Alexander (1955), McMannis (1955), Verrall (1955), Robinson (1963), Smedes (1967, and unpublished mapping), Roberts (1972), Schmidt (1975, and unpublished mapping), Monroe (1976), Tilford (1976), Tysdal (1976), Karasevich et al. (1981), Ruppel et al. (1983), Brandon (1984), Sheedlo (1984), O'Neill (unpublished mapping)

1.0 Turn right at stop sign onto Montana Street, and proceed north on Business Loop I-15.

1.6 Intersection. Take Montana Highway 41 N toward Twin Bridges.

2.4 Waste water plant is on the left.

The highway follows the floodplain of the Beaverhead River for the next few miles. A smooth gravel surface rises to the fault-bounded Ruby Mountains on the right. The central and southern Ruby Mountains are mostly amphibolite facies Archean rocks, including spectacularly folded metasedimentary sequences. The northern part of the range includes faulted panels of Paleozoic sedimentary rocks. To the left in the distance is McCartney (or McCarty) Mountain, cored by late Cretaceous granite. In the middle distance is the Hogback, a ridge of Quadrant Quartzite overlying a late Cretaceous thrust.

5.3 Roadcuts of gravel are on the right for the next few miles.

8.8 Highway climbs to the surface of the gravel deposit from the floodplain.

15.4 Milepost 13. Stop at large paved pullout on the left for overview of Point-of-Rocks.

STOP 1. Point-of-Rocks View. (by C.J. Schmidt and J.W. Sears)

Bedrock crops out where the Beaverhead River slices through thick Tertiary basin sediments at Point-of-Rocks. Slightly cleaved Mission Canyon Limestone forms the bluffs at the east end of the outcrops. The Amsden, Quadrant, Phosphoria and Dinwoody formations appear successively to the left in normal stratigraphic order in a west-dipping structural panel.

A petroleum exploration well drilled through a normal Paleozoic section about one mile west of here, and encountered Precambrian rocks at a depth of 6138 feet. These rocks form the footwall for the thrust structures, as shown on the cross section (Plate 1). They rise toward the east on the flank of the ancient Ruby-Highlands uplift which collapsed along a series of normal faults.

Point-of-Rocks provides the easternmost exposures of the McCartney Mountain salient, a broad, eastwardly convex pattern of folds and thrusts between Dillon and Melrose. Transport direction on the thrusts, as inferred from associated fold orientations and solution cleavage patterns, defines a regionally radial displacement pattern (Brumbaugh, 1973). Brumbaugh (1973) proposed that intrusion of the Pioneer batholith resulted in the radial displacement pattern. Brandon (1984) and Schmidt and others (1988) attributed the geometry and movement pattern to interaction of thin-skinned thrusts of the salient and the basement-cored Biltmore and Rochester anticlines. The relative merits of these two ideas may be discussed further once we have examined some critical field evidence for each.

Seismic reflection profile C.G.G.-3 (A-A', Figure 2) passes just north of Point-of-Rocks, and continues eastward into the Beaverhead basin (Lopez and Schmidt, 1985). Figure 3 shows Lopez and Schmidt's (1985) interpretation of the seismic line. Coherent reflectors marking the Cambrian and Devonian rocks and the basement-cover contact are progressively down-dropped to the east along a set of E or NE-dipping faults. Three of these faults have been mapped at the surface farther northwest, where they trend NW and dip NE.

The westernmost normal fault cuts off the east end of the Point-of-Rocks structural panel, and drops the Paleozoic section down-to-the-east about 4000 feet. The cumulative displacement of the five faults is about 12,000 feet, and they bound a complex half-graben that contains at least 8,000 feet of Tertiary sediments.

The normal faults slice up the west edge of a large Precambrian-cored block which appears to have originally been a Laramide foreland uplift including the parts of the Highland and Ruby Mountains. West-directed reverse faults and anticlines internally segmented this block. In the Ruby Range east of this stop, several NE-dipping reverse faults occur with basement-cored Laramide folds (Tysdal, 1976;

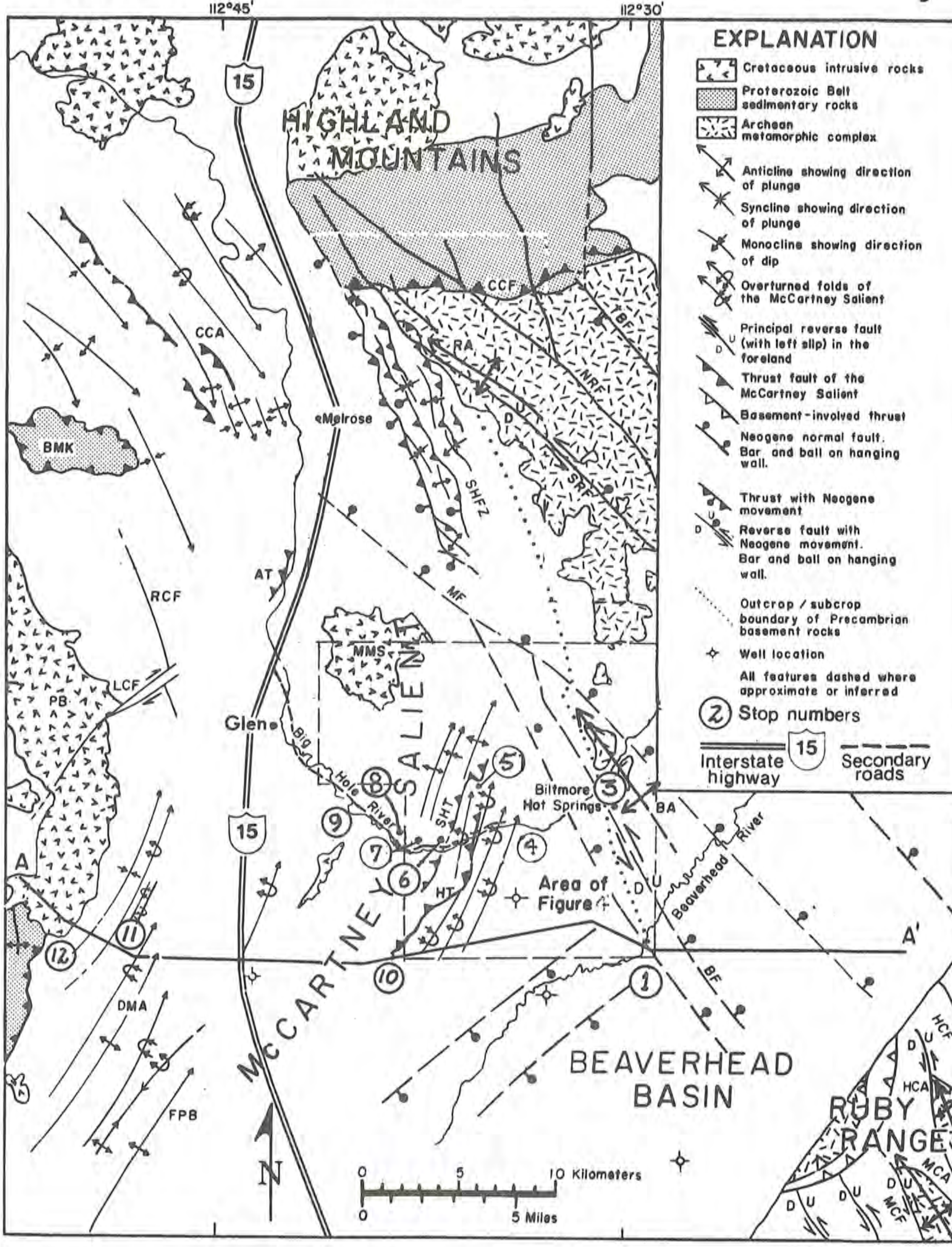


Figure 2. Tectonic map of the McCartney Mountain salient showing the location of Figure 4, and line of cross section A-A' (Figure 3). Modified from Ruppel and others, 1983, and Schmidt and others, 1988).

1981; Schmidt and Garihan, 1983). The normal faults in Figure 3 may be reactivated Laramide faults (Schmidt and Garihan, 1986).

Removal of the Cenozoic movement restores the basement-cored Biltmore anticline along the northeastern margin of the McCartney Mountain salient (Figure 3B). The basement-cover contact on the flank of the Biltmore anticline crops out at Stop 3, 6 miles north of here.

Continue north on Montana 41.

16.1 Enter Madison County.

17.0 Cross Beaverhead River. Tertiary sediments overlap Madison Limestone at the north end of the ridge on the left. Marshy ground on left near end of bedrock outcrop may represent springs
discharging along the fault zone.

19.3 Floodplain of the Beaverhead River, facing into the Twin Bridges basin. Tertiary beds crop out on the left in the Biltmore Hills with numerous vertebrate fossil localities.

25.5 Milepost 23. Turn left onto the "Burma Road", a farm access road which follows the course of the Big Hole River for 17 miles. "Novich" family names appear on a signpost at the intersection. Stop near intersection.

STOP 2. Overview of Ruby and Tobacco Root Mountains. (by C.J. Schmidt)

The Tobacco Root Mountains form the skyline to the northeast. Their structure resembles that of the western Ruby Range - both have NW-trending reverse faults that involve basement and cover, and both have range-bounding normal faults along their west sides (Figure 1).

The southwest Montana transverse zone cuts the northern Tobacco Root mountains, with at least 15 km of net eastward transport for rocks in thrust sheets on the north side of the zone (Schmidt and O'Niell, 1983). This displacement may link into basement-involved thrusts along the western margins of the Tobacco Root and Ruby Mountains, and the area now occupied by the Jefferson and Beaverhead basins may have once been part of a major Laramide uplift, the Ruby-Tobacco Root arch of Schmidt and others (1988).

McBride and others (in press) suggest that late Cenozoic extension and structural inversion of the Ruby-Tobacco Root arch formed the Jefferson and Beaverhead valleys.

Figure 3B shows that the Beaverhead valley was once structurally higher than the thrusts of the McCartney Mountain salient. This structural relief could be due to uplift along a basement thrust or along high angle reverse faults.

Proceed west on Burma Road.

The grassy slopes ahead are thick gravel deposits of probable late Miocene-Pliocene age (Hanneman, 1989). The dark, treed stripes are isolated bedrock ridges of Archean rocks and steeply dipping, west-facing Paleozoic rocks.

27.9 Concrete bridges over Big Hole River.

28.9 Cattle guard.

30.3 Archean sillimanite-zone gneiss and schist. A ranch is on the left.

30.8 Old log cabin and stone dugout building are on the right.

31.3 Road climbs. Frame schoolhouse in distance on the left. Big Hole River valley cuts across the Tertiary gravel and Archean rocks.

31.6 Stop at base of grade where road curves to right. Large wooden gate and a farm driveway are on the left. Rocks crop out on the right.

STOP 3. Basement/cover contact on flank of Biltmore anticline. (by C.J. Schmidt)

The well-foliated basement rocks here form the core of the NW-trending Biltmore anticline (Figure 4), first recognized by Brandon (1984). The foliation has a low angular discordance with the bedding in the Cambrian Flathead Sandstone, and appears to have been folded or rotated during folding of the cover rocks. The same phenomenon occurs in other

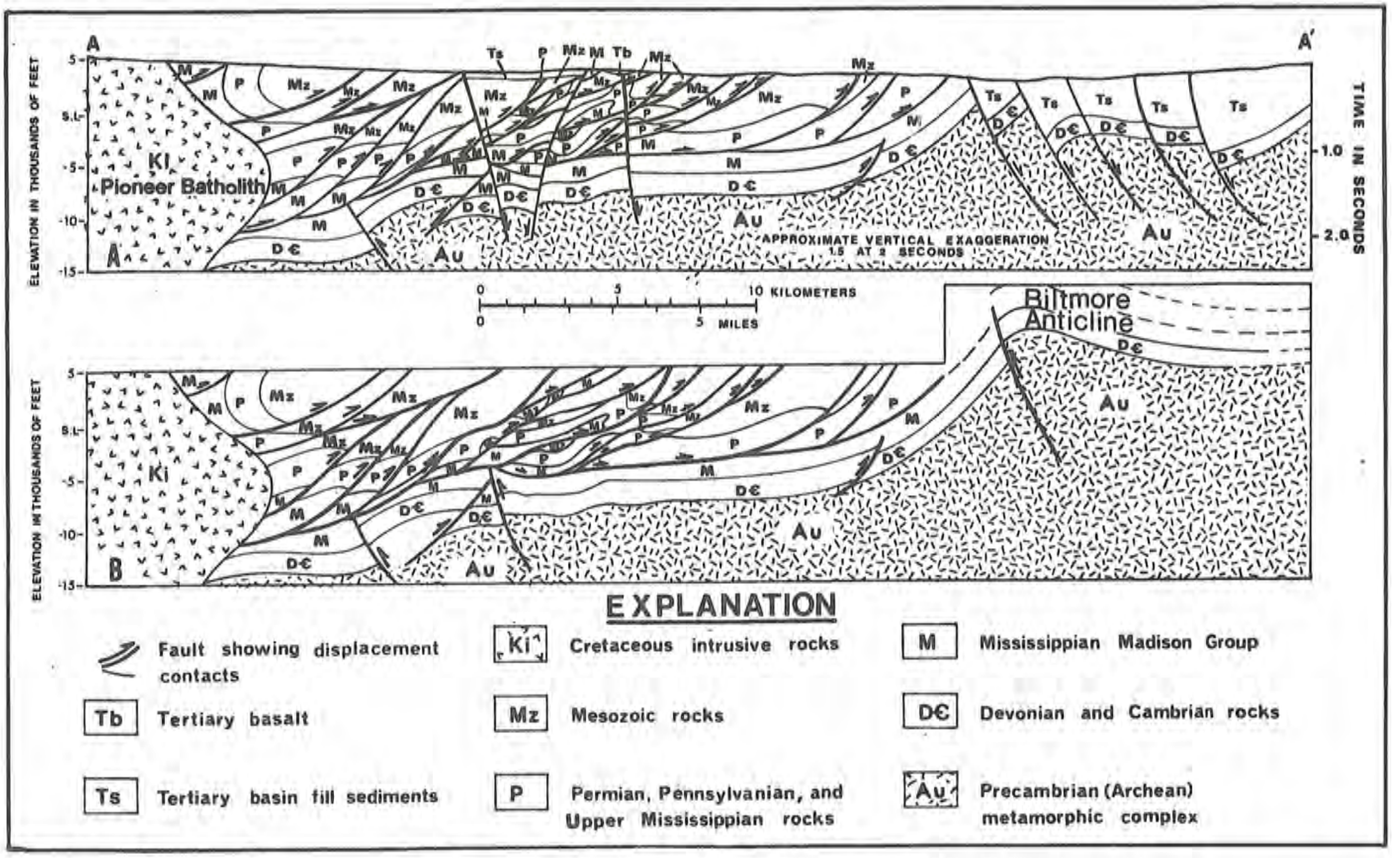


Figure 3. A. Cross section interpretation of section A-A' (Figure 2) based on seismic reflection data (after Lopez and Schmidt, 1985); B. Cross-section restored for Neogene movement showing Biltmore anticline and other foreland structures (after Schmidt and others, 1988).

NW-trending basement-cored anticlines in southwestern Montana (Wagner, 1957; Schmidt and Garihan, 1983; Miller, 1987: Schmidt and Chase, 1989) Poles to folded foliation define a fold axis that plunges 45 degrees to the southwest (Brandon, 1984).

The Biltmore anticline modified the geometry of the McCartney Mountain salient. Brandon (1984) and Schmidt and others (1988) argued that the Biltmore anticline formed before the thin-skinned structures of the salient and deflected thrust sheets that impinged on it into a more northerly trend. They also suggested that much of the internal strain (most notably pressure-solution cleavage in the Kootenai Formation) and inferred out-of-sequence thrusting near Sandy Hollow (Stops 5, 6 and 7) was a product of shortening of thrust sheets against an uplifted basement-cored anticline. Tysdal (1988) noted a similar change in thrust orientation in the Blacktail Mountains farther south, but argued that a NW-trending basement-cored uplift post-dated thrusting and folded the thin-skinned thrusts to the NW adjacent to the basement structure. Either model explains the bending of the thrusts along the northern edge of the McCartney Mountain salient, but the basement buttress model also explains the internal shortening and out-of-sequence thrusting within the salient. Similar cleavage features and out-of-sequence thrusts occur where thin-skinned thrusts impinge upon basement-cored anticlines in the northern Tobacco Root Mountains (Schmidt and others, 1988; Genovese and Schmidt, 1988).

The Flathead Sandstone is overturned at this stop, and faces west. It is part of a steeply-dipping, west-facing panel of Paleozoic rocks

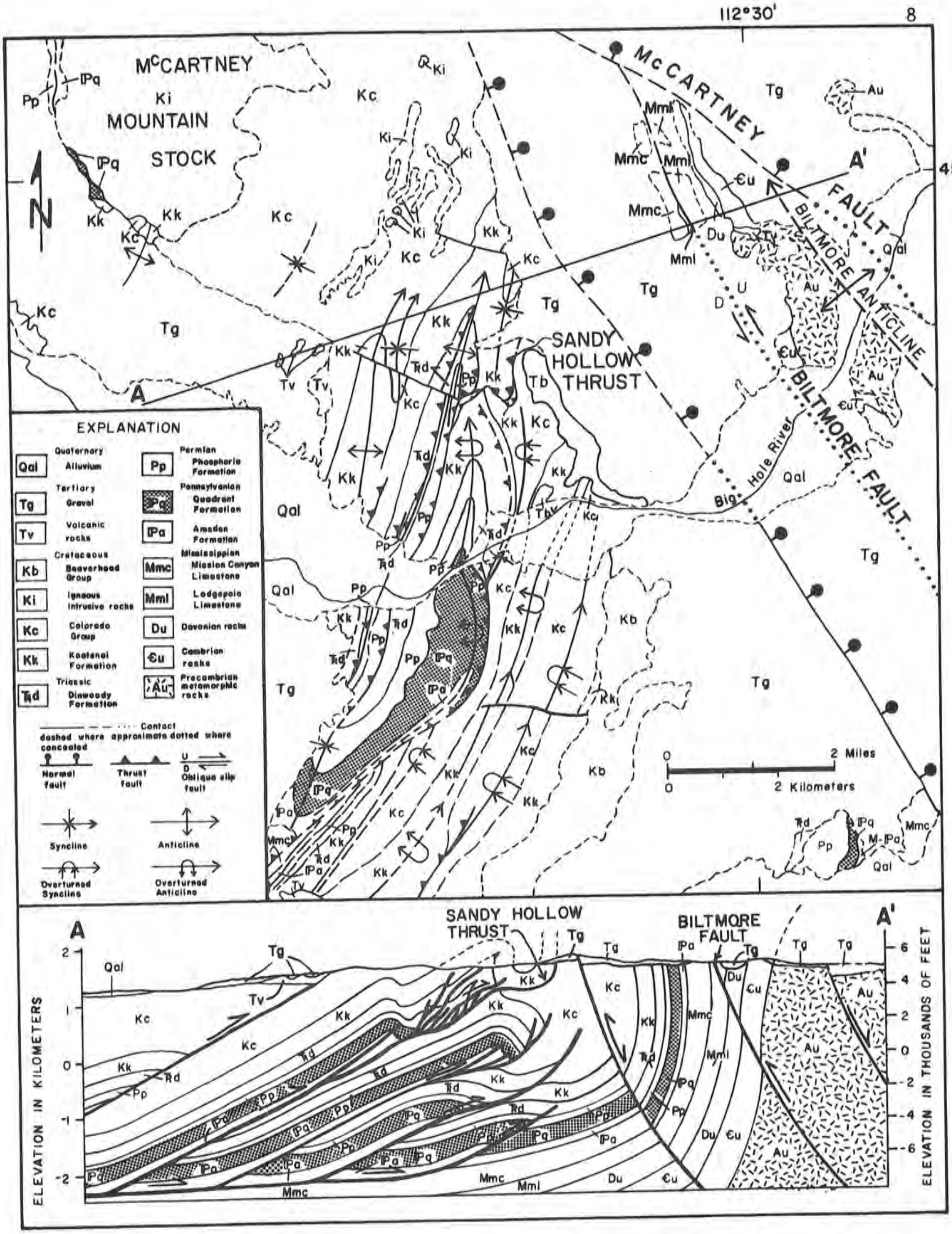


Figure 4. Geologic map of the east-central McCartney Mountain salient (modified after Brumbaugh, 1973; Brandon, 1984; and H. Dresser, unpublished mapping); B. Cross section A-A' based on down-plunge projections of Brandon (1984) and seismic line interpretation of Lopez and Schmidt (1985) (after Schmidt and others, 1988). See Figure 2 for location of area.

extending some 5 miles along strike. Steep dips are rare along the flanks of basement-cored anticlines in this region. The Biltmore anticline reached an advanced stage of fold-fault development compared to others of this type. Several minor thrusts cut the steep Paleozoic beds north of here. A major NE-dipping thrust or reverse fault may subtend the Biltmore anticline in the subsurface.

Continue west along Burma Road

31.9 Cambrian dolomite crops out in gulch to right.

32.3 Gravel pit is on the right.

33.8 Weathered Miocene/Pliocene gravel is in road cuts on the right.

34.3 Stop near cattleguard.

STOP 4. Geologic relationships at east end of McCartney Mountain salient. (by J.W. Sears)

The Big Hole River valley cuts through thick Tertiary sedimentary deposits and volcanic rocks to reveal spectacularly folded and thrusted Paleozoic and Mesozoic strata west of this stop. The cover photograph of this guidebook is a down-plunge aerial view of these beautifully exposed structures, photographed and interpreted by Hugh Dresser.

Steep gravelled hills rise 700 feet on both sides of the river. The gravel forms a thick deposit which appears to dip gently to the east. The base of the deposit is a profound unconformity that cuts across basalt flows and tuffaceous sandstones and truncates the fold-thrust structures of the McCartney Mountain salient with angular discordance. The unconformity itself appears to be tilted, rising over 1000 feet in four miles to the northwest, and rising 200 feet in four miles to the southwest.

The age of the gravel is poorly constrained. It overlies Middle Eocene Block Mountain basalt. Upper parts of the deposit contain Clarendonian/Hemphillian fossils in the Biltmore hills across the valley, placing part of it in the upper Miocene (Hoffman, 1971; Petkewich, 1972). Hanneman (1989) reported a K-Ar date of 3.7 Ma for an ash bed in part of the unit northeast of here. The gravel drapes the hills and conceals the internal structure of the deposit, but Brandon (1984) thought that a large fault passes through the area of this stop, and several faults show where the seismic line crosses this deposit (Lopez and Schmidt, 1985). The relationships between the dated parts of this deposit are not resolved.

Hanneman (1989) interpreted this unit as a braidplain deposit. It has clasts of Archean and Phanerozoic units derived from the Highland Mountains, and Belt quartzite clasts derived from the Pioneer Mountains. The deposit appears to continue south and east of this site across the Ruby Range where it becomes finer grained and thinner. Sears and others (1989) believe it may be an enormous fan laid down by the ancestral Big Hole River as it spread from the Pioneer Mountains into a desert depression. After deposition, extensional faults segmented and tilted the deposit as the Ruby Range rose across the toe of the fan. The present drainage then cut through the deposit in Pleistocene time.

The basalt in the roadcut is part of the Block Mountain basalt flow that Chadwick (1981) dated at 46 Ma by the K-Ar whole rock method. It is an outlier of the Challis-Lowland Creek volcanic fields. The flow overlies folded Cretaceous rocks with angular unconformity. The unconformity itself slopes northeast: the elevation of its trace drops 800 feet from Block Mountain to this point.

In the middle distance, the Hogback is a thrust plate of Quadrant Quartzite cut by the Big Hole River canyon. The Hogback thrust marks the break in slope on the east side of the ridge, where the resistant Quadrant overlies Colorado shale.

The low, rolling country east of the Hogback is a major synclinorium containing two main synclines and an anticline, all overturned to the east. Kootenai and Colorado beds express the folds at the surface. The Burma Road crosses these folds in the next 1.5 miles.

The regional cross-section (Plate 1) shows the synclinorium perched on a major thrust which places Quadrant Quartzite over Colorado shale. Well MP-1, located two miles south of this stop, drilled into Quadrant about 3000 feet above its interpreted regional level. This thrust plate is the leading edge of the McCartney Mountain salient, and according to the cross-section (Plate 1), has about five miles of displacement. The leading thrust is entirely buried.

Continue west on Burma Road.

34.6 Well-developed columnar joints in Block Mountain basalt on the right.

35.0 Overturned, east-facing Colorado sandstone beds appear beneath the Block Mountain basalt on the right, in the Block Mountain syncline.

35.1 Quarry on the right is in Colorado black shale.

35.2 Cross the axial trace of the overturned Block Mountain anticline in Kootenai redbeds and limestones on the right. Proceed up section to the west in normal stratigraphic order into Colorado sandstone and shale.

35.9 The cattleguard is near the axial trace of the Buffalo Jump syncline in Colorado sandstone. Proceed down section to the west as the road crosses the overturned western limb.

36.1 Turn right onto the dirt road at the edge of the large field. Pass through a wire gate and proceed up the dirt road along Sandy Hollow. After .6 miles, take the left fork and proceed for an additional .8 miles up Sandy Hollow wash. Stop where the road curves to the west, before it enters a narrow rocky canyon cut in Phosphoria chert.

The road along Sandy Hollow traverses the steep east limb of the Sandy Hollow anticline in strike valleys cut into Kootenai shale. The anticline plunges north, and Quadrant, Phosphoria, Dinwoody, Morrison and Kootenai beds successively plunge out in the hills west of the road. The anticline continues south of the Big Hole River, where the Hogback thrust cuts across the vertical eastern limb. The high ridge on the west is a strike ridge of Phosphoria chert in the hangingwall of the Sandy Hollow thrust.

STOP 5. Sandy Hollow Thrust Ramp (Dresser) and Sandy Hollow Duplex (Hendrix). The location of stops 5, 6 and 7 are shown on the cover of this guidebook.

<u>Sandy Hollow Thrust Ramp</u> (by H.W. Dresser)

The Sandy Hollow thrust cuts NE-plunging folds crumpled by SE-directed compression. The steps in the Sandy Hollow thrust were controlled by the folds. The riser of each step ramps up along the west flank of an anticline. The platform then cuts across the axial plane of the anticline and that of the adjacent syncline to the east to rise up again on the west flank of the next anticline. The platform of the exposed step dips to the northeast, cutting the gently plunging axes of the folds. It is on this complex surface that Ziegler anticline and Coal Draw syncline have been thrust over Sandy Hollow anticline and Buffalo Jump syncline.

The duplex structures and megabreccias at a step in the Sandy Hollow thrust are beautifully exposed at this location. A decollement in the lower part of the gastropod limestone member of the Kootenai Formation allows small-scale duplex structures to develop in the upper part of the limestone under the overriding Sandy Hollow thrust. These are described by Hendrix below.

Figure 5 shows a large irregular slab of gastropod limestone that was torn from the west flank of Sandy Hollow anticline in the autochthon and stretched out along the thrust. As the eastern flank of the Ziegler anticline moved up and across the step, pieces of the brittle basal Kootenai conglomerate broke from it to remain as scattered blocks, forming a megabreccia. At the same time, the thin-bedded Dinwoody limestones crumpled into small disharmonic folds as they slid across the step and over the Kootenai blocks. Colorado sandstone broken from the western flank of Buffalo Jump syncline was carried eastward to lodge at the base of the next fault riser.

These relationships indicate that the thrusting followed most of the folding. This is also clearly shown where the steeply dipping beds of the Colorado on the west flank

Figure 5. High angle oblique aerial photograph of the Sandy Hollow thrust fault in the areaof Stop 5. Photo by H. Dresser.

of Buffalo Jump syncline are truncated by the platform of the step. When a step-bedding thrust, like the Pine Mountain thrust in the Appalachians, is later folded, the autochthonous beds below the folded platform of the step remain parallel to the fault. Here, the fault cuts across these beds. Still, the exposed platform of the Sandy Hollow thrust is gently warped. The fault dips eastward to the east of the steeply dipping Colorado sandstone on the west flank of Buffalo Jump syncline. Because this warp overlies uniformly dipping beds of the Colorado, I believe it may be an original inflection of the fault surface. However, the fault surface also may have been folded by compression against the riser to the east after thrusting stopped.

<u>Sandy Hollow Duplex</u> (by T. Hendrix)

(This discussion is modified from the description of Stop V-7 for the 1989 International Geological Congress field guide V "The frontal thrust belt in Montana" (Schmidt, 1989).)

At this location, the Sandy Hollow thrust cuts across the Sandy Hollow anticline. A spectacular, three-tiered duplex structure is exposed in the 27-meter-thick gastropod member of the Kootenai Formation on the steep, eastern limb of the anticline.

The structure (Figure 6) consists of three packages of tight-to-open, concentric anticlines and synclines bounded by sigmoidal-shaped thrust faults. Disjunctive spaced cleavage occurs sporadically in 15-30 cm-thick micrites at the base of competent packstone-wackestone units which also contain conjugate shear fractures and tensional <u>ac</u> and <u>bc</u> joints.

Each duplex package consists of one competent packstone/wackestone unit 1-3 meters thick and one incompetent black shale unit of approximately equal thickness. Three decollements - one exposed and two inferred - separate the duplexes and a thick basal unit (A) which is undeformed. Shortening by folding, left-reverse slip thrusting and cleavage is 58 percent in the lowest duplex, 32 percent in the middle duplex and 14 percent in the upper.

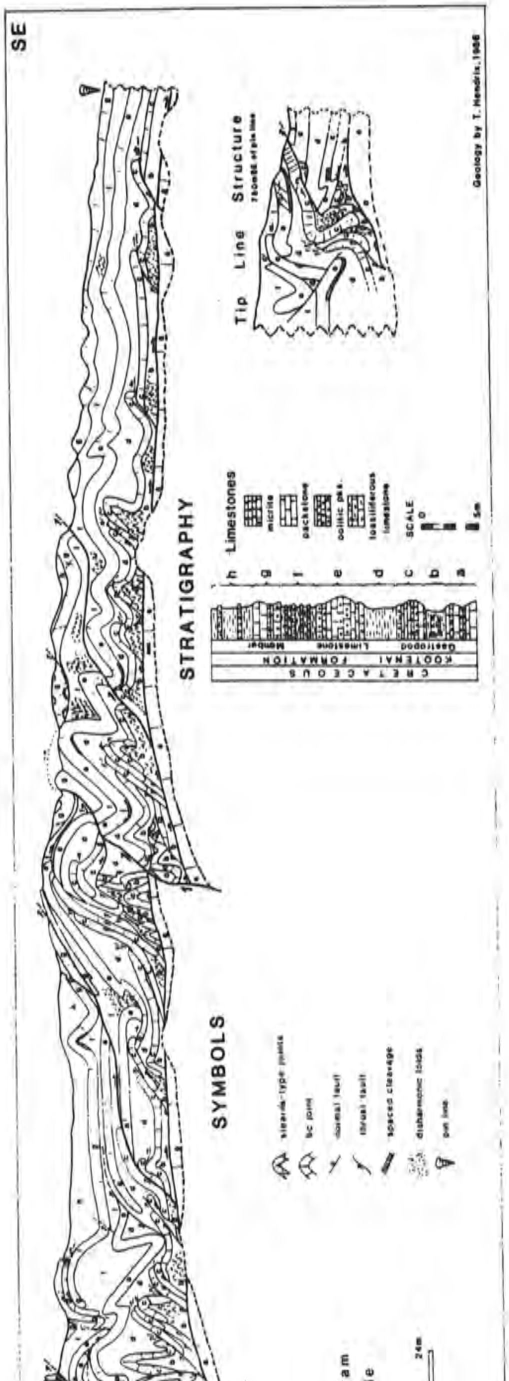


Figure 6. Sketch of the Sandy Hollow duplex structure by T.E. Hendrix.

Preliminary work on calcite twinning, cleavage, oolds, and gastropods in the competent limestones, as well as analysis of the many folds, faults, and joints in the structure indicates the following sequence of deformation:

1) A pre-duplex stage in which layer-parallel shortening occurred by production of pressure-solution cleavage in the micrites;

2) A duplex stage in which deformation moved from hinterland to foreland in each duplex accompanied by formation of disharmonic folds and rotation of cleavage; and

3) A late (flattening) stage accompanied by formation of a second cleavage in shales and micrites in the cores of tight lift-off anticlines and the formation of several widely-spaced, out-of-sequence thrusts.

Analysis of structures within the duplexes suggests that the multiple duplex structure was formed by impingement of the Sandy Hollow allochthon on the nose and eastern limb of the Sandy Hollow anticline. The allochthon, moving upward and eastward across a flat in the Sandy Hollow thrust, collided with the gastropod member of the Kootenai Formation, peeled the upper 27-meters of this member loose from its competent base and moved it southeastward as three more-or-less independent duplexes floored by incompetent shales.

The out-of-sequence thrusting, early folding before thrusting, and strong cleavage development at Sandy Hollow and the general shape of the McCartney Mountain salient have been inferred to largely be products of "buttressing" against a foreland basement structure, the Biltmore anticline (Schmidt and others, 1988).

Return to Burma Road.

39.1 Turn right and continue west on Burma Road.

39.2 Terrace with gravel mantle cuts the Phosphoria Formation ahead and to the right.

39.5 Notch Bottom Fishing Access is on the left. South of the river, a large kink-fold of the Quadrant Quartzite defines the Sandy Hollow anticline. The alluvium buries the tip line of the Hogback thrust.

39.7 The canyon of the Big Hole River may be a Pliocene-Pleistocene feature. The erosional surface at the top of the Hogback ridge is of unknown age, but it could represent the exhumed unconformity at the base of the Miocene-Pliocene gravel.

40.0 Emerge from the canyon. On the right is the Quadrant/Phosphoria contact on the gentle west limb of the Sandy Hollow anticline. Proceed up section to the west through Dinwoody, Morrison, and Kootenai Formations in the footwall of the Sandy Hollow thrust.

40.5 Cross cattleguard, and proceed around curve to right. Stop opposite hayfield and farm road.

STOP 6. Sandy Hollow Thrust. (by H.W. Dresser)

At this location the Phosphoria Formation has been thrust over the lower part of the Kootenai Formation along a riser in the Sandy Hollow step thrust. The small step thrusts that cut the shattered cherts of the Phosphoria presumably reflect the geometry of the Sandy Hollow thrust. Because the axes of the two small folds in the hanging walls of the thrusts do not coincide with the inflections of the steps, the folds appear to have slid along thrusts from their origins at steps farther down dip. An indication that these faults may have developed in succession from east to west is shown by the fault at the west edge of the outcrop. In a smooth arc this fault cuts off the top of the underlying step-generated anticline.

Continue west on Burma Road.

40.7 At the top of the hayfield, the road curves to the left. The small ridge in the gulch is Phosphoria quartzite, thrust over Dinwoody shale. Round the curve and note the sharp E-facing anticline/syncline pair in the Dinwoody shales and brown limestones. The road now crosses a series of strike ridges as it proceeds up section to the west through the Dinwoody, Morrison and Kootenai formations.

41.1 Stop opposite broad outcrop of Kootenai limestones and shales. This low ridge is just east of a corral and ranch house on the north side of the road.

STOP 7. Out-of-Sequence Thrusts in Kootenai Formation (by H.W. Dresser).

At this location the NE-plunging Creasy Gulch anticline and syncline have unfolded up plunge into a thrust-faulted structural terrace (Figure 7). The three limestones of the middle Kootenai exposed in this outcrop consist of a basal yellow-weathering unit, a light-grey, fracture-cleaved middle unit, and a dark-grey upper unit. The interpreted succession of faults (F1 to F5) is shown on Figure 7. Faulting probably began with steep reverse faults at the eastern edge of the outcrop. The limestones folded and broke successively westward, each fault being of gentler dip than its predecessor. The key to this interpretation lies in the small anticlinsal fold in the middle and upper limestone beds near the bottom center of the outcrop. The fold formed and then broke along a small-displacement fault (F1). The dark-grey upper limestone at the top of this fold was cut by the succeeding thrust (F2) and tightly compressed as it was transported upward. When it stuck, the fault branched and broke across its west side to transport the light-grey fracture-cleaved middle unit over the top of it (F3). The dark-grey upper unit then slid across the top of the bedding (F4 and F5), cutting off the thrust (F3) that bounds the base and end of the light-gray fracture-cleaved middle unit.

Proceed west on Burma Road.

Road crosses up section through the Kootenai Formation to the west.

41.7 Stop where road curves to the left at a dry gulch. Note trace of old road close to fence on the left, cut off by the current road.

STOP 8. Sill in basal Colorado shale. (by J.W. Sears)

This sill dips west on the flank of the Creasy Gulch anticline, and continues north for 1.5 miles at this stratigraphic horizon. It does not cross the axis of the anticline. This sill is one of a family of sills in the Colorado shales (Plate 1). Several occur north and south of this location at higher stratigraphic levels in the Colorado. They appear to be associated with the McCartney Mountain stock, a late Cretaceous granodiorite intrusion (Eaton, 1983).

Closely spaced fractures cut this sill, approximately normally to the contacts of the sill. They strike parallel with the Creasy Gulch anticline, but do not lie in its axial plane. Rather, they are folded with the bedding. The fractures mimic joints in Colorado sandstones and spaced cleavage in Kootenai micritic limestone (as seen at stop 7), in that all of these planar features are generally normal to bedding in this area. If bedding is horizontal, they are vertical, if bedding is vertical, they are horizontal. They apparently formed by bedding parallel shortening and stretching before formation of the map-scale folds and thrusts.

Continue west on Burma Road.

41.9 On the right, Tertiary rocks overlap or are faulted against Colorado shales. The badlands are light-colored mudstones of the Renova Formation, which yield Oligocene vertebrate fossils (Hoffman, 1971). McCartney Mountain contains a thick section of hornfelsic Colorado shales, near the contact of the McCartney Mountain stock.

42.5 A smooth gravel surface flanks McCartney Mountain. The SW margin of the mountain appears to be a normal fault, down on the SW (Hanneman, 1989).

44.4 Road curves around ranch buildings.

45.1 Cross two bridges over Big Hole River.

45.3 Glen Fishing Access

46.0 End of Burma Road. Turn left on paved road (Old US 91) at stop sign.

46.1 Steeply-dipping Kootenai Formation crops out in low hills to right standing above surface of gravel fan.

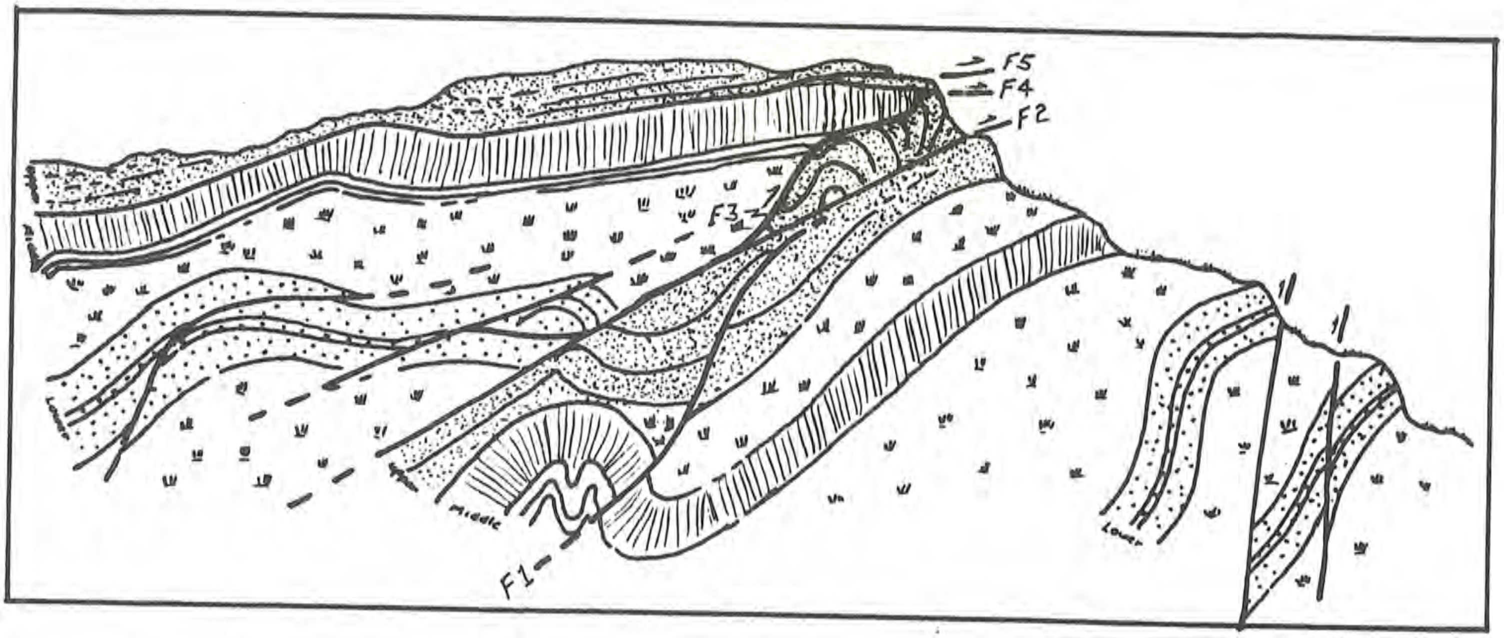


Figure 7. Sketch of faults in middle Kootenai Formation limestone near Creasy Gulch, sequence of faulting beings wiht F1.

46.8 Block Mountain basalt is ahead in distance. On the left, the contact between the McCartney Mountain stock and the Colorado Group can be seen. The stock underlies the rocky, forested area of the mountain on the north.

47.7 Gravel pit is on the left.

48.8 Stop along road opposite bouldery ridge.

STOP 9. Massive dacite sill in Colorado shale. (by J.W. Sears)

This sill is 174 to 225 meters thick, and is a hornblende-biotite dacite porphyry (Eaton, 1983). It has an apparent strike length of seven miles (Plate 1). The sill appears to be an offshoot of the Pioneer batholith, and Eaton (1983) suggested it may connect the batholith and the McCartney Mountain stock.

The sill apparently intruded near a thrust fault (Eaton, 1983). It inflates west-dipping Colorado shale, but converges west toward Quadrant Quartzite in the Apex anticline. The anticline may form the hangingwall of a thrust, as shown on the cross section (Plate 1), because the Quadrant is nearly 5000 feet above its regional level determined from nearby well AQ 27-22. This thrust may extend north along the Big Hole River as the Angler's thrust of Brumbaugh (1973). The cross section (Plate 1) shows this sill connected with the Pioneer batholith, which conformably intrudes the base of the Quadrant along the line of the section. Brandon (1984) showed a similar interpretation for a cross section linking the McCartney Mountain stock with the Pioneer batholith.

Continue south on old US 91.

50.8 Hill in the middle distance on the left is Quadrant Quartzite on the Apex anticline.

53.1 Turn left at right angle cross road at section line, cross cattleguard, and proceed east toward Hogback microwave tower.

53.7 Cross cattleguard, stay on main road.

54.4 Turn left onto one lane road to microwave tower.

54.5 Tertiary basalt flow unconformably overlaps tilted Paleozoic rocks. To the east, this basalt overlies the gravel deposit we discussed at stop 4.

54.7 Ridge of steeply dipping Quadrant Quartzite is on the right.

55.6 Stop near microwave tower.

STOP 10. Structure of the Hogback. (by J.W. Sears)

The Hogback thrust arches west from the Big Hole River. At this point, the fault places contorted shales and limestones of the "Amsden Formation" (Kibbey, Lombard and Conover Ranch formations as used by Pearson and Childs, field trip 3, this guidebook) over vertical to steeply overturned Quadrant Quartzite. A synclinorium of Cretaceous rocks occupies the low ground in the footwall to the east. In the hangingwall, the Quadrant is folded into a broad, N-plunging syncline above the disharmonically folded "Amsden". Mission Canyon limestone appears to the south in a hangingwall ramp.

Figure 8 shows that the Hogback thrust formed after the Sandy Hollow anticline and Buffalo Jump syncline, and is thus an out-of-sequence structure.

Return to intersection with old US 91.

58.1 Cross US 91. Proceed due west toward Birch Creek.

61.4 Underpass beneath I-15. AQ 27-22, drilled just south of here, penetrated Archean basement at a depth of 11,835 feet.
Hill to the north is brecciated Quadrant Quartzite in the Apex anticline (Brandon, 1984).

62.6 A farm is on the right.

64.2 Sharp curve to right.

64.3 Long John Road No. 607 on the left follows the axial trace of a NE-plunging overturned syncline in Colorado shale.

64.7 Cross Birch Creek, stop at next curve to left.

STOP 11. Cave Gulch syncline. (by J.W. Sears)

The Cave Gulch syncline is one of several NE-plunging folds in the Paleozoic and Mesozoic rocks on the eastern flank of the Pioneer batholith. These folds are all asymmetric, overturned to the east. The Cave Gulch syncline has a weak, spaced cleavage in pelitic rocks of the Colorado Group. This is the southern limit of a cleavage domain that Geiger (1986) traced from Birch Creek north to Melrose. The cleavage increases in intensity to the north where the thrust belt impinges on the Highland Mountains and the Boulder batholith (Geiger, 1986). Paleo-temperatures of Paleozoic rocks determined from conodont color alteration (Sweet and others, 1981) increased northward from less than 50 C near Dillon, to over 200 C near Melrose.

Continue west on Birch Creek Road.

Proceed down section to the west on steep limb of Cave Gulch syncline/Birch Creek anticline.

66.1 Beaverhead National Forest Boundary.

66.2 Enter canyon cut into Quadrant Quartzite.
66.7 Canyon Mountain Gulch on the left exposes Mission Canyon limestone. The Birch Creek anticline is disharmonic above the Mission Canyon limestone.

67.7 Town of Farlin. This is a copper-silver district. Old mine dumps are on the right.

68.0 Stop at Farlin smelter site. Mine dumps are on the right. The mines followed the contact between the Madison limestone and the Pioneer batholith.

STOP 12. Contact of Pioneer batholith. (by J.W.Sears)

Birch Creek follows a major discontinuity in the contact of the Pioneer batholith. South of Birch Creek, the contact crosses thrust plates carrying Belt Supergroup and younger rocks. The contact steps up to the base of the Quadrant Quartzite northeast of this locality, and follows the strata conformably for over

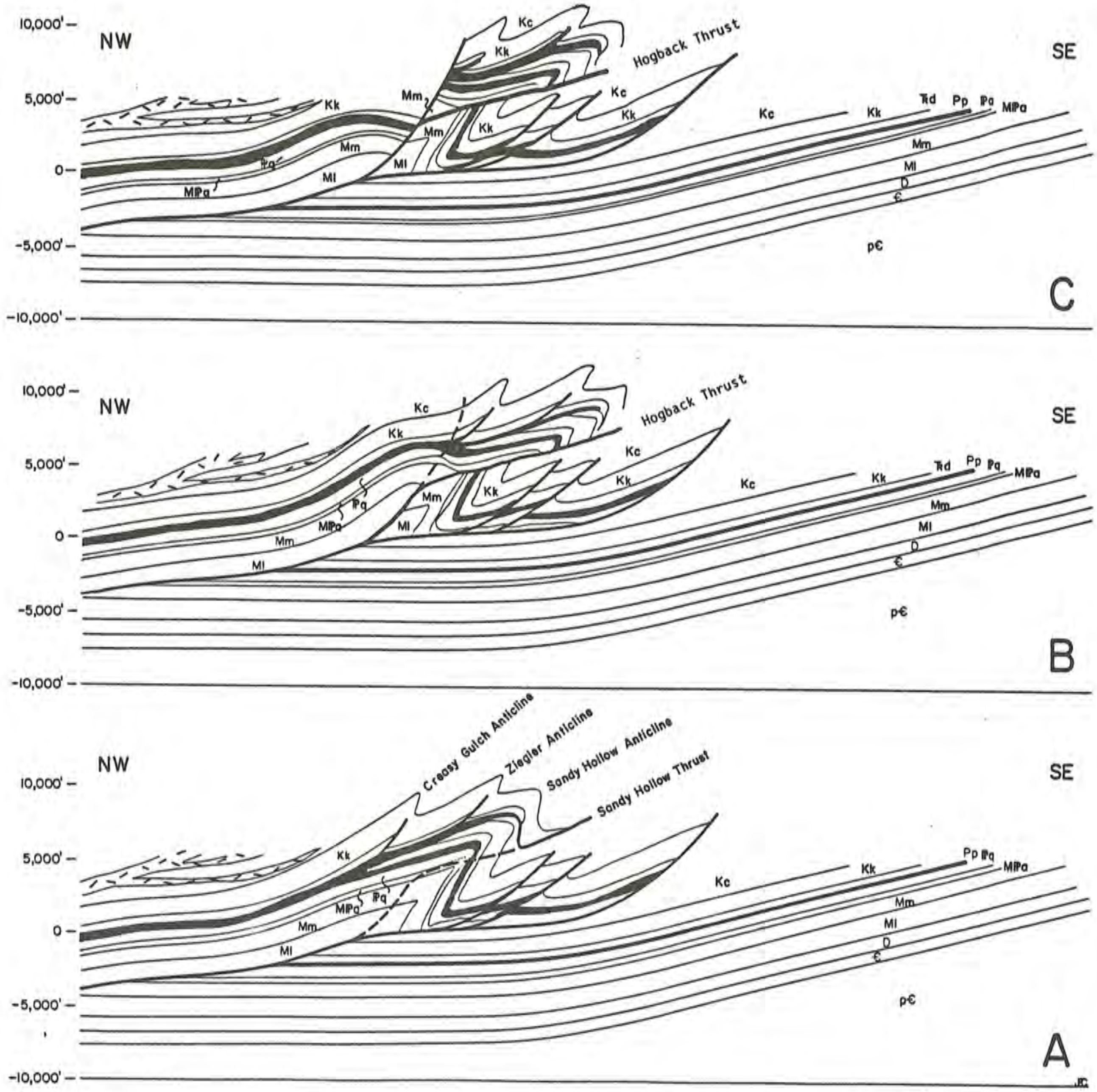


Figure 8. Schematic development of a cross section through the Hogback near Stop 10.
A. Structure before Hogback thrust formed.
B. Hogback thrust cuts across axial planes of older folds.
C. Normal fault cuts west edge of Hogback.

ten miles along strike. The Quadrant and younger units dip east off the batholith, facing into a synclinorium along the Big Hole River. Structures in the Sandy Hollow-Hogback-Apex area require over 10 miles of cumulative horizontal displacement of the Mississippian and younger rocks above the autochthon at this contact of the Pioneer batholith. The cross section (Plate 1) shows the batholith as a laccolithic body overlying the autochthonous Paleozoic and Precambrian rocks. The close timing between emplacement of the batholith and thrusting suggests that the batholith formed an important part of the east-tapering orogenic wedge that moved toward the Highland-Ruby foreland uplift.

Continue west on Birch Creek Road.

70.0 Turn left on road leading to Western Montana College Birch Creek Outdoor Education Center.

70.3 WMC Outdoor Education Center. Field trip ends.

Acknowledgements

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NORTHWEST GEOLOGY, V. 18., p. 21-35, 1989

ROAD LOG NO. 2
THE RED ROCK FAULT AND COMPLEXLY DEFORMED STRUCTURES IN THE TENDOY AND FOUR EYES CANYON THRUST SHEETS --EXAMPLES OF LATE CENOZOIC AND LATE MESOZOIC DEFORMATION IN SOUTHWESTERN MONTANA

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Initial point: Western Montana College, parking lot on SW corner of campus
Distance: 103.4 miles
Highways: I-15, Dell Frontage Road, Big Sheep Creek Road
Field Stops: 3

No. 1- Big Sheep Creek Road
No. 2- Deadwood Gulch off of Big Sheep Creek Road; 1/4 mile foot traverse
No. 3- Big Sheep Creek Road

Introduction

This field trip is intended to provide a look at structural features at some key locations within the region that I am currently mapping (principally the Dixon Mountain and Dell quadrangles near Lima). Some discussion of the Red Rock fault (**STOP 1**) was included in two presentations at meetings of the Geological Society of America (Bartholomew, 1988b; Stickney, Bartholomew, and Wilde, 1987) as well as in our regional synthesis of the Montana - Idaho basin and range (Stickney and Bartholomew, 1987). Detailed mapping of many of the fault scarps along the Red Rock fault was done by Johnson (1981).

The outcrop sketches at **STOPS 2 and 3**, along with the structural data from those specific outcrops, were originally used for two stops on a field trip for the Rocky Mountain section of the American Association of Petroleum Geologist at Boise, Idaho and informally released as an open-file report (Bartholomew, 1987). That data for the outcrop at **STOP 2** plus a preliminary version of the geological map and an abbreviated discussion were included as Stop V-3 (Bartholomew, 1989b) for International Geological Congress field trip T38O. A discussion of the complete data set for **STOP 2** was presented at the Rocky Mountain section of the Geological Society of America (Bartholomew, 1988a).

ROAD LOG

Miles	
00.00	Parking lot on SW corner of campus of Western Montana College; leave parking lot by turning west (right) onto Poindexter.
	0.10
00.10	Turn south (left) onto South Atlantic.
	0.80
00.90	Turn south (left) onto Interstate 15.
	39.40
40.30	Take exit 23 (Dell exit) off of Interstate 15 (Dell is on the east side of the Interstate and is the last place to get gas or food).
	0.25
40.55	Turn west (right) at stop sign at end of exit ramp.
	0.05
40.60	Turn south (left) on frontage road (note sign marked "Big Sheep Creek") on west side of Interstate 15.
	1.60
42.20	Turn west (right) on to Big Sheep Creek Road (note sign).
	2.25
44.45	**STOP I**. Cross the scarp (**Figure 1A**) of the Sheep Creeks segment of the Red Rock fault (Stickney and Bartholomew, 1987) and park along

Miles

the side of the road. (See discussion of **STOP 1** below.)

0.15

44.60 Cross first bridge over Big Sheep Creek. Beaverhead conglomerate is exposed in the creek upstream and a small, Holocene, tectonic (?) terrace (Ha_2, **Figure 2**) is preserved downstream.

0.25

44.85 Good exposure of Beaverhead conglomerate. The Beaverhead forms the footwall beneath the Tendoy thrust sheet but is generally not well exposed in easily accessible locations. This outcrop is typical of exposures in the Big Sheep Creek area. For reviews of the age, stratigraphy, and significance of the Beaverhead Group see Nichols and others (1985) and Ryder and Scholten (1973).

1.50

46.35 The basal fault of the Tendoy thrust system is located approximately along the shallow gulley extending downhill from the powerline pole on the opposite (south) side of Big Sheep Creek. At this point the basal fault strikes northeast-southwest and dips moderately northwestward. The footwall rocks are Beaverhead conglomerate. The rocks to be examined at this stop (**Figure 3**) lie above this basal fault and consist of the well-exposed Mississippian carbonates visible directly ahead, above the bend in the road.

0.05

46.40 East end of exposures sketched in **Figure 4** (**Stop 1** of Perry, 1982).

0.50

46.90 West end of exposures sketched in **Figure 4**.

0.05

46.95 **STOP 2**. Park here at the turn-off to the south (left) for Deadwood Gulch; the exposures shown in **Figure 3** and **4** also can be viewed from a distance by proceeding along the Deadwood Gulch road (0.3 miles) across the bridge and parking in the cleared grassy area; then walking eastward parallel to the power line to the pole mentioned at 46.35. At this turn-off the basal fault at 46.35 still strikes southwest but now lies structurally above a plate of Mississippian carbonates bounded on the east by a structurally lower thrust. This lower thrust strikes northwest and dips moderately southwest above Beaverhead conglomerate of the footwall. Folds in this lower plate also trend generally northward. (See discussion of **STOP 2** below).

0.00

46.95 From Deadwood Gulch turn-off, proceed westward on Big Sheep Creek Road.

0.15

47.10 Pass sign pointing south to Deadwood Gulch.

3.15

50.25 Pass Muddy Creek Road on north (right) side.

1.20

51.45 Cross second bridge over Big Sheep Creek.

0.20

51.65 Cross third bridge over Big Sheep Creek.

0.05

51.70 **STOP 3**. The outcrops sketched in **Figure 9** lie along the opposite side (south) of Big Sheep Creek but can be seen in their entirety from this location. To examine them in more detail just turn back and cross over the preceding bridge. These Mississippian carbonates are part of the Four Eyes Canyon thrust sheet. (See discussion of **STOP 3** below).

51.70

103.4 Retrace route back to Dillon.

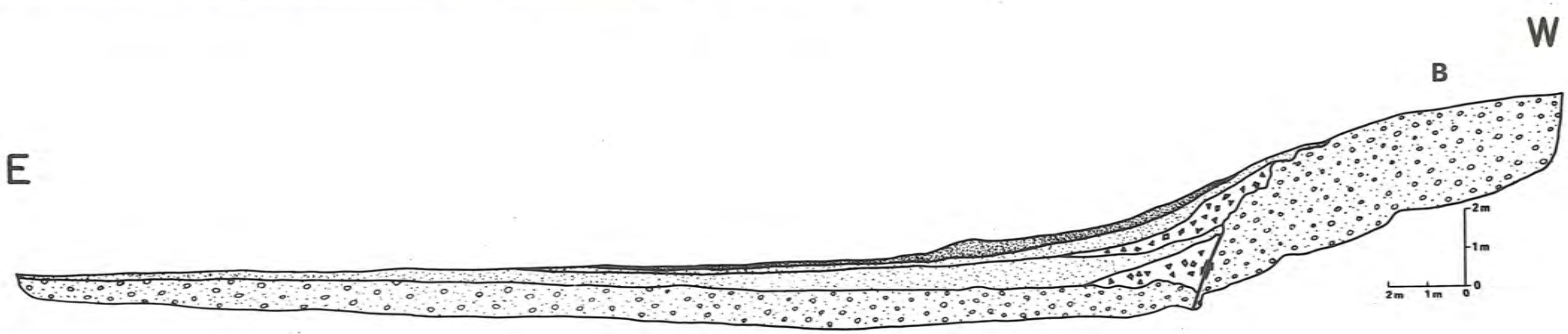
STOP 1: DELL 7.5'-QUADRANGLE; SEC. 20, T13S, R10W (FIGURES 1 AND 2).

This fault scarp (**Figures 1A and 2**) was trenched (Stickney, Bartholomew and Wilde, 1987) just a few miles south of here along Little Sheep Creek where two post- glacial offsets of probable late Wisconsin outwash gravels have occurred (**Figure 1B**). Carbon-14

A

Figure I. A- View looking northwestward from Big Sheep Creek road along scarp of Red Rock fault. Beaverhead conglomerate forms bedrock on brush-covered slopes of hanging wall in foregorund (left central portion of picture). East-facing forested slope (upper left portion of the picture) is underlain by Paleozoic rocks of Tendoy Thrust sheet. B-Generalized sketch of trench log across Sheep Creeks segment of Red Rock fault at Little Sheep Creek (modified after Stickney, Bartholomew and Wilde, 1987); circle & dot pattern -probable Wisconsin outwash gravels; Triangle-colluvial wedges; light shading-B soil horizons; dark shading-A soil horizons.

B



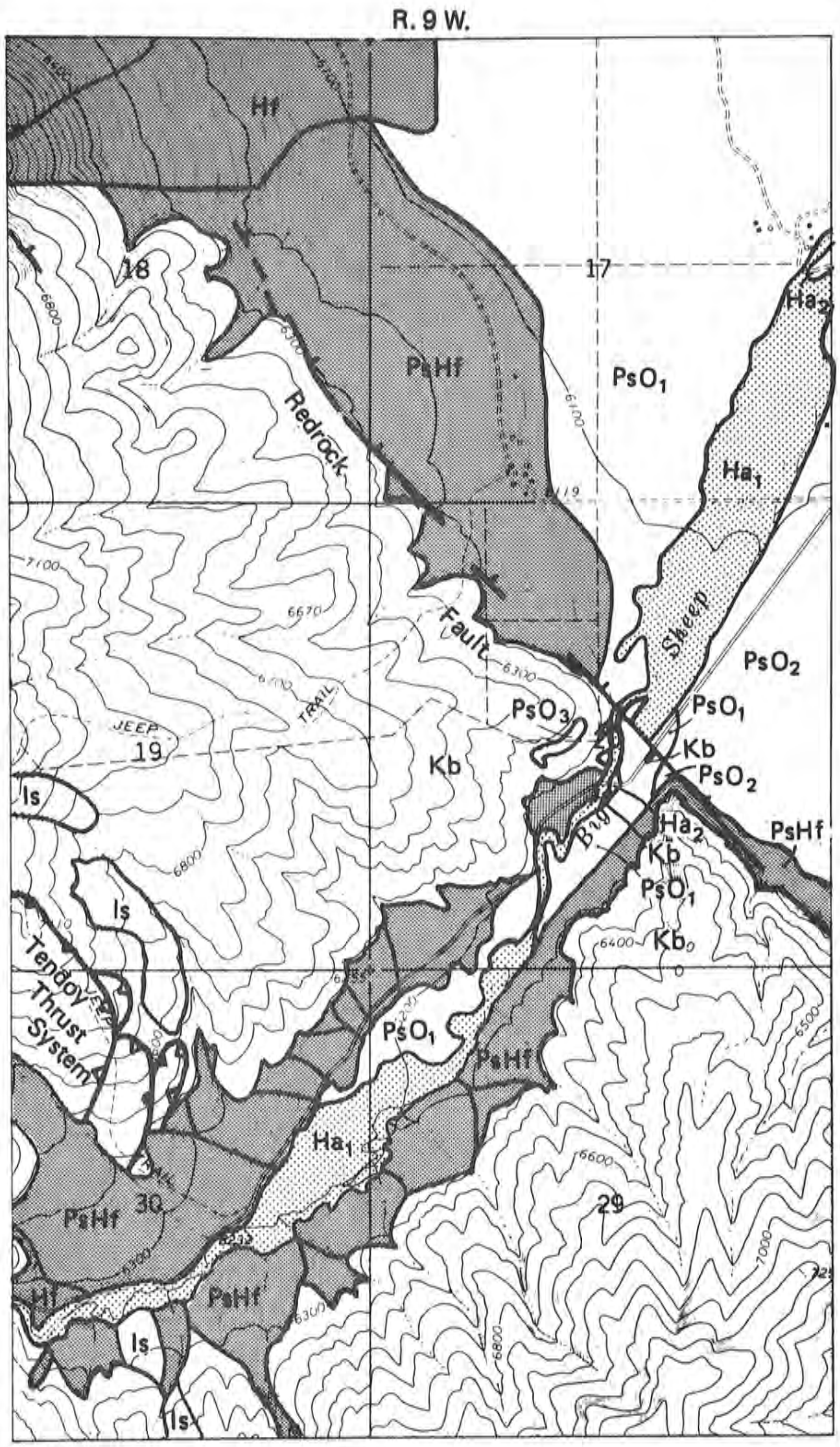


Figure 2. Generalized geologic map of late Cenozoic deposits near the mouth of the Big Sheep Creek Canyon Kb - Beaverhead Conglomerate (Cretaceous); ls-landslide; PsO_3- probable pre-Wisconsin terrace deposit; PsO_2 - older Wisconsin (?) outwash fan and terrace deposits; PsO_1 - younger Wisconsin outwash fan and terrace deposits; Ha_2 - older Holocence Terrace deposts:Ha_1 -younger Holocene alluvium and present-day floodplain; PsHf - older (Pleistocene/Holocene) alluvial-debris fan deposits; Hf - younger (Holocene) alluvial-debris fan deposits. lighter shading used for Ha_1 darker shading used for all alluvial-debris fan deposits; outwash fans and equivalent terraces are unshaded.

ages of the soils above and below the upper colluvial wedge indicate that the last movement along this fault segment was late Holocene (Bartholomew, 1988b) and occurred about 3000 years BP ± 800 years. The older colluvial wedge lies directly on outwash gravels suggesting that the earlier movement occurred before soil developed on top of the outwash. This would suggest a very late Pleistocene age for the earlier movement.

Here, at Big Sheep Creek (**Figure 2**), a one-meter high erosional scarp between terraces on the hanging wall appears to be the offset equivalent of the one-meter high erosional scarp between the two probable Wisconsin outwash fans on the footwall. This suggests that the Red Rock fault scarp, of several meters height, that separates the erosional scarps was formed entirely since the younger (lower) outwash fan was deposited; this inference is consistent with the trench information obtained at Little Sheep Creek that showed two post-glacial offsets.

Beaverhead conglomerate is the bedrock exposed in both this roadcut and in the stream banks near the bridge just around the nearby curve in the road. Approximately 2-3 miles northwestward along the Red Rock fault, Quadrant sandstones form the bedrock of the hanging wall of the fault along the east-facing slope of Dixon Mountain. There, the *en echelon* scarp (NW part of sec. 18, **Figure 2**) is the highest scarp (15-20 meters) found along the entire Red Rock fault. Johnson (1981) had not mapped this prominent scarp, which is located well up the slope on Dixon Mountain, and thus concluded that the last movement of the fault along Dixon Mountain was substantially older than that here at Big Sheep Creek. North of Dixon Mountain, however, I have mapped a very young (late Holocene ?), 0.5-meter high scarp at the mouth of Little Water Canyon, suggesting that the Sheep Creeks segment does not end here in section 18 (as previously implied by Johnson, 1981) but extends to the vicinity of Little Water Canyon. North of there, the last movement along the Timber Butte segment of the fault does appear to be late Pleistocene (Stickney and Bartholomew, 1987) as Johnson (1981) noted.

STOP 2: DIXON MOUNTAIN 7.5'-QUADRANGLE; SEC. 25, 36,T13S, R10W (FIGURES 3,4,5, & 6)

A major detachment surface exists within the Tendoy thrust sheet (**Figure 3**) as recognized by Perry (1982). This fault lies structurally above the outcrops sketched in **Figure 4** but below the Pennsylvanian sandstones that form the cliffs along the southeastern flank of Dixon Mountain. Below this detachment fault the structure is less consistent than above it -- stereograms (**Figures 5,6, and 7**) and graphic plots (**Figures 6E and 7D**) show considerable scatter suggestive of complex deformation below the detachment fault and less scatter above. The structurally more uniform strata above (west of) the detachment fault (**Figure 3**) undergoes a change in attitude just north of Big Sheep Creek. North of Big Sheep Creek, 130 poles-to-bedding define a narrow range for the mean attitude: N10°W, 30°SW - using the geometric center (GC) of the 20% contour area or N1° E, 33°SW- using the GC of the 10% contour area. South of Big Sheep Creek, 78 poles-to-bedding have two areas of higher density that indicate a more westerly trend for mean bedding attitudes than that to the north. Because of the small population I used (**Figure 5C**) the geometric centers of both 7.5% contoured areas (S_1GC = N72° E at 57°; S_2GC = N32°E at 46°) from **Figure 5B** along with the geometric center of the 10% contour area for **Figure 5A** (NGC = 89°E at 57°) to define the (lateral ramp) axis of rotation (LRAR = S78°W at 32°SW) for this flexure near Big Sheep Creek. This flexure corresponds to the northern end of the Deadwood Gulch plate (**Figure 3**) and thus is interpreted as a fold above an obliquely trending lateral ramp over the Deadwood Gulch Plate.

The 107 poles-to-bedding in the Deadwood Gulch plate (**Figures 3 and 5E**) show high density areas consistent with NW-striking, SW-dipping bedding, folded about NW-trending axes; but both the 6% and 3% areas are widely scattered and do not define an area for determination of mean bedding attitude. The 65 poles-to-bedding in the basal plates north of Big Sheep Creek (**Figure 3 and 5D**) also exhibit considerable scatter.

Fold orientation and attitude data

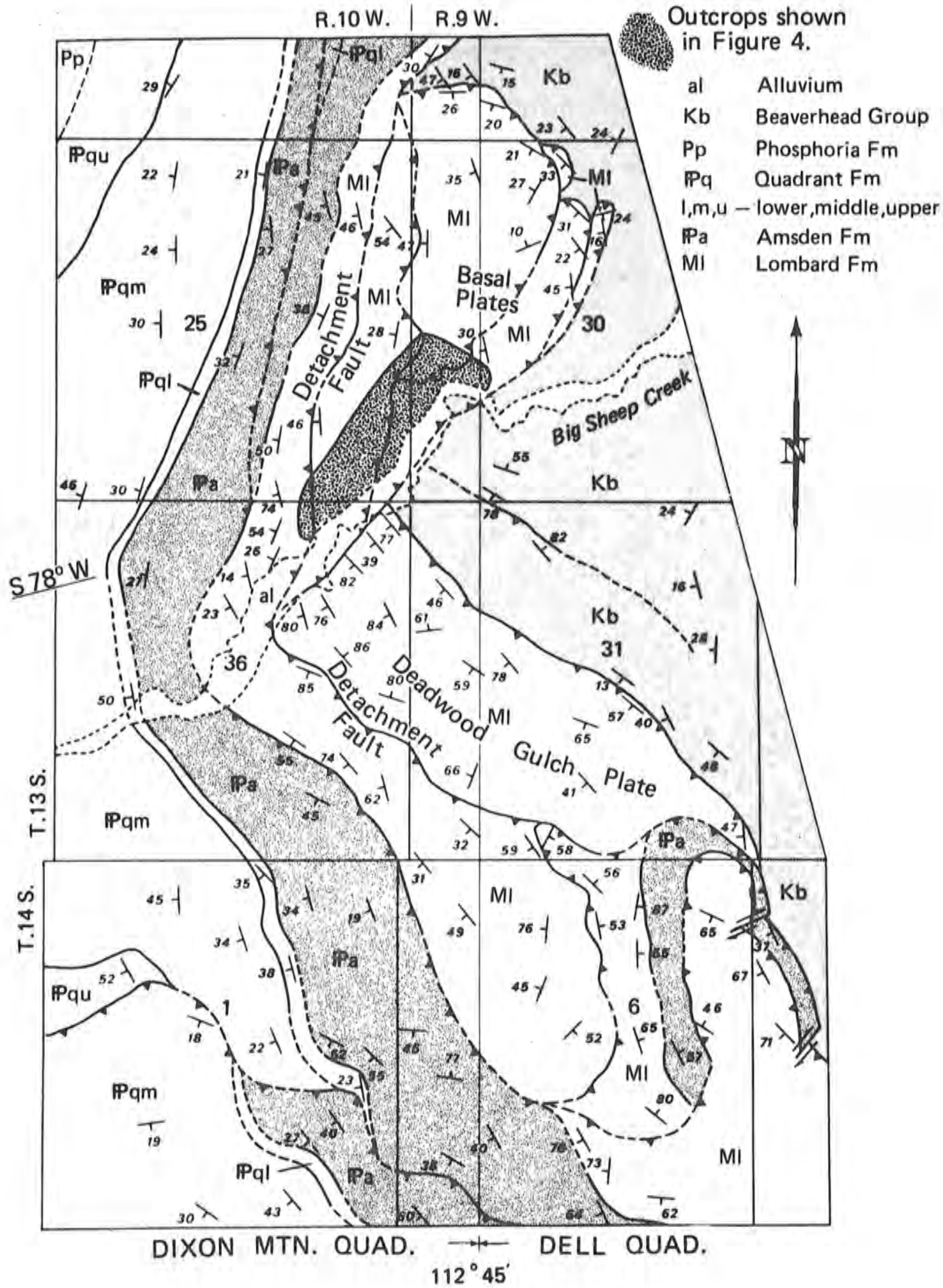


Figure 3. Generalized geologic map of composite duplex at the base of the Tendoy thrust system along Big Sheep Creek (modified from Bartholomew, 1989b).

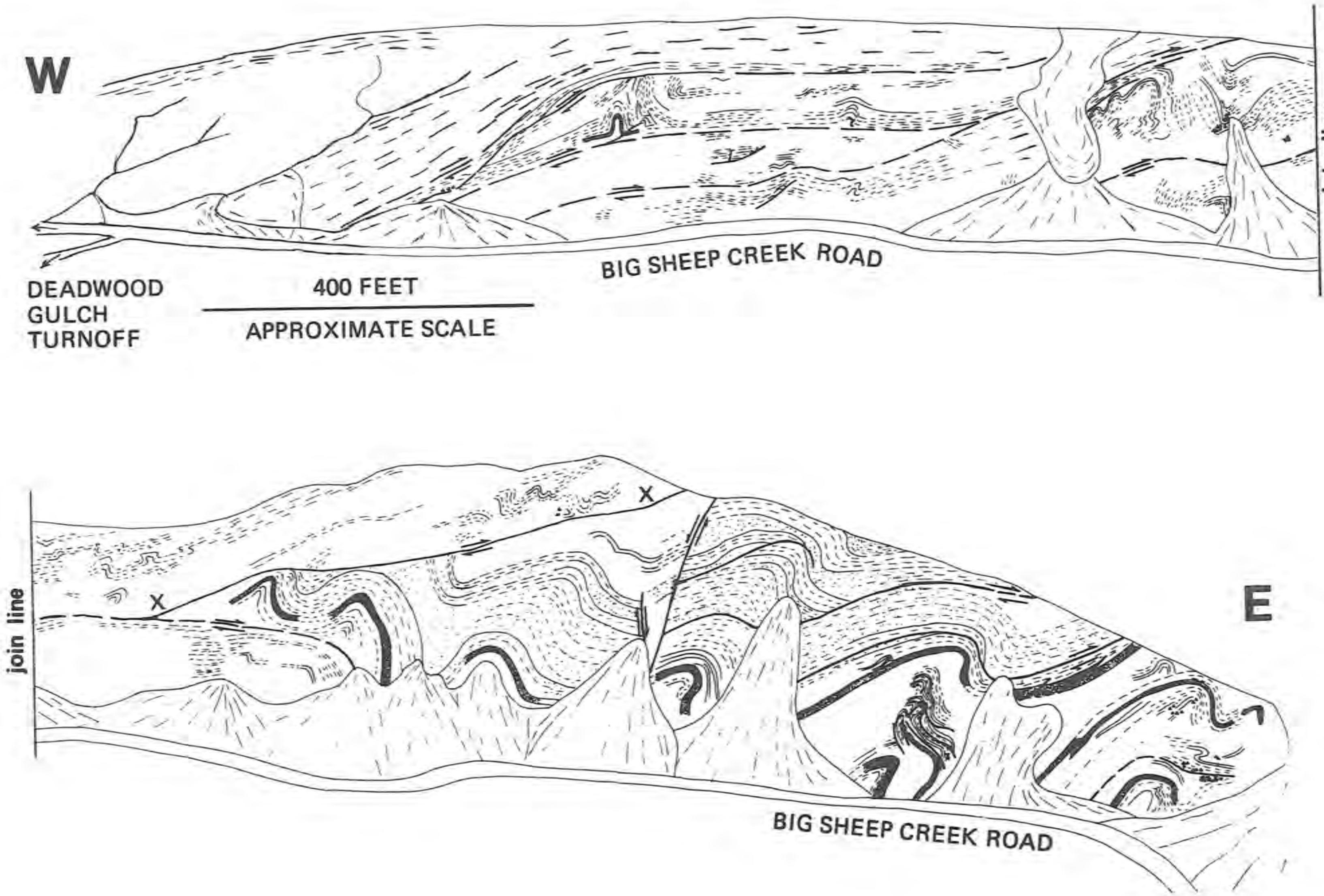
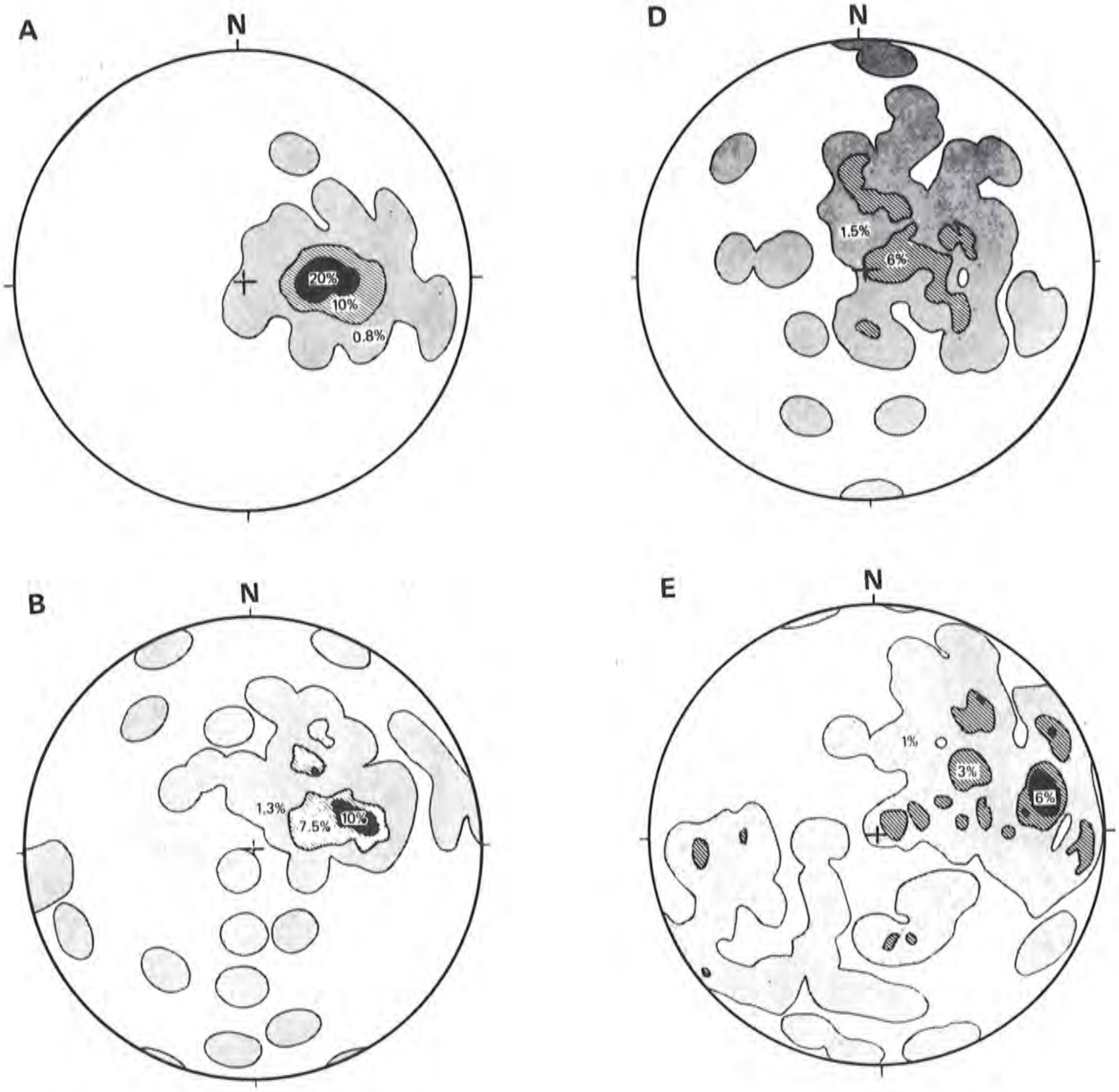


Figure 4. *Sketch of outcrops within the basal plates of the duplex along Big Sheep Creek (from Bartholomew, 1989b). Bedding is defined by dashes and solid lines; breccias are represented by triangles; carbonate sands are dotted pattern; marker beds are shaded; faults are heavy lines; alluvial-debris fans and talus deposits are outlined.*



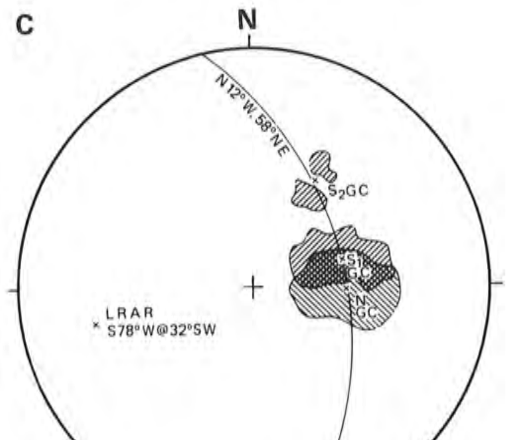
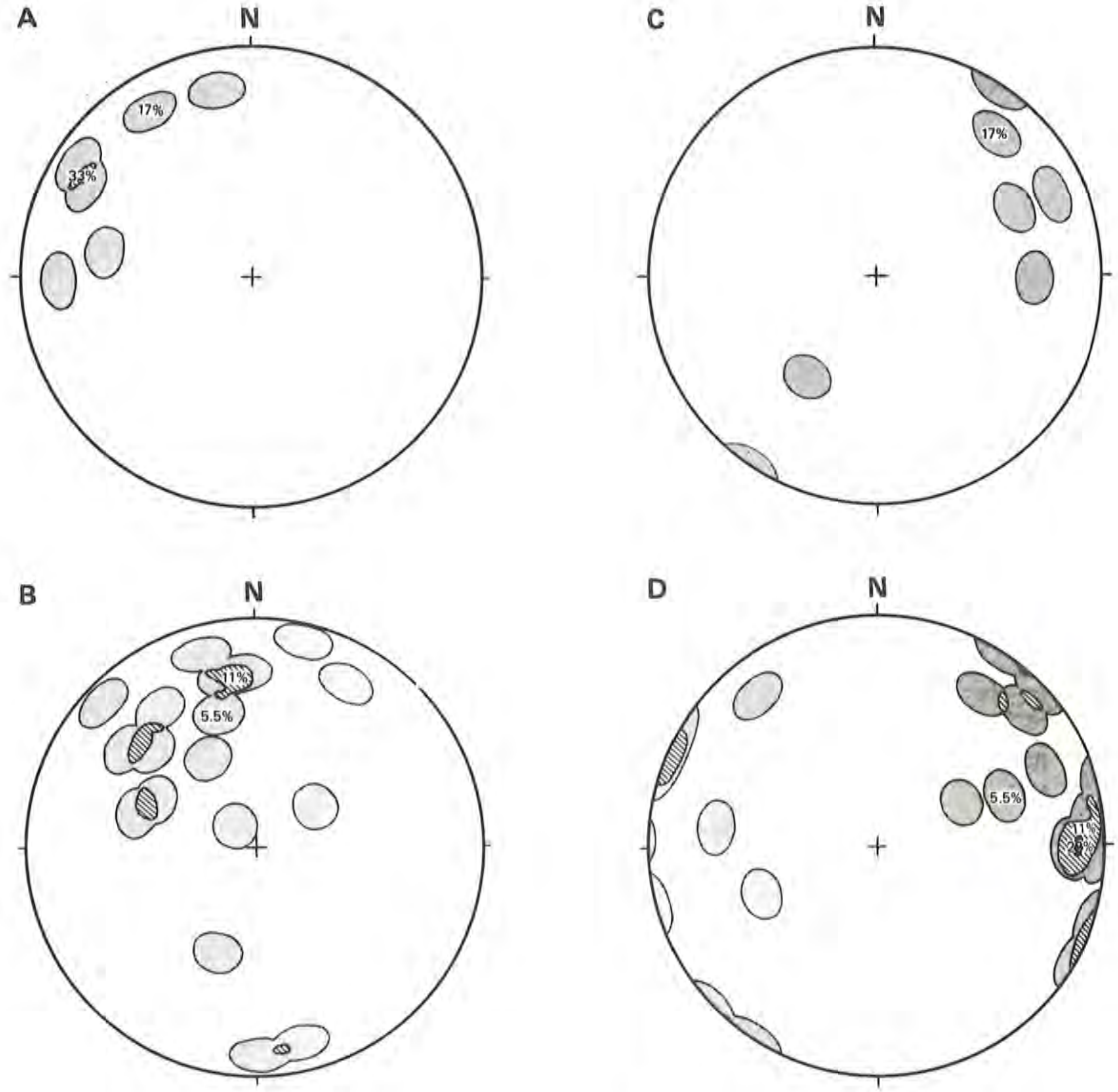


Figure 5. Stereographic projections of poles-to-bedding within the area shown in Figure 3 (excluding sketched outcrops in Figure 4). A-130 poles from north of bend above detachment; B-78 poles from south of bend above detachment; C-lateral ramp axis of rotation (LRAR) obtained from geometric centers (GC) of data concentrations in A and B; D-65 poles from basal plates below detachment; E-107 poles from Deadwood Gulch plate below detachment.



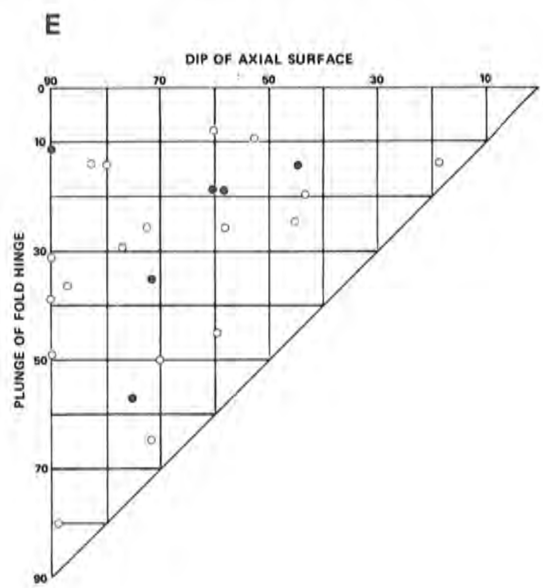


Figure 6. Stereographic projections and fold attitude plot for fold data from area shown in Figure 3. A-6 fold axes above detachment; B-18 fold axes below detachment; C-6 poles-to-axial-surfaces above detachment; D-18 poles-to-axial-surfaces below detachment; E-Fleuty (1964) plot of fold attitudes, solid dots - above detachment, open dots - below detachment.

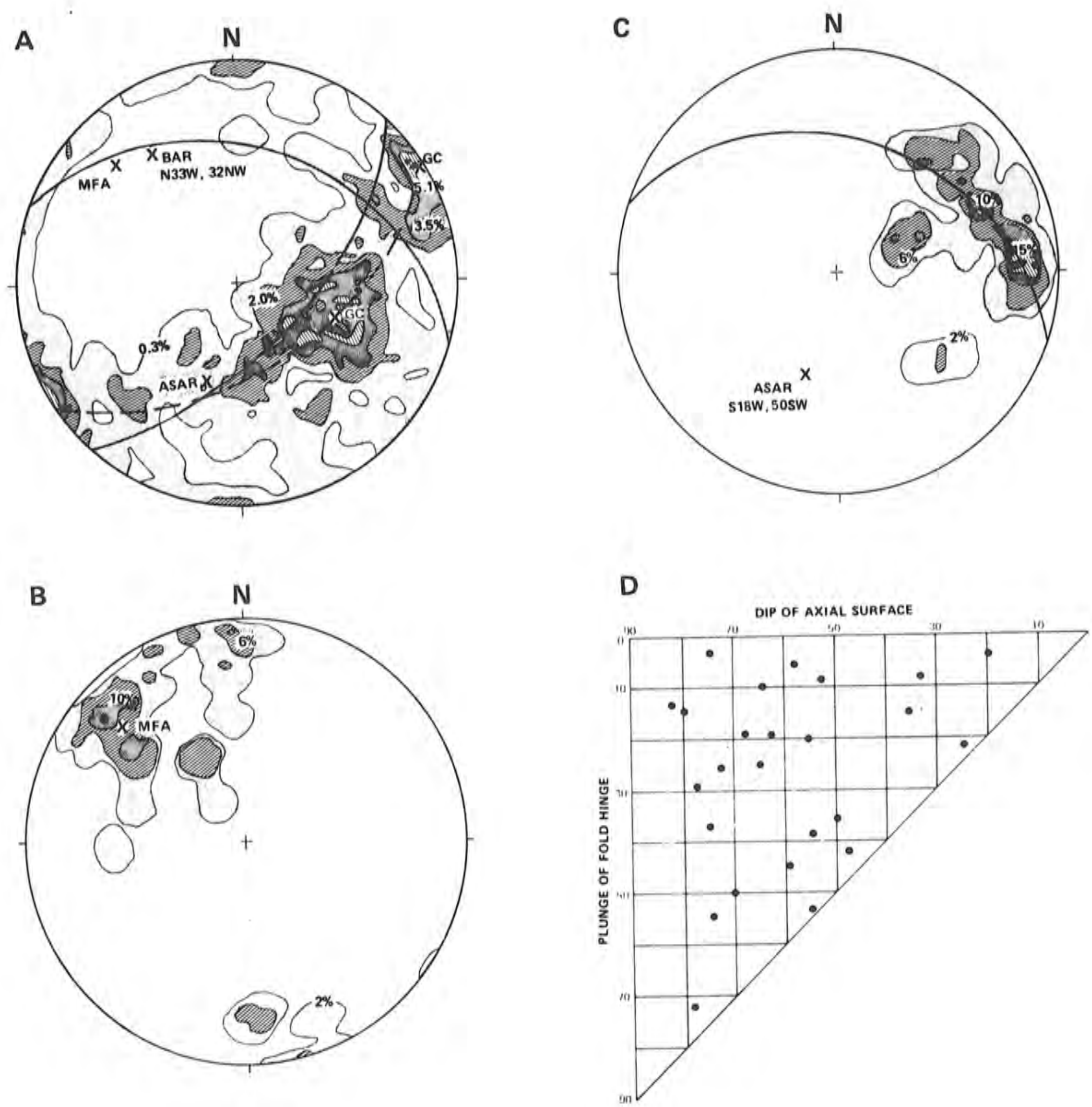


Figure 7. Stereographic projections and fold attitude plot of data from outcrops sketched in ***Figure 4*** *at* ***STOP 2****. A-128 poles-to-bedding; GC-geometric centers of data concentrations within 3.5% contour marked by "X"; MFA-mean fold axis (from 7B); ASAR - axial-suface axis of rotation (from 7C); BAR-bedding axis of rotation (obtained from geometric centers); B-24 fold axes with mean fold axis (MFA) defined by geometric center of area enclosed by 6% contour; C-24 poles-to-axial surfaces with (axial surface) axis of rotation (ASAR) defined from geometric centers of areas enclosed by 10% contours; D-Fleuty (1964) plot of 25 fold attitudes.*

(**Figure 6**) is very limited for this area.Fold axes (**Figures 6A,B**) generally trend NW-SE both above and below the detachment fault and thus are consistent with an inferred NE direction of transport for the Tendoy thrust sheet. Considerable scatter of both fold axes and poles-to-axial-surfaces (**Figures 6C,D**) are suggestive of complex deformation with folding about NW-trending axes as well as warping above oblique-trending lateral ramps. A Fleuty (1964) plot (**Figure 6E**) with a wide range of fold attitudes confirms a complex deformational history.

Comparison of structural data for the whole region (**Figures 3,5, and 6**) with that (**Figure 7**) for the well exposed outcrops sketched in **Figure 4** provides additional confirmation of a complex deformational history. Overall, the 128 poles-to-bedding (**Figure 7A**) do show folding about a crudely defined northwest (N33^{0}W at 30^{0}NW) axis of rotation (BAR) using the geometric centers (GC) of the largest concentration of data within the 3.5% contours. This axis of rotation lies near the Median Fold Axis (MFA; N48^{0}W at 25^{0}NW) of 24 fold axes (**Figure 7B**). Both the fold axes and poles-to-axial-surfaces (**Figure 7C**) show indications of folding about a NE-SW axis of rotation, but a specific axis of rotation (S18^{0}W, 50^{0}SW) could only be obtained from the axial surface data (ASAR). The poles-to-bedding show a dearth of SE-dipping bedding which, when coupled with axes and axial surfaces data, suggest that the plate containing the sketched outcrops (**Figure 4**) ramped over the end of the structurally lower Deadwood Gulch plate (south of Big Sheep Creek) after internal folding about the NW-trending axes. Thus a NE-trending lateral ramp produced a flexure (a NE-trending fold) as a result of a late-stage development of the deformational sequence responsible for the NW-trending folds and faults.

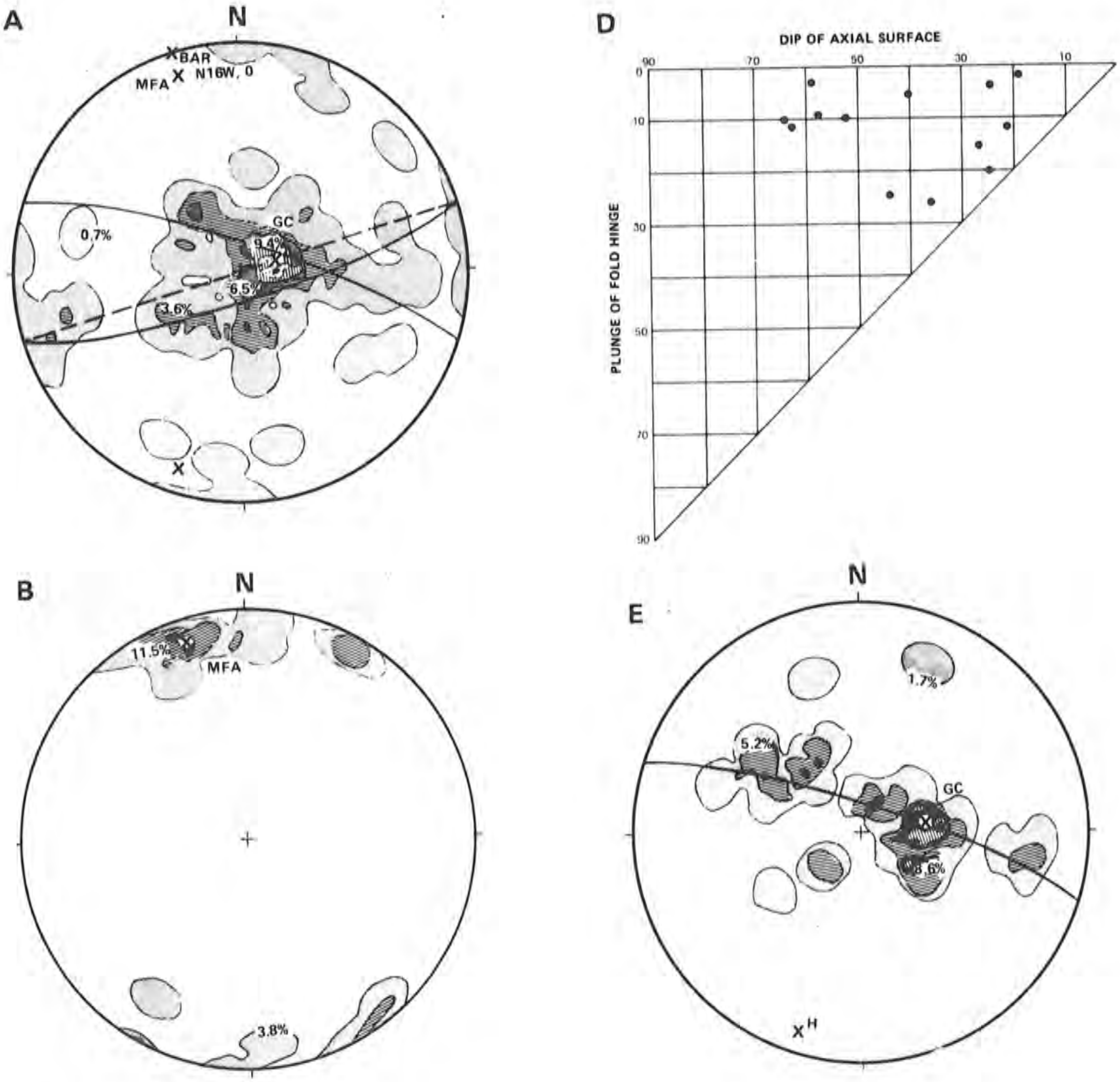
A Fleuty (1964) plot (**Figure 7D**) of fold attitudes in the outcrop (**Figure 4**) like that for the whole region (**Figure 6**), shows a wide variation from upright to gently inclined axial surfaces and from subhorizontal to steeply plunging hinges. Such wide variations in fold axes and attitudes, as well as poles to both bedding and axial surfaces, may be characteristic of broken-up plates above lateral ramps. As an interesting note, the upper plate (**Figure 4**) of the sketched outcrop within the Tendoy thrust sheet has numerous occurrences of tectonic breccia (small triangles) found both along faults and in hinge zones of folds.

Readily apparent in the east-central portion of the sketched outcrops is the relatively undeformed fault (labeled "X" on **Figure 4**) which truncates carbonate sand beds. Measurements along this fault yield strikes of N35-40^{0}E and dips of 15^{0}-25^{0}NW; it is younger than the folded thrusts below it. This relative sequence of faulting when considered with emplacement of this (sketched) plate over the Deadwood Gulch plate (south of Big Sheep Creek), suggests that imbrication proceeded from the basal fault upward. Mapping of the basal plates just north of Big Sheep Creek (**Figure 3**) and to the east of **Figure 4** also shows that basal plates, appear to have been first impeded by relief on the footwall, folded and then were overridden by successively higher plates. To what extent this imbrication sequence for these basal Tendoy plates is applicable to the larger-scale imbricate fan that comprises the Tendoy system has yet to be worked out.

STOP 3: CABOOSE CANYON 7.5'-QUADRANGLE, SEC. 15 T14S, R10W (FIGURES 5,6, & 7)

Analysis of the structural data (**Figure 8**) for this outcrop (**Figure 9**) within Mississ-ippian carbonates of the Four Eyes Canyon thrust sheet shows some interesting con-trasts, as well as similarities, with that of the Tendoy thrust sheet. Apparent differences may be the result of small available sample size due to a lack of detailed mapping in this area. They may, however, be real structural differences that reflect either the structural position of the sketched outcrops within the thrust sheets or variations in the structural evolution of the Four Eyes and Tendoy thrust sheets.

The 69 poles-to-bedding (**Figure 8A**) show considerable scatter, but yet less dispersion than those in the Tendoy thrust sheet (**Figures 5 and 7A**). Most bedding at this outcrop is subhorizontal to gently inclined. Using the geometric center (GC) of



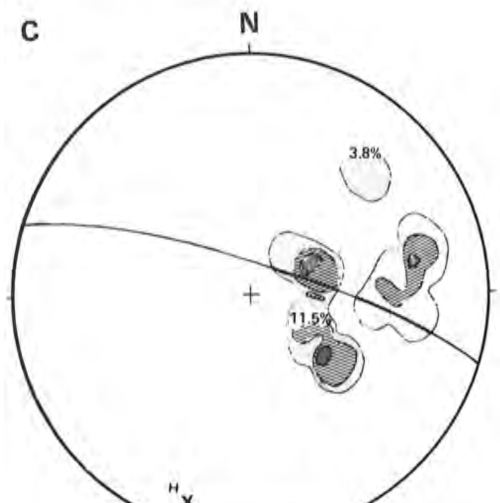


*Figure 8. Stereographic projections and fold attitude plot of data from outcrops sketched in **Figure 9** at **STOP 3**. A-69 poles-to-bedding; MFA-mean fold axis (from 8B), GC-geometric center of area with 6.5% contour is marked by "X", BAR-bedding axis of rotation from 6.5% GC; B-13 fold axes with mean fold axis (MFA) obtained from geometric center of largest concentration of data; C- 13 poles-to-axial surfaces; D-Fleuty (1964) plot of 13 fold attitudes; E-29 poles-to-fault-surfaces; hinge (H) axis of rotation obtained from geometric center of areas within 8.6% contours.*

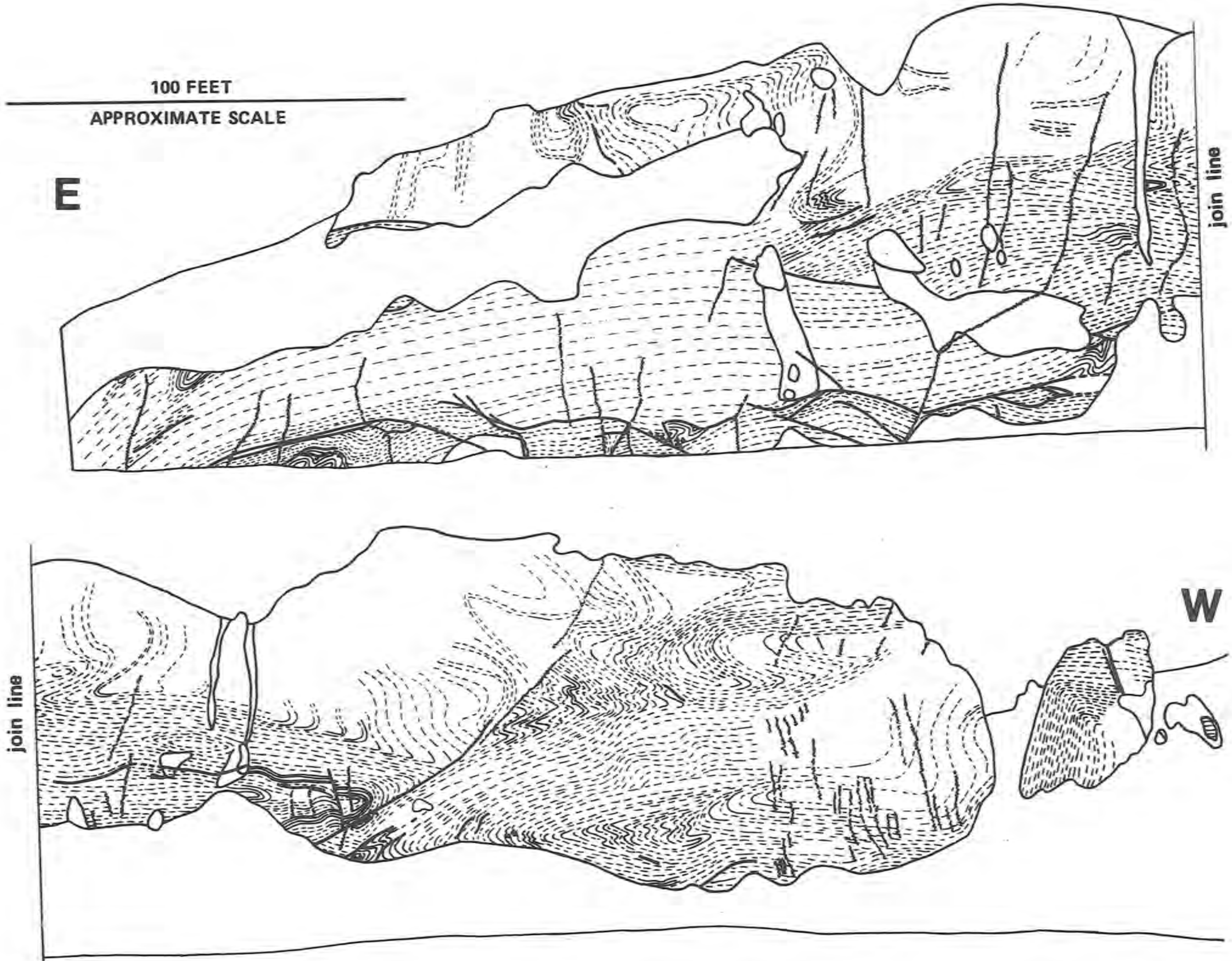


Figure 9. Sketch of outcrops at STOP 3 within the Four Eyes Canyon thrust sheet. Bedding is defined by dashed and solid lines; breccia is represented by triangles; veins are zigzag lines; faults are heavy lines.

the 6.5% contour, a poorly defined girdle suggests a subhorizontal axis of rotation at N16°W (BAR). The median of the largest concentration of the 13 fold axes (**Figure 8B**) is N16°W at 11°NW (MFA; also shown on **Figure 8A**). Both the axes and poles-to-axial-surfaces (**Figure 8C**) exhibit some dispersion similar to that of the Tendoy sheet (**Figures 6 and 7**), but the data is insufficient to define an axis of rotation. The 29 poles-to-fault-surfaces (**Figure 8E**) do, however, define a girdle; using the geometric center (GC) of the 8.6% contour, the axis of rotation is S19°W at 10°W (H). This "folding" of the fault surfaces reflects the orientation of the ramp-flat flexures visible in the sketch (**Figure 9**). Hinge attitudes of ramp-flat flexures (H on **Figures 8A,C,E**) do coincide with the trend of a few fold axes; however, the axis of rotation (S19°W, 10°SW) is definitely oblique to the trend of the median fold axis (MFA)-(N16°W). These ramp-flat flexures may account for dispersion of both bedding and axial surfaces (**Figures 8B,C**).

In contrast to the Tendoy thrust sheet (**Figures 6E, 7D**), the attitudes of 13 folds plotted on a Fleuty (1964) graph (**Figure 8D**) vary only moderately--from gently to steeply inclined axial surfaces and from subhorizontal to gently plunging axes. Breccia development is comparable with the Tendoy sheet. Here, as at **STOP 2**, breccia is found both along faults and within fold cores, where it likely is a mechanism to alleviate the "space and detachment" problems of tight folds.

Taken as a whole the data at this stop suggest only one deformation sequence; the variations in bedding result from the oblique trend (35°) of ramp-flat flexures relative to the dominant trend of folds. The visible outcrop structures (**Figure 9**) and measured surfaces coupled with a consistently oblique trend of ramp-flat flexures, suggests that tight folding primarily preceded faulting with breccia development accompanying both.

Unfortunately not much data on fault surfaces could be measured at **STOP 2** to compare with that at **STOP 3**. Because of the similiarities of data at both stops it may be that ramp-flat flexures at **STOP 2** are also oblique to the dominant trend of folds; certainly this is the case regarding the flexure above the lateral ramp of the Deadwood Gulch plate. Perhaps within plates containing large variations in bedding and fold orientations, oblique and lateral ramps are the primary features which cause dispersion of earlier folded bedding and folds. Because the data at both of these stops indicate that NW- and NE-trending folds are developing during a single deformational sequence, care must exercised before inferring on the basis of orientation that any particular fold set(s) are inherited structures from an earlier deformational event. Such a conclusion regarding folds, like the NE- trend ing Little Water syncline of the Tendoy thrust sheet, are probably not warranted without other confirming structural data. Bartholomew (l989a) suggested that the Little Water syncline is, in fact, a late structural feature developed within the Tendoy thrust sheet.

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FIELD TRIP GUIDE, ROADLOG, AND SUMMARY OF CRETACEOUS VOLCANIC GEOLOGY, DILLON TO BANNACK, BEAVERHEAD COUNTY, MONTANA

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OUTLINE OF TRIP

This field trip will cover the geology between Dillon, Mont., and the Bannack mining district, which is about 18 mi west southwest of Dillon (fig. 1). The geology that will be emphasized on the field trip involves Upper Cretaceous volcanic rocks and shallowly emplaced intrusive rocks, structure and stratigraphy of the thrust-faulted and folded strata near Badger Pass and Bannack, and the mining history and economic geology of the Bannack district. As planned, the field trip will leave Dillon heading south on Interstate Highway I-15, turn west on Montana Highway 278, leave this highway near Ermont Gulch, and return to it again near Badger Pass. The trip will then continue west on Highway 278 to Grasshopper Creek valley, turn south in Grasshopper Creek valley, and proceed to Bannack (fig. 2). Ten stops are planned along the route and in the Bannack area, where rocks and structural relationships will be examined. A lunch stop is planned at Bannack State Park. Placer mining activities in recent years along Grasshopper Creek downstream from Bannack have disrupted road access to some of the planned stops, and hence access to those stops is by 4-wheel-drive vehicle only.

REGIONAL GEOLOGIC SETTING

Dillon is located near the north-trending boundary between the Montana thrust belt to the west and the Rocky Mountain foreland to the east. The actual location of this boundary near Dillon is uncertain, however, for it is buried beneath post-thrusting Tertiary sedimentary deposits and volcanic rocks that occupy the broad Beaverhead River valley. Ruppel and Lopez (1984) divide the thrust belt into an eastern "frontal fold and thrust zone," which is a gradational zone between the thrust belt and the foreland, and two major thrust plates to the west, the Grasshopper plate and the Medicine Lodge plate. The area of figure 2 is within the frontal fold and thrust zone.

Rocks of the foreland and the frontal fold and thrust zone are similar stratigraphically and temporally and include crystalline basement, mainly of Archean age; sedimentary strata of Proterozoic, Paleozoic, and Mesozoic age; igneous rocks, both intrusive and extrusive, mostly of late Mesozoic and early Cenozoic age; and basin-fill, glacial, and alluvial deposits of Cenozoic age. The crystalline basement is widely exposed east of the

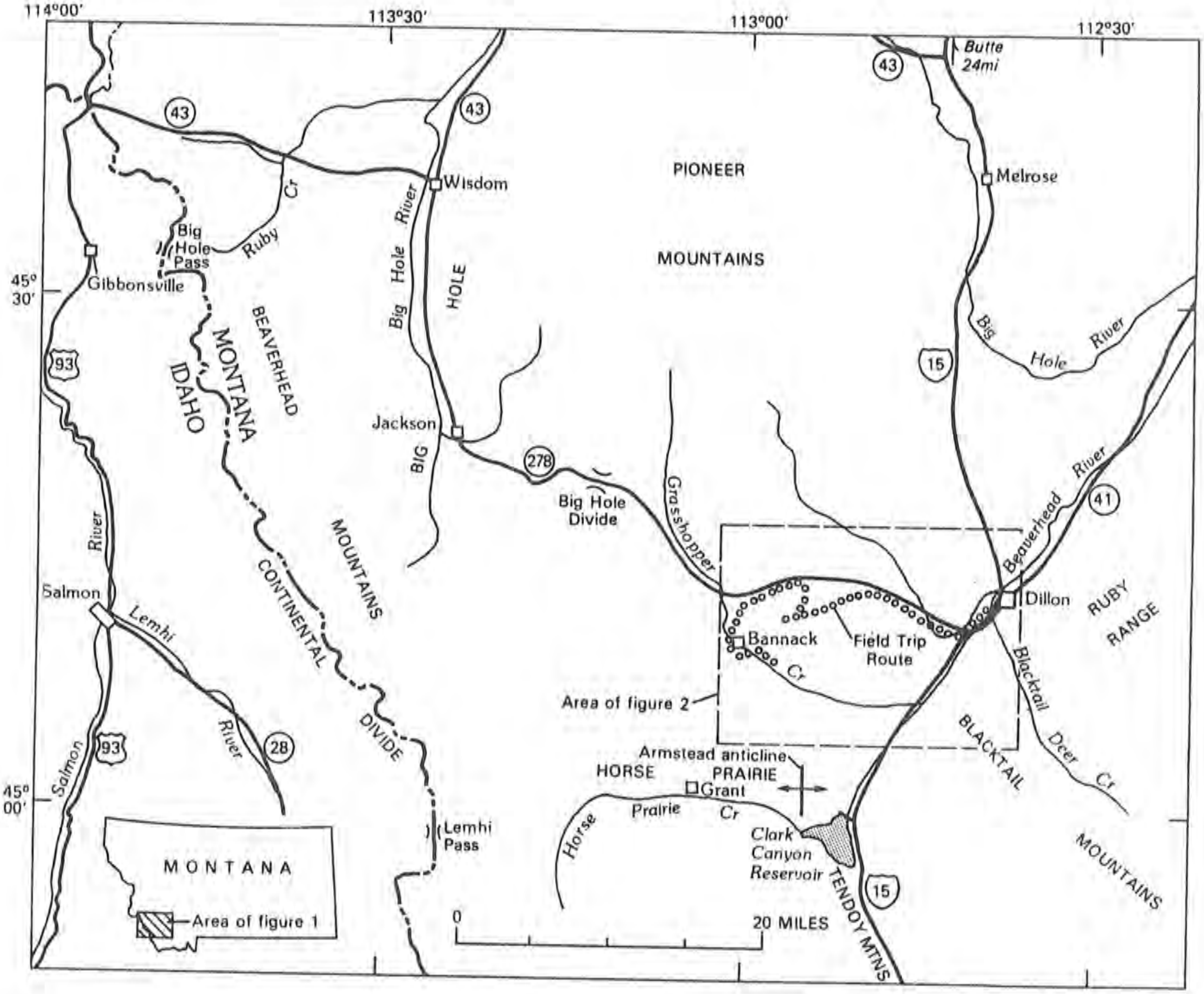

Figure 1.--Index map showing parts of southwestern Montana and east-central Idaho

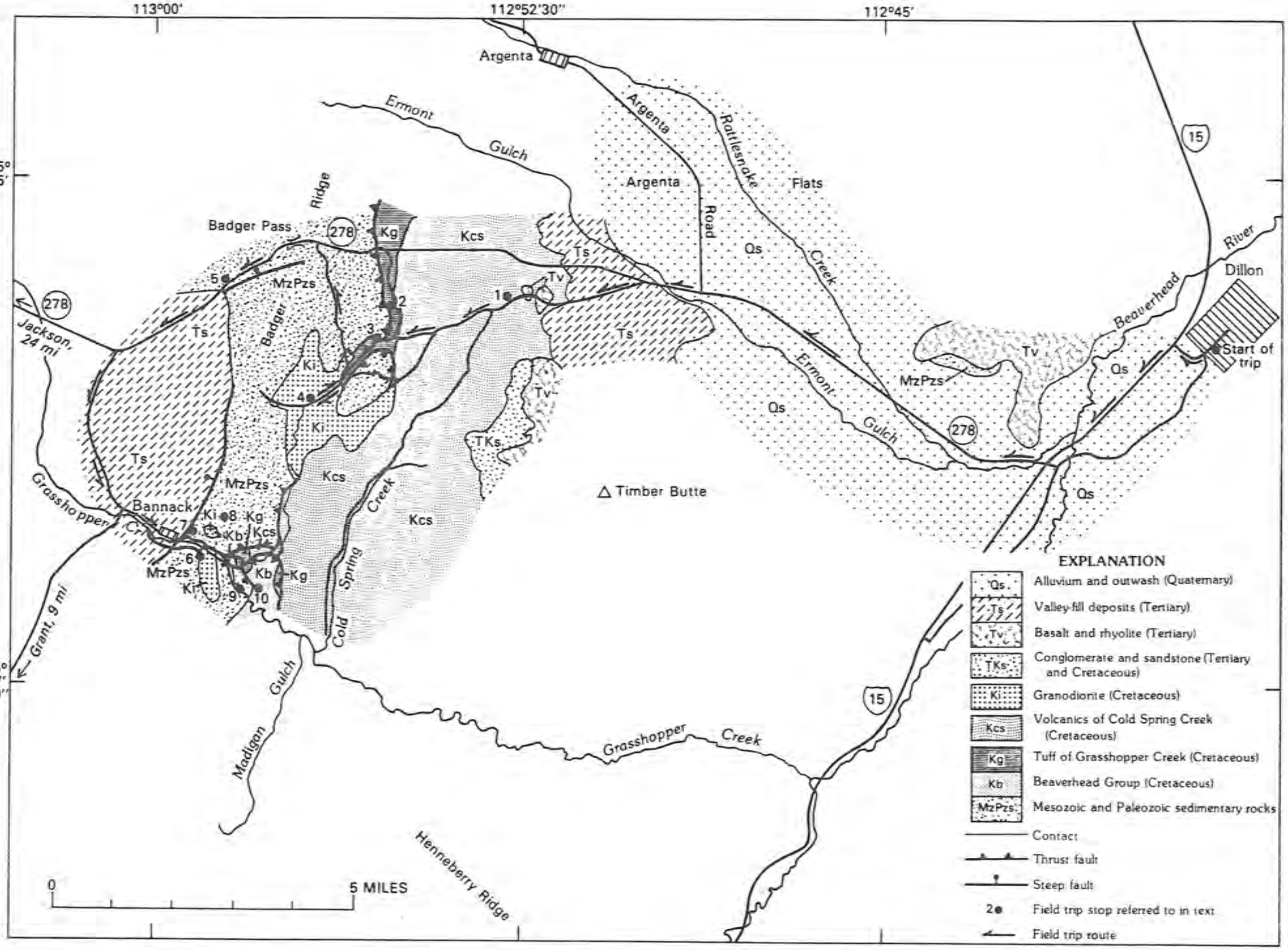

Figure 2.--Generalized geologic map and field trip route, Dillon to Bannack, Beaverhead County, Montana

thrust belt. The broad low Ruby Range east of Dillon typifies these exposures. The Archean basement is also exposed in the frontal fold and thrust zone (the Armstead anticline) and as thrust slices in higher thrust plates to the west (in the Bloody Dick Creek, Medicine Lodge Creek, and Maiden Peak areas about 40 mi southwest of Dillon). Sedimentary strata of Proterozoic age, probably all of the Belt Supergroup in the general region of Dillon, are exposed mainly in the thrust belt. Near Argenta, Belt strata are the oldest rocks exposed, and they are overlain in depositional contact by Cambrian and younger strata. Except for the Argenta area, which is in the frontal fold and thrust zone as defined by Ruppel and Lopez (1984), Belt strata are confined to the Grasshopper plate and higher thrust plates in the region west of Dillon. Paleozoic and Mesozoic strata are widely distributed east of the thrust belt in the region east of Dillon and in the eastern part of the thrust belt, where their base is in depositional contact with Belt strata in some places (Argenta) and with Archean crystalline rocks in others (Blacktail Mountains and Armstead anticline). Changes in sedimentary facies from the foreland westward into the thrust belt, especially of some of the marine Paleozoic units, are partly the result of telescoping by the thrusts (Ruppel and Lopez, 1984).

Phanerozoic igneous rocks in the Dillon region are of Late Cretaceous and Tertiary age. Most of the plutons are Late Cretaceous in age and intermediate in composition, such as monzogranite, granodiorite, and tonalite; chemically they are mostly calc-alkalic. Cretaceous volcanic rocks, including the Elkhorn Mountains Volcanics and those discussed below, are associated on a regional basis with the Cretaceous plutons. Tertiary volcanic rocks, chiefly Eocene in age, are present in isolated patches in a 100-mi-long belt that trends northward through Dillon and includes the Lowland Creek Volcanics near Butte, Mont., and the Trusty Gulch Volcanics near Melrose, Mont. Within 20 mi of Dillon, to the south and southwest, the Eocene volcanics are mainly a bimodal suite of basalt and rhyolite.

Tertiary deposits that fill the basins and locally cap upland areas are commonly from less than one hundred to many thousands of feet thick and contain a major pyroclastic component, especially in tuffaceous mudstone. Other deposits consist of locally derived, fluvially deposited, fine- to coarse-grained detritus. So far as is known, all such deposits in the Dillon area are younger than the Eocene volcanic rocks. The boundaries of the basins in many places are high-angle faults, but in other places, such as west of Dillon, the middle to upper Tertiary deposits lap far westward onto the east flank of Badger Ridge.

CRETACEOUS VOLCANIC ROCKS

Upper Cretaceous volcanic rocks occupy a small volcanic field that underlies at least 50 sq mi west and southwest of Dillon, in the treeless rolling sagebrush country east of Badger Ridge and in lower Grasshopper Creek valley (fig. 2). These rocks extend an unknown, but probably short, distance beneath younger deposits northward from their northern limit of exposure at Ermont Gulch and eastward from their present exposed limit near Timber Butte and lower Grasshopper Creek. In addition, an unknown amount of these deposits is covered by a thrust plate to the west. The southern limit, according to mapping by Lowell (1965), is the north flank of Henneberry Ridge. In some of the earliest large-scale geologic mapping in this area (Myers, 1952; Lowell, 1965), these rocks were interpreted as Tertiary. This age was accepted until Snee and Sutter (1979) provided evidence that they are Cretaceous on the basis of K/Ar age determinations. The Cretaceous age has been confirmed by more recent determinations using the $^{40}Ar/^{39}Ar$ technique and refined to a range of about 73-80 Ma (analyses by L.W. Snee in Ivy, 1989). However, these ages were determined on samples from the upper part of the volcanic sequence and on related subvolcanic intrusives, and the lower part of the sequence is known only to be about 80 Ma or older.

The Cretaceous volcanic rocks consist of two dissimilar units: an upper unit of intermediate volcanic breccia, lava flows, and related sedimentary deposits and intrusive bodies and a lower unit of zeolitic silicic tuff. In this report, the upper unit will be referred to as "volcanics of Cold Spring Creek," and the tuff unit will be referred to as "tuff of Grasshopper Creek," as they were by Ivy (1989) and Pearson (1988). Myers (1952) and Lowell (1965) called the upper unit "Andesite." Myers (1952) referred to the tuff unit merely as "Tuff," and Lowell (1965) called it "Early tuff."

The volcanic rocks are in depositional contact on conglomerate and sandstone of the Upper Cretaceous Beaverhead Group at most places and on older Cretaceous units such as Kootenai Formation or Paleozoic strata at others. In lower Grasshopper Creek (geology in this area not shown on figure 2), the tuff of Grasshopper Creek has been deposited unconformably across tilted Kootenai Formation that dips as much as 80°, although where deposited on the Beaverhead Group the base of the tuff seems to be conformable. In the Madigan Gulch area, the tuff is apparently in depositional contact with Mississippian formations.

The Upper Cretaceous volcanic rocks are overlain unconformably by rocks of at least three different units. North of Ermont Gulch and along Highway 278, the volcanic rocks are covered by fluvial basin-fill deposits of Miocene(?) age. Along their east side, they are overlain by conglomerate and sandstone that may be latest Cretaceous or early Tertiary age. This conglomerate and sandstone unit has been referred to the Beaverhead Group with some hesitancy by Lowell (1965) and definitely by De la Tour-du-Pin (1983), Johnson (1986), and Thomas (1981). Eocene lava flows and pyroclastic deposits overlie the Cretaceous volcanic rocks locally in lower Grasshopper Creek.

Structurally, the Cretaceous volcanic rocks are only mildly deformed except along their western edge, where they have been overridden by a thrust sheet of older rocks. Overall, these rocks occupy a shallow structural basin: they generally dip eastward at about 10°-40° along their west edge, tend to flatten farther east toward the center of the basin, and dip west at some easternmost exposures. Minor structures that affect the rocks within the basin include rather sparse faults and gentle folds. The thrust fault along the west edge is best exposed about 1 mi east of Bannack on the north side of Grasshopper Creek, where the usual eastward homoclinal dips are steepened greatly. Beneath the upper plate of Mississippian limestone, the lower plate rocks, consisting of the Beaverhead Group, the tuff of Grasshopper Creek, and the volcanics of Cold Spring Creek, have all been tilted to vertical.

Tuff of Grasshopper Creek

The tuff of Grasshopper Creek crops out discontinuously around the periphery of the Cretaceous volcanic rocks. Only the western margin of the basin is shown on figure 2. The exposure is extensive from Highway 278 northward to Ermont Gulch in an area that seems to be the trough of a shallow syncline and that probably marks the north end of the structural basin. Southward along the east side of Badger Ridge, east of the main thrust fault, the tuff is discontinuously covered by the overlying volcanics of Cold Spring Creek and in part cut out by the thrust. Thickness of the unit ranges from a few tens of feet to >1,000 ft.

The tuff is well indurated, forms low rolling topography, and is less resistant to erosion than the Paleozoic limestone to the west. In general appearance, the light color of the tuff contrasts with other rocks. The color typically ranges from yellowish gray, light olive gray, pinkish gray, pale red, to white, as well as other pale shades. Manganese dendrites are common, and limonite coats fracture surfaces, giving the rock a pale yellow hue in many places.

The tuff unit consists of massive beds a few feet to several tens of feet thick that in places alternate with thinner zones of platy to flaggy rocks that are finer grained and better sorted. The massive beds are interpreted as pyroclastic-flow deposits, and the platy rocks are probably fallout-tuff deposits. In most of the outcrop area, the pyroclastic-flow deposits have a compaction foliation that resulted from collapse of pumice fragments. This structure seems to be a reliable indicator of bedding attitude. Flattened pumice fragments commonly are 0.2-2 in. in diameter and <0.1-0.4 in. thick. Flattening of the pumice fragments to produce the compaction foliation is tentatively ascribed to orogenic deformation and later magmatic heating and not to compaction during welding when the deposit was hot, because the foliation seems to be best developed where the unit is most deformed near faults and intrusives. In addition, the pyroclastic-flow deposits contain variable amounts of accidental pyroclastic fragments of sedimentary rock and angular to rounded fragments of non-pumiceous juvenile igneous rock.

The tuff is very sparsely porphyritic. Local angular fragments of quartz are presumed to be pyrogenic. Plagioclase phenocrysts are uncommon and almost entirely altered to authigenic minerals. As determined by X-ray diffraction, the tuff is composed largely of authigenic quartz, feldspar (commonly both plagioclase and potassium feldspar), and zeolites (mordenite, clinoptilolite, and in one sample, analcime). In the northern and western outcrops of the tuff, especially near intrusives, zeolites are sporadic, and many samples consist mainly of authigenic (or metamorphic) quartz and feldspar. In southeastern outcrops, clinoptilolite is the most abundant mineral.

Volcanics of Cold Spring Creek

Volcanics of Cold Spring Creek include volcanic breccia, lava flows, a dome, several related intrusives, and minor volcanic conglomerate and volcanic sandstone, mostly of dacitic or andesitic composition. The individual units are not shown separately on fig. 2. These rocks overlie or intrude the tuff of Grasshopper Creek at most places. Their chemical petrology has been investigated by Ivy (1989) and Ivy and others (1988), and their isotopic ages have been determined by L.W. Snee (<u>in</u> Ivy, 1989).

The rocks are generally calc alkalic; they are mostly porphyritic high-K dacite and minor dacite and andesite. Phenocrysts constitute from a few percent to several tens of percent. The phenocrysts are predominantly plagioclase, and varying amounts of hornblende, biotite, clinopyroxene, orthopyroxene, and quartz are present.

Volcanic breccia and lava flows constitute the bulk of the unit. Most of the breccias appear to be flow breccias. The breccia fragments in any particular outcrop area are rather uniform in composition and size, commonly from one to several inches long, and embedded in a nonfragmental matrix that is similar lithologically to the fragments and appears to be chilled lava. Some of the breccias are lahars in which the fragments are embedded in finely fragmental material; others are interpreted as volcanic conglomerate, although the distinction among the various types of breccia is not always clear. Unbrecciated or slightly brecciated lava flows are massive to flow layered. Folded and contorted flow layers are common. A doughnut-shaped body of uniform lava north of Grasshopper Creek and east of Cold Spring Creek has been interpreted by Ivy (1989) as a volcanic dome. This body is almost 2 mi in diameter. On its exterior perimeter, the rock of the dome seems to overlie volcanic breccia. The core of the dome is occupied by a circular plug (Meyer, 1980) that is altered to a phyllic assemblage and mineralized with sulfides. The surrounding rock of the dome is altered to a propylitic assemblage. The dome has a weak to moderately strong foliation that dips gently to moderately toward the center, suggesting a funnel-shaped intrusion that perhaps reached the surface and formed a dome.

Along the east side of the outcrop belt of volcanic rocks of Cold Spring Creek, a more or less concordant sheet of intrusive rock is exposed for a distance of 10 mi from a point just south of Ermont Gulch to a point about 0.5 mi south of Grasshopper Creek. This body is called the McDowell Spring intrusive sheet. Differences in elevation within the sheet, especially in cliffs along Grasshopper Creek, indicate that the sheet is at least 400 ft thick. It intrudes the tuff of Grasshopper Creek and several phases of the volcanics of Cold Spring Creek, including the dome mentioned in the preceding paragraph. The sheet has not been shown to be in contact with the plug in the center of the dome nor with extrusive rocks south of Grasshopper Creek that Ivy (1989) interprets as younger than the McDowell Spring sheet. The intrusive relations are observed most commonly in the form of dikes that emanate from the sheet and extend into the country rock for as much as 1,000 ft. No definite top of the sheet has been found, and except for the dikes, the body might be interpreted as a very large lava flow. The rock of the sheet is massive to coarsely flow layered and weathers to fine grus and to rounded forms along foliation and exfoliation surfaces. Except near contacts, weathered surfaces are a distinctive greenish brown, and joints are commonly a distinctive orange. At some places where the sheet and related dikes are chilled against extrusive rocks, the contact can be recognized only because the country rock is volcanic breccia, whereas the rock of the sheet is uniform and not brecciated.

PALEOZOIC AND MESOZOIC ROCKS OF BADGER RIDGE

The stratified rocks exposed on Badger Ridge, between Badger Pass and Bannack, range from Lower Mississippian to Cretaceous. The Lodgepole Limestone is the oldest unit recognized, and the Beaverhead Group, the youngest. A stratigraphic column and a brief description of the units are given in figure 3. These units were folded and faulted during the thrusting that is evident along the east side of Badger Ridge and near Grasshopper Creek east of Bannack. The units were also deformed prior to thrusting, according to Lowell (1965) and Johnson and Sears (1988); Johnson and Sears (1988) interpreted the earlier deformation as of Laramide style and the younger one as of Sevier style.

BLUE WING MINING DISTRICT

The Blue Wing district adjoins the Bannack district on the north and is about half way between Bannack and Highway 278 (fig. 2).

Ore was discovered in the Blue Wing district in 1864, and the first mine developed, the Kent, became the first silver mine in Montana (Shenon, 1931). In contrast to the Bannack district (discussed below), the Blue Wing district is chiefly a silver district, and its total production is much smaller but probably in excess of $2,000,000 (Geach, 1972).

The geology of the Blue Wing district is strikingly similar to that of the Bannack district. The main ore bodies are replacement deposits and short veins in Mississippian limestone near the contact with fine-grained granodiorite. In addition, a few veins in granodiorite have been mined. The granodiorite body is more than 1.5 mi wide and 2 mi long but is probably relatively thin, as it seems to have intruded along a flat or gently west-dipping thrust fault (the same thrust exposed on the east side of the Bannack district). If this intrusive body has a root or feeder pipe beneath it, as seems likely, its location is unknown. The largest mine in the district is the New Departure, which was developed in a klippe of Mississippian rocks. The klippe, which is about 0.5 mi wide and 1 mi long, is partly in fault contact with Cretaceous volcanic rocks and partly is underlain by the granodiorite body that is inferred to have intruded along the thrust contact. The ore bodies are in limestone near the intrusive contacts.

Much of the richer ore mined was oxidized to a brown to black aggregate of iron and manganese oxides. Primary ore minerals include sphalerite, galena, chalcopyrite, pyrite, polybasite, tetrahedrite, and pyrargyrite in a gangue of quartz, calcite, and rhodochrosite.

BANNACK MINING DISTRICT

History

Bannack holds a unique position in the mining and political history of Montana, chiefly because it was the first discovery that led to the development of a major mining district and because it was the first capital of the Territory of Montana. In recognition of this and because of its picturesque appearance, its preservation as Bannack State Park is richly deserved. Much of the information that follows was derived from Geach (1972), Sassman (1941), and Shenon (1931).

The first white men to visit the area were members of the Lewis and Clark expedition who made their way up the Beaverhead River in August, 1805. They went through the present site of Dillon, passed the mouth of Grasshopper Creek, which they named Willard's Creek, and continued south and west over the mountains through Lemhi Pass (fig. 1). On their return the following year, William Clark and 19 others came south through Big Hole valley, crossed over Big Hole Divide (probably where the present Highway 278 crosses), and went down Grasshopper Creek on their way to a cache on Horse Prairie Creek to the south (fig. 1). Thus, they were within sight of Bannack, undoubtedly without giving gold or mining a passing thought.

Figure 3.-- Stratigraphic column in the Badger Pass-Grasshopper Creek area

Age	Unit	Thickness* (ft)	Description
Quaternary	Alluvium and outwash	0-150	Gravel and sand
Tertiary	Valley-fill deposits	0->300	Upper part, fluvial conglomerate and sandstone; lower part, stacked paleosols and local sandy and pebbly channel fillings
	Volcanic rocks	0-1,200	Basalt lava flows and pyroclastic deposits; rhyolite lava flows, welded ash-flow tuff, and fallout tuff deposits
	Conglomerate and sandstone. (Upper Beaverhead conglomerate of Johnson, 1986)	0-1,300	Fluvial conglomerate and sandstone and minor lacustrine limestone. Conglomerate composed mostly of mixed lithologies: Proterozoic, quartzite, Paleozoic and Mesozoic limestone and sandstone, and locally derived igneous rocks; in places one lithology predominates
Cretaceous	Granodiorite		Gray, fine grained. Contains pyroxene, biotite, and hornblende
	Volcanics of Cold Spring Creek. **Stop 1**	100-1,600	Porphyritic volcanic breccia, lava flows, a volcanic dome, and related intrusives and sedimentary deposits, of intermediate composition. Phenocrysts of plagioclase, biotite, hornblende, clinopyroxene, orthopyroxene, and locally quartz, in various combinations.
	Tuff of Grasshopper Creek. **Stops 2 and 3**	100-1,000	Yellowish-gray, light gray, pale red and white pyroclastic-flow and fallout-tuff deposits; very slightly porphyritic; siliceous, feldspathic, and zeolitic. Compaction foliation common
	Beaverhead Group. **Stops 9 and 10**	200-3,000	Limestone-pebble and limestone-cobble conglomerate and brown calcareous quartz sandstone. Matrix of conglomerate is mostly quartz sand and calcite cement. Limestone pebbles and cobbles are mostly derived originally from Mississippian formations
	Kootenai Formation	1,200	Three members (from base to top): (1) sandstone and conglomerate; (2) interbedded sandstone, shale, and limestone; (3) gastropod limestone
Triassic	Dinwoody Formation	200-400	Gray to grayish-brown siltstone, fine-grained sandstone, and brown-weathering fossiliferous limestone. Only the brown-weathering limestone is evident near Badger Pass
Permian	Phosphoria Formation	300	Sandstone, cherty sandstone and quartzite, phosphatic mudstone, dolomite, and cherty dolomite
Pennsylvanian	Quadrant Quartzite	650	Light-gray, tan, and white brown-weathering medium- to fine-grained thick-bedded to massive orthoquartzite
Mississippian	Conover Ranch Formation. **Stop 5**	100	Red commonly calcareous mudstone, siltstone, and sandstone; red and gray limestone and sandy limestone
	Lombard Limestone. **Stops 3,7, and 8**	500	Light- to medium-gray thin- to thick-bedded limestone. Internally contorted by folding
	Kibbey Sandstone. **Stops 2, 7, and 9**	150	Pale-yellow, yellowish-orange, and reddish-brown argillaceous calcareous sandstone, siltstone, and mudstone. Evaporite solution breccia present locally
	Mission Canyon Limestone. **Stop 9**	1,000	Light-gray medium- to thick-bedded limestone and dolomitic limestone, and locally near top, medium-gray dolomite
	Lodgepole Limestone	800	Light- to dark-gray thin-bedded limestone. Calcareous mudstone and siltstone form thin partings between limestone beds

* Thicknesses estimated from the Badger Pass-Grasshopper Creek area or extrapolated from nearby areas (Lowell, 1965; Tysdal, 1988; Myers, 1952).

In 1862, a group of prospectors, who had come into east-central Idaho from the south, crossed the Beaverhead Mountains, probably at Big Hole Pass east of Gibbonsville, Idaho, and discovered gold about July 10 in the streams at the head of Ruby Creek, which is about 10 miles southwest of the present town of Wisdom, Mont. In order to bring supplies by wagon from Idaho to the new diggings, the miners followed the Indian trail over Lemhi Pass, went down Horse Prairie Creek, and then turned north into upper Grasshopper Creek valley. Within weeks, other prospectors followed this route from the Salmon River country, and on July 28, 1862, members of a party that included John White and William Eads, panned the gravels where they crossed a creek and found colors. Not aware that Lewis and Clark had named the creek Willard's Creek, they named it Grasshopper Creek, which name has survived.

News of the discovery spread rapidly. Wagon trains and parties of various size throughout the region were diverted from their original destinations by the reports of gold and headed for Grasshopper Creek. That first year about 400 persons wintered at Bannack, as the miners named the new camp, and by September, 1863, the population had grown to between 3,000 and 4,000. Bannack became the first capital of Montana Territory after it was established in May, 1864.

The richest placer ground available for working with primitive hand methods was soon depleted, and a lack of sufficient water prevented efficient mining. Discovery of the Alder Gulch placers near Virginia City in 1863 also resulted in a major exodus from Bannack. The water problem was partially solved when ditches were completed, beginning in 1863 but particularly after 1866, and as a result, placer mining was revived. The ditch water also allowed the miners to work the bench gravels as much as 100 ft above creek level. A further impetus was provided in the 1890's with the introduction of floating dredges that continued to operate until 1902. Placer mining by various techniques has persisted off and on until the present time. The creek has now been placered for 7 mi below Bannack.

The first lode mine of consequence in Montana was the Dakota, claimed in November, 1862, only a few months after the original placer discovery. Rich gold ore was mined from near the surface on several of the 12 Dakota claims, which under regulations then extant were only 100 ft long. Those claims and workings are now covered by the patented Gold Bug and Blue Grass claims located about 1,500 ft northeast of Grasshopper Creek. Most of the lode mines, however, were developed on the southwest side of the creek. A group of claims in the central part of the district was consolidated into the Golden Leaf Mining Company in 1890. This company and its successors and lessees mined from the Golden Leaf (or Sleeping Princess) group intermittently through 1955.

Most of the metal production from the Bannack district, which was almost entirely gold, was obtained prior to consistent record keeping that began in 1902. Various estimates of production have been made based on company records, hearsay, interviews, and newspaper accounts. These estimates range to as much as 500,000 oz gold. Considering the volume of placer gravel worked, the number and size of lode mines, and the fact that the richest gravels and ores were mined in the earliest years by a large number of individuals, this figure may not be far from the truth. Placer production has probably exceeded lode production by a factor of about three or four.

Geology

The lode mines of the Bannack district are along the sides of the narrow gorge of Grasshopper Creek where it flows southeast through a north-trending ridge (Badger Ridge) of folded and thrust-faulted strata of Paleozoic and Mesozoic age. The bulk of the rocks exposed in the ridge are Mississippian through Triassic. They have been thrust over Upper Cretaceous detrital sedimentary and volcanic rocks exposed along the east flank of the ridge. Most of the orebodies are localized in limestone on the periphyry of a granodiorite stock that is exposed on the south side of the valley about 1 mi downstream from the town of Bannack. The stock is here termed the Bannack stock. A smaller stock about 0.2 mi north of Grasshopper Creek is referred to as the Anniversary stock.

The chief sedimentary rocks in the district are cliff-forming beds of the Mississippian Lodgepole Limestone and Mission Canyon Limestone, which constitute the Madison Group. For more than 2 mi north of the district, the ridge is capped by these two units. Within the district, however, contact metamorphism has caused recrystallization of the normally light to dark gray limestone to produce fine- to coarse-grained white to light-gray marble. The extent of the metamorphism has made the identification of the formations at many localities difficult. Locally, calc-silicate skarn is present at the contact of the marble and the granodiorite; both exoskarn and endoskarn have been recognized.

Also exposed are the Upper Mississippian Lombard Limestone and Kibbey Sandstone on the east and south sides of the district and the Pennsylvanian and Mississippian Conover Ranch Formation (formerly called Amsden Formation in this area) and Quadrant Quartzite on the west side of the district. All of the Paleozoic formations are juxtaposed in complex fault relationships.

On the northeast side of Grasshopper Creek, east of the district, a thrust plate consisting of Mississippian rocks lies on an Upper Cretaceous sequence, consisting of the Beaverhead Group, the tuff of Grasshopper Creek, and the volcanics of Cold Spring Creek. These Cretaceous units have been tilted to vertical beneath the thrust, but less than a mile to the east the beds have flattened to a gentle southeast dip, and deformation of the rocks seems to be minor. The Beaverhead, which is chiefly red-weathering limestone-pebble conglomerate with a quartz-sand matrix, contains elongate masses of Mississippian limestone as much as 1 mi long that are interpreted as exotic blocks similar to those described in the Beaverhead Group in the Tendoy Range to the south (Perry and Sando, 1983). Near Bannack, these blocks have previously been interpreted as klippe (Lowell, 1965; Thomas, 1981; Johnson and Sears, 1988). East of Bannack, well exposed contacts of these blocks with sandstone and conglomerate of the Beaverhead clearly indicate that they are not tectonic contacts. The masses are tentatively interpreted as blocks broken off of a nearby, but not definitely identified, thrust plate after it became exposed at the surface. If this interpretation is correct, the thrust probably did not continue eastward much farther than its present eastern trace.

The igneous rocks in the district consist of medium-gray fine-grained granodiorite that forms the Bannack stock about 1 mi long and 0.5 mi wide, the smaller Anniversary stock about 0.25 mi in diameter, and numerous dikes and small irregular bodies, which are well exposed in cuts west of the Gold Bug mine. The lode mines are associated spatially with both of the stocks, which are 0.2 mi apart and hence probably apophyses of a single, large body at depth. The two stocks intrude Mississippian formations, but the dikes and other small bodies are especially abundant in the Cretaceous volcanic rocks on the east side of the district. In general, the intrusive rocks are slightly altered and are less resistant than the limestone country rock. Although the age of these intrusive rocks has not been determined directly, they are probably Late Cretaceous (less than about 75 Ma) on the basis of K/Ar and $^{40}Ar/^{39}Ar$ determinations on similar rocks a few miles to the east and north (oral commun., L.W. Snee, 1988). Thrusting had probably ceased before intrusion of granodiorite began.

Mineral deposits

The principal lode deposits of the Bannack district are replacement bodies in skarn derived from limestone or marble at contacts of the two stocks. The most favorable location for ore deposition is where the recrystallized limestone (or skarn, if present) grades outward into relatively unrecrystallized limestone. The reason for this localization is uncertain, but perhaps the marmorization caused volume changes that resulted in increased permeability for ore-forming fluids in this zone. The ore bodies are tabular, pipelike, or irregular, and some are veinlike, though typically short and discontinuous.

The primary ore consists of gold-bearing quartz and pyrite and commonly the skarn minerals garnet, diopside, vesuvianite, specularite, and magnetite. Minor amounts of chalcopyrite are widespread, and galena and sphalerite are sporadic in their distribution. The early-mined ore was oxidized and enriched in gold in the near-surface environment, as compared to the unoxidized ore. The oxidized ore commonly consisted of aggregates of earthy iron oxides and quartz; manganese oxides, carbonate minerals, and secondary copper minerals are present locally. These ores were particularly desirable as they could be treated merely by crushing followed by amalgamation or cyanidation. The primary sulfide ore required more complex treatment by milling equipment not readily available in the early days.

In terms of production, the chief lode mines of the district are the Golden Leaf group, the Excelsior, and the Hendricks, all on the southwest side of Grasshopper Creek, and the Gold Bug, which includes the original Dakota claims, on the northeast side. Several other mines produced smaller amounts. The Golden Leaf group was by far the largest lode mine in the district; it produced between about 75,000 and 125,000 oz of gold between the 1860's and 1955.

ROADLOG

0.0* (0.0)** Begin mileage at southwest corner of Western Montana College at the corner of East Poindexter and South Atlantic Streets. Drive south onto access road to Interstate Highway I-15.

0.9 (0.9) Overpass over I-15. Low hills directly ahead (west) are underlain by Tertiary volcanic rocks. Turn left onto entrance ramp. Drive south on I-15. The highway is on the alluvial plain of Beaverhead River. Quaternary alluvium in the valley is underlain by Tertiary sedimentary deposits in many places, but exposures of Tertiary volcanics and of Paleozoic sedimentary rocks at some places in the valley suggests that the thickness of Tertiary deposits is highly variable in the Beaverhead River valley and perhaps nowhere in the valley are they as thick as in many of the basins in southwestern Montana.

On the skyline to the left (east) is the south end of the Ruby Range, which is underlain by Archean crystalline rocks. To the southeast, separated from the Ruby Range by the valley of Blacktail Deer Creek, are the Blacktail Mountains underlain by Paleozoic and Mesozoic strata in the highest part, by Archean crystalline rocks similar to those in the Ruby Range at the far southeast end, and by Tertiary volcanic rocks forming the grassy slopes at the northwest end just east of I-15. The steep northeast face of the Blacktail Mountains is the result of Tertiary uplift along the steep Blacktail fault whose trace is near the base of the mountains and at or near the site of an older reverse fault (Tysdal, 1988). Four miles straight ahead to the southwest, the Beaverhead River flows through a narrow gap. The rocks forming the gap are Eocene rhyolite lava flows and domes. Low hills to the right (west), about 1 mi away across the Beaverhead River valley, are also Tertiary lava flows; these rocks have not been mapped or studied, but they may well be Eocene, the age of all similar volcanic rocks in the Dillon vicinity whose age is known.

3.4 (2.4) Cross bridge over Beaverhead River.

3.7 (0.3) Leave I-15 at Exit 59 and turn right (west) on Montana Highway 278. Exposures in low hills on right for next 2 mi are part of the Tertiary volcanic rocks seen previously from I-15. Mississippian limestone crops out locally beneath the volcanics (Ruppel and others, 1983). Upon leaving the flood plain of Beaverhead River, the highway begins to climb up the toe of a large, gently sloping alluvial apron, which a few miles farther to the northwest is called Argenta Flats. The apron formed chiefly by deposition of glacial outwash from Rattlesnake Creek during the Pleistocene. The apron has its apex at the mouth of the canyon of Rattlesnake Creek near the village of Argenta, which is about 4 mi below the glacial terminus. A stratigraphic test hole drilled on Argenta Flats 3.5 mi east of Argenta indicated that there the Quaternary gravel is about 150 ft thick.

7.9 (4.2) Baldy Mountain is the high mountain straight ahead. The contact between the Pioneer batholith to the north and quartzite of the Proterozoic Missoula Group to the south is in the notch at the summit of the mountain.

10.7 (2.8) Argenta Road to right. Continue straight ahead. Juniper covered ridges in distance on right

* Cumulative mileage.
**Incremental mileage.

are Paleozoic and Mesozoic sedimentary rocks east of Argenta in the frontal fold and thrust zone.

11.3 (0.6) Cross Ermont Gulch and adjacent Ermont Road to right. As Ermont Gulch is approached, the highway descends from the level of Argenta Flats. Here Ermont Gulch forms the approximate contact between the Quaternary gravels of Argenta Flats and Tertiary strata that form the 300-ft-high mesa to the south and that underlie some of the low rolling country ahead. The Tertiary sediments exposed intermittently in roadcuts along the highway for the next few miles are composed of stacked paleosols locally separated by minor channel gravels and sands. Similar paleosols a few miles to the southeast yielded oreodont bones and a camel tooth that Ralph Nichols (oral commun., 1984) identified and suggested were Miocene. Kay and others (1958) also gave a Miocene age for these beds. Overlying the paleosol sequence at several places are weakly cemented to well cemented calcareous fluvial gravel deposits that may be late Miocene or Pliocene age (D.L. Hanneman, oral commun., 1988). At many places the Miocene and Pliocene beds are overlain by thin pediment gravels.

11.5 (0.2) Turn left. This is the "old Dillon-Bannack stage road."

12.0 (0.5) A stratigraphic test hole (NE1/4, NE1/4 sec 10, T 7 S, R 10 W) near here penetrated 150 ft of gravel, sand, and clay (Quaternary and Tertiary?); 520 ft of clay and minor sand and gravel (Miocene?); and 130 ft of mafic volcanic rocks and some non-volcanic detritus, including 30 ft of massive basalt (Eocene?) at the bottom of the hole. Total depth, 800 ft.

12.9 (0.9) Base of Miocene(?) deposits is near stock pens on right. Contact is not exposed because of thick soil and colluvium. Miocene(?) deposits here are probably underlain by Cretaceous volcanic rocks. South of this valley, however, Eocene basalt flows occur between the Miocene deposits and the Cretaceous volcanic rocks, but these flows may pinch out south of the road.

13.4 (0.5) Flow-banded rhyolite on right. Two small bodies are present. The larger body is also exposed across gully to south. The rhyolite is probably intrusive into Cretaceous volcanics, although the relations are not clear cut. Rhyolite lava flows and ash-flow tuff a few miles to the south are Eocene (about 48 Ma according to $^{40}Ar/^{39}Ar$ determinations by L.W. Snee, written commun., 1988), suggesting that these bodies may also be Eocene.

13.8 (0.4) <u>STOP 1.</u> Park along road and walk north up gully to see volcanic breccia and a fine-grained intrusive; both are parts of the volcanics of Cold Spring Creek. The volcanic breccia in this area resembles laharic breccias, whereas many of the volcanic breccias in the Cold Spring Creek have a lava-like matrix and are considered flow breccias. The base of the McDowell Spring intrusive sheet is exposed about 450 ft north of the road. The sheet is chilled against volcanic breccia. Steep-sided hills visible about 2 mi to the south are also composed of the McDowell Spring sheet. Their height, as well as the height of cliffs along Grasshopper Creek farther to the south, suggest that the sheet is more than 400 ft thick.

Return to vehicles and continue driving west through volcanics of Cold Spring Creek. Yellowish-brown altered rock in road bed is at the contact of the sheet and the volcanic breccia; the contact here could be a fault. Purple and gray volcanic breccias above road to right.

14.4 (0.6) Cold Spring Creek road to left at McDowell Spring. Continue straight ahead.

14.7 (0.3) Outcrops along road are of a dike that emanates from the McDowell Spring sheet and seems to be vertical. Northward, the dike maintains a thickness of about 100 ft for a distance of 1,000 ft. Then it gradually thickens and develops a flat bottom similar to the contact observed at Stop 1. To the south, the dike gradually thins and ends.

15.5 (0.8) Turn right at road junction onto Badger Ridge spur road. Road continues over breccias, lava flows, and an occasional small dike, all part of the volcanics of Cold Spring Creek.

16.2 (0.7) Approximate contact between volcanics of Cold Spring Creek and underlying tuff of Grasshopper Creek. Contact along road is covered by a bouldery surficial deposit (landslide or debris flow) that probably came from the canyon ahead.

16.3 (0.8) Road junction. Turn right.

16.9 (0.6) <u>STOP 2.</u> Park along road. The contact between tuff of Grasshopper Creek and volcanics of Cold Spring Creek is in the road at this stop.

The main purpose of this stop is to see Kibbey Sandstone in typical exposures. See figure 3 for brief description of the Kibbey. Walk northwest about 500 ft, staying north of bottom of small valley. First 500 ft of traverse, if one stays above the alluvium in the valley bottom, is in tuff of Grasshopper Creek. After walking 500 ft northwest, a major thrust fault (called Ermont thrust by Thomas, 1981, and by others) is crossed, and the bedrock is Kibbey Sandstone, which is moderately well exposed for next few hundred feet.

Return to vehicles, turn them around, and return to road junction at mileage 16.3.

17.5 (0.6) Turn right.

17.7 (0.2) Road junction to left. Road to south goes to New Departure mine. Continue straight ahead. Tuff of Grasshopper Creek is exposed in and along road.

17.8 (0.1) <u>STOP 3</u> Pull off road to right beside low rounded hill. The vehicles will be parked on the trace of a thrust fault that separates Mississippian strata in the low rounded hill from tuff of Grasshopper Creek exposed in roadcuts near the vehicles, on lower slope above road to south, and in gully to west. We will examine the tuff in the roadcuts and the Upper Mississippian Lombard Limestone on the top and north side of the hill. See figure 3 for brief description of the Lombard. The Lombard and Kibbey will also be seen at Bannack in a more deformed and metamorphosed condition. The thrust in this general area seems to be deformed. At Stop 2 the thrust dips to the west; here the thrust dips to the north about 40^{o}; 900 ft south of Stop 3 and 150 ft higher the thrust dips to the east. The hill to the south is the north end of the New Departure klippe, which is capped by Mississippian strata (mainly the Lombard and Kibbey) and is completely surrounded by Cretaceous igneous rocks. The north half of the klippe is underlain by and surrounded by tuff of Grasshopper Creek; the south half is surrounded by, and at least partly underlain by, fine-grained granodiorite that intruded into the thrust at the base of the klippe. The variations in elevation of the thrust trace and attitude of the thrust plane in this area may be caused by later high angle faulting, later folding, or a lateral ramp in the thrust itself. Lombard Limestone here is tightly folded on a small scale, as is typical of the unit at many places, and it locally contains corals that confirm its identity (W.J. Sando, oral commun., 1987). Kibbey Sandstone is poorly exposed on the west flank and low on the north-east flank of the hill at Stop 3.

Return to vehicles and continue driving west parallel to the thrust trace, which stays above road level on the left. In the next 0.6 mi, roadcuts are alternately in light-colored tuff of Grasshopper Creek and in small, orange-weathering, fine-grained intrusives, probably apophyses from the larger mass of granodiorite to the west and south. Timbered hills to west and north are capped by Quadrant Quartzite.

18.7 (0.9) Road junction. Road to north goes to Highway 278.

18.8 (0.1) Cross north-trending contact between tuff of Grasshopper Creek to east and granodiorite to west. Road junction on left is just beyond contact. Continue straight ahead.

19.2 (0.4) Road cut exposes granodiorite. Roads and workings visible on hill directly ahead explored skarn and replacement deposits along the western margin of the granodiorite.

19.4 (0.2) STOP 4. Examine granodiorite exposed in and along road. This body is 2 mi wide east-west and about 3 mi long north-south. Most of the mines in the Blue Wing mining district are near this body of granodiorite. The rock appears to be very similar to the granodiorite at Bannack. Note the bleaching of the Paleozoic carbonate rocks adjacent to the granodiorite to the west and southwest. In the granodiorite, note the epidote along joint surfaces and the green cast resulting from slight chloritization of mafic minerals. The granodiorite has a pronounced orange color in weathered outcrops.

The tree-covered ridges to the north are underlain by Quadrant Quartzite disposed in north-plunging folds.

Discuss the Blue Wing district.

After unloading passengers, vehicles will continue ahead about 0.25 mi, turn around at road junction, and return to pick up passengers. Return to the road junction at mileage 18.7.

20.6 (1.2) Road junction. Turn left and drive north to return to Highway 278. This road is mainly in float of Quadrant Quartzite, although a few small and inconspicuous outcrops of granodiorite may be seen in the first 0.5 mile. The Quadrant is, or was before intrusion of the granodiorite, presumably in thrust contact with tuff of Grasshopper Creek. Thus, the thrust here is either a different one than is present at Stops 2 and 3, or if it is the same one, the thrust here cuts down section and down slope to the east toward Stop 3 and toward the southeast to the New Departure klippe.

21.2 (0.6) Excellent view to right across the Beaverhead River valley to the Ruby Range. The high mountains in the distance a 5:00 o'clock are in the Snowcrest Range.

21.8 (0.6) Road intersection in saddle is in Quadrant Quartzite. Turn to right. Road to left goes to microwave station on ridge. Saddle is near trough of syncline, probably a doubly plunging syncline whose trough is in the treeless valley that extends down the slope to the north, crosses the highway, and extends about 1 mi beyond. The trough is underlain by the Lower Permian

Phosphoria Formation in most places and by the Lower Triassic Dinwoody Formation locally. Timbered ridges of Quadrant flank the valley. Excellent view of the southern Pioneer Mountains straight ahead. The high country is underlain by the Pioneer batholith.

23.2 (1.4) Highway 278. Turn left.

23.6 (0.4) Badger Pass. Gravel road straight ahead is old highway to Jackson that rejoins the modern highway several miles ahead. Stay on main highway. Quadrant Quartzite and overlying Phosphoria Formation exposed just north of the highway at Badger Pass. Bare flat area just south of pass is underlain by a thin layer of upper(?) Tertiary gravel that caps Mission Canyon Limestone. Thus, a probable east-trending fault through Badger Pass is indicated.

24.2 (0.6) Highway crosses approximate trace of an east-trending fault that Ruppel (1982) has named the Badger Pass fault and interprets as a strike-slip fault.

24.8 (0.6) STOP 5. Conover Ranch Formation (Upper Mississippian and Lower Pennsylvanian) is well exposed in roadcut. The Conover Ranch is here at least 100 ft thick, and the base is not exposed. In most places in this area the Conover Ranch is thinner than here, being cut out partly or entirely by thrust faults, and perhaps its original thickness was variable as well. The Conover Ranch, formerly called Amsden Formation in this region, grades into Quadrant Quartzite in upper 20 ft of exposure. See figure 3 for brief description of the Conover Ranch. Timbered hill southeast of highway is Mission Canyon Limestone. The relations suggest that a northeast-trending fault is in the valley adjacent to the highway because the normally intervening Kibbey Sandstone and Lombard Limestone seem to be absent.

West of the exposures of the Conover Ranch are Tertiary deposits that occupy most of upper Grasshopper Creek valley to great depth. Where exposed, the deposits are fluvial and lacustrine and are clay rich, presumably from the alteration of volcanic ash. Vertebrate fossils collected about 3 mi to the northwest are late Oligocene and early Miocene (Fields and others, 1985), suggesting that the beds exposed along the highway may also be Oligocene or Miocene.

The view to the west is across Grasshopper Creek valley to Big Hole Divide, the timbered ridge on the skyline about 10 mi away. Big Hole Divide is underlain by Middle Proterozoic Missoula Group (Belt Supergroup). Structurally, those rocks are part of the Grasshopper thrust plate (Ruppel and Lopez, 1984). Where it crosses the highway, the trace of the thrust fault that marks the eastern limit of the Grasshopper plate is buried by Tertiary strata in Grasshopper Creek valley.

27.2 (2.4) Turn left on road to Bannack. Road continues south in Grasshopper Creek valley over Tertiary and Quaternary deposits.

30.2 (3.0) Junction with road south to Grant in Horse Prairie. Continue straight ahead toward Bannack. Note hydraulic placer tailings across Grasshopper Creek to south. These placer workings are above the level of Holocene gravels along Grasshopper Creek and are partly or entirely within the Tertiary strata in Grasshopper Creek basin.

30.9 (0.7) Turn right on road to campground (but do not enter campground). Continue straight ahead and cross bridge over Grasshopper Creek to picnic area for lunch at mileage 31.1.

After lunch, continue driving east on gravel road that by-passes Bannack on the south side of Grasshopper Creek. The road passes the Hendricks millsite (mileage 31.3), which is fenced and posted with signs warning of contamination. The danger is presumably from either mercury or cyanide. Mercury would seem the most likely, because an amalgamation plant was installed in 1918 and mercury is relatively immobile in the mill tailings. Cyanide processing of the ore was added in 1919, but it is unlikely that a hazzard from that source would remain since mining ceased in 1941, as cyanide breaks down readily in the surface environment.

31.4 (0.5) View, up gully to right, of the Hendricks mine workings in which magnetite skarn developed along bedding-plane fault zones near steeply dipping granodiorite dikes. The dikes are intensely altered to clays and were not recognized in the mine workings. The Hendricks mine is within an area which has been withdrawn from mineral entry as part of the Bannack historical site.

31.6 (0.2) Bridge over Grasshopper Creek. Do not cross bridge. Continue straight ahead. Pass small hydraulic placer workings on both sides of road. This placering removed colluvium and a thin layer of stream gravel that lay on an irregular surface of Mississippian limestone.

32.0 (0.4) STOP 6. Park near old jaw crusher. Walk 200 ft to east onto small knob for overview of geology of Bannack mining district and discussion of mining history.

On west side of knob, the contact is crossed between medium-gray fine-grained granodiorite of the Bannack stock and the Mission Canyon Limestone, which has been bleached and recrystallized to marble along the contact. Here, as elsewhere along the contact, the marble contains minor concentrations of light green skarn. The eastern part of the knob consists of dark brown marble which is cut by numerous white quartz veins and contains skarn.

The knob we are standing on is near the western contact of the Bannack granodiorite stock. This contact extends south southwest up the slope from this knob and is crisscrossed by numerous mine roads and covered by dumps. In the middle part of the slope, the contact turns southeast and then east; it's approximate location can be seen readily from a distance because trees grow on the carbonate rocks but not on the granodiorite. The southern contact of the Bannack stock appears to dip to the north, and the western contact dips steeply to the west. The eastern contact, which passes through the Excelsior mine (the headframe visible about 0.6 mi southeast of this stop), appears to dip to the west. The granodiorite has intruded the core of a large overturned anticline.

The Priscilla adit is in the steep gully just south of this knob. The large dump due south is at the portal of the Golden Leaf workings. The large dump to the southwest is at the Wallace portal, and the dump farther up slope is the Wadams stope, just below and to the east of the prominent knob of Quadrant Quartzite on the skyline. The dump visible to the south behind the Golden Leaf is at the Thompson workings, and the white cut in the saddle farther south is on the French Lode claim. All of these workings explore the contact between the Bannack stock and the massive recrystallized Mission Canyon Limestone and locally the Lodgepole Limestone.

These old workings include large stopes that extend through a vertical interval of at least 800 ft. The workings extend below the elevation of Grasshopper Creek. The site of the Golden Leaf mill is located on the south side of Grasshopper Creek east of the knob where we are standing.

The prominent knob of white limestone across Grasshopper Creek to the east northeast that has numerous prospect pits at the base is intruded by a granodiorite dike swarm probably representing a northern marginal zone of the Bannack stock. Greenish-gray-weathering rock visible on the southeastern slope of this knob is granodiorite near the Gold Bug mine. This intrusive mass appears to be a sheetlike body dipping gently to the southwest. The granodiorite is underlain by mixed marble and skarn that pass abruptly downward into intensely deformed and locally graphitic limestone (Lodgepole Limestone ?), which may be in the core of the overturned anticline discussed below.

Looking northeast, directly across the creek and up the gully that contains the electric-power lines, gray-green outcrops are of granodiorite of the Anniversary stock which is separated from the granodiorite dikes of the Gold Bug mine area by bleached Mission Canyon Limestone. Prospects along the margins of this stock explore specularite- and magnetite-bearing skarn, which seems to occur along minor dikes and faults.

The large reclaimed areas on either side of Grasshopper Creek are recent placer workings. The paleoplacers extend well up from the present valley bottom. For example, colluvium in the gulch below the Gold Bug mine was mined in 1988 up the slope to and including the dumps of the Gold Bug. Many old underground workings in the gravels were found during the recent placer mining. These workings explored and mined some of the rich gravels along the bedrock contact. One of the interesting features of the Bannack district is the presence of placer deposits extending at least 0.5 mi upstream from the presently exposed lode deposits, which has interesting ramifications regarding paleodrainage. Grasshopper Creek probably drained south through the Tertiary basin to the west prior to its diversion across Badger Ridge. The diversion may have been accomplished by late Tertiary block faulting or by extrusion of basalt that is in the basin a few miles to the south.

Turn vehicles around and return to bridge. Cross bridge and stay on road that turns to the right. Brown to gray cliffs ahead are Mission Canyon Limestone. Origin and significance of brecciation and limonite-staining are uncertain but may be the result of movement on a fault in the valley.

32.6 (0.6) STOP 7. Examine inverted Mississippian section consisting of Lombard Limestone, Kibbey Sandstone, and Mission Canyon Limestone. The Kibbey forms the grassy slope between the massive light-gray cliffs of the Mission Canyon to the west and the dark gray lower cliffs of the Lombard to the east. Walk up slope to north a few hundred feet to see exposure of the inverted contact between Lombard and Kibbey and to compare these units here with the same units observed a few miles to the north earlier in the day.

About 350 ft east of Stop 7, the upside-down Lombard is in thrust contact with right-side-up(?) Mission Canyon. This thrust is not well exposed here but will be seen at Stop 8.

32.8 (0.2) Turn left on steep rough road. [Although 4-wheel drive should not be needed, low-clearance passenger cars could have difficulty. Beware of dropoffs in or adjacent to road from recent storm runoff.] Going up this road, first 0.2 mi is in metamorphosed Mission Canyon Limestone; next 0.2 mi crosses the small Anniversary granodiorite stock similar to the larger Bannack stock on south side of creek; the road then goes back into Mission Canyon Limestone and continues in it to Stop 8.

33.1 (0.3) Road splits. Stay to left.

33.3 (0.2) Prospect on right is in magnetite-rich skarn along fault that bounds septum of marble in the Anniversary stock.

33.4 (0.1) STOP 8. Stop before steep spot in road and walk approximately 0.1 mi farther up road. Thrust contact between inverted Lombard above and right-side-up(?) Mission Canyon below is exposed on cliff to west about 40 ft above gully. Examine thrust.

Turn vehicles around and return to road along Grasshopper Creek. Excellent view of western contact of the Bannack stock to the south.

33.9 (0.5) Turn left and drive southeast down Grasshopper Creek through placer workings.

34.0 (0.1) Road splits. Stay left. Medium green-gray granodiorite in small exposures in roadcut on left.

34.1 (0.1) Road to left leads to Gold Bug mine.

34.3 (0.2) Road splits. Stay right.

34.4 (0.1) Take left turn. Do not cross creek.

34.5 (0.1) First bedrock outcrops and roadcuts on left beyond (southeast of) placer tailings are red conglomerate of the Beaverhead Group. Next roadcuts (100 yds farther) are Lombard Limestone in probable fault contact with the Beaverhead. Both formations and the fault(?) between them are cut off by a small intrusive up hill to the northeast about 200 ft, and the limestone in the roadcuts is intruded by dikes of very fine grained gray granodiorite with quartz phenocrysts. Both the Beaverhead and the Lombard in these exposures are in the lower plate of a thrust, the same thrust discussed at Stops 2 and 3. The upper plate is visible in the limestone cliffs at the top of the canyon wall to the north. The structure in the lower part of the canyon, especially on the northeast side of the creek, for the next mile downstream is poorly known.

In the gully to the south the headframe of the Excelsior mine is visible. The Excelsior workings are inaccessible but are reported to explore a pipe-like breccia zone and a vein along the eastern margin of the Bannack stock.

34.6 (0.1) Road splits. Stay to right.

Low cliffs ahead on left (east to southeast) are vertical beds of the Beaverhead Group. The road skirts the cliffs so that the sandy limestone-cobble and limestone-pebble conglomerate can be observed at close range from the vehicle.

34.7 (0.1) Road blocked ahead. Turn vehicles around and return to road intersection at mileage 34.4. Turn left and cross Grasshopper Creek on new bridge (mileage 34.9).

35.1 (0.4) Road splits in reclaimed placer area. Stay left.

35.3 (0.2) Using 4-wheel drive if available, ford Grasshopper Creek, rejoin old road on northeast side, and continue down creek. More placer tailings on left; these gravels were probably piled to a height of about 30-40 ft by a dredge operating in the creek.

Low cliffy outcrops across creek are Mission Canyon Limestone in lower part and Lodgepole Limestone in upper part, both inverted and dipping about 15^{o}-20^{o} west. These beds are part of the overturned limb of an east-verging anticline that continues south at least as far as the southwest corner of the Bannack 7.5-minute quadrangle (2 mi southwest of this locality), and from there it may be continuous with the Madigan Gulch anticline, named and mapped by Lowell (1965) as far south as Horse Prairie, which is about 13 mi south of Grasshopper Creek. The axial region of this anticline is cut off sharply by the Bannack stock southwest of here but is tentatively identified north of the stock and east of the last stop (Stop 8). In the area north of the Gold Bug mine, where the formations can be recognized through the obscuring effects of metamorphism, a block of Lodgepole Limestone is separated from Mission Canyon Limestone on either side by steep north-trending faults. The block of Lodgepole may be the faulted core of the same anticline that is present south of Grasshopper Creek. Northeast from the area north of the Gold Bug, the Lodgepole seems to become a sheared-out wedge within Mission Canyon in the upper plate of a thrust.

35.7 (0.4) Mission Canyon Limestone is exposed in cliffs on the southeast side of the creek. The Mission Canyon in this area is known to be complexly deformed internally, but the nature or system of this deformation has yet to be worked out, partly because of poorly defined bedding and recrystallization of the limestone.

36.0 (0.3) <u>STOP 9.</u> At large southward bend in Grasshopper Creek. Vertical contact between the Beaverhead Group to the east and Lombard Limestone to the west in spectacular exposures. The Beaverhead and its basal contact have been tilted to vertical. The Lombard has been tightly folded and these small scale folds have been sheared apart along several nearly horizontal faults that are visible in the cliff exposures. Lowell (1965) interpreted this contact as a steep fault, although he recognized that the Mesozoic and Paleozoic strata normally beneath the Beaverhead had been intensely deformed before deposition of the Beaverhead. Johnson (1986) interpreted this contact as an unconformity rather than a steep fault. Evidence for an unconformity can be found about 200 ft above creek level both to the north and south. To the north, one or more beds of Lombard project several feet from the plane of the contact upward (stratigraphically) into the Beaverhead. Conglomerate of the Beaverhead seems to have been deposited around this bed, which at the time of initial deposition of the conglomerate, was a ridge a few feet high. To the south, beds of the Beaverhead seem to roll over to horizontal and to be in depositional contact with tightly folded Lombard, although it is possible that this conglomerate is a much younger deposit than the vertically dipping Beaverhead a few feet away. Up the slope to the south, the Lombard is gradually cut out beneath the Beaverhead; then farther up the slope, the Kibbey is gradually cut out; and in the steep timbered gully below the skyline, the Beaverhead is in contact with the Mission Canyon. The Beaverhead continues in contact with the Mission Canyon for at least 1 mi beyond the skyline to the south, although intercalations of Beaverhead within the Mission Canyon in that interval hint at major structural complications along that contact.

The deformation of the Mississippian rocks that preceded deposition of the Beaverhead was interpreted by Johnson and Sears (1988) as basement-involved and of Laramide style, whereas the later deformation that involved the Beaverhead and produced the overlying thrust was interpreted as thin-skin thrusting of Sevier style.

The Kibbey Sandstone is exposed just west of the Lombard both north and south of the creek at this stop. A few "beds" of limestone in the Kibbey are interpreted as tectonic slices. A body of breccia about 100 ft in diameter 50 ft above the road on the northeast side of the creek is located at or near the contact between the Kibbey and the Lombard. Blocks in the breccia are both Kibbey and Lombard. Lack of deformation within the breccia indicates that the breccia is not tectonic; it may have formed by solution and collapse, perhaps solution of evaporites that are common in the Kibbey.

Turn vehicles around and drive back upstream, recrossing Grasshopper Creek twice, to main placer workings on northeast side of creek.

36.8 (0.8) Road splits in reclaimed placer workings. Turn right.

36.9 (0.1) Turn sharply to right, and using 4-wheel drive, climb steep slope out of placer workings to right of fenced shaft. Continue upslope on bulldozed trail to intersection with better road (mileage 37.0).

37.3 (0.4) Vertical contact between the Beaverhead Group to the west and overlying tuff of Grasshopper Creek to the east. The tuff of Grasshopper Creek is intruded by numerous dark-brown to nearly black fine-grained altered andesite dikes and irregular bodies that are exposed along the road for the next 0.5 mi. Some of these dikes occur at the margins of well indurated breccia zones that contain fragments of the dike rock. The magma may have intruded along near vertical faults.

37.8 (0.5) STOP 10. Turn off road to right and park in flat area. Walk about 0.3 mi to southeast along old road (or drive part way along this road if passable) to observe the relations between the Beaverhead Group and a large mass of limestone that forms the skyline to the east. This and other similar masses extend along the strike of the Beaverhead near its top for about 2.5 mi. These masses, which consist mainly of Madison Group limestone and are a few tens of feet to more than 1 mi long, were interpreted originally by Lowell (1965) as klippe, and that interpretation was adopted by Thomas (1981) and Johnson (1986). They are interpreted here, however, as exotic blocks similar to those in the Tendoy Range to the south described by Perry and Sando (1983). Most exposures of the contact between Beaverhead and the exotic blocks show some shearing, but generally the shearing is slight, and locally the contact exhibits no shearing whatever. These relations are interpreted as proof that the blocks were emplaced at the surface and not by some deeper tectonic process. The blocks are envisioned as being derived from a thrust sheet that came to the surface or perhaps some other uplifted block. Which thrust sheet this was is not known. The overlying thrust sheet that is visible to the north from this locality contains the proper rock units to be a source of the blocks, but that thrust involves younger volcanic rocks in the footwall, indicating that that thrust is too young, or at least, that the latest movement on that thrust is too young. The blocks were emplaced by a process that may have combined, at one place or another, sliding, rolling, and gliding down a slope. The block we will examine is composed of the

Mission Canyon Limestone, but higher parts of the same block (about 0.1 mi to the north) also contain Lodgepole Limestone in apparently normal contact with the Mission Canyon.

Return to vehicles and drive back to Bannack. **End of trip.**

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MAXIMUM EXTENT OF LATE PLIOCENE (?)/EARLY PLEISTOCENE GLACIATION IN SOUTHWESTERN MONTANA

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A long Pliocene (?)/Early Pleistocene glacial sequence has been reported by us (Turner, et al. 1988) in southwestern Montana, based on field and laboratory research in 1964 (Dort and Turner 1964) and 1985-1988. (Turner, et al. 1987, 1988).

Our work has been concentrated in Central Beaverhead County, southwest of Dillon, Montana. Preliminary evidence indicates at least six pre-Bull Lake glacial advances that originated outside the area and moved from north to south. Thicknesses of the early tills range to > 200 m and ice thicknesses to > 600 m. The topographic constraints on the late Pleistocene glaciations and the evidence for glacial origin of some of the older tills have been covered previously (Turner, et al. 1988). Evidence of Pliocene (?) through Mid-Pleistocene glaciation in the mountain West is well-established (Birkeland, et al. 1971, Dort and Turner 1964, Dort 1965, Staatz 1979), however, long sequences, where time relationships can be established, are rare.

Much of our efforts in 1988 were directed toward determining the maximum extent, thickness, location, and flow direction of the largest of these early glacial advances into southwestern Montana. What we found is summarized in Figures 1 and 2. Field and laboratory work will continue on this problem during 1989 and beyond. In summary, the largest glacial advance into this area came from an, as yet, unknown source in the north. The age of this glaciation, called the Beaverhead Glaciation, based on weathering, degradation and topographic location of the tills is considered to be Late Pliocene or Early Pleistocene in age. It extended from the north side of the area at least 75 km to the south, across the Continental Divide at Bannock Pass, into what is now Idaho. The main lobe, the Horse Prairie Lobe, had a maximum width of 20 km and thicknesses of at least 600 m. Subsidiary lobes: 1) spilled west over Big Hole Pass (Big Hole Pass Lobe) for a short distance; 2) passed east over Badger Pass (Badger Pass Lobe) for about 23 km, to leave large till deposits west of the town of Dillon in the Beaverhead Valley; 3) advanced east down Horse Prairie Creek to the Beaverhead River and then north down the Beaverhead (Clark Canyon Lobe) for about 32 km; 4) moved south up Medicine Lodge Creek (Medicine Lodge Lobe) for some 11 km. The main lobe and each of the subsidiary lobes left large till deposits that are, in many sites, over 400 m thick.

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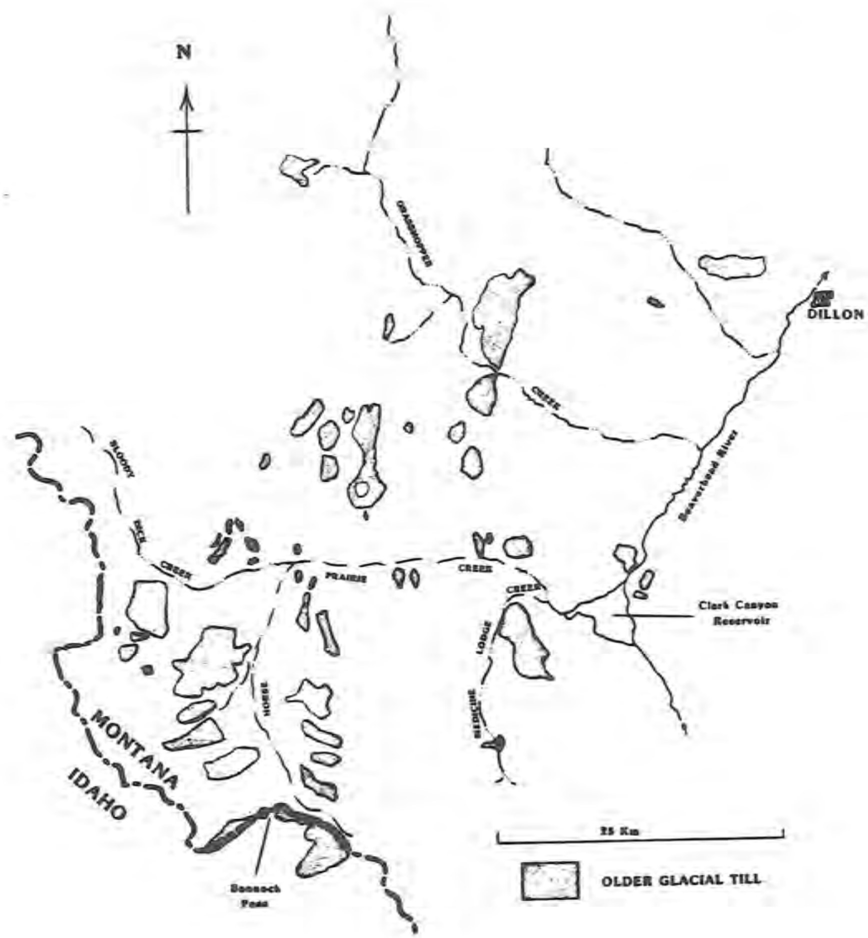

Figure 1. Location and extent of older glacial till of southwestern Montana.

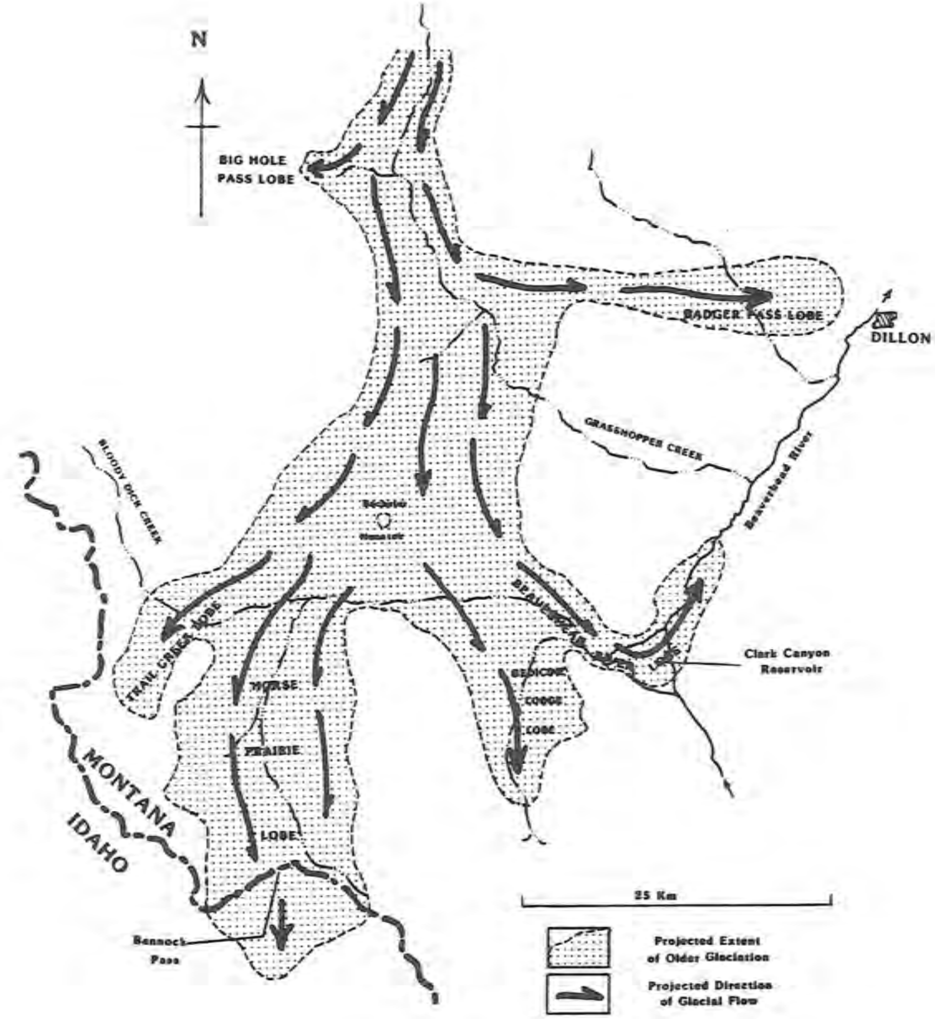

Figure 2. Projected maximum extent of older glaciation and direction of glacial flow of older glaciation in southwestern Montana.

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The Big Hole River Gravel: Structural datum for late Cenozoic faulting in southwestern Montana

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A blanket of stream-washed gravel and associated debris flows provides a structural datum for late Cenozoic block faulting and stream organization in southwestern Montana. The deposit forms hills up to 200 m high along the margins of the Pioneer and Highland Mountains and caps a high-level surface in the Ruby Mountains. In the Sweetwater Creek area of the Ruby Mountains, it overlies rocks as young as ten Ma (Fritz and others, this volume) and is overlain by a four Ma basalt on Timber Hill. Near Biltmore, it contains Hemphillian/Clarendonian (upper Miocene) vertebrate fossils (Hoffman, 1971). Hanneman (1989) included this unit in Sequence 4 of the Cenozoic basin-fill stratigraphy, bracketed between 17 and four Ma.

We believe that this gravel deposit is of sufficient regional significance and continuity to warrant an informal stratigraphic name. Because it is well exposed along the Big Hole River between Twin Bridges and Glen, we propose the informal term "Big Hole River gravel" for this unit.

The Big Hole River gravel caps an irregular surface cut on rocks ranging in age from Archean to Tertiary. It buries hills of Eocene volcanics, Quadrant quartzite and Archean basement and covers surfaces of low relief cut on softer Cenozoic and Mesozoic sedimentary rocks. The buried hills have a relief of up to 50 meters and include Dutchman Mountain, The Hogback and the Apex anticline in the Dillon area.

The base of the Big Hole River gravel is a profound angular unconformity. Rocks as young as Oligocene have up to 25 degrees of angular discordance with the gravel. Much of the deformation of the truncated pre-Tertiary rocks is of late Cretaceous age. and includes folding, thrust faulting, basement uplifts and deformation associated with granite intrusions. Some of the pre-gravel deformation may relate to Cenozoic regional extension.

The Big Hole River gravel is up to 200 m thick near McCartney (McCarty) Mountain, and thins to about 20 m in the Sweetwater Creek area. It is mostly coarse-grained, poorly consolidated conglomerate. Grain size varies from sand and pebbles to boulders and blocks up to ten m in diameter. Clasts vary from being grain-supported to matrix-supported in coarse-grained sand. The largest boulders are very angular whereas small boulders and cobbles are for the most part well-rounded. The largest and most angular clasts occur near the base of the unit.

Clast compositions are very distinctive and provide important clues to the provenance of the gravel because of the varied bedrock geology of the region. The large angular clasts near the base of the unit tend to be locally derived; they often match sources exposed within a few kilometers. The boulders commonly occur in trains that link clasts with source. These trains were probably deposited in old stream channels that are now inverted to form sinuous easterly trending ridges.

On the east shoulder of McCartney Mountain, the gravel includes blocks of McCartney Mountain granite, bright red boulders of Beaverhead Conglomerate which crops out on the north flank of the mountain, and boulders of Archean gneiss which match basement exposed in the Highland Mountains. On the eastern flank

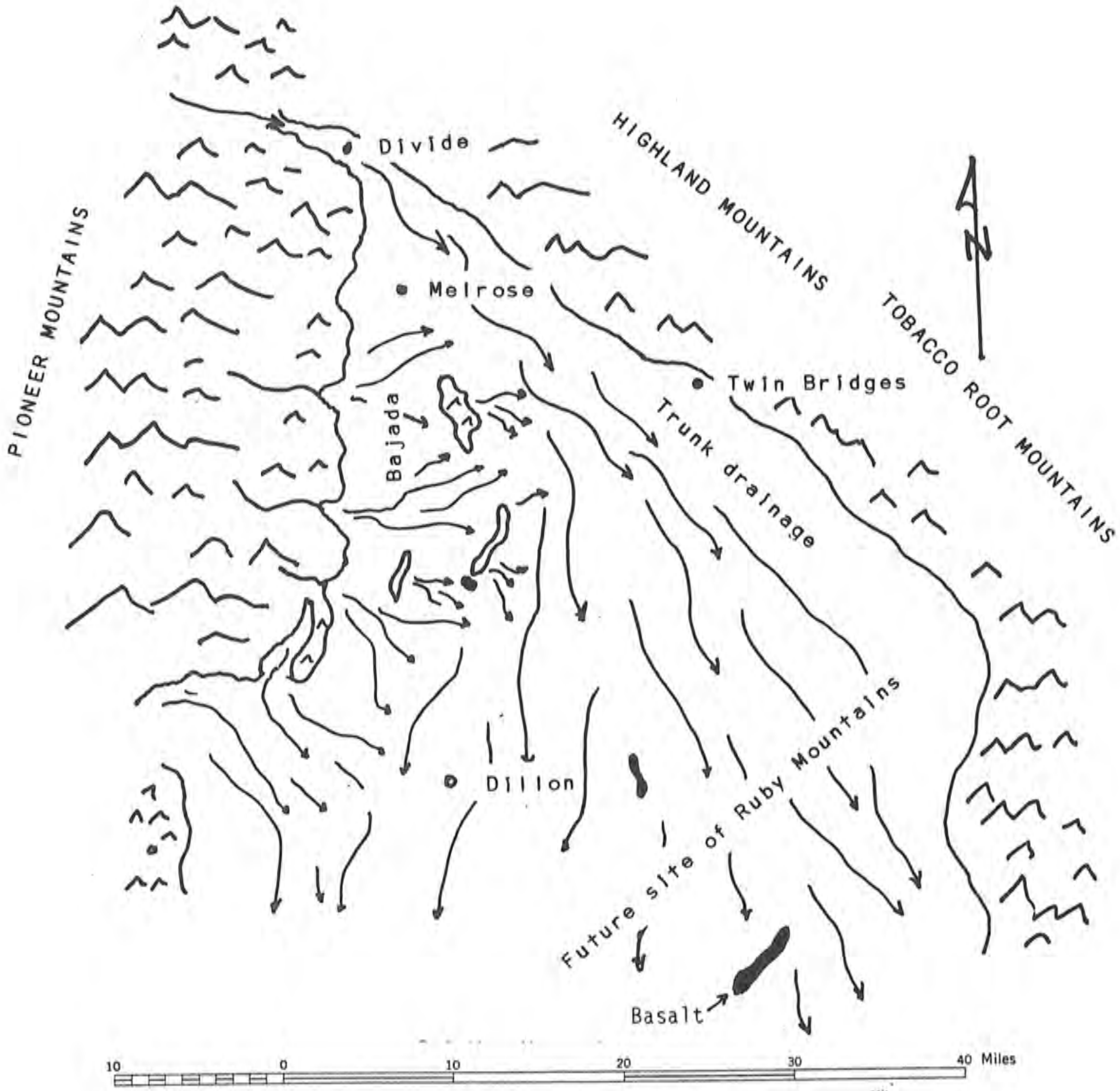

Figure 1. Schematic diagram showing the depositional system for the Big Hole River gravel.

of the Hogback are boulder trains derived from the Phosphoria, Dinwoody and Quadrant formations which match rocks exposed in the immediate vicinity. In Frying Pan Gulch east of Dutchman Mountain, the basal boulders are made of local Quadrant quartzite and granite from a stock exposed to the west of Dutchman Mountain.

Some large blocks appear to have traveled farther from their source. Southeast of the Hogback, a 1-m angular boulder of distinctively cleaved middle Kootenai limestone matches a source 35 km distant in the Melrose area.

Down slope from the local sources, the angular boulders mix with deposits of generally well-rounded small boulders and cobbles of the Precambrian Belt Supergroup, Archean metamorphic complex, Cretaceous granite, Eocene volcanics, and Mesozoic hornfels. All of these lithologies crop out in either the Pioneer or Highland Mountains, tens of km to the northwest. The rounded clasts become smaller toward the southeast; in the Sweetwater Creek area they are no larger than pebbles.

Few sedimentary structures exist in the Big Hole gravel. Nevertheless, because of the shape of the depositional units, the size, shape and composition of the clasts, and associated features we believe the gravel was transported as channelized debris flows and bedload material. These mass-flow and fluvial processes may have taken place on large alluvial fans that graded basinward into a bajada. Hanneman (1989) interpreted this unit to be a braid plain deposit, based on sedimentology of outcrops along the Big Hole River.

Specifically, we propose that alluvial fans extending from the Pioneer and Highland Mountains merged with a large trunk drainage capable of transporting cobbles and small boulders for many tens of kilometers (Figure 1). Because of the distribution of clast compositions and sizes, unit thickness, and source rocks, we believe that the headwaters of the trunk drainage were high in the Pioneer Mountains, and that the drainage flowed from northwest to southeast along flanks of the Pioneer and Highland Mountains and McCartney Mountain, somewhat parallel with the modern Big Hole River. The drainage then spread out into a large alluvial fan over the present site of the Ruby Mountains. We suggest that the Big Hole River gravel accumulated in an isolated basin of internal drainage.

The Big Hole River gravel provides important constraints on the late Cenozoic deformation of the region because it is broken by extensional faults and tilted into several different structural blocks. Because the gravel occurs in the Ruby Range at Timber Hill now isolated from its source and stranded on a high-level surface we believe that the Ruby Range rose after its deposition. This inference is substantiated by a well-exposed northwest trending fault that cuts the gravel and a capping 4 Ma basalt at Timber Hill. This fault exhibits at least 200 m of vertical displacement and can be traced across the Ruby Range and the Beaverhead Valley to the Pioneer Mountains. The fault marking the northeast face of the Blacktail Deer Range also cuts the Big Hole River gravel, as do faults on the south and west edges of McCartney Mountain and the Hogback.

Sometime after the structural disruption of the gravel, an integrated stream system with external drainage formed. The modern Big Hole and Beaverhead Rivers cut across fault blocks that tilt the Big Hole River gravel. South of McCartney Mountain, the Big Hole River has incised a canyon up to 200 meters deep across the tilted gravel and underlying units.

In summary, we proposed the informal term "Big Hole River gravel" for a poorly consolidated late Tertiary conglomerate unit in southwestern Montana. Although we need to better constrain the age of this unit by dating additional overlying basalt flows, we suggest that the unit was deposited sometime between ten and four Ma.

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Age, Chemistry, and Sedimentology of Late Cretaceous and Tertiary Volcanic and Volcaniclastic Rocks in the Beaverhead and Upper Ruby River Basins, Southwestern Montana: A Preliminary Report

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ABSTRACT

Rhyolitic volcanic and volcaniclastic rocks occur around the margins of the Beaverhead and Upper Ruby River basins. Primary pyroclastic deposits include: welded and non-welded ash-flow tuffs, ground surge deposits, lava flows and air fall ash. Also represented are debris and hyperconcentrated flood-flow deposits and fluvial and eolian reworked volcanic debris. Rocks at the Frying Pan Basin locality on the western margin of the Beaverhead Basin were produced primarily during a volcanic episode around 41 Ma and possibly during a second minor event around 33 Ma. The Timber Hill/ Sweetwater Pass area contains a 67 Ma silicified ash-flow tuff and extensive rhyolitic ash-flow tuffs and volcanic sediments deposited around 10 Ma.

Explosive volcanism that produced these rocks presumably contributed to the sediment supply in the Tertiary intermontane basin of southwestern Montana. The degree to which these influenced patterns of sedimentation needs to be addressed before tectonic and climatic interpretations can be made from these same sedimentation patterns.

Introduction

In recent work, we have found numerous exposures of proximal and medial rhyolitic volcanic and volcaniclastic rocks exposed around the margins of the Beaverhead and Upper Ruby River basins. These rocks consist of lava flows, welded ash-flow tuffs, non-welded ash-flow tuffs, airfall ash deposits, ground surge deposits, debris and hyperconcentrated flood-flow deposits and volcanic sandstone deposited by unidirectional flowing water in braided and meandering streams.

Previously, little attention has been focused on these deposits other than brief mention on geologic maps and general reports such as Chadwick, 1978, 1981, 1985) or in our preliminary work (Fritz, 1986; Matthews and Fritz, 1988). No work has been done on the radiometric dates or chemistry of most of the volcanics in these basins and no one has investigated their mode of emplacement. Traditionally, many of these rocks have been lumped either with undifferentiated Tertiary Volcanics or assigned to either the Renova or Six Mile Creek Formations of Kuenzi and Fields (1971).

The purpose of this report is to present preliminary results of our research on the mapping, radiometric ages, geochemistry and depositional environments of the volcaniclastic rocks. Detailed interpretations of this preliminary data will follow in later papers.

For this paper we use the terms proximal, medial and basinal as follows. Proximal volcanics include those lava flows and primary ash-flow tuffs (usually welded) that were deposited at or near volcanic complexes. Medial volcanic and volcaniclastic rocks are comprised of scarce lava flows and dominated by ash-flow tuffs, ground-surge deposits, airfall-ash and exhibit much transport and reworking of volcanic material by debris and hyperconcentrated flood-flow, streams and wind. Basinal deposits refer to normal sedimentary basin fill, the Renova and Six Mile Creek Formations, that contain abundant volcanic material.

Significance of Studies on Volcaniclastic Rocks

Even though volcaniclastic rocks in the Beaverhead and Upper Ruby River basins have

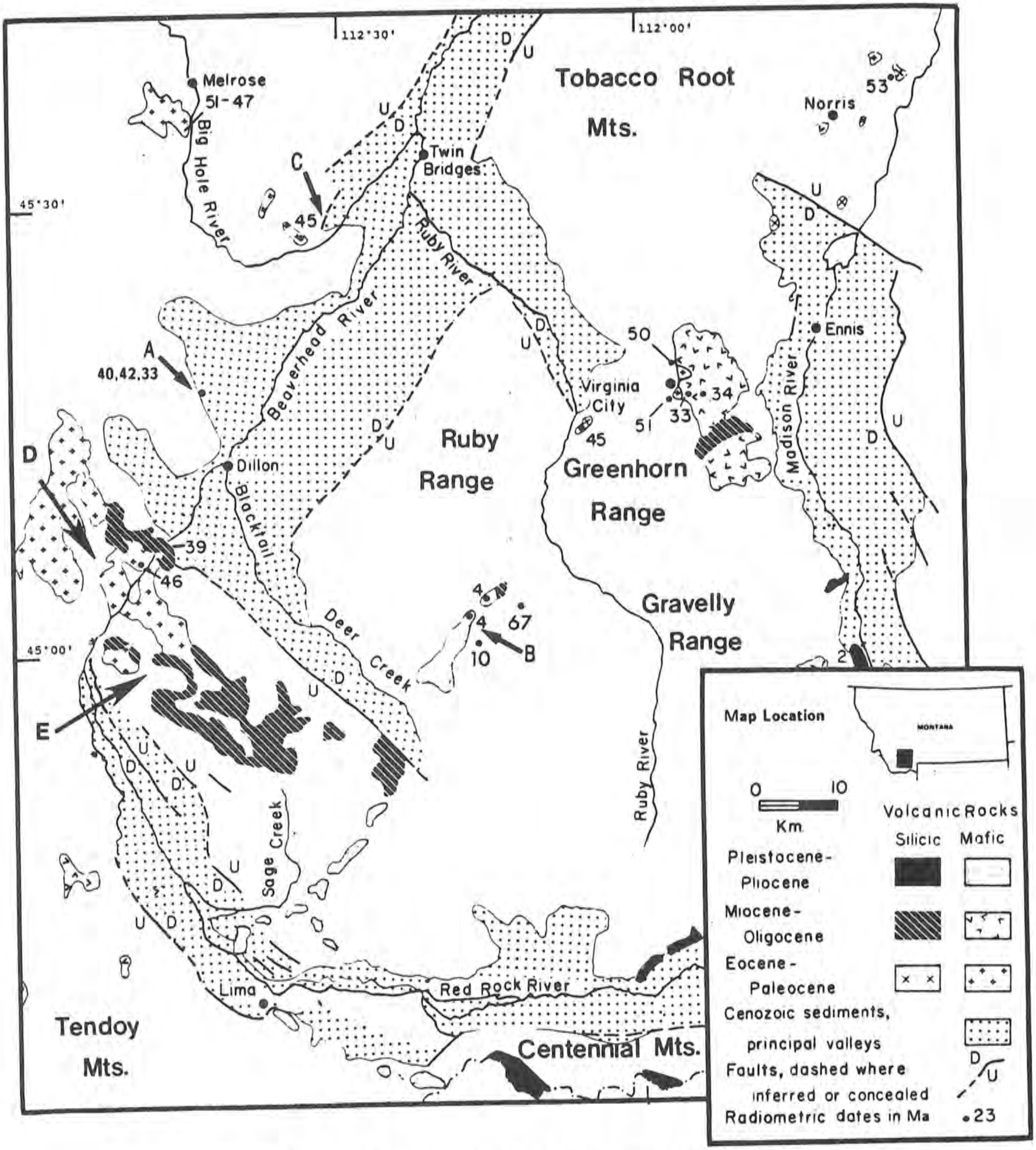


Figure 1. Location map of the Beaverhead and Upper Ruby River basins in southwestern Montana showing the ages and compositions of various volcanic fields and associated sediment fill of the Renova and Six Mile Creek formations. Arrows point to the five main field localities proposed for this study (A - Frying Pan Basin; B - Timber Hill/Sweetwater Pass; C - Block Mountain; D - Grasshopper Creek; E - Clark Canyon). Dates in the vicinity of 8"A" from Matthews and Fritz (1988) and this paper; at "B" from this paper. Dates at A & B give the most reliable dates from Table 1. See Table 1 and Appendix A for other dates and their interpreted reliabilities. Base map and other dates compiled from Chadwick (1981).

not been described in detail, they may provide important clues to unraveling the Tertiary history of southwestern Montana. For example, previous authors have suggested that most of the volcanic component of the Tertiary sedimentary basin fill (Renova and Six Mile Creek Formations) came from outside of the depositional basin, possibly from the Western Cascades (Fields and others, 1985). However, the numerous exposures of welded and non-welded ash-flow tuffs, airfall ash, surge and reworked volcaniclastic sediments exposed around the margin of the Beaverhead and Upper Ruby River basins seem to indicate nearby volcanic complexes.

Recently, Thompson, Fields and Alt (1981, 1982) argued for at least four wet to arid regional, or possibly even global, climatic fluctuations during the Tertiary. Much of their evidence was based on sedimentation patterns in the intermontane basins of southwestern Montana and interpreted as being characteristic of arid regions. However, Thompson and others (1981, 1982) did not consider the effect that episodic addition of large volumes of volcanic sediment might have on sedimentation patterns regardless of climate. Instead they argue that most of the volcanic input into the sedimentary basins of southwestern Montana came from the Western Cascades and had no direct influence on sedimentation.

Previous studies both in areas of modern volcanism and ones of Tertiary volcanic rocks have determined that regardless of climate, massive input of unconsolidated volcaniclastic sediment from explosive volcanism can produce processes and environments that traditionally have been associated with arid and desert environments. Thus, volcanism can produce a "mock aridity" in the sedimentary record. Kuenzi and others (1979) and Vessell and Davies (1981), for example, describe alluvial fans, braided streams and fan deltas in a wet tropical environment in Guatemala that were caused by episodic sediment input during eruptions of Volcan Fuego. When later described in the stratigraphic record, these deposits might well be mistaken as indicators for arid climatic conditions or as resulting from rapid tectonic uplift rather than from volcanism.

In previous work on Eocene volcaniclastic sediments of the Absaroka Volcanic Supergroup in Yellowstone Park, Fritz (1980, 1982) found braided stream, debris flow, hyperconcentrated flood-flow and fan-type sequences in areas of very rapid deposition. In these same areas however, many well-preserved plants indicated that, even though various taxa represented cool to tropical conditions, all grew in areas of high rain fall. Thus, if climates had been interpreted solely on sedimentation patterns, ignoring the volcanic input and paleobotanical data, the climates would have been interpreted as arid.

Smith (1986, 1987a, 1987b) describes and discusses various types of mass flow, stream flow and alluvial fan processes and depositional environments in the Neogene Deschutes Formation in central Oregon. This material resulted from the episodic addition of volcanic material and volcaniclastic sediment into the basin of deposition. Rapid episodic input of sediment appears to have controlled the patterns of sedimentation to a greater extent than that of tectonism or climatic changes. In additional studies on Miocene Volcaniclastic rocks of the Ellensburg Formation, central Washington, Smith (1988a, 1988b) again found volcanism, rather than climate or tectonism, to be the major factor influencing sedimentation.

Numerous case studies of recent explosive volcanic processes also show that explosive volcanism has major effects on terrestrial sedimentation patterns. The 1980 eruption of Mount St. Helens provided an excellent opportunity to develop models of changing sediment patterns resulting from the addition of volcanic material following explosive volcanism. In the Toutle, Cowlitz and Muddy River drainages, the addition of volcaniclastic debris in the form of lahars, hyperconcentrated flood-flow, debris flows and airfall tephra changed previously meandering stream systems into temporarily braided systems. Work on the sedimentology of the flows and their subsequent modification (e.g. Fritz and Harrison, 1985a; Harrison and Fritz, 1982; Pierson, 1982, 1985; Pierson and Scott, 1985; Janda and others, 1981; Waitt and others, 1983) aid interpretations of medial and basinal volcaniclastic deposits.

Studies of sedimentation patterns following other recent explosive volcanic eruptions have also been developed and these are further expanding our understanding of sedimentation around volcanic vents. Naranjo and others (1986) and Fritz and others (1986) describe mass flow and hyperconcentrated flood-flow conditions in the vicinity of Nevado del Ruiz, Colombia. Preliminary investigations of El Chichon, Mexico also provide details of volcaniclastic sedimentation following the 1982 eruption and the effect of this sedimentation on burial and preservation of plants (Burnham and Spicer, 1986). Additional studies at Mount Rainier (Schmincke, 1967), Mount St. Helens (Mullineaux and Crandell, 1962), Volcan Fuego, Guatemala (Kuenzi and others, 1979; Vessell and Davies, 1981) and several recent texts (Fisher and Schmincke, 1985; Cas and Wright, 1987) are beginning to fill in the gap in understanding "volcano-sedimentary" rocks and processes.

This is not to argue that tectonism or climatic changes did not also influence sedimentation patterns in the basins of southwestern Montana but that it is important to differentiate the effects of each. Furthermore, we suggest that the control of explosive volcanism, in addition to tectonism and climate, must be considered in interpretations of the Tertiary basin fill in southwestern Montana.

<u>General Description of Volcanism in Southwestern Montana</u>

Volcanic and volcaniclastic deposits are well known in central and southwestern Montana and range in age from late Cretaceous to Miocene and later (Armstrong, 1975; Axelrod, 1966; Chadwick, 1981, 1985; Everden and James, 1964; Fritz and Harrison, 1985b; Fields and others, 1985; Lipman and others, 1972; Marvin and others, 1980; Smith and Luedke, 1984; Snyder and others, 1976). Generally, these rocks fall into at least four age groups or volcanic centers. The oldest, the silicic Elkhorn volcaniclastic rocks, were produced during the late Cretaceous (ca. 85-70 Ma) presumably from volcanic vents near Butte, Montana and were probably associated with the intrusion of the Idaho Batholith (Chadwick, 1981). Volcaniclastic sediments and ash-flows of the Elkhorn volcanics occur throughout southwestern Montana. The Cretaceous volcanics are mostly andesitic to rhyo-dacitic in composition and were deposited as flows, tuffs and ash-flow tuffs. In the Timber Hill/Sweetwater Pass area, we have obtained a preliminary date (Table 1) of ca. 67.1 Ma from a highly silicified, possible air-fall ash unit. An even older date of 95.1 Ma was obtained from an underlying ash-flow tuff. However because the sample contains visible garnets and contamination from underlying basement, we believe it to be too old and argue that the 67.1 Ma date from the air-fall ash more closely approximates the true age. The Timber Hill/Sweetwater Pass dates suggest that volcanism occurred at this time in the proposed field area.

Intermediate-composition volcanism occurred in southwestern Montana, Wyoming and Idaho during the Eocene (Chadwick, 1981, 1985; Fritz and Harrison, 1985b). The resulting volcanic pile includes the Absaroka, Clarno and Challis volcanics, among others. These rocks are represented almost entirely as volcaniclastic sediments in southwestern Montana; few flows or ash-flow tuffs have been described. Volcanic rocks of the Eocene group range in age from 58 to 41 Ma and are mostly andesitic in composition.

During the late Eocene/early Oligocene to Miocene (38-28 Ma) volcanism occurred from scattered volcanic vents throughout southwestern Montana. This Oligocene episode produced a bimodal assemblage of basalt and rhyolitic volcanic rocks. South of the field area proposed for this study, plagioclase-rich rhyolitic porphyries crop out in Beaverhead canyon (Chadwick, 1978, 1981). We have recently determined that the ash-flow tuffs in Frying Pan Basin belong to the early part of this episode. Conventional K-Ar whole-rock analyses yield dates of ca. 41 Ma and ca. 33 Ma (Matthews and Fritz, 1988; Table 1). We suspect that additional exposures in Frying Pan basin and exposures of volcaniclastic sediments along Grasshopper Creek and at Clark Canyon will correlate with these rhyolitic volcanics.

A few volcanic rocks were produced in southwestern Montana during the late Pliocene

Table 1. Results of K-Ar radiometric age determinations for volcaniclastic rocks at Frying Pan Basin, and Sweetwater Pass, Montana. Dates performed Georgia Institute of Technology under the direction of J. M. Wampler. See Appendix A for location and description of each sample. Dates for Sweetwater Pass should be considered preliminary and approximate. No errors have yet been calculated.

Sample	Method	Mass[1]	Mass[2]	K%	Radiogenic Argon %	Radiogenic Argon pmol/g	Ma[3]	+/- (Ma)
FRYING PAN BASIN								
MFP-100	Whole rock	0.0996	0.9510	4.78	74.13	335.01	40.0	0.8
MFP-101	Whole rock	0.0870	0.0910	3.29	34.83	243.87	42.2	2.1
MFP-102	Whole rock	0.1337	0.1359	2.34	32.00	134.71	32.9	1.8
SS4+1	Whole rock	0.1055	0.1003	4.90	78.94	359.75	41.8	0.8
MFP-115	Whole rock	0.1165	0.1067	5.47	88.14	341.22	35.6	0.7
S6-6M	Whole rock	0.9060	0.0999	4.73	66.60	439.15	52.7	1.2
S1-2	Whole rock	0.0967	0.0981	3.64	74.03	311.08	48.6	1.0
HB	Mineral	0.1101	0.1063	1.07	65.25	084.28	44.7	1.0
SWEETWATER PASS								
106-C	Whole rock	0.1006	0.0925	5.27	80.56	093.37	10.2	
401-A	Whole rock	0.1004	0.1182	1.27	52.35	214.59	95.1	
402-A	Whole rock	0.1115	0.1035	0.37	33.81	044.20	67.1	
121-A	Ash shards	0.1034	0.1099	2.75	40.92	189.21	39.2	

1. Dry mass of argon sample, grams.
2. Dry mass of potassium sample, grams.
3. Apparent age, millions of years ago.

Table 2. Chemistry of volcaniclastic rocks at Frying Pan Basin and Sweetwater Pass, Montana based on whole-rock X-ray fluorescence analysis. Values for major oxides given as weight percent; trace elements as parts per million. K-Ar analysis was performed on the samples MFP-100, MFP-101 MFP-102, and MFP-115. Various trace element ratios provided to illustrate the significantly different chemical composition of MFP-102. Values for Frying Pan Basin from X-Ray Assay; ones from Sweetwater Pass from Rigaku 3070 XRF Spectrometer at Georgia State University. See Appendix A for location and description of each sample.

	FRYING PAN BASIN							TIMBER HILL		
	MFP-100	MFP-101	MFP-102	MFP-115	MFP-205	MFP-207	MFP-800	108-A	303-A	505-A
MAJOR ELEMENTS										
SiO_2	68.6	80.9	59.9	71.6	77.1	73.7	81.3	69.36	70.03	66.9
Al_2O_3	12.2	8.78	14.9	12.5	12.5	12.2	9.17	12.42	12.47	13.05
CaO	1.37	0.27	2.68	0.59	0.12	0.48	0.33	1.68	1.82	2.09
MgO	0.61	0.07	1.36	0.21	0.05	0.27	0.06	0.83	0.78	1.40
Na_2O	2.19	2.84	1.53	2.04	4.36	2.39	2.91	2.11	2.13	1.63
K_2O	5.51	3.63	2.54	6.59	4.90	6.20	3.65	4.73	5.08	4.19
Fe_2O_3	1.53	0.12	3.80	1.70	0.21	1.02	0.17	2.91	2.32	3.51
MnO	0.02	<0.01	0.04	0.02	<0.01	0.03	<0.01	0.04	0.03	0.06
TiO_2	0.01	0.08	0.60	0.15	0.11	0.09	0.09	0.37	0.27	0.50
P_2O_5	0.02	0.03	0.17	0.02	0.03	0.02	0.03	0.06	0.04	0.09
LOI	8.08	2.85	12.6	4.23	0.54	3.62	2.47	7.4	7.43	9.74
SUM	100.4	99.6	100.3	99.8	100.0	100.1	100.3	101.91	102.4	103.16
FeO	<0.1	<0.1	<0.1	0.3	<0.1	0.2	<0.1			
TRACE ELEMENTS										
Cr	17	17	55	14	18	<10	16			
Rb	248	192	126	246	248	284	175			
Sr	234	<10	630	13	<10	<10	20			
Y	85	35	17	45	68	69	51			
Zr	235	187	218	330	250	204	191			
Nb	64	48	38	27	62	76	92			
Ba	152	110	838	131	91	92	107			
VARIOUS RATIOS										
Cr/Y	0.2	0.49	3.24	0.31	0.26	<0.14	0.31			
Zr/Nb	3.67	3.90	5.74	12.2	4.03	2.68	3.08			
Zr/Y	2.67	5.34	12.82	7.33	3.68	2.96	3.75			
Y/Nb	1.33	0.73	0.45	1.67	1.10	0.91	0.82			
Zr/Ba	1.55	1.7	0.26	1.89	2.75	2.22	1.79			
Nb/Ba	0.42	0.44	0.05	0.15	0.68	0.83	0.58			
Al_2O_3/TiO_2	122	110	24.8	83.3	113.6	135.6	101.9	33.6	46.2	26.1
CaO/NaO	0.63	0.1	1.75	0.29	0.03	0.20	0.11	0.80	0.85	1.28

and Pleistocene. These include the Yellowstone Plateau Volcanic Field (2.2 Ma - 0.06 Ma, Christiansen and Blank, 1972) and rhyolite ash flows in the Madison Valley. In the Beaverhead and Upper Ruby River basins this period of volcanism is represented by scattered basalt flows that date at about 4.0 Ma (Marvin and others, 1974; Chadwick, 1981). A preliminary date of ca. 10 Ma from pumice cobbles in a fluvially-reworked deposit at Sweetwater Pass (Table 1) shows that explosive volcanism from this period also influenced conditions within the Upper Ruby River basin.

Field Localities

The rocks we are studying occur around the margins of the Beaverhead and Upper Ruby River basins. We are currently studying at least five known localities and continue to search for and map new exposures of the units.

Specific field localities include: 1) Frying Pan Basin approximately 20 km northwest of Dillon; 2) in the Ruby Range on Timber Hill and at Sweetwater Pass along the western margin of the Upper Ruby River basin, 35 km east of Dillon; 3) along the Big Hole River near Block Mountain 22 Km north of Dillon; 4) at exposures along Grasshopper Creek 20 km south of Dillon; 5) exposures in Clark Canyon 30 km south of Dillon.

The pyroclastic deposits at Frying Pan Basin (Fig. 1, Locality A) occur in two distinct sequences separated into the northern and southern exposures (Fig. 2). Reworked volcaniclastic sediments (volcanic sandstone, siltstone, conglomerate and debris flow deposits) are interbedded with the pyroclastic deposits in the northern section of Frying Pan Basin (Fig. 3). The southern exposures of pyroclastic rocks consist of a basal layer of pyroclastic sediment overlain by a sequence of volcaniclastic sediment overlain by a sequence of pyroclastic deposits (Fig. 5). These consist of an ash-flow tuff deposit, a ground-surge deposit with carbonized logs at the top and an associated pumice-rich ash flow-tuff. This is overlain by an incipiently welded, devitrified pyroclastic ash-flow tuff with stretched and flattened pumice fragments. The volcanic rocks overlie deformed Cretaceous and older rocks.

Preliminary K-Ar dates show these volcanics to have been produced during at least two episodes, one ca. 41 Ma and another ca. 33 Ma (Table 1). Chemistry is typical of continental rhyolites (Table 2) and trace elements show at least two groupings that may be useful for correlations. The younger date (32.9 +/- 1.8 Ma; sample MFP-102) comes from a rock that appears to have a lower silica content; at first we thought the high CaO, Ba, Sr, MgO values and the large loss on ignition suggested the presence of secondary calcite. However, when silica is recalculated based on the large loss on ignition silica values are still lower than the other samples. Furthermore, x-ray diffraction shows only plagioclase, biotite, quartz and glass in the sample. Thus, we argue that sample MFP-102 has a chemistry quite different than the other samples (Table 2) and has not been affected by weathering or secondary alteration. Because this sample also comes from the highest rocks exposed in the section, the 32.9 +/- 1.8 ma date may well represent a true age. In summary, we argue that the dates around 41 Ma represent valid ages for most of the volcanism at Frying Pan Basin. In addition, we acknowledge the possibility that the 33 Ma and even the 52 Ma date approximate true ages.

These medial volcanics and volcaniclastic sediments in Frying Pan Basin appear similar in age and composition to the rhyolitic ash and tuffaceous sandstone that comprise much of the Oligocene Renova Formation. However, because these rocks are more proximal volcanics than the basinal sediments of the Renova Formation, they have not been traditionally mapped as basin fill, but included with the volcanics instead. The relationship between these and other exposures of rocks intermediate between proximal vent facies and basin fill sediments needs to be established in order to correctly understand the depositional conditions in the basin during the middle Tertiary.

Rocks at Timber Hill and Sweetwater Pass at the eastern edge of the Ruby Range (Fig. 1, Locality B) consist of nearly 100 m of vertical exposure of reworked rhyolitic volcaniclastic sediments, biotite and sanidine-bearing crystal airfall ash deposits and welded ash-flow tuffs and ground-surge

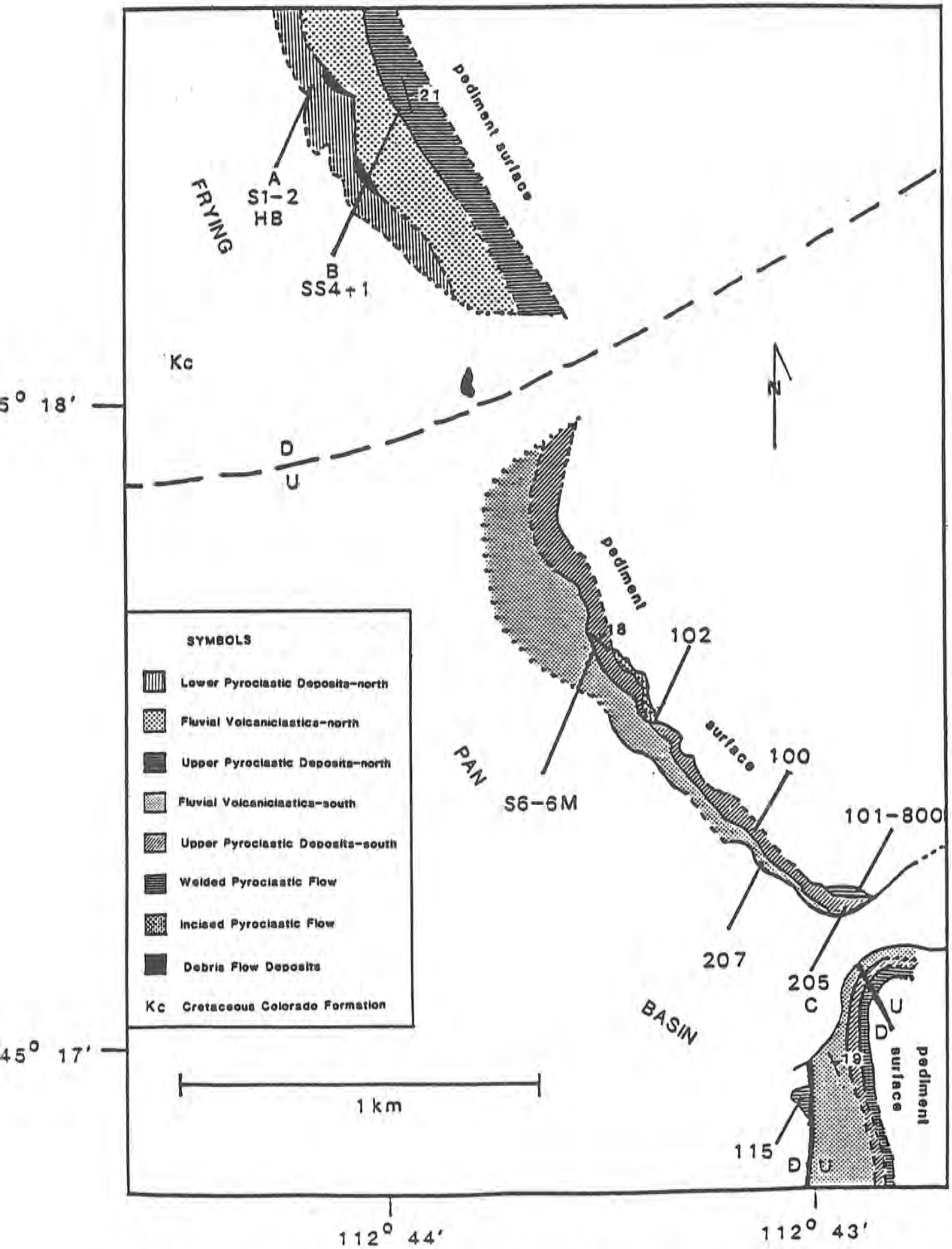


Figure 2. Geologic map of Frying Pan Basin showing sample localities discussed in this paper.

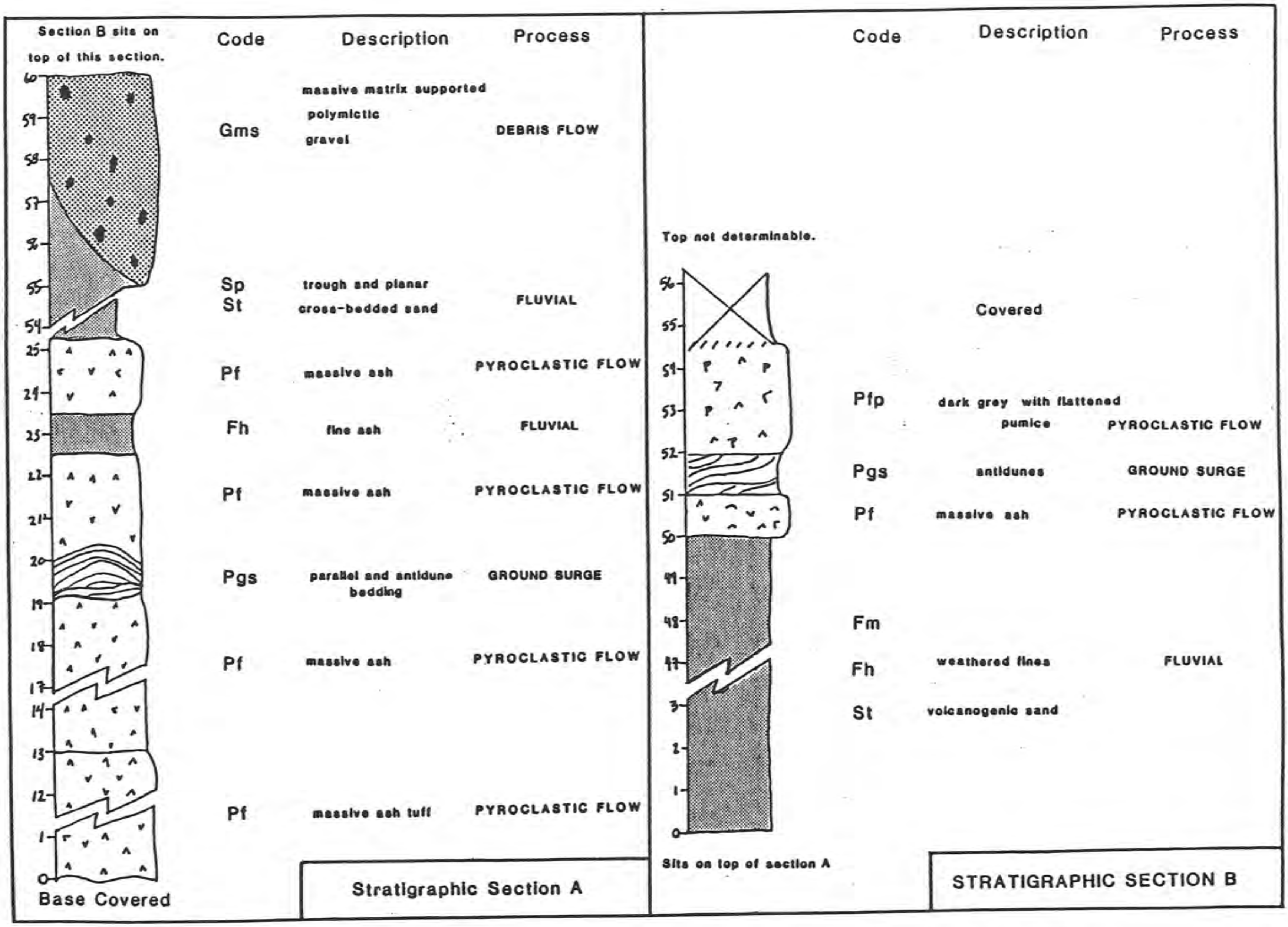


Figure 3. Vertical columnar sections of the northern exposures of pyroclastic, fluvial and debris-flow deposits at Frying Pan Basin, Montana.

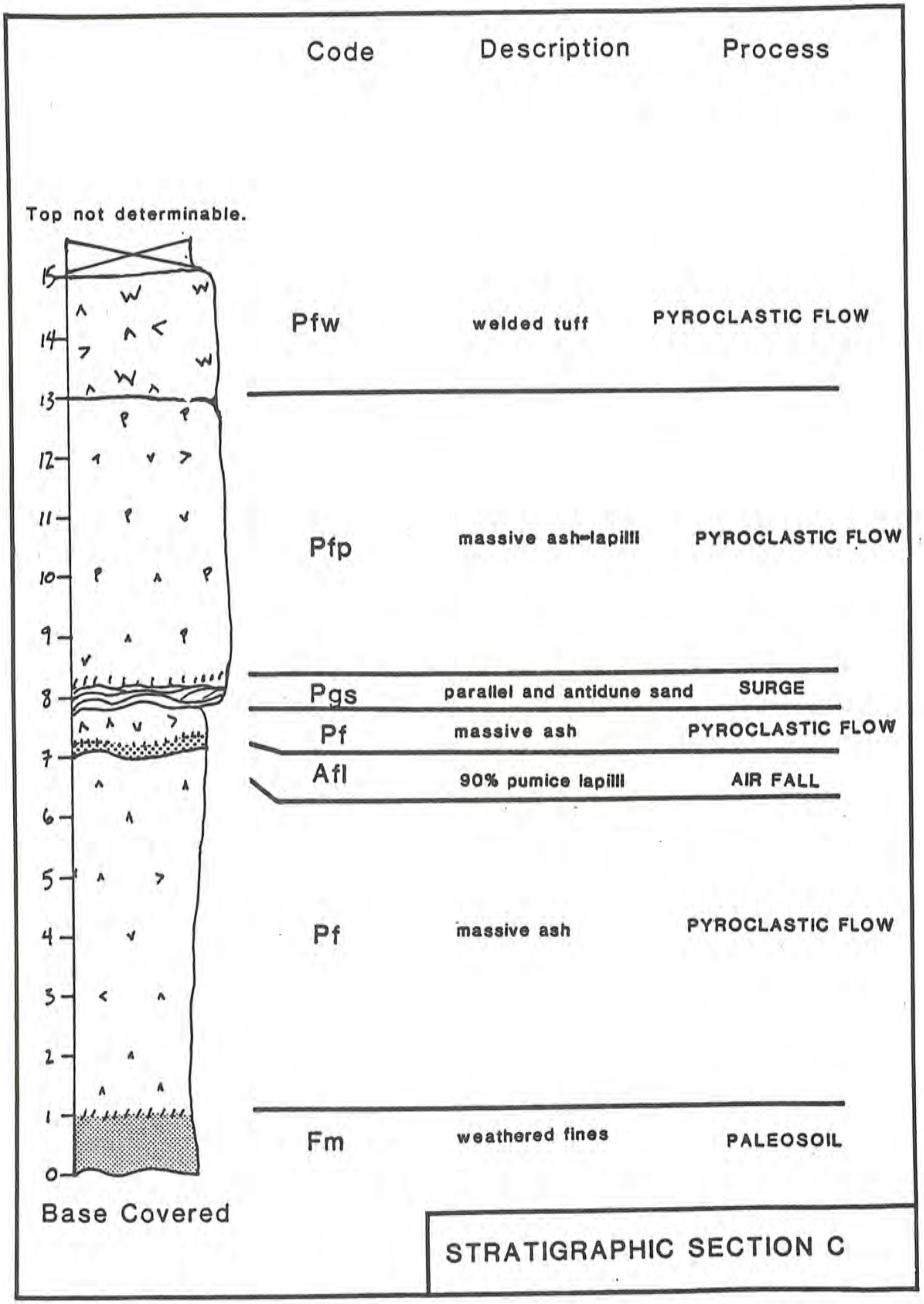


Figure 4. Vertical columnar section of the southern exposures of pyroclastic and fluvial deposits at Frying Pan Basin, Montana. Figure 2 gives the section location.

deposits. Preliminary K-Ar dates suggest an age of ca. 10 Ma, but additional work is needed. An older volcanic episode is suggested by preliminary K-Ar dates of ca. 67.1 Ma from highly silicified ash-flow tuffs and airfall ash units near an exhumed vent complex. A date of ca. 39 Ma from ash grains in sediments of the Renova Formation may represent a third volcanic episode that produced ash that was transported and deposited at this locality.

The volcanic rocks at Timber Hill/Sweetwater Pass rest on Precambrian basement and are overlain by a 4 Ma basalt flow (Marvin and others, 1974; Chadwick, 1981; Figure 5). The sedimentary structures are well-exposed and provide an excellent opportunity to describe how the input of massive amounts of rhyolitic ash controlled the sedimentation patterns in the Beaverhead Basin.

Volcanic-rich sediments to the east, in the central part of the Upper Ruby River basin, have been described by Monroe (1976) and mapped as Renova and Six Mile Creek formations. However, Monroe (1976) did not mention the volcaniclastic sediments and ash flows at the Timber Hill locality or include them with the basin-fill sediments. Even though Marvin and others (1974) dated the overlying 4 Ma basalt flow, they did not consider the underlying rhyolitic rocks.

Additional exposure of volcanic rocks and volcaniclastic sediment occur at Grasshopper Canyon (Fig. 1, Locality D). Because of the large volume of welded ash-flow tuffs, coarse-grained debris flow deposits, lava flows and hypabyssal intrusive rocks, this area appears to be either the site of a volcanic complex or much nearer to one than the other localities. Chadwick (1981) published two dates of ca. 39 Ma from rhyolite flows from near this area and we suspect that the medial volcaniclastic deposits of Frying Pan Basin to the north may have come from this proximal area. We have yet to analyze our samples from this locality but believe that they will yield similar dates to those at Frying Pan Basin.

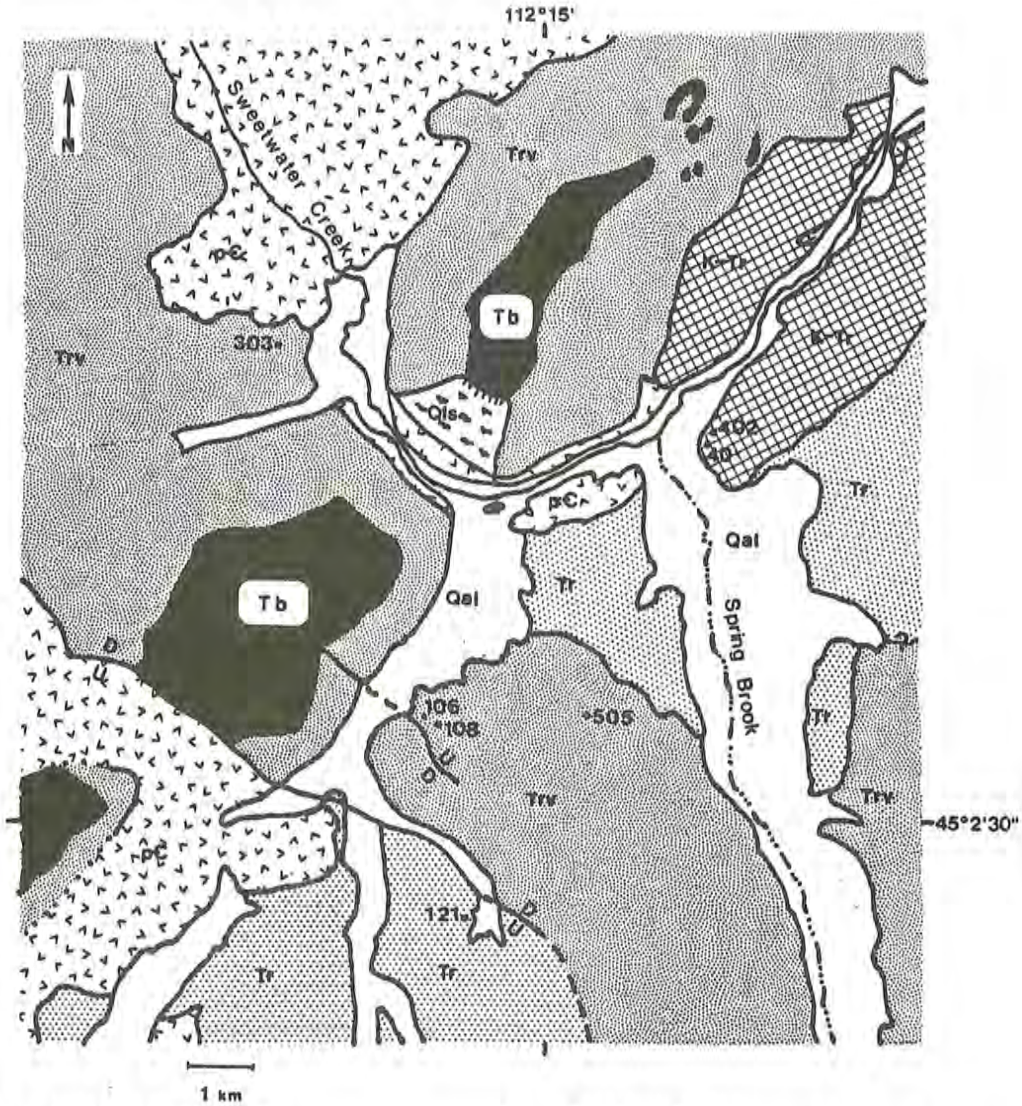
Exposure of medial-type volcaniclastic deposits also occur at Block Mountain (Fig. 1, Locality C) north of Dillon and at Clark Canyon (Fig. 1, Locality E) south of Dillon. No information exists on the ages or chemistry of these exposures. However, based on preliminary observation, they appear similar to the localities previously mentioned.

<u>Summary</u>

In their study on depositional rates and Tertiary climates, Thompson and others (1981, 1982) relied heavily on sedimentation patterns to infer Tertiary climates. However, in order to correctly compare the non-marine sedimentation record to global climatic trends the effect of sedimentation patterns produced by explosive volcanism must first be considered. The close association of several possible rhyolitic eruptive centers, volcaniclastic rocks and volcanic-rich basin fill of early Oligocene age in the Beaverhead and Upper Ruby River basins makes this an ideal locality to study the effects of volcanism on sedimentation. This information must be incorporated into climatic interpretations for these basins.

We suggest that the following conclusions can be drawn from our preliminary work on the volcanic and volcaniclastic rocks of the Beaverhead and Upper Ruby River basins:

1. High silica rhyolitic and dacitic volcanic and volcaniclastic rocks from explosive volcanism were produced from the Late Cretaceous to Late Tertiary in the Beaverhead and Upper Ruby River Basins.
2. These volcanic episodes presumably provided sediment and influenced patterns of sedimentation within the Tertiary basin fill. However, the degree of this influence has yet to be quantified.
3. Volcanic rocks at Frying Pan Basin were produced from at least two different episodes, one at 41 Ma and the other around 32-33 Ma.
4. Ash-flow tuffs and volcaniclastic units at Sweetwater Pass represent latest Cretaceous volcanism (ca. 67.1 Ma) and a much later episode of approximately 10 Ma.
5. Additional studies of the age and chemistry are needed in order to correlate among units and to trace material from proximal volcanics to



Qal	Quaternary alluvium	Tr	Tertiary Renova
Qls	Quaternary landslide	K-Tr	Cretaceous-Tertiary altered rhyolite
Tb	Tertiary basalt	pC	Precambrian basement
Trv	Tertiary rhyolite volcaniclastics		

Figure 5. Geologic map of the Timber Hill/Sweetwater Pass area showing sample localities discussed in this paper.

medial pyroclastic and volcaniclastic units out into sedimentary basin fill.

Acknowledgements

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APPENDIX A
SAMPLE DESCRIPTIONS

FRYING PAN BASIN

Sample No. MFP-100
NW 1/4, NW 1/4, S28, T6S, R9W; lat 45° 17' 20" N, lon 112° 43' 40" W.

The outcrop at this locality consists of a 3.5 meter thick deposit of grey pumice-rich pyroclastic ash-flow tuff with flattened pumice (aspect ratio of ca. 10). The pumice varies in abundance (30% to 50% by visual estimate) and is in a matrix of slightly compacted glass shards and ash with phenocrysts of unaltered biotite (<1%), abundant smoky quartz (5%), and pyrogenic euhedral fractured sanidine phenocrysts (3%). No lithic fragments were identified in hand-sample or thin-section. No devitrification of glass shards or alteration of biotite was evidenced indicating a lack of alteration for this sample. We believe the date of 40.8 +/- 0.8 Ma represents a close approximation of the age of emplacement of this pyroclastic ash-flow.

Sample No. MFP-101
SE 1/4, NW 1/4, S28, T6S, R9W; lat 45° 17' 20" N, lon 112° 43' 40" W.

The outcrop from this locality consists of grey to pink welded-tuff which exhibits concholdal fracture. It contains anhedral smoky quartz grains (2%), euhedral plagioclase (2%), hexagonal tabular biotite (5%), and prismatic hornblende (2%). Welding of this material did not occur as a result of compaction. Although original Y-shaped shards show some flattening, the main welding process for this zone was sintering of the glass particles at their points of contact. The plagioclase grains exhibit penetrative fractures indicating they are pyrogenic minerals that crystallized in the magma chamber and were fractured during eruption. The axiolitic texture is well developed on nearly all glass shards in this zone suggesting moderate devitrification. However, the devitrification is not complete, as the original glass shards and texture of the rock are still well-preserved. Since axiolitic texture is typically formed before the rock cools we suggest the date and chemistry for this sample are representative.

Sample No. MFP-102
SW 1/4, SW 1/4, S21, T6S, R9W; lat 45° 17' 28" N, lon 112° 43' 20" W.

The outcrop from which sample MFP-102 was collected is stratigraphically the highest pyroclastic deposit in Frying Pan Basin. The unit is distinctly lens shaped and clearly truncates other laterally continuous pyroclastic units. Sample MFP-102 has a different chemistry from the other samples (Table 2). The chemical basis for saying the rock is different from the others comes from a TiO_2 value significantly higher than that reported for the other samples and from the reported trace element values and ratios. In hand sample the rock is a homogeneous massive tuff with crystals and pumice grains <1 mm, x-ray diffraction shows only quartz, plagioclase, biotite and glass. In thin section, the sample exhibits frequent irregularly shaped dark blebs of glass with smooth unaltered margins showing no signs of devitrification. The glass blebs are imbedded in a fine groundmass of ash and pumice. The lack of devitrification of the glass and unweathered biotite present in MFP-102 indicates that the rock has not undergone significant alteration that would result in a loss of radiogenic argon. We believe the apparent age calculated for MFP-102 is representative.

Sample No. MFP-115
NE 1/4, SW 1/4, S28, T6S, R9W; lat 45° 16' 55" N, lon 112° 43' 10" W.

Sample MFP-115 also has a younger apparent age than the other rocks (Table 3). It has a composition similar to the other samples described. The rock dated comes from a small pyroclastic deposit on the down-thrown side of a fault in the southern portion of Frying Pan Basin (Figure 2). The composition of this sample suggests it is similar to the other Frying Pan ash-flow tuffs (Table 2). The sample has abundant unaltered glass shards in thin section (no axiolitic texture or reaction rims). We suggest that the apparent age reported for this unit is valid based on a lack of obvious weathering in thin section or hand sample and on the similarity of the composition of the sample to the other rock samples from Frying Pan Basin. We suggest that this deposit was associated with the younger event suggested by MFP-102.

Sample No. MFP-205
SE 1/4, NW 1/4, S28, T6S, R9W; lat 45° 17' 20" N, lon 112° 43' 40" W.

The outcrop at this locality consists of a 4 m thick deposit of tan to yellow pumice-rich pyroclastic ash-flow tuff with flattened pumice (aspect ratio of ca. 10). The pumice is flattened in a plane parallel to bedding resulting in a crudely developed fabric in the rock. The pumice varies in abundance (30% to 50% of volume by visual estimate) and is in a matrix of slightly compacted glass shards and ash with phenocrysts of unaltered biotite (<1%), abundant smoky quartz (5%), and pyrogenic euhedral fractured sanidine phenocrysts (3%). The material analyzed was from the center of the flow unit. No lithic fragments were identified in hand-sample or thin-section. No biotite alteration or glass devitrification was evidenced indicating a lack of alteration for this sample. We believe the chemistry reported for this sample is representative.

Sample No. MFP-207
NW 1/4, NW 1/4, S28, T6S, R9W; lat 45° 17' 15" N, lon 112° 43' 43" W.

The outcrop at this locality consists of a 3.2 meter thick deposit of tan to grey pumice-rich pyroclastic ash-flow tuff with flattened pumice (aspect ratio of ca. 10). The pumice is flattened in a plane parallel to bedding resulting in a crudely developed fabric in the rock. The pumice varies in abundance (30% to 50% of volume by visual estimate) and is in a matrix of slightly compacted glass shards and ash with phenocrysts of unaltered biotite (<1%), abundant smoky quartz (5%), and pyrogenic euhedral fractured sanidine phenocrysts (3%). The material analyzed was from the center of the flow unit. No lithic fragments were identified in thin-section or hand-sample. No biotite alteration or glass devitrification was evidenced indicating a lack of alteration for this sample. We believe the chemistry reported for this sample is representative.

Sample No. MFP-800
SE 1/4, NW 1/4, S28, T6S, R9W; lat 45° 17' 20" N, lon 112° 43' 40" W.

Sample 800 is from the same hand sample as sample 101.

Sample No. MFP-SS4+1
SE 1/4, SW 1/4, S17, T6S, R9W; lat 45° 18' 25" N, lon 112° 43' 55" W.

The outcrop that this sample was collected from is a pyroclastic ground-surge deposit that is 0.85 m thick. The deposit has hexagonal unaltered tabular biotite, euhedral plagioclase, and anhedral smoky quartz. This unit may have incorporated significant lithic constituents making the apparent age generated for this sample too large.

Sample No. MFP-S6-6M
SE 1/4, SE 1/4, S20, T6S, R9W; lat 45° 17' 40" N, lon 112° 43' 30" W.

The outcrop that this sample was collected from is a 2 m thick white pyroclastic ash-flow tuff deposited on top of weathered fines showing paleosol development. It is the lowest stratigraphic deposit of the southern exposures in Frying Pan Basin. No visible alteration is detected in hand sample. The date for this unit groups with the other dates from the southern exposure suggesting a 41 Ma event.

Sample No. MFP-S1-2
NE 1/4, SW 1/4, S17, T6S, R9W; lat 45° 18' 25" N, lon 112° 44' 10" W.

This sample was collected from the lowest stratigraphic unit in the northern section of Frying Pan Basin. It is a white biotite-rich massive ash-flow tuff. The biotite grains are tabular, hexagonal, and unaltered. Other mineral grains include euhedral plagioclase and anhedral quartz.
This sample may include older lithic material making the apparent age too large.

Sample No. MFP-HB
NE 1/4, SW 1/4, S17, T6S, R9W; lat 45° 18' 25" N, lon 112° 44' 10" W.

This sample is a heavy mineral separate consisting of 90% prismatic hornblende and 10% hexagonal-tabular biotite. The unit this sample was collected from is a ground-surge showing a great enrichment relative to pumice and ash of hornblende and biotite. The ground-surge occurs sandwiched between two related pyroclastic flows. However, we believe the apparent age reported for this sample is too large because of extraneous argon trapped by the minerals before they were erupted.

SWEETWATER PASS/TIMBER HILL

Sample No. 106
SW 1/4, SE 1/4, S18, T9S, R5W; lat 45° 2' 49" N, lon 112° 15' 38" W.

The outcrop at this locality consists of an 8 meter thick deposit of fluvially reworked volcaniclastic conglomerate and sandstone with pumice clasts up to 3 cm in diameter. Sedimentary structures include trough cross-bedded sandstone and conglomerate, massive grain supported conglomerate in channel fill lenses. Sample 106 was collected as several pumice clasts one meter above the base of the unit. The clasts were cleaned with ultrasound to remove clay, and then dated by conventional K-Ar. The material dated was essentially fine-grained glass shards; devitrification may have allowed significant argon to escape, making the apparent age of 10.1 Ma too young. However, we believe the date to be a fairly close approximation of the true age.

Sample 108
SW 1/4, SE 1/4, S18, T9S, R5W; lat 45° 2' 48" N, lon 112° 15' 36" W.

The outcrop at this locality consists of an 11.5 m thick deposit of fine-grained pyroclastic material resting on a well-developed paleosol. The lower part of the sandstone consists of trough and plane-bedded pyroclastic surge deposits overlain by massive partially welded ash-flow tuff. Sample 108 was taken about 3 meters above the paleosol, well into the massive ash-flow tuff. XRF analysis was performed on the sample and glass fragments of about 1 mm in diameter were picked from the tuff and analyzed by experimental K-Ar procedure. Because we could not remove all of the included Precambrian garnets, we suspect the apparent age of 19.1 Ma is much too old and that the true age is closer to that of the underlying sample 106. This locality appears to correlate, both by physical stratigraphy and by chemical similarity, to Samples 303 and 505.

Sample No. 121
NW 1/4, SE 1/4, S19, T9S, R5W; lat 45° 2' 4" N, lon 112° 15' 27" W.

This locality is a thick unit of massive reworked fine-grained sandstone mapped as the Renova Formation in other parts of the Upper Ruby River Basin. The sandstone contains fine-grained ash shards, large amounts of clay and a few crystals in addition to other detrital sedimentary grains. Sample 121 was taken 2 m above the base of the outcrop and split into two portions for K-Ar analysis. The clay and shards less than 120 um were removed from one portion by ultrasound and sieving; the other portion was analyzed without treatment. The treated portion yielded a date of 39.1 Ma, well within the range of ages assigned to the Renova Formation by Fields and others (1985). The apparent age of 106 Ma from the untreated portion is surely from contamination of detrital grains from older underlying units.

Sample No. 303
NE 1/4, SE 1/4, S12, T9S, R6W; lat 45° 3' 50" N, lon 112° 16' 25" W.

This unit is a 7 m thick deposit of fine-grained pyroclastic material resting on trough cross-bedded sandstone and conglomerate. The lower 5.5 m contain pyroclastic surge deposits and ash-flow tuff, as in Sample No. 108. The upper part of the unit consists of reworked pyroclastic material in trough cross-bedded sandstone and cross-bedded and massive conglomerate. Sample 303 was taken 2 m above the base of the outcrop. This locality appears, both by physical stratigraphy and by chemical similarity, to correlate with samples 108 and 505.

Sample No. 401
SW 1/4, SE 1/4, S8, T9S, R5W; lat 45° 3' 41" N, lon 112° 14' 21" W.

This unit is extends laterally for over 1 km and is about 30 m thick at this locality. The unit consists of a fine-grained, red-brown silicified sandstone presumed to have been hydrothermally altered in places and originally deposited as an ash-flow tuff. The unit rests directly on Precambrian basement gneiss and Sample 401 came from 3 m above this contact. Zones within the sample contained visible garnets and other detrital material from the underlying gneiss. A fraction with little observable contamination yielded a K-Ar date of 95.1 Ma; a second analysis from a zone with visible garnets gave an apparent age of 171 Ma. we argue that both of the dates are too old because of contamination from the underlying basement.

Sample No. 402
NW 1/4, SE 1/4, S8, T9S, R5W; lat 45° 3' 49" N, lon 112° 14' 14" W.

Sample 402 was collected several meters north of Sample 401 and 60-75 cm higher in the section from a 60 cm-thick zone of normally graded plane beds of pumice and ash interpreted as either air-fall ash or reworked hyperconcentrated flood-flow deposits. This unit is also highly silicified and hydrothermally altered in places. The sample was collected from the least altered zone possible. Because an airfall deposit should contain no contamination from underlying basement, we argue that the K-Ar age of 67.1 Ma approximates the true age for this unit. However, a second K-Ar date of 107 Ma may reflect possible contamination as well.

Sample No. 505

SW 1/4, SW 1/4, S19, T9S, R6W; lat 45° 2' 52" N, lon 112° 14' 52" W.

The deposit at this locality consists of a 3 m-thick pyroclastic deposit resting on a paleosol. There appears to be a series of three cross-bedded and plane-bedded pyroclastic surge deposits overlain by massive ash-flow tuffs. The sample analyzed by XRF came from the thickest massive ash-flow tuff 2 m above the base of the outcrop. This locality appears to correlate, both by physical stratigraphy and by similarity of chemistry, to Samples 108 and 303.

NORTHWEST GEOLOGY, V. 18, p. 85, 1989

MINERAL RESOURCE ACTIVITY FORECASTING IN THE EASTERN PIONEER MOUNTAINS, SOUTHWEST MONTANA

by

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An assessment of geologic favorability for mineral potential, commodity economics, current and historic activity, and land availability and accessibility was undertaken in order to forecast where mineral resource related activity may occur in the East Pioneers IA (a study area designated by the Forest Service for implementation of the 1986 Beaverhead National Forest Plan).

The results indicate that by combining these factors, it is possible to delineate areas that are likely to experience activity related to mining and mineral exploration. The analysis is intended as a planning tool that would aid in coordinating these activities with other natural resource uses and thereby reduce conflicts.

NORTHWEST GEOLOGY, V. 18, p. 86, 1989

NUMERICAL DATING OF PINEDALE FLUVIAL TERRACES NEAR WEST YELLOWSTONE, MONTANA, USING OBSIDIAN HYDRATION DATING TECHNIQUES

by

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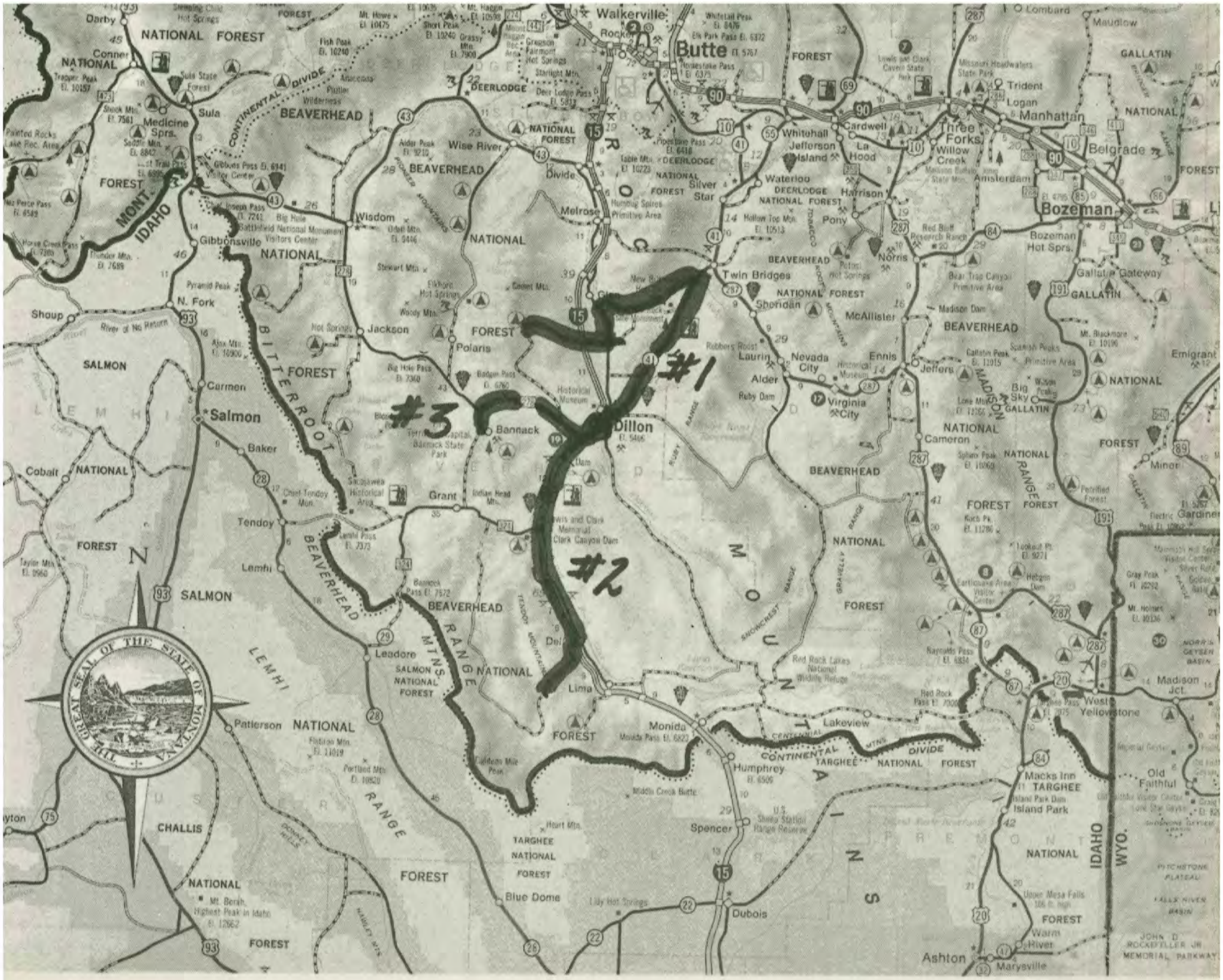
A set of five fluvial terraces was investigated near West Yellowstone, Montana. These terraces were formed by the progressive down-cutting of the Madison River through an obsidian-rich outwash plain in latest Pinedale time. Samples were collected at 20 cm intervals to a depth of one meter. From 60 to 99 hydration rind measurements on detrital obsidian grains were taken from the 20 to 60 cm depths in each pit, and statistically analyzed using non-parametric techniques. The modern sandbar deposits from 0 to 20 cm depth were not analyzed statistically.

The results imply that during transport, the rinds are only partially reworked. Each group of measurements records at least three hydration events which have been interpreted to have resulted from the initial cooling of an obsidian flow, Bull Lake equivalent glacial reworking and Pinedale equivalent glacial reworking. Peaks for hydration rinds of both Pinedale age and Bull Lake age agree closely with those reported by Pierce and others (1976). The scatter of rind thicknesses around each of three peaks is attributed to differing hydration rates for each of the obsidian flows that served as source areas for the outwash plain. Each of the lower five surfaces also have rinds that date from the reworking of that surface by fluvial processes with the modern sandbar displaying significantly more "zero" thickness rinds.

There is no apparent difference between the data from the five upper surfaces, indicating that these terraces were cut in a shorter time than the technique can discern. Using the hydration calibration curve from Pierce and others (1976), all of the other terraces were formed about 20,000+/-3,000 years. This conclusion disagrees with Nash's (1984) evaluation of these terraces based on scarp morphology. However, the scarp morphology dating technique was calibrated against a minimum carbon 14 date that may be several thousand years too young.



1989 Tobacco Root Geological Society Field Trips

1 Sears and others, July 20

2 Bartholomew, July 21

3 Pearson and Childs, July 22

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