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An overlap zone between a Laramide Rocky Mountain foreland structure and Sevier-style thrust structures near Bannack Montana

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AN OVERLAP ZONE BETWEEN
A LARAMIDE ROCKY MOUNTAIN FORELAND STRUCTURE AND
SEVIER-STYLE THRUST STRUCTURES NEAR BANNACK, MONTANA

BY

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ABSTRACT

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An Overlap Zone Between a Laramide Rocky Mountain Foreland Structure and Sevier-Style Thrust Structures Near Bannack, Montana

Director: Jim Sears

Near Bannack, Montana, unusual preservation of late Cretaceous synorogenic conglomerates and volcanic rocks provides an opportunity to evaluate the evolution of the overlap zone between the overthrust belt and the Rocky Mountain foreland. This sequence of Beaverhead conglomerates and volcanic rocks defines a stratigraphic sequence that is similar to the Beaverhead type section in some major aspects.

Crosscutting and overlapping relationships between the late Cretaceous sequence of Beaverhead conglomerates and volcanic rocks, and fold and thrust structures in the Armstead Hills, define two structural episodes. The Archean-cored Armstead anticline was initially uplifted along a Laramide basement-rooted fault. Paleozoic rocks were drape folded over the uplifted basement block. Late Cretaceous syntectonic Beaverhead conglomerates and overlying volcanic rocks were then deposited on a flank of this foreland structure. Beaverhead conglomerates were also deposited on an associated low-amplitude fold. Sevier-style thrusts then advanced into the area. The Ermont and associated Sevier-style thrusts cut the foreland structure and displaced it eastward.

The interaction between Sevier-style thrust structures and the Laramide structure resulted in anomalous development of thrust structures. Younger-over-older thrust faults and thrusts that cut down-section in the direction of transport formed in this overlap zone.

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Chapter 1

INTRODUCTION

Near Bannack, Montana, unusual preservation of late Cretaceous synorogenic conglomerates and volcanic rocks provides an opportunity to evaluate the evolution of the overlap zone between the overthrust belt and the Rocky Mountain foreland. This study was undertaken to determine the geometry and timing of the overlap zone where the Ermont thrust system intersects the Archean-cored Armstead anticline.

1.1. Location

The study area is located in Beaverhead County, Montana, approximately 28 km. southwest of Dillon (Fig.1-1). The area is in the Armstead Hills, a northern extension of the Tendoy Range. Mapping covered an area of approximately 135 km^2 in parts of the Bannack, Burns Mountain, Eli Spring, and Daly's 71/2' quadrangles and Grant 15' quadrangle.

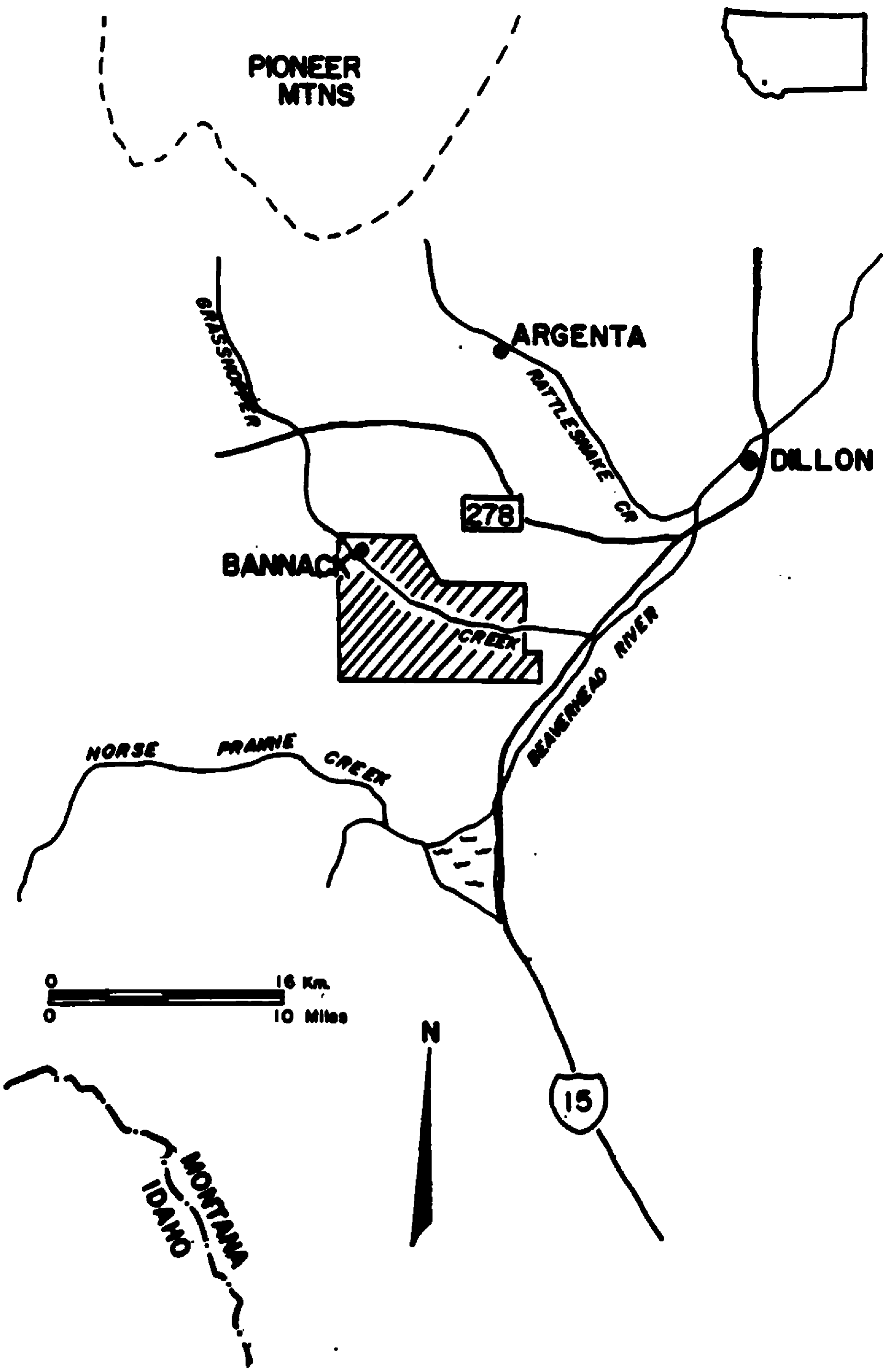


Figure 1-1: Thesis Location Map

1.2. Regional Structural Setting

Southwestern Montana is the meeting ground of two structural provinces: 1) the largely allochthonous rocks of the Cordilleran thrust belt; and 2) relatively autochthonous rocks of the Rocky Mountain foreland (e.g. Scholten, 1968, DuBois, 1982, Beutner, 1977). Following Armstrong (1968) and Beutner (1977), Perry and others (1983) adopted the terms Sevier-style for the western allochthonous province and Laramide for the eastern para-autochthonous province. Laramide structures are rooted in Archean basement rocks. Sevier-style structures are the classic "thin-skinned" fold and thrust structures.

Sevier-style thrust structures generally post-date local basement-involved Laramide structures (Tysdal, 1986, Schmidt and Garihan, 1983). The disruption of the basement in the foreland caused anomalous development of the thrust belt. The McCartney's Mountain thrust belt salient may have formed in a structural basin of the foreland (Brandon, 1984). Anomalous cleavage developed in the thrust terrane near Melrose, Montana against a basement uplift (Geiger, 1985). Pre-existing foreland structures control strike and stratigraphic position of the Tendoy thrust (Perry et al., 1983, Perry et al., 1981, Kulik, 1984). In some cases, reactivated Laramide structures deformed Sevier-style structures (Perry et al., 1986) or Laramide and Sevier-style structures may have formed contemporaneously (Lageson and Miller, 1986).

Ruppel and Lopez (1984) recognize three parts to the Cordilleran thrust belt in southwest Montana and eastern Idaho (Fig.1-2): 1)the Medicine Lodge thrust plate; 2)the Grasshopper thrust plate; and 3)the frontal fold and thrust zone. The

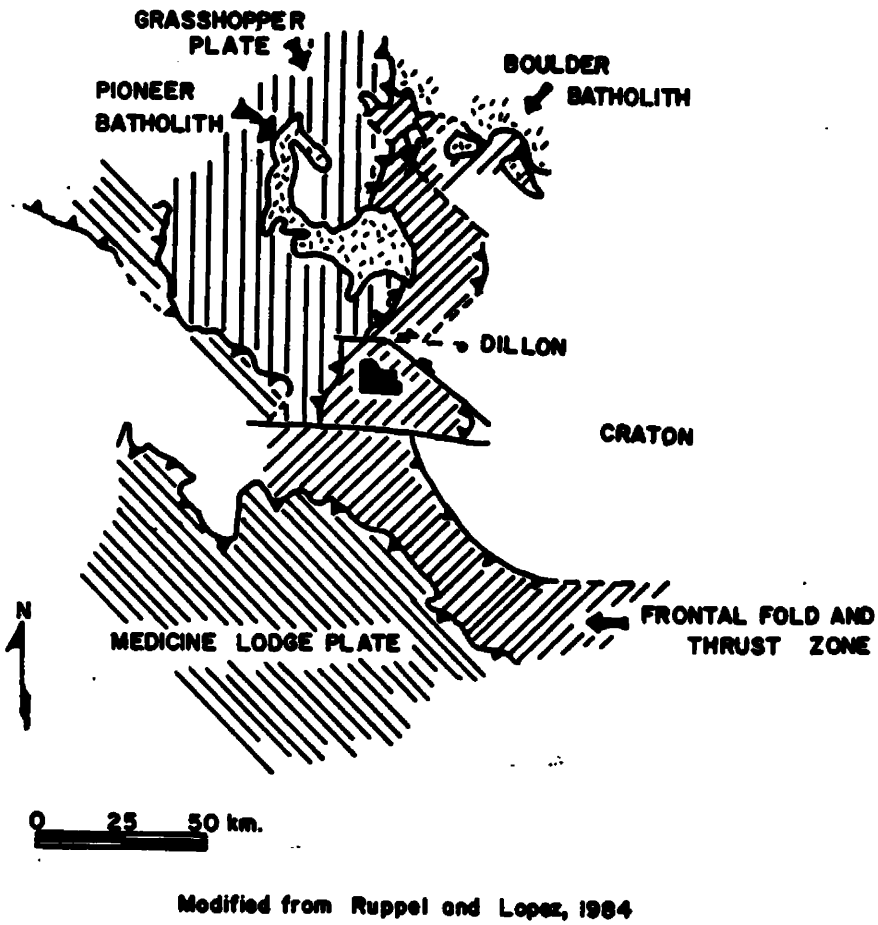


Figure 1-2: Regional Tectonic Map

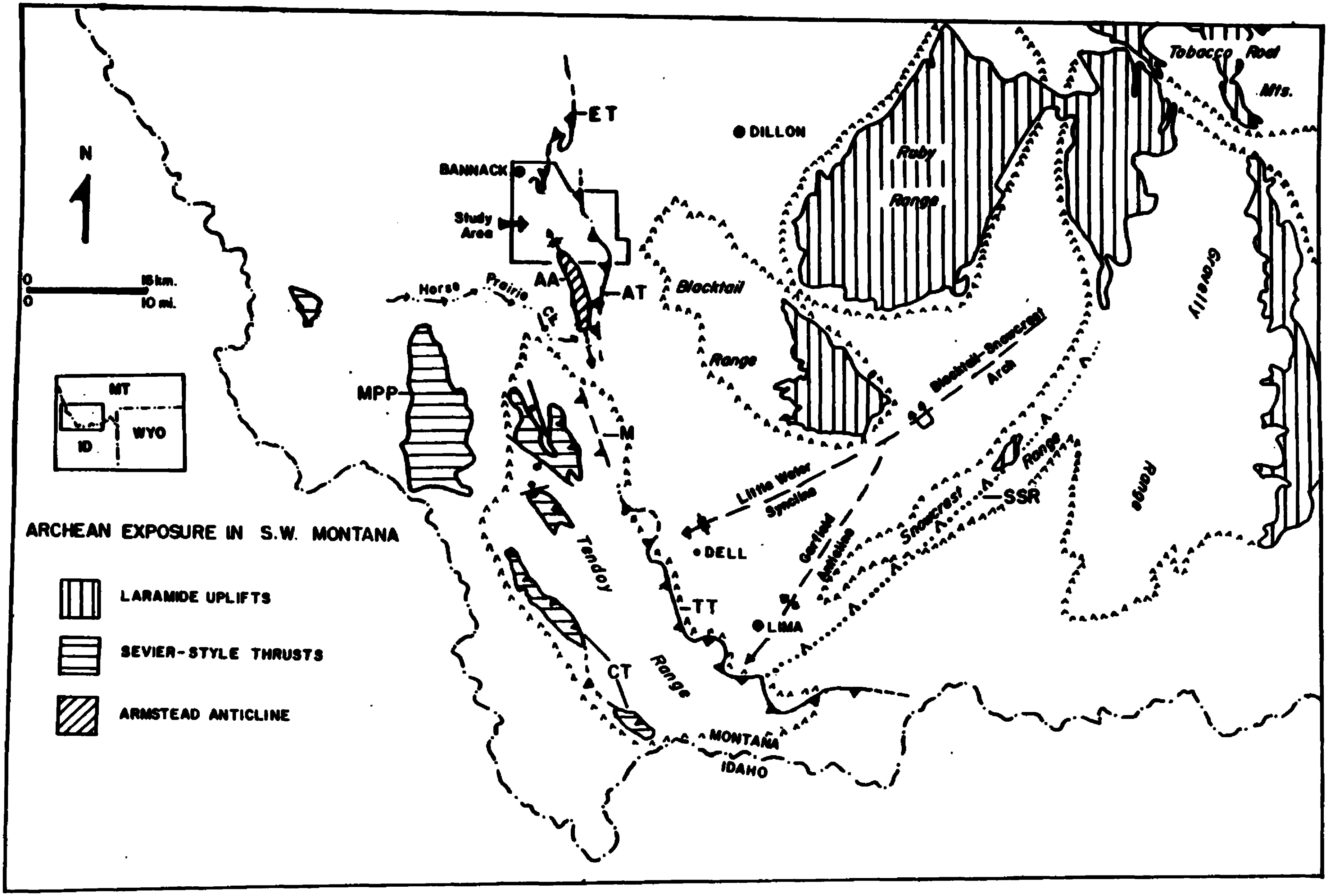
Medicine Lodge and Grasshopper thrust plates are large, thick allochthonous slabs that display internally consistent structures and stratigraphic sequences (Ruppel and Lopez, 1984). Tertiary sediments bury the Grasshopper plate ten to fifteen kilometers north of Bannack (Thomas, 1981). The frontal fold and thrust zone is the leading imbricate fan of the Grasshopper plate and is the easternmost zone of Sevier-style folding and thrusting (Ruppel and Lopez, 1984). The Armstead Hills lie within the frontal fold and thrust zone (Fig.1-2). East of this zone, Laramide structures deformed the craton in the Rocky Mountain foreland.

Large areas of Archean rocks crop out in the Rocky Mountain foreland province (Fig.1-3) because of late Cretaceous and Tertiary uplift (Scholten et al., 1955, Perry et al., 1983, Schwartz, 1982). Archean rocks also crop out along the eastern edge of the thrust belt where they have been carried on Sevier-style thrusts (Fig.1-3).

The Tendoy thrust (Fig.1-3) is the leading edge of the thrust belt in southwest Montana (Ruppel and Lopez, 1984). West of the Tendoy fault, the Cabin thrust carries Archean rocks over Mississippian and older rocks (DuBois, 1982). Archean rocks carried on this thrust underlie the Maiden Peak Prong of the Tendoy Range (DuBois, 1982, M'Gonigie, 1965). Several other thrust faults east of the Maiden Peak Prong (Fig.1-3) carry Archean rocks, but normal faults complicate the structures and make correlation of the thrust surfaces difficult (DuBois, 1982).

Figure 1-3: Regional Basement Map

Regional distribution of Archean rocks in southwest Montana. AA=Armstead anticline, AT=Armstead thrust, CT=Cabin thrust, ET=Ermont thrust, M=McKenzie thrust system, MPP=Maiden Peak Prong of the Tendoy Range, TT=Tendoy thrust.



ET
DILLON
Tobacco Root
Mts.
Ruby
Range
BANNACK
Study
Area
N
0 16 km.
0 10 mi.
Horse Prairie Ck.
AA
AT
Blacktail
Range
Gravelly
Range
MT
WYO
ID
MPP
M
Blacktail - Snowcrest
Arch
Little Water
Syncline
Snowcrest
Range
SSR
ARCHEAN EXPOSURE IN S.W. MONTANA
Tendoy
Range
DELL
Garfield
Anticline
LARAMIDE UPLIFTS
TT
LIMA
SEVIER-STYLE THRUSTS
CT
ARMSTEAD ANTICLINE
MONTANA
IDAHO

The Blacktail-Snowcrest arch is a southeast-verging fold structure within the Laramide structural province (Fig.1-3). The Archean core of this fold crops out in the southeastern part of the Blacktail range, east of the Bannack area. Northwest-dipping Paleozoic sediments unconformably overlie the Archean rocks along the northwest limb of the fold (Scholten et al., 1955). The southeastern limb of the fold underlies the Snowcrest range. Structural data in the Snowcrest range indicates deformation associated with the Blacktail-Snowcrest arch is younger than the late Cretaceous Frontier Formation (Hadley, 1969). The axis of the fold lies between the Blacktail and Snowcrest ranges (Perry et al, 1983). Gravity and drill hole data indicate the Blacktail-Snowcrest arch is a hanging wall anticline of a blind thrust with up to 6,000 meters of vertical displacement (Perry et al., 1983). This fault, the sub-Snowcrest Range fault (Fig.1-3) of Perry and others (1981), may have a Mississippian ancestry (Perry et al., 1983). Archean rocks in the Ruby and Tobacco Root ranges may be the northern extension of the Blacktail-Snowcrest arch (Karasavich et al., 1981). The Blacktail-Snowcrest arch splits into smaller scale folds (Fig.1-3) near its southwest end (Scholten et al., 1955). The southernmost of the folds is the Garfield anticline which plunges beneath the Tendoy fault (Scholten et al., 1955, Perry et al., 1981). The Little Water Syncline to the north appears to similarly plunge beneath the Tendoy fault (DuBois, 1982). Archean rocks carried on Sevier-style thrusts west of the Tendoy fault are spatially associated with these southwest-plunging folds. Gravity and aeromagnetic trends associated with the sub-Snowcrest Range fault are also continuous to the southwest beneath the Tendoy fault (Kulik, 1984, Perry et al., 1983). It is therefore very plausible that Archean exposures west of the Tendoy fault are the result of Sevier-style structures impinging on Laramide foreland structures (Armstrong and Dick, 1974, Perry et al., 1983).

Within the Rocky Mountain foreland province more than 30 northwest-trending faults cut basement rocks (Tysdal, 1970, Schmidt and Garihan, 1983). These faults have been interpreted as upthrusts (Tysdal, 1970) and as northeastward dipping reverse faults (Schmidt and Garihan, 1983). Many of these faults have attendant north plunging anticlines and synclines along their uplifted and downdropped blocks respectively. The plunge and geometry of these folds show that they are drape folds of the cover formed above basement block faults (Schmidt and Garihan, 1983, Tysdal, 1970). The north plunge of the folds may be related to northeastward rotation of the basement blocks (Tysdal,1970). Structural data in the southern Madison Range indicates these faults post-date the more regional Laramide uplifts (Tysdal, 1986).

1.3. Structural Setting of Bannack Area

Three major structures underlie the Armstead Hills: 1) the Tendoy(?) thrust; 2) the Archean-cored Armstead anticline; and 3) the Ermont thrust (Plate 1).

The Tendoy thrust defines the leading edge of the frontal fold and thrust zone (Ruppel and Lopez, 1984). This fault can be traced northward from southwest of Lima, Montana, to a point northwest of Dell, Montana. At this point, the continuity of the thrust is disrupted by the McKenzie thrust system of Perry and others (1985) (Fig.1-3). This structural zone marks the boundary between the

Laramide province to the east, and the Sevier-style province to the west. The Tendoy fault carries Mississippian rocks over late Cretaceous to early Paleocene(?) syntectonic Beaverhead conglomerates along much of its exposed length (Hammons,1981). Near Lima, Montana, the thrust cuts up- section in the hanging wall from Pennsylvanian Quadrant Formation to the late Cretaceous Aspen Formation (Perry et al.,1983, Hammons, 1981). The fault passes southeastward into a complex set of structures within the Cretaceous Frontier Formation (Perry et al.,1983). Lowell(1965) and Coryell (1983) have mapped the Tendoy(?) thrust in the Armstead Hills which also carries Mississippian and Pennsylvanian rocks over Beaverhead conglomerates. However, structural complications associated with the McKenzie thrust system to the south of the Bannack area indicate the thrust in the Armstead Hills is not the same structure (Perry, pers.comm. 1986). I propose that the thrust in the Armstead Hills be named the Armstead thrust and will refer to it as such.

The Archean core of the Armstead anticline underlies a shallow topographic basin within the Armstead Hills. Archean rocks of this doubly-plunging fold continue south to Horse Prairie Creek (Fig.1-3). A partial exposure of the Archean-core of the fold, about 3 km. south of Horse Prairie Creek (Brant et al., 1949, Hayden, 1872) is now concealed beneath the Hap Hawkins reservoir.

The Ermont thrust places Mississippian limestones over late Cretaceous Beaverhead conglomerates and associated volcanic rocks and extends 24 km. northward out of the map area (Thomas, 1981). The thrust fades into a complex set of structures at its southern end near Bannack. Tertiary sediments bury the thrust on its northern end, and it may die out in fold structures found north of the Tertiary cover (Thomas, 1981). Thrust structures further north are cut by the Pioneer batholith complex.

Several recent studies (Thomas, 1981, Coryell, 1983, Hammons, 1981) have focused on each of these structures but do not fully address their interrelationships.

1.4. Purpose

Late Cretaceous syntectonic Beaverhead conglomerates and volcanic rocks are either crosscut by, or overlap the three major structures. Beaverhead conglomerates and Cretaceous volcanic rocks crop out on the flanks of the Armstead Hills in the footwall of thrust structures but unconformably overlie associated fold structures. Prior to this study, the details of these structural and stratigraphic relationships had not been documented.

Thomas (1981) reported that the late Cretaceous volcanic rocks and Beaverhead conglomerates were cut by the Ermont thrust. Mapping by Lowell (1965) and Coryell (1983) documented that the Armstead thrust truncated Beaverhead conglomerates. It was therefore reasonable to assume that fold structures between these two thrusts, including the Armstead anticline, were associated with Sevier-style thrusting. Based on this assumption, these fold structures were also perceived as being younger than the conglomerates and volcanic rocks. This implied that exposures of these late Cretaceous rocks occupied the footwall of the frontal fold and thrust zone. However, without detailed analysis of structural and stratigraphic relationships between the late Cretaceous sequence of rocks and the fold and thrust structures, this assumption was only tentative.

The study area also was selected because of the rather unusual exposure of Archean rocks in the core of the Armstead anticline. Archean rocks exposed in the core of the Armstead anticline do not fit into either of the above classifications of Archean exposures in southwest Montana.

The abrupt termination of both the Ermont and Tendoy thrusts as they are traced into the Armstead Hills was also somewhat enigmatic. Neither of these structural terminations had any readily apparent explanation.

1.5. Methods

The late Cretaceous sequence of Beaverhead conglomerates and volcanic rocks were deposited during the same time that structures were evolving in the area. Therefore, these rocks were recognized as having the potential of providing time constraints on the evolution of structures in the Bannack area. To take advantage of this potential, I mapped in detail the structural relationships between this sequence of rocks and the thrusts and folds in the area. I also gathered data that would allow interpretation of the stratigraphic relationships within this sequence of conglomerates and volcanic rocks.

Armed with this data, I constructed cross sections and developed a model which clarifies some of the structural problems in the Armstead Hills.

Chapter 2

ROCK TYPES

2.1. SEDIMENTARY AND VOLCANIC ROCKS

2.1.1. Archean through Triassic

Earlier workers provided thorough descriptions of the Archean (Young, 1982) and Paleozoic through early Mesozoic (Coryell, 1983, Hildreth, 1980, Thomas, 1981, Lowell, 1965) sections. Since this is a structural study, no further descriptions of these rocks are necessary. Formation thicknesses reported on the stratigraphic column (Plate 1) are based on mapping and reflect minimum thicknesses found in the field.

2.1.2. Late Cretaceous to early Paleocene(?)

Two distinct types of the Cretaceous to early Paleocene (?) Beaverhead syntectonic conglomerates are exposed in the map area. The two conglomerate units are stratigraphically separated by a sequence of volcanic rocks believed to be Cretaceous in age (Thomas, 1981, Snee and Sutter, 1979). Crosscutting and overlapping relationships between these rocks and the older structurally deformed Archean through early Mesozoic rocks, provide details about the evolution of structures in the area. For this reason, these rocks require more thorough descriptions.

2.1.2.1. Lower Beaverhead Conglomerate

The stratigraphically lower Beaverhead conglomerate is a limestone-pebble conglomerate with minor coarse- to medium-grained sand beds. Outcrops of the conglomerate are reddish-brown or grey in color and frequently form resistant ridges and cliff faces. The conglomerates are clast-supported and form beds .5 m. to 10 m. in thickness. Pebbles are subangular to rounded and range from <1 cm. to >20 cm. in diameter. The pebbles are 80 to 90% limestone with recognizable Mississippian fossils common, and 10 to 20% quartzite plus chert. The conglomerate matrix and sand beds are composed of medium- to coarse-grained carbonate-cemented sands. Sand grains are predominately chert and quartz. Reddish-brown to maroon sand beds generally occur as lenses within the conglomerates.

2.1.2.2. Volcanic Rocks

Unconformably overlying the limestone-pebble conglomerate is a bedded tuff unit. This unit is white to tan to reddish-brown in color, fine-grained to aphanitic, and displays a well-developed platey parting in the lower part of the unit. The platey partings are developed sub-parallel to beds defined in hand sample by variations in color and/or grain size. The platey tuffs are porcelaneous and composed of subequal amounts of matrix and pumice fragments. Bedding is defined by variations in concentration of pumice fragments. Thin bedding, platey partings, and grading of pumice fragments into beds indicate the deposits may have been deposited in a still water environment (Thomas, 1981). Planar zones of platey parting are intercalated with tuffs without platey parting in the lower part of this unit. The lack of platey parting possibly represents episodes of subaerial deposition. Full thickness of this unit is unknown due to a lack of distinct bedding in the sub-aerially deposited tuffs. The thickest continuous section of this rock unit is in NW 1/4 Sec.16, T.8S., R.11W., where approximately 30 meters of the platey tuffs are exposed. North of this exposure, in Sec.9, T.8S., R.11W., this unit unconformably overlies the limestone-pebble conglomerate. At this location the volcanic rock is deeply eroded and bedding attitudes are difficult to find. Thomas (1981) found that the conglomerate-tuff contact is a 20 degree angular unconformity. A similar angle may be extrapolated from geometric constraints observed in this area.

An andesitic agglomerate unit unconformably overlies the tuff unit. The contact is best exposed in SE1/4 Sec. 21, SW1/4 Sec.22 and Sec.27,T.8S.,R.11W. The rock matrix is composed of green to brown to purple, medium- to fine-grained andesite with 5-30% plagioclase phenocrysts, 1-5% hornblende phenocrysts and occasional biotite phenocrysts. Plagioclase phenocrysts display a distinct zonation in thin section. Clasts are of the same composition and range from 1 to 20 cm. in size. Thomas (1981) estimated a minimum thickness of 300 meters for this rock unit where it is exposed north of the map area. Thickness of the unit in this area is unknown due to a lack of distinct bedding. However, geometric constraints indicate Thomas's estimate is reasonable.

A volcanic agglomerate with andesitic fragments is exposed on the Grayling syncline. In NW1/4 Sec.7, T.9S., R.10W., this agglomerate forms a small lense within the andesitic agglomerate. This shows that the agglomerate with the felsic matrix is coeval with the andesitic agglomerate.

2.1.2.3. Upper Beaverhead Conglomerate

Quartzite and limestone-pebble conglomerates outcrop in the eastern part of the map area. This unit contains pebbles of red to maroon, medium- to coarse-grained quartzite, which probably originated from the Belt Supergroup quartzites which crop out to the west (Ryder and Scholten, 1973, Ruppel and Lopez, 1984). Exposures of this unit along the north side of Grasshopper Creek also contain highly weathered andesite fragments (Fig.2-1). Visual estimates of andesite

Figure 2-1: Andesite Fragments in Upper Beaverhead Conglomerate

abundance range from 3-5%. However, voids in the conglomerate which most likely represent weathered-out andesite, would account for another 3 to 5%. Fifty to eighty percent of the pebbles are pre-Cambrian quartzites, the remainder are Paleozoic limestone, quartzite, and chert. The conglomerates are clast-supported with a matrix of medium- to coarse-grained, carbonate-cemented sands. The conglomerates are intercalated with fine- to coarse-grained, tan to reddish-brown, carbonate-cemented sandstones and pebble conglomerates which dominate the unit south of Grasshopper Creek. Lowell (1965) was uncertain about the stratigraphic relationships between the andesitic agglomerate and the quartzite-limestone conglomerate. However, several exposures of the contact (NE1/4 Sec.19,N1/2 Sec.18, T.8S.,R.10W., Fig.2-2) indicate this unit unconformably overlies the andesitic agglomerate. This relationship is also supported by the presence of andesite within the conglomerate.

A

Figure 2-2: Upper Beaverhead-Andesitic Agglomerate Contact

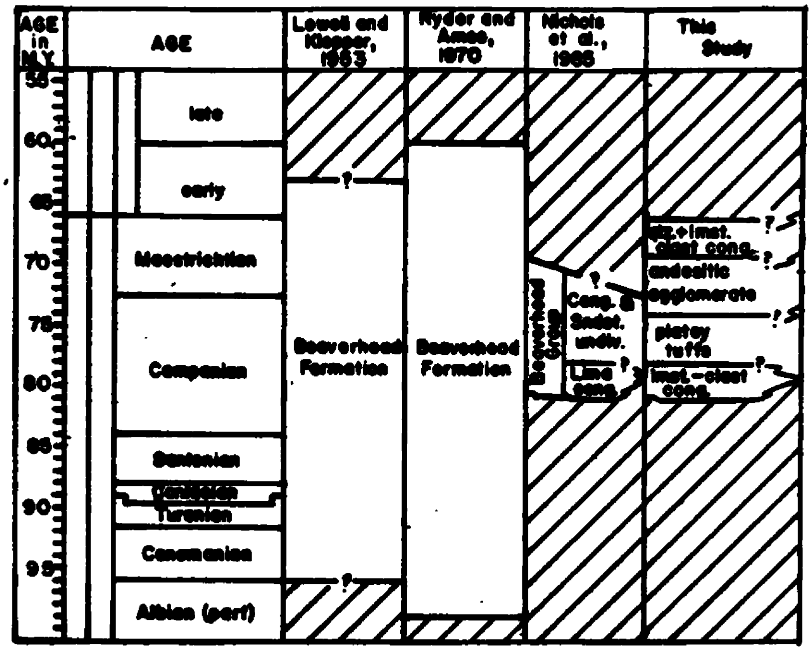
A) Looking northeast at contact
B) Looking north at contact

B

2.1.2.4. Correlation and Age

Beaverhead Conglomerate Lowell and Klepper (1953) first proposed the name Beaverhead Formation for a section of conglomerate, sandstone, siltstone, and limestone that outcrops over a 1,000 $km.^2$ area in Beaverhead County, Montana. The type section is in McKnight Canyon, 10 km. west of Dell, Montana. A late Cretaceous to Paleocene or Eocene age was proposed for the formation. This age assignment was based on paleontological evidence and structural relations. Later palynology studies (Ryder and Ames, 1970) indicated an Albian to Paleocene age. Most recently, Nichols et al. (1985) raised the section of syntectonic deposits from formation to group status and raised the Lima Limestone-conglomerate unit of Ryder and Scholten (1973) to formation status and named it the Lima Conglomerate. Based on further palynological studies, they proposed a maximum Campanian age for Beaverhead conglomerates. They also concluded that a post Maestrichtian age is unlikely for any Beaverhead conglomerates. Since different lithofacies within the Beaverhead may represent different phases of orogeny (Haley, 1983, Nichols et al., 1985), it is plausible that some rocks within the Beaverhead may be younger than Maestrichtian. Beaverhead age studies are summarized in Fig.2-3 which also includes my interpretation of the age relations with Cretaceous volcanic rocks exposed in the Bannack area.

The upper Beaverhead conglomerate cut by the Armstead thrust (Plate 1) in the eastern part of the map area was mapped as the Kidd quartzite conglomerate unit by Ryder and Scholten (1973). This conglomerate unit is younger than the Lima limestone conglomerate unit described in the same study, and is therefore



Modified from Nichols et al., 1985

Figure 2-3: Beaverhead Group Age Correlations

probably younger than middle Campanian (78 Ma). Ryder and Scholten (1973) did not map the limestone-pebble conglomerate that outcrops in the western part of the map area, and therefore correlation is suspect. However, since stratigraphic relationships indicate this unit is older than the Kidd quartzite conglomerate in the eastern part of the map area, it is most easily correlated with either the Lima limestone conglomerate unit in the Dell or Lima areas or McKnight limestone conglomerate unit of Ryder and Scholten (1973). The Lima limestone conglomerate unit in the Dell area and the Mcknight limestone conglomerate unit both contain significant percentages of Belt quartzite pebbles. Belt quartzite was not recognized in the limestone conglomerate in the map area. Therefore, this unit is tentatively correlated with the Lima limestone conglomerate unit in the Lima area which is the Lima Conglomerate of Nichols and others (1985). Limestone conglomerates exposed north of the map area have also been correlated with the Lima limestone conglomerate (Thomas, 1981). This correlation, coupled with palynology data (Nichols et al., 1985), suggests a middle Campanian (78-81 Ma) age for the iimestone conglomerate.

Volcanic Rocks Lowell (1965) assigned a Tertiary age to the platey tuffs and andesitic agglomerates. More reccent work (Thomas,1981) assigned a Cretaceous age to this volcanic sequence based on late Cretaceous (69-74 Ma) dates from the andesites (Snee and Sutter, 1979). The bedded tuff-andesitic agglomerate sequence in the map area occupies the same stratigraphic position as, and is continuous with, the same sequence mapped to the north by Thomas (1981). These rocks are therefore considered to be late Cretaceous in age.

The volcanic rocks are stratigraphically bounded by Beaverhead conglomerates and are therefore part of the stratigraphic sequence. For this reason, they are considered part of the Beaverhead Group of Nichols and others (1985)(North American Stratigraphic Code, 1983, p.858-859).

2.1.2.5. Summary

The sequence of two lithologically distinct congiomerates and stratigraphically intervening volcanic rocks records an episode of deposition bracketed in time by the two conglomerate units. The younger conglomerate unit is supposedly Maestrichtian or older (Nichols et al, 1985) and overlies the andesites dated at 69 to 74 Ma. As argued above, the older conglomerate unit is probably 78 to 81 Ma in age. This sequence of rocks therefore represents deposition from approximately 81 to perhaps 65 million years ago (Fig.2-3).

It is Interesting to compare this stratigraphic sequence with the Beaverhead type section in McKnight Canyon. At this location a lacustrine limestone unit which is reported to be up to 620 m. thick (Ryder and Scholten, 1973) is overlain by conglomerates with Belt quartzite clasts and underlain by limestone conglomerates (Lowell and Klepper, 1953). This intervening lacustrine environment correlates with the probable lacustrine environment in which the platey tuffs were deposited. Lowell (1965) reports andesite clasts in conglomerates overlying the middle limestone unit exposed in Clark Canyon, located approximately 20 km. southeast of the area. This also correlates with the stratigraphic sequence in the map area where conglomerates with andesite clasts overlie the stratigraphically intermediate volcanic rocks. The limestone and platey tuffs may represent deposition in a foredeep lake, that later filled with conglomerates shed from the advancing thrust sheets.

2.1.3. Tertiary Volcanic Rocks

Several volcanic rock types of Tertiary age are found in the area. Scattered exposures of light-gray to yellow-gray volcanics are found on the Madigan Gulch anticline. These rocks have a porphyritic texture with 5-10% plagioclase phenocrysts and 5-10% quartz phenocrysts. Welded tuffs also can be found in float overlying the Cretaceous andesitic agglomerates and in places the platey tuffs. The youngest volcanic rock in the area is Paleocene to Eocene basalt (Chadwick, 1981).

2.2. INTRUSIVE ROCKS

2.2.1. Granodiorite

Two granodiorite stocks are near Bannack. The larger was the locus of hard rock mining activity at Bannack and presumably was the source of rich placer gold deposits in the area.

The fine-grained granodiorite is composed of 60-70% plagioclase (An 40), up to 10% orthoclase, and 15-20% green hornblende (Thomas, 1981, This study). The larger stock has a fairly well developed marble contact aureole with the Madison Group limestones.

2.2.2. Andesite and Rhyolite

Deeply weathered andesites and rhyolites intrude Beaverhead conglomerates near Bannack. These rocks generally form dikes and sills in the conglomerate and a small stock (NE 1/4 Sec.8,T.8S.,R.11W.). Extensive weathering of the dikes and sills precluded detailed mapping so they are not shown on the map. These intrusions are quite pervasive west of the Ermont thrust; however, they were not recognized east of this thrust, except for a small andesite sill(?) which is partly exposed where it is cut by Grasshopper Creek (SE 1/4 Sec.8, T.8S.,R.11W.).

Thomas (1981) found that andesite intrusions north of the map area crosscut the andesitic agglomerates.

Chapter 3

GEOLOGIC STRUCTURES

Three large-scale folds and three major faults dominate the structure of the Bannack area (Plate 1). From west to east, the folds are the Madigan Gulch anticline, the Armstead anticline, and the Grayling syncline. Archean through Triassic rocks are involved in these eastward-verging folds. The westernmost fault is the Ermont thrust which places Madison group limestones over Beaverhead conglomerates and overlying Cretaceous volcanic rocks. A possible southern extension of the Ermont thrust (plate 1, loc. A), south of Grasshopper Creek, places upper Mississippian and Pennsylvanian rocks over lower and middle Mississippian rocks and, farther south (plate 1, loc. B), over Beaverhead conglomerates. The easternmost exposed fault is the Armstead thrust which places Madison group limestones, Quadrant quartzite and Cretaceous andesitic agglomerate over Beaverhead conglomerates. A third major fault juxtaposed Mississippian and Archean rocks along the west limb of the Armstead anticline (plate 1, loc. C). A smaller but significant fault is exposed on the west limb of the Armstead anticiine (plate 1, loc. D). It is nearly vertical where exposed and is interpreted as a reverse fault for reasons to be discussed later.

3.1. FOLDS

The Madigan Gulch anticline is a southward-plunging, eastward-verging fold, cored by Mississippian limestones (plate 1). The fold axis trends approximately N24W and plunges about 7 degrees to the south (Coryell, 1983). The northern part of the fold has been cut by a possible southern extension of the Ermont thrust, which caused local overturning of the east limb. Two southward-verging, superimposed folds may also be related to the thrust.

Hayden (1872) first recognized the Armstead anticline. Brant and others (1949) later named it and described it as a southward-plunging asymmetrical anticline. The southern portion of the fold observed by Brant et al. (1949) and Eardley (1872) is now flooded by the Hap Hawkins Reservoir behind Clark Canyon dam. In its northern portion, the structure is a northward-plunging, eastward-verging fold, truncated on the west limb by a fault that places Mississippian limestones against the Archean core of the fold (plate 1). South of the map area the fold axis trends N4W to N13W and plunges approximately 5 degrees northward (Coryell, 1983). Northeast trending sinistral faults on the east limb of the fold are interpreted as tear faults associated with thrusting.

The Grayling syncline is a broad, eastward-verging fold with Cambrian through Triassic rocks exposed on its limbs (Plate 1). The fold trends N10W to N25W and plunges 11 degrees to the north (Coryell, 1983). The east limb of the fold is truncated by the Armstead thrust.

While the Madigan Gulch anticline and the Grayling syncline appear to be relatively simple structures, the Armstead anticline is more complex. A wide range of dips and variable formation thicknesses are displayed on the east limb of the fold. A large part of this can be attributed to intraformational folding which is quite evident in the Lodgepole Limestone and upper Madison Group limestones. While intraformational folding may explain most of the thickening observed, air photos indicate other structures may be partially responsible. Duplication of linear features (bedding?) within the Mission Canyon Limestone in Sec.33 T.8S.,R.11W. indicates small scale thrusting may have locally thickened the formation. Another structural trend of the fold is the increase in dip and eventual overturning of beds as the fold limb is traced from north to south. Where the Paleozoic beds wrap around the nose of the fold, beds dip moderately to steeply eastward. Farther south, beds are generally overturned. This may reflect an increased displacement on the underlying Armstead thrust as the fold is traced southward. This interpretation is supported by the presence of sinistral tear faults on the east limb of the fold. The fold also displays a significant increase in plunge from south to north. South of the map area the fold plunges approximately 5 degrees to the north (Coryell, 1983). Plunge calculations based on the Cambrian-Archean unconformity on the north end of the fold indicate a 25 degree plunge to the north. I believe the complex structure of the Armstead anticline is related to its complex history, which will be documented and discussed below.

Bedding in the platey tuffs in Secs. 21 and 22,T.8S.,R.11W. define a north-trending fold. The axis of this fold is parallel to, but not on trend with the axis of the Armstead anticline. I believe this structure may be related to ramping of the Armstead thrust in the subsurface.

3.2. FAULTS

The Ermont thrust carries Mississippian limestones over Beaverhead conglomerates and Cretaceous volcanic rocks. North of the map area, the thrust dips 25 to 30 degrees to the west (Thomas, 1981), but near Bannack it steepens to 35 to 40 degrees. In the north wall of Grasshopper Creek, the fault cuts down section from west to east in the hanging wall through the Lodgepole Limestone (Fig.3-1A). This shows that the hanging wall limestone was deformed before formation of the thrust structure, perhaps on the flank of a fold as in Fig.3-1B.

South of Grasshopper Creek, a thrust carrying uppermost Madison Group limestone and a thin veneer of Quadrant Quartzite crosscuts the Madigan Gulch anticline (plate 1, loc. A). Older Mississippian limestones are exposed in the footwall; this, therefore is a younger-over-older thrust fault. The fault overturned the footwall beds where it intersects the east limb of the anticline. The lower Beaverhead conglomerates were caught-up in this overturned part of the fold (SW1/4 Sec.17, NE1/4 Sec.19, NW1/4 Sec.20, T.8S., R.11W.). A window into this thrust exists in a deeply incised drainage in SE1/4 Sec.24, T.8S., R.12W. This window shows upper Mississippian limestones thrusted over Lodgepole Limestones. The footwall limestone is deformed into low-amplitude (.2-.5 meter) folds which have no consistent orientation.

An outcrop in SE1/4 Sec. 18, T.8S., R.11W., may be part of the thrust described above. This outcrop exposes Mississippian limestone and Quadrant Quartzite in fault contact with the Dinwoody Formation and underlying Phosphoria Formation. The Mississippian and Pennsylvanian rocks are the same as those

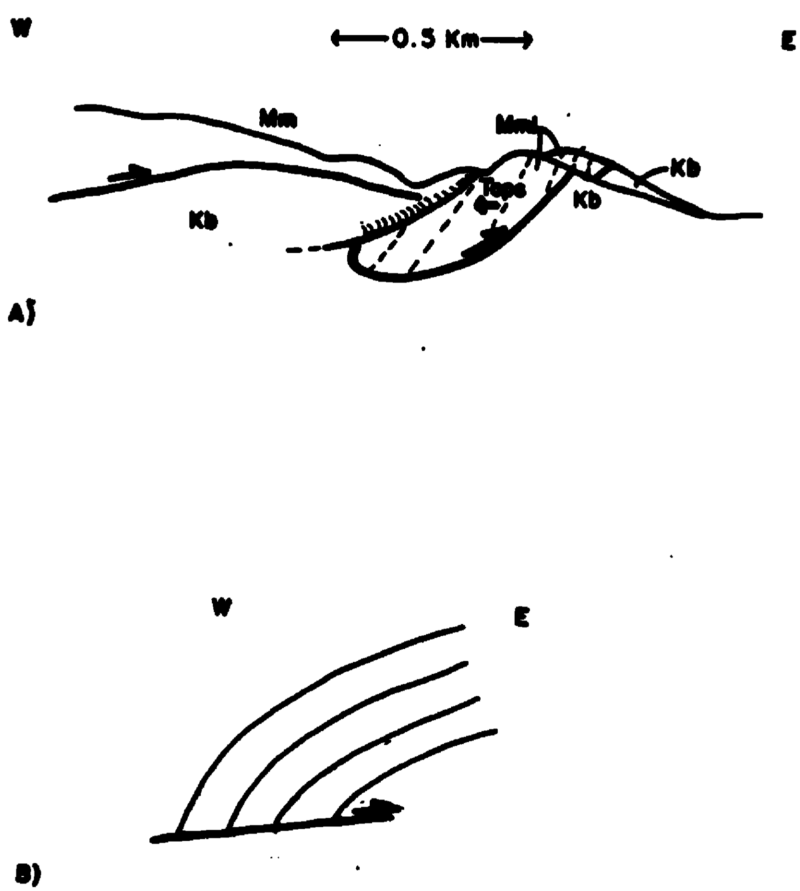


Figure 3-1: Sketch of Ermont thrust cutting down-section

A) Sketch of thrust looking north.

B) Sketch of how Ermont thrust may have developed, cutting through a pre-existing fold.

exposed in the hanging wall of the thrust to the east. The fault contact dips steeply to the west. If this is indeed part of the thrust, it has been rotated through a considerable angle. An alternative interpretation for this fault is that it may be part of an extensional fault that bounds the valley to the west.

In the southwestern corner of the map area, a thrust carries Mississippian limestones and unconformably overlying Beaverhead conglomerates over Beaverhead conglomerates (plate 1, loc. B). This thrust carried a similar part of the section in the hanging wall and is on trend with the thrust to the north; therefore, it may be the same thrust. This implies the fault has climbed up-section to Beaverhead conglomerates in the footwall. This portion of the fault also appears to change stratigraphic position in the hanging wall. Formations in the hanging wall are difficult to identify because exposures of the limestone are mostly on dip slopes; however, several clues exist. In Sec. 36, T.8S., R.12W., small exposures of Quadrant Quartzite are in the hanging wall. In the S.E. cornor of Sec.1, T.9S., R12W., hanging wall beds are thin-bedded (.2m to .5m thick) limestones, which may belong to the Lodgepole Limestone. This would indicate the fault is cutting down section in the hanging wall as it is traced from north to south. Lateral ramping is also indicated where the southern trace of this thrust is lost in the Beaverhead conglomerate, implying the thrust surface has cut the Madison Group-Beaverhead unconformity, and Beaverhead conglomerates are thrust over Beaverhead conglomerates. Superimposed southward-verging folds in Sec. 19, T.8S., R.11W. may also reflect a lateral ramp of the thrust surface. Geometrical constraints indicate the fault dips at about 10 degrees throughout its exposed length between Grasshopper Creek and the southwest corner of the map area (cross sections B-B' and C-C", Plate 2). Coryell (1983) calculated a dip of 12 degrees for the fault where it is exposed farther south. This is a fairly flat dip considering the changes in stratigraphic level in both the hanging wall and footwall. This most likely indicates later flat faults crosscutting folded beds which were already unconformably overlain by Beaverhead conglomerates.

Interpretations of the fault on the west limb of the Armstead anticline (plate 1, loc. C) include normal faulting (Kupsch, 1950, Brant et al., 1949), younger-over-older thrust faulting (Lowell, 1965), and listric normal faulting over a subsurface ramp (Coryell, 1983). Coryell also entertained the idea that the fault could be a west directed reverse fault, later rotated to the east by thrusting. The common denominator of these interpretations is that the fault dips steeply to the west. As will be discussed later, I agree with Lowell's (1965) interpretation of a younger-over-older thrust fault (cross sections B-B' thru D-D', Plate 2), which is consistent with obvious exposures along Grasshopper Creek.

The Armstead thrust is exposed or inferred for approximately 8 km. of strike length in the eastern part of the map area. Where the fault truncates the Grayling syncline, it carries Mississippian and Pennsylvanian rocks over Beaverhead conglomerates. This fault has not previously been recognized north of the Grayling syncline (Lowell, 1965, Coryell, 1983). However, this study concludes that the fault continues to the north where it places Cretaceous volcanic rocks over the upper Beaverhead conglomerates (cross sections B-B' and C-C", Plate 2). This portion of the fault is not well exposed due to the high degree of weathering of both the volcanic rocks and conglomerates. However, mapping of the contact is aided by a striking contrast in vegetative cover. The volcanic rocks support a dense population of sage brush while the conglomerates have only grasses growing on them. Two features of the contact strongly indicate a thrust relationship. As established above, the andesitic agglomerates are older than the upper Beaverhead conglomerate. In Secs.30 and 31, T.8S., R.11W., the andesitic agglomerate overlies the conglomerate, which requires a structural interpretation of the contact. The contact also has a striking continuity in trend with the Armstead thrust to the south, where it places Paleozoic rocks over the conglomerates. The thrust interpretation of this contact only requires the thrust to cut up-section in the hanging wall from Paleozoic rocks to the unconformably overlying Cretaceous volcanic rocks, which is quite reasonable considering the northward-plunge of the Grayling syncline.

Another minor thrust fault is exposed near Bannack, just east of the Ermont thrust (Plate 1). This fault cuts through stratigraphic unconformities making it difficult to document; however, several relationships indicate the fault exists. The contact between the limestone conglomerate and andesitic agglomerate north of Grasshopper Creek (Sec.16,T.8S.,R.11W.) dips to the west at about 40 degrees. This contact has stratigraphically lower limestone conglomerates over stratigraphically higher andesitic agglomerates, therefore requiring a structural explanation. A structural interpretation is also required to explain the structurally higher position of the platey tuffs with respect to the stratigraphically higher andesitic agglomerates in Sec.9,T.8S.,R.11W. Platey tuffs exposed in a deeply incised northeast-trending gully (NW1/4 Sec.16., T.8S.,R.11W.) are structurally lower than the older limestone-clast conglomerates to the northwest. This contact also requires a structural interpretation. The best hard evidence for this thrust is found just north of the section line between Secs. 9 and 16, T.8S.,R.11W.. A prospect pit at this location exposes a gouge zone 5 to 10 cm. wide that dips 40 degrees to the west. While this structure has andesitic agglomerate in both the footwall and hanging wall, it is continuous with other unconformabie relationships in the area, and is therefore interpreted as an exposure of the thrust. Displacement on this thrust is translated into strike-slip movement which cuts a klippe of Paleozoic rocks in Sec.17,T.8S.,R.11W.

A thrust which places Mississippian limestones over Mississippian limestones can be traced for about 1.5 km. through Sec.5, T.8S., R.11W.

A structurally complex outcrop on the north side of Grasshopper Creek (SE1/4 Sec.8,T.8S.,R.11W.) eludes satisfactory interpretation. This outcrop contains at least three faults which cut Madison Group limestones and includes a rotated angular unconformity that can be traced south for 8 km. (see discussion under Crosscutting and Overlapping Relationships). One of the faults in this outcrop (#1 in Fig.3-2) appears to be a thrust fault continuous with the Ermont thrust to the east (cross section A-A', Plate 2). This fault crosscuts the other two faults in the outcrop and is therefore the youngest. This fault is probably responsible for the klippe of Madison Group limestones that overlies Beaverhead congiomerates (Plate 1). A second fault in this outcrop (#2 in Fig.3-2) suggests at least two interpretations. One interpretation is that this fault is a portion of the thrust that cuts the Madigan Gulch anticline. This interpretation stems from the relationship between the fault surface and the underlying overturned folds, which is geometrically the same as the thrust-overturned bed relationship exposed on the northern part of the Madigan Gulch anticline. The argument against this interpretation is that this fault does not cut the limestone-pebble conglomerate.

Since other thrusts in the area post date the limestone-pebble conglomerate, it is difficult to understand why the conglomerate is not cut by this fault. A possible counter-arguement is the thrust fault could have affectively "bulldozed" the conglomerate into its current upright position. The second interpretation is based on the fact that this fault does not cut the conglomerate. This would indicate the fault preceded deposition of the conglomerate, and is therefore related to Laramide structural development. If this interpretation is correct, the fault was rotated along with the conglomerate beds and was therefore originally near vertical. The third fault in this outcrop (#3 in Fig.3-2) has no apparent correlative in the area.

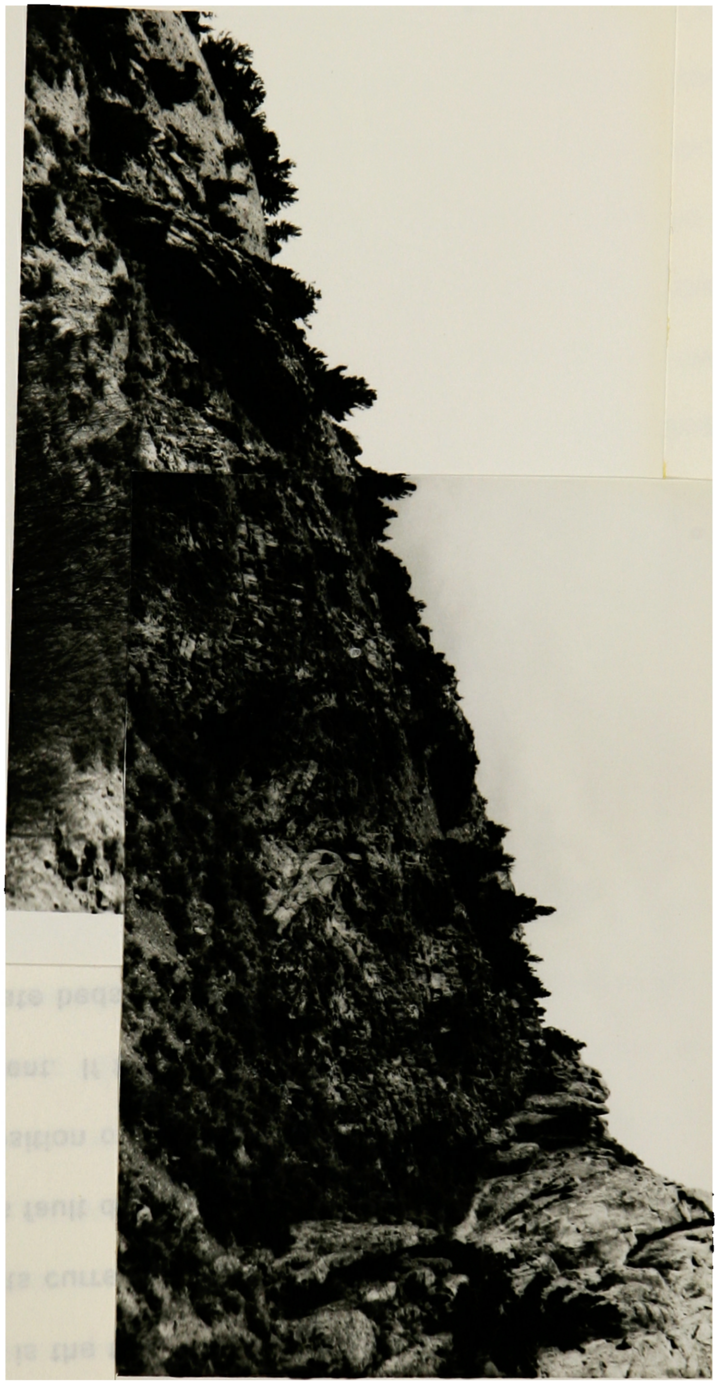
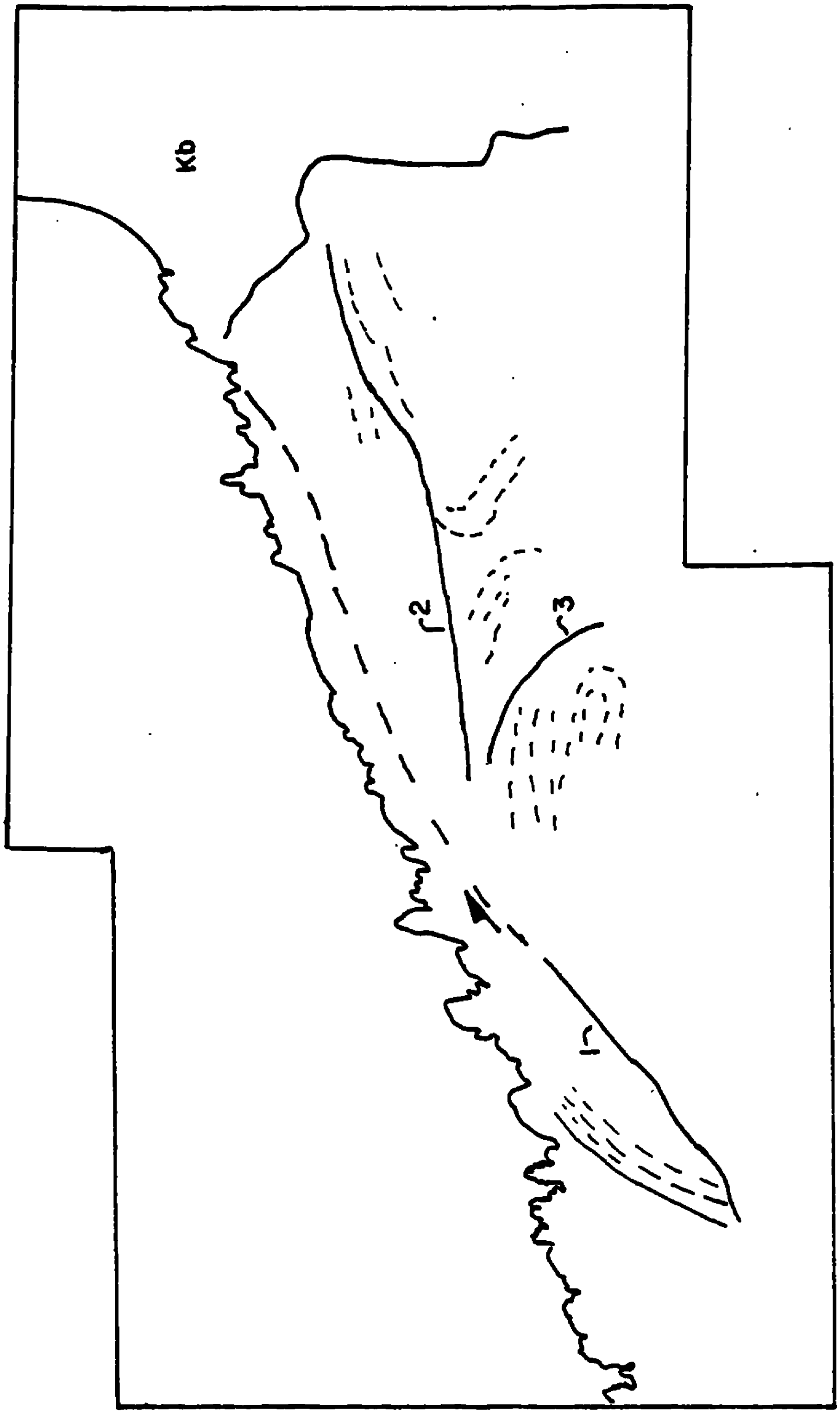


Figure 3-2: Outcrop on north side of Grasshopper Creek, near Bannack



3.3. LINEAMENT

Discontinuity of thrust structures and changes in Beaverhead bedding attitudes and facies on either side of Grasshopper Creek define a lineament. Termination of the trace of the Ermont thrust near Bannack requires a structural interpretation. The klippe of Madison Group limestones overlying Beaverhead conglomerates near Bannack (S.E.1/4 Sec.8,T.8S.,R.11W.) have no structural correlative on the south side of Grasshopper Creek. The structural level of the Beaverhead conglomerates underlying the klippe is anomalously low with respect to levels further south. The Armstead fault also appears to be offset where it crosses Grasshopper Creek. The quartzite-limestone-clast Beaverhead conglomerates on the north side of Grasshopper Creek dip gently to the south, while beds in the same rocks south of Grasshopper Creek dip gently northeast. Beaverhed conglomerates are also distinctly finer grained on the south side of the creek. Contrary to the apparent displacement of structures along or sub-parallel to the creek is the continuity of the thrust fault exposed in Secs.9,16,and 17,T.8S.,R.11W. No single structure can be envisioned that would satisfactorily explain these relationships.

3.4. CROSSCUTTING AND OVERLAPPING RELATIONSHIPS

Beaverhead conglomerates and the stratigraphically intermediate Cretaceous volcanic rocks are involved in crosscutting and overlapping relationships that reveal the structural history of the area.

North of Grasshopper Creek, the limestone-pebble conglomerate unit and overlying volcanic rocks are truncated by the Ermont thrust. Therefore, the Ermont thrust post-dates the Cretaceous volcanic rocks thought to be 69 to 74 m.y. old (Snee and Sutter, 1979). As established above, the Armstead thrust carries the Cretaceous volcanic rocks over the younger Beaverhead conglomerates and therefore post-dates both of these rock units.

Due to deep erosion of the Cretaceous volcanic rocks, the contact between the volcanic rocks and the east limb of the Armstead anticline is obscure. However, the contact is exposed on the north plunging axis of the fold (plate 1, loc. E) and shows the Cretaceous volcanic rocks overlap the fold (Fig.3-3).

Figure 3-3: Cretaceous tuff overlapping upper Mississippian Limestones on Armstead anticline

The tuffs also overlie Triassic rocks exposed in the core of the Grayling syncline.

The overlying andesitic agglomerates also overly these Triassic rocks. Between these two obvious exposures of the overlapping relationship, the contact is poorly exposed. However, along the east limb of the Armstead anticline, float rocks with andesitic agglomerate in depositional contact with Paleozoic rocks also attest to the overlapping relationship. The position of the volcanic rocks unconformably on Paleozoic rocks on the east limb of the Armstead anticline and in the core of the Grayling syncline, implies that these Paleozoic rocks were deformed before deposition of the volcanic rocks. Therefore, the Armstead anticline was folded, at least in part, before thrusting.

The limestone-pebble conglomerates unconformably overlie Paleozoic rocks exposed on the limbs of the Madigan Gulch anticline. This unconformity is exposed on both limbs of the fold. Conglomerate beds on the west limb of the fold dip moderately to the west, while beds on the east limb dip steeply to the east, thus conforming to the fold structure in the pre-Beaverhead rocks (cross section C-C", Plate 2). This implies the sub-conglomerate unconformity was involved in the folding, and therefore pre-dates the folding. The unconformity is on top of Mississippian limestones on the west limb of the fold; however, rocks as young as Permian are overlain by the conglomerate on the east limb. This implies that the Paleozoic rocks were deformed before deposition of the conglomerates. In the SW1/4 Sec. 33,T.8S.,R.11W. near the nose of the Armstead anticline, a small exposure of limestone-pebble conglomerate appears to overlie Mississippian Mission Canyon Formation, which is in fault contact with the west limb of the Armstead anticline. The fault predates the Cretaceous andesitic agglomerate and may pre-date the limestone-pebble conglomerate. The limestone-pebble conglomerate is not exposed anywhere east of this location within the map area. This feature could have several explanations. The most simple interpretation is the limestone-pebble conglomerate was not deposited in the eastern part of the area. This could mean the eastern most exposure of the conglomerate marks the line between erosion of source rocks and deposition of the conglomerate. This could imply that the Armstead anticline was the source for the conglomerate, and both the source structure and the resultant sediments remain exposed. A second explanation may be that the limestone-pebble conglomerate was deposited east of present exposures and later eroded. Both interpretations imply that this conglomerate was derived from the east as Ryder and Scholten (1973) proposed for most Beaverhead limestone-pebble conglomerates. However, it is possible that that this conglomerate was derived from the west (Haley, pers.comm., 1986). I propose that Beaverhead conglomerate sedimentation was partially controlled by the pre-existing Armstead anticline. Conglomerates could have been deposited west of the foreland structure while being eroded from the uplift.

The quartzite-limestone-pebble conglomerate is thought to be derived from Belt Supergroup rocks in thrust plates to the west. In the eastern part of the area it is truncated by the Armstead thrust. Immediately east of the map area this unit overlies Paleozoic rocks ranging from Mississippian to Cretaceous in age (Lowell, 1965). This also indicates the Paleozoic rocks were deformed before deposition of the younger conglomerate unit.

3.5. Summary

Cross-cutting and overlapping relationships indicate considerable folding and some faulting had taken place before deposition of conglomerates and Cretaceous volcanic rocks. Furthermore, the Cretaceous volcanic rocks that predate thrusting, post-date initial folding of the Armstead anticline. This implies the Armstead anticline predates thrusting, and is related to Laramide structural developments. The steep fault exposed on the west limb of the Armstead anticline, which is older than the andesitic agglomerate, also attests that deformation preceded thrusting.

Chapter 4

CONCLUSIONS

The Laramide structure was formed in response to west-directed, basement-rooted reverse faulting. This basement cored foreland bulge may be related to the northwest-trending reverse faults of Schmidt and Garihan (1983). The steep fault exposed on the west side of the nose of the Armstead anticline (Plate 1, loc. D) is interpreted as a splay of the unexposed, larger-scale, reverse fault. The Laramide structure was eroded and then overlain by late Cretaceous Beaverhead conglomerates and volcanic rocks (Fig.4-1 A and C). A possible southern extension of the Ermont thrust (Plate 1, loc. A) cut Paleozoic rocks and unconformably overlying conglomerates and volcanic rocks. This thrust is responsible for the klippe of Paleozoic rocks to the east of the Madigan Gulch anticline. Where the thrust underlies the klippe, it is an older-over-younger thrust fault. However, where the fault cuts the Madigan Gulch anticline, it is a younger-over- older thrust fault. The younger-over-older thrust fault in the southwestern corner of the area (Plate 1, loc.B, Fig.4-1D) may be a continuation of this fault with an intervening lateral ramp. The Madigan Gulch anticline is a hanging wall fold which involved Paleozoic rocks, the Paleozoic-late Cretaceous unconformity, and the Ermont(?) thrust. This fold formed over the younger-over-older thrust fault that cuts the west limb of the Armstead anticline. This thrust turns into a blind thrust along its northern trace (Fig.4-1 B, cross sections B-B' and C-C", Plate 2).

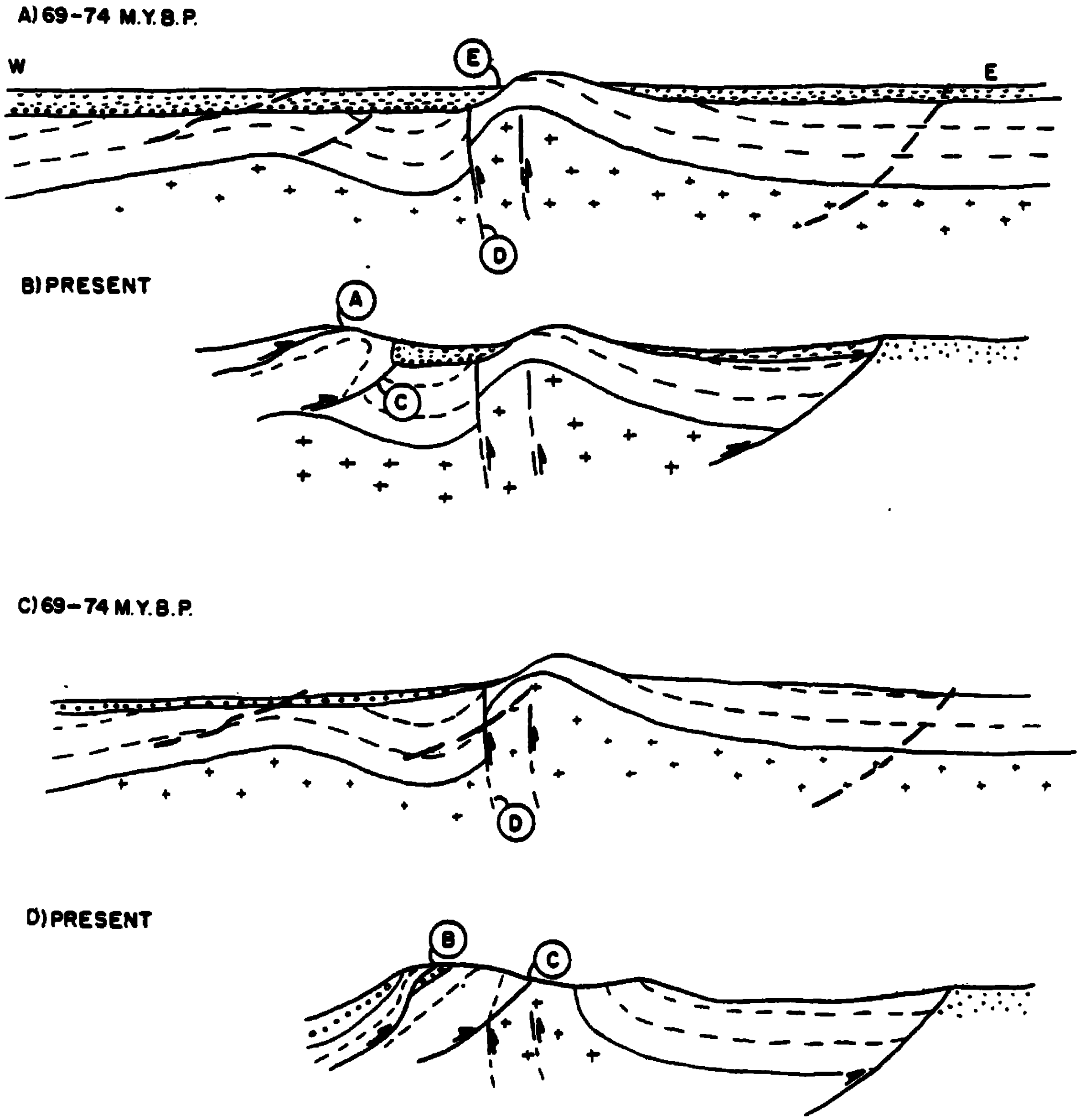


Figure 4-1: Schematic Cross Sections

Cross sections showing how structures in the Armstead Hills evolved. Sections are from south (C&D) to north (A&B). Circled letters correspond to locations on Geologic map (Plate 1).

The Armstead thrust cut the east limb of the pre-existing Laramide structure and gently folded this limb into the Grayling syncline (cross section E-E', Plate 2). This thrust also cut the Paleozoic-late Cretaceous unconformity and carried the andesitic agglomerates over the upper Beaverhead conglomerates. Steepening and overturning of the east limb of the pre-existing structure also accompanied displacement along the thrust.

Time relationships between the thrust faults are not clear. The southern extension of the Ermont thrust may have preceeded the thrust cutting the west limb of the Armstead anticline. The Ermont(?) thrust dips east where it underlies the klippe, but dips west where it cuts the Madigan Gulch anticline. This indicates that the thrust was folded along with the Madigan Gulch anticline. This folding also may have involved the Ermont thrust north of Grasshopper Creek. The Armstead thrust may have formed before or after the more western thrusts.

Thrusts in the Bannack area developed after deposition of the late Cretaceous volcanic rocks (69 to 74 Ma). The Armstead thrust cuts Beaverhead conglomerates that are younger than the volcanic rocks and may have developed in earliest Paleocene time.

The sequence of late Cretaceous Beaverhead conglomerates and volcanic rocks define a stratigraphic sequence. The stratigraphic contacts within this sequence of rocks are all unconformable. This shows that this sequence of rocks was deposited while structures were forming in the area.

Crosscutting and overlapping relationships between the late Cretaceous sequence of conglomerates and volcanic rocks and fold and thrust structures define two structural events in the Armstead Hills. The earlier Laramide event created a foreland bulge. Sevier-style thrust structures then cut the pre-existing Laramide structure. The interaction of these structures resulted in younger over older thrust faults, thrust faults that cut down-section in the direction of transport, and thrust faults that cut through and displace stratigraphic unconformities.

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