Structural geology of the Badger Pass area southwest Montana

Gerald M. Thomas

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STRUCTURAL GEOLOGY
OF THE BADGER PASS AREA,
SOUTHWEST MONTANA

by

Gerald M. Thomas

B.A., University of Colorado, 1978

Presented in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

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Geology

Structural Geology of the Badger Pass Area, Southwest Montana

Director: Robert Weidman

Badger Pass lies at the southern edge of the Pioneer Mountains, approximately 23 km west of Dillon. The map area, 8x24 square kilometers, is a part of the Rocky Mountain thrust belt where two thrust faults, the Ermont and Kelley, dominate the structure.

The Ermont, which is the easternmost thrust in the area, dips gently westward along a 24 km NNE-trending trace. In the overlying Ermont plate, a 4-5 kilometer-wide zone of Madison limestones and younger Paleozoic strata have been folded and thrust eastward over late Cretaceous Beaverhead Formation and tuffs. The plate was later intruded by Cretaceous granodiorite and andesite. Orientation of small folds, tear faults, drag folds and a window of Cretaceous tuff indicate a transport direction of S80°E to 10°E and at least 5 km movement.

To the west, the Kelley thrust has brought Precambrian Belt quartzite over an eastward-overturned syncline of Madison Group limestone. The fault dips westward at 25°-50°, with locally steeper segments, and has been offset by tear faults. A transport direction of S86°E to 10°E is inferred from orientation of tear faults and surface trace of the thrust. Although precise calculation of net slip is not possible, it appears that the stratigraphic throw, Precambrian on Madison, is at least 2,000 m, comparable to that of major overthrusts in the Rocky Mountain thrust belt.

The timing of thrusting has been bracketed as Late Cretaceous, approximately 71-68 m.y.b.p., by comparing ages of pre-thrust Cretaceous Beaverhead and volcanics to post-thrust granodiorite and andesite intrusives. Ramp thrusts, deformation in front of the Kelley thrust and westward steepening of thrust faults suggests that the Kelley thrust preceded the Ermont thrust.
I greatly appreciate the assistance and encouragement that my advisor Robert Weidman provided throughout this project. I would also like to thank Dave Alt for suggesting a thesis in southwestern Montana and for his creative comments on my interpretations. Robert Pearson, Ed Ruppel and the University of Montana Field Program provided many insights into the regional geology. My colleagues contributed many hours of sometimes enlightening and always interesting discussions. Finally, I would like to thank Ginger Gheen for her unfaltering moral support.
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Plate 1 Geologic Map in Pocket
CHAPTER 1
INTRODUCTION

Purpose

The objective of this study was to resolve discrepancies in previous mapping and structural interpretation (Lowell, 1965; Myers, 1952) and provide more detail on thrust movement direction and structural style in the Bannack to Argenta area of southwestern Montana. Field investigations emphasized the structural characteristics, continuity and movement of the Kelley and Ermont thrust faults. To determine these structural relations I also defined the sedimentary formations, the volcanic units and the igneous intrusions.

The dominant structural feature at Badger Pass is a plate of Paleozoic and Mesozoic rocks thrust over a thick sequence of rhyolitic tuffs and volcanic andesites. The thrust fault has been designated the Ermont thrust by Myers (1952) after the nearby mining area, Section 35, T6S, R11W.

This study proposes that the Ermont thrust and overlying Ermont Plate constitute a mappable structure which has a continuous 24 km NNE-trending trace. Other structures include: the Kelley thrust, a plunging overturned syncline below and east of the Kelley thrust, and an imbricate fault zone along the western boundary of the Ermont Plate.

General

Geologic structure has long been a source of concern in
southwest Montana. Correlation of the Cordilleran overthrust belt of Idaho and Wyoming and the Montana disturbed belt makes an appealing argument for continuing the overthrust belt through southwest Montana. On the other hand, distinctive range-front normal faults define most of the mountain blocks in apparent Basin and Range style. The tectonic pattern of the region apparently combines both structural styles, which makes general statements about tectonic style in southwest Montana risky and illustrates the importance of using observable field relations to determine the structural characteristics of particular areas.

Location

The study area is between the old mining communities of Bannack and Argenta approximately 23 kilometers west of Dillon, Montana (Figure 1). General access to the area is by way of Highway 278, which connects Dillon and the Bighole Valley. Numerous Forest Service, BLM and private roads provide easy local access. The area is bounded on the west by Taylor Creek and the Tertiary valley fill of the same basin, on the north by Rattlesnake Creek, on the south by Grasshopper Creek and on the east by an irregular and arbitrary line through the andesitic volcanics. These boundaries encompass some 80 km² of sage and evergreen-covered foothills.

Elevations range from 1739 meters along Grasshopper Creek to 2351 meters in Section 29 east of Taylor Creek. Fir covered ridges rise 30m-90m above the sagebrush covered...
Previous Work

Previous mapping in the area, Lowell (1965) and Myers (1952), was done as a small part of two-degree mapping projects for Upper Missouri River Basin development projects. They described and mapped several thrust faults intertwined with a complex sequence of normal faulting. This is especially evident on Lowell's (1965) map at and near Badger Pass. Many of Lowell's fault contacts differ substantially from those of the present study. Field investigations indicate that a depositional contact on Lowell's map is actually a low angle thrust contact continuous with the Ermont thrust mapped to the north by Myers.

Shenon (1931) published a geologic map and ore deposit evaluation for the Bannack and Argenta mining districts and Sahinen (1934) produced a similar study for some of the smaller mines closer to Badger Pass. Both of these reports concentrated on structures with ore potential, but some notice was made of the thrust faults and related deformation. Shenon (1931) believed "the thrusting near Bannack probably belongs to the great system of overthrusting faults which extend from Canada on the north, well into Utah on the south."

Detailed mapping has been done in several structurally similar regions adjacent to the study area. Hobbs (1967) described Paleozoic and Precambrian units and a sequence of thrust faults and large-scale folds in the Argenta area north
of Rattlesnake Creek. Reynolds (1962) and Brant and others (1949), mapped Mississippian sections thrust over several rock sequences from Precambrian in the Armstead Anticline to the Cretaceous Beaverhead Formation near Bannack.

Brumbaugh's (1973) structural analysis of Laramide deformation in southwestern Montana relied on dates and mapping from the Pioneer Mountains to determine timing of deformation and details of structural development. Several of his analytical procedures for determining the direction of tectonic transport were used in this study, and a combination of Brumbaugh's (1973) analytical technique and Snee's recent dating (1978, 1979, in progress) provided data for my interpretation of structural chronology (Figure 7, Chapter 4).
CHAPTER 2
SEDIMENTARY ROCK UNITS

Upper Paleozoic rocks are the most common units in the study area but Precambrian to Tertiary formations are exposed. All of these units are described, but since this is principally a structural investigation I have included only brief lithologic descriptions, pertinent references and the reasons for respective formation designations.

Belt Supergroup

Precambrian Belt quartzites are exposed in the core of the Argenta anticline and above the Kelley thrust. These consist of 600-1,000 meters of pink to light gray feldspathic quartzite with abundant planar crossbeds which are hematite-stained and at low angle to the regular bedding. The sequence has been tentatively assigned to the Missoula Group or its equivalent (this author; Ruppel, personal communication; Zimbalman, masters degree in progress, Univ. of Colo.). Closer correlations of the Belt quartzites in much of southwest Montana is needed. Most authors (Myers, 1952; Fraser and Waldrop, 1972; Hobbs, 1967) have identified Belt-type argillites and quartzites but have not identified the formations.

Until the Belt stratigraphy has been determined the designation of Missoula Group quartzites is tentative only. This also constrains estimates of the horizontal displace-
ments in nearby overthrusts. Ruppel (1978) described major
motion on the Medicine Lodge thrust plate west of the thesis
area on the basis of correlation between Precambrian sequen-
ces in Montana and central Idaho. Unfortunately similar facies
descriptions do not exist for the quartzites exposed in my
study area.

Hasmark Formation

The Cambrian rocks exposed in the Argenta anticline re-
semble abbreviated carbonate sections, without Flathead or
Park, to the north and west of Argenta (Fraser and Waldrop,
1972; Hanson, 1952; Ruppel, personal communication). At Er-
mont the section contains 60 meters of interbedded dolomite
and sandy dolomite. The sequence disconformably overlies
Belt quartzites and conformably underlies the Jefferson For-

The Hasmark formation is dominated by brown to light
tan dolomite with a fine grained sugary texture. It is dom-
inantly thick bedded although fine laminae (2mm-1cm) are
often evident and localized zones of chert lenses are common
in the lower and middle parts of the sequence. Several sandy
and silty dolomite layers are interbedded with the thick
dolomite beds and a distinct sandy member occurs at the base
of the formation.

Myers (1952) tentatively identified the well bedded do-
lomites as Pilgrim dolomite and attributed the absence of
Meagher and Park formations to "mid-Cambrian uplift, block

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faulting and erosion," which also appears to have removed the Flathead and Wolsey formations. However, regional work after Myers's investigation (Fraser and Waldrop, 1972; Hobbs, 1967; Harrison, 1952; Jeff Black, masters thesis in progress, Montana State University; E-an Zen, personal communication) indicates several similar, abbreviated sections in southwest Montana. These sequences have been correlated with and identified as Hasmark.

Hanson (1952, p15) suggests that, "although the Hasmark has yielded no distinctive fossils its stratigraphic position above fossiliferous units indicates time equivalence to all or part of the Meagher, Park and Pilgrim time." Hobbs (1967) describes the Cambrian rocks on the north side of Rattlesnake Creek, just north of my study area, as Hasmark. Fraser and Waldrop (1972), at Wise River 56 km north, describe a 244 meter thick sequence of Upper and Middle Cambrian Hasmark and Silver Hill as "light-dark gray, massive to thin-bedded dolomite and dolomitic limestone, increasingly sandy at base, grading downward into Silver Hill, 0-25' (7.6m) of interlaminated sandstone and dolomite." Cambrian rocks in my area are similar to these units and they have therefore been tentatively assigned to the Hasmark Formation.

Jefferson Dolomite

The Devonian Jefferson is a dark blue to black, thickly bedded dolomite. It outcrops throughout the Ermont mining area and is host rock for much of the mineralization in the
area (Shenon, 1931; Sahinen, 1936).

The upper part is a black and dark brownish sugary textured dolomite with a distinctive fetid odor on freshly broken surfaces. Beds range from 0.5-2.0 meters thick with several 4-8 meter zones of massive dolomite.

Myers (1952) separates a lower gray dolomite member, "gray, sugary-textures weakly mottled dolomite: locally sandy or conglomeratic at base." The change from upper to lower Jefferson is vague in the Ermont area and no attempt was made to separate them. Total thickness of the Jefferson Formation is approximately 200 meters.

Three Forks Formation

Excellent exposures of the Devonian Three Forks shale occur in a backhoe pit in the SE1, Section 35, T6S, R11W. Bedding varies from 2-20cm thick in the brown, slaty shale. Bedding is highly deformed with small crinkle folds on the limbs of larger folds having 1-2 meter amplitudes and 0.5-1.0 meter wavelengths. These folds are often broken and overrun by shales from the fold limbs (Figure 6).

Thickness is approximately 50m to 70m. These are only estimates because outside of the excavations exposures are rare and the contact must be mapped by float.

Madison Group

Mississippian Madison Group limestones are the dominant
and most widely occurring rocks in the area. They form a distinct outcrop swath which runs approximately north-south along the eastern fringe of the Pioneer Mountains, through the thesis area, past Armstead and through the Beaverhead Mountains well into Idaho (Ross, Andrews and Witkind, 1955). The Madison Group consists of the Lodgepole Formation and the overlying Mission Canyon Limestone (Collier and Cutucart, 1922; Sloss and Moritz, 1949).

**Lodgepole Formation.** The lower Mississippian Lodgepole Formation consists of thin bedded, fine-grained, dense, dark blue limestone with interbedded thin red shales. Total unit thickness was estimated as 200-250 meters, comparable values of 230m and 290m were measured to the north by Myers (1952) and Hobbs (1967).

**Mission Canyon Limestone.** The lower Mississippian Mission Canyon Limestone, Upper Madison Group, is usually a bluish-gray, fine to coarse-grained limestone which weathers to a light gray. Some oolitic lime units and crinoid-rich units also occur. Distinct brown and black chert nodule zones are abundant within the upper part of the formation, becoming less common although not rare in the lower section.

An interesting study by Hildreth (1980) indicates that Big Snowy limestones occur above the Mission Canyon and beneath the Amsden on the east side of the Armstead anticline, approximately 20 miles south of Badger Pass. It is possible that some of the limestones below the Amsden near Badger Pass
are also Big Snowy. But in this report I have relied on Hobbs's (1967, p49) correlation and description of Mission Canyon lithologies on the north side of Rattlesnake Creek, which are based on stratigraphic position between typical Lodgepole and Amsden lithologies, fossil identification and lithologic similarity to strata described by Scholten and others (1955, p345-404) near Lima, Montana.

Myers (1952) estimated the Mission Canyon to be 160-190 meters thick, averaged throughout the southern Pioneers. Thicknesses increase to the north to 275-305 meters in the Melrose area (Theodosis, 1956). My own values are 180-200 meters. The great width of Mission Canyon outcrops between Bannack and the Bannack Stage Road is due partly to dip slopes and partly to repetition by thrusting and folding, especially within a few miles of Bannack.

Large, massive, irregular jasperoid bodies often occur near the top of the Mission Canyon in the western part of the area. Colors of the jasperoid masses range from very pale orange to dark reddish-brown when fresh and pale yellowish-orange to dusky red when weathered. Lowell (1965) mapped some of these jasperoid outcrops as Phosphoria Formation chert (SW1/4, Section 2; NW1/4, Section 21; T7S, R11W) but the occurrence of limestone fragments in the jasperoid conflicts with his interpretation. It is more probable that the jasperoid resulted either from karst collapse, since there are other karst features adjacent to the jasperoid, or from tectonic brecciation and silicification, since several jas-

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peroids occur near fault contacts. Unfortunately, my petrographic studies did not provide conclusive evidence for either of these hypotheses.

Amsden Formation

The Mississippian-Pennsylvanian Amsden Formation is poorly exposed and was mapped by float. The thickness generally ranges from 10 to 30 meters. However, a 70 meter-thick section of interbedded gray, red and yellow siltstones, sandstone and limestones outcrop along a roadcut in Section 17, T7S, R11W. To the north in Section 21, T6S, R11W, similar limestone beds are fairly well exposed, with red-yellow siltstone float as ground cover. Myers (1952) estimated 72 meters of Amsden northeast of Argenta.

Quadrant Formation

Pennsylvanian Quadrant quartzites dominate the landscape adjacent to Badger Pass, where folds in the upper plate of the Ermont thrust are delineated by fir-covered hogbacks of white quartzites which rise 90-180 meters above their sage-covered surroundings.

Beneath this fir-clad veranda is an extremely well-indurated quartzite fractured into 0.5-6 meter talus blocks which often cover the adjacent slopes. The quartzite is a fine-grained, clean quartz sand cemented by silica and often stained by iron oxides. Cross-bedding is common. The Quad-
rant is generally 190-200 meters thick but thickens southward; Lowell (1965) mapped 366 meters of Quadrant only 11 miles south of Badger Pass.

Phosphoria Formation

South of Badger Pass Lowell (1965) mapped Permian rocks according to the terminology of McKelvey and others (1956). McKelvey’s format divided the Permian into three formations: the chert, mudstone and phosphatic rocks of the Phosphoria; the Shedhorn quartz sandstones; and the Park City carbonate rocks (from Lowell, 1965). Unfortunately, criteria for the formational breakdown into members are not evident in the thesis area. Therefore, all Permian cherts and sandstones have been classified as Phosphoria for this study.

Outcrops near Badger Pass reveal 80 to 110 meters of Phosphoria section. As Lowell (1965) commented, the outcrops commonly form small flatirons on dip slopes of the Quadrant between broad swales of brush cover. The most prominently exposed part of the Phosphoria is a 10-25m thick chert bed near the base of the formation. The overlying 30 to 45 meters consists of gray-brown chert, siltstone and salt and pepper sandstones. No distinct Phosphoria-Dinwoody contacts were seen as the contact zone was always in poorly exposed, sage-covered swales, which were assumed to be Dinwoody shales.
Dinwoody Formation

Brown weathering, gray to light brown, silty limestones of the Triassic Dinwoody Formation outcrop in only a few areas, all within 5 kilometers of Badger Pass. All outcrops are within synclinal troughs in the Ermont plate. Exposures are usually poor to fair but the observable characteristics fit Theodosius' (1956) description of the Dinwoody Formation. As in most of southwestern Montana the most characteristic feature of the Dinwoody is the deep brown color on weathered surfaces, abundant Lingula and assorted gastropods. Formational classification is further confirmed by the stratigraphic position above the Phosphoria.

There are no complete sections of Dinwoody in the study area. A lower shale unit, 30-60 meters thick, is overlain by 10-30 meters of thinly-bedded limestone, but it is in thrust contact with overlying Madison Group limestones. North of Rattlesnake Creek Hobbs (1967) reported 135 meters of relatively uniform Dinwoody, consisting of 48 meters of shale overlain by 87 meters of limestones.

Beaverhead Formation

Within the Badger Pass area the Cretaceous Beaverhead Formation consists of interbedded conglomerates, sands and shales. The conglomerate contains rounded to subangular limestone pebbles, cobbles and some boulders. Most of these clasts are Madison Group limestones. Shale beds are generally
bright red. Shale and conglomerate units are between 5 and 10 meters thick, although some 20-30 meter sections of conglomerate occur near Bannack.

The thickest Beaverhead section also occurs near Bannack where a 900 meter section is in fault contact with Madison Group limestones. Other exposures of Beaverhead, along the Ermont thrust, range from 20 to 80 meters thick.

Beaverhead Formation descriptions by other authors (Ryder and Scholten, 1973; Wilson, 1970; Lowell and Klepper, 1953) have included an uppermost quartzite conglomerate unit. No similar unit is exposed in the Badger Pass area.

Palynological analyses of limestone conglomerate units that were sampled near Lima by Ryder and Ames (1970), Ryder and Scholten (1973) and Wilson (1970). These pollen and spore analyses suggest a Campanian and Maastrichtian age for the upper Beaverhead conglomerates (page 39). Because the exposures of Beaverhead in and near the thesis area include only the lower limestone conglomerate and shales, the formation is assumed to be late Cretaceous or older.

Tertiary Sediments

Clastic sediments form a thick sequence of Tertiary rocks. Sandstone, silts and poorly consolidated gravels fill an extensive basin along the west edge of the study area. The Tertiary age is based on work done by Lowell (1965) who cited fossil and stratigraphic correlation with other intermontane basins. No attempt was made to describe or measure the full sequence.
CHAPTER 3

IGNEOUS ROCKS

Volcanics

Volcanic rocks exposed in the eastern third of the study area are the northern part of a thick volcanic package which extends south and east to Armstead and the Blacktail Range (Lowell, 1965; Scholten and others, 1955). The lower rocks of this package are Cretaceous and consist of platy tuffs overlain by andesitic flows, agglomerates and tuffs. These are overlain by Tertiary andesites, rhyolites and basalts which extend east into the Beaverhead Valley.

Platy Tuffs. The lowermost Cretaceous volcanics are light tan, very fine-grained tuffs with well developed platy parting. These rocks are generally hard, but no welded textures were observed. The lower contact is in slight, 20°, angular unconformity with the Beaverhead Formation, Sections 2 and 11, T7S, R11W; Sections 9 and 17, T8S, R11W. Unit thickness ranges from 120-300 meters.

Petrographic study shows altered pumice fragments (0.2-0.8mm) in an altered groundmass which contains some possible relic fragments. A few quartz and plagioclase feldspar crystals (less than 0.3mm) occur in the matrix. The rock is essentially half matrix and half pumice fragments with a small percentage of quartz and plagioclase crystals.

Fine, parallel laminae and platy parting first suggest a water-worked tuff origin. Early workers (Myers, 1952;
Lowell, 1965) refrained from proposing specific origins and merely described the rock. Reynolds (1962) suggested that the relic fragmental textures and the angularity of the crystals and lithic fragments provide ample evidence that these were ash fall deposits. This latter suggestion appears to be compatible with the petrography and the possibility of deposition in a still water environment.

A severely altered outcrop of this tuff occurs in a window of the Ermont thrust approximately 2.5 km southwest of Ermont. The rock is highly silicified and many of the feldspars have been completely argillized. The groundmass and relic textures are congruous with the platy tuff but the percentage compositions have been significantly changed.

**Andesitic Volcanics.** Cretaceous andesitic and Tertiary volcanics outcrop east of and overlie the tuff sequence. The lithology is dominated by thick andesitic agglomerates in depositional contact with flows and some thin, interbedded rhyolitic flows and tuffs. Figure 2 is a simplified cross section of a part of the andesitic sequence approximately one mile east of the thrust contact Section 34, T7S, R11W. This thesis does not attempt a detailed description of the complete andesite section, but rock outcrops within a few kilometers of the thrust contact contain units similar to those in Figure 2. The full sequence has not been measured but the minimum thickness is 300 meters.

The flows are usually dark green to reddish brown ande-
FIGURE 2. SCHEMATIC DIAGRAM OF VOLCANIC SEQUENCE
STATION 102, SECTION 34, T 7S, R II W
sites with varying amounts of white feldspar phenocrysts. Fine partings (1-20 mm apart) are widespread and often occur in larger (1-1.5 m) sets. The sets and partings can often be traced for several meters before soil or vegetation cover the exposures.

Interbedded volcanic agglomerates contain rounded clasts of purple porphyritic andesite and some rhyolite in an andesite pyroclastic matrix. The clasts form from 10-30% of the total rock and may be up to a foot in diameter, although they average closer to six inches.

Intrusives

Granodiorite. Cretaceous granodiorites occur as small stocks which have outcrop exposures up to 1.5-2 km^2. They occur in several parts of the Bannack mining district and 3 to 6 kilometers northeast in the Iron Mask and Del Monte mining areas. Almost all the productive mines in the district are located within or close to the zone of contact metamorphism where the granodiorite intruded Madison limestones.

The granodiorite is fine-grained and grayish-green. Lath-shaped plagioclase feldspars makes up 60-75 percent of the rock. Plagioclase extinction angles indicate andesine (An30-An50) composition. Orthoclase constitutes approximately 10 percent of the rock. Green hornblende ranges from 15-25 percent with the higher amounts occurring near the metamorphosed contact with the Madison. This analysis generally concurs with Shenon's (1931) petrographic work except that
his hornblende percentages were much lower, probably because of samples taken farther from the intrusive contact.

**Andesite.** A second intrusive rock type consists of Cretaceous porphyritic andesite. The most conspicuous occurrences are beneath and surrounding Madison limestone at and near the New Departure mine, but small bodies of andesite intrude the Ermont plate in many places near Badger Pass.

Petrographic study shows that a typical andesite contains 10-15% hornblende with occasional biotite crystals up to 2mm in diameter. Phenocrysts of plagioclase (labradorite) and hornblende are set in a groundmass of very fine-grained alkali feldspar, hornblende and pyroxene. Many of the andesites contain small percentages of quartz, generally less than 2%. Reynolds (1962) reports that alteration minerals along fractures are zeolites and clay minerals which have replaced feldspars along fractures and cleavages.

Lowell (1965) included this andesite in his agglomerate, flow and tuff sequence. However, field relations indicate that the porphyritic andesite is a separate rock unit which cross-cuts those volcanics. Partings and inter-unit contacts in the volcanic andesite sequence have distinct north-north-east trends which cease at the porphyritic andesite contact. No agglomerates or tuffaceous units occur within the porphyritic andesite, even though they are common in the volcanic sequence a few hundred meters south. Also a distinct marble zone occurs at the andesite-Madison contact in Sections 22, 23, 26 and 27, indicating a contact metamorphism due to the
intrusive andesite.

**Trachyte Porphyry.** A small plug of porphyritic trachyte intrudes the tuff and thrust splays in Section 34, T6S, R11W, 2 kilometers west of the Ermont mining district. The rock is light gray and has large orthoclase (2mm) phenocrysts in a fine-grained potassium feldspar matrix. Myers (1952) suggested the intrusion may have been a source for the platy tuffs. No age dates or more detailed information are available for this rock.

**Rhyolites.** Two semicircular exposures of rhyolite occur in Sections 33 and 32, T6S, R11W. The combined surface area is approximately 12 km² with thicknesses varying from 35 meters to 200 meters. Well defined and extensive banding, which often forms curved, noselike patterns suggests a lava dome origin.

Several lines of evidence indicate fluid emplacement rather than a pyroclastic origin. White banding prevalent in samples (#177) and (#253) are 1-3mm thick and continue for several inches to several feet. The frequent and continuous bands of purple-gray, obvious through most of the outcrop, change from straight-planar features to curved or rollover patterns in several areas. Large lava flow channels, 1.5 to 5 meters wide and 2-3 meters deep, are outlined by the white banding. This banding is probably fluidal banding similar to descriptions by Lipman and Christenson (1966).

Other discrepancies between these rhyolite flows and
literature descriptions of ash-fall and ash-flow units (Chapin and Lowell, 1979; Ross and Smith, 1960) include the absence of pumice and rock fragments, continuity and length of bands and euhedral feldspar phenocrysts. Sharp post-thrust contacts, vent-type outcrop patterns, and lack of weathered surfaces beneath the rhyolite also indicate a vent and flow genesis.

Several characteristics suggest that vent sources for the rhyolite occur within the exposure limits. Well-foliated flow structures grade inward to coarser non-foliated rocks in the Section 33 exposure. The foliation attitudes imply a roughly accurate pattern around the core. The Section 32 pod is almost completely non-foliated, has sharp contacts with the country rock and appears to be an intrusively emplaced rhyolite. And finally, the circular hillslope outcrops are not typical of erosionally remnant volcanics. These criteria may not prove a vent origin but they at least suggest an interesting hypothesis for further research.
CHAPTER 4
STRUCTURE

Regional Structure

The late Cretaceous and Tertiary orogenic belts of the Rocky Mountains can be separated into structures associated with thick Paleozoic and Mesozoic trough sequences on the west and structures associated with relatively thin shelf sediments on the east. Thick sedimentary sequences in the western division (Eardley, 1962) have been moved horizontally as thin sheets above low angle thrust faults. The eastern division extends through the shelf region of central and eastern Wyoming, central Colorado, eastern Utah and central New Mexico, and is characterized by large, crystalline basement uplifts.

Scholten (1968, p111) characterizes much of southwest Montana as a "meeting ground" of the two tectonic provinces mentioned by Eardley (1962). Ruppel (1978) proposed that even though large-scale low-angle thrust systems occur in southwestern Montana, the divergent traces of the thrust systems suggest that different segments of the fold and thrust belt come together and overlap. However, Ruppel also states that the regional distribution of thrust related deformation requires a broader explanation than that applied locally in the southern Beaverhead Mountains by Scholten and Ramsrott (1968).

Comparison of the southeast Canadian Cordillera (Bally and others, 1966; Price and Mountjoy, 1970), the Idaho-Wyo-
ming overthrust, (Hayes, 1976) and the fold and thrust belt of southwestern Montana (Eardley, 1962; Scholten and Ramspott, 1968; Huppell, 1978) reveals several common features. These characteristics include general overthrust of Paleozoic-Mesozoic sedimentary trough assemblages over clastic wedge sequences; concentric folding and thrust faults within the clastic wedge sequences, deformational changes according to lateral and vertical stratigraphic changes (usually thickness and facies), low angle thrust sheets and high oil and gas potential. The thrust faults define sheets that have moved horizontally a few or many kilometers, are rather thin and are usually characterized by an absence of burial metamorphism (Eardley, 1962, p297).

In general this agrees with Eardley's (1962) interpretation that the belt of thrusting in southwest Montana is a continuation of the fold and thrust belt of western Wyoming and eastern Idaho under the Snake River volcanic field.

Ermont Thrust

Mississippian and lower Paleozoic strata have been brought over late Cretaceous conglomerates and volcanics along the horizontal to gently west-dipping Ermont thrust, named by Myers (1952). Surface traces of the fault continue for 24 kilometers along a north-northeast trend through and beyond the field area (Myers, 1952; Lowell, 1965; this study). Cross sections A-A' through H-H' (Figures 4 and 5) illustrate details of the fault and overlying Ermont plate.
FIGURE 3: CROSS SECTIONS A-A'; B-B'; C-C'. SEE GEOLOGIC MAP FOR EXACT LOCATIONS
NO VERTICAL EXAGGERATION
FIGURE 4: CROSS SECTIONS D-D' THROUGH H-H'. SEE GEOLOGIC MAP FOR EXACT LOCATIONS.

NO VERTICAL EXAGGERATION

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Thrust plane exposures of Mission Canyon Limestone over the Beaverhead conglomerates in sections 11 and 2 (T7S, R11W) have a westward dip of $0^\circ-15^\circ$ (B-B'). Several small prospect pits are near this contact and one 15 foot adit on the contact exposes a distinct clayey gouge zone approximately 3 meters thick. Also, within sections 11 and 2 are three small klippen of limestone above Beaverhead conglomerate. Beaverhead in this area consists of a limestone pebble conglomerate with some quartzite pebbles in a red sandy matrix; the rock is moderate to well-cemented by calcite. Individual exposures up to 25 meters thick occur in sections 11, 2, 1, 21 and a 300 meter thick section in the Bannack mining district (G-G' and H-H'). This may indicate a slight increase in net transport between the two regions as the thrust over­rides the tuffaceous rocks which outcrop above and east of the Beaverhead.

Approximately 1.5 kilometers southeast of Badger Pass, the Ermont thrust plate overrides the volcanic andesite package (Cross-section F-F'). Flow foliation and unit boundaries within the andesites indicate a steepened attitude near the thrust suggesting fault drag. Similar drag is better exposed and more prominent to the south (G-G' and H-H').

Near the Bannack mining district, the dip of the Ermont thrust steepens from $25^\circ-30^\circ$ west (Section 4) to $32^\circ-48^\circ$ west (Sections 17 and 8). The change is dramatically exposed in outcrops of Madison limestones over deformed Beaverhead (Figure 5). The interlayered red silts and blue-gray con­
A) MADISON THRUST AGAINST BEAVERHEAD

B) SPLAY DEVELOPS BEHIND THE LEADING EDGE

C) THRUST SPLAY "RAMPS OVER" MADISON AND BEAVERHEAD

D) CONTINUED THRUSTING OVERTURNS BEDS BELOW THE RAMP; IN MADISON AND BEAVERHEAD

FIGURE 5 RAMPING SEQUENCE IN ERMONT THRUST, (SE ¼, Sec.8) NEAR BANNACK
glomerates in the Beaverhead now form an eastward overturned fold in front of the Ermont thrust. The attitude and severity of this deformation is not compatible with Lowell's (1965) interpretation of normal faulting in this area. It appears that the thrust plane has "ramped over" an imbricated block of Madison (SW₁, Section 8) with resultant steeper reverse motion (Figure 5). A block of Madison was thrust into contact with the Beaverhead and then was overridden when a weak zone on the west side of the block developed into the present Ermont thrust surface.

North of the ramp area, Upper Paleozoic formations in the Ermont plate have been folded into an elongated series of roughly parallel folds. Along a 7 km N-S trend the orientation of the trace of fold axes varies from N25E to N15W. This roughly parallels the N15E to N10W surface trace of the Ermont thrust.

These broad, open folds are cut by the thrust faults. Three previous authors (Shenon, 1931; Lowell, 1965; and Myers, 1952) indicate complex but less intense deformation in the volcanics. Relative degrees of deformation may 1) reflect variation in the mechanical properties of the rocks or 2) indicate that the most intense folding probably occurred during the early episodes.

Several lines of structural data indicate that folding mainly preceded but was in part contemporaneous with thrusting. First, the anticlinal-synclinal sequence is displaced by at least two east-west tear faults. Second, the Ermont
thrust has been folded and the fold attitudes are compatible with thrust deformation attitudes (see page 42). Third, the fold sequence appears to be truncated by the back-limb thrusts and fourth; Shenon (1931, p66) describes a series of north-trending folds which have been broken and displaced along thrust fault surfaces in the Argenta area.

**Associated Deformation.** Movement on the Ermont thrust was generally in a ESE to ENE direction as indicated by drag folds in the underlying Three Forks shales, minor folding in the hanging wall, trend of the Ermont thrust trace, and orientation of tear faults. In the SW_4^, Section 35 (Cross-section B-B'), Ermont mining district, excellent exposures of drag folds in the Three Forks shales have been uncovered by backhoe pits. The axial planes in these exposures (Fig. 6) dip 30°-60° west and trend N5°-10° east. This attitude is contrary to that of drag folds which could have been produced by flexural slip on the Argenta anticline, and is attributed to eastward movement of the overlying Ermont plate. The underlying weaker strata were dragged into these overturned or asymmetrical minor folds.

Regional studies have suggested similar deformation. McGonigle (1965) felt that the Medicine Lodge thrust and its associated thrusts, in the Beaverhead Mountains, originated as sheets of Madison Limestone moving over shales of the Three Forks Formation. Ruppel (1978, p15) also notes the occurrence of deformation zones in the Mississippian shale and shaly limestone along other thrust faults in southwest
Figure 6: Drag folds in Three Forks Shale, below Ermont Thrust.
Located in Ermont Mining District (SE1/4, SEC 35)
Orientation of axial planes ≈ N7E, 54NW
Montana.

Several small folds occur 2 kilometers southeast of Ermont (Cross-section B-B'). The folds vary in amplitude from 15 meters to 30 meters and in wave length from 183 to 190 meters. They occur in Madison limestones of the Ermont thrust plate near its eastern margin. The folds can be traced for approximately 500 meters.

The axial traces of these folds vary from N15E to N30E. I believe the folds were caused by movement on the Ermont thrust and therefore lie perpendicular to the transport direction inferred from other data. Examples of similar thrust-induced minor folding are described by Shenon (1931) on the hanging wall side of thrust faults near and within the Bannack mining area.

Small folds near the toe of thrusts are common near McCarthy Mountain (Brumbaugh, 1972, p72), the Tendoy Mountains (Brant, 1949) and the Argenta anticline (Brant, 1949).

Imbricate Thrusts

A sequence of imbricate thrusts along the western boundary of the Ermont Plate have brought Madison limestone above Phosphoria cherts and Quadrant quartzites along a 6.5 kilometer fault zone from the Road Agent Rock area to the north edge of T7S (Cross-sections C-C' and D-D'). Within T6S, the imbricate zone appears to blend into the southern extension of the Thief Creek thrust (Myers, 1952).

Brumbaugh's (1972) and Brumbaugh and Dresser's (1976)
structural analysis of deformation near McCartney's Mountain cites back-limb faults similar to the imbricate thrusts of the Badger Pass area. They also bring Madison limestones over the back-limb of an anticline containing younger Paleozoics (Brumbaugh, p45).

South of Section 21 (T7S, R11W) granodiorite and andesite intrusives truncate the imbricate zone as well as the continuation of the Ermont thrust. The existence of fault zones and intrusives in one area may have produced the fracturing necessary for the intense mineralization in the Blue Wing Mining district, 4-5 km northeast of Bannack, (Shenon, 1931).

Development of the Ermont Thrust

An intriguing theory of genesis and development of the Ermont thrust is suggested by similarities with bedding plane thrusts, such as the Pine Mountain fault of the Appalachians (Rich, 1934). These faults originate from fracture surfaces that parallel bedding in zones of slippage and cut diagonally across or "step up" through relatively competent units (Rich, 1934; Billings, 1972). When movement occurs, anticlines form above the steps and flat-bottomed synclines form above the bedding plane portion of the fracture (Brumbaugh, 1973, p80).

Work in the Canadian Rockies by Douglas (1950) indicated several phases of subsequent deformation of bedding plane thrusts. Anticlinal and synclinal warps (described
above) are produced as a direct result of initial slip along the thrust. If the stresses are not released entirely by displacement of the overlying plate, but are transmitted into the mass beneath, step faulting and associated folding will take place in this lower mass accentuating the initial warps of the overlying thrust plane into anticlines and synclines (Douglas, 1950). Thus movement beneath older thrusts produces stacking and folding above the plane of movement. This is especially important in the Rocky Mountain Overthrust belt where series of thrust plates are stacked one on another with fold sequences in each plate producing accentuated folds in the overlying mass.

If folding in the thrust plane and overlying strata does not completely alleviate the stress other back limb thrusts could be initiated causing new surfaces to develop backward toward the sources of stress application.

This model of bedding plane thrusts adequately explains most of the structural features of the Ermont and back-limb thrusts and agrees with the data presented in this paper. Other authors (Brumbaugh, 1973; Brumbaugh and Dresser, 1976) have used this model to explain similar deformation along the Sandy Hollow thrust, in the McCarthy Mountain area, approximately 30 kilometers to the northeast.

Kelley Thrust

Precambrian quartzites have been brought over an eastward-overturned syncline of Madison limestone along the Kelley
thrust. This thrust is exposed near the northwestern boundary of the thesis area (Sections 32, 33, 28, 21 and 16; T6S, R11W) and continues 15-17 kilometers north of Kelley Reservoir. The northern extension of the fault has been cut by the Pioneer Batholith, a late Cretaceous quartz monzonite-granodiorite intrusion (Snee, 1978). Near Taylor Creek (section 6) the southern extension is covered by a thick accumulation of Tertiary sediments (Lowell, 1965). Total exposed length of the fault trace is approximately 30 kilometers.

For 5-7 km south of Kelley Reservoir the surface contacts of the thrust indicate an average westward dip of $40^\circ$-$50^\circ$, coinciding with Myers' (1952) estimate of "about $45^\circ$ to the west" north of Kelley Reservoir. South of the Argenta Guard Station (section 21) the Kelley thrust steepens to an approximately $60^\circ$-$70^\circ$ westward dip for 5 kilometers. Outcrops of the Belt quartzites and Madison limestones occupy opposite sides of the drainage for the next few kilometers as the Kelley thrust follows the Taylor Creek drainage to the south edge of Section 6, where it has been covered by Tertiary sediments.

As mentioned previously an overturned syncline in the Mississippian limestones lies beneath and east of the Kelley thrust. This is the nose of a wide (1.5-2 km) syncline of Paleozoic and Mesozoic rocks which continues 12-13 km north of Rattlesnake Creek (Myers, 1952). Stratigraphically higher units, up to and including the lower Cretaceous Kootenai Formation (Myers, 1952) outcrop to the north, indicating a
gentle northward plunge.

Tectonic transport on the Kelley thrust was generally to the east or northeast. Tear faults, surface trace of the thrust and trend of the deformed syncline in front of the thrust indicate a transport direction on N86°15'E (Figure 4b, p46). Myers (1952) estimated a minimum displacement of 8 kilometers and Ruppel (personal communication) suggests that the Kelley thrust may be the sole fault for the Grasshopper plate, an approximately 40 km wide zone of Precambrian and Cambrian rocks (Zimbalman, D., masters thesis in progress, University of Colo.) which may have moved 10 kilometers or more.

A possible continuation of the Kelley thrust is exposed north of the Pioneer batholith in the Wise River quadrangle, where a thick sequence of Belt quartzites have been thrust over a disharmonically folded and overturned syncline of Paleozoic and Mesozoic rocks along the Johnson thrust fault (Moore, 1956; Fraser and Waldrop, 1972). Fraser and Waldrop suggest that the horizontal displacement along this thrust is at least 10.5 kilometers.

Stratigraphic throw along the Kelley cannot be exactly defined until Belt stratigraphy and correlation have been resolved for extreme southwestern Montana. However a minimum throw is suggested by comparison with similar thrust faults in the region. Fraser and Waldrop (1972) have estimated 4 kilometers of stratigraphic throw on the Johnson overthrust based on a thrust contact of Belt over Colorado and at least 300 meters of missing Precambrian section. Myers (1952) mapped Cretaceous sediments below the Kelley thrust only 22
kilometers north near Birch Creek, implying a stratigraphic throw of 3.5-4 kilometers. Just north of Kelley Reservoir Belt rocks are in thrust contact with Quadrant, and Hobbs (1967) suggests "the minimum stratigraphic separation is approximately 2.5 kilometers and is probably much more since the relative stratigraphic position of Precambrian Unit 1 is not known." Hobbs (1967) calculated this separation using estimates of 1500 meters of overridden Paleozoic sediments and 950 meters of upper Precambrian sediments.

The Kelley thrust has moved Belt quartzites into contact with middle Lodgepole limestones, thus overriding the Cambrian, Devonian, lowermost Mississippian and probably a thick section of Belt. The Paleozoic units have an approximate thickness of 500 meters, near Ermont. Other authors (Sloss and Moritz, 1951; McMannis, 1965; Hanson, 1952; Dutro and others, 1975; Lowell, 1965) estimate the thickness of similar lower Paleozoic sections in southwest Montana to range from 380-600 meters.

The combination of 380-600 meters of overridden Paleozoic section and 950 meters of Precambrian sediments suggests a minimum stratigraphic throw of approximately 1500 meters. Estimates of stratigraphic throw increase northward from 1500 meters south of Kelley Reservoir to 2500 meters just north of Rattlesnake Creek to perhaps 4,000 meters at Wise River.

In review, the characteristics of the Kelley thrust, within the thesis area, include a fault contact of Precambrian Belt quartzites over Madison Group limestones. The
fault trends approximately north-south, dips 0-50° west, is offset by an east-west tear fault and has major stratigraphic throw.

CHAPTER 5
CHRONOLOGY

The deformational chronology presented in Figure 7 has been determined by comparing ages of the lower plate conglomerates and volcanics to post-thrust granodiorite and andesite intrusions. Pre-thrust deposition of limestone conglomerates in the Beaverhead Formation correlates with conglomerates defined by Ryder and Ames (1970) as middle to late Cretaceous. The overturned syncline of Madison Limestone, the ramp thrust geometry and the successive steepening of thrusts to the west suggests that the Kelley thrusting preceded Ermont thrusting and that the overturned syncline was deformed prior to motion on the Kelley thrust.

Granodiorite intrusives and andesite porphyry intrusives within and north of the Badger Pass area have been dated at 66-71 m.y.b.p. and andesite extrusives have been dated at 69-74 m.y.b.p., by Snee and Sutter (1978, 1979, 1981 personal communication). The intrusives cut along and through the Ermont thrust suggesting post-thrust intrusion although not ruling out some contemporaneous activity. The chronology in Figure 7 displays the relative timing of late Cretaceous volcanism, intrusive activity and thrusting.
CHAPTER 6
STRUCTURAL ANALYSIS

The structural analysis followed here utilizes an abbreviated approach to a model developed by Crosby (1969). This approach analyzes structural elements that give evidence of rock movement during deformation. Crosby (1969) empirically weighted each element according to its value as a direct measure of movement direction. His use of weighting factors and a statistical mean equation to determine the kinematic significance of structural elements appears to be a logical
and objective method of relating geometric patterns in the rock record to movement direction.

Analysis of the data in this study has been abbreviated by using a qualitative evaluation of the significance of azimuths for each structural element. This differs from Crosby's (1969) model by omitting the statistical evaluation of weighting factors. The approach is logical in that Crosby's weighting factors are also a qualitative assessment of each element's net worth. Since the study area was smaller than Crosby's, with fewer observations, it was reasonable to analyze the data on hand-plotted equal-area projections rather than by using the computer model.

Seven structural elements were investigated in the field and are listed below in qualitative order:

Most Indicative
- Trend of slickensides along thrust surfaces and bedding planes
- Poles to axial planes of small folds on the upper plate
- Poles to axial planes of drag folds in the lower plate
- Perpendiculars to strike of thrust surfaces
- Trend of tear faults
- Perpendiculars to bedding plane strikes
- Poles to axial planes of large-scale folds in the upper plate

Least Indicative
Slickensides should have the greatest significance since they are a direct measure of the last movement along any fault surfaces. Drag folds in the lower plate and small folds in the upper plate near its present eastern edge are almost as valuable an indication of the horizontal component of movement. All of these folds are concentric flexural slip folds (Billings, 1975, p199) and the movement directions were perpendicular to their hinge lines. The horizontal movement direction is therefore the azimuth of the poles of the axial planes.

Movement on thrust faults is generally close to perpendicular to their surface trace (Billings, 1975; Crosby, 1969; Royce and others, 1975) and fold hinges parallel the strike of such faults. When these attitudes differ, the thrust fault traces become subordinate. However, in this study the attitudes are very similar and the thrust plane attitudes are moderately weighted.

Tear faults are also moderately weighted because of their direct relation to thrust movement. It is important to note that these faults are confined to the upper plates of the thrusts and are not related to previously existing fracture surfaces. The possibility exists that tear fault orientations should be more highly regarded but once again their attitudes were generally close to elements of higher rank.

Bedding attitudes and axial planes of larger-scale folds were given a relatively low indicative value because of the possibility that they did not reflect thrust induced deforma-
tion. As it turned out, azimuths of perpendiculars to bedding strikes and axial traces of large folds in the upper plate (Figures 8a and 8b) are distinctly compatible with the other structural elements, indicating contemporaneous thrust movement and fold generation as well as the possibility of detachment induced folding.

Processing Orientation Data

Attitude measurements were made with a Brunton compass on all structural elements. An effort was made to distribute the observation stations evenly through the study area to the extent that exposures permitted.

The thesis area was divided into seven domains according to structural character and geography. A file was then made of attitudes of deformation structures within each domain. Data from this file were plotted on equal-area diagrams to determine the orientation of compression or movement which produced the deformation. These directions were determined by plotting dots for azimuths of the seven structural elements mentioned on page 40 (see dots on Figures 8a and 8b and structural data in Appendix). The arrows in Figures 8a and 8b show the mean azimuths for each element. These plots normally contain only four or five elements since all elements were not evident in each domain.

A single movement azimuth was then plotted by best fit to the qualitatively weighted arrows. The resultant movement direction was plotted within the proper domain (Figure 10) and
on an equal-area diagram with movement directions for all domains (Figure 9).

Structural Implications of Data Analysis

Similarities between the indicated horizontal mean movement directions for each domain signify a continuity in structural development for the whole area. Movement azimuths for the Ermont plate have an average orientation of S80E with a variance of ±10°. This indicates that the Ermont thrust is continuous through the study area and that motion on the thrust was to the east-southeast.

Orientations of large-scale folds in the Ermont Plate are within a few degrees of being perpendicular to the movement azimuths, indicating a congruous origin, possibly as folds over a detachment surface.

A third implication from the data analysis is the compatibility of Kelley thrust azimuths and Ermont thrust azimuths. Data from domains six and seven indicate thrust movement on the Kelley fault as S86±10°E, well within the variance suggested for the Ermont. Comparison of data from this study and Myers's (1952) study to the north prove the continuity of fault pattern and thrust motion for the Kelley thrust.

Data from the Argenta anticline (Domain 5) were plotted as a separate domain for strata in the footwall of the Ermont thrust. However, the movement azimuth (S72E) is close to the average orientation for Ermont plate azimuths. Combined with the fold and thrust evidence east of the Argenta anticline
Figure 8a: Schematic Equal-area projections for Domains 1-4. Arrows indicate mean movement azimuths for various structural elements.

- Thrust Surface
- Bedding Attitudes
- Tear Faults
- Slickensides
- Lg-Scale Folds
- Sm-Scale Folds

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Figure 8b: Schematic Equal-area projections for Domains 5-7. Arrows indicate structural elements as in Fig.4a.
Figure 9: Mean Movement Directions For Full Thesis Area. Numbers Refer To Specific Domains.
FIG 10: DOMAIN BOUNDARIES FOR STRUCTURAL ANALYSIS. ARROWS INDICATE MEAN MOVEMENT DIRECTIONS AS PER FIGURE 9. BASE MAP IS REDUCED FROM MAP 1 IN POCKET.
it suggests that the Argenta anticline may have been caused by compression along a low-angle fault below the Ermont thrust. A thrust in this area might be a continuation of the detachment surfaces at McCarthy Mountain (Brumbaugh, 1972).

Regional analysis of the structural movements causing deformation in the thrust belts of southwestern Montana and along the Idaho-Wyoming line suggests a common genesis. Brumbaugh's (1972) structural analysis of the horizontal movements near McCartney Mountain (~35 km northeast) defined a thrust salient with movement azimuths averaging S81E but with a 26° divergence defining the structural arc. Theodosis (1956) cites northeast thrust motion in the Melrose area, and movement on other low-angle "Laramide" thrust faults in southwestern Montana (Ruppel, 1978; Scholten, 1973, 1968a, b; Scholten and others, 1965) is generally eastward to northeastward.

Movement directions, deformation characteristics and regional relations all indicate continuity of thrust movement within the study area, as well as continuity between Ermont and Kelley thrusting and general thrust motion in the fold and thrust belt of southwestern Montana.
CHAPTER 7
SUMMARY STATEMENTS

Analysis and classification of the structural characteristics of the Kelley and Ermont thrusts indicate that a fold and thrust model applies to the deformation in the Badger Pass area. The two thrust faults have dominated the deformational history and this study has grouped the structural elements accordingly.

The Ermont thrust, a continuous, low-angle thrust fault was produced by movement in a S80°±10°E direction bringing folded Paleozoic sediments over volcanic and conglomeratic deposits. This motion produced drag folds, larger-scale folds, tear faults and imbricate thrusts. Thrusting apparently developed along a detachment surface in lower Madison and/or upper Three Forks shales because of the comparative ease of plastic deformation within them. Intrusive activity took place after thrusting and often followed the fault zone.

The Kelley thrust has brought Precambrian Belt sediments over Mississippian rocks. Deformation associated with thrusting produced tear faults, small folds in the upper plate, and an overturned syncline east of the fault. These structural elements indicate a tectonic transport direction of S86°10E consistent with the motion on the Ermont thrust.

Late Cretaceous events included Beaverhead and volcanic deposition followed by thrusting, which proceeded eastward from the Kelley to the Ermont thrusts. Granodiorite and andesite intrusions then cut into and along the thrust plates.
taceous.

Styles, direction of motion and chronology for both thrusts are compatible with the general characteristics of the Overthrust Belt in southwestern Montana and the Idaho-Wyoming thrust belt.

Several questions for future research have been raised by this study. Has the Argenta anticline been thrust into its present position? Do similar thrust sequences exist east of the Argenta area? What is the source and chronological sequence of the extensive volcanic package? Can significant mineralization be located by following the low-angle intrusive contacts?

Analysis of deformational characteristics is a simple but cogent method for interpreting a fold and thrust sequence. Many similar areas exist in this region and throughout the overthrust belt. It is my hope that comparable studies be done in these regions to define movement directions.
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Domain #1 - Bannack Area

**Bedding** - N10E, 47W; N16E, 32W; N20E; 15W
   - N38E, 71NW; N10E, 30W; N10E, 47W; N20E, 15W
   - N25E, 39NW; N3W, 8E, N2W, 15E; N6E, 25W; N8E, 35W
   - N38E, 29W; N20E, 32W; N50W

**Thrust Surface** - N5E, 38W; N, 30W; N50E, 45W
   - N30E, 24W, N20E, 40W; N35W, 45W
   - N15E, 47W; N18E, 70W; N16E, 65W; N27E, 29W;
     N10E, 35W; N25W, 8W; N20W, 8W, N10E, 20W

**Slickensides** - 35, N45W; 10, S75E; 50, N73W; 30, N73W; 60, N75W

Domain #2 - Road Agent Area

**Bedding** - N3E, 50W; N3E, 10W; N, 30W; N, 20W; N4W, 20W; N8E, 20E;
   - N24E, 15E, N9W, 30W; N, 17W; N4E, 20W; N18E, 40W; N5E, 37W;
   - N9E, 40W; N20E, 28W, N10E, 55W; N9E, 15W; N5E, 60W; N12E,
     55W; N15E, 56W

**Lg-Scale Fold Hinges** - N15E, 40W; N, 90; N10W, 80W; N10W,
   85E; N5W, 80W

**Tear Faults** - N80W, 90; N85W, 85SW
   - N87W, 90; N90W, 85N

**Slickensides** - 47, N78E; 30, S88W; 10, S86W; 20, S87W

**Thrust Surface** - N40E, 20W; N5E, 45W; N5E, 20W; N10E, 10W; N10E, 5W
   - N50W, 60SW; N10E, 0

**Small Fold Hinges** - N10W, 75E; N7E, 38W; N3W, 25W; N7E, 35W, N20W, 40W

Domain #3 - Badger Pass

**Stratification** - N8W, 30W; N15W, 43Wp N9E, 40W; N6E, 20W; N7E, 50W;
   - N16W, 45E; N20E, 8W; N8W, 65W; N4E, 55W; N3E, 36W;
   - N4E, 20W; N2E, 15W, N12E, 5W; N3E, 40W; N30E, 12SE

**Tear Faults** - N87E, 80N; N88W, 90; N86W, 85N

**Lg-Scale Folds** - N5W, 80W; N21W, 90; N12W, 90; N15W, 70W;
   - N, 90; N10W, 90; N15W, 60W
Thrust Surface - N5E, 0; N10E, 10W; N50E, 15E; N20E, 25W; N8E, 10W; N10E, 3W; N4E, 40W; N12E, 3W; N3W, 30W; N4W, 40W

Slickensides - 14, S81W; 10, N88E; 10, N85E; 50, N90E

Domain #4 - Ermont South

Stratification - N17E, 15W; N19E, 16W; N15E, 20E; N8W, 30E; N26E, 25W; N30E, 30W; N9W, 20W; N13W, 35W; N8W, 34W; N13W, 70W; N9W, 36W; N14W, 51W

Lg-Scale Folds - N10E, 90; N7W, 90; N3E, 80W

Sm-Scale Folds - N28E, 70W; N20E, 80W; N28E, 70W; N17E, 90W; N30E, 75W; N13E, 80W; N18E, 90; N20E, 80W; N7E, 50W; N10E, 55W

Thrust Surface - N14E, 15W; N15E, 0; N20E, 5W; N20E, 15E; N8W, 60W; N3W, 35W; N10W, 5W; N20E, 35E; N25E, 30E; N5E, 65W; N8E, 35W; N3W, 20W; N3E, 30W

Slickensides - 10, S80W; 5, S85E, 10, S89W

Domain #5 - Argenta Anticline

Stratification - N42E, 15E; N43E, 10E; N45E, 20E; N40E, 12E; N20E, 25E; N30E, 10E; N40E, 20E; N38E, 25E; N38E, 20E; N72W, 24W; N8E, 20W; N13W, 24W; N13E, 15W, N10E, 5W; N9W, 25W; N20W, 11W; N32W, 23W; N10E, 0

Lg-Scale Folds - N14E, 85W; N20E, 80W; N10E, 80W; N3W, 85W

Drag Folds - N5E, 50W; N7E, 54NW; N15E, 50W; N30E, 30W

Domain #6 - Overturned Syncline

Stratification - N20E, 40W; N40E, 33W; N52E, 36W; N38E, 28W; N38E, 24W; N15E, 15W; N30E, 27W (overturned) - N35E, 23W; N20W, 35W; N12E, 30E; N31E, 21W; N8W, 51W; N24W, 64W; N22E, 25W; N20E, 40W; N35E, 50W; N25E, 35W

Lg-Scale Folds - N37E, 80W; N25E, 75W; N30E, 90; N10E, 90

Attitudes on Thrust - N4E, 50W; N2E, 45W; N30E, 30W; N14E, 24W; N5E, 45W
Domain #7 - Kelley Thrust

*Stratification* - N7W, 35W; N5W, 30W; N4W, 27W; N19W, 34W; N20W, 25W;
N7W, 40W; N9W, 22W; N10W, 35W; N8W, 35W; N50W, 20W;
N30W, 32W

*Tear Fault* - S85E, 90; N87E, 90

*Thrust* - N15E, 45W; N20E, 80W; N15E, 90
N5E, 30W; N3W, 0; N2E, 10W; N10E, 60W; N10E, 10W