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GEOLOGY OF A SECTION OF THE NORTHWEST
TOBACCO ROOT MOUNTAINS, MADISON
COUNTY, SOUTHWEST MONTANA

by

Kiff James Samuelson

A Thesis
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Master of Science
Department of Geology

Western Michigan University
Kalamazoo, Michigan
December 1984
The northwest Tobacco Root Mountains are located on the boundary between two major tectonic provinces: the fold and thrust belt and the Rocky Mountain foreland. Deformation typical of the Rocky Mountain foreland is present in the form of two major northwest-trending faults with associated folds. Paleozoic rocks were passively draped over at least one of the elevated Precambrian blocks. Foliation of the Precambrian rocks also appears to have been gently folded in the process.

Folds and thrusts occur within the Precambrian and Paleozoic rocks, on the westernmost flank of the range, appearing to follow the general trend of the fold and thrust belt. The two major thrusts dip gently northwest and show dip-slip movement. The Paleozoic thrust block is developed in thick carbonate units along the attenuated limb of an eastwardly verging anticline; and the Precambrian thrust block consists of schists, amphibolites, and quartzites with foliation trends cut by the thrust plane.
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INTRODUCTION

The purpose of this study is to analyze the structural features in a segment of the western slopes of the Tobacco Root Mountains, an area not previously mapped in detail. Mapping on a scale of 1:24000 was done to show the relationship between near-vertical northwest trending faults and low-angle thrust faults involving Precambrian and Paleozoic rock. The research involved studying the style and geometrical characteristics of the structures (faults and folds), the extent of their interrelationships, the fault movements involved, and the behavior of the basement rocks in each deformation style. This area is particularly interesting in that it is located on the boundary between the fold and thrust belt and the Rocky Mountain foreland.

The area described in this paper is located in Madison County, Montana, on the western slopes of the Tobacco Root Mountains, approximately 40 miles southeast of Butte and 20 miles south of Whitehall. It covers approximately 35 square miles extending from Bear Gulch on the south to Brooks Creek on the north and from the western front of the range into the Precambrian core on the east (Figures 1 and 3).

Geologic Setting

The west flank of the Tobacco Root Mountains is largely made up of Paleozoic limestones, minor shales, and sandstones. These rocks rest unconformably upon Precambrian gneisses, and both have been
Figure 1—Location map of the study area, Tobacco Root Mountains, Madison County, southwest Montana (modified from Vitaliano, and others, 1979).
intruded by igneous rock, folded, and subsequently, block-faulted.

The Precambrian terrain is composed of Archean rock which is located about 80 kilometers northwest of the boundary between the Churchill and Wyoming provinces (Figure 2). Major fault trends in the terrain are northwest, northeast, and east-west. These fault trends may have been initiated during middle Precambrian time in response to compressive forces associated with accretion of the Churchill terrain to the Wyoming craton. This Precambrian (Churchill) terrain formed part of a southern barrier to late Precambrian Belt sedimentation, as outlined by Burchfiel and Davis (1975) and Schmidt (1975). Schmidt and Garihan (1979) have suggested that this barrier may have developed during late Precambrian rifting, preventing the deposition of Belt sediments in the area.

The Paleozoic formations which unconformably overlie the Precambrian rocks are shelf deposits associated with the Cordilleran geosycline of western North America. These formations represent a fluctuating marine environment of an Atlantic-type trailing margin (Stewart, 1976).

Tectonic changes during Mesozoic and Cenezoic time were related to the emplacement of igneous rocks, deformation during the Sevier and Laramide orogenies, and Basin and Range type block faulting. The closest magmatic belt is the Idaho-Montana porphyry belt (Chadwick, 1981). Along the southeastern edge of this belt lies the Boulder batholith which is exposed 13 kilometers northwest of the study area (Figure 8).
Figure 2—Exposures of pre-Belt basement with major anticlinorium and synclinorium of southwest Montana, in the following mountain ranges: Highland Mountains(H), Tobacco Root Range(TR), Madison Range(M), Gallatin Range(GA), Ruby Range(R), Blacktail Range(B), Tendoy Range(T), Greenhorn Range(G), Snowcrest Range(S), Gravelly Range(GR), and the Absaroka Range(A) (modified from Fountain and Desmarais, 1981; and Schmidt, 1981).
The Sevier orogeny (late Jurassic-Cretaceous) resulted in a foreland fold and thrust belt within an arcuate pattern. One section of this pattern is called the Central Montana Salient (McMannis, 1965). The Tobacco Root Mountains lie on the Southwest edge of this salient (Figure 10).

Laramide deformations (Late Cretaceous to middle Eocene) gave rise to basement uplifts of the Wyoming province style of deformation (Prucha, Graham, & Nickelson, 1965). The Tobacco Root Mountain area is one of the northwesternmost uplifts. The Precambrian basement rocks form a large domal uplift with arches radiating outward (Figure 2), extending as individual segments, one plunging to the southwest and the other south (Scholten, 1967). According to Schmidt and Garihan (1979), the uplift was facilitated by movement along northwest-southeast faults spaced roughly 7 to 10 kilometers apart (Figure 8). These northwest faults trend subparallel to the Lewis and Clark ("mega-shear") linement (Sales, 1968). Sevier and Laramide age orogenies resulted in the superposition of two different styles of deformation; uplifted Precambrian basement rocks with associated "draped" Paleozoic formations and folded and thrustsed Precambrian and Paleozoic rocks.

The study area also lies within part of the Intermountain Seismic Belt (R. E. Smith & Sbar, 1974) where elongated blocks were tilted and elevated relative to down-dropped grabens. This block-faulted terrain forms the present topographic relief of the Tobacco Root Mountains.
REVIEW OF SELECTED LITERATURE

The earliest geologic report of the study area was made by Hayden (1872). Investigations on the general geology and ore deposits in the area have since been made by Winchell (1914); Tansley, Schafer, and Hart (1933); and Reyner (1947). Hayden's report related the physiography of the area to descriptions of rock formations and structures. Winchell's study contains a description of the geology of the district and its ore deposits; whereas Tansley, Schafer, and Hart (1933) produced a geologic map of the Tobacco Root Mountains. Reyner (1947) presented a general geologic appraisal and ore survey and produced a map showing more specifically the area described in this paper.

Johns (1961) concluded from his study of the southern Tidal Wave mining district that three fault groups in the district trend northwest, easterly, and northeasterly.

Reid (1957) made a general study of the bedrock geology of the northwestern corner of the Tobacco Root Mountains. This study was extended and modified by Hanley (1975), who made a detailed study of the metamorphic petrology of the Precambrian rocks of the northern and western Tobacco Root Mountains. Schmidt (1975) discussed the structural geology within the Paleozoic rocks in the northern part of the mapped area.

Kuenzi and Fields (1971) investigated the Tertiary stratigraphy and structure of the Jefferson basin, on the west side of the range,
and Burfiend (1967) conducted a gravity survey of the northern Tobacco Root Mountain, J. L. Smith (1970). Further studies and maps have been made by Vitaliano et al. (1979) and Gillmeister (1972). Their areas of study are either inclusive or adjacent to previous studies.
METHODOLOGY

For a period of 12 weeks, the study area was traversed, observations were made, and structural measurements were taken using a Brunton compass. Data locations were plotted on aerial photographs. A structural data map and rock contact map were produced in the field. Igneous intrusions were sampled as were the various Precambrian lithologies of the Precambrian Hellroaring thrust block. A third map was produced in the laboratory using photogeologic procedures employing a mirror stereoscope and transparent overlays. Upon completion of the three individual maps, they were overlaid, and a single composite geologic map was produced (Figure 3, Plate I). Three cross-sections were then constructed (Plate II). The structural data were plotted on a Schmidt stereographic projection to facilitate statistical evaluations. Counting was accomplished using the Kalsbeck method outlined by Ragan (1973). Igneous rocks were cut into slabs and mineralogically analyzed by staining with sodium cobaltinitrate to determine the feldspar content and a petrographic study was made on the Precambrian rock samples from which a lithologic map was produced (Figure 13).
Figure 3—Geologic map of the study area along the northwest flank of the Tobacco Root Mountains. (see also Plate I).
STRATIGRAPHY

General Statement

Precambrian metamorphic rocks and Paleozoic sedimentary rocks up to the Madison Group (Mississippian) are well exposed in the study area. These have been intruded by Late Cretaceous stocks and sills similar petrographically to the Tobacco Root batholith, which intruded the Precambrian metamorphic rocks of the core of the range (J. L. Smith, 1970). The Jefferson basin is filled with Oligocene and Miocene tuffaceous sands, conglomerates, and mudstones of the Bozeman Group and capped with Quaternary pediment gravels and alluvium (Kuenzi & Fields, 1971). A complete generalized stratigraphic column of the study area, and that area adjacent to it, of the Tobacco Root Mountains is depicted in Figure 4.

Description of Stratigraphic Column

Precambrian Rocks

The Precambrian rocks of the Tobacco Root Mountains are correlative to the metamorphic rocks of the Churchill province in the Canadian Shield (1.7 b.y.). They unconformably underlie the unmetamorphosed, dominantly sedimentary rocks of the area. These Precambrian rocks are believed to be a stratiform sequence of epiclastic, volcanioclastic, and carbonate sedimentary rocks (Vitaliano et al., 1979) which have been folded and metamorphosed during at
Figure 4 (from Mc Lane, 1974).
least three Precambrian episodes of deformation. They were originally divided by Peale (1896), Tansley et al. (1933), and Reid (1957) into two distinct mappable units: the Pony series, consisting of a layered sequence of metasediments, primarily quartzofeldspathic gneiss, hornblende gneiss, amphibolites, and iron formation; and the Cherry Creek series, consisting of dolomitic marbles, aluminous schists, and a variety of gneisses.

A third distinct lithology was interpreted by Gillmeister (1972), Cordua (1974), and Hanley (1975). The three units have been termed the Spuhler Peak Formation, the Garnet Gneiss unit, and the Gneiss of Catarck Mountain, respectively. These lithologic groupings may be correlative to the Precambrian rock which occurs as an allochthonous block known as the Hellroaring thrust, lying on the western flank of the Tobacco Root Mountains. The allochthonous Precambrian rock appears to be divided into two portions by an eastwardly trending fault. The lithologic sequence of the southern portion consists of interbedded aluminous schists with varying amounts of quartz, garnet, and hornblende; amphibolites; and micaceous quartzites. These units appear to lense out along strike, ranging in thickness from 0.6 to 6 meters. Mineral assemblages including the biotite-hornblende-garnet assemblage would be indicative of lower amphibolite-grade metamorphic conditions. Other major minerals present are quartz and plagioclase with minor amounts of kyanite and epidote.
Paleozoic Rocks

The Paleozoic section above the Precambrian metamorphic core is roughly 1,554 meters thick. Formations from Middle Cambrian age through Mississippian age are present. The section is roughly 80% carbonate and 20% sandstone and mudstone (McLane, 1972). Two major unconformities of regional extent are present. Besides the Precambrian-Cambrian unconformity, there is a surface of disconformity between the Maywood Formation (Middle Devonian) and the Snowy Range Formation (Upper Cambrian), which was formed as a result of pre-Maywood erosions (Myers, 1952). Sedimentary rocks ranging in age from Pennsylvanian through Cretaceous are found on the northern and eastern flanks of the Tobacco Root Mountains, but are absent from the study area.

The Paleozoic rocks from the Flathead Formation through the Madison Group are well-exposed in the area (Figure 5). Generally, the rocks dip toward the west and are exposed in ascending order of the stratigraphic column from east to west. Locally, due to complex folding and faulting, the beds are repeated or missing entirely.

Cambrian Systems

Flathead Formations. The Flathead Formation, the basal member of the middle Cambrian age, is approximately 38 meters thick. It consists of glauconitic, light red silica-cemented, medium-grained, well sorted and rounded quartz sandstone which is typically cross-bedded.
Figure 5 - Paleozoic rock locations which tilt to the west.
The sandstone lies nonconformably upon the Precambrian metamorphic complex. Interbedded quartzite and green shale beds are present toward the top of the formation.

Wolsey Formation. The Wolsey Formation, lying conformably upon the Flathead Formation, is a glauconitic olive to gold-brown, calcareous and micaceous silty shale. Lenses of siltstone with burrows occur throughout. The upper portion is interlayered with shale and limestone. The Wolsey Formation is about 75 meters thick.

Meagher Formation. The Meagher Formation, which lies conformably upon the Wolsey Formation, has a mottled appearance and ranges from dark gray to black in color. At the base is a re-crystallized biomicrite, with fragmented fossil materials near the bottom. Towards the middle, it is a blocky, mottled dolomite which grades into an oolitic grainstone with cross-bedding. The upper portion is thinly-bedded bio-sparite with algal coated grains. The Meagher Formation is a cliff former, approximately 137 meters thick.

Park Formation. The Park Formation lies conformably upon the Meagher Formation. It is a soft, green to black, non-calcareous, fissile shale. It is a valley former, about 46 meters thick.

Pilgrim Formation. The Pilgrim Formation consists of about 110 meters of dolomite with color ranging from a medium-to-light gray mottled tone. The Pilgrim is finely laminated limestone at the base containing crystalline interclasts with massive cross-bedded dolomite near the top.
Maywood Formation. The Maywood Formation as described by Hanson (1952) is upper Cambrian and lower Devonian age. It has a thickness of 34 meters and is composed of cream-colored siltstone and black to greenish-gray shale.

Devonian Systems

Jefferson Formation. The Jefferson Formation is a dark dolomite varying from black to gray. It contains algal structures as well as black chert nodules. The dolomite emits a distinct hydrogen sulfide odor when broken. This cliff-forming rock is approximately 305 meters thick.

Three Forks Formation. The Three Forks Formation contains green shale in the lower layers, a fossiliferous limestone in the middle, and an upper layer of fine-grained tan sandstone with some siltstone. The Three Forks Formation conformably overlies the Jefferson Formation and is approximately 69 meters thick.

Mississippian Systems

Madison Group. The Madison Group is made up of cliff-forming carbonates. It consists of the Lodgepole and Mission Canyon Formations. The Lodgepole is a gray limestone which is thinly bedded, fossiliferous, and is approximately 312 meters thick. It grades into the Mission Canyon which is a massive white-to-gray limestone with cera nodules, approximately 366 meters thick.
Late Cretaceous-Early Tertiary Intrusive Rock

Igneous rocks have been defined as stocks, sills, and dikes (Figure 6). Stocks intrude the entire stratigraphic section at the front of the range near Bear Gulch (profile C-C', Plate II) and Dry Boulder Gulch. They intrude Precambrian metamorphic rock at the head of Bear Gulch.

In the lower Bear Gulch, a quartz monzodiorite stock occupies an area of approximately 1.2 square kilometers. Although the stock has probably intruded the entire stratigraphic section, it is visible at the surface in only the Madison carbonates and the Three Forks Formation. Although the primary composition of the intrusion is quartz monzodiorite (Figure 7), it changes to tonalite as it approaches the contact with the country rock. The quartz monzodiorite is a gray, medium-grained rock consisting of plagioclase, orthoclase, hornblende, and quartz. Near the contact with the country rock, the intrusive contains dark gray xenolith with compositions tending toward diorite. The inclusions probably represent incompletely absorbed fragments of the country rock (Winchell, 1914).

Another stock is present along the north side of Dry Boulder Gulch, covering an approximate area of one square kilometer. The intrusion again is inferred to cut the entire section, and truncates the southernmost section of the Beall Canyon thrust block. The coloring and composition of the rock in Dry Boulder Gulch is similar to that of Bear Gulch, with the compositional range being from
Figure 6- Igneous intrusive locations, including stocks, sills, and dikes.
Figure 7- Triangular diagram for the system quartz-alkali feldspar-plagioclase of the plutonic rocks.
quartz monzodiorite to granite. It, too, contains dark gray xenoliths.

A third stock lies at the head of Bear Gulch and is emplaced in the Pony metamorphic complex. It occupies an area of 0.4 square kilometer. Its texture and color range from even-grained to porphyritic, white to light gray. Its composition is primarily granodiorite.

A quartz monzonite to quartz monzodiorite sill extends almost continuously along the eastern edge of the Paleozoic formations from the head of Dry Boulder Gulch northward into Beall Canyon. It is bounded on the east by Precambrian metamorphic rocks which comprise the core of the range. The southernmost exposure of the sill is found on the south side of the Dry Boulder Gulch beneath the Flathead Formation. Northward, the sill is exposed between the Pilgrim Formation and the Pony metamorphics, eliminating the Park, Meagher, Wolsey, and Flathead Formations. In this area, the sill is about 500 meters thick and appears to have assimilated rocks through upper Cambrian age. Further north at Hulbert Gulch, the sill engulfs a block of Cambrian Meagher Formation and appears to split into two segments. The western part is 330 meters thick and intrudes the Jefferson Formation (Devonian).

North of Bumby Gulch, the western and eastern sections merge and begin to intertongue with the sedimentary section. It appears that the sill is intruded along the major lithologic boundaries, narrowing within each of the intruded carbonate formations. The sill is a red-brown weathering rock with phenocrysts of orthoclase.
imbedded in a medium-grained to aphanitic groundmass composed of orthoclase, plagioclase, hornblende, and biotite. The primary composition is quartz monzonite porphyry; however, it ranges in composition from quartz monzonite to tonalite, probably as a result of assimilation of the country rock.

The most prominent mafic dike of the area cross-cuts the Bear Gulch stock and is about 25 meters thick. The rock is a dark brown to black, aphanitic basalt (Reyner, 1947). A second mafic dike cuts the stock at the mouth of Dry Boulder Gulch. Other minor silicic sills and basic dikes occur throughout the study area.

According to Vitaliano et al. (1979), these Late Cretaceous-Early Tertiary intrusives of the area were emplaced in one major surge with compositional variation due to assimilation of country rock and in place differentiation. J. L. Smith (1970), using modal and chemical analysis, indicated that dioritic rock is restricted to satellite intrusions along the northwest side, near the Tobacco Root batholith, with the rock becoming more silicic toward the southeast.

Cenozoic Deposits

Cenozoic deposits exist in the form of basin fill, floodplain sediments, glacial debris, and colluvial materials. Basin fill of the fault-bounded Jefferson basin include aeolian silts of the Six-mile Creek Formation, volcanic debris of the Renova Formation (Kuenzi & Fields, 1971) and floodplain sediments. The pediment is covered along the west side of the range by broad alluvial fans.
radiating out from Dry Boulder Gulch and Bear Gulch. Lateral moraine glacial deposits occur in Bumby Gulch and Dry Boulder Gulch.
DEFORMATIONAL FEATURES OF THE
ROCKY MOUNTAIN FORELAND

Pre-Thrust Uplift

The study area lies on the northwestern flank of a large northwesterly plunging arch (Figure 2) named the Madison-Gallatin Arch (Scholten, 1967) and the Tobacco Root Anticlinorium (Schmidt, 1975). In the northwest Tobacco Root Mountains this broad arch, defined by the attitude of the lowermost Cambrian strata, is oriented 40 degrees north, 25 degrees west (Figure 2).

Paleozoic formations are draped over the arch. Excluding the areas that have been folded and thrust, these Paleozoic formations show a gentle dip near the core of the range. The Cambrian rocks which unconformably overlie the Precambrian metamorphic rock, are tilted to the west with dips varying from 30 degrees to 40 degrees west. There is a lowermost portion of the Cambrian formation lying southeast of the study area, and closer to the crest of the Tobacco Root Anticlinorium. Existing there are dips of 5 degrees to 10 degrees west. The bedding planes become steeper toward the western flank of the range, where the Mississippian formations dip 55 degrees to 85 degrees west. This can be best seen along cross-section line C-C' (Plate II) north of Bear Gulch.

The arching in the southwestern Montana area may have been active by mid-Cretaceous time as indicated by provenance studies conducted 50 kilometers west, in the Pioneer Mountains (Schwartz,
1972). The deltaic sequence of the Blackleaf formation implies that an elevated eastern landmass was in existence. Further studies (Schmidt, 1973; Schmidt, Vitaliano, & Exkerty, 1977; Smedes & Schmidt, 1979) indicate that arching was active prior to the deposition of the Elkhorn Mountains Volcanics, based on the regional configuration of conglomerates occurring on the sub-Elkhorn Mountains Volcanics' erosion surface. Although some foreland uplift continued during and after thrusting, a significant amount had occurred beforehand to noticeably deflect the thrusting on the west flank of the arch (Samuelson & Schmidt, 1981; Schmidt, 1975).

Northwest-Southeast Faults

The uplift of the Tobacco Root Anticlinorium apparently occurred, not as a single arching, but in a series of northwest-elongate blocks bounded by prominent northwest-trending faults, which appear to be the oldest and largest in the Tobacco Root Mountains (Schmidt & Hendrix, 1981). Two of these faults cross the study area: the Bismark fault and the B and H fault (Figure 8).

Of the two northwesterly faults, the most evident is the Bismark fault which cuts across Beall Creek north of the Strawn mine. It has brought Precambrian hornblende gneiss into fault contact with Cambrian formations. The Bismark fault may be the continuation of the Spanish Peaks fault trend (Reid, 1957). Study of the Bismark fault-line on the Landsat imagery indicates that the fault is 100 to 150 kilometers long (Samuelson & Schmidt, 1981). The Bismark fault strikes north 50 degrees west and dips 86 degrees northeast in Beall
Figure 8 - Major northwest-southeast faults of the region (from Schmidt, 1981).
Gulch north of the Strawn mine. Reid (1957) postulated a vertical movement from 6.1 to 9.0 kilometers, to explain the present Cambrian-Precambrian contact configuration. Hanley (1975) suggested the possibility of a horizontal displacement with a minimum of 2.8 kilometers left-lateral slip to explain the present outcrop geometry.

Well exposed slickensides along the fault (68 degrees south, 60 degrees east) indicates an oblique movement for the Bismark fault responsible for the offset of the Cambrian-Precambrian contact. As measured off the map, the lower Cambrian units have been offset 5.1 kilometers. The apparent oblique-slip, based on slickenside orientation and net-slip, is 7 kilometers. Thus the Bismark fault is a near vertical oblique-slip fault, north side up and toward the northwest.

The B and H fault is not well-exposed and exists primarily within the Precambrian rock at the head of Bear Gulch close to the B and H mine. Reid (1957) described the fault as having brought the Precambrian metamorphic rocks into the contact with the Meagher Formation (Cambrian). However, this cannot be verified with certainty, due to poor exposure and heavily timbered terrain. The existence of this fault is clearly indicated by the truncation of Precambrian amphibolite units. A shear zone within the Precambrian rocks and mineralization at the B and H, and other mines lying parallel to the fault zone, verify the fault's existence. Another indication of the presence of a northwest trending fault is an apparent one kilometer right-lateral separation of a granodioritic intrusion between the B and H mine and Smelter Mountain.
The alignment of mines and prospects along this B and H fault trend continues across the southern Tobacco Root Mountains and may be expressed as a northwest-trending anticline (Buck Creek Anticline) in the Madison Range (Hall, 1960). Compared with the Bismark fault, there has been a minimal amount of offset of the B and H fault during the Laramide orogeny.

Study of the basin fill by aerial photography indicates that if the fault extends to the northwest, then there appears to be a line separating a dissected pediment from a less dissected pediment of the Jefferson basin. There is the possibility of late Cenozoic movement along the northwest extension of the B and H fault, with the southern side moving up, relative to the northern side movement.

Late Precambrian Ancestry to Northwest Faults

Based on slip and separation data collected on northwest faults, Schmidt and Garihan (1979) postulated that the faults are related to a major period of northeast-southwest rifting during the opening of the Belt basin (Schmidt & Garihan, 1979).

Reid (1957) first suggested that the Bismark fault displayed a horst movement during Precambrian time, with the northern block moving upward. Mapping by Hanley (1975) clearly indicates that Precambrian metamorphic units separated by the fault do not become aligned when Laramide slip is restored. Hanley found that the total displacement of the Precambrian units are on the order of three times the Laramide slip. Determination of the horizontal component of movement is difficult due to igneous intrusion along the fault.
Because of the emplacement of the Tobacco Root batholith, correlation of similar rock types appearing on opposite sides of the fault is uncertain. A regional compilation of major Precambrian rock assemblages by Vitaliano et al. (1979), however, may permit some estimates to be made in spite of the presence of the Tobacco Root batholith. It has been determined that a garnet schist-marble-quartzofeldspathic gneiss sequence truncated by the fault, has a 15 kilometer left separation of the Precambrian units (Samuelson & Schmidt, 1981). This is approximately three times the 5.1 kilometers of Laramide offset.

Folding Associated With Northwest Faults

The Laramide movement, although one-third the magnitude of Precambrian displacement, was a result of stresses released along the same zone of weakness. According to statistical evaluation (Figure 9), the Precambrian foliation trends appear to have been flexed and have a fold axis orientation of (B) 35 degrees north, 34 degrees east. Hanley (1975) also noted a gentle folding of the Precambrian rock adjacent to the Bismark fault. It was not until the Bismark fault was reactivated, during the Laramide Orogeny, that the overlying Paleozoic formations were folded, with a fold axis developing 40 degrees north, 24 degrees west. The northwesterly plunge of the folded Cambrian rock diverges from the northeast trend of the fold axis in the folded Precambrian rock, due to the fact that the Cambrian formations were deposited with moderate angular unconformity above the foliated Precambrian rocks.
Figure 9 - Stereographic plots, depicting folded (Cambrian) bedding and flexed (Precambrian) foliations.
DEFORMATIONAL FEATURES OF THE FOLD AND THRUST BELT

Pattern and Relative Age of Thrusting

Thrust faults and associated asymmetrical folds exist along the western flank of the Tobacco Root Mountains for a distance of about 15 kilometers (Figure 10). Thrusts strike north-northeast and dip 30 to 40 degrees west. The folds associated with the faults are generally overturned to the east with axial traces paralleling the strike of the faults.

Two major thrusts, the Hellroaring thrust on the west and the Beall Canyon thrust, about one kilometer east of the Hellroaring thrust, are present in the study area (Figure 11). Both are exposed discontinuously along the western front of the range due to post-Laramide normal faulting, basin filling, and pedimentation which obscures their traces. The Beall Canyon thrust is the more continuous of the two faults. In the northern part of the study area, it truncates the gently arched Brooks Creek anticline and merges with the northeasterly-trending Mayflower Mine fault near the hinge of the anticline. Field relationships cannot conclusively prove that the Beall Canyon thrust cuts the Bismark fault because of heavily timbered west-facing dip slopes on the western flank of the range. However, aerial photographic interpretation suggests that the Beall Canyon thrust overrides the Bismark fault. Initial movement along the Bismark fault, and associated folding of the Paleozoic section, therefore appears to have been followed by thrusting.
Figure 10- Thrust faults of the study area with respect to structures north of the area (from Schmidt, 1981).
Figure 11- Hellroaring and Beall Canyon thrust block locations.
The Beall Canyon Thrust

The Beall Canyon thrust at its northernmost segment was originally named the Mill Canyon fault by Schmidt (1975), who interpreted it as a splay or continuation of the Bismark fault. It now appears more likely that it is a thrust which developed after the Bismark fault and which connects with the thrust in Beall Canyon about one kilometer to the south (Samuelson & Schmidt, 1981).

The Beall Canyon thrust strikes north 20 to 25 degrees west and dips west at 40 to 50 degrees, and places Cambrian and Devonian strata over the Precambrian metamorphic complex. The younger-over-older relationship is a result of asymmetrical folds formed to the west and subsequently thrusted onto the Precambrian cored uplift and the hanging wall of the Bismark fault.

The allochthonous Paleozoic rocks are highly folded, with two distinct fold orientations (Figure 9). One orientation of axial traces trends slightly northeast while the other trends southwest and lies perpendicular to the thrust plane. The north-trending fold is directly related to the compressive stress which resulted in thrusting. The west-trending folds appear to have been caused by secondary stresses developed parallel to the strike of the thrust on the hanging wall. Analysis of both sets and their relationship to the adjacent fault (Schmidt, 1975) indicates nearly pure dip slip for the thrust.

The thrust splays into two segments at Mill Canyon rejoining at the mouth of Wyckham Creek. The easternmost splay, which brings
Mission Canyon limestone (Mississippian) over the Precambrian meta-
morphic rock (Schmidt, 1975), again shows a younger-over-older rela-
tionship. The fault dips 30 to 45 degrees west with well-developed
slickensides plunging due west (Samuelson & Schmidt, 1981). At the
mouth of Wyckham Creek the fault bends in a westerly direction and is
covered by the pediment gravel of the Jefferson basin.

The Beall Canyon thrust surfaces north of Beall Canyon near the
trace of the Bismark fault. Gently dipping Mission Canyon limestone
and Lodgepole limestone (Mississippian) are thrust over the Pilgrim
limestone (Cambrian). This portion of the fault strikes north 40 to
45 degrees east and dips gently north 20 to 30 degrees west as
determined by the three point method. The fault trace is exposed for
about two kilometers. It bends to the west and disappears beneath
the unconsolidated pediment gravels north of Bumby Gulch.

The thrust reappears 3 kilometers to the south (Figure 12)
between Bumby Gulch and Hulbert Gulch (T. 2 S., R. 5 W., sec 23). It
strikes north 30 degrees east, dips 30 to 35 degrees west, and trun-
cates folded Devonian and Mississippian rocks with a separation of
about 650 meters (Profile B-B', Plate II). Within the thrust Beall
Canyon block, Mississippian and Devonian rocks are folded into an
overturned, moderately inclined syncline-anticline pair verging
toward the west. The anticlinal hinge is subparallel to the fault
trace which suggests the predominant movement direction is dip-slip.
The fold axle orientation shifts from north 17 degrees west to north
18 degrees east (Figure 12). The two domains of folding $B_1$ and $B_2$
may reflect diverse stress orientations on the leading edge of a
Figure 12- Stereographic plots of structural data for the Hellroaring and Beall Canyon thrust blocks.
thrust block or the secondary forces applied to the Beall Canyon thrust block by the overlying Precambrian (Hellroaring) thrust block. A spaced cleavage which occurs in the Lodgepole limestone (Mississippian) on the overturned limb of the syncline in the Beall Canyon block is not axial planar, but strikes parallel to the Hellroaring thrust and dips at nearly right angles to the thrust plane. The Beall Canyon thrust plane and Paleozoic fold axis extend about 3 kilometers further south, where they are truncated by an igneous intrusion.

Hellroaring Thrust

The Hellroaring thrust is exposed to the west of the Beall Canyon thrust (Figure 12). The fault trace is subparallel to the Beall Canyon thrust (north 30 degrees east) and dips 30 to 35 degrees west. The lower plate (Beall Canyon) consists of folded Devonian and Mississippian rocks while the upper plate (Hellroaring) consists of Precambrian aluminous schists, interlayered with quartzite, marble, and amphibolite (Figure 13). These rocks are significantly different in composition from the rocks of the Precambrian metamorphic complex which occur on the east side of the map area. Similar lithologies have been described as the Spuhler Peak Formation (Gillmeister, 1972), located 10.3 kilometers to the southeast.

The foliations of the Precambrian rocks on the upper plate of the Hellroaring thrust change trend from north-south (dip southeast) as northeast-southwest (dip east). In the northernmost section of the thrust block, the foliations trend east-west and dip north. In
Figure 13—Hellroaring thrust block, lithologies and structure. Light areas, with foliation symbol, consist of interlayered biotite schist with varying amounts of hornblende and garnet; and amphibolite. Queried where uncertain.
general, foliations are cut obliquely by the Hellroaring thrust (Profile B-B', Plate II), and the fold axis of the lower plate parallels the thrust (Figure 12). This suggests that movement on the fault was predominantly dip-slip. A minimum dip-slip displacement of 3 kilometers is estimated considering the thickness of the Paleozoic section cut by the fault. Foliation trends are also cut in places by at least two shear zones in the Hellroaring block (Figure 13). The shear zones appear to have been injected by quartz and garnet-rich fluids, and may have formed during the fold and thrust phase of deformation.

The Hellroaring thrust block is divided along a possible fault evidenced by the abrupt change in rock type, the presence of higher temperature mineral assemblages adjacent to the fault, the shift of foliation orientation, and a change in topographic expression. The northern portions of the block has limited outcrop exposure and consists primarily of metabasite rock.
SIGNIFICANCE OF THRUSTING IN BASEMENT ROCKS

Low angle thrusting of Precambrian metamorphic basement rocks, such as that seen in the Hellroaring thrust, and inferred for the Beall Canyon thrust, occurs along the frontal portion of the fold and thrust belt of the Cordillera in the western United States. In most cases epidermal sheets of miogeoclinal rocks have been transported eastward along detachment horizons within the sedimentary section.

Ruppel (1978) and Coppinger (1980) cited possible examples of thrusted Precambrian metamorphic rocks in the Medicine Lodge thrust system of the Beaverhead Mountains. Another example of thrusted Precambrian metamorphic rocks in this same thrust system was cited by Dubois (1981) for the northern Tendoy Range. Occurrence of allochthonous Precambrian metamorphic rocks in the frontal zones of the fold and thrust belt have been indicated by Schmidt (1975) and Schmidt and Hendrix (1981) along the Jefferson Canyon-Mayflower mine fault in the northern Tobacco Root Mountains. Anomalous blocks of Precambrian rock overlie younger rocks within the Ruby and Blacktail ranges and may be related to gravity sliding of anisotropic Precambrian blocks off the crests of these uplifts (Achuff, 1981; Tysdal, 1970). Low angle thrusts with allochthonous Precambrian metamorphic rock also occur within the Rocky Mountain foreland of this region. The Greenhorn and Snowcrest thrusts in the Greenhorn, Snowcrest, and Gravelly ranges have been described by Beck (1960), Hadley (1960, 1980), Hall (1960), Mann (1960), Perry (1962), Swanson
(1950), and Tilford (1978) describing thrusting of basement rock in the western Madison Range.

A number of hypotheses have been offered for the involvement of the Precambrian metamorphic rocks in the thrusts of southwest Montana. R. L. Armstrong (1975), Ruppel (1978), and Sloss (1954) suggest that a positive tectonic element, the Lemhi Arch, developed in late Precambrian time, and was emergent intermittently during Paleozoic time. This may have acted as a buttress during Cordilleran folding and thrusting within the Medicine Lodge thrust system (Samuelson & Schmidt, 1981). This implies that the Precambrian basement rocks, being considerably higher here than elsewhere in the fold and thrust belt, can be expected to be involved in thrusting. Schmidt (1975) and Schmidt and Hendrix (1981) explained the thrusted pieces of Precambrian basement in the northern Tobacco Root Range analogously. They indicated that the frontal thrusts of the tear thrust zone encountered uplifted foreland blocks at depth within the Belt basin, breaking off pieces along foliation planes. Tilford (1978) suggested the thrusted blocks of Precambrian in the Greenhorn, Snowcrest, and Gravelly ranges were folded during upthrusting.

It appears that low angle thrusting, involving Precambrian rock of the western Tobacco Root Mountains was a result of three sets of circumstances: (1) the area's ductility was increased due to heating associated with magmatic arc migration, (2) the Precambrian core of the Tobacco Root Mountains was elevated enough so that the thrusting impinged upon the arched rock, and (3) the Precambrian rock consisted of a layered and foliated sequence which is highly anisotropic. In
effect, the anisotropy of these rocks did not permit them to behave significantly differently from the overlying layered Paleozoic section. Therefore, the increase in ductility, the elevated structural position of these rocks, and their anisotropic nature lead a mechanical behavior similar to the sedimentary rocks of the epidermal thrusts of the fold and thrust belt (Samuelson & Schmidt, 1981).
CENOZOIC NORMAL FAULTING

West of the study area, the Jefferson basin began filling by early Oligocene time. The Oligocene Renova Formation is inferred to be the oldest Cenozoic sedimentary unit within the basin (Kuenzi & Fields, 1971). During this time, it is unlikely that there was much movement along the normal fault, which would account for the predominance of mudstones in the Renova Formation.

The occurrence of locally derived fanglomerates in the overlying Sixmile Creek Formation (late Miocene-early Pliocene) and in the northern Jefferson basin (Kuenzi & Fields, 1971) suggest that major normal faulting along the Tobacco Root Mountains range-marginal fault, began in late Miocene time. Post-middle Pliocene, pre-late Pleistocene movement on this fault caused the Sixmile Creek strata to be gently tilted eastward toward the range. Estimates of dip separation range from 910 meters to 1,800 meters (Kuenzi & Fields, 1971; Pardee, 1950).

The Tobacco Root Mountains range-marginal fault lies several kilometers from the western front of the range as indicated by a gravimetric anomaly (Burfiend, 1967). The fault scarp abruptly changes trend in several places along the western portion of the study area (Figure 14). Just north of Beall Canyon the trend changes from north-south to northeast-southwest. Near Hellroaring Gulch there is a north-south trend, and at Coal Creek Canyon, it changes again to a northeast-southwest trend. These frequent changes in
Figure 14 - Aerial photograph mosaic illustrating the change of trend along the range front fault trace.
strike of the late Cenozoic range-marginal fault scarp are also typical of the Madison and Bridger Ranges. They occur where major northwest trending Laramide faults meet the range-marginal fault and apparently reflect the influence of these previously developed structures (Samuelson & Schmidt, 1981).
GEOLOGIC HISTORY

The Wyoming-Superior Precambrian province (Fountain & Desmarais, 1980), an aggregate of preexisting Archean proto-continents, had sufficient tectonic stability to support plate marginal mio-geosyncline-eugeosyncline development by 2150 m.y. (Goodwin, 1974). An accretionary sedimentary prism of epicratonic shelf, mio-geosyncline, and eugeosyncline sedimentation developed out from the margin of the Wyoming craton. The eugeosynclinal environment may have evolved into a converging plate margin (Bird, Toksoz, & Sleep, 1975) initiating the accretion of the Churchill province to the Wyoming continent (Fountain & Desmarais, 1980). The accreted sedimentary prism of the Tobacco Root Mountains developed as a stratiform sequence of epiclastic, volcano-clastic, and carbonate sedimentary rock (Vitaliano et al., 1979).

Deformation and regional metamorphism occurred during the Dillion event (1700-1500 m.y.) (Giletti, 1966), with the closing of the marginal basin along reverse fault upthrusts possibly correlative to the east-west zone of weakness of the Mayflower Mine fault-Jefferson Canyon fault, north of the study area. The Bismark and B and H faults (northwest) and the northeast trending shear faults may have also been created at this time. Later stages of continent-continent collision produced regional uplift (doming) (Bird et al., 1975), which may have caused the Tobacco Root Mountains area to become a southern barrier to the accumulating sediments of the Late
Precambrian Belt-basin. This belt sediment barrier may have been further uplifted along northwest faults, as a result of northeast-southwest extensional rift tectonics, in Late Precambrian time (Schmidt & Garihan, 1979).

During this time, from 1450 m.y. and apparently until 850 m.y., the accreting cratonic shield featured a broad central plateau which may have provided the necessary provenance and regional transport slope (Goodwin, 1974) for the accumulation of sediments along the western margin of the North American craton, in the Belt basin, and the Cordilleran geosyncline.

Paleozoic sediments of the area accumulated in an unstable shelf environment, with continually fluctuating sea level. The Cambrian sediments deposited were sandstone and siltstone overlain by alternating limestones and shales. During Ordovician time, the Klamath-Sierra island arc formed to the west, in present-day California and Oregon, beginning subduction tectonics. By Devonian time, the compressional forces acting on the west side of the island arc shifted to the eastern margin of the Cordilleran marginal sea (Burchfiel and Davis, 1975). The Tobacco Root Mountain area became a positive element during Devonian time (Suttner, Schwartz, & James, 1981) with Ordovician and Silurian sediments having been eroded or not deposited. Shales and limestone were deposited on the area of late Devonian time and were later overlain by the accumulation of extensive carbonates during Mississippian time. During Pennsylvanian time, the outlying deposits of the study area became terrestrial and shallow marine.
During Mesozoic time, subduction tectonics continued to the west, and resulted in plutonic-volcanic arc activity in the craton with the development of a batholith complex in central Idaho and southwest Montana (Burchfiel & Davis, 1972; Hyndman, 1979). Increased ductility in conjunction with expanding igneous intrusion and regional tectonic compressive forces produced crustal shortening by thrusting during the Sevier orogeny (Late Jurassic-Cretaceous). However, thrusting of the Hellroaring and Beall Canyon blocks was preceded by vertical uplift, possibly by the development of a thermal welt over these rising batholiths (Suttner et al., 1981). As the subducting plate's rate of movement slowed, the angle of subduction increased, and the magmatic arc shifted eastward. This may have caused basement uplifts to occur as the Rocky Mountains foreland during Laramide time (Late Cretaceous-mid Eocene) along the Bismark and B and H faults.

The Sevier and Laramide orogenies had dramatically affected the area by late Cretaceous to Eocene time, with Precambrian fault blocks becoming reactivated along previous zones of weakness (Schmidt & Hendrix, 1981). The initial uplifting of the Rocky Mountain foreland preceded the thrusting and folding of the miogeosyncline and shelf deposits from west to east. Intrusion of the Boulder batholith, the Tobacco Root batholith and satellite stock and sills, accompanied the folding and thrusting (Robinson, Klepper, & Obradovich, 1968).

During mid to late Cenozoic time, extensional (Basin-Range) tectonics affected the area through uplift of Precambrian-cored basement blocks along normal faults. This fragmentation of the crust may
be attributed to a plastically extending substratum at a depth (R. E. Smith & Sbar, 1974; Stewart, 1972) produced by magmatic activity migrating eastward, intraplate weaknesses (R. B. Smith, 1978), and extensional forces created by the formation of transform fault tectonics to the southwest (Coney, 1978).

The intermontane Jefferson basin (graben) was formed between these uplifted blocks and was filled by mudstones during Oligocene time. Following this was a broad regional uplift during the Miocene epoch, with block faulting and volcanism. Major epierogenic uplift, during the Pliocene epoch, produced broad alluvial fans radiating out from Dry Boulder Gulch and Bear Gulch. During Pleistocene time, basin fill was partially eroded due to continued uplift (Kuenzi & Fields, 1971). Alpine glaciation in the higher valleys cut cirques and deposited glacial debris in the gulches of the Tobacco Root Mountains with stream erosion and rockslides occurring in the gulches.
CONCLUSION

The western Tobacco Root Mountains are part of a zone of overlap in the fold and thrust belt and the Rocky Mountain foreland. The foreland was elevated by recurrent movement along northwest-trending faults which originally developed during Late Precambrian time. Uplift of the foreland blocks was accompanied by folding of the Paleozoic sedimentary section with the formation of northwesterly plunging asymmetrical folds. The Precambrian rock adjacent to the northwest faults also appear to be gently folded.

Initial phases of Laramide faulting were followed by low-angle thrusting associated with eastward migration of the fold and thrust belt. The Beall Canyon thrust developed in asymmetrically folded Paleozoic rocks, along the west flank of the Precambrian-cored foreland uplift. Thrusting attenuated the east limb of these asymmetrical folds. The Hellroaring thrust transported layered Precambrian metamorphic rock over the folded Paleozoic Beall Canyon block.

In both thrust belt and foreland deformation, the Precambrian rocks are folded adjacent to the faults. The thrust belt folding of the allochthonous Precambrian rock may be due to their anisotropic nature, causing them to behave mechanically similar to the overlying Paleozoic section. The Precambrian folding in the foreland deformation occurred in late stages of faulting (Schmidt & Garihan, 1980) along corners of major blocks (Tysdal, 1981).


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PLATES

Geology of a Section of the Northwest Tobacco Root Mountains, Madison County, Southwest Montana

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