Tectonic significance of the pass fault, central Bridger Range, southwest Montana

by Carol Jean Craiglow

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Science
Montana State University

Abstract:
The Pass fault of the Ross Pass fault zone in the central Bridger Range of southwest Montana is significant in that it marks the tectonic boundary between Archean metamorphic rocks of the basement or foreland province to the south and Proterozoic Belt Supergroup rocks of the batholithic province to the north. As such, it represents the juncture of two major rock types and styles of deformation within one range: "thick-skinned" basement-involved deformation to the south and "thin-skinned" deformation without significant basement involvement to the north.

The Pass fault formed during the Paleocene Epoch at the southeast comer of the Helena salient. At the time of its formation, the Pass fault had a strike of approximately N21E with a net slip of roughly 1.3 miles (2.2 km). It was an oblique slip thrust fault with predominantly dip slip movement and represented an oblique footwall ramp at the leading edge of the Helena salient. In this context, it was the structural link between the Jefferson Canyon transverse zone, a large-scale lateral ramp at the southern margin of the Helena salient, and the Battle Ridge monocline, a frontal footwall ramp at the southeast edge of the Helena salient.

In latest Paleocene to earliest Eocene time, the southern and central portions of the Bridger Range were uplifted into a large foreland anticline by a large zone of west-dipping, east-verging blind thrusts. The present-day Bridger Range represents the eastern limb of this east-verging, asymmetric foreland anticline. Subsequent Neogene extensional normal faulting down-dropped the crest and western portion of the range which underlie the adjacent Three Forks Basin.

A final important aspect of the Pass fault is that it occupies the approximate location of the ancestral Willow Creek fault which marked the southern boundary of the Proterozoic Belt Basin. Evidence for this is the presence of the extremely coarse, arkosic conglomerate of the LaHood Formation only to the north of the Pass fault. Throughout Phanerozoic time, local stratigraphic variations north and south of the Pass fault indicate sporadic tectonism occurred at this long-active zone of weakness.

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APPROVAL

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Carol Jean Craiglow

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The Pass fault of the Ross Pass fault zone in the central Bridger Range of southwest Montana is significant in that it marks the tectonic boundary between Archean metamorphic rocks of the basement or foreland province to the south and Proterozoic Belt Supergroup rocks of the batholithic province to the north. As such, it represents the juncture of two major rock types and styles of deformation within one range: "thick-skinned" basement-involved deformation to the south and "thin-skinned" deformation without significant basement involvement to the north.

The Pass fault formed during the Paleocene Epoch at the southeast corner of the Helena salient. At the time of its formation, the Pass fault had a strike of approximately N21E with a net slip of roughly 1.3 miles (2.2 km). It was an oblique slip thrust fault with predominantly dip slip movement and represented an oblique footwall ramp at the leading edge of the Helena salient. In this context, it was the structural link between the Jefferson Canyon transverse zone, a large-scale lateral ramp at the southern margin of the Helena salient, and the Battle Ridge monocline, a frontal footwall ramp at the southeast edge of the Helena salient.

In latest Paleocene to earliest Eocene time, the southern and central portions of the Bridger Range were uplifted into a large foreland anticline by a large zone of west-dipping, east-verging blind thrusts. The present-day Bridger Range represents the eastern limb of this east-verging, asymmetric foreland anticline. Subsequent Neogene extensional normal faulting down-dropped the crest and western portion of the range which underlie the adjacent Three Forks Basin.

A final important aspect of the Pass fault is that it occupies the approximate location of the ancestral Willow Creek fault which marked the southern boundary of the Proterozoic Belt Basin. Evidence for this is the presence of the extremely coarse, arkosic conglomerate of the LaHood Formation only to the north of the Pass fault. Throughout Phanerozoic time, local stratigraphic variations north and south of the Pass fault indicate sporadic tectonism occurred at this long-active zone of weakness.

INTRODUCTION

Regional Setting

The Pass fault of the Ross Pass fault zone in the central Bridger Range of southwest Montana (Fig. 1) is significant in that it marks the tectonic boundary between Archean metamorphic rocks of the basement or foreland province to the south and Proterozoic Belt Supergroup rocks of the batholithic province to the north (McMannis, 1965). As such, it represents the juncture of two major rock types and styles of deformation within one range: "thick-skinned" basement-involved deformation to the south and "thin-skinned" deformation without significant basement involvement to the north.

The foreland province is characterized by asymmetric, fault-bounded uplifts of Archean crystalline rocks which trend north-northwest and extend from New Mexico to Montana (Burchfiel, 1981). The southern Bridger Range and the Tobacco Root Mountains represent the northern extent of the foreland province in southwest Montana. The Tobacco Root Mountains are truncated on the north by the Jefferson Canyon transverse zone which represents the boundary between the foreland province and the batholithic province (Schmidt and O'Neill, 1982).

The batholithic province of McMannis (1965) is more accurately referred to as the Helena salient of the Cordilleran fold and thrust belt (Woodward, 1981)(Fig. 2), and occupies the site of the Proterozoic Belt Basin. This structural salient is a convex-eastward lobe of folding and thrusting bound by left-lateral tear thrusts to the north and right-lateral tear thrusts (Jefferson Canyon transverse zone) to the south.

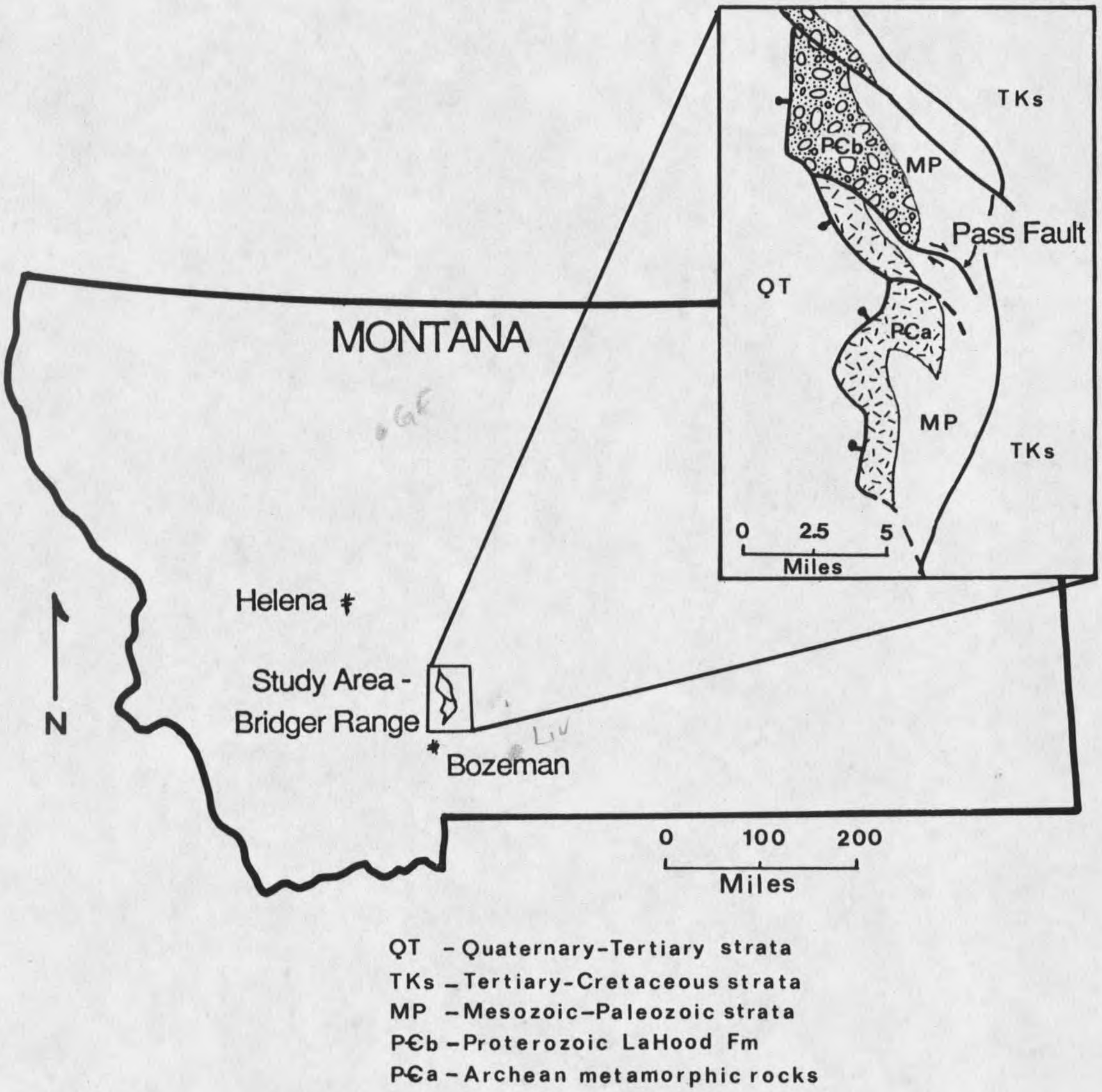

Figure 1: Index map showing location of study area.

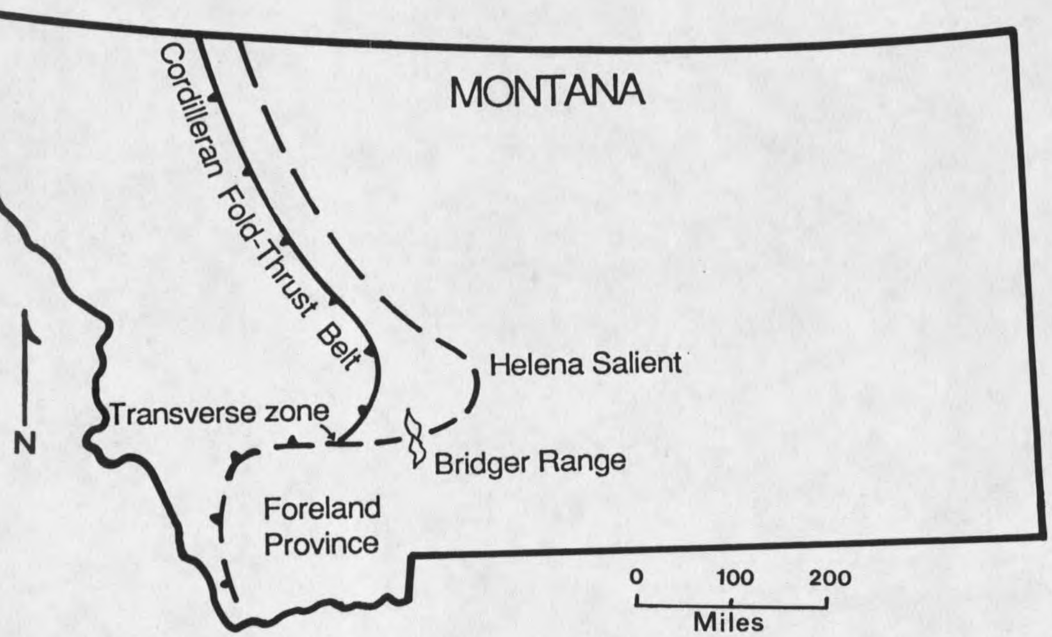

Figure 2: Map showing location of Jefferson Canyon transverse zone and Helena salient of Cordilleran fold and thrust belt (modified from Woodward, 1981).

There is an important relationship between the present-day Helena salient of the Cordilleran fold and thrust belt to the Helena embayment of the Proterozoic Belt basin. Harrison et al (1974) set forth the concept that the Proterozoic structures have influenced Phanerozoic tectonic patterns in southwest Montana. The Proterozoic Belt basin and the Helena embayment have strongly localized the present position of the Cordilleran fold and thrust belt and the Helena salient, respectively.

The Helena embayment is thought to have been the eastward extent of a northwest-southeast trending ensialic rift basin (Belt basin) which developed at the western edge of the craton in Proterozoic time (Harrison et al, 1974). The presence of the extremely coarse, arkosic conglomerate of the Proterozoic LaHood Formation along a narrow east-west band is evidence that the southern margin of this basin was fault-bounded (McMannis, 1963). This fault has been variously named the Willow Creek fault (Harrison et al, 1974) or the Perry Line (Winston, personal communication) and is widely regarded to be the precursor of the southern margin of the Helena salient.

Purpose of Investigation

McMannis (1952, 1955) and Skipp and McMannis (1971) mapped the Ross Pass fault zone as part of their regional studies of the Bridger Range and the Sedan Quadrangle, respectively. Since their work in the area, many details of the structural framework of the southern and eastern margins of the Helena salient of the fold and thrust belt have been studied and resolved. Schmidt and O'Neill (1982) have worked extensively on the Jefferson Canyon transverse zone (west of the Bridgers) and Woodward (1981) identified the Battle Ridge monocline (northeast of the Bridgers) as the southeastern margin of the Helena salient.

No detailed structural analysis has been conducted on the intervening

Ross Pass fault zone which best displays the overlapping styles of deformation. This study was undertaken to provide new information regarding the Ross Pass fault zone and its genetic relationship to the surrounding structures of the Helena salient by determining the net slip of the Pass fault.

There are three possible net slip determinations: dip slip, strike slip or oblique slip. If movement was dominantly dip slip, the Pass fault could have formed as a frontal ramp along the leading edge of the Helena salient with strike perpendicular to tectonic transport as in the Battle Ridge monocline. If the displacement was primarily strike slip, the Pass fault may represent a lateral ramp with strike parallel to tectonic transport, similar to parts of the Jefferson Canyon transverse zone. If the Pass fault exhibits oblique slip, its strike is oblique to the thrust transport direction and is in an intermediate position relative to the situations described above. An accurate interpretation of the net slip along the Pass fault will provide greater structural insight into the tectonic framework of the southern margin of the Helena salient.

Location and Access

The Ross Pass fault zone is located in the central Bridger Range approximately 10 miles (16 km) north of Bozeman in Gallatin County, Montana (Fig. 1). The present-day exposure of the Pass Fault extends sinuously about 7 miles (11.2 km) in a northwest-southeast direction. The fault zone averages 2-3 miles (3.2-4.8 km) in width (Plate 1).

The western portions of the fault zone may be accessed by the Forest Service road up Corbly Gulch (misspelled as Corby Gulch on the U.S.G.S. Belgrade Quadrangle) and by obtaining permission from various private landowners. The eastern exposures around Ross Pass may be reached by an unimproved logging road up the middle fork of Brackett Creek which is open only in the summer months.

Field Procedures

Field work was accomplished during portions of the 1982-84 field seasons. Mapping was done on the U.S.G.S. Sedan and Belgrade 1:62,500 quadrangles in conjunction with 1981 color aerial photographs from the U.S. Forest Service. The final base map (Plate 1) consists of pertinent segments of both maps joined at their common border and enlarged to a scale of 1:13,340.

Stratigraphy

Various workers have undertaken stratigraphic studies in and near the Bridger Range which provide the foundation for structural analysis. These workers include: Sloss and Moritz (1951), McMannis (1955, 1963, 1965), Skipp and McMannis (1971), Fryxell (1982) and Guthrie (1984).

Stratigraphic sequences within the Bridger Range are summarized in Table 1. The oldest rocks in this area are the Archean metamorphic rocks found in the southern Bridger Range which are composed dominantly of quartzo-feldspathic gneiss with minor amounts of amphibolite and garnet gneiss.

The Proterozoic Lahood Formation of the Belt Supergroup (McMannis, 1963) is in fault contact with the Archean rocks and crops out only in the northern part of the Bridger Range (north of the Pass Fault). The LaHood Formation consists of arkose and very coarse arkosic conglomerate.

AGE			UNIT	DESCRIPTION	THICKNESS
CENOZOIC	Quaternary		Colluvium	Unconsolidated slope and talus deposits	Variable
CENOZOIC	Quaternary		Glacial deposits	Outwash and morainal material	Variable
CENOZOIC	Tertiary		Dike	Andesite-syenite; injected along plane of Pass Fault	2'-300'
MESOZOIC	Cretaceous	Up.	Colorado Group	Grey shale with green sandstone and volcanic detritus	2000'
MESOZOIC	Cretaceous	Lo.	Kootenai fm.	Chert-pebble conglomerate with tan sandstone	340-400'
MESOZOIC	Jurassic		Morrison fm.	Variegated shale with interbedded thin sandstone	110-445'
MESOZOIC	Jurassic		Ellis Group	Interbedded miciritc limestone, shale,sandstone	20-360'
PALEOZOIC	Penn.		Quadrant fm.	Pale yellow to white quartz arenite	40-165'
PALEOZOIC	Penn.		Amsden fm.	Light gray dolomite, interbedded thin sandstone	11-189'
PALEOZOIC	Mississippian	Upper	Big Snowy Group	Interbedded limestone, red siltstone, basal dolomite	0-434'
PALEOZOIC	Mississippian	Lower	Mission Canyon fm.	Massive, light gray limestone	430-950'
PALEOZOIC	Mississippian	Lower	Lodgepole fm.	Thin-bedded fossiliferous limestone	750-810'
PALEOZOIC	Devonian	Upper	Three Forks-Sappington fms.	Gray limestone, yellow siltstone	155-156'
PALEOZOIC	Devonian	Upper	Maywood-Jefferson fms.	Dolomite, limestone, mudstone, siltstone	536-712'
PALEOZOIC	Cambrian	Upper	Snowy Range fm.	Limestone pebble conglomerate, green shale	163-280'
PALEOZOIC	Cambrian	Upper	Pilgrim fm.	Blue-gold mottled oolitic limestone	363-433'
PALEOZOIC	Cambrian	Middle	Park fm.	Green and maroon fissile shale	188-192'
PALEOZOIC	Cambrian	Middle	Meagher fm.	Thin-bedded dense limestone above and below massive limestone	368-370'
PALEOZOIC	Cambrian	Middle	Wolsey fm.	Green and maroon micaceous shale	152-210'
PALEOZOIC	Cambrian	Middle	Flathead fm.	Red, tan sandstone, arkosic	119-142'
PRECAMBRIAN	Proterozoic		LaHood fm.	Coarse, massive, poorly-bedded arkose and conglomeratic arkose	6000'+
			— Fault —		
PRECAMBRIAN	Archean		Archean	Quartzo-feldspathic gneiss, amphibolite	?

Table 1: Stratigraphic sequence in central Bridger Range.

Paleozoic rocks in the Bridger Range consist of a miogeoclinal shelf sequence composed dominantly of carbonate rocks with some interbedded fine-grained clastics.

Mesozoic strata encountered in the study area include interbedded clastics and argillaceous limestone.

Tertiary strata are not encountered in the study area.

Structural Framework

The structural features surrounding the Bridger Range can be generally separated into Sevier-style fold and thrust structures related to the Helena salient (Battle Ridge monocline, Horseshoe Hills and Jefferson Canyon transverse zone), Laramide foreland structures (Gallatin Range and Tobacco Root Mountains), and the late Cenozoic Three Forks Basin (Fig. 3).

The Battle Ridge monocline represents the southeast margin of the Helena salient and seismic data suggest it is the surface expression of a west-dipping, blind thrust which soles into a basal decollement within Belt strata (Garrett, 1972; Woodward, 1981). This listric thrust fault apparently ramped upward due to the buttressing effect of Archean rocks in the footwall of an inferred normal fault (Garrett, 1972).

The Horseshoe Hills (Fig. 3) consist of a series of north-northeast trending, west-northwest dipping thrusts (Verrall, 1955). Southeast-verging anticlines and synclines trend generally parallel to the thrusts and plunge gently to the southwest. Verrall (1955) recognized that the thrusts probably sole into a regional decollement at or near the base of the Belt Supergroup. Schmidt and O'Neill (1982) suggest that the fold-fault relationships are typical of forelimb thrusts developed above splays which have ramped upward from a basal decollement.

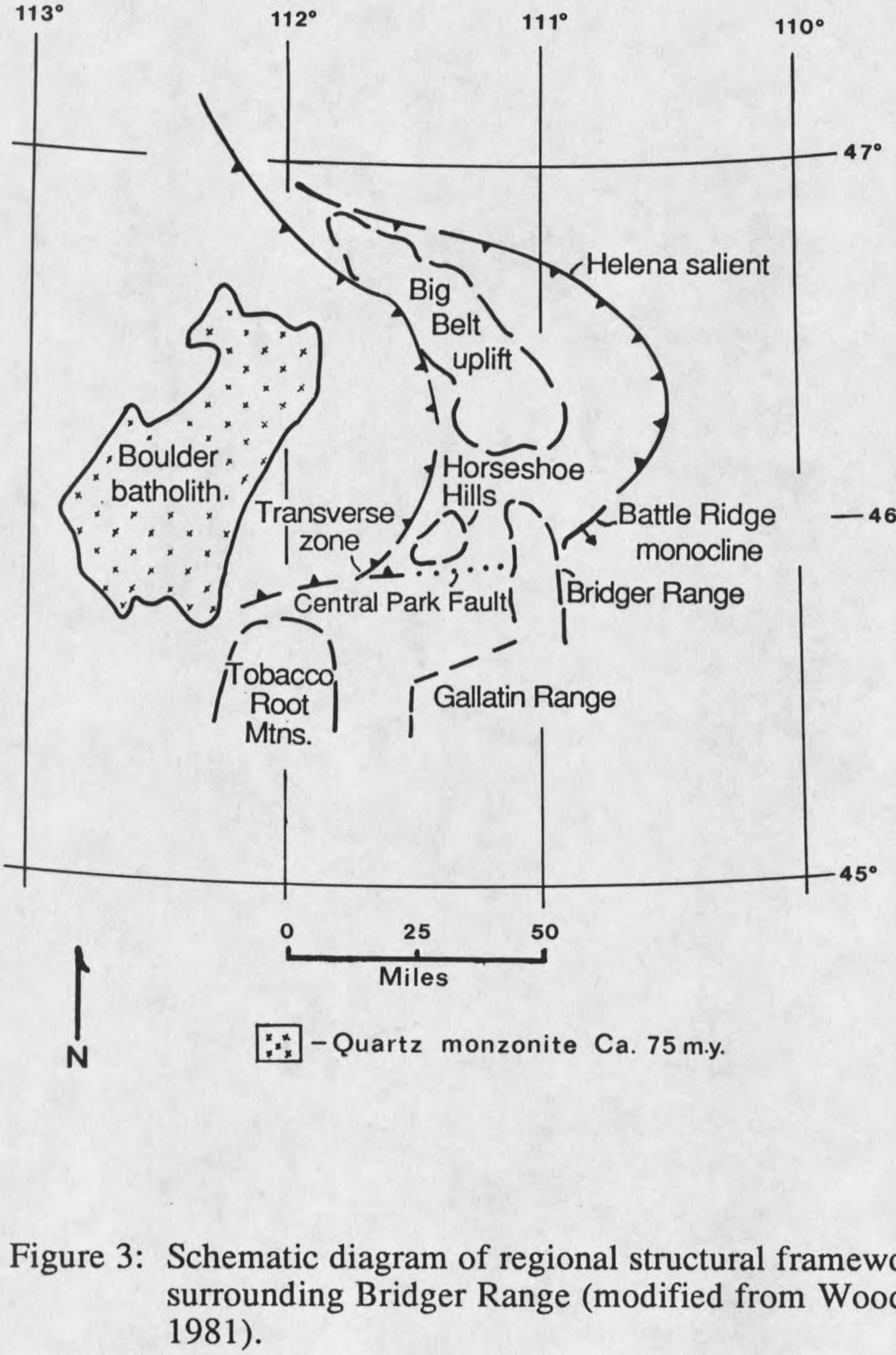

Figure 3: Schematic diagram of regional structural framework surrounding Bridger Range (modified from Woodward, 1981).

The Jefferson Canyon transverse zone marks the southern margin of the Helena salient and coincides closely with the aforementioned Proterozoic Willow Creek fault zone (Harrison et al, 1974). This transverse zone consists of a complex, anastomozing system of east-trending, north-dipping oblique slip thrusts which merge eastward into north-trending, west-dipping thrust faults (Schmidt and O'Neill, 1982). It brings allochthonous Belt Supergroup and Phanerozoic rocks on the north into contact with Archean crystalline rocks on the south. The apparent 9.5 miles (15 km) of eastward tectonic transport of the allochthonous rocks occurred on one or more decollement horizons at or near the base of the Belt sedimentary sequence (Schmidt and O'Neill, 1982). Schmidt and O'Neill (1982) suggest that the easternmost extent of the Jefferson Canyon transverse zone is the Battle Ridge monocline.

The Gallatin Range is an Archean-cored foreland uplift which is bound on the northwest by a high-angle normal fault and is overlain by an extensive cover of Eocene volcanic rocks (Chadwick, 1972). The uplift contains numerous northwest-plunging, southeast-verging folds on its northern end which are cored by Archean metamorphic rocks and typically involve overlying Paleozoic and Mesozoic strata (Schmidt and Garihan, 1983). Several of these northwest-trending folds are similar in overall geometry to folds encountered elsewhere in the foreland region south of the Jefferson Canyon transverse zone (Schmidt and O'Neill, 1982)

The Tobacco Root Mountains consist of a large Archean-cored, fault bounded uplift which is truncated on its northern end by the Jefferson Canyon transverse zone. The northern end of the uplift is marked by at least six northwest-trending, northeast-dipping basement faults and related foreland anticlines (Schmidt and O'Neill, 1982). These faults involve Archean metamorphic rocks and overlying Paleozoic and Mesozoic strata.

The late Cenozoic Three Forks Basin which lies immediately west of the Bridger Range is an east-west trending physiographic feature with important subsurface structural implications. The Bridger Range proper is separated from the basin on the west by the Bridger normal fault which represents the eastern boundary of Neogene basin-range extension north of the Snake River Plain (Reynolds, 1979).

Especially significant to this study is the subsurface Central Park fault (Fig. 3), which trends east-west and is inferred to be an extension of the Jefferson Canyon transverse zone (Davis et al, 1965). The Bouguer gravity and aeromagnetic study of Davis et al (1965) concluded that the northern edge of an east-west trending oval depression which lies between Belgrade and the Bridger Range represents a vertical fault (Central Park fault) that brings the Belt Supergroup into contact with Archean metamorphic rocks.

STRUCTURAL GEOMETRY

Folds

Folds associated with the Ross Pass fault zone, RPFZ, conform overall to the concentric or parallel style of folding which is commonly found in areas of thin-skinned deformation (Dahlstròm, 1969). Simply-curved (concentric) and pseudo-similar folds occur in the study area. Pseudo-similar folds are a special type of concentric fold in which only the thin incompetent units in a sequence flow toward the hinge. The folds are generally cylindrical in nature as poles to the folded surface, when plotted on a stereogram, lie within 20° of the best fit circle.The major folds in the study area contain axial surfaces which strike northeast to east and are steeply dipping. The interlimb angles range from gentle to tight. The study area has been divided into three fault-bounded domains to facilitate the discussion of folding associated with the RPFZ (Fig. 4).

Domain I

Domain I is the area lying north and northeast of the Ross Peak fault (Fig. 4). This area is dominated by a large, open, concentric S fold involving Paleozoic - Mesozoic strata (Plate 1). The upper Mississippian Mission Canyon Formation has acted as a competent beam which has controlled the wavelength of the fold.

The northeastern end of the S fold is a very large, open syncline which has an interlimb angle of approximately 90° and approaches a cylindrical