



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

© Copyright by Carol Jean Craiglow (1986)

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.

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
Bozeman, Montana

March 1986

MAIN LIB
N378
C8445
Cop. 2

APPROVAL

of a thesis submitted by
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.

2/25/86
Date

Dave Coe
Chairperson, Graduate Committee

Approved for the Major Department

2/25/86
Date

Stephen G. Austin
Head, Major Department

Approved for the College of Graduate Studies

March 6, 1986
Date

Henry L. Parsons
Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the library shall make it available to borrowers under the rules of the library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of the source is made.

Permission for extensive quotations from or reproduction of this thesis may be granted from my major professor, or in his absence, by the Director of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the materials in this thesis for financial gain shall not be allowed without my written permission.

Carol Craighlow
Signature

2-21-86
Date

ACKNOWLEDGEMENTS

I would like to thank John S. Williams for introducing me to innovative ideas regarding the structural geology of the Rocky Mountain region which led to the idea for this thesis.

I am also grateful to the late Dr. Robert Chadwick who provided much moral support and encouragement during the course of this study.

I thank Dr. Stephan Custer for the discussions we had and Dr. David Lageson and Dr. John Montagne for reading the drafts.

I would also like to gratefully acknowledge the financial support which made this study possible from the Grand Junction, CO Chapter of the American Institute of Mining Engineers, the Montana Bureau of Mines and Geology and ARCO.

I also thank the numerous private landowners on the western flank of the Bridger Range who granted me access to the study area via their land.

TABLE OF CONTENTS

	Page
LIST OF TABLES.....	vi
LIST OF FIGURES.....	vii
LIST OF PLATES.....	viii
ABSTRACT.....	ix
INTRODUCTION.....	1
Regional Setting.....	1
Purpose of Investigation.....	4
Location and Access.....	5
Field Procedures.....	5
Stratigraphy.....	5
Structural Framework.....	8
STRUCTURAL GEOMETRY.....	12
Folds.....	12
Domain I.....	12
Domain II.....	14
Domain III.....	18
Faults.....	22
Ross Peak Fault.....	22
Pass Fault.....	22
Potter's Gulch Fault.....	25
Structural Synthesis.....	27
DISCUSSION.....	34
CONCLUSION.....	36
REFERENCES CITED.....	38

LIST OF TABLES

	Page
1. Stratigraphic sequence in Bridger Range.....	7

LIST OF FIGURES

	Page
1. Index map showing location of study area.....	2
2. Map of Jefferson Canyon transverse zone and Helena salient.....	3
3. Regional structural framework.....	9
4. Fold domains in study area.....	13
5. Contoured pole-density diagram of S fold in Domain I.....	15
6. Contoured pole-density diagrams of Ross Pass folds-Domain II.....	16
7. Eastern upright limb of monocline-Domain II.....	17
8. Contoured pole-density diagram of large-scale anticline-Domain III.....	19
9. Map of complex structure in Meagher Limestone-Domain III.....	20
10. Disharmonic folding within Meagher Limestone.....	21
11. Cataclastic shear zone along trace of Pass fault.....	24
12. Near vertical andesitic dike which has intruded Pass fault.....	24
13. Horse slice of Archean rocks bounded by Cambrian Meagher Limestone.....	26
14. Block diagram showing inferred relationship of RPFZ to surrounding features.....	29
15. Sequential restoration of hingelines of major folds in the hanging wall of Pass fault.....	31
16. Map depicting relationship of Pass fault to southern margin of Helena salient.....	33

LIST OF PLATES

1. Geologic Map of Ross Pass Fault Zone.
2. Structure Cross-Sections.

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.

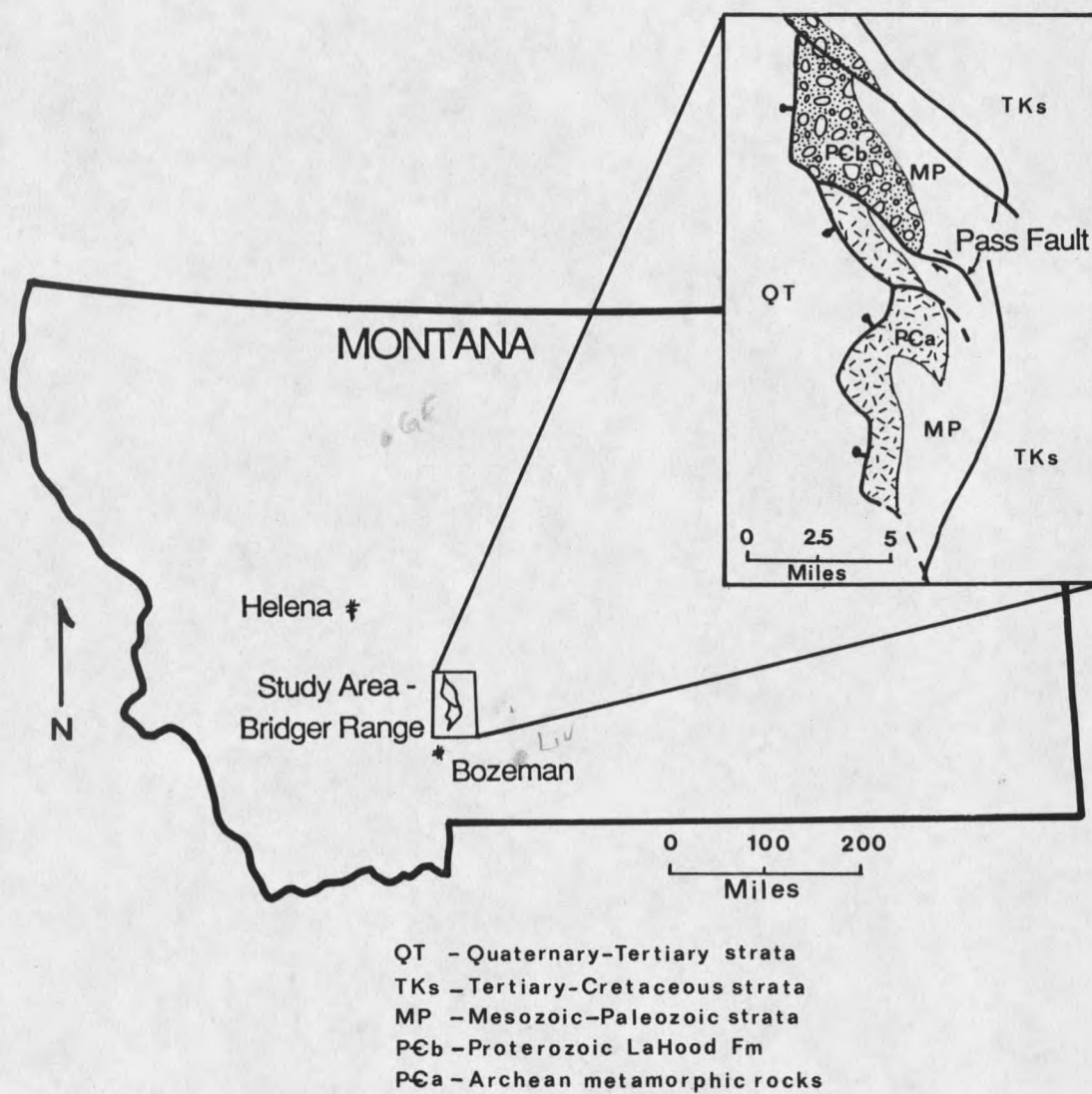


Figure 1: Index map showing location of study area.

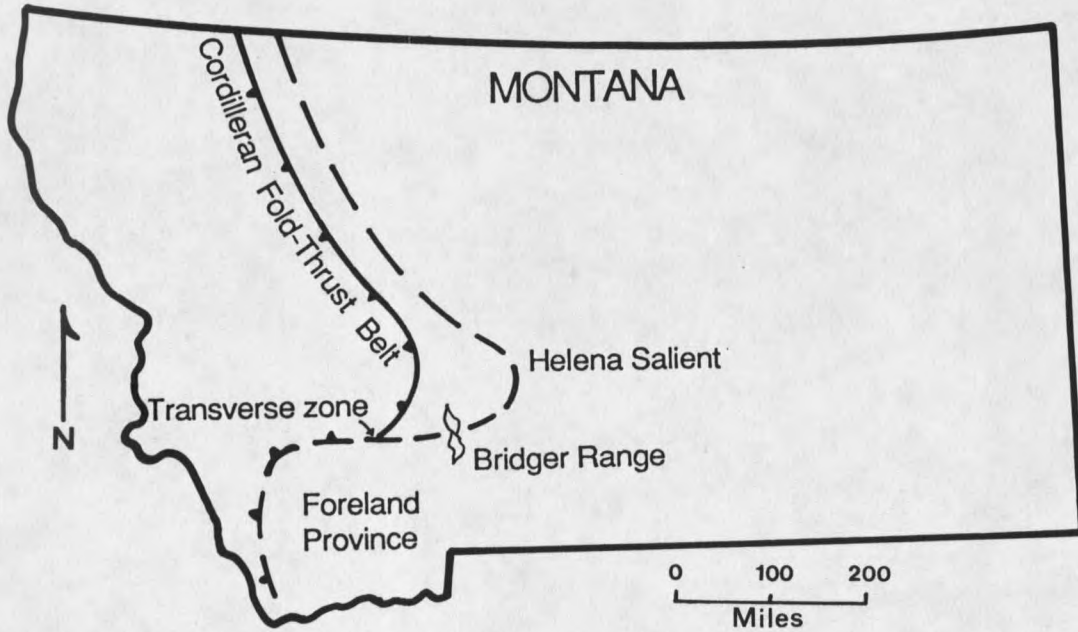


Figure 2: Map showing location of Jefferson Canyon transverse zone and Helena salient of Cordilleran fold and thrust belt (modified from Woodward, 1981).

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

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.

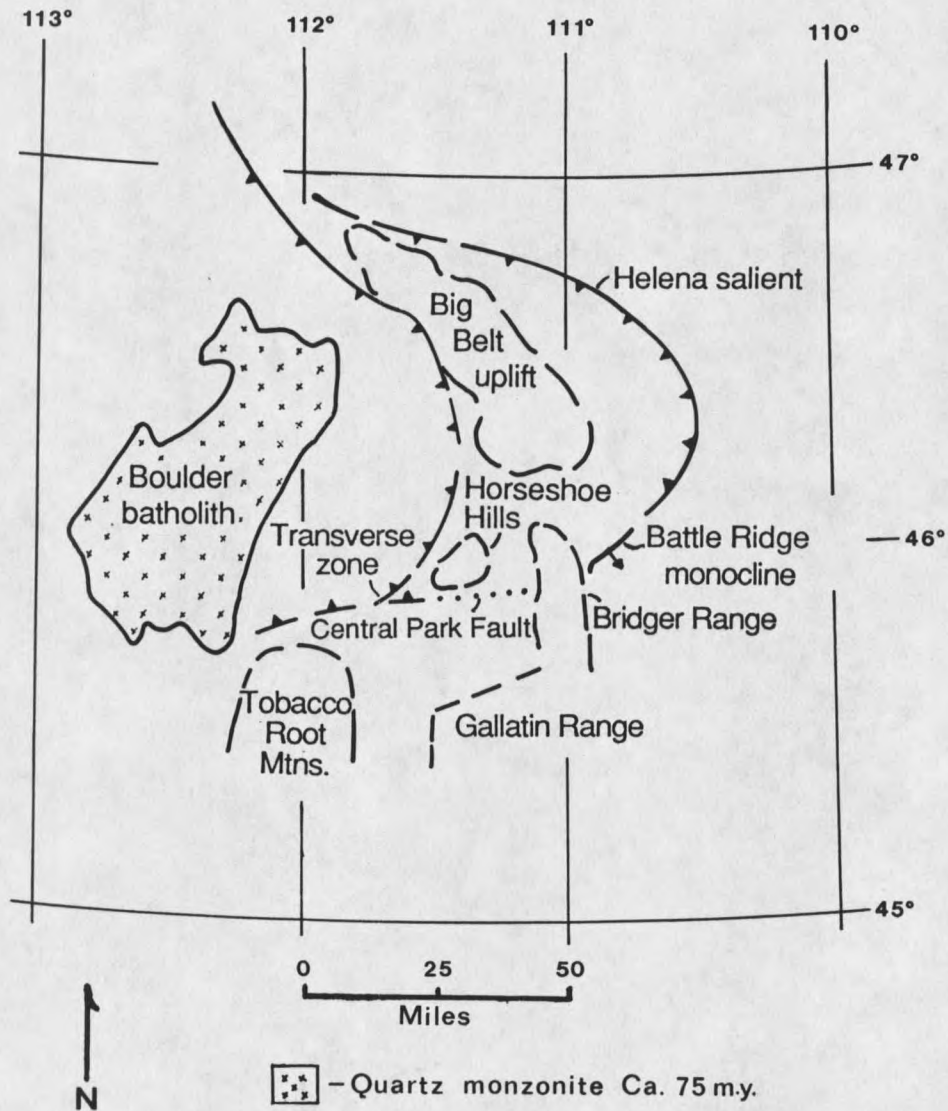


Figure 3: Schematic diagram of regional structural framework surrounding Bridger Range (modified from Woodward, 1981).

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, anastomosing 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 (Dahlström, 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

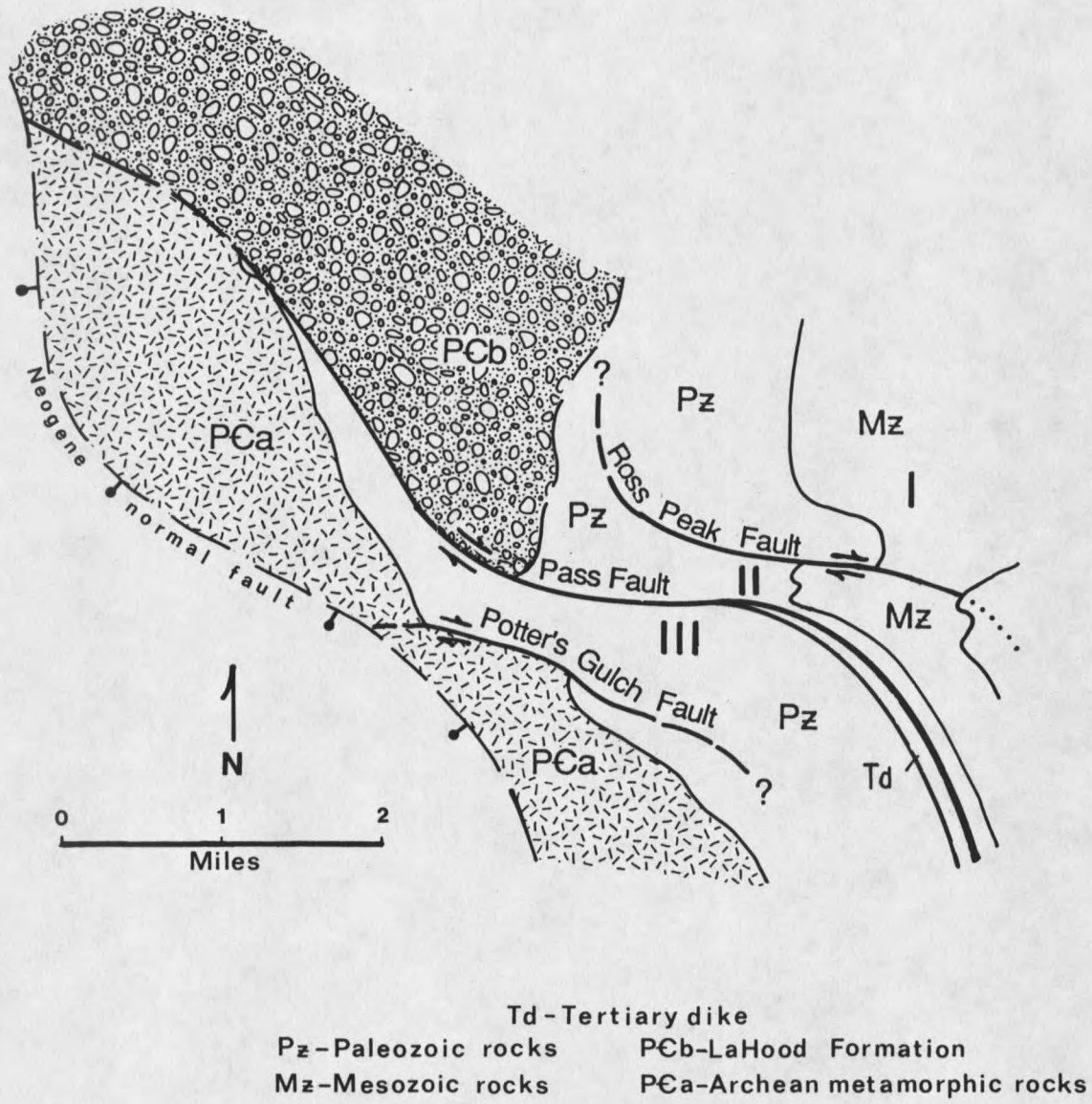


Figure 4: Schematic diagram showing Fold Domains in study area in relation to faulting.

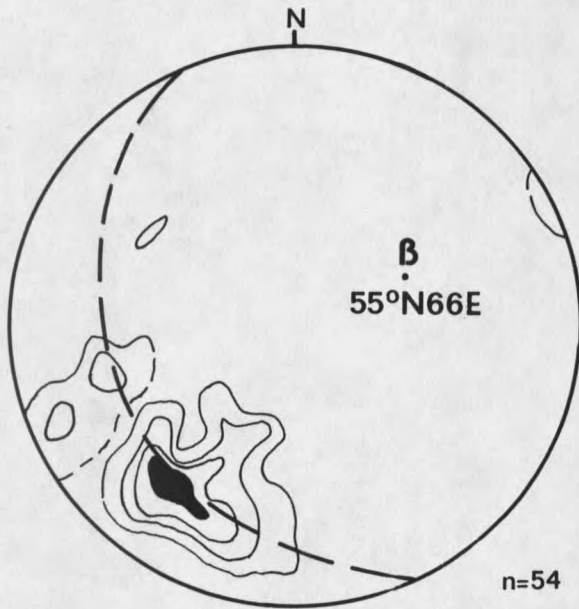
geometry. Its axial surface strikes east to east-northeast and its fold axis plunges 55° N66E (Fig. 5). The southeastern part of the S fold is composed of an open, overturned anticline with an interlimb angle of approximately 60° . Its axial surface strikes east-northeast to northeast and its hingeline plunges 66° N2E (Fig. 5).

Domain II

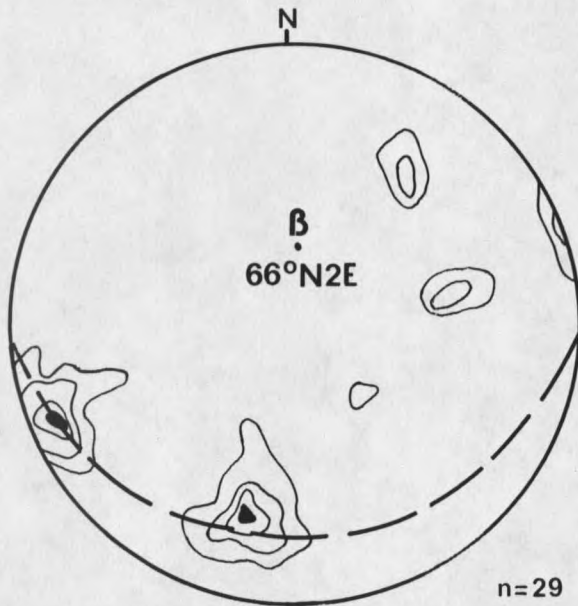
Domain II consists of rocks ranging from Proterozoic to Cretaceous age which lie between the Ross Peak fault and the Pass fault (Plate I). The major folding in Domain II is found in the Ross Pass area in the form of three subparallel folds comprising a syncline-anticline-syncline series. These folds conform to an overall pseudo-similar fold style. Their axial surfaces strike generally east-west and the folds display broad to tight interlimb angles. The plunge of the hingeline of the northern syncline is 56° N20W. The hingeline of the intermediate anticline plunges 68° N7W. The plunge of the hingeline of the southern syncline is 66° S57W (Fig. 6).

A large-scale monocline is found in the SE1/4, Sec. 4, T1N, R6E in the Cambrian Meagher Limestone (Fig. 7). The hingeline of the monocline is subhorizontal and trends north-south for about 1/4 mile. As Figure 7 shows, the middlemost, massive member of the Meagher Limestone forms the eastern vertical limb of the monocline. The overlying thinly-bedded member of the Meagher has been folded somewhat disharmonically due to the inherent ductility contrasts within its layers. The exposure immediately south of Dry Creek reveals an S fold which is also the result of disharmonic folding in the thinly-bedded portions of the Meagher Limestone.

Another large-scale fold is found in the Cambrian Meagher Limestone in

**ANTICLINE OF S FOLD**

Contoured at 2, 5, 10, 20%
per 1% area of net.

**SYNCLINE OF S FOLD**

Contoured at 4, 10, 15, 20%
per 1% area of net.

Figure 5: Contoured pole-density diagrams of S fold in Domain I.

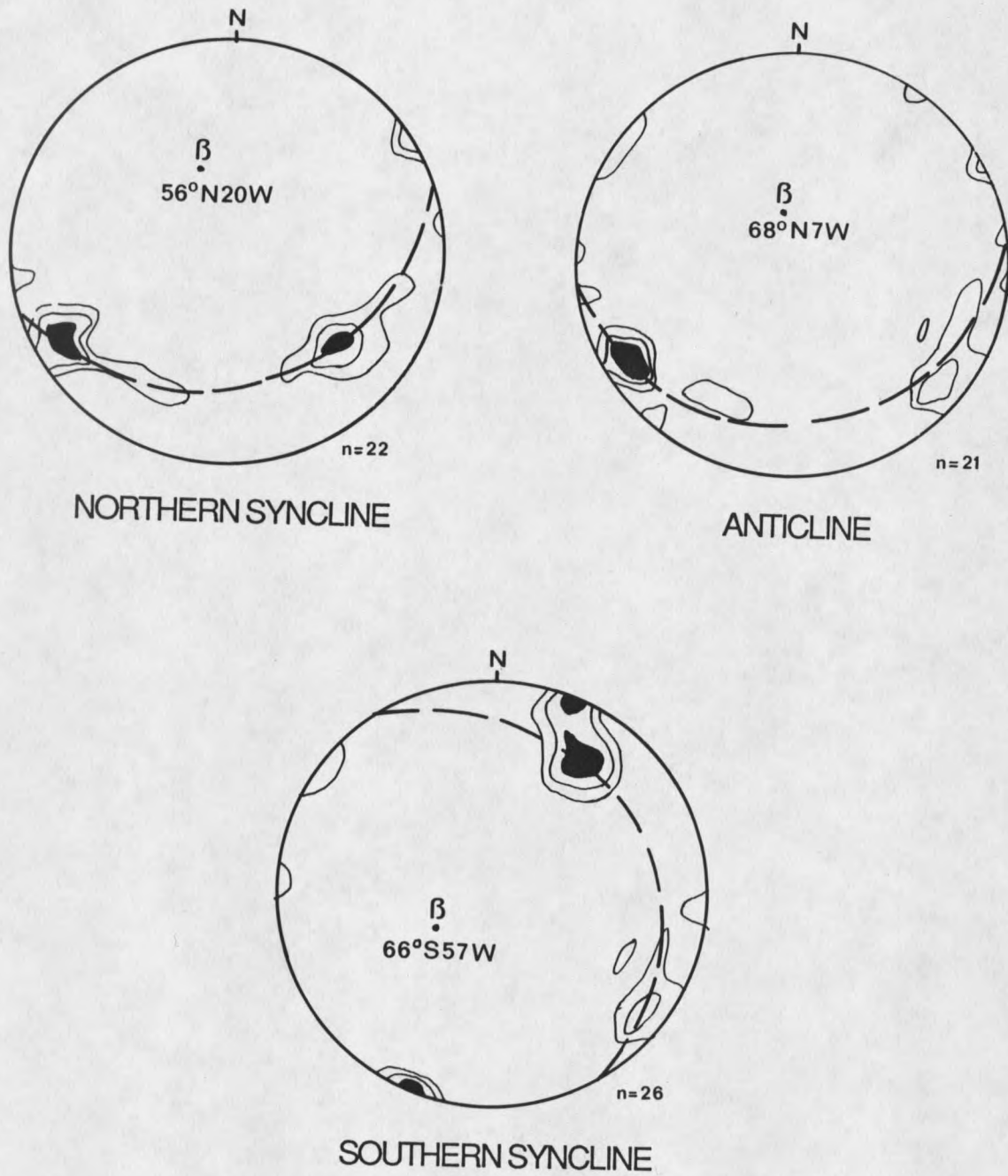


Figure 6: Contoured pole-density diagrams of folds in Ross Pass - Domain II. Contoured at 5, 10, 20% per 1% area of net.

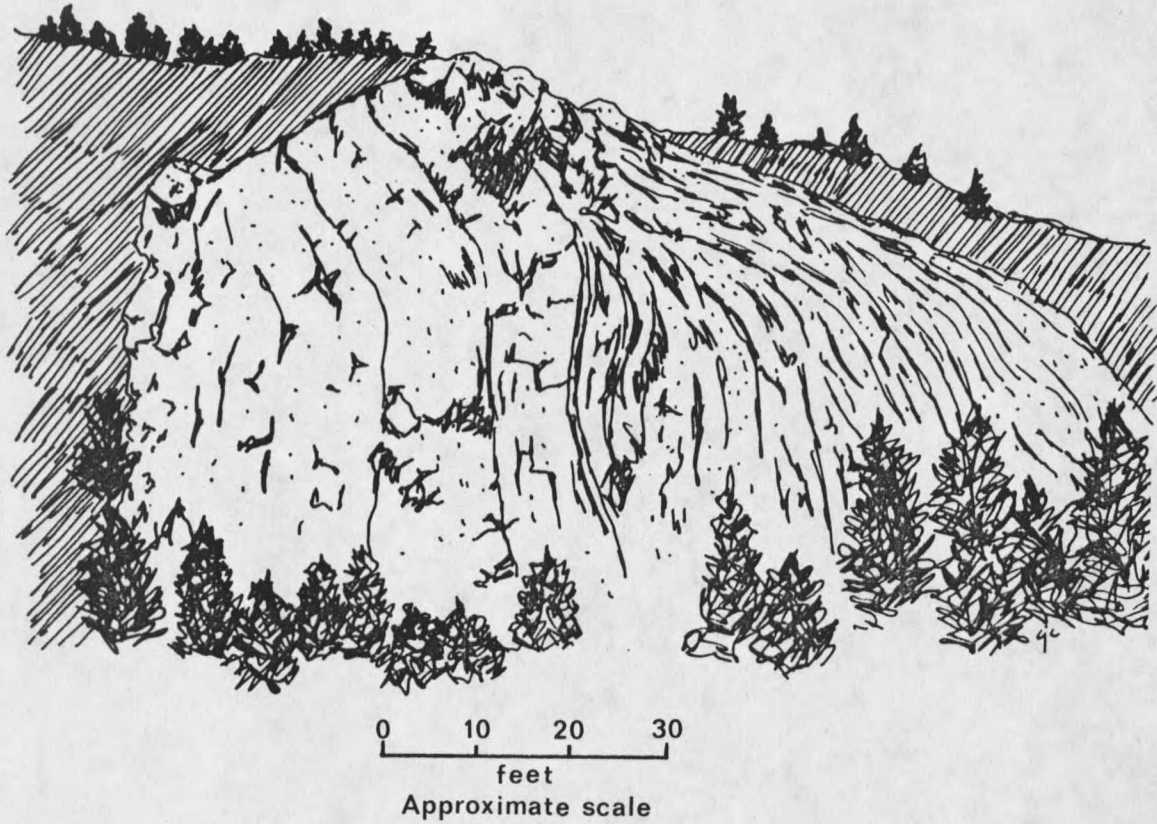


Figure 7: South-facing view of eastern upright limb of monocline in the Cambrian Meagher Limestone (SE1/4, Sec. 4, T1N, R6E), Domain II. Note curvature in overlying thinly-bedded layers.

the SW1/4, NE1/4, Sec. 9, T1N, R6E. This open, concentric anticline approaches a cylindrical geometry and its fold axis plunges 46° N97E.

Lastly, a major anticlinal fold is found in the Proterozoic LaHood Formation north of the Pass fault in Sec. 30, T2N, R6E. This fold is easily observed from a distance, but locally, bedding attitudes or fold axes were impossible to measure due to the poorly-defined bedding surfaces within the LaHood Formation. The fold axis is estimated to be near horizontal and the axial surface trends N10E.

Domain III

Domain III consists of Archean, Proterozoic and Paleozoic strata between the Pass fault and the Potter's Gulch fault. The only large-scale folding in this Domain is the broad open anticline in the Paleozoic strata south of Ross Pass. This fold is concentric in style and its axial surface strikes N40E. The fold axis plunges 18° S54E (Fig. 8).

Small-scale folding is found in the Meagher Limestone directly north of the Potter's Gulch fault in the SW1/4, Sec. 9, T1N, R6E. This area displays a very complex structural geometry due to the folding/faulting within the Meagher Limestone (Fig. 9). A syncline is found in the eastern part of this area with an axial surface striking N55W and a fold axis plunging 22° S48E.

The final area in Domain III which displays folding is in the SE1/4, Sec. 5, T1N, R6E. This small-scale folding (Fig. 10) is actually disharmonic folding within the thinly-bedded limestone layers overlying the massive member of the Meagher Limestone.

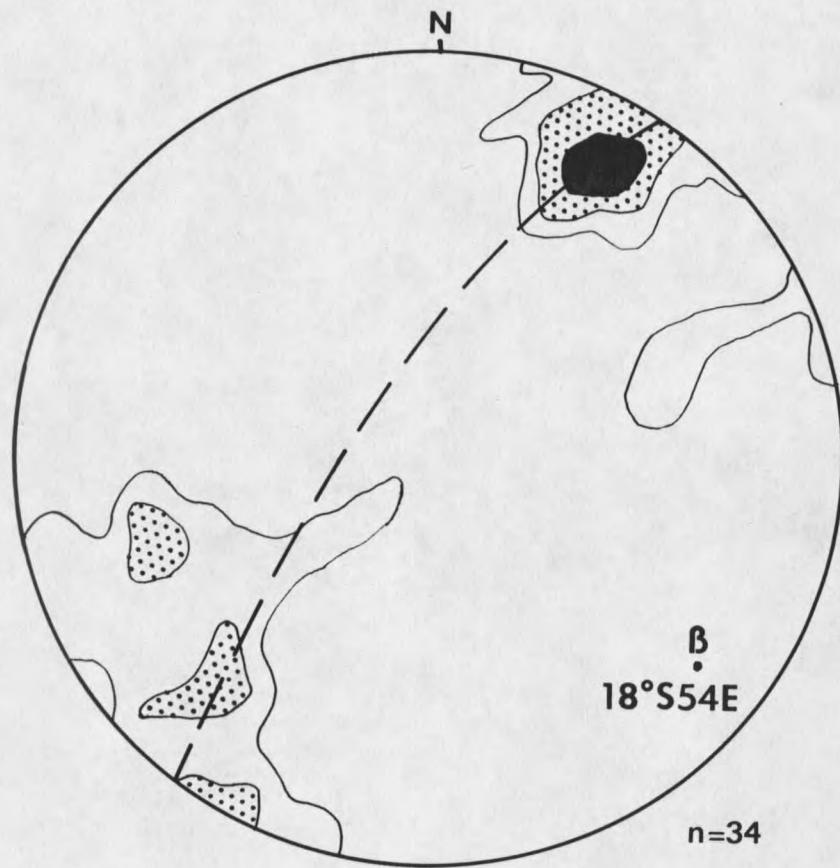


Figure 8: Contoured pole-density diagram of large-scale anticline - Domain III. Contoured at 3, 6, 12% per 1% area of net.

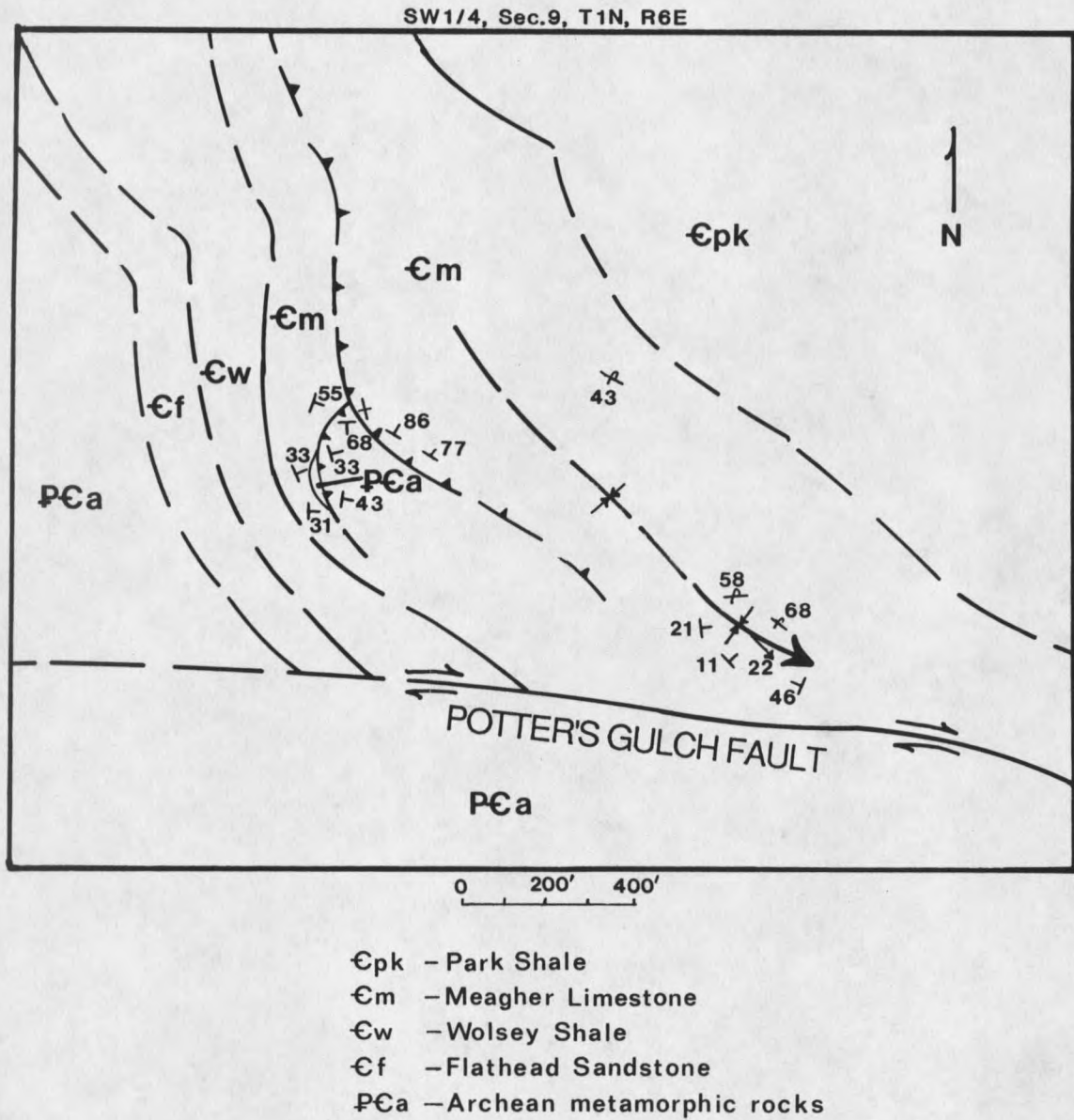


Figure 9: Detail of complex structure involving Meagher Limestone north of Potter's Gulch fault - Domain II. Note sliver of Archean metamorphic rock bounded by Meagher Limestone.

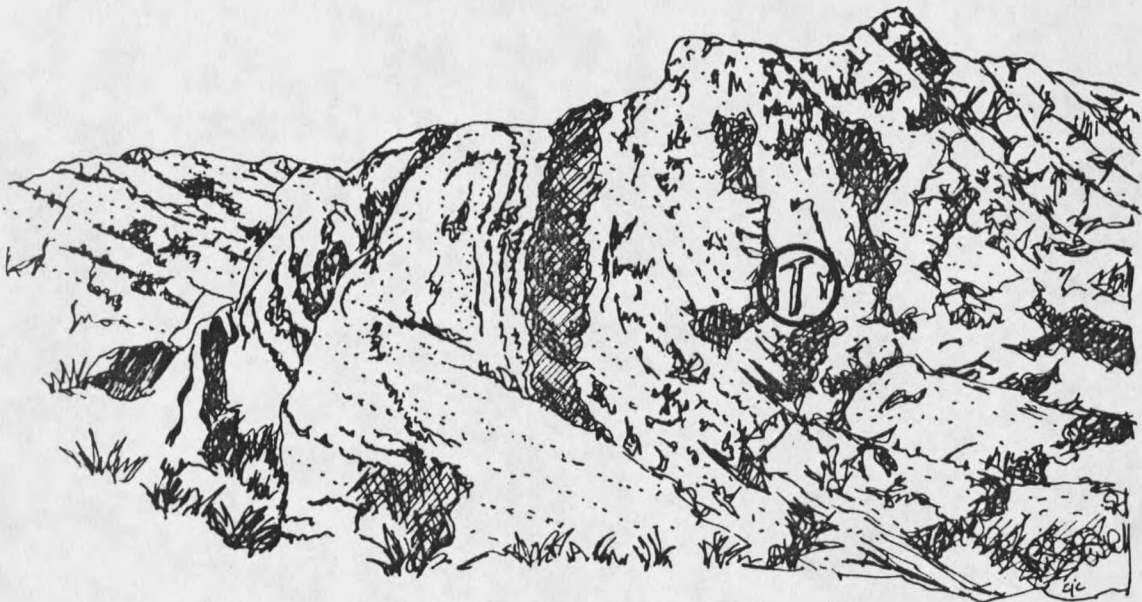


Figure 10: Disharmonic folding within Meagher Limestone in SE1/4, Sec. 5, T1N, R6E. Note hammer for scale (circled).

Faults

Ross Peak Fault

The Ross Peak fault is the northernmost fault of the RPFZ and its trace trends north-south to east-west and extends for about 3 miles (Plate 1). This fault offsets rocks of Lower Paleozoic through Upper Mesozoic age. McMannis (1952, p. 147) suggested that the Ross Peak fault, although "obscure", extended further to the northwest and died out in the LaHood Formation. However, no evidence of offset was found in the intervening Flathead, Wolsey or Meagher formations to warrant that interpretation. Rather, the Ross Peak fault appears to die out within the Park Shale on its northwestern end. The eastern extent is covered by Quaternary glacial deposits and colluvium.

The actual fault plane of the Ross Peak fault is not discernible in the field. On the basis of map pattern, the fault plane is inferred to dip steeply to the north/northeast (Plate 2b-d). No evidence of a zone of cataclasis along the fault trace was found.

Right-lateral separation occurs in the area to the south of Ross Peak. Here the massive Mississippian Mission Canyon Limestone has been offset as much as 3,470 feet (11,280 m). The inferred net slip will be addressed in the discussion section.

Pass Fault

The Pass fault is the major fault of the RPFZ and it trends generally northwest-southeast for approximately 7 miles (11.2 km). This fault is most significant in that it brings the Proterozoic LaHood Formation into contact

with Archean crystalline rocks in a younger-over-older relationship. The Pass fault is truncated on its western end by younger, extensional normal faulting and dies out in lower Cretaceous rocks on its eastern end. The map pattern of the Pass fault suggests that its attitude ranges from near-vertical to steeply-dipping toward the northeast (Plate 1).

why so?

The fault surface of the Pass fault is in no place exposed and there is very little topographic expression to denote its presence. Commonly, a zone of cataclastically-deformed rock ranging from 5-30 feet (1.5-9 m) in width marks the fault trace. This zone is especially noticeable at the northwestern end of the fault where the LaHood Formation and Archean crystalline rocks are brought into contact (Fig. 11). A highly-fractured cataclasite is found locally along the Pass fault in the area between Dry Fork and Limestone Creek.

oient check
Mapland Creek

The fault plane has been intruded by a Tertiary age (McMannis, 1955) andesitic dike which can be traced discontinuously for approximately 3 miles (4.8 km) in the vicinity of Ross Pass and to the southeast. Thin-sections revealed that the dike is composed of a very-fine grained, layered, andesitic rock at its extremities and a coarse-grained, olivine-bearing syenite in its central portion. Radiometric dating of the dike was not possible due to its weathered nature in the steeply-dipping to near vertical exposures (Fig. 12). For the majority of its length the dike is found in the Pennsylvanian Amsden interval and at its southern extent cuts upsection across Pennsylvanian, Jurassic and lower Cretaceous strata. Skipp and McMannis (1971) mapped this dike as extending northward from the Pass fault via the Amsden Formation to the trace of the Ross Peak fault. However, several attempts to identify the dike along the Ross Peak fault trace proved fruitless and it was concluded that the dike must die out along the Pass fault.

why does
a dike do
present
dating?

A maximum of 6,980 feet (22,690 m) of right-lateral separation is

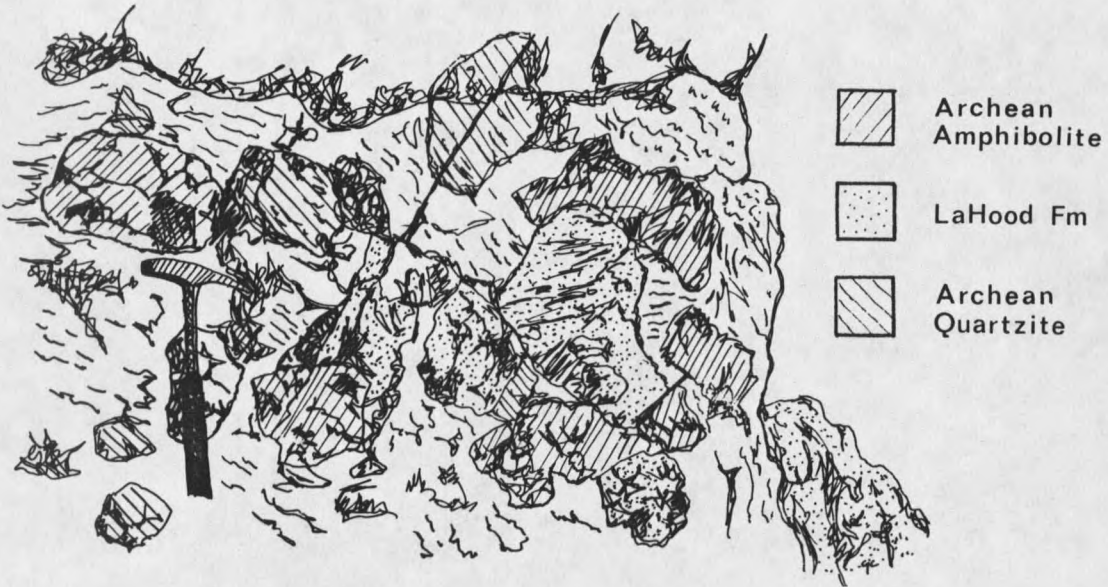


Figure 11: Cataclastic shear zone at Pass fault in NE1/4, NE1/4, Sec. 36, T2N, R5E.



Figure 12: Near vertical andesitic dike which has intruded Pass fault (NW1/4, SW1/4, Sec. 11, T1N, R6E).

evident along the Pass fault where the contact between the Middle Cambrian Wolsey Shale and Meagher Limestone has been offset. There are no linear piercing points which can be followed across the Pass fault and there are no slickensides along the trace of the fault with which to determine the net slip directly. Therefore the net slip must be inferred from map relationships and the attitudes of strata in the vicinity of the fault. The net slip will be discussed in detail in the structural synthesis section which follows.

Potter's Gulch Fault

The Potter's Gulch fault is the southern-most fault of the RPFZ (Plate 1). This was McMannis' Dry Fork fault and is herein re-named due to the fact that his original base map mistakenly labeled Potter's Gulch as Dry Fork. Also, the fault trace exploits a portion of Potter's Gulch while it barely crosses Dry Fork. The Potter's Gulch fault brings Middle Cambrian Flathead, Wolsey, Meagher and Park formations into contact with Archean crystalline rocks.

This fault is somewhat enigmatic in that the motion along the fault based upon stratigraphic separation appears to be left-lateral (Plate 1). However, portions of the Flathead Sandstone have been sheared out at the Flathead-Archean contact, (NE1/4, Sec. 16 and SE1/4, Sec. 9, T1N, R6E), giving the false impression of left-lateral motion. Due to this fact, the actual stratigraphic separation along the fault can not be determined.

Approximately 500 feet (1,500 m) north of the Potter's Gulch fault is a zone of complex, disharmonically-folded Meagher Limestone with a fault-bounded horse slice of Archean amphibolite and garnet schist (Fig 13). This horse slice is approximately 20 feet (65 m) thick and is surrounded on either side by cliffs of Meagher Limestone.

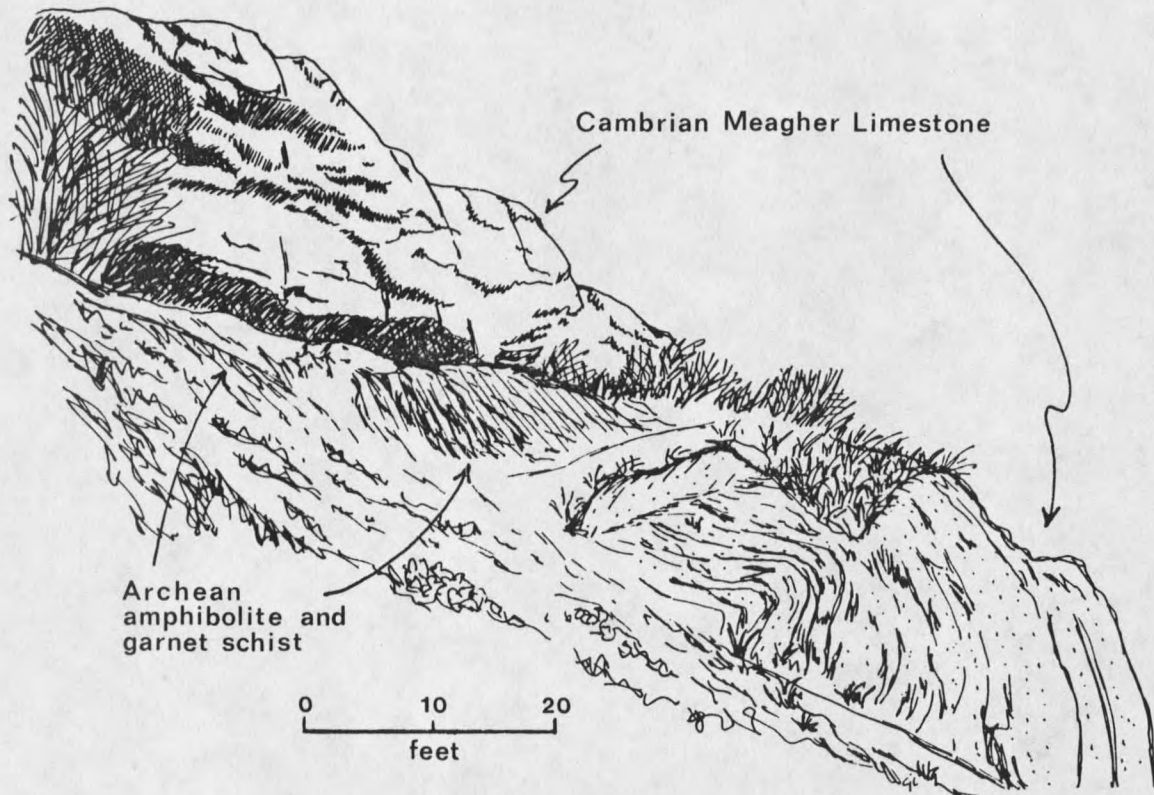


Figure 13: Horse slice of Archean amphibolite and garnet schist bounded by Cambrian Meagher Limestone.

On the basis of topographic expression, the fault plane is interpreted to be near-vertical to slightly dipping to the south-southwest. In this context the southern block has moved upward (Plate 1).

Structural Synthesis

Two primary models have been put forth regarding the origin of the faults which comprise the RPFZ. Schmidt and O'Neill (1982) proposed that the faults formed in latest Cretaceous and Paleocene time following a period of foreland deformation which uplifted the Bridger Range. They suggested that the faults were "refracted" around the northern end of the large, asymmetric foreland anticline which acted as a buttress to eastward translation along the Jefferson Canyon transverse zone.

A second model for the origin of the RPFZ suggests that Paleocene Sevier-style thrusting within the RPFZ predates the foreland uplift style of deformation in the Bridger Range. Lageson and Zim (1986, in press) indicate that the area occupied by the present-day Bridger Range, the Three Forks Basin and the Horseshoe Hills was uplifted during latest Paleocene to earliest Eocene time into a large, asymmetric foreland anticline by a large "subthrust" zone of west-dipping, east-verging blind thrusts which underlies the southern half of the Bridger Range. They cite the following evidence in support of this model: 1) the strike of the Paleocene Fort Union Formation changes abruptly from northeast near the Battle Ridge monocline to north parallel to the Bridger Range, and 2) the northeast-trending anticlines and synclines north of and sub-parallel to the Battle Ridge monocline are deflected to a north-south trend at their southern terminations.

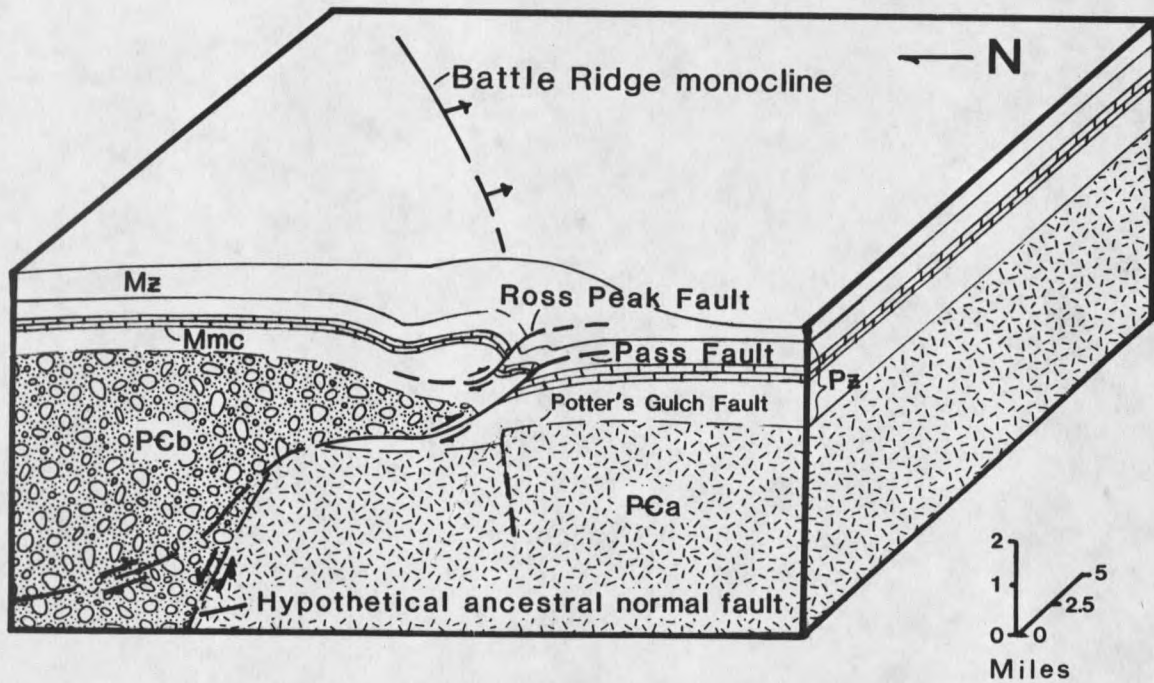
Thus, the present-day Bridger Range is the eastern, vertical to over-turned limb of a large basement-cored foreland uplift. The crest and

western portion of the uplift have subsequently been down-dropped as a result of Neogene normal faulting and underlie the adjoining Three Forks basin (Lageson and Zim, 1985). The Horseshoe Hills represent the northern part of the western limb of the former north-northwest plunging Laramide anticline, as interpreted in a down-plunge projection.

When the Bridger Range is restored to its post-thrusting, pre-foreland uplift configuration and envisioned in such a way that the vertical strata along the crest are near horizontal, the structural relationships within the RPFZ correlate well with the regional structural framework. Figure 14 is a schematic block diagram which portrays this pre-uplift setting. It should be noted that the present-day map view of the essentially vertical eastern limb represents, in effect, a cross-sectional view.

In this context, it can be seen that the thrust surface of the Pass fault follows a simple staircase trajectory which cuts upsection in the direction of tectonic transport (Fig. 14). The portion of the fault between Ross Pass and Dry Fork (Plate 1) represents an oblique footwall ramp which formed due to buckling of the Mississippian Madison Limestone. This ramp connects two flats: to the south in the Upper Paleozoic-Mesozoic section and to the north within the LaHood Formation. This staircase trajectory is postulated to continue northward where the fault surface encounters the Archean crystalline buttress (Fig. 14). Further to the north, the Pass fault soles into a decollement developed near the base of the LaHood Formation (Fig. 14).

The syncline-anticline-syncline triplet in Ross Pass (Domain II) developed in the hanging wall of the Pass fault and the footwall of the Ross Peak fault. The folds represent sigmoidal drag-folds which formed in the relatively ductile Pennsylvanian-Jurassic section as a result of impingement between the bounding faults. These folds and their implications will be discussed below.



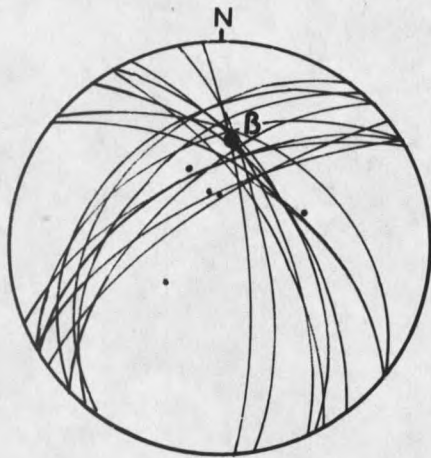
- Mz — Mesozoic rocks
- Mmc — Mission Canyon Fm.
- Pz — Paleozoic rocks
- PCb — Proterozoic LaHood Fm.
- PCa — Archean metamorphic rocks

Figure 14: Schematic block diagram showing inferred relationship of RPFZ to surrounding features prior to early Eocene uplift.

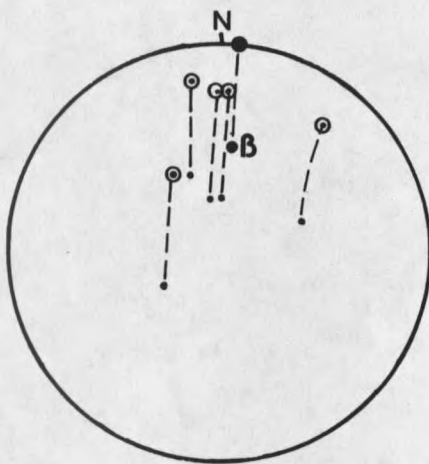
The Ross Peak fault represents a hanging wall imbricate which trends sub-parallel to the footwall ramp and southern flat of the Pass fault (Fig. 14). This fault displays reverse oblique-slip displacement as well and dies out within the Middle Cambrian Park Shale. The large S-fold above the Ross Peak fault apparently developed above the hanging wall cutoff which truncates the brittle Madison Limestone.

The Potter's Gulch fault is a relatively minor fault which represents a small amount of reverse movement on a former normal fault within the Archean metamorphic rocks (Fig. 14). When viewed in cross-section, it can be seen that the Potter's Gulch fault formed as the relatively thin Middle Cambrian section encountered the uplifted Archean buttress to the south. As a result, the thin Flathead Sandstone and the ductile Wolsey Shale have been sheared out locally along the fault trace and the Meagher Limestone and Park Shale are in fault contact with metamorphic rock. The disharmonic folding and faulting in the Meagher Limestone immediately north of the fault (Fig. 9) represent strain which developed at the hanging wall ramp.

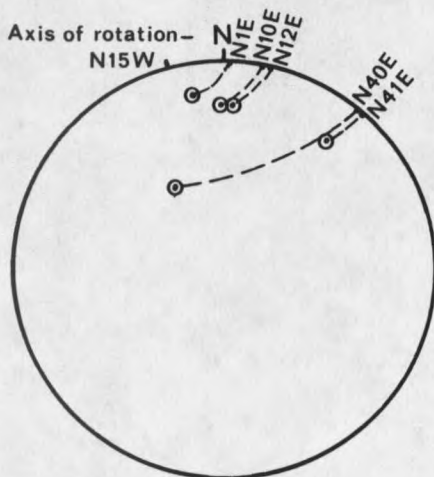
Although the net slip of the Pass fault can not be measured directly, an indirect means is possible through stereographic restoration of the hanging wall folds above the Ross Peak and Pass faults. One of the basic axioms of detachment-style fold and thrust belts is that the hingelines of hanging wall folds trend parallel to the strike of the underlying thrusts (Dahlstrom, 1970). Therefore, if the hingelines of the folds above the Ross Peak and Pass faults are restored to their trends prior to uplift, an indication of the orientation of the faults can be determined. This restoration was attained by determining the β axis of the large scale ancestral Laramide foreland anticline from average strikes along its eastern limb (Bridger Range) and the northern remnant of its western limb (Horseshoe Hills) (Fig. 15). This axis was restored to horizontal and then the eastern limb containing the folds was also



Determination of β point for large inferred fold in which the Horseshoe Hills represent the western limb and the Bridger Range is the eastern limb. β axis = $47^\circ\text{N}5\text{E}$. Other points are the hingelines of the 5 major folds in the hanging wall of the Pass Fault.



Restoration of β axis to horizontal and accompanying shift of 5 hingelines.



Restoration of 5 hingelines of eastern limb (Bridger Range) to horizontal. Rotated about average strike of $\text{N}15\text{W}$. Average trend of restored hingelines is $\text{N}21\text{E}$.

Figure 15: Sequential restoration of hingelines of 5 major folds in the hanging wall of Pass fault.

restored to a horizontal attitude, giving a close approximation of their post-thrusting orientation. The resultant average trend of the fold hingelines is N21E. Thus, the underlying Pass fault may have had a strike of approximately N21E or north-northeast.

From this restoration it can be seen that at the end of Paleocene time, prior to foreland uplift, the Pass fault was a north-northeast striking, oblique-slip thrust fault. Figure 16 shows this orientation in map view and demonstrates that the Pass fault had a predominant component of dip-slip movement. Since displacement along the Pass fault was dominantly dip-slip and the map view essentially represents a cross-sectional view, the separation evident along the fault, 1.3 miles (2.2 km), may be used as a rough approximation of the net slip.

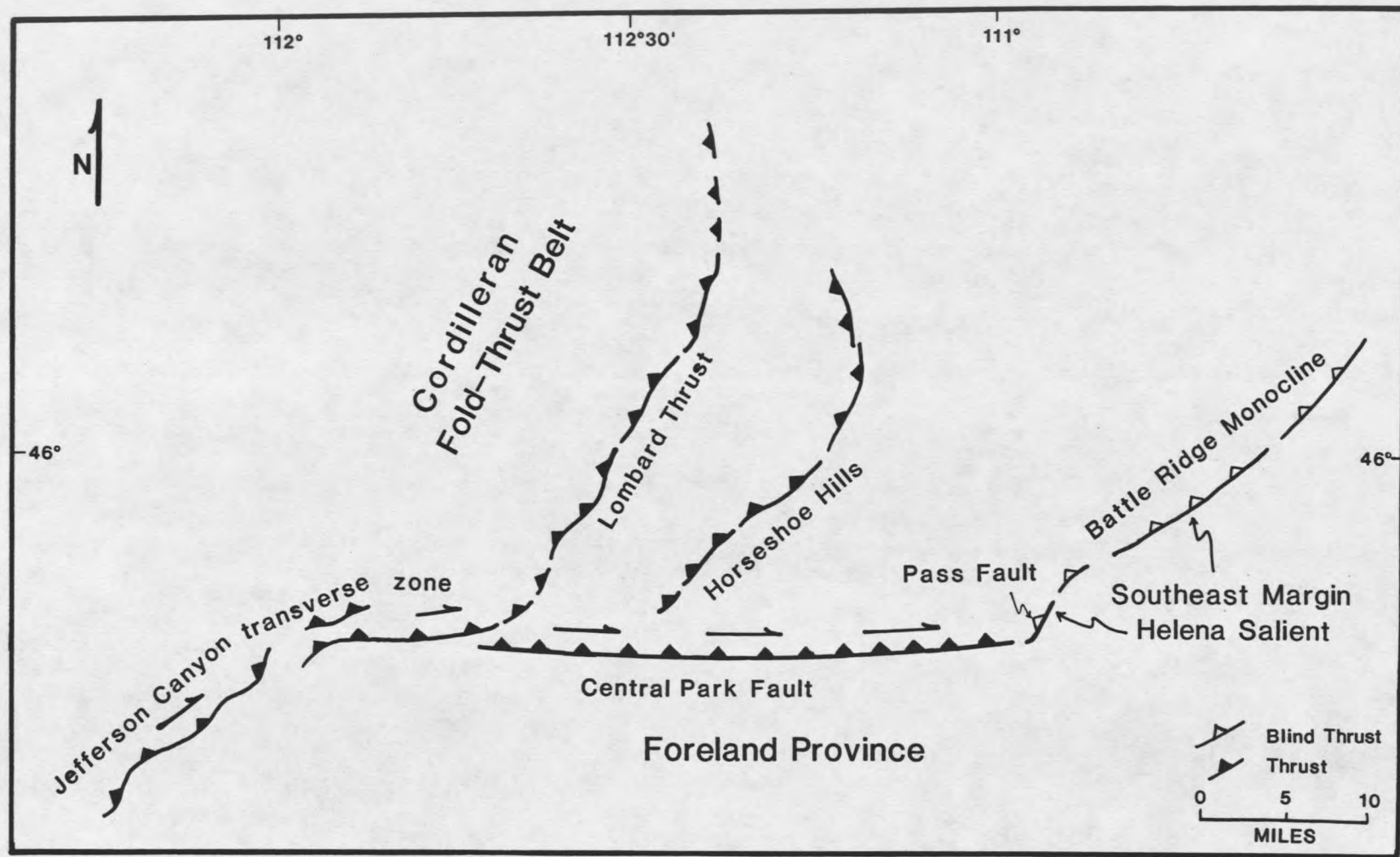


Figure 16: Schematic map depicting the relationship of the Pass Fault to the other major structural features of the southern margin of the Helena salient (modified from Schmidt and Garihan, 1983 and Woodward, 1981).

DISCUSSION

From the preceding Structural Synthesis it has been demonstrated that the Pass fault had a strike of approximately N21E and an oblique-slip sense of movement with a dominant component of dip-slip. In this framework, the Pass fault formed as a footwall ramp at the leading edge of the Helena salient with strike slightly oblique to tectonic transport (Fig. 16).

The overall geometry of the Pass fault is very similar to the north-northeast striking, west-dipping thrusts of the Jefferson Canyon transverse zone (Fig. 16) (Schmidt and O'Neill, 1982). The Jefferson Canyon transverse zone is a large-scale lateral ramp composed of east-trending, north-dipping oblique-slip thrusts which merge eastward into north-trending, west-dipping thrusts. It brings the allochthonous Proterozoic LaHood Formation and overlying Paleozoic strata to the north into contact with Archean metamorphic rocks of the foreland province to the south (Fig. 16). Schmidt and O'Neill (1982) have documented 6 to 10 miles (11 to 16 km) of eastward tectonic transport along the Jefferson Canyon transverse zone.

Displacement was transmitted to the RPFZ from the Jefferson Canyon transverse zone via the Central Park fault, which has subsequently been down-dropped and underlies the Three Forks Basin. On the basis of geophysical evidence (Davis et al, 1965), the Central Park fault is thought to mark the contact between the LaHood Formation to the north and Archean crystalline rocks to the south.

The fold-thrust structures present in the Horseshoe Hills represent the western limb of the former foreland anticline and were at one time

contiguous with the structures present in the northern Bridger Range (Verrall, 1955). The 6 to 10 miles (11 to 16 km) of eastward translation along the Jefferson Canyon transverse zone has been accommodated through thrusting in the Horseshoe Hills which connects in the subsurface with the larger Lombard thrust to the northwest (Schmidt and O'Neill, 1982). The relatively small net slip of the Pass fault (1.3 miles or 2.2 km) is consistent with the fact that the Pass fault developed at the leading edge of the Helena salient where folds and thrusts were dying out (Fig. 16).

The Archean crystalline rocks in the southern Bridger Range were probably originally continuous with the Archean of the Gallatin Range. Prior to Tertiary uplift of the eastern Bridger Range and down-dropping of the western portion, Archean rocks extended from the southern Bridger Range across the Three Forks basin (south of the Central Park fault) to the Tobacco Root Mountains (Schmidt and O'Neill, 1982).

Finally, it should be noted that the presence of the coarsely-conglomeratic LaHood Formation north of the Pass fault is also evidence that it occupies the approximate site of the ancestral Proterozoic Willow Creek normal fault (Fig. 14) (McMannis, 1963 and Harrison et al, 1974). This long-lived zone of weakness sporadically influenced sedimentation in the vicinity of the Bridger Range throughout Paleozoic and Mesozoic time (McMannis, 1965; Guthrie, 1984) and was re-activated by compressive stresses during latest Cretaceous through latest Paleocene time.

CONCLUSION

The Ross Pass fault zone in the central Bridger Range of southwest Montana represents the interior of a thrust system which developed at the leading edge of the Helena salient of the Cordilleran fold and thrust belt. This thrust system marks the juncture of two styles of deformation within one range: Sevier-style fold-thrust structures to the north and a Laramide foreland uplift to the south. The RPFZ resulted from compressive stresses applied primarily during Paleocene time.

The Pass fault is the major fault within the RPFZ and was an oblique-slip thrust fault with a dominant dip-slip component which formed as a footwall ramp at the leading edge of the southeast corner of the Helena salient. The net slip along the Pass fault was approximately 1.3 miles (2.2 km) and it trended north-northeast at the time of movement.

As such, it was genetically related to the southern margin of the Helena salient on the west (Jefferson Canyon transverse zone) and the southeast margin to the east (Battle Ridge monocline). Subsequent early Eocene subthrusting has uplifted the Bridger Range and the RPFZ into its present-day configuration.

Another important aspect of the RPFZ is the presence of the coarse, arkosic LaHood Formation to the north of the Pass fault which is evidence for a long-lived ancestry for the fault zone. McMannis (1963) noted that the Paleocene compressive stresses which caused the RPFZ exploited the pre-existing Proterozoic Willow Creek normal fault that formed the southern margin of the Belt Basin.

In conclusion, the Ross Pass fault zone represents the interior of a thrust

system which formed during the Paleocene Epoch at the site of a long-lived zone of crustal weakness that has been intermittently active from Proterozoic through Phanerozoic time.

REFERENCES CITED

- Burchfiel, B.C., 1981, Geologic history of the central western United States: Syllabus to Accompany American Association of Petroleum Geologists Continuing Education Course, Montana Geological Society, Billings, Mt., p. 1-11.
- Chadwick, R.A., 1972, Volcanism in Montana: Northwest Geology, vol. 1, p. 1-20.
- Dahlstrom, C.D.A., 1970, Structural geology in the eastern margin of the Canadian Rocky Mountains: Bulletin Canadian Petroleum Geologists, v. 18, p. 322-406.
- Davis, W.E., Kinoshita, W.T., and Robinson, G.D., 1965, Bouguer gravity, aeromagnetic, and generalized geologic map of the eastern part of the Three Forks basin, Broadwater, Madison, and Gallatin Counties, Montana: U.S.G.S. Geophysical Inventory Map GP-498, Scale 1:62,500.
- Fryxell, Jenny C., 1982, Depositional environments and provenance of arkosic sandstone, Park Shale, Middle Cambrian, Bridger Range, southwestern Montana: unpublished M.S. thesis, Montana State University, 95 p.
- Garrett, H.L., 1972, Structural geology of the Crazy Mountains Basin: Montana Geological Society 21st Annual Field Conference Guidebook, p 113-118.
- Guthrie, Gary Eich, 1984, Stratigraphy and depositional environment of the Upper Mississippian Big Snowy Group in the Bridger Range, southwest Montana: unpublished M.S. thesis, Montana State University, 105 p.
- Harrison, J.E., Griggs, A.B., and Wells, J.D., 1974, Tectonic features of the Precambrian Belt basin and their influence on post-Belt structures: U.S.G.S. Prof. Paper 866, 15 p.

- Lageson, David R., and Zim, John C., 1985, Uplifted basement wedges in the northern Rocky Mountain foreland: Geological Society of America Abstracts with Programs (Boise), vol. 17, no. 4, p. 250.
- Lageson, David R., and Zim, John C., 1986 in press, Superimposed tectonism from Proterozoic to Recent recorded in the Bridger Range, southwestern Montana: American Association of Petroleum Geologists Bulletin.
- McMannis, W.J., 1955, Geology of the Bridger Range, Montana: Geological Society of America Bulletin, v. 66, p. 1385-1430.
- McMannis, W.J., 1963, LaHood Formation - a coarse facies of the Belt Series in southwestern Montana: Geological Society of America Bulletin, v. 74, p. 407-436.
- McMannis, W.J., 1963, Resume of depositional and structural history of western Montana: American Association of Petroleum Geologists Bulletin, v. 49, no. 11, p. 1801-1823.
- Pardee, J.T., 1950, Late Cenozoic block faulting in western Montana: Geological Society of America Bulletin, v. 61, p. 359-406.
- Reynolds, M.W., 1979, Character and extent of basin-range faulting, western Montana and east-central Idaho: Rocky Mountain Association of Geologists and Utah Geological Association Basin and Range Symposium and Great Basin Field Conference Guidebook, p. 185-193.
- Schmidt, Christopher J., and O'Neill, J. Michael, 1982, Structural evolution of the southwest Montana transverse zone, in Powers, R.W., editor, The overthrust belt from Alaska to Mexico: Rocky Mountain Association of Geologists, p. 193-218.
- Schmidt, Christopher J., and Garihan, John M., 1983, Laramide tectonic development of the Rocky Mountain foreland of southwestern Montana, in Lowell, James D., editor, Rocky Mountain basins and uplifts: Rocky Mountain Association of Geologists, p. 271-294.
- Skipp, Betty, and McMannis, W.J., 1971, Geologic map of the Sedan quadrangle, Gallatin and Park Counties, Montana: U.S.G.S. Open

File Report 71-264, 2 sheets.

Sloss, L.L., and Moritz, C.A., 1951, Paleozoic stratigraphy of southwestern Montana: American Association of Petroleum Geologists Bulletin, v. 35, p. 2135-2169.

Verrall, Peter, 1955, Geology of the Horseshoe Hills Area, Montana: unpublished Ph.D. thesis, Princeton University, Princeton, New Jersey, 261 p.

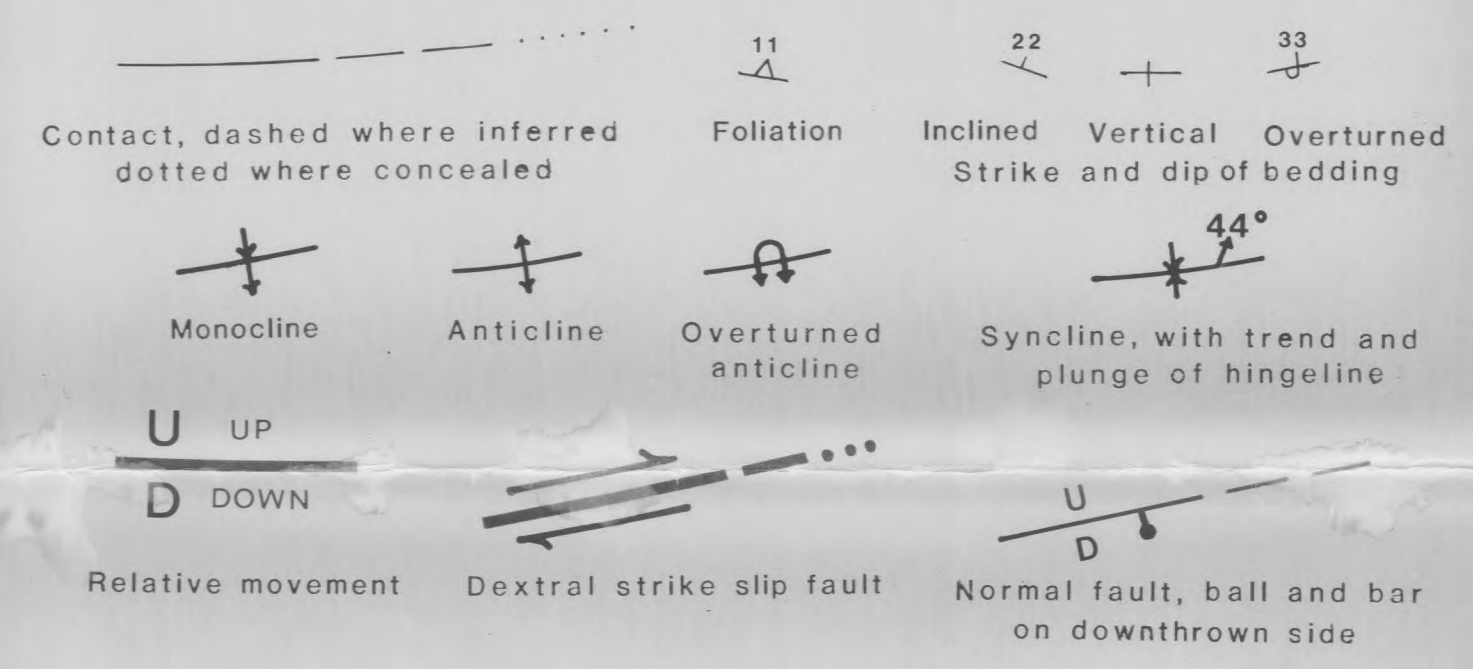
Woodward, Lee, 1981, Tectonic framework of the disturbed belt of west-central Montana: American Association of Petroleum Geologists Bulletin, v. 65, no. 2, p. 291-302.

PLATE 1 - GEOLOGIC MAP OF THE ROSS PASS FAULT ZONE



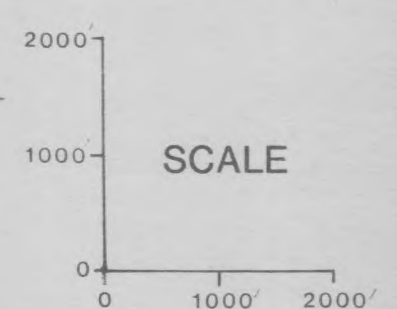
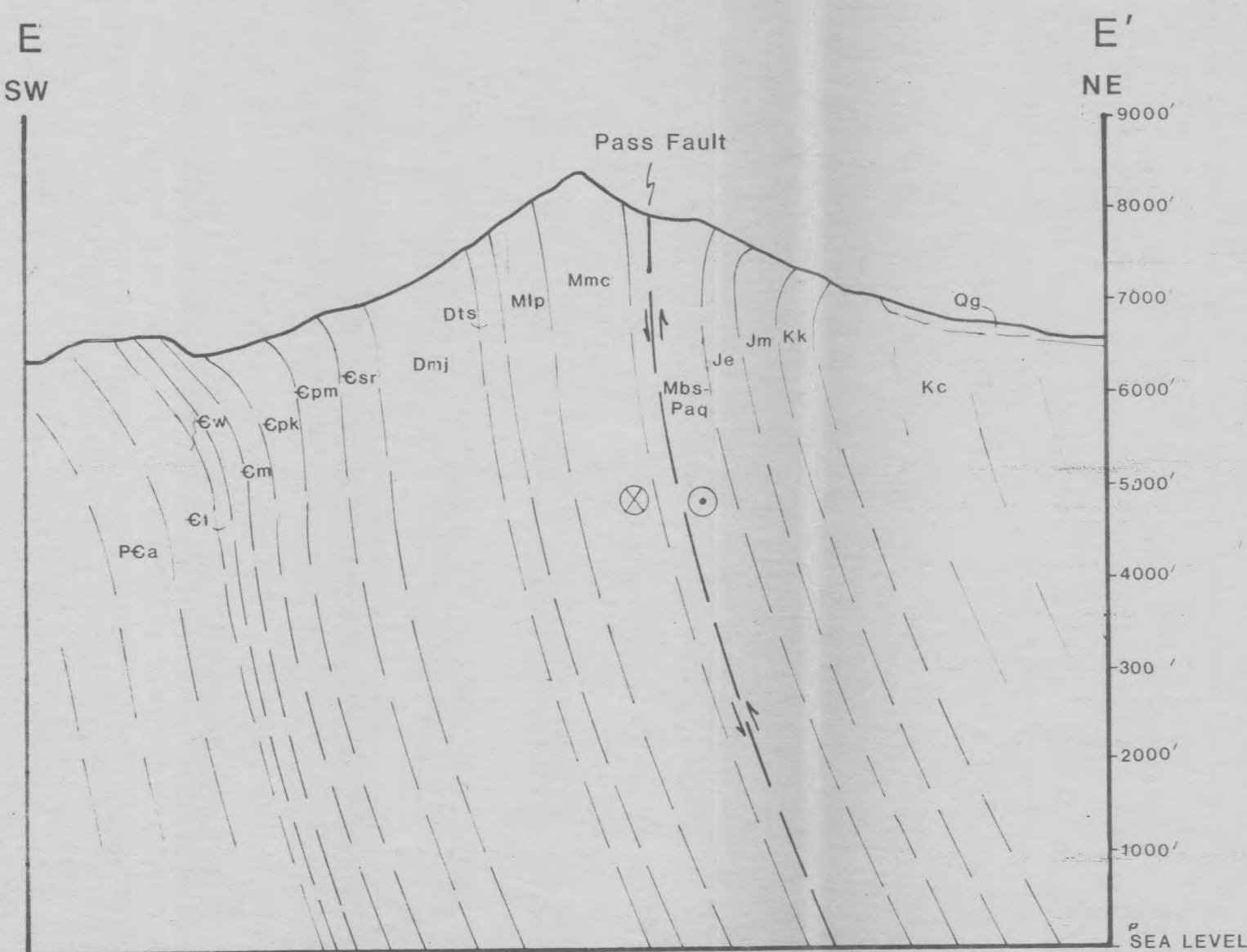
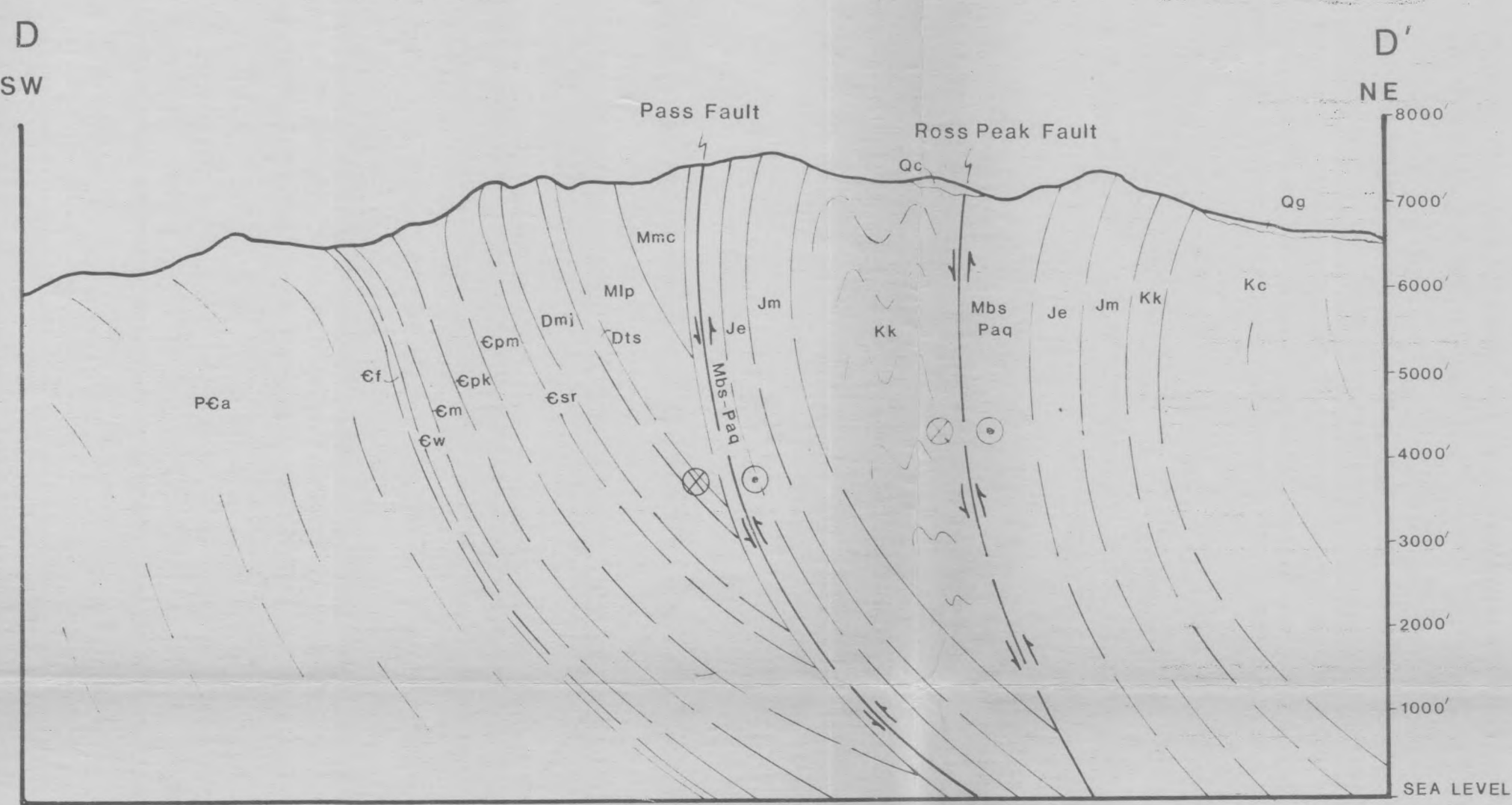
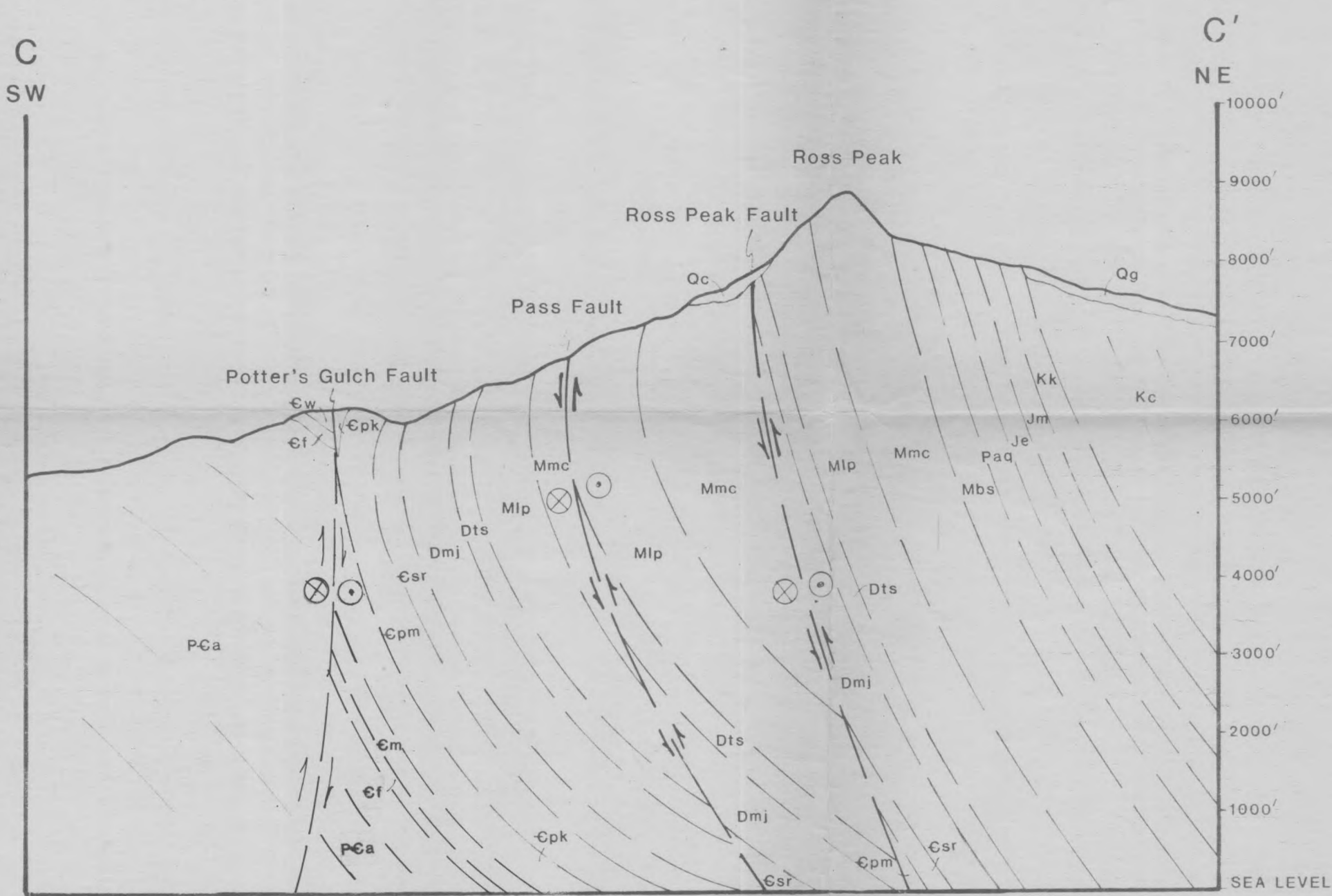
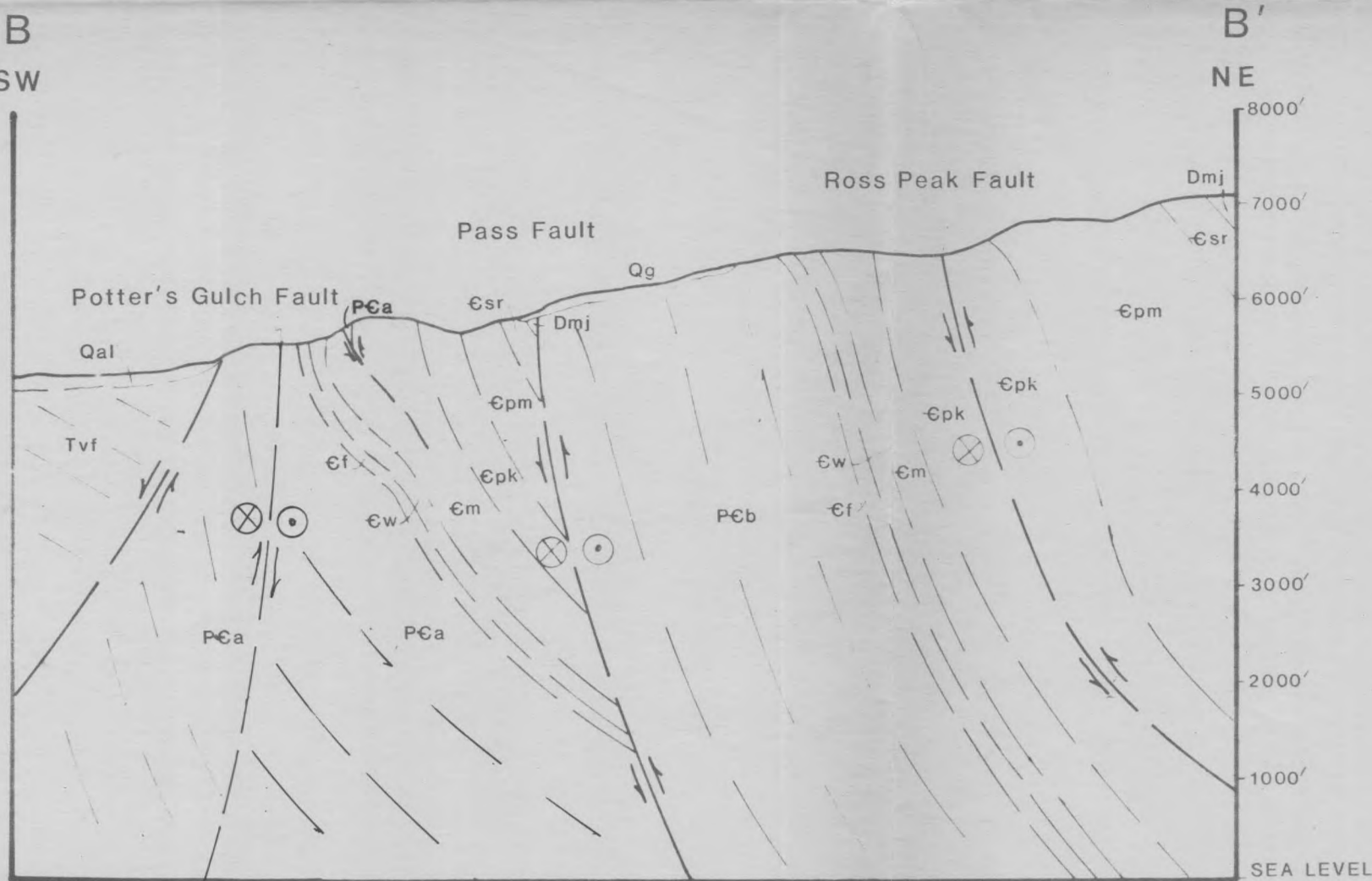
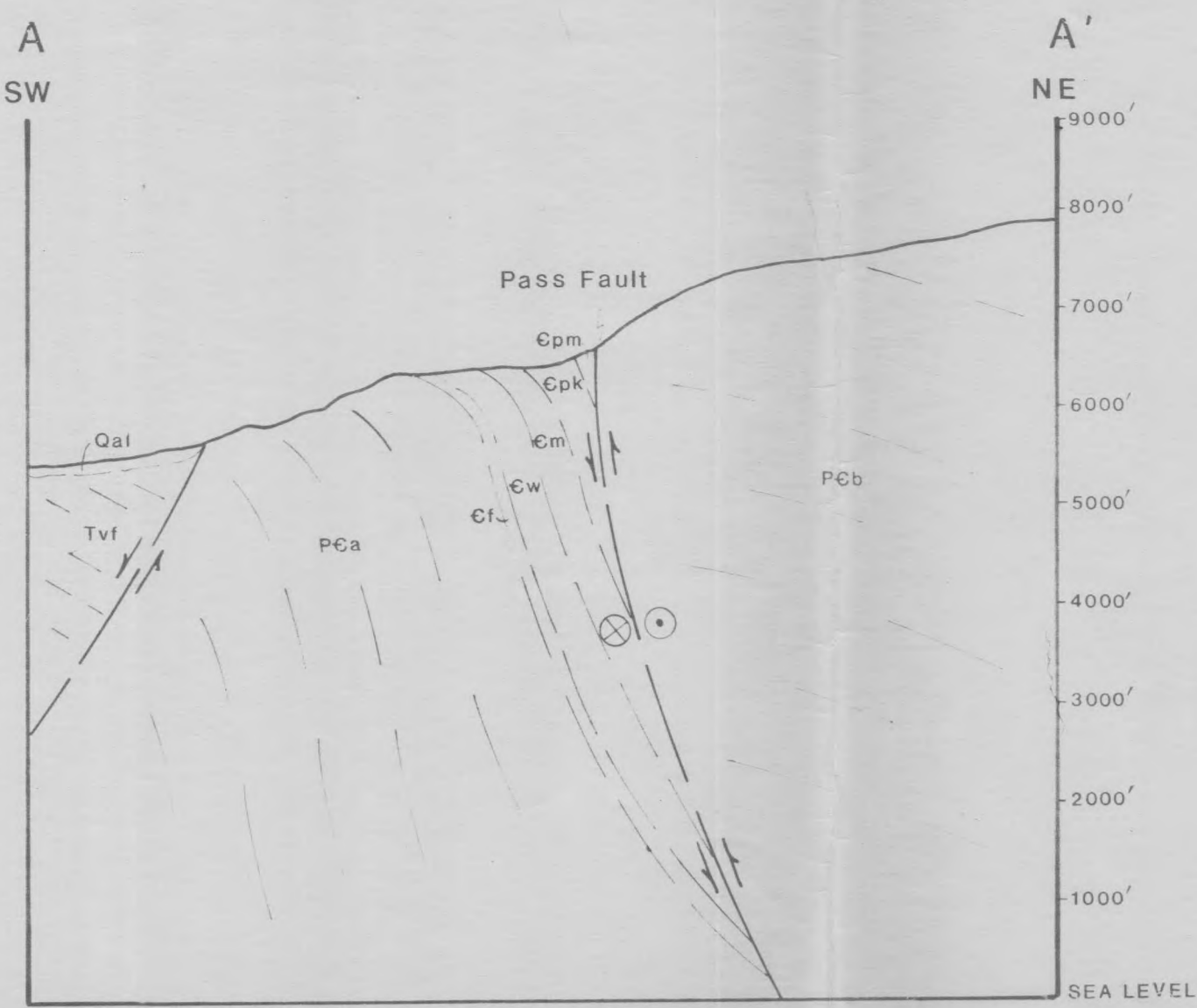
LEGEND

ERA PERIOD	Symbol	Description
CENOZOIC	Qc	Colluvium
	Qg	Glacial deposits
	Td	Dike
MESOZOIC	Kc	Colorado Group
	Kk	Kootenai fm.
	Jm	Morrison fm.
	Je	Ellis Group
	Paq	Amsden - Quadrant fms.
MISSISSIPPIAN	Mbs	Big Snowy Group
	Mmc	Mission Canyon fm.
	Mlp	Lodgepole limestone
DEVONIAN	Dts	Three Forks - Sappington fms.
	Dmj	Maywood - Jefferson fms.
	Sr	Snowy Range fm.
CAMBRIAN	Ep	Pilgrim limestone
	Ep	Park shale
	Em	Meagher limestone
	Es	Wolsey shale
PRE-CAMBRIAN	Peb	LaHood Fm. of Belt Supergroup
	Pea	Archean metamorphics



Map compiled from field mapping by Craiglow (1982-1984) and data from McMannis (1955) and Skipp and McMannis (1971).

PLATE 2 - STRUCTURE CROSS-SECTIONS



3 WKS USE 19/86
INTER [REDACTED]

MAY 03 1986

Wes

