University of Montana

ScholarWorks at University of Montana

Graduate Student Theses, Dissertations, & Professional Papers

Graduate School

1984

Structure of the Rattlesnake area west-central Montana

Ian A. Watson
The University of Montana

Follow this and additional works at: https://scholarworks.umt.edu/etd

Let us know how access to this document benefits you.

Recommended Citation

COPYRIGHT ACT OF 1976

STRUCTURE OF THE RATTLESNAKE AREA,

WEST-CENTRAL MONTANA

By

Ian A. Watson

B.S., Washington State University, 1982

Presented in partial fulfillment of the
requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1984

Approved by:

James W. Sears
Chairman, Board of Examiners

[signature]
Dean, Graduate School

_10/30/84_
Date

Watson, Ian A., M.S., September 1984   Geology

Structure of the Rattlesnake area, west-central Montana.

Director: Dr. James W. Sears

Middle Proterozoic Belt Supergroup rocks within the Rattlesnake area underwent two major phases of deformation, Late Cretaceous Laramide compression and Eocene extension. The northeast-directed Laramide compression generated a variety of deformation ranging from ductile flow to brittle flexural slip folding. Associated structures include small and large scale folds, thrust faults, and cleavage. These Laramide structures were later overprinted by Eocene extensional features which rotated and refolded large panels of rock in the area.

I have delineated three major structures within the field area; the Spring Gulch fault, the Lime Kiln fault, and the Wisherd syncline. These features represent the boundaries between three structural domains; the Spring Gulch block, the Lime Kiln block, and the Wisherd block. Distribution of structural styles within these structural domains varies from a gradational transition of ductile to brittle fabrics within the Spring Gulch block to abrupt juxtaposition of brittle and ductile fabrics across the Spring Gulch fault.

Relationships between structural terranes were controlled by a two-step history. First, northeast-directed Laramide compression formed a large anticline-syncline pair and developed both brittle and ductile fabrics. These structures were dissected by the Eocene Spring Gulch fault which juxtaposed ductile fabrics of the Spring Gulch block against brittle fabrics of the Lime Kiln block.

ACKNOWLEDGEMENTS

I am deeply indebted to Dr. James Sears, who recommended this project, for his guidance and support. His supervision and insights throughout the study were invaluable. Drs. Johnnie Moore and Andy Sheldon also deserve thanks for serving on the thesis committee and carefully reviewing the manuscript.

I would like to thank Steve Davis, Mike Whalen, Bill Brandon, and other graduate students for their helpful ideas and suggestions. Conversations with them were always enlightening, in one way or another. I also gratefully acknowledge Sped Byers for his computer assistance.

My family deserves my deepest gratitude for their support throughout my education. Their unending patience is truly appreciated.

Finally, I would like to give special thanks to Jamie Batty, whose support and encouragement during the hectic final stages of this project were invaluable.

TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Laramide orogenesis profoundly affected western Montana during Late Mesozoic to early Cenozoic times. Detailed relationships within and between thrust plates of the Laramide fold and thrust belt are poorly understood, creating serious problems in regional structural and stratigraphic interpretations. In addition, Tertiary extensional deformation overprinted many of the Laramide structures, further complicating the structural geometry. The Rattlesnake area (fig. 1) contains the boundaries of a number of proposed structural terranes and is ideal for the study of Laramide compressional and later Tertiary extensional deformation in west-central Montana. The purpose of this work is to determine structural boundaries and define structural styles within the Rattlesnake area.

Geologic Setting

The Rattlesnake area lies within the central part of the Montana fold and thrust belt (fig. 2)and is structurally bounded by the Clarkfork-Ninemile fault to the southwest, the Jocko fault to the west, and the Blackfoot thrust to the south (fig. 1). Central and western parts of the area contain major southeasterly-trending normal and thrust faults, as well as a variety of mesoscopic structures. These features are less prominent in the northeastern part of the area as deformation dies out along the gently dipping eastern limb of the Wisherd syncline.
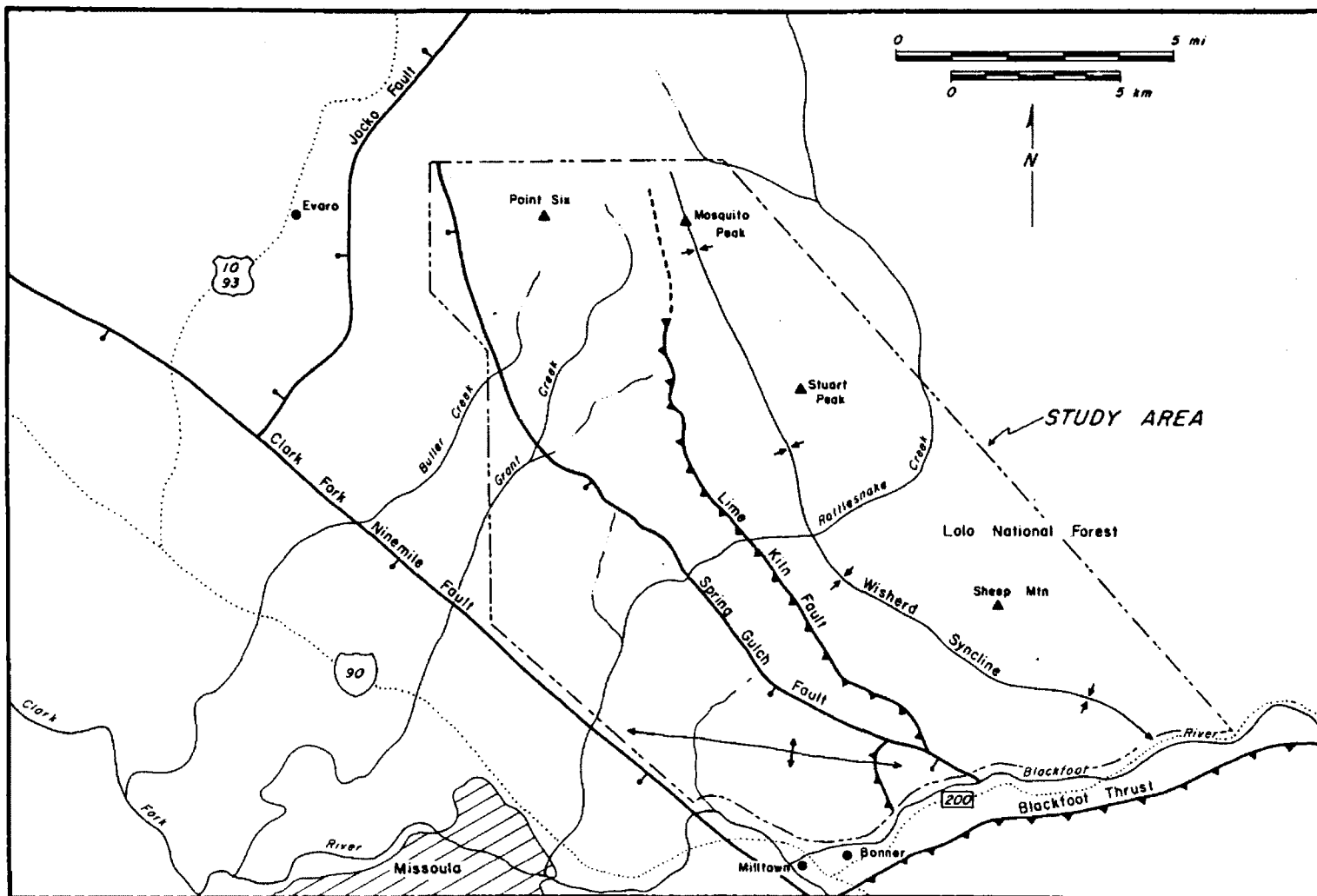
Figure 1.   Location of study area and major structural features
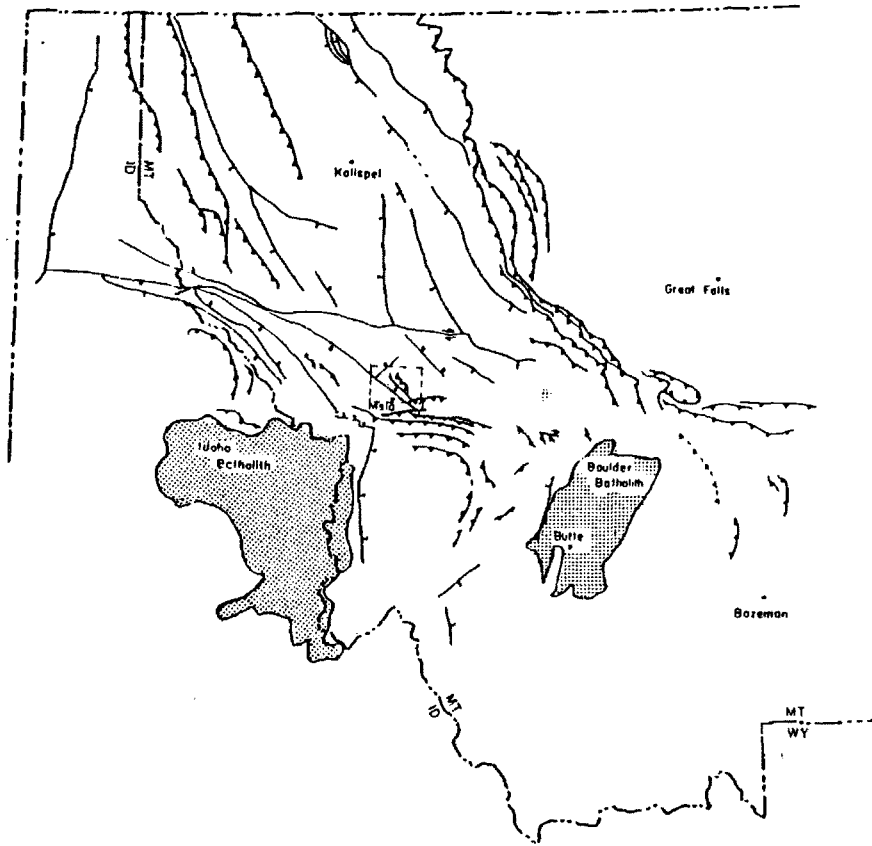
Figure 2. Generalized structural geology of northwestern
Montana and northern Idaho. Insert indicates
location of fig. 1. Modified from Winston (1982).

Rocks within the Rattlesnake area range in age from the Middle Proterozoic (Y) Helena Formation through the Middle Cambrian Silver Hill Formation. The section, approximately 8 km thick, is relatively continuous with gradational depositional contacts between the eight Proterozoic Belt formations. The Belt-Cambrian contact appears unconformable.

Regional Tectonic History

Pre-Laramide tectonic conditions, especially those surrounding Belt sedimentation, are unclear. Winston (1982) believes Precambrian basement blockfaulting controlled deposition of Proterozoic sediments and localized later compressional and extensional structures. The importance of these block faults apparently diminished during the Paleozoic, which had few deformational events and was characterized by a trailing continental margin setting (Harrison et al., 1980).

The late Cretaceous to early Eocene Laramide orogeny produced the northwest-trending fold and thrust belt of western Montana. This thrust belt, exceeding 200 km in width (Ruppel et al., 1981), consists of a series of east-directed thrust plates created by east- west compression. Harrison et al. (1980) suggests these thrust plates were translated 180 km across western Montana and northern Idaho. The age of thrust faulting, as determined from cross-cutting relationships between thrust faults and intrusions, is established at approximately 80 mya (Obradovich and Cobban, 1975) and is progressively younger from the western to the eastern part of the thrust belt (Ruppel et al., 1981).

Eocene extension created a series of northwest- trending normal and strike-slip faults which truncated many of the Laramide compressional structures. Some of these faults show up to 29 km of offset and may represent re-activated Laramide structures (Lonn, 1984; Wallace and Lidke, 1980).

Previous Work

Nelson and Dobell (1961) completed the first detailed geologic mapping in the study area when they prepared the topographic base maps and mapped the geology of the Bonner quadrangle. Wallace and Lidke (1980) later updated and expanded the Nelson and Dobell map as part of a geologic report on the Rattlesnake Wilderness Area. Much of the mapping used for Wallace and Lidke (1980) appears on several other USGS publications, including Harrison (1981), Mudge and Earhart (1979), and Wallace et al. (1978). Wallace and Lidke (1980) also defined the Rattlesnake thrust system and described various lithologies and structures within the Rattlesnake Wilderness Area. Ruppel et al. (1981) later put this work into a regional framework by describing how the various thrust plates in western Montana and east-central Idaho relate to each other. Finally, Sears (1983) suggested the area represents part of a much larger regional structure related to a major basement ramp.

STRATIGRAPHY

The Belt Supergroup, a reportedly 20 km thick sequence of Middle Proterozoic metasediments (Harrison et al., 1974), underlies much of western Montana, northern Idaho, and parts of eastern Washington. It is composed of repetitive, fine-grained clastic and carbonate sequences which are subdivided into four major divisions: (1) the Lower Belt, (2) the Ravalli Group, (3) the middle Belt carbonates, and (4) the Missoula Group (Harrison et al., 1974). While each of these divisions exhibits distinct lithologic sequences, many depositional features are consistent throughout the section. These similarities, combined with structural complexities, lateral facies changes, and diagenetic alteration, commonly obscure many of the stratigraphic relations between the Belt units. Therefore, stratigraphic correlations across the Belt basin (fig. 3) are tentative.

Phanerozoic rocks ranging from Middle Cambrian strata to Quaternary alluvium unconformably overlie the Belt in western Montana. This discontinuous section is only locally preserved with the best exposures cropping out east of Missoula.

A relatively continuous 8 km thick section ranging from the Proterozoic Helena Formation to the Cambrian Silver Hill Formation crops out within the Rattlesnake area (fig. 4). Missoula Group strata compose the bulk of this section, but middle Belt carbonates, Cambrian sedimentary rocks, and Proterozoic (Z) diabase sills are also present. These rocks generally become younger from west to east with the youngest
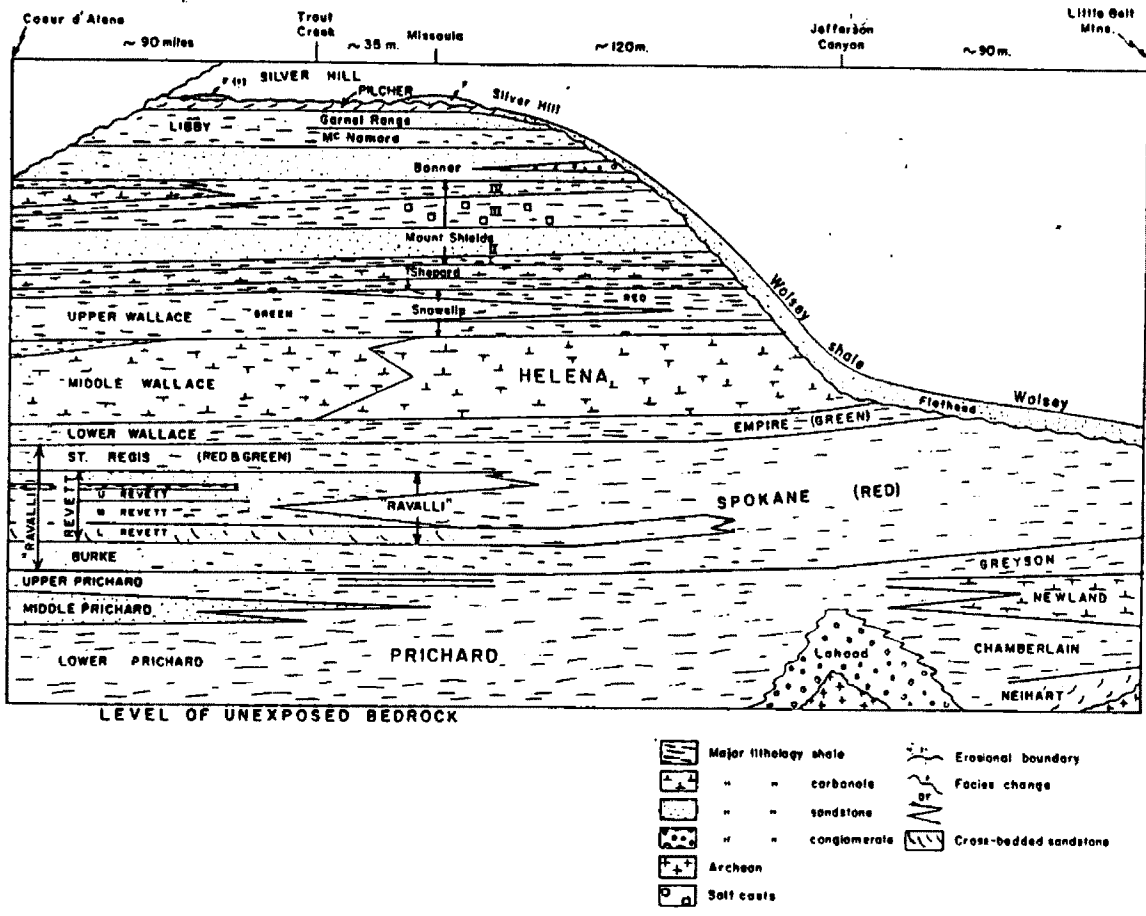
Figure 3. Schematic cross section through the Belt Basin (taken from Wehrenberg (1983))

FORMATION NAME		THICKNESS (meters)	DESCRIPTION
Silver Hill		200	Lower part dominantly reddish and greenish shale with a few qtzitic and limy interbeds. Bedding ranges from 1-5cm. Grades upward into dark gray oolitic limestone beds.
Pilcher		360	Whitish and reddish medium- to coarse-grained quartzite with 2-3% argillaceous interbeds. Bedding ranges from 10 cm-2m, with an average from 20-70cm. Festoon and planar crossbeds with hematite staining on foresets are dominant.
Garnet Range		1170	Grayish-green interbedded, impure quartzite and impure argillite. Quartzite beds vary from 2cm-1m thick, whereas argillites range 1-10cm. Sedimentary structures include hommocky cross-stratification, planar laminations, and minor cross-bedding. Abundant detrital muscovite and chlorite concentrated on bedding surfaces is distinctive.
McNamara		1200	Red and green interbedded argillites, siltites, and buff fine-grained quartzites. Argillites are dominant and identified by pure clay beds. Bedding ranges from 5mm-2m with coarse-grained beds being thicker. Mud cracks, mud chips, clayballs, water expulsion structures, salt casts, and cross-bedding are all present. Pure clay beds, abundant mud chips, and chert beds are distinctive.
Bonner		400	Pink, buff, or purple, medium- to coarse-grained feld-spathic quartzite. Beds range from 2-70cm, averaging around 20cm. Both planar and festoon cross-bedding are present, with some channeling present.
Mount Shields 1		450	Interbedded red argillite, tan-weathering siltite, and fine-grained quartzite. Argillite beds range from 1-3cm and siltite beds range from 2-5cm. Includes abundant small-scale cross-bedding, salt casts, mud cracks, and stromatolites.
Mount Shields 2		700	Buff, fine- to medium-grained feldspathic quartzite. Both cross-bedded and planar laminated beds are present. This unit is coarser grained near the base and top.
Mount Shields 3		450	Interbedded buff-weathering, medium-grained quartzite, and red argillite beds. Bedding ranges from 1-5cm with coarser-grained beds being thicker. Sedimentary structures include small-scale cross-bedding, ripple marks, and mud cracks.
Shepard		460	Dominated by green dolomite- or calcite-bearing, thinly laminated siltite and argillite beds. Bedding ranges from 1-15cm. Commonly contains oolitic beds, small stromatolites, and pyrite. Sedimentary structures include small-scale cross-bedding, mud cracks, and flaser beds.
Snowslip		1100	Interbeds of locally discontinuous beds of red argillite, siltite and quartzite. Small amounts of similar green lithologies are present. Bedding ranges from 2cm-1m with coarser-grained beds generally being thicker. Cross-bedding, ripple marks, mud cracks, and water expulsion structures are common.
Helena		3000(?)	Alternating yellowish-weathering and dark-gray weathering limestone, limy argillite, and limy siltite. Beds range from 5mm-1m. Sedimentary structures include minor cross-bedding and horizontal and vertical ribbon structures.
Base not exposed			

Middle Cambrian

Proterozoic (Y)

Figure 4. Generalized stratigraphic column from the Rattlesnake area. Thicknesses and descriptions are modified from Wallace and Lidke (1980) and Nelson and Dobell (1961).

Cambrian strata cropping out along the hinge of the Wisherd syncline in the eastern part of the area.

Depositional contacts between the Proterozoic Belt formations are gradational over many meters, creating somewhat arbitrary boundaries. Generally, I have defined the contacts as the point where the dominant rock type changes. For example, the contact between the Bonner and McNamara Formations is the point where Bonner quartzites are more dominant than McNamara argillites. I feel this is a more appropriate distinction than the first occurrence of an oxidized red bed or a reduced green bed because diagenetic overprinting may have altered red and green beds (Winston, 1983).

The Helena Formation, dominantly calcareous siltite with quartzite interbeds, is restricted to the western and southwestern regions of the field area. It represents the carbonate-rich facies equivalent of the Wallace Formation, which crops out further to the west (Harrison et al., 1974). The study area lies at the transition between the interstratified Helena and Wallace Formations. Harrison et al. (1974) identified Wallace Formation rocks 8 km to the west, while Wallace et al. (1978) found Helena Formation rocks to the east.

Wallace and Lidke (1980) assigned the middle Belt carbonate rocks within the study area to the Helena Formation on the basis of their calcite content. However, they admit both Helena and Wallace lithologies exist in the area. I concur with this decision and will also generalize all middle Belt rocks in this study as Helena formation.

Stratigraphically overlying and northeast of the Helena Formation are Missoula Group rocks, a 6100 m thick sequence of repetitive argillites and quartzites which are subdivided into seven formations in the Missoula area (fig. 4). The Missoula Group shows great variation in lithologies and dominates the field area. Contrary to Nelson and Dobell's (1961) suggestion, the upper contact of the Missoula Group appears unconformable with the overlying Cambrian strata within the area.

Small sections of Middle Cambrian Silver Hill Formation, a calcareous silty shale and limestone, crop out on some of the ridges in the central part of the study area, but are usually poorly exposed. Dutro et al. (1975) found Middle Cambrian fossil assemblages within this sequence, supporting the Silver Hill Formation classification.

Quaternary alluvium, outwash, and till lie within stream channels, floodplains, and glacial basins in the Rattlesnake area. Van der Poel (1979) and Nelson and Dobell (1961) describe these deposits in detail.

Diabase sills rich in plagioclase and augite are the only igneous rocks within the field area. These sills stratigraphically lie within the Mt. Shields Formation and are commonly altered. Just north of Bonner on Montana State Highway 200, the sills were heavily sheared and mylonitized by the Laramide Blackfoot thrust, limiting their age to pre-Laramide thrusting. Wallace and Lidke (1980) suggest an age of 750 mya based on similar sills in the Sun River area. Obradovich and Peterman (1968) support this with a 760 mya age date of similar diabase sills and dikes in the Alberton area.

Rocks within the area underwent lower greenschist facies metamorphism as established by mineral assemblages of actinolite, chlorite, epidote, and plagioclase in the diabase sills. I attempted to constrain the pressure-temperature conditions during metamorphism by examining fluid inclusions in quartz-filled tension gashes, but the inclusions were too small and gas-rich to provide useful information. However, local studies by Nelson and Dobell (1961) and Harrison et al. (1974) support the lower greenschist classification.

STRUCTURAL GEOLOGY

Late Cretaceous to Eocene compressional structures within the Rattlesnake area were later cut by Tertiary extensional faults. The Laramide compression developed northeast- trending large and small-scale folds, thrust faults, and cleavage, with deformation ranging from ductile flow to brittle fracture. These features were overprinted by Tertiary normal and strike-slip faults which rotated and refolded large panels of rock within the area.

A number of important structural features surround the study area (fig. 1). The most prominent of these is the northwest-trending Clarkfork-Ninemile fault, which bounds the field area to the southwest. Harrison et al. (1980) estimates 29 km of right-lateral strike-slip movement combined with a large component of down-to-the-south dip-slip motion for this fault. In addition, the Clarkfork-Ninemile fault is part of the Osburn-Hope fault system of the Coeur d'Alene district (Winston, 1982) and closely corresponds to the Lewis and Clark line, a major structural feature which transects western Montana. The Jocko fault, a down-to-the-west normal fault, represents a prominent extensional structure just west of the field area. Although the amount of displacement is not well-documented, the Jocko fault truncates major structures, such as the Purcell anticlinorium, and juxtaposes middle Belt rocks against Missoula Group strata. The final significant structural feature which borders the field area is the Blackfoot thrust, a Laramide age thrust fault located southeast of the study area. This

fault, which marks the boundary between the Rattlesnake area and the Sapphire plate, lies at a structurally higher level than structures within the study area. Both the Jocko and Blackfoot faults are cut by the apparently younger Clarkfork-Ninemile fault.

Ages for these structures are mostly extrapolated from other studies in western Montana which show similar relationships between compressional and extensional events. The only age constraints on deformation within the study area are the Cambrian rocks that are cleaved and folded, establishing maximum age of compression, and the Quaternary sediment overlying the extensional faults, placing a minimum limit on extension. However, Sears (1983) can trace similar compressional structures into Early Cretaceous strata east of the field area, confining the compressional deformation to post-Early Cretaceous. Likewise, Constenius (1982) attributes much of the Tertiary-filled basin development in western Montana to related extensional deformation, establishing a minimum age of Eocene for extension.

Below I shall examine the structures within the Rattlesnake area from a number of perspectives. First, I will describe and interpret the deformational properties of the rocks and their resultant structural fabrics. This information is then incorporated in discussions of the structural geometry and major structural elements. Finally, I will propose a developmental model for the structures within the study area and discuss the regional implications of my conclusions.

Differential Response to Stress between Rock Types

The response to stress differs greatly in the various stratigraphic units throughout the study area. In part, this controls the distribution of structural styles, localizes deformation, and helps explain the structural history of the area.

Variation in stress response is directly related to the competence contrast between rock units (Ramberg, 1964). Generally, differences in competence, which are controlled primarily by grain size and mineralogy, localize deformation in the less competent layers while leaving the more competent layers relatively undeformed (Hobbs et al., 1976). Therefore, coarser-grained quartzose units behave much more competently and show less small-scale deformation than the argillaceous units under similar conditions of deformation.

I subdivided the rocks in this study into three main groups based on their response to stress (fig. 5). These groups are interlayered, creating a repetitive sequence of rigid structural beams and relatively incompetent layers. Variation of stress response within individual formations creates some inconsistencies, but I believe the classification is valid on the large scale.

Group one, consisting of the Helena, Shepard, Garnet Range, and Silver Hill Formations, takes up much of the small-scale deformation within the area. In general, the relatively incompetent members have abundant fine-grained beds and compositional weaknesses, such as detrital phyllosilicates aligned parallel to bedding, which deform more

COMPETENCE	Group 3	Pilcher Formation Bonner Formation Mt. Shields 2 Formation
	Group 2	McNamara Formation Mt. Shields 3 Formation Mt. Shields 1 Formation Snowslip Formation
	Group 1	Silver Hill Formation Garnet Range Formation Shepard Formation Helena Formation

Figure 5. Classification of different lithologies based on response to stress.

easily than surrounding units. Mesoscopic structures include shear cleavages, slaty cleavage, drag folds, and kink folds.

The calcareous Helena and Shepard Formations localize most of the deformation in the lower part of the section by the development of a pervasive shear cleavage. Lonn (1984) noted similar relationships in the Tarkio area, where he suggested these units serve as major glide zones. The calcareous composition is a likely reason for the concentration of strain in the Helena and Shepard Formations, because calcite and dolomite readily deform under high lithostatic loads (Groshong, 1972).

In the upper part of the section, the Garnet Range Formation localizes much of the deformation through a series of parasitic folds and cleaved beds. Detrital muscovite and chlorite on bedding surfaces provide excellent glide surfaces for small-scale flexural slip folding. Nelson and Dobell (1961) attributed the high strain in this unit to the difference in competence between the Garnet Range Formation and the overlying Pilcher Formation.

Group two, which includes the Snowslip, Mt. Shields 1, Mt. Shields 3, and McNamara Formations, represents an intermediate level of competence in the study area. Some of the local deformation is concentrated in these units, but not to the extent of group one members. The average composition of group two units is more quartzose than group one, but much finer-grained than group three. Small-scale drag folds, thrust faults, cleaved beds, and slickensides are the main mesoscopic structures in group two.

Group three, the most competent rocks within the study area, consists of the Mt. Shields 2, Bonner, and Pilcher Formations. For the most part, these units act as "rigid" sheets and localize very little of the small-scale deformation. They are dominantly medium to coarse-grained, recrystallized quartzites which show minor flexural slip folding and no penetrative deformation.

Structural Styles

A complete range of structural styles from ductile flow to brittle flexural slip folding occurs within the study area. Where uninterrupted by faulting, the change from ductile to brittle deformation is gradational over a small transition zone. Therefore I shall subdivide the structural styles into two major groups, a ductile zone and a brittle zone, which are separated by a small transition zone (fig. 6).

Determination of structural style is based both on field observations of mesoscopic structures and microstructural analysis. Cleavage development, type of folding, and associated structures are the primary tools for classification. While boundaries between different structural styles are somewhat arbitrary, they are based on features generally accepted as brittle and ductile structures (Wilson, 1982; Ramsay, 1967; and Hobbs et al., 1976).

Ductile Deformation

The Helena, Shepard, and lower Snowslip Formations, which are confined to the western part of the field area, contain most of the ductile deformation. As previously discussed, these units had compositional weaknesses which localized deformation. The ductile zone is easterly- bounded by a transitional zone in the southern part of the field area and by the Spring Gulch fault in the northern part.
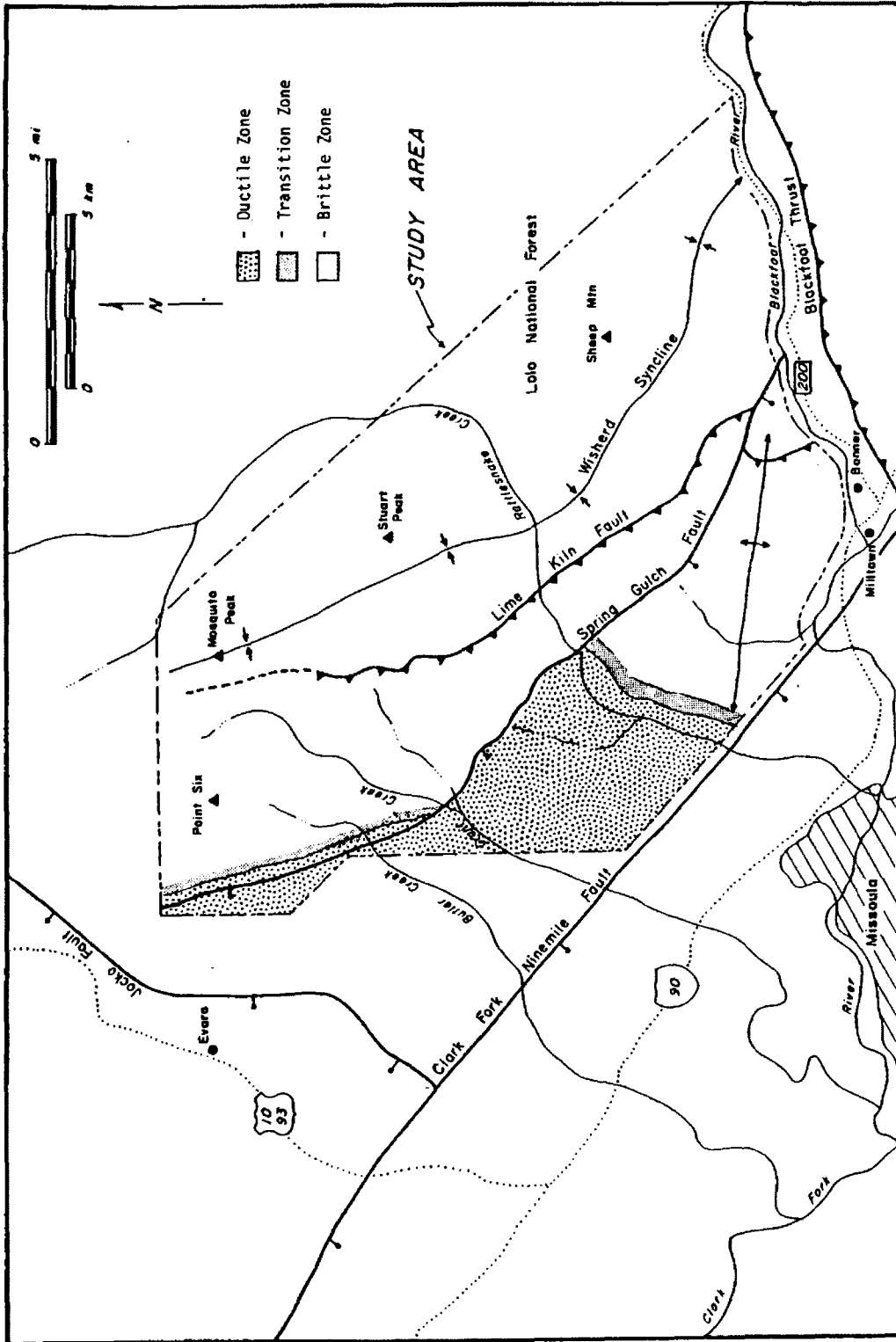
19

Figure 6. Location of brittle, ductile, and transitional fabrics within the Rattlesnake area.

A penetrative shear cleavage dominates the structural fabric within the ductile zone. This cleavage is often sub-parallel to bedding and usually contains a stretching lineation, which is defined by elongated calcite or pyrite along cleavage planes. In general, the stretched calcite grains occur in the Helena Formation while the elongated pyrite crystals are in the Shepard Formation. Spacing between cleavage planes ranges from 2-8 mm in fine-grained beds to 3-4 cm in the more quartzitic layers. Some quartzites lack the cleavage entirely. Where cleavage does cross quartzitic beds it is convergently refracted. Ductile deformation is further shown by irregular curved intersections of bedding and cleavage (Hansen, 1971).

Folding of bedding and cleavage is common in the ductile zone. Sheath folds, which are conical in shape, deform both bedding and cleavage into oval-shaped folds. These relatively rare features are usually 15-50 cm in length and are concentrated in fine-grained calcareous beds. A more common type of folding of shear cleavage is normal kink folding (terminology after Wilson,1982). Most often, the 1-10 cm amplitude kink folds are asymmetric-to-the-northeast single folds, but conjugate sets are present in the Spring Gulch area.

Both normal and thrust faults occur in the ductile zone. Small-scale thrust faults, which are fairly common, show minor offset (usually less than 1 m) and are both east and west-directed. These faults usually lack well-developed slickensides. Normal faults are rare, show little offset on the outcrop scale, and are commonly localized over earlier kink folds.

Microstructural features in the ductile zone are similar to those observed on the mesoscopic scale. The rocks are penetratively deformed by a strong cleavage which stretched and aligned calcite and phyllosilicate grains. Bedding is indistinct because of re-orientation of calcite and phyllosilicates grains into cleavage planes. In addition, secondary calcite has recrystallized along cleavage planes, further obscuring bedding. Bedding and cleavage are deformed by kink folds, microthrusts, and isoclinal folds with thickened hinges on the thin section scale.

Near the transition zone cleavage intensity decreases and becomes more widely spaced (=1cm). This is accompanied by linear bedding-cleavage intersections, increased angles between bedding and cleavage, and increased frequency of mesoscopic folding of bedding.

Brittle Deformation

Brittle deformation, the dominant structural style within most Missoula Group rocks, controls the fabric in the eastern three quarters of the field area (fig. 6). Flexural slip folds, thrust faults, and associated cleavage are the major mesoscopic structures within the brittle zone. These features vary greatly in intensity. Abundant mesoscopic folds and cleaved beds are common west of the Wisherd syncline, but these structures abruptly decrease to the east until rocks in the easternmost part of the study area are virtually undeformed on the outcrop scale.

Most of the bedding folds within the brittle zone, which vary in height from 1cm-50m, are asymmetrical and have close to tight interlimb angles. The fine-grained rocks are usually more tightly folded than the coarse- grained strata. The majority of the folds in the brittle zone are parasitic folds of the Wisherd syncline, but others are related to small-scale thrust faults. These folds are often well-preserved in hanging wall anticline and footwall syncline pairs. As in the ductile zone, most thrust faults dip to the west, but east-dipping thrusts are present. Slickensides along bedding planes, caused by interbed slip during folding, are common throughout the brittle zone. In many of the coarser- grained rocks, this is the only observable deformation on the outcrop scale. Also associated with folding in coarse-grained beds are sigmoidal en echelon tension gashes. These range in size from 3-15 cm long and are infilled with secondary quartz.

Cleavage in the brittle zone is mostly fracture cleavage, but slaty cleavage is present in pelitic beds. Both the fracture and slaty cleavages are axial planar, but show cleavage refraction. Convergent cleavage fans in more competent layers are the result of this refraction. Spacing of slaty cleavage varies from 1-5 mm, with closer spacing occurring in finer-grained beds. A similar response to grain size occurs in the fracture cleavage, where spacing between cleavage planes varies from 5 mm-5 cm. Minor crenulation cleavage, which aligns detrital muscovite and chlorite on bedding surfaces, occurs in the Garnet Range Formation. Spacing of this cleavage varies from 1-2 mm.

Microstructures in the brittle zone show the same structural styles and variation in style as the mesoscopic structures. Most rocks lack penetrative slaty cleavage, but do exhibit convergently refracted fracture cleavage. Alignment of chlorite and muscovite grains along cleavage planes defines the fracture and slaty cleavages. Quartz grains in the matrix and quartzose beds usually remain undeformed as cleavage is refracted around them. Overprinting the fracture and slaty cleavage is a crenulation cleavage, which also aligns muscovite and chlorite grains. The crenulation cleavage is much less penetrative than the fracture and slaty cleavages, as evidenced by more abundant refraction around quartz grains. Small-scale thrust faults and associated folds also occur on the microscopic scale.

A decrease in strain from west to east within the brittle zone is also recognizable on the microscopic scale. West of the Wisherd syncline fracture cleavage is strongly developed, transposing many primary sedimentary features. However, samples collected east of the Wisherd syncline commonly show relatively undeformed mud cracks, graded beds, and tangential cross-lamination.

Transitional Zone

The transitional zone represents a narrow segment of rocks whose fabric contains both brittle and ductile structures. Located between the brittle and ductile zones (fig. 6), it is only well-exposed in the southern part of the study area. Structures within the transitional zone are intermediate and gradational between the brittle and ductile

zones. The transition is well-exposed in the Woods Gulch area.

Interpretations

Both the brittle and ductile structural styles in the study area are a response to the same northeast-directed compressive stress. The gradational nature between the two deformation zones strongly suggests this.   In the ductile zone, the stress is concentrated as simple shear in relatively incompetent rock units. As rock competence increases in the brittle zone, the stress becomes dominated by pure shear.

Mesoscopic and microscopic structures within the ductile zone provide the best evidence for ductile deformation resulting from a northeast-directed shear stress.   For example, the shear cleavage exhibits a non-linear intersection with bedding. This suggests bedding acted passively as the rocks ductiley "flowed" along cleavage planes. Flowage is also evident in the microfabrics where some of the calcite and mica grains have flowed around more resistant quartz grains.   Other structures, such as normal kink folds (Wilson, 1982) and sheath folds (Cobbold and Quinquis, 1980), are diagnostic of high shear environments. Cobbold and Quinquis (1980) suggest a shear strain of 10 for the generation of sheath folds. Finally, stretching lineations on cleavage planes in the Helena and Shepard Formations establish a northeast direction of shearing.

Pure shear rather than simple shear controls deformation within the brittle zone.   Similar style flexural slip folding, axial planar cleavage development, and thrust faulting are the main responses to the

stress. All three types of structures have orientations which relate them to each other; and to the same deformational event. In addition, these orientations are fairly consistent with the stretching lineations in the ductile zone, suggesting the same northeast-directed stress is responsible for both deformational styles.

Structural Geometry

The structural geometry within the field area is controlled by the Spring Gulch fault, the Lime Kiln fault, and the Wisherd syncline (fig. 7). Both Laramide compression and later Tertiary extension are represented in these structures; their relationships to each other and to the rocks between them delineates much of the structural history of the area.

I have divided the field area into structural domains, used stereonet and cross-section data to support these divisions, and compiled a structural synthesis combining the data. My interpretations differ from others previously presented (Wallace and Lidke, 1980; Nelson and Dobell, 1961), but a number of lines of evidence support their validity.

Structural Domains

The study area is divided into three major structural domains: 1) the Spring Gulch block; 2) the Lime Kiln block; and 3) the Wisherd block (fig. 7). These blocks are structurally separated from each other by the Spring Gulch and Lime Kiln faults and are characterized by a combination of structural styles and stratigraphic relations. In the northern part of the area, the distinction between the Lime Kiln and Wisherd blocks is unclear as the bounding fault, the Lime Kiln fault, dies out into a syncline. Below are descriptions of the various
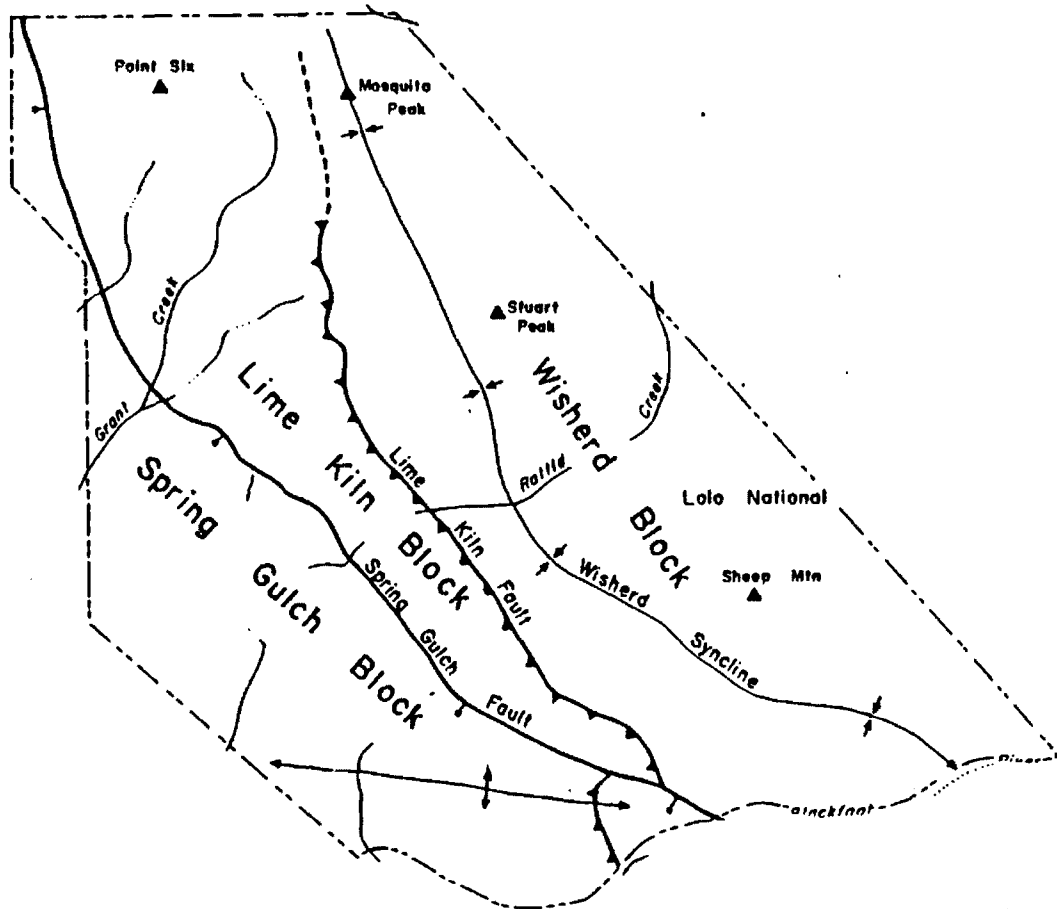
Figure 7. Location of major structural terranes and structural elements within the Rattlesnake area.

structural domains and their bounding faults.

The Spring Gulch block, the southernmost domain, is fault-bounded within the field area by the Clarkfork-Ninemile fault to the southwest and the Spring Gulch fault to the northeast. In addition, it is probably bounded to the northeast by the Jocko fault and to the southeast by the Blackfoot thrust, but these relations are not seen within the study area. Although dominated to the west by Helena Formation rocks, the Spring Gulch block contains a continuous west-dipping section of Belt rocks ranging from the Helena Formation to the McNamara Formation. Structural style within the Spring Gulch block varies from ductile deformation in the western part to brittle flexural slip folding in the eastern regions. In fact, almost all the ductile deformation within the study area is contained in the Spring Gulch block.

In the southern part of the Spring Gulch block, the rocks are doubly plunging and refolded into the Bonner Mountain antiform (terminology modified from Nelson and Dobell 1961). This west-northwest trending fold (N75W) represents the only major structural feature within the study area which does not plunge consistently to the south or southeast. In addition, the general plunge direction of the Spring Gulch block is northerly.

The Spring Gulch fault, which separates the Spring Gulch and Lime Kiln blocks, is a steep , west-dipping normal fault which may have some strike-slip movement on it. A three point solution indicates the fault dips 70 degrees to the southwest near Grant Creek. Although created during Eocene extension, the Spring Gulch fault has the same north to

northwest-trending orientation as Laramide thrust faults and folds in the study area, but is more steeply dipping. This suggests the compressional fabric influenced the placement of later extensional structures. Similar relationships were found by Lonn (1984) and Constenius (1982).

The central domain, the Lime Kiln block, lies between the Spring Gulch fault and the Lime Kiln fault (fig. 7). The intersection of the Spring Gulch and Lime Kiln faults defines the southeastern limit of this block. Rocks within the Lime Kiln block range from the Shepard to McNamara Formations and show little ductile deformation, except near the Spring Gulch fault in the northern part of the area. Instead, deformation is dominated by small-scale thrust faults and south to southeasterly plunging flexural slip folds. For the most part, the south-dipping units within the Lime Kiln block are overturned. Exceptions to this rule lie along the ridge between Point Six and Mosquito Peak, where beds are approximately vertical.

The Lime Kiln fault is a west-dipping thrust fault with relatively minor displacement (less than 800 m). It is offset by the later Spring Gulch fault to the south and dies out up plunge into a syncline to the north. Although the Lime Kiln fault has a steep dip (about 55 from three point solution near Rattlesnake Creek), I interpret it as a thrust fault which was steepened by later rotation; a process common near the central parts of orogenic belts (Coward, 1983).

The Wisherd block lies northeast of the Lime Kiln fault. Strata ranging from the Mt. Shields Formation to the Silver Hill Formation crops out in this block, but the Garnet Range and McNamara Formations

are the dominant units exposed. Most of the deformation in this domain is related to the Wisherd syncline, a large south to southeasterly plunging structure. Exclusively brittle deformation occurs in this block, with small-scale flexural slip folds, thrust faults, and associated local cleavage representing the major mesoscopic structures. As previously mentioned, the intensity of deformation decreases to a very low level near the eastern part of the Wisherd block. This approximately corresponds to the east limb of the Wisherd syncline.

Stereonet Data

Stereographic projections of mesoscopic structural data show distinctions between the various blocks and variation within individual blocks. Over 2500 attitude readings of bedding, cleavage, bedding-cleavage intersections, fold axes, and slickensides were collected during field work. This data was mainly plotted using a computer program (Achuff, 1981), but some was plotted by hand. In general, structural data is subdivided into pi diagrams of bedding, pi diagrams of cleavage, and plots of lineations, which include both bedding-cleavage intersections and axes of mesoscopic folds.

Pi diagrams of bedding (fig. 8) and plots of lineations (fig. 9) outline the structural plunge of the domains and support the difference between the Spring Gulch block and the Lime Kiln block. Structures within the Spring Gulch block are dominantly plunging to the north, whereas the structures in the adjacent Lime Kiln block are south to southeasterly plunging. Assuming that the same northeast-directed
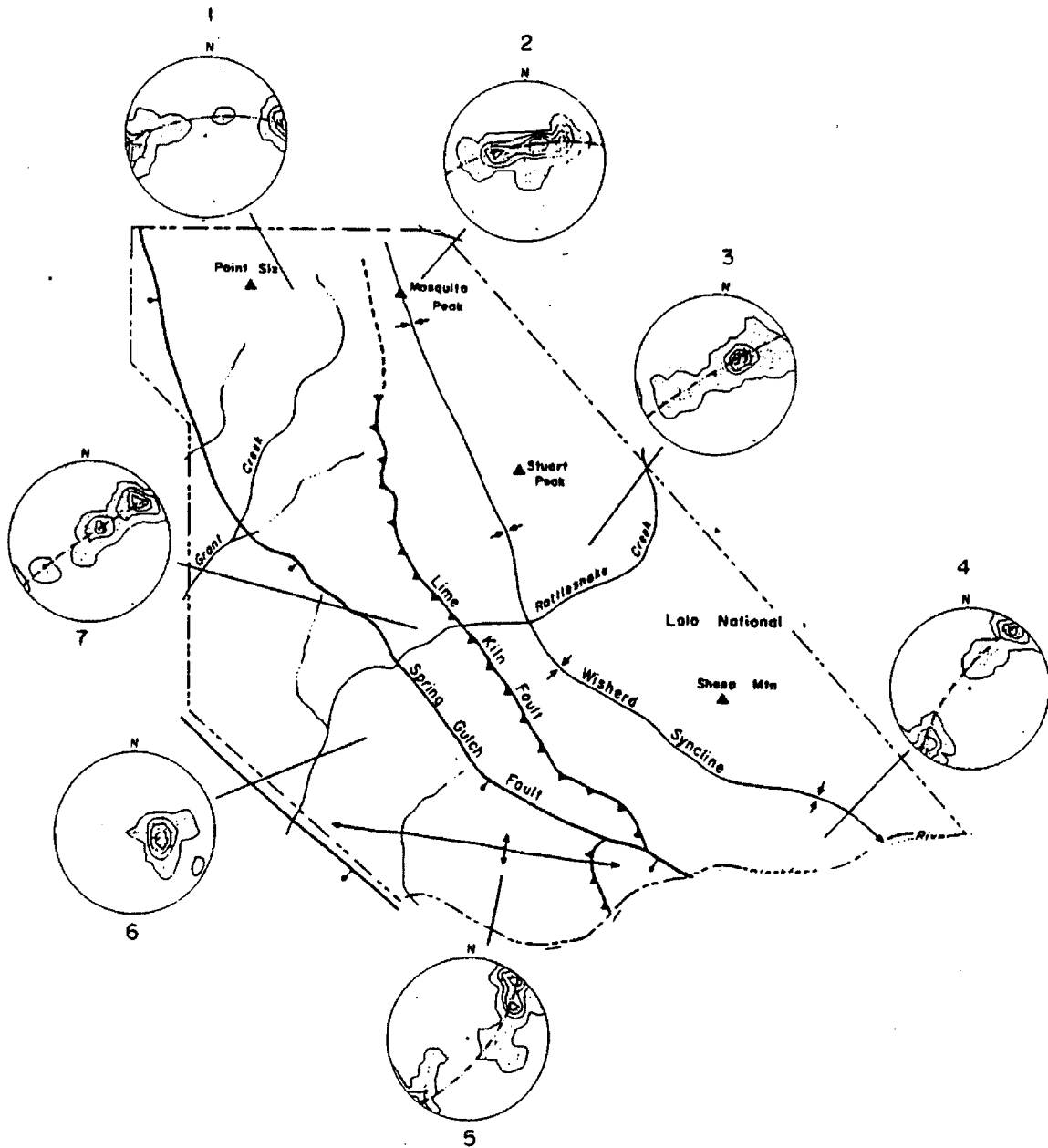
Figure 8. Pi diagrams of bedding within the various structural terranes. Parameters for plots outlined in Appendix A.
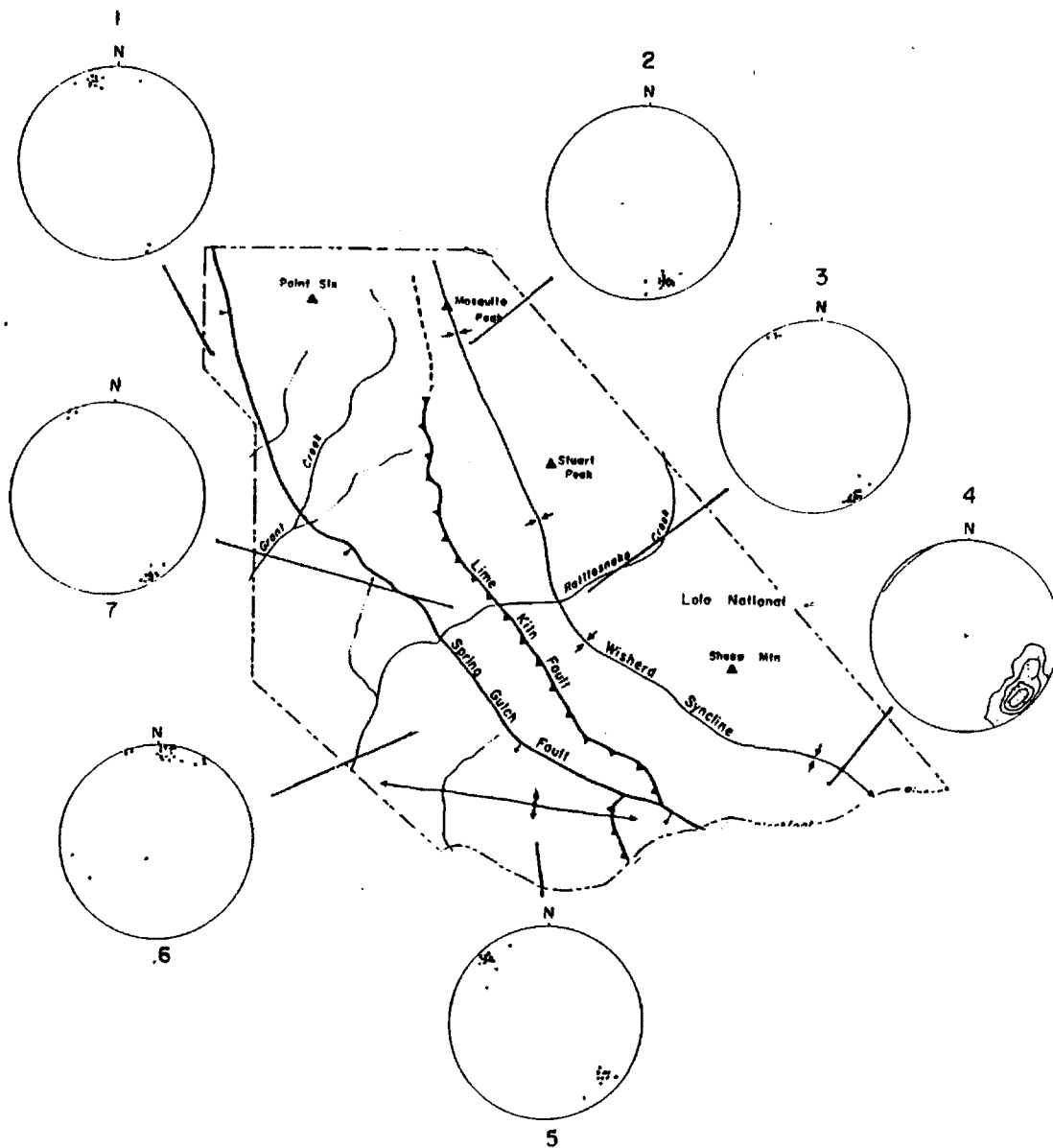
Figure 9. Plots of lineations within the various structural terranes. Lineations include both bedding-cleavage intersections and fold hinges. Parameters for plots outlined in Appendix A.

Laramide compressional event formed fabrics in both rocks, the difference in plunge orientation suggests the Spring Gulch block was rotated by the later Spring Gulch fault.

Conversely, plunge between the Lime Kiln block and the Wisherd block is fairly consistent, suggesting little to no post-Laramide rotation along the Lime Kiln fault. I propose the lack of rotation is due to a small amount of offset (less than 800 m) along the Lime Kiln fault, which would limit the amount of rotation possible. Cross-sections also support this theory.

A systematic variation in plunge within the Lime Kiln and Wisherd blocks is also delineated by pi diagrams of bedding and plots of fold hinges. In the northernmost part of the field area, where the Lime Kiln and Wisherd blocks are not separated by the Lime Kiln fault, the mean plunge direction consistently trends S12E and plunges 18 SE. Further south, along Rattlesnake Creek, the plunge flattens and the trend becomes more southeasterly (S32E/6 SE). Still further south, along the Blackfoot River, the plunge direction trends even more easterly and the plunge again becomes steeper (S49E/14 SE). Similar relations within the Spring Gulch block are uncertain.

Pi diagrams of cleavage further support rotation of the Spring Gulch block along the Spring Gulch fault (fig. 10). The cleavage of the Spring Gulch block has horizontal orientations and was folded by north-plunging kink folds. In contrast, cleavage orientations in the Lime Kiln and Wisherd blocks are close to vertical and are not folded. Most of the variation observed in these blocks is attributed to cleavage refraction; thus the rotation is post-cleavage development.
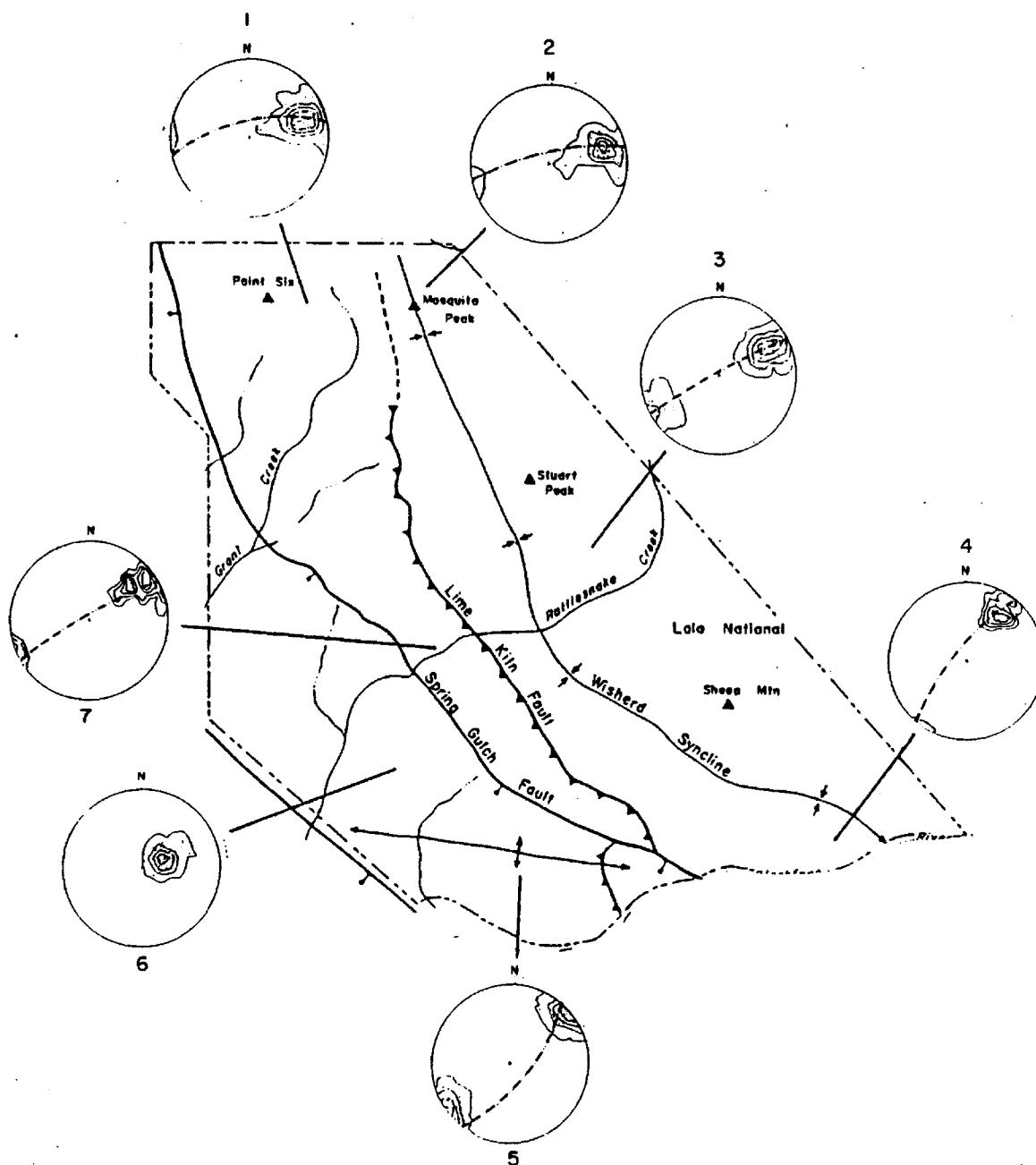
Figure 10. Pi diagrams of cleavage within the various structural terranes. Parameters for plots outlined in Appendix A.

Pi diagrams of cleavage confirm the change in regional plunge in the Lime Kiln and Wisherd blocks suggested by the bedding data. Again, the cleavage orientation changes from a dominantly north-south trend (S15E) in the northern part of the study area to a southeasterly trend (S45E) along the Blackfoot River further south. The amount of plunge is difficult to determine from cleavage data.

All three types of mesoscopic data analyzed have orientations similar to each other and to the large scale structures in the study area. This implies there was one major east to northeasterly-directed deformational event which produced folding, thrust faulting, and associated cleavage development. Northeast-trending slickensides along bedding planes, which should parallel the direction of compression, also support an east to northeasterly-directed stress. Apparently fabrics created by this stress were later rotated and deformed in the Spring Gulch block, but not in the Lime Kiln and Wisherd blocks.

Cross-sections

Cross-sections provide another method for analysis of relationships between the three structural blocks. I constructed a series of balanced cross-sections using guidelines proposed by Dahlstrom (1969) to show how the structure varies from north to south within the study area. Because the rocks in the Lime Kiln and Wisherd blocks are plunging to the south, structurally higher levels are shown in the southern parts of the study area. This is partly counterbalanced by lower topography to the south, but not entirely. Figures 11-14 mainly show relationships between the

Figure 11. A-A'   Refer to Plate 1 for location of section line. No vertical exaggeration

Figure 12. B-B'   Refer to Plate 1 for location of section line. No vertical exaggeration

Figure 13. C-C' Refer to Plate 1 for location of section line.

No vertical exaggeration
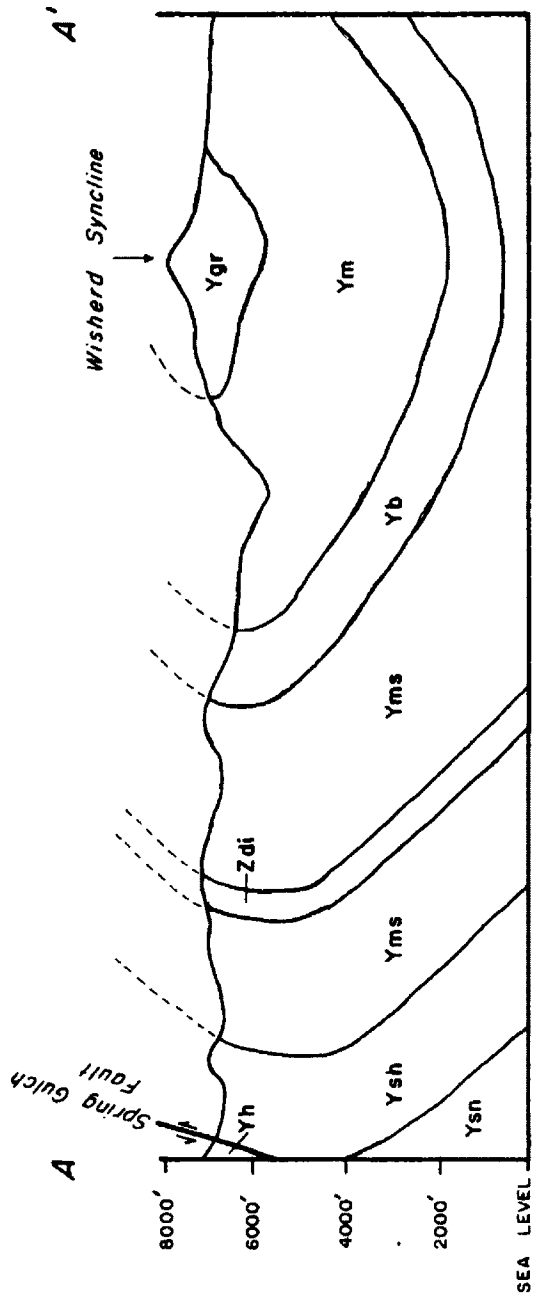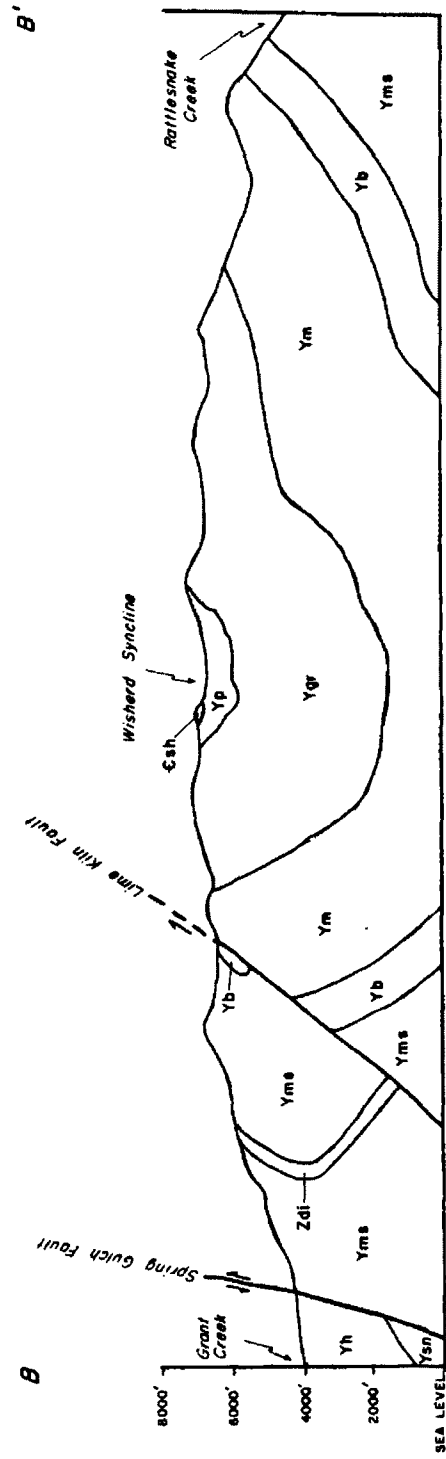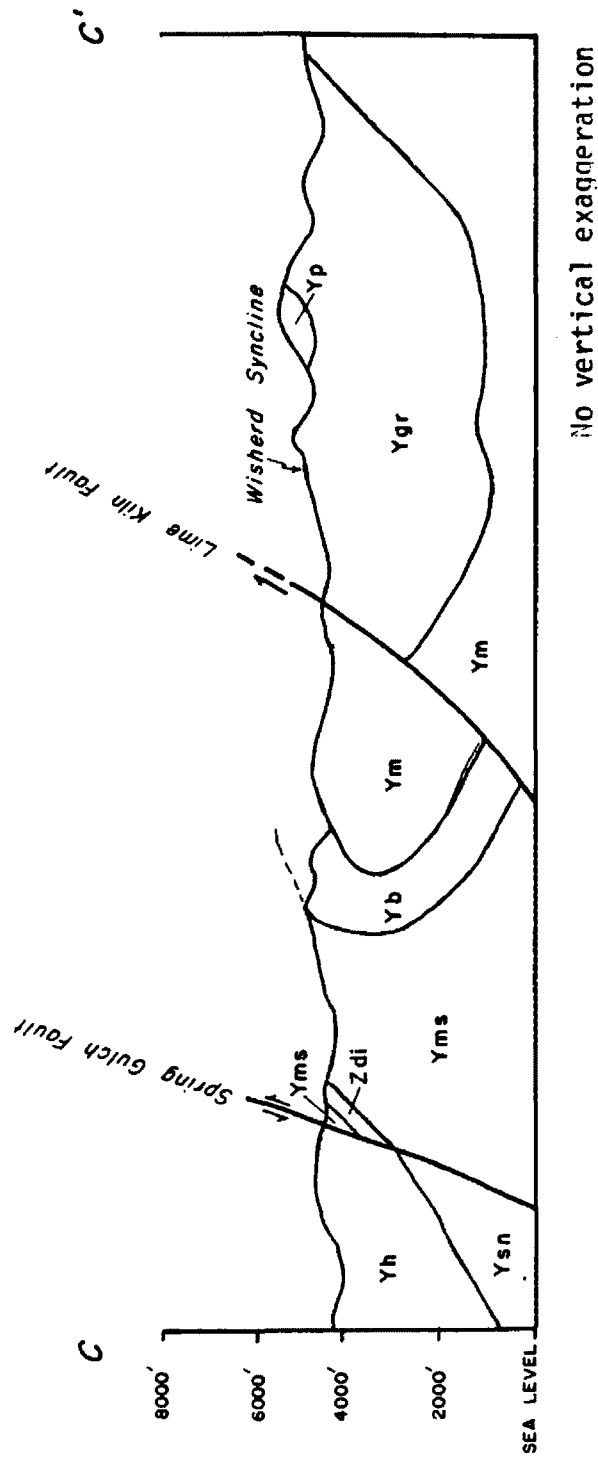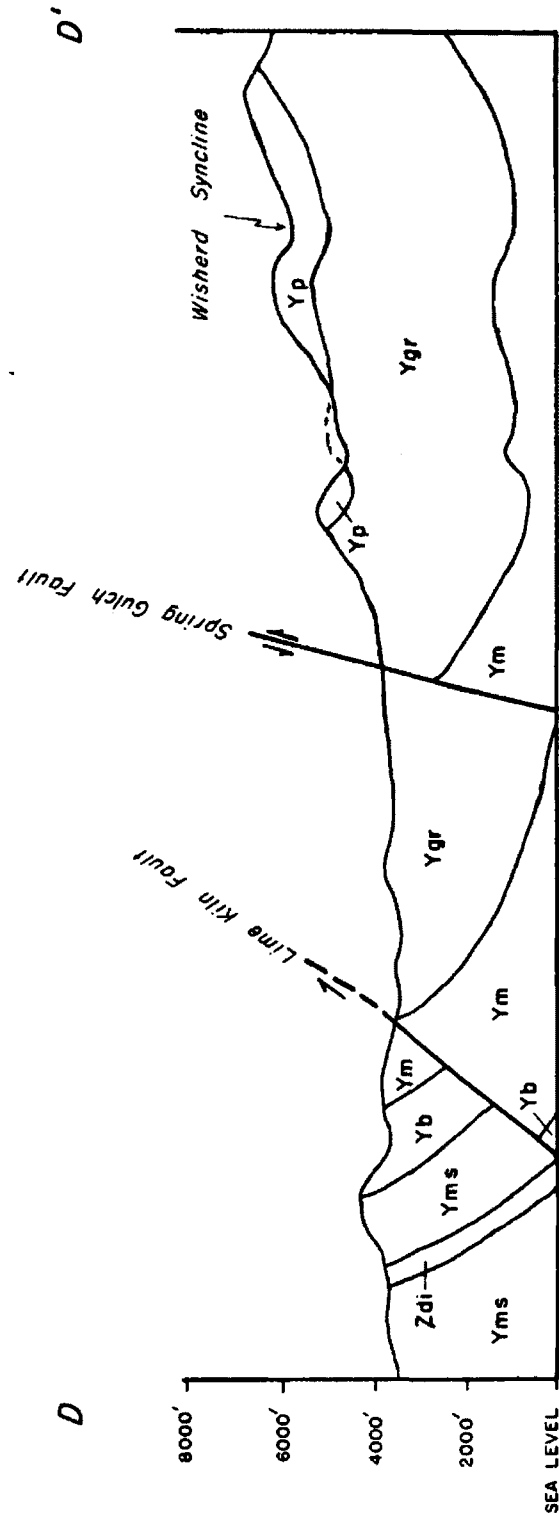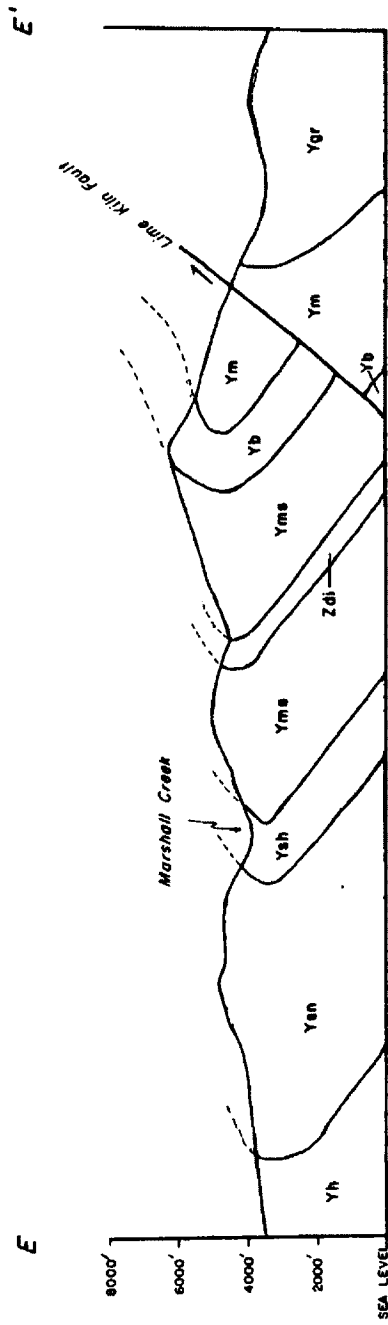
Figure 14. D-D' Refer to Plate 1 for location of section line.

Figure 15. E-E' Refer to Plate 1 for location of section line.

Spring Gulch, Lime Kiln, and Wisherd blocks, while figure 15 concentrates on the region within Spring Gulch block.

In the northern part of the study area (fig. 11), only two structural domains are present; the Spring Gulch block and a combination domain of the Lime Kiln and Wisherd blocks. These two eastern blocks are combined because the Lime Kiln fault is absent in this region. Deformation in this section is mostly localized around the Wisherd syncline. In addition, relationships between the Spring Gulch block and the eastern block show heavily sheared south-dipping Helena rocks in fault contact with overturned south-dipping Shepard strata. Therefore, a minimum stratigraphic separation of 1200 m, the width of the Snowslip Formation, must have occurred on the Spring Gulch fault.

Further south, in figures 12 and 13, all three structural domains are represented as the Lime Kiln fault is present. Both sections show the Helena Formation of the Spring Gulch block in fault contact with overturned Mt. Shields Formation rocks of the Lime Kiln block, representing at least 1600 m of stratigraphic separation along the Spring Gulch fault. The Lime Kiln block shows overturned beds at the surface in both figures 12 and 13, but these beds are interpreted to fold into an overturned syncline in the subsurface. Minimal displacement (less than 800 m) along the Lime Kiln fault truncates the subsurface syncline. The upright strata within the Wisherd block are folded around the Wisherd syncline.

Figure 14 shows two structural domains, the Spring Gulch block and the Wisherd block. The Lime Kiln block's southernmost boundary is north of this section line. However, the Lime Kiln fault, which was offset by

the Spring Gulch fault is still present. Southwest of the Lime Kiln fault, the eastern part of the Spring Gulch block is preserved. Thicknesses and offset of these units along the Lime Kiln fault may be slighty inaccurate since this section line is drawn oblique to the major structures in the Spring Gulch block. Rocks between the Lime Kiln and Spring Gulch faults are upright and have probably also undergone considerable rotation along the Spring Gulch fault. The Wisherd block is dominated at this level by the Garnet Range and Pilcher Formations which are folded by the Wisherd syncline.

The final cross-section, figure 15, lies completely within the Spring Gulch block. All the major relations found in the other sections, such as a shear fabric to the west, overturned beds which form a syncline in the subsurface in the central region, and truncation of the subsurface overturned syncline by the Lime Kiln fault to the east, are present. This suggests the structures in figure 15 are the same as the structures in the more northerly sections, only they have undergone clockwise rotation along the Spring Gulch fault.

Structural Synthesis

Figure 16 summarizes the structural history of the Rattlesnake area in four steps. This schematic model only shows the development of the section contained within the field area. In reality, Paleozoic rocks overlie the section and more Belt rocks underlie the Helena Formation.
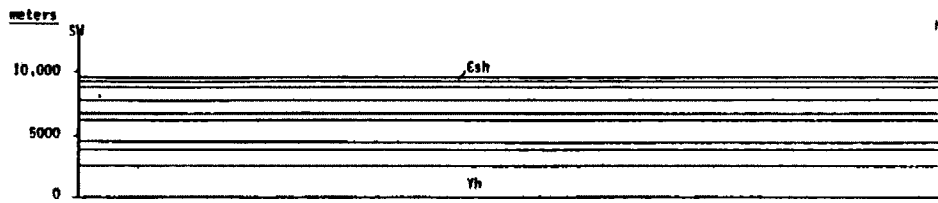
Step 1 - Pre-Laramide structural setting of the field area.
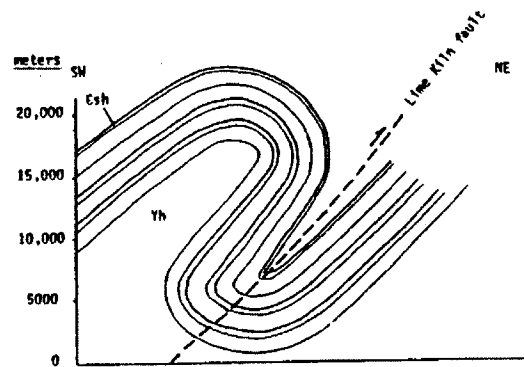
Step 2 - Laramide compression forms overturned anticline-syncline pair.

Figure 16. Structural history of the Rattlesnake area.
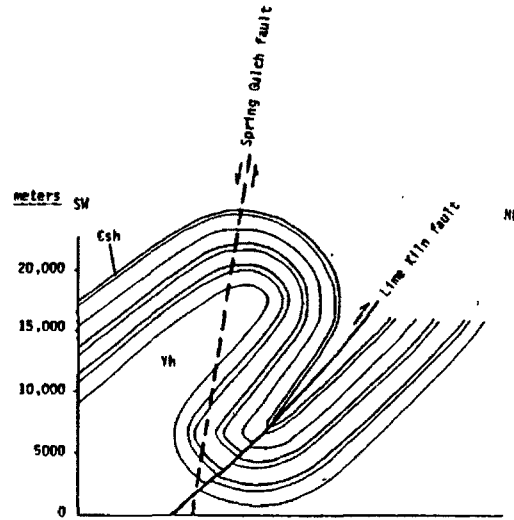
Step 3 - Continued Laramide compression generates
offset along the Lime Kiln fault.
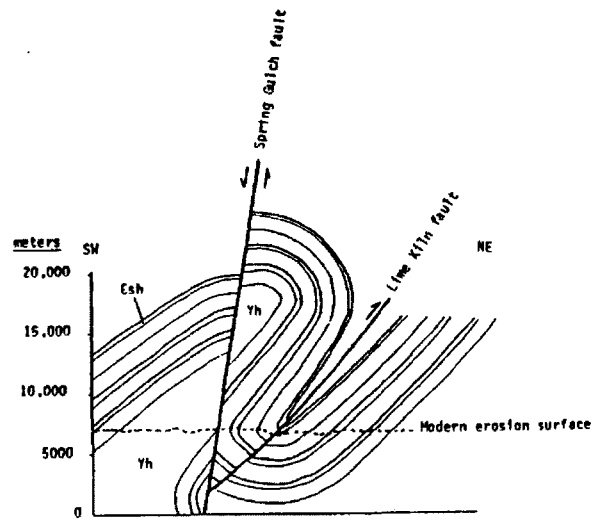
Step 4 - Eocene extension produces the Spring Gulch
fault which drops the core of the anticline
against the overturned limb. Erosion yields
the present structural setting.

Figure 16 (continued)

Strata within the area were flat-lying and undeformed prior to Laramide orogenesis (step 1, fig. 16). This structural setting changed as northeast-directed compression folded the rocks into an overturned anticline-syncline pair during Late Cretaceous Laramide orogenesis (step 2, fig. 16). I suggest this folding event created both the brittle and ductile fabrics found within the study area. Both the Helena and Shepard Formations are near the core of the anticline, where compressional stress is much higher than further out on the fold (Ramsay, 1967). This higher compressive stress, combined with a high burial load and compositional weaknesses, caused ductile flow in the Helena and Shepard Formations. In contrast, the other rocks further out on the fold were under a lesser compressive stress, had less lithostatic load, and therefore deformed in a brittle manner.

Continued Laramide compression developed the Lime Kiln fault (step 3, fig. 16), a forelimb thrust (Dahlstrom, 1970). As previously mentioned, this fault has little offset and has an orientation consistent with both small and large scale folds. In addition, kink folds of cleavage in the Helena Formation, which have coaxial orientations to the mesoscopic bedding folds, formed during this period.

The final deformation event in the Rattlesnake area occurred during Tertiary extension when the Spring Gulch fault developed. This down-to-the-southwest fault juxtaposed the ductile core of the anticline developed in step 2 against the brittlely deformed northeastern limb of the same anticline (step 4, fig.16). Rotation of fabric in the down-dropped side also occurred, as evidenced by cross-sections and stereonet data. Movement along the Spring Gulch fault may have also

folded the rocks in the Spring Gulch block into the Bonner Mountain antiform. This is uncertain because either normal or right-lateral strike-slip movement on either the Spring Gulch or Clarkfork-Ninemile faults could have produced this later folding, depending on the geometry of the fault at depth.

Subsequent erosion removed the top of the anticline, preserving the structural setting observed today. These relations are:

1) Overturned ductiley deformed rocks within the Spring Gulch block.

2) An overturned section of brittlely deformed Missoula Group strata within the Lime Kiln block.

3) Brittlely deformed upright upper Missoula Group rocks folded around the Wisherd syncline in the Wisherd block.

This model requires a great deal of erosion in the region. I feel this is supported in part by the fact that Prichard rocks, which supposedly were overlain by 13 km of rock, crop out 30 km to the west of the Rattlesnake area (Harrison, 1981). In addition, the metamorphic grade of rocks within the Rattlesnake area never exceeded greenschist facies because unroofing of sediments from the crest of the anticline during deformation prevented high burial loads.

Regional Implications

The conclusions of this study contradict Wallace and Lidke's (1980) and Ruppel et al.'s (1981) interpretation of the Rattlesnake area. Both investigators suggested the study area was structurally represented by the Rattlesnake plate, a large thrust plate whose leading edge lies 1-2 km east of the Wisherd syncline. I can not support the presence of this plate for two reasons. First, I did not find conclusive field evidence for the existence of the leading thrust fault. Most of the deformation along its proposed trace is better explained as parasitic folding and mesoscopic thrust faulting associated with the Wisherd syncline. Secondly, I can not support the existence of a major fault with fabric data. In other words, both the structural style and orientation of structural fabric is continuous across the proposed thrust fault. If a thrust fault does exist just east of the Wisherd syncline, it is a minor fault with little rotation, and would not constitute a major plate boundary.

Locally, relationships between the Rattlesnake area and surrounding structural terrains may clarify the development of structures within the study area. For example, Sears et al. (1984) suggests much of the cleavage development within the field area is due to the south-bounding Sapphire plate being thrust to the north; thus producing high lithostatic loads and subsequent cleavage development in the footwall. Therefore rocks north of the Sapphire plate, such as the Rattlesnake area, are penetratively cleaved while the rocks within the Sapphire

plate are generally not. Another important structural trend which may project into the field area is the Purcell anticlinorium, a large antiformal structure which lies northwest of the field area (Harrison, 1981). West of the Jocko fault, the Purcell anticlinorium exposes Prichard rocks in its core and forms an anticline-syncline pair with a synclinal structure analogous to the Wisherd syncline. Therefore, the field area anticline and the Purcell anticlinorium may be the same structure; except uplift east of the Jocko fault caused erosion of this structure in the study area.

On the larger scale, Sears (1983) suggests the field area lies near the center of a 250 km long continuous east-west trending structure which may represent a large south-facing basement ramp. He proposes that this structure deforms rocks ranging in age from the Proterozoic (Y) Prichard Formation in the west to Early Cretaceous strata at the eastern end, therefore limiting the age of deformation to post-Early Cretaceous. In addition, steeper and more southeasterly plunge orientations occur in this zone than in areas further to the north. Evidence within and around the study area supports this hypothesis. Structural trends, such as fabric orientations and deformational styles, are generally continuous with those west and east of the field area. The local variation in plunge within the field area is possibly due to later rotation on the Clarkfork- Ninemile and Jocko faults.

Finally, the general structural trend of Laramide compressional features overprinted by Cenozoic extensional structures corresponds well to similar deformational histories observed in northwestern Montana (Wallace and Hosterman, 1956; Hall, 1968; Winston, 1982; Lonn, 1984)

and southern Canada (Bally et al., ·1966; Price, 1966). The major difference is deformation is northeast-directed in the study area while east-directed deformation is more common to the north and south. Sears´ (1983) south-facing ramp model may explain these variations in orientation. Other possible explanations include: 1) the emplacement of the Idaho batholith producing northeast-directed stress (Harrison et al., 1980; Talbot and Hyndman, 1973), and; 2) Precambrian basement block faults forming a buttress which causes rotation of the stress direction (Winston, 1982). Evidence within the field area can not conclusively support or refute any of these hypotheses.

SUMMARY

Summarizing, the study area underwent two major phases of deformation. First, Laramide orogenesis produced a northeast-directed compressive stress which created large and small-scale folding, thrust faulting, and cleavage development. In addition, structural styles ranging from ductile flow to brittle flexural slip folding formed during this deformational event. Secondly, Tertiary extension, manifested in strike-slip and normal faults, overprinted many of the Laramide structures. Large panels of rocks within the field area were rotated and refolded by these later extensional structures, giving different structural fabric orientations across the faults. Finally, subsequent erosion developed the topography observed today.

This general sequence of events corresponds well with other studies done in the region, but contradicts Wallace and Lidke's (1980) and Ruppel et al's (1981) conclusion that the field area is structurally represented by the Rattlesnake plate. Instead, I believe the field area is best described as a southeasterly plunging anticline-syncline pair which may be related to Sears' (1983) basement ramp.

REFERENCES

Achuff, J.M., 1981, Folding and faulting in the northern Blacktail Range, Beaverhead County, Montana, unpublished Masters thesis, University of Montana

Bally, A.W., P.L. Gordy, and G.A. Stewart, 1966, Structure, seismic data, and orogenic evolution of southern Canadian Rocky Mountains: Bull. Can. Petr. Geol., v. 14, p. 337-381

Cobbold, P.R., H. Quinquis, 1980, Development of sheath folds in shear regimes: Jour. Struct. Geol., v. 2, n. 1, p.119-126

Constenius, K.N., 1982, Relationships between the Kishenehn Basin and the Flathead listric normal fault system and Lewis thrust salient, in Powers, R.B. ed., Geologic studies of the Cordilleran Thrust Belt: Rocky Mountain Assoc. of Geologists, p. 817-830

Coward, M.P., 1983, Thrust tectonics, thin skinned or thick skinned, and the continuation of thrusts to deep in the crust: Jour. Struct. Geol., v. 5, n. 2, p. 113-123

Dahlstrom, C.D.A., 1969, Balanced cross-sections: Can. J. Earth Sci., v. 6, p. 743-757

Dahlstrom, C.D.A., 1970, Structural geology in the eastern margin of the Canadian Rocky Mountains: Bull. Can. Pet. Geology, v. 18, p. 332-406

Dutro, J.T., E-an Zen, and M.E. Taylor, 1975, Middle Cambrian in the Pioneer Mountains, southwest Montana: [abs.], Geological Society of America Abstracts with programs, v. 7, p.1062

Groshong, R.H., 1972, Strain calculated from twinning in calcite: Geological Soc. of America Bull., v. 83, p. 2025-2038

Hall, Frank W., 1968, Bedrock geology, north half of Missoula 30 quadrangle, Montana: unpublished PhD dissertation, University of Montana, Missoula, 253 p.

Harrison, J.E., 1981, Generalized geologic map of the Wallace 1+2 quadranngle, Montana and Idaho, U.S. Geological Surv., Miscellaneous Field Studies Map MF-1354-A

Harrison, J.E., A.B. Griggs, and J.D. Wells, 1974, Tectonic features of the Precambrian Belt Basin and their influence on post-Belt structures: U.S. Geological Surv. Prof. Paper 866, 15 p.

Harrison, J.E., M.D. Kleinkopf, and J.D. Wells, 1980, Phanerozoic thrusting in Proterozoic Belt rocks, northwestern United States: Geology, v. 8, p.407-411

Hobbs, B.E., W.D. Means, and P.F. Williams, 1976, An Outline of Structural Geology, John Wiley and Sons, New York, 572 p.

Lonn, J., 1984, Structural geology of the Tarkio Area, Mineral County, Montana: unpublished Masters thesis, University of Montana, Missoula, 51 p.

Mudge, M.R., and R.L. Earhart, 1979, Structure and structure contour of the Choteau 1+2 quadrangle, Lewis and Clark, Teton, Powell, Missoula, lake, Flathead, and Cascade Counties Montana: U.S. Geological Survey Open File Report 78-863, 2 sheets, scale 1:250,000

Nelson, W.H., and J.P. Dobell, 1961, Geology of the Bonner quadrangle, Montana: U.S. Geological Survey Bull. 1111-F, p. 189-235

Obradovich, J.D., and W.A. Cobban, 1975, A time-scale for the Late Cretaceous of the western interior of North America: Geol. Assoc. Canada Sp. Paper 13, p. 31-54

Obradovich, J.D., and Z.E. Peterman, 1968, Geochronology of the Belt Series, Montana: Can. J. Earth Sci., v. 5, p. 737-747

Price, R.A., 1966, Flathead map area, British Columbia and Alberta, Geol. Surv. Canada Mem. 336, 219 p.

Ramberg, H., 1964, Selective buckling of composite layers with contracted rheological properties-a theory for simultaneous formation of several orders of folds: Tectonophysics, v. 1, p. 307-341

Ramsay, J.G., 1967, Folding and Fracturing of Rocks, McGraw-Hill, New York, 568 p.

Ruppel, E.T., C.A. Wallace, R.G. Schmidt, D.A. Lopez, 1981, Preliminary interpretation of the thrust belt in southwest and west-central Montana and east-central Idaho: Montana Geol. Soc. Field Conf. Guidebook, p. 139-159

Sears, J.W., 1983, A continental margin ramp in the Cordilleran thrust belt along the Montana lineament: [abs.] Geol. Soc. of America Abstracts with programs, v. 15, n. 6, p.682

Sears, J.W., I. Watson, and J. Lonn, 1984, Cleavage distribution as a function of structural level in the western Montana thrust belt: Northwest Scientific Assoc. Program and Abstracts, no. 146.

Stewart, J.H., 1976, Late Precambrian evolution of North America: plate
     tectonics implication: Geology, v. 4, no. 1, p. 11-15
Talbot, J.L.,   and D.W.   Hyndman, 1973, Relationship of the Idaho
     batholith structures to the Montana lineament: Northwest Geology,
     v. 2, p. 48-52

Van der Poel, W.I., 1979, A reconnaissance of the late Tertiary and
     Quaternary   geology,   geomorphology,   and contemporary surface
     hydrology of the Rattlesnake Creek area, Missoula County, Montana:
     unpublished Masters thesis, University of Montana, 68 p.

Wallace, C.A., M.R. Klepper, A.B. French, and D.M. Scarborough, 1978,
     Preliminary geologic map of the northwestern part of the Butte 1+2
     quadrangle, Montana: U.S.   Geological Survey Open-File Report
     78-371, 3 sheets, scale 1:250,000 and 1:125,000

Wallace, C.A., and D.L. Lidke, 1980, Geologic map of the Rattlesnake
     Wilderness   Area,   Missoula,   Montana: U.S.   Geological Survey
     Miscellaneous Field Studies Map MF-1235A

Wehrenberg, J.P., 1983, The Geologic Development of Western Montana:
     University of Montana, Missoula, Montana, 41 p.

Winston, D., 1983, Sedimentology and stratigraphy of the Missoula Group:
     in Programs and Abstracts, Belt Symposium 2, p. 35-37.

Winston, D., P. Jacob, D.O. Baldwin, and J.P. Reid, 1982, Proterozoic
     block faulting in the Belt basin, Montana and Idaho: Its effect on
     Rocky Mountain thrusting and Basin and Range Extension:
     unpublished manuscript.

APPENDIX A

Parameters for Stereonet Plots

Bedding

Station	Number of data points	Location of maxima (M) or pole to girdle (G)	Contour intervals (% per 1% area)				
			1	2	3	4	5
1	69	169/20 (G)	1.6	8.3	15	22	29
2	123	168/16 (G)	0.7	4.9	9	13	17
3	202	143/4 (G)	0.4	10	17	28	38
4	62	131/14 (G)	1.5	7.4	13	19	25
5	58	306/20 (G)	1.7	6.3	11	15	20
6	54	106/61 (M)	1.6	10	19	28	37
7	64	148/6 (G)	1.6	6.7	12	17	22

Cleavage

Station	Number of data points	Location of maxima (M) or pole to girdle (G)	Contour intervals (% per 1% area)				
			1	2	3	4	5
1	52	172/14 (G)	1.9	8.6	15	22	29
2	53	168/12 (G)	1.9	10	19	27	36
3	80	150/4 (G)	1.2	6.9	13	18	24
4	28	129/8 (G)	6.2	14	22	29	37
5	77	310/18 (G)	1.3	11	20	30	36
6	46	067/25 (M)	2.2	17	31	45	60
7	38	150/8 (G)	5.6	9.7	14	18	23

Lineations

Station	Number of data points	Location of Maxima (M) pole to girdle (G)	Contour intervals (% per 1% area)				
			1	2	3	4	5
1	14	343/12 (M)	-	-	-	-	-
2	21	163/15 (M)	-	-	-	-	-
3	22	147/6 (M)	-	-	-	-	-
4	38	136/16 (M)	3.2	13	22	28	38
5	23	315/2 (M)	-	-	-	-	-
6	16	010/8 (M)	-	-	-	-	-
7	15	149/8 (M)	-	-	-	-	-