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STRUCTURAL AND METAMORPHIC GEOLOGY OF THE BASS LAKE AREA,
NORTHERN BITTERROOT RANGE, RAVALLI COUNTY MONTANA

By

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B.S., Bates College, 1971

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1975

Approved by:

A handwritten signature in cursive script, appearing to read "James K. ...", is written over a horizontal line.
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A handwritten signature in cursive script, appearing to read "John Stewart", is written over a horizontal line.
Dean, Graduate School

A handwritten date "Dec 9, 1975" is written over a horizontal line.
Date

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Williams, R. David, M.S., Winter, 1976

Geology

Structural and Metamorphic Geology of the Bass Lake Area, Northern Bitterroot Range, Ravalli County Montana (53 pp.)

Director: James L. Talbot

The northeast border of the Idaho batholith is a structurally complex area which is important for an understanding of the history of the Sapphire tectonic block.

Field mapping in the Bass Lake area was conducted during the summer of 1972, approximately 50 days being spent in the field. Field work consisted of mapping lithology and structures and collecting samples for laboratory investigation.

Geologic mapping in the Bass Lake area in the northern Bitterroot Range has delineated a series of nappe type structures in highly deformed and metamorphosed rocks of the Precambrian Ravalli and Prichard formations.

The area mapped lies within 2Km of the contact with the Idaho batholith and the rocks have been metamorphosed to the upper amphibolite facies. The rise of the Idaho batholith supplied the gravitational potential for the sliding of the Sapphire tectonic block to the east. In the Bass Lake area this sliding was manifested first by the development of large scale nappe type structures and later by the formation of a zone of intense cataclasis, this being represented by the frontal zone gneiss which occurs along the front of the Bitterroot Range. The final stages of uplift of the Idaho batholith were accommodated by faulting along the range front.

Associated with the development of nappe type structures were the transposition of pre-existing mesoscopic folds and the tectonic displacement of pre-existing diabase sills and anorthosites. Numerous dikes and sills of granitic and pegmatitic material were associated with the intrusion of the Idaho batholith. The development of range front faulting was accompanied by slight mineralization along the fault zone.

ACKNOWLEDGMENTS

Several people have been especially helpful during the course of this thesis. Dr. James Talbot, my advisor, has been extremely helpful in all aspects of the thesis. Many discussions with Dr. Ron Chase, of Western Michigan University, were of great assistance. Discussions with Dr. Jack Wehrenberg and fellow graduate student, Ed Flood, have also been helpful.

Steve Balogh did an excellent job of preparing thin sections for this study.

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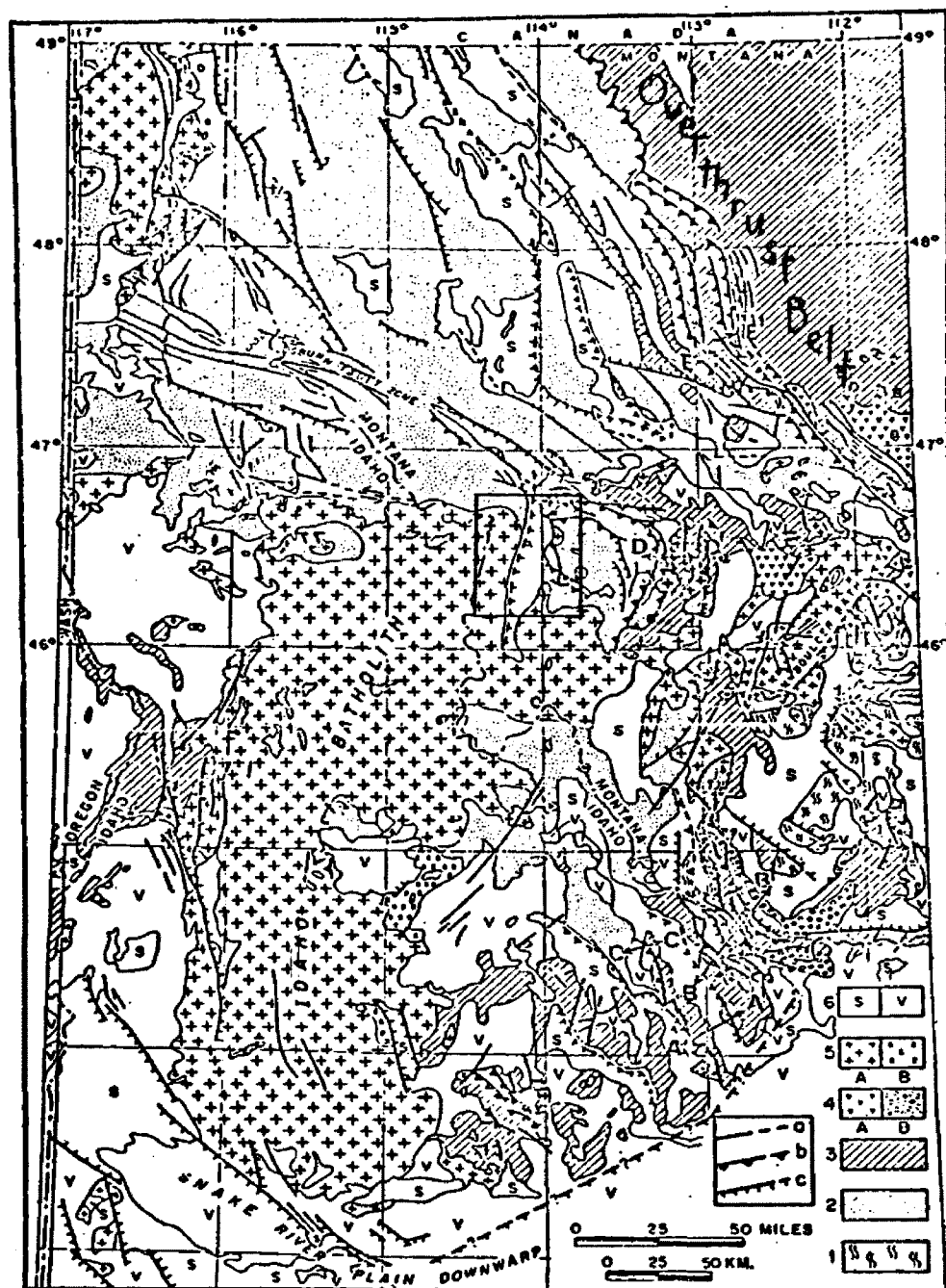
CHAPTER 1

INTRODUCTION

Geologic Setting

Western Montana is dominated by several structural elements; 1) the Idaho batholith, 2) the Montana lineament (Osburn fault zone of fig. 1), a major strike-slip zone of uncertain movement; and 3) the overthrust belt, a band of overthrusts from the west extending south from the Canadian border to west-central Montana. (See Figure 1)

In western Montana, the Idaho batholith intrudes rocks of the Precambrian Belt Supergroup and is at least partially responsible for metamorphism in the Belt rocks. The intrusion and uplift of the batholith resulted in both thrust faulting and gravity induced gliding (Chase and Talbot, 1973; Scholten, 1965, 1973). The uplift unit is bordered on the north by the Lolo Creek and Mormon Saddle faults (Wehrenberg, 1972) and on the east by a zone of intensely sheared rock known as the frontal zone gneiss (Fig. 2). The frontal zone gneiss, present along the entire western edge of the Bitterroot Valley represents the separation plane between the high grade rocks of the infrastructure associated with the batholith and the low grade rocks of the suprastructure (Chase and Talbot, 1973). Rocks adjacent to the northeast border of the Idaho batholith have been regionally metamorphosed to sillimanite grade and have been tentatively correlated with the Prichard and Ravalli formations of the Belt Supergroup (Langton, 1935). Metamorphic isograds are



- 1 = Precambrian crystalline basement;
 2 = Late Precambrian sediments of Belt geosyncline: quartzites, pelites, and metamorphic equivalents near Idaho batholith;
 3 = Paleozoic and Mesozoic rocks of Cordilleran geosyncline and adjacent cratonic shelf (pre-tectonic);
 4 = Mid-Cretaceous to Eocene rocks on cratonic shelf (syntectonic): A = Elkhorn and Adel Mountain volcanics near Boulder batholith; B = Golden Spike Formation west of Boulder batholith and Beaverhead Conglomerate in extreme southwest Montana;
 5 = Granitoid batholiths and stocks (syntectonic): A = Cretaceous; B = Tertiary;
 6 = Eocene to Recent sediments (s) and volcanics (v) (post-tectonic).

- a = unclassified faults;
 b = upthrusts, overthrusts and gliding sheets;
 c = normal faults (largely or wholly post-orogenic).

Fig. 1--Tectonic map of the northern Rocky Mountains after Scholten (1968) Approximate area of Figure 2 is blocked out in center.

only grossly related to the geometry of the batholith's border, the grade decreasing to the north and east (Wehrenberg, 1975).

Locally, the picture is complicated by the presence of later high angle normal faults along the front of the Bitterroot Valley. These, together with the frontal zone, combine to give the Bitterroot scarp a distinctive convex slope. While most of the valley is composed of valley fill, rare outcrops of Belt rocks have been reported (Chase, 1972, personal communication).

It has been suggested that the Bitterroot Range structures represent an analogous but smaller version of the Shuswap and Valhalla terranes (Chase, 1968). In the Shuswap and Valhalla terranes, high grade rocks of the infrastructure are separated from the low grade rocks of the suprastructure by a narrow zone or plane of separation, the "abscherung" zone (Hyndman, 1968; Reesor, 1965).

If the proposed model is correct, structures similar to those in the Valhalla area might be expected. These are: penetrative crushing and/or mylonitization, cataclastic units overlapping the eastern front of the range, flattened foliation over the crest of the range, and the orientation of the cataclasis controlled by an earlier anisotropy (Reesor, 1965).

The Bass Lake area is important because it is within 1 kilometer of the northeast border of the Idaho batholith, and a comparison between structures in the Bass Lake area (infrastructure) and structures within the frontal zone gneiss (abscherung zone) may help detail the mode of emplacement of the Idaho batholith.

Explanation of Fig. 2

Reconnaissance maps

- 1 - Lindgren (1904, Plate 1)
- 2 - Langton (1935, Fig. 3)
- 3 - Ross (1950, Plate 4)
- 11 - Nold (1968, Ph.D. Dissertation, University of Montana)

Detailed maps

- 4 - Groff (1954, M.S. thesis, University of Montana, Plate 2)
- 5 - Anderson (1959, M.S. thesis, University of Montana, Plate 1)
- 6 - Chase (1961, M.S. thesis, University of Montana, Plate 2)
- 7 - Berg (unpublished)
- 8 - Pevear (1964, unpublished report submitted to the Ward Development Company, Plate 1)
- 9 - Berg (1965, Plate 1)
- 10 - Chase (1968, Ph.D. Dissertation, University of Montana)
- 12 - Wehrenberg (1972, Northwest Geology)

Northeastern border of the Idaho batholith

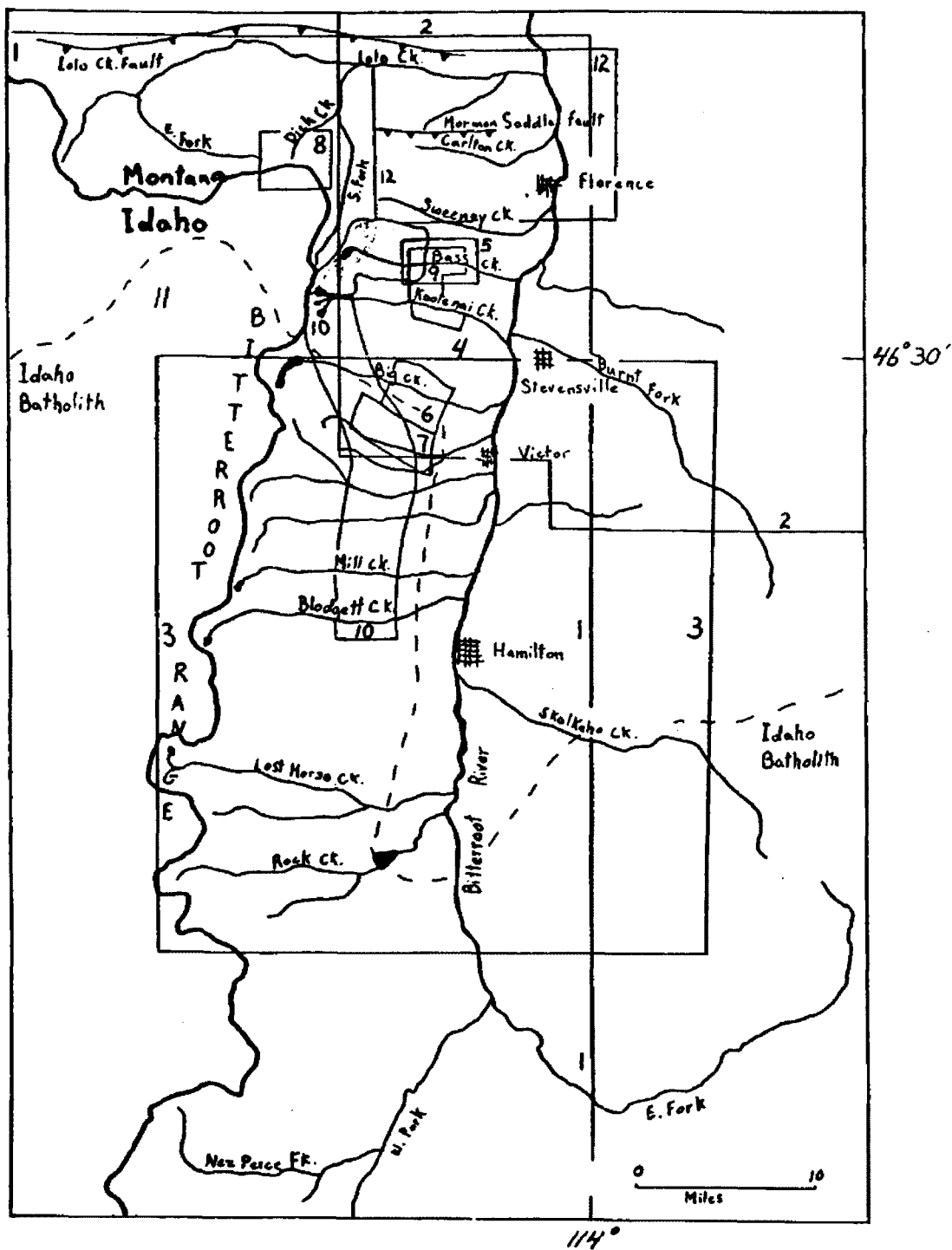


Fig. 2.--Map showing location and previous investigations. Study area is shaded.

Present Study

The purpose of the present study was twofold: 1) to study the structures of the infrastructure of the Bass Lake area, and 2) to complete a structural analysis of the Bass Creek frontal zone gneiss. Structural work consisted of a comparison between structures in the infrastructure and structures in the frontal zone gneiss.

The area mapped (Figure 2) is within the Selway-Bitterroot wilderness, which includes most of the Bitterroot Range, a north-south trending range extending south from Lolo Creek and including the boundary between Idaho and Montana.

A total of 55 days were spent in the field during the summer of 1972. Traverses, across the prevailing structural trend were done with a topographic map and altimeter. Where possible, lithologic contacts were traced on the ground.

During the fall and winter of 1972-73, laboratory investigations were carried out on data and samples collected in the field. Approximately 90 thin sections were examined for textural and lithologic variation. Modal analyses were performed on some granitic gneiss and quartzofeldspathic gneiss samples to determine if granitic gneiss units within the quartzofeldspathic gneiss could be distinguished on this basis (refer to Table 1). The compositions of the two units are virtually identical and they could not be distinguished from one another.

Structural data such as attitudes of foliation, lineations, and folds were plotted and contoured. Contouring of stereographic projections was done using a computer program modified by Talbot and Jones (1964).

This program (called POLDEN) is currently available at the University of Montana.

Previous Investigations (Figure 2).

Little work has been done in the upper Bass Creek area, but numerous studies, both reconnaissance and detailed, have been made in the surrounding areas. Reconnaissance studies were undertaken by Lindgren (1904), Langton (1935), Ross (1950), and Nold (1968).

Detailed work in the lower Bass Creek area has been done by Cheney (1972) and Berg (1965) on the anorthosite first described by Anderson (1959). Groff (1954) described the petrography of the Kootenai Creek area, just south of Bass Creek. Chase (1968) mapped an area extending from the Kootenai Lakes area to Blodgett Canyon. In addition, Chase did detailed structural work in the frontal zone and units adjacent to the batholith. Wehrenberg (1972) mapped the area around Lolo Peak and south as far as the Sweeney Lakes area.

Other studies in the northern Bitterroots dealing with similar rock units or structures nearby are Chase (1961), White (1969) and Berg (1960, unpublished report).

CHAPTER II

FIELD AND PETROGRAPHIC RELATIONSHIPS

General Lithologies

The study area is entirely within the high grade metamorphic rocks surrounding the Idaho batholith. The rocks are in the upper amphibolite facies of regional metamorphism. The metamorphic rocks have been subdivided into two lithologies; a gray weathering gneiss or quartzofeldspathic gneiss and a red weathering gneiss or pelitic schist. The quartzofeldspathic gneiss has been correlated with the Ravalli group of the precambrian Belt Supergroup. The pelitic schist has been correlated with the Prichard formation, the basal unit of the precambrian Belt Supergroup (Anderson, 1959; Chase, 1968, 1973; Wehrenberg, 1968, 1972). Minor units present in the pelitic schist and quartzofeldspathic gneiss include numerous granitic pods, lenses, dikes and sills which probably represent apophyses of the nearby Idaho batholith. Also included are small bodies of amphibolite, calc-silicate gneiss, pegmatite and anorthosite.

Pelitic Schist

Field Relations. The pelitic schist is characterized by a red-brown surface weathering coloration and considerable compositional layering. The pelitic schist commonly forms large unstable talus slopes as on the sides of Saint Joseph peak (see pg. 37). The pelitic schist

is well foliated, the foliation being accentuated by numerous pods and lenses of concordant granitic and pegmatitic material which may comprise up to thirty percent of the rock. At the outcrop the pelitic schist is seen to be comprised mainly of quartz, biotite and plagioclase. Sillimanite is commonly visible within a schistosity which is defined by the parallel orientation of muscovite and biotite. The pelitic schist is highly deformed and it is impossible to trace a single horizon for any distance. In some areas a mineral streaking lineation is present. A weak crenulation cleavage is rare.

Pods and lenses of generally discordant amphibolite are common. Other minor units within the pelitic schist include; calc-silicate gneiss units, and several small bodies of anorthosite. Calc-silicate units are both discordant and concordant and may be rimmed with a reaction rim of grossularite, epidote and actinolite.

The correlation of the pelitic schist with the Prichard formation is based on a comparison with similar lithologies described by Chase (1968, 1973) and Wehrenberg (1968, 1972) in nearby areas. These lithologies were correlated with the Prichard formation on the basis of composition, general stratigraphic position and in the case of Wehrenberg's area, relict sedimentary bedding features.

The pelitic schist in the present study area is continuous with these Prichard equivalents mapped in the above studies.

Petrography. The pelitic schist consists of quartz (20-40%), plagioclase (20-40%), K-feldspar (10-30%), biotite (5-15%), muscovite (0-10%), and sillimanite (0-10%). The presence of sillimanite, muscovite and K-feldspar indicate the pelitic schist is in the upper amphibolite facies.

Quartz occurs as anhedral grains and commonly displays undulose extinction and sutured grain boundaries. Plagioclase is typically oligoclase (An 25*) though it ranges in composition from An 22 to An 30. Plagioclase is commonly myrmekitic. Where present, K-feldspar occurs with quartz and plagioclase. The K-feldspar is orthoclase and may be perthitic. Muscovite is a common constituent though not present in all samples. Muscovite often has ragged outlines which indicate that muscovite may not be in equilibrium in the pelitic schist. Biotite (pleochroic formula X = light brown-clear; Z = reddish brown) is present in all thin sections. Biotite is commonly altered to chlorite and magnetite ilmenite. Sillimanite, where it occurs with both muscovite and K-feldspar, does not share grain boundaries with both. Sillimanite occurs most commonly with biotite. This observation tends to support work done by Carmichael (1969) which suggests that the following reactions are involved in the sillimanite isograd: $2 \text{ muscovite} + \text{albite} + 3 (\text{Mg, Fe})^{++} + \text{H}_2\text{O} \rightleftharpoons \text{biotite} + 3 \text{ sillimanite} + 3 \text{ quartz} + \text{K}^+ + \text{Na}^+ + 4\text{H}^+$, $3 \text{ kyanite} + 3 \text{ quartz} + 2 \text{ K}^+ + 3\text{H}_2\text{O} \rightleftharpoons 2 \text{ muscovite} + 2\text{H}^+$, $\text{biotite} + \text{Na}^+ + 6\text{H}^+ \rightleftharpoons \text{albite} + \text{K}^+ + 3 (\text{Mg, Fe})^{++} + 4\text{H}_2\text{O}$. The net result of this series is the

*Determined by Michel-Levy method for flat stage determination of plagioclase composition (Troger, 1971, pg. 129).

idealized reaction, $3 \text{ kyanite} \rightleftharpoons 3 \text{ sillimanite}$. The close association of biotite and sillimanite in the pelitic schist seems to underscore the importance of biotite in the reaction.

Accessory minerals include chlorite after biotite, magnetite-ilmenite, zircon, (mostly associated with pleochroic haloes in biotite), sphene and rutile. Schistosity in the pelitic schist is well defined by biotite, muscovite, and sillimanite. An ill defined crenulation cleavage is visible in some thin sections. Micas which define the crenulations have been recrystallized into polygonal arcs and subsequently deformed further as evidenced by uneven extinction.

Quartzofeldspathic Gneiss

Field Relations. This unit was originally called the grey weathering gneiss because of its characteristic color in weathered outcrops (Groff, 1954), but has more recently been called the quartzofeldspathic gneiss (Chase, 1968, 1973). The quartzofeldspathic gneiss has received less attention than the pelitic schist for two reasons: the more thoroughly studied anorthosites occur more commonly in the pelitic schist, and the quartzofeldspathic gneiss is commonly less accessible than the pelitic schist. The quartzofeldspathic gneiss is considerably more massive than the pelitic schist and tends to form cliffs such as those found near Bass Lake, along the ridge between Bass Creek and Kootenai Creek and around the Heavenly Twins south of the study area. The quartzofeldspathic gneiss contains pods of calc-silicate gneiss, biotite-rich pods and lenses as well as granitic and pegmatitic material.

Its composition, though variable is more consistent than that of the pelitic schist. In several areas the quartzofeldspathic gneiss is intimately associated with granitic material. This granitic material fits several of Hyndman's (1972) criteria for distinguishing "granitized" rock from magmatically emplaced granites. These are: gradational contacts, margins are not chilled, foliation passes continuously into regional structure, dikes show no dilation, some metamorphic minerals are present (garnet), and these small granitic bodies show no visible connection to a magma source. This seems to indicate there has been some "marginal granitization" as one might expect adjacent to a deep seated granitic contact.

The quartzofeldspathic gneiss has a schistosity defined primarily by biotite-rich layers. Granitic and pegmatitic lenses are commonly concordant while calc-silicate pods and biotite pods are often discordant. An estimate of the percentage of granitic and pegmatitic material in the quartzofeldspathic gneiss is difficult because of the similarity in color and composition.

At the outcrop the quartzofeldspathic gneiss is seen to be composed of quartz, feldspar and biotite. Unlike the pelitic schist, the quartzofeldspathic gneiss does not commonly break along the foliation.

The quartzofeldspathic gneiss like the pelitic schist, is highly deformed and tracing a single layer within the quartzofeldspathic gneiss for any distance is impossible. Biotite rich pods within the quartzofeldspathic gneiss are commonly lineated.

The correlation of the quartzofeldspathic gneiss with the Ravalli is based on the stratigraphic relations between the Ravalli group and the Prichard formation. The composition of the gneiss unit is comparable to several units within the Belt Supergroup (Chase, 1968, 1973), but the presence of the Prichard formation and the calc-silicate unit mapped by Chase (1968), (Wallace formation?) nearby makes it most likely the quartzofeldspathic gneiss correlates with the Ravalli group.

Petrography. The quartzofeldspathic gneiss contains plagioclase, quartz, K-feldspar and biotite. Biotite is similar to that in the pelitic schist, pleochroic formula Z = reddish brown, X = light brown - clear. Where it has been deformed into folds, the biotite has been recrystallized into polygonal arcs. This contrasts with muscovite and biotite in the pelitic schist, which show evidence of further deformation following the development of polygonal arcs. Biotite defines a poor schistosity in thin section. The plagioclase is of oligoclase composition (An 27-28). It sometimes shows deformed albite twinning. The Plagioclase not uncommonly displays myrmekitic texture. Quartz is typically strained with sutured boundaries and undulose extinction. The K-feldspar (orthoclase) is rarely perthitic and may be slightly deformed. Accessory minerals are muscovite, magnetite-ilmenite, chlorite altering from biotite, zircon (commonly associated with pleochroic haloes in biotite), sericite altering from plagioclase, sphene and rutile. Sillimanite is rare in the quartzofeldspathic gneiss. The mineral association indicates that the quartzofeldspathic gneiss has been metamorphosed to the upper amphibolite facies.

Texturally the quartzofeldspathic gneiss varies from slightly schistose to an almost granitic texture. Unlike the pelitic schist, the quartzofeldspathic gneiss contains no evidence of an earlier schistosity.

Table 1.

	<u>Present Study</u>		<u>Chase (1968)</u>	
	Average	Range	Average	Range
Quartz	32.3	(19.6-42.9)	50.8	(17-83)
Plagioclase	32.8	(21.5-49.4)	28.1	(4-68)
K-feldspar	29.8	(21.6-48.7)	7.1	(0-28)
Biotite	5.2	(2.7-9.4)	12.7	(4-24)
		5 samples		12 samples

Modal analyses were performed on five samples of quartzofeldspathic gneiss using stained slabs (see Table 1). An average of 1300 points were counted on each slab. Using techniques similar to those outlined by Chayes (1956), precision on stained slabs is $\pm 3\%$ for each major constituent.

These analyses appear to reflect real differences between the quartzofeldspathic gneiss in the area studied by Chase (1968, 1973), which is south of the present study area, and the quartzofeldspathic gneiss in the present study area. These differences are probably due to several factors, the most important being considerable marginal granitization in the Bass Lake area. This may explain the increase in potassium in the

rocks of the present study area. Other factors are the general compositional variation present in the quartzofeldspathic gneiss as an original sedimentary unit, and the possible inclusion of granitic rocks of similar composition.

Minor Units

Calc-silicate gneiss. Calc-silicate gneiss units have been reported in both the pelitic schist and the quartzofeldspathic gneiss (Chase, 1968, Anderson, 1959, Wehrenberg, 1972). In the present study area calc-silicate gneiss commonly occurs as small, (up to 1 meter in length) discordant pods, some of which are surrounded by reaction rims of hornblende and garnet. The calc-silicate gneiss is composed of quartz, andesine (An 32), a clinopyroxene (probably diopside) as well as hornblende and/or actinolite. Accessory minerals include rutile, sphene and magnetite-ilmenite.

The texture is poikiloblastic with quartz and plagioclase in hornblende. The amphiboles define a good lineation and gneissosity. Quartz and plagioclase show evidence of deformation in the form of undulose extinction and deformed twin lamellae.

There are two possible origins for calc-silicate rocks in the present study area. 1) calc-silicate pods may represent original limey beds within the sediment which have been disrupted to such an extent as to no longer be recognizable as layers, 2) calc-silicate pods may represent "tectonically" displaced slivers of the Wallace formation, a lime-rich formation which overlies the Ravalli group. In the case of calc-silicate pods within the pelitic schist (Prichard) the first case seems the most

likely. For calc-silicate pods within the quartzofeldspathic gneiss (Ravalli) and for the large areas of calc-silicate gneiss which occur in the area studied by Chase (1968, 1973), the second alternative seems reasonable.

Minerals present in the calc-silicate pods are compatible with the grade of metamorphism in the surrounding rocks.

The calc-silicate gneiss shows no evidence of deformation and is the most competent of the units in the present study area and it reflects virtually none of the complex structure which surrounds it.

Pegmatites. Pegmatites are ubiquitous particularly in the pelitic schist where they are more easily recognized than in the quartzofeldspathic gneiss. Generally pegmatites are concordant and show boudinage structures. Pegmatites are composed of quartz and feldspars with occasional large books of muscovite and biotite. Pegmatites in the quartzofeldspathic gneiss typically have mafic selvages, possibly indicating an anatectic origin while pegmatites in the pelitic schist commonly lack mafic selvages.

It is within a pegmatite that the only significant mineralization occurs, this being an old mine on the side of St. Joseph Peak which was worked for silver bearing galena.

Granites. There are numerous small granitic bodies occurring throughout the study area. The granitic rocks occur as dikes and sills and crosscut all other structures and lithologies. Most of these are probably closely related to the Idaho batholith, and their abundance increases as the batholith contact is approached. Granitic rocks typically consist of quartz (19% - 43%), plagioclase (16% - 40%), K-feldspar (23% - 42%), biotite (Trace - 15%), and rarely, muscovite. Quartz is

often strained as evidenced by sutured grain boundaries and undulose extinction. Plagioclase is typically oligoclase and may be slightly zoned and strained. K-feldspar is orthoclase and may be perthitic or poikilitic. Biotite is similar to that in the pelitic schist and quartzofeldspathic gneiss. Muscovite is not common in the granites examined. Accessory minerals include apatite, chlorite, zircon, sphene, garnet, magnetite and ilmenite. Texture is commonly granitic.

"Granitic" rocks ranged in composition from quartz monzonite to granite. Because of the distinct color difference, granitic units are much more obvious in the pelitic schist. Granitic units in quartzofeldspathic gneiss generally cannot be distinguished.

Anorthosite and amphibolite. Two of the more complex and interesting problems in the northern Bitterroot range are the occurrence and origin of the anorthosites and amphibolites, both of which occur in the present study area.

Amphibolite occurs throughout the study area in both the pelitic schist and the quartzofeldspathic gneiss. Amphibolites are slightly more common in the pelitic schist. Amphibolite units occur as discordant pods and lenses ranging in size from 1 meter to over 30 meters. Some amphibolites are spatially associated with pegmatites occurring as an irregular rim around a layer pegmatite body, possibly indicating some sort of a genetic relationship.

A typical amphibolite contains hornblende, \pm almandine, labradorite (An 55), quartz and magnetite-ilmenite. Amphibolites are commonly extremely poikiloblastic with quartz in hornblende. In the amphibolites examined there was no pattern to the inclusions.

The amphibolites in the northern Bitterroot range remain a promising area for further research. Some unanswered questions are: are all amphibolites meta diabases as suggested by Wehrenberg (1972) and Berg (1964)? Are there variations in the bulk chemistry and if so, what is their significance? Is there any connection between the amphibolites in the northern Bitterroot Range and a small ultramafic body (Jens, 1973) near Lolo Pass? A detailed study of the amphibolites could possibly answer these questions.

The anorthosites in the Bass Creek area have been the focus of much of the previous geologic investigations in the northern Bitterroot Range (Anderson, 1959; Berg, 1964; Cheney, 1972). Anorthosite is found in the present study area only in a small outcrop in the center of a large talus slope east of Lappi Lake. It may correlate with a body of anorthosite on the north side of Bass Creek mapped by Anderson (1959). In thin section the anorthosite has a dusty appearance due to sericitization of the plagioclase. Numerous anorthosite bodies occur outside the study area, both to the north and south. Some of these have been the subject of considerable study by Berg (1961, 1964) and Cheney (1972).

After studying the anorthosites, Berg and Cheney reached different conclusions on their origins. Berg (1964) concluded that the anorthosites were an anatectic residuum while Cheney (1972) concluded the anorthosite was intruded as a magma.

Both of these hypotheses raise problems. The anatectic residuum is rejected by Cheney primarily because field evidence suggests that the anorthosite predates the metamorphism. Cheney admits the problems involved in his own hypothesis, those being the high temperatures involved

(1100°C) and the "time problem". If the anorthosite is of similar age with other dated anorthosites, it is older than the Prichard formation and thus could not have been intruded into the Prichard. If it were intruded into the Prichard formation that would make it a good deal younger than other anorthosites. This dilemma could be resolved if what is called Prichard were in fact pre-Belt basement, however there is no evidence that this is the case. The high grade gneisses of the study area are not similar to descriptions of existing pre-Belt basement in Montana.

Field work by Berg (1964) and the author in the area south of the present study area (in the Kootenai and Big Creek area) reveals the anorthosites to be almost pencil shaped bodies which can be traced from one ridge to another in spite of the intervening glacial valleys. This pattern of occurrence does not necessarily argue against magmatic emplacement but rather for considerable displacement associated with the complex structural events in the area.

Frontal Zone Gneiss

While not occurring within the map area, the frontal zone is nonetheless an important unit for this study. The frontal zone gneiss occurs along the eastern front of the Bitterroot Range for a distance of nearly 75 miles. The frontal zone gneiss is considered to be a thick zone of cataclasis which resulted from gravity sliding of the Sapphire block eastward away from the Idaho batholith infrastructure (Hyndman, Talbot and Chase, 1975). The frontal zone gneiss is approximately 500 meters thick with a gradual transition to unshered rocks at the base of the frontal zone gneiss. The apparent thickness of the frontal zone gneiss is commonly thinner at higher elevations.

Rocks within the frontal zone gneiss are intensely deformed, a prominent foliation dips approximately 30° to the east as does a pervasive lineation caused by mineral streaking. Folds within the frontal zone gneiss deform the schistosity. In more quartz rich units the trace of a slight relict incipient axial plane schistosity is superimposed on the mineral streaking lineation. There are numerous zones within the frontal zone gneiss where deformation is both less and more intense than average. The frontal zone gneiss contains numerous concordant pods and lenses of pegmatite. Infrequent dark gray augen gneiss layers probably represent amphibolite layers.

The frontal zone gneiss is found cutting across a wide variety of rock types along the front of the Bitterroot Range. In the region near the present study it occurs within the pelitic schist and an orthogneiss. The pelitic schist is found in Bass Canyon while the orthogneiss is found in Larry Creek, a small creek one kilometer north of Bass Creek. Wehrenberg (1972, personal communication) has reported the occurrence of a similar rock type in Sweeney Creek as well, though not in the frontal zone.

In hand specimen the frontal zone gneiss varies considerably both in grain size and color. Grain size varies from medium grained to very fine grained in more intensely sheared layers. Color varies from the red brown typical of the pelitic schist and gray in more quartz rich horizons to a very dark gray in augen gneiss units. White "eyes" of quartz or feldspar are quite common.

In thin section the frontal zone gneiss shows obvious evidence of the intense deformation which it has undergone. All minerals in the frontal

zone show evidence of strong shearing. Both biotite and muscovite are strongly aligned. One sample displays prominent crush layering along the foliation. Both quartz and plagioclase are strained as evidenced by undulose extinction and deformed twin lamellae. Muscovite and biotite have also been strained and display uneven extinction.

In spite of its compositional similarity to the pelitic schist, in thin section the mineralogy of the frontal zone gneiss is suggestive of retrogressive metamorphism (Anderson, 1959). Biotite is pleochroic in green-light green rather than the red brown -- clear pleochroism common in the pelitic schist in the infrastructure. All samples examined lacked sillimanite. One sample displayed a garnet (Almandine?) which was badly fractured with quartz included in the garnet. Feldspars commonly display some sericitization which is probably responsible for the "dusty" appearance feldspars have in hand specimen. Some feldspar augen have completely altered to muscovite. Wehrenberg (1974, personal communication) reports an occurrence of kyanite in the Larry Creek area. The mineral assemblages now present are indicative of a grade of metamorphism no higher than the kyanite zone of the amphibolite facies and perhaps as low as the garnet zone of the greenschist facies.

To the east of the frontal zone is the fault zone which marks the front of the Bitterroot Range. The rock in the fault zone is highly altered and virtually disintegrates when struck with a hammer.

In hand specimen the rock is a waxey green to light green with no hint of an original texture. In thin section much the same is true, the rock being composed almost entirely of chlorite and calcite and showing no evidence of relict metamorphic texture.

Petrogenesis

Previous workers have correlated the quartzofeldspathic gneiss and pelitic schist with the Ravalli and Prichard formations of the Belt Supergroup. As Chase (1968) notes, this correlation should be considered tenuous as there are several units in the Belt with compositions similar to the pelitic schist and quartzofeldspathic gneiss. In the Lolo Peak area this correlation is based on relict bedding and structural considerations as well (Wehrenberg, 1972).

The pelitic schist, because of its compositional variation, its overall composition and the apparent lithologic layering is almost certainly of sedimentary parentage. The quartzofeldspathic gneiss occurs in two localities in the present study area. Verifying that these two occurrences in fact represent the same unit is difficult. There are differences in appearance between the two areas, but these probably represent only compositional variation and a difference in the degree of "marginal granitization". The possibility that the quartzofeldspathic gneiss in the Bass Lake area represents pre-Belt basement is intriguing, but remains unsubstantiated.

The sporadic occurrences of sillimanite-orthoclase assemblages in what are typically sillimanite-muscovite assemblages is explicable because commonly the muscovite is not in equilibrium. The lack of a well defined sillimanite-muscovite, sillimanite-orthoclase isograd in the Bass Lake area is probably due to the local zones of higher PH_2O (Evans and Guidotti, 1966). Adding to the complexity is the possibility that some structural events may post date the most intense metamorphism, further obscuring where the sillimanite-orthoclase sillimanite-muscovite isograd should be.

Variable pressure metamorphism has given rise to occurrences of kyanite and cordierite in micaceous layers within the anorthosites of Bass Canyon (Cheney, 1972). The occurrence of cordierite with sillimanite may be due to the rapid uplift of the Bitterroot Range concurrent with the last major episode of deformation (Cheney, 1972).

The occurrence of anatectic pegmatites in the quartzofeldspathic gneiss is evidenced by mafic selvages, lack of spatial relationship to the Idaho batholith, and their concordant nature. The possibility of "marginal granitization" and the mineral assemblages present suggest temperatures and pressures compatible with catazonal conditions adjacent to a granite batholith.

Rocks later to become the frontal zone were metamorphosed to the sillimanite-muscovite or sillimanite-orthoclase zone of the amphibolite facies by the same event. Following this, retrograde metamorphism took place during the intense shearing which marked the formation of the frontal zone gneiss. This retrograde event has left the frontal zone in several different metamorphic stages varying from the kyanite zone of the amphibolite facies to the garnet zone of the greenschist facies, (different portions of the frontal zone having undergone retrograde metamorphism in different degrees). Some further alteration followed the development of normal faults along the front of the Bitterroot Range. Rocks are highly chloritized and some mineralization occurred in these fault zones.

CHAPTER III

STRUCTURE

As noted below, the Bass Lake area retains the imprint of several major structural events.* In the metamorphic units, there are at least four major structural events; 1) events prior to the emplacement of the Idaho batholith, 2) events associated with the rise of the Idaho batholith, 3) events associated with the horizontal movement of material off the batholith (formation of the frontal zone gneiss), and 4) post frontal zone gneiss movements.

Structural work was done in both the frontal zone and in the quartzofeldspathic gneiss at Bass Lake. The quartzofeldspathic gneiss was chosen because it tends to more fully reflect the structural history (Chase, 1972 personal communication). Lineations, fold axes, and poles of foliation were plotted on the lower hemisphere of an equal area net.

Pre-batholith events within the metamorphic units of the northeast border zone have been studied by several authors, most notably Chase (1968, 1973), Nold (1968), and Cheney (1972). Norwick studied the lower Prichard formation metamorphism northwest of Missoula to the Canadian border (1972). Hietenan (1968) and Reid, et. al., (1973), among others,

*Throughout this chapter, the following notations will be used; S_0 -lithologic layering, S_1 -schistosity, S_2 -axial planes of small scale mesoscopic folds, L-lineations, F-axes of folds. Descriptive fold nomenclature is after Turner and Weiss (1963).

have done considerable work in other areas surrounding the Idaho batholith. Reid, et. al. (1973) postulate several pre-batholith structural and metamorphic events perhaps related to igneous intrusions determined by age dating. Norwick has evidence for amphibolite grade load metamorphism within some parts of the Prichard during Precambrian time. This probably represents the earliest known pre-batholith event. Chase (1968, 1973) provides the most complete summary to date on structural events in the northern Bitterroot Range. In the area directly south of Bass Lake in the Kootenai Lakes area, Chase observed the earlier deformation (F_1) marked by a parallelism of the schistosity (S_1) and lithologic layering. A second generation of folds (F_2) in the Kootenai Lakes area is represented both by a mica schistosity parallel to lithologic layering around fold noses and by the development of a new axial plane schistosity. Near South Kootenai Lake, the F_2 fold axis now plunges 65 S45W. The schistosity (S_1) predates the F_2 event. A third folding event F_3 is characterized by flexural slip folds which deform F_2 folds and locally develop axial plane schistosity. The F_3 event is probably concurrent with the emplacement of the Idaho batholith (Chase, 1968). Chase (1968) and Wehrenberg (1972) note an F_4 deformation marked by broad warping.

Structural Analysis in the Quartzofeldspathic Gneiss

Structural analysis in the quartzofeldspathic gneiss is complicated both by the lack of suitable outcrop for a three dimensional view of structures and by the extent of "marginal granitization" in the Bass

Lake area where structural work on the infrastructure was done. Folds in the quartzofeldspathic gneiss (see Figures 3 and 4) are typically expressed by biotite layers within the gneiss. Where not outlined by biotite, folds are nearly impossible to detect. Folds are variable in style but most commonly they are tightly appressed rootless intrafolial folds. Other folds display incipient axial plane schistosity. Some of the rootless intrafolial folds are arranged en echelon with discontinuities (see Figure 4) suggesting a shear component was present during transposition. There appears to have been considerable flowage associated with this transposition. Considerable pegmatitic material often ptygmatically folded is also present in the quartzofeldspathic gneiss.

While there appear to be at least two episodes of folding in the quartzofeldspathic gneiss, interpretation is complicated by the lack of differentiation of their orientations (see Figures 5B and 5D). Measured fold axes reveal only a diffuse maximum within a plane, which is also the schistosity. There are two possible explanations for a fold pattern of this type. The first is an earlier set of folds which have been transposed by large amounts of shear into parallelism with the shear direction. Alternatively later folds have been superimposed on a large earlier fold. Lacking evidence of overprinting it is necessary to rely on earlier structural analyses to decide which of the above possibilities is more likely. The second possibility is less likely because folds in the area studied show evidence of deformation and flowage. If these were later folds then an additional deformation would have to be proposed. Any large fold which could produce the pattern in Figure 5B would be at an angle to prevailing structures and outcrop patterns. There is no evidence to

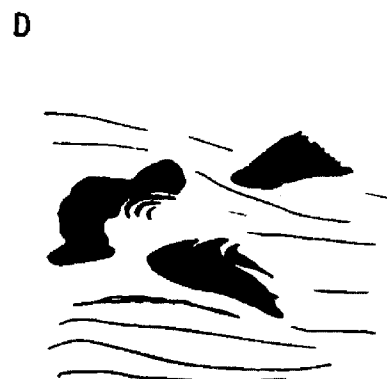
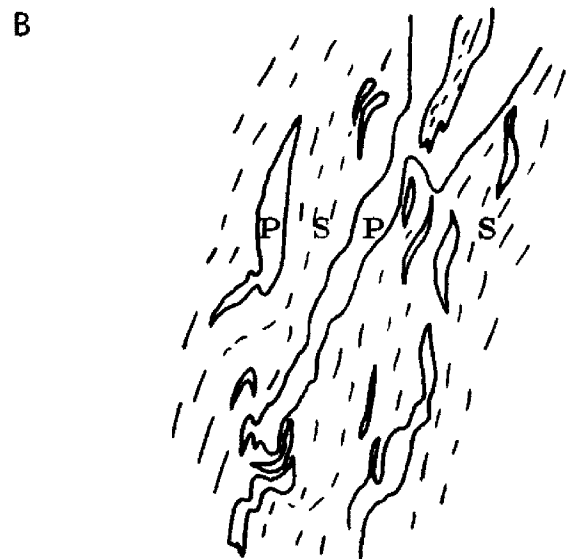
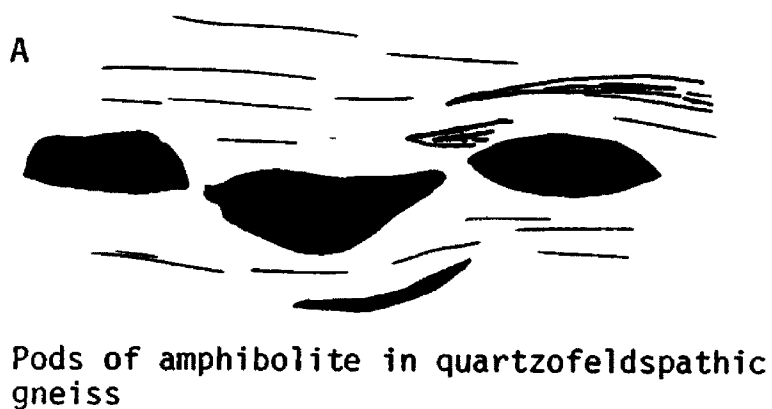
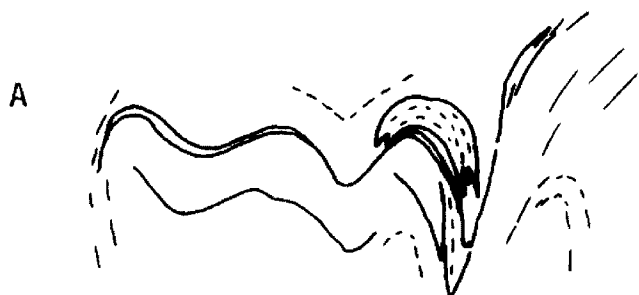
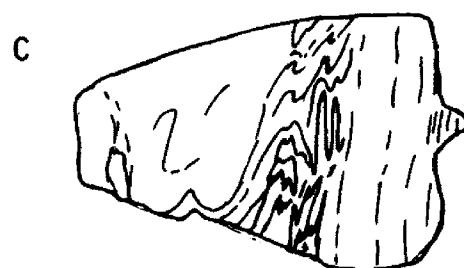


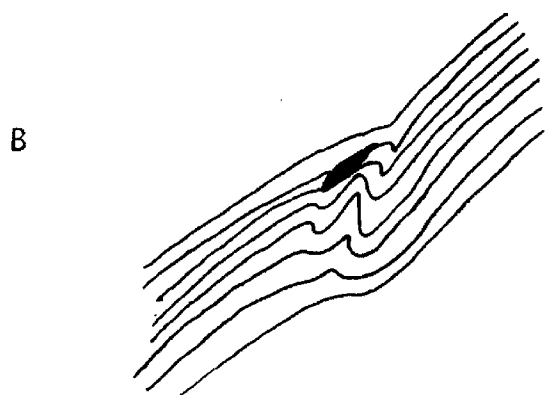
Fig. 3--Structures in Quartzofeldspathic Gneiss and Pelitic Schist.
Bar equals 1 meter.



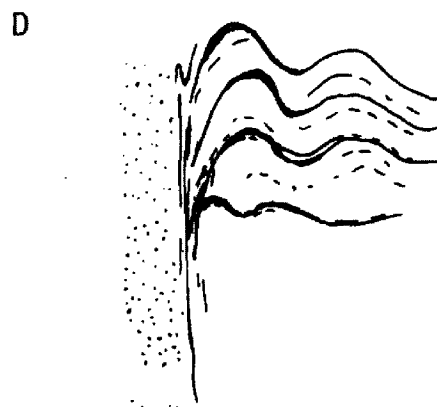
Folds in quartzofeldspathic gneiss
Bass Lake area.



Folds in a boulder of highly
deformed quartzofeldspathic
gneiss.



Folds in a more pelitic part of the
quartzofeldspathic gneiss in the
Bass Lake area, small dark pod is
pegmatite.

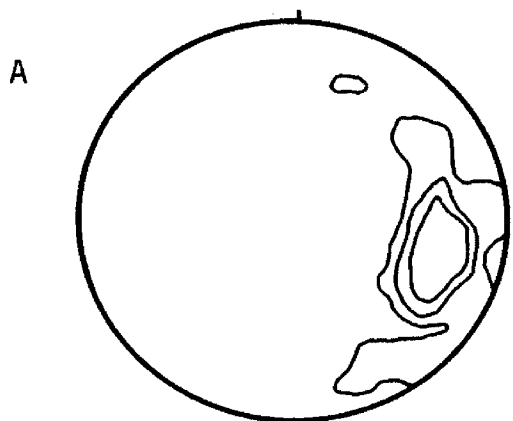


Small granitic dike adjacent
to folded quartzofeldspathic
gneiss in the Bass Lake area.

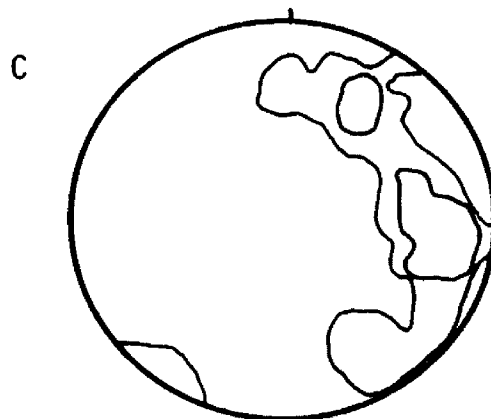
Fig. 4.--Structures in Quartzofeldspathic Gneiss.
Bar equals 1 meter.

support this. More likely, during the formation of the large scale folds proposed, earlier folds were transposed by large amounts of shear to produce the fold pattern in Figure 5B. A slight variation between the dip of the folds and the foliation may represent incomplete transposition or a local variation in either the folds or the foliation. The transposed folds probably represent the F_2 and F_3 of Chase (1968, 1973). Other fold types occur too infrequently to make generalizations about them.

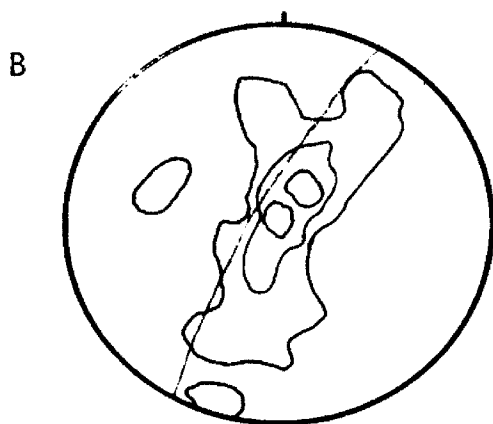
Microscopic examination adds little additional evidence on the structural history of the quartzofeldspathic gneiss. In thin section, S_1 has been subsequently deformed in kinks or small chevron folds, biotite and muscovite have been recrystallized into polygonal arcs indicating some post kinematic recrystallization. Some micas in polygonal arcs display uneven extinction. This is probably due to some later relatively minor movement. Porphyroblasts display no internal fabric regardless of which unit they occur within. Other microscopic features are discussed in the petrology section. Chase (1968, 1973) and Nold find the emplacement of the Idaho batholith postdates the penetrative deformation and regional metamorphism. In the Bass Lake area, there are at least two generations of pegmatites. An anatectic pegmatite is evidenced by a lack of spatial relationship to the Idaho batholith, mafic selvages and a concordant appearance. Less common are pegmatites lacking mafic selvages. Pegmatites are commonly parallel to layering and schistosity (see Figure 3B), and have been subsequently folded and boudined by structural events which postdate the early transposition (F_1). Later granitic dikes truncate all structures and appear unfolded.



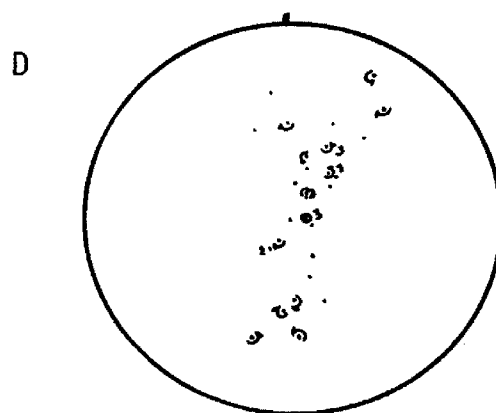
Type I fold axes in the Bass Creek area frontal zone gneiss.
60 points



Type I fold axes in the Larry Creek area frontal zone gneiss.
28 points

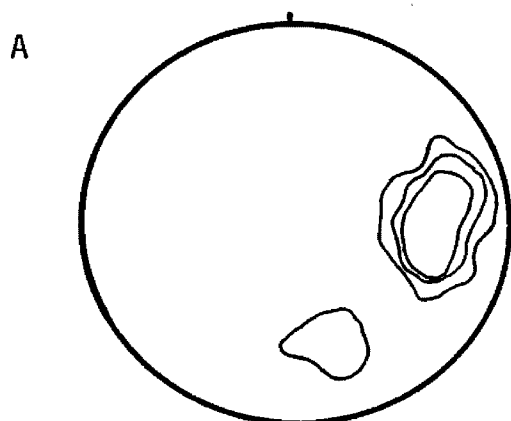


Fold axes in the Bass Lake area,
quartzofeldspathic gneiss.
44
Great circle represents the approxi-
mate foliation in the Bass Lake area.

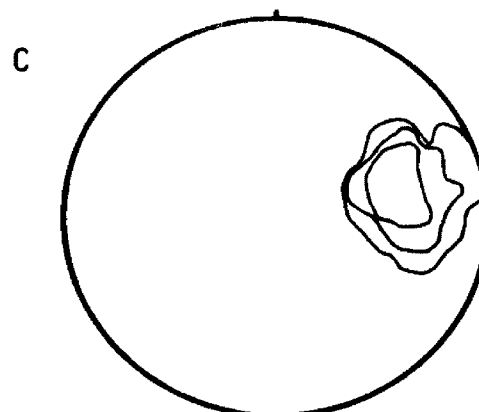


Fold axes in the Bass Lake area showing asymmetry.

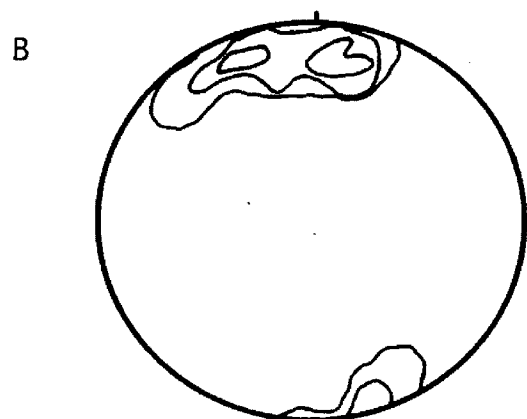
Fig. 5--Stereographic projections of structural data contoured at 1%, 5%, and 10% area. 5D is a plot of individual fold axes in the Bass Lake area showing the direction of asymmetry.



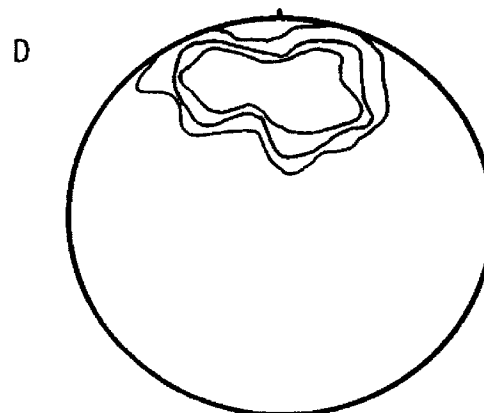
Lineations in the Bass Creek area,
frontal zone gneiss.
21 points



Lineations in the Larry Creek
area, frontal zone gneiss.
13 points



Type II folds in the Bass Creek
area, frontal zone gneiss.
11 points



Type II folds in the Larry Creek
area, frontal zone gneiss.
20 points

Fig. 6--Stereographic projections of structural data other than Type I
folds contoured at 1%, 5%, and 10% area.

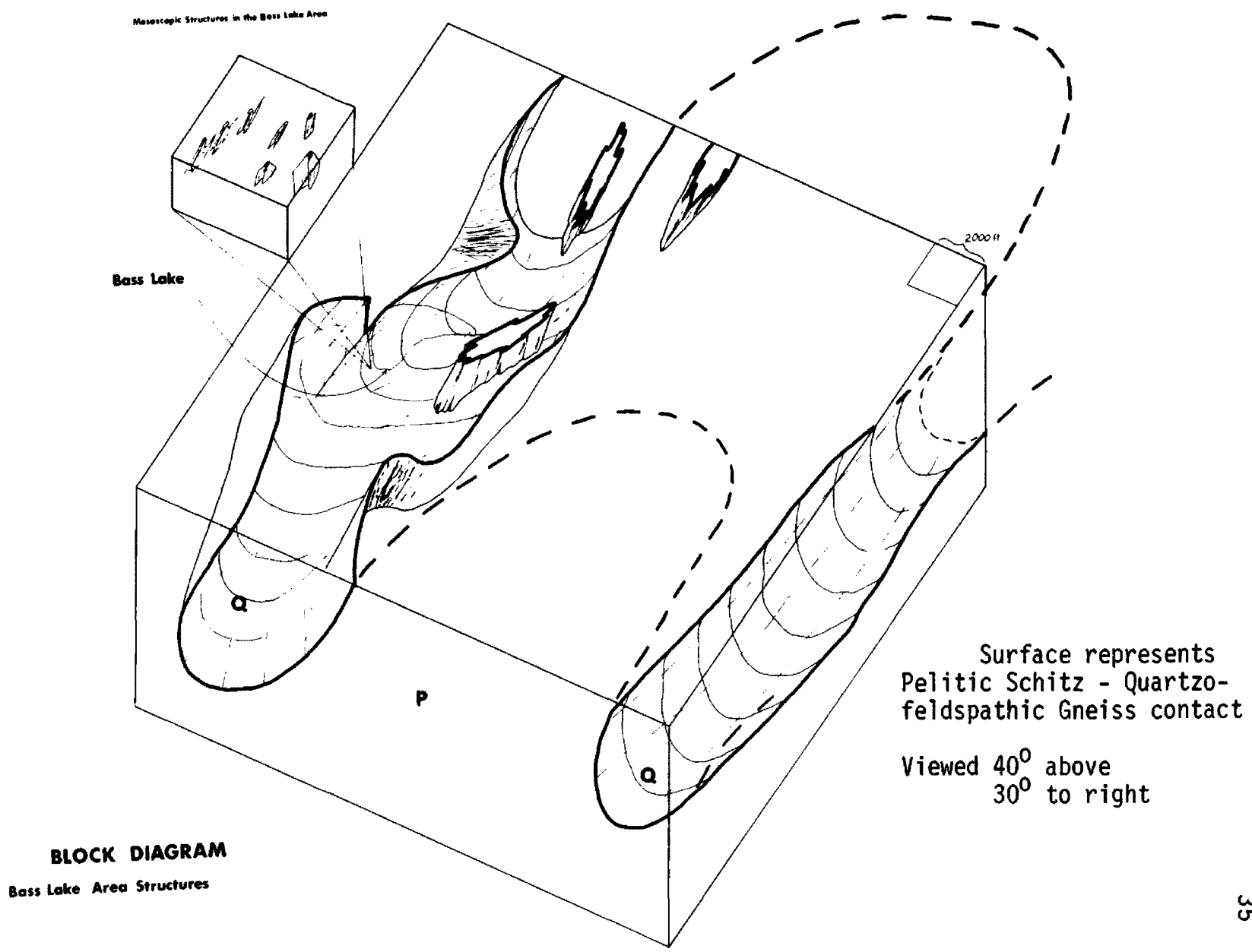
F_2 and F_3 folding were prior to a proposed macrofolding involving both the pelitic schist and the quartzofeldspathic gneiss. This fold or series of folds is a large scale similar style fold trending approximately N30E and represents the core of a nappe type structure. The fold appears to plunge to the south and the axial plane dips steeply to the west (Figure 7). Considerable flowage and displacement is associated with this folding as evidenced by numerous slivers of one unit interlayered with the other unit for most of the length of the contact. The slivers, or inliers, of pelitic schist shown in Figure 7 east of Bass and Sweeney Lakes are indicative of the shearing movements. Chase (1973, personal communication) reports folds similar to those in the Bass Lake area in the St. Mary peak area, about 5-6 kilometers to the south of Bass Creek. Folds in the St. Mary peak area fold the same units as those in the Bass Lake area. In addition, Chase reports an accumulation of granitic material in the core zones of his structures. In the Bass Lake area, the amount of granitic material in the quartzofeldspathic gneiss is compatible with the above observation on the folds (refer back to Table 1). Evidence for the Bass Lake synform is based on the observed outcrop pattern, the correlation of the quartzofeldspathic gneiss in the Bass Lake area with the quartzofeldspathic gneiss occurring east of Lappi Lake (see Figure 7 and map), and minor structures in the Bass Lake area as shown in Figure 7. Minor structures (see inset, Figure 8 and Figures 5B and D) lie approximately in the great circle defined by the axial plane (surface) of the synform. These structures represent the F_2 and F_3 of Chase (1968, 1973) and have been transposed during the proposed folding to produce their present pattern.

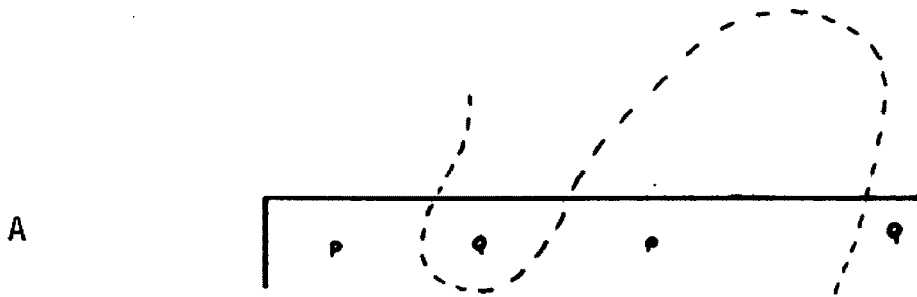
Alternate explanations of the observed outcrop pattern include; two pelitic schist units rather than one (Figure 8C), two quartzofeldspathic gneiss units, one of which represents pre-Belt basement (Figure 8B), or no fold at all, merely a tilted series of beds with two pelitic schist units and two quartzofeldspathic gneiss units (Figure 8D). Other explanations would need to be more complex. The above explanations, C and D, are unsatisfactory for stratigraphic reasons as, in the northern Bitterroot Range, evidence suggests only the lowermost Belt units are in contact with the Idaho batholith (Wehrenberg, 1972; Chase, 1968, 1973). Within the lower part of the Belt Supergroup there is no sequence of units similar to those pictures in 8C and 8D. Descriptions of preBelt basement from both Idaho and Montana are not especially similar to the quartzofeldspathic gneiss. However, Reid, et. al. (1973) are able to distinguish pre-Belt basement only on the basis of age dates and since very little age dating work has been done in the Bitterroot Range, no definitive conclusion is possible.

While large scale nappe and gravity gliding structures are common in many of the world's deformed belts (Kern and Martin, 1959, Geze, de Sitter and Trumphy, 1952; Scholten and Ramspott, 1968; Mudge, 1970; Price, 1969, 1971; and Robinson, Klepper and Obradovich, 1968), nappe structures in a tectonic position similar to those in the northern Bitterroot Range are not common. In the northern Bitterroots, a belt of nappe type structures exists in the metamorphic units in contact with the Idaho batholith adjacent to the northeastern border of the batholith trending roughly parallel to the border of the batholith. The rising batholith provided the needed gravitational potential for movement to take place.

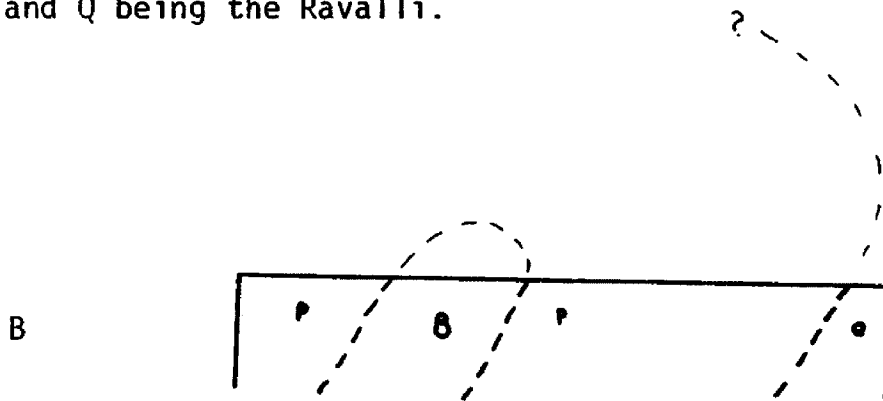
In this case, there is no need for lengthy thrust planes. Material has slid directly off the rising batholith. This sliding involves a complex series of events featuring folding and sliding, perhaps involving more than one period of sliding. The local effects of this are the formation of the frontal zone gneiss and the belt of nappe type structures in the infrastructure units in the northern Bitterroot range. Effects farther away are found in the numerous west dipping thrust plates. These extend for considerable distance to the east, more than 100 kilometers if the farthest estimate is used (Scholten, 1968; Chase and Talbot, 1973).

The proposed folds, frontal zone gneiss and thrust sheets are part of a sequence of events caused by the rise of the Idaho batholith, the exact form this rise manifested itself depending on the temperature and depth the batholith had attained.

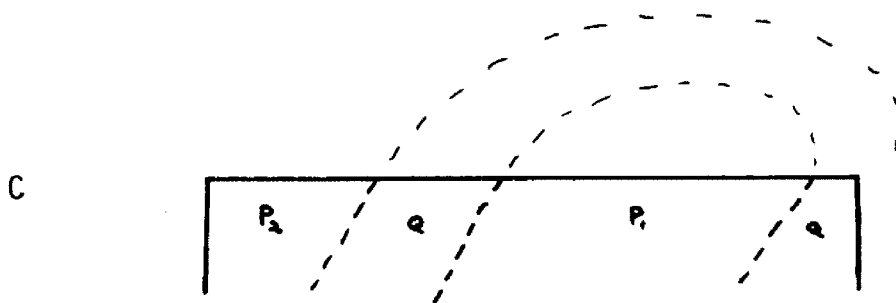




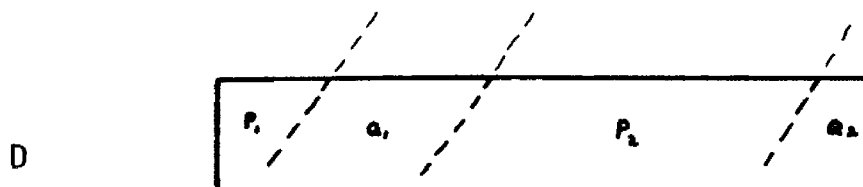
Case A is the hypothesis put forth in this thesis, P being the Prichard and Q being the Ravalli.



Possible alternative explanation based on the existence of pre-Belt basement (B), P again being Prichard and Q, Ravalli.



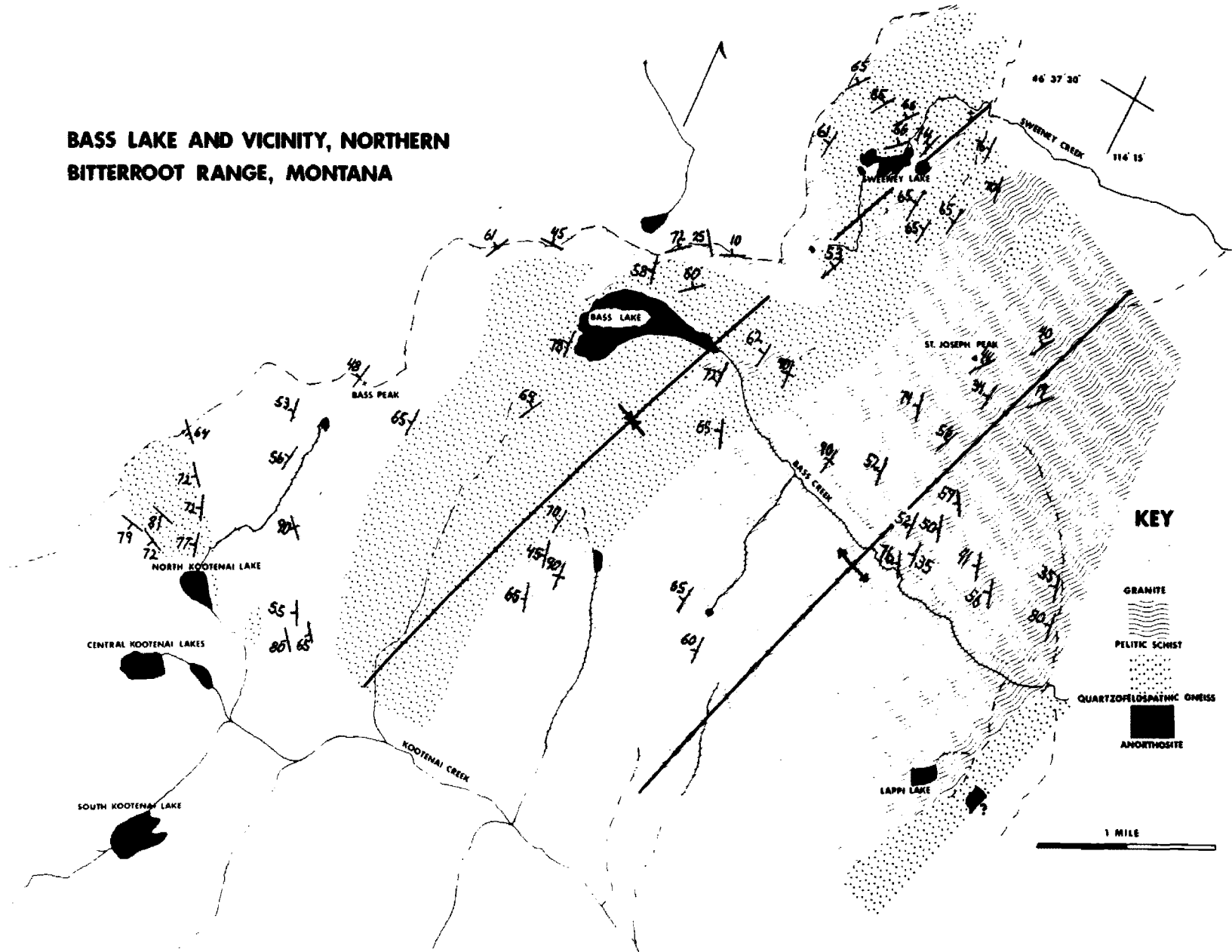
Another alternative having 2 pelitic schist units.



An alternative based on having 4 different units.

Fig. 8--Explanation of outcrop pattern.

**BASS LAKE AND VICINITY, NORTHERN
BITTERROOT RANGE, MONTANA**



Structural Analysis in the Frontal Zone Gneiss

The formation of the frontal zone gneiss is the post batholith event of greatest significance in the Bitterroot range. Structures in the frontal zone are more numerous, more consistent and more spectacular than in the units west of (structurally below) the frontal zone. Prominent structures in the frontal zone are a pervasive lineation trending down dip within the foliation (see Figures 6A and 6C) and a set of folds sub-parallel to the lineation. These folds have been called the Type I folds (see Figures 5A and 5C). In a case such as this, the lineation represents the movement direction, and the foliation the movement plane (Hansen, 1971).

Folds within the frontal zone gneiss lie generally within a plane (Figures 5A and 5C). The great circle defined by the folds is essentially parallel to that defined by the movement plane. Any hypothesis seeking to explain these folds must take this into account. The folds in the frontal zone have either been created parallel to the movement direction or they must have been rotated into parallelism. If the folds were formed during the development of the frontal zone gneiss, it is difficult to explain why they form a great circle pattern. However, if the folds were rotated, it becomes possible to explain the observed pattern. Because of the complexities involved, it is difficult to determine the exact sequence of events in this rotation. However, folds within the infrastructure units, probably the F_2 and F_3 folds, were rotated by rigid body rotation and smeared into parallelism with the movement direction, not necessarily in that order.

Making some assumptions, it is possible to calculate the minimum movement needed to rotate folds into their present orientation. These calculations are based on a simple shear model. The model assumes ho-

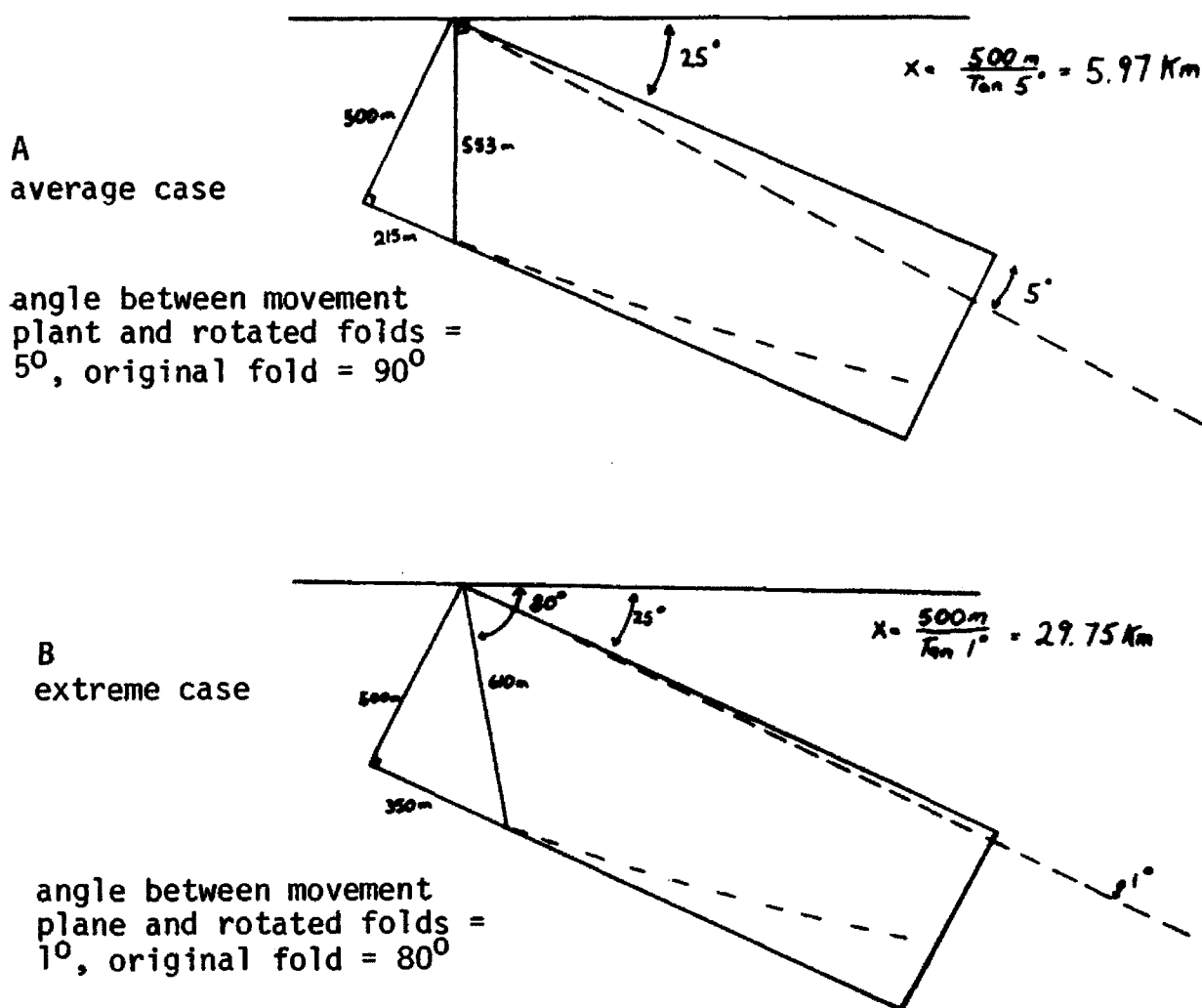


Fig. 9--Calculation of movement needed for rotation of folds

monogeneous movement within a 500 meter thick zone dipping 25° to the west. Case A represents a typical case for the Bass Creek area; a near vertical fold rotated to within 5° of the movement plane. Case B represents a less typical but still possible occurrence; a fold plunging 80° to the east and

rotated to within 1° of the movement plane. These conditions represent normal variation in the folds measured. These calculations give movements of 5.97 Km and 29.75 Km respectively. This represents a range for movement in the frontal zone but does not necessarily represent the total amount of movement involved in material sliding off the batholith as other zones may have been present but have been eroded away.

The sub-parallel, or Type I, folds are typically moderately tight similar style folds. A second fold type was called Type II and postdates the Type I folds (see Figures 6B and 6D). The Type II folds are quite open similar style folds. This fold type is of less importance and probably developed during the last stages of frontal zone movement. That the Type II folds postdate the more pronounced Type I is evidenced by overprinting.

The Type II folds are more common in Larry Creek, a small creek approximately 1 kilometer north of Bass Creek. The frontal zone in Larry Creek cuts through a more uniform rock type than the frontal zone in Bass Creek. This unit may be an orthogneiss. The difference in lithology may explain why Type I folds are less common in Larry Creek. Lineations in Larry Creek are quite similar to those in Bass Creek (see Figures 6A and 6C). The slight variation is probably due to the fact that movement in the frontal zone was not homogeneous, some units showing more intense shearing than others. The variation may also be an expression of a slight northward component to the movement.

In the Bass Creek area, micaceous layers within the frontal zone display crenulations transverse to the direction of tectonic transport (30° to the east). These crenulations represent late frontal zone movement

similar to the Type II folds. That the frontal zone movement is expressed in these differing styles reflects the variations in lithology and intensity of shearing. The more micaceous layers in the frontal zone are commonly the most heavily sheared. Pegmatites, which are common in the frontal zone form boudins and lenses along the movement plane. Groff (1954) reported pegmatite cutting across frontal zone structures in Kootenai Creek, south of Bass Creek. Anderson (1959) and the present author did not observe this in Bass Creek.

An extensive thin section study of the frontal zone gneiss was not within the scope of this project. Thin sections which were examined suggest the following: late frontal zone movement is evidenced by uneven extinction in micas and feldspars and undulose extinction in micas. Strongly folded quartz rich units of the pelitic schist have maintained an incipient axial plane schistosity which is very rarely visible as a lineation in hand specimen. This is probably a relict infrastructure structure. Some K-feldspar augen have been altered to muscovite. The muscovite in these augen has been strongly oriented during frontal zone movement. Some retrograde features as discussed in the petrology section are also present.

The frontal zone represents a zone of substantial movement. Exactly how much movement has taken place is difficult to determine; however, the present author would be skeptical of assigning more than 20 kilometers of movement to the frontal zone as studied. This is on the basis of correlations in the Kootenai Creek area by Chase (1973, personal communication) and on the basis of the structural work done for this project. However,

the possibility of other zones of movement which were at one time above the frontal zone can not be discounted.

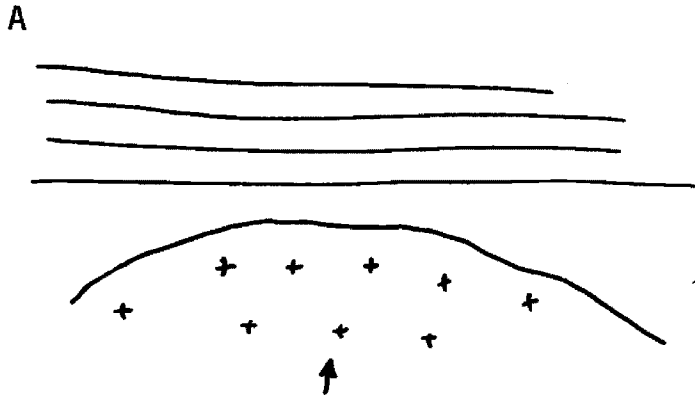
CHAPTER IV

STRUCTURAL ANALYSIS-INTERPRETIVE

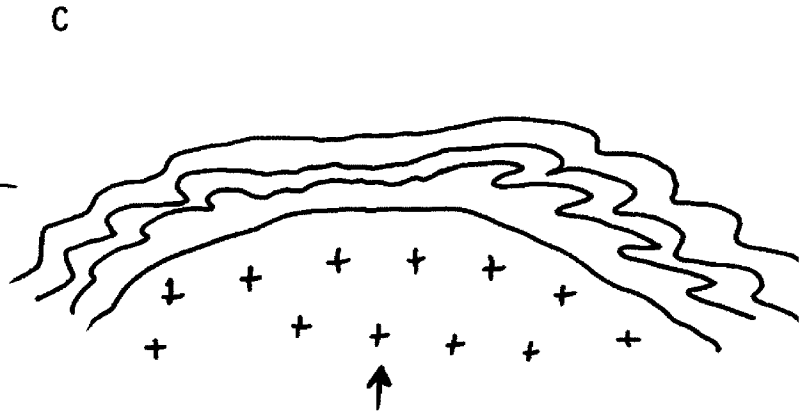
An interpretive structural analysis in the Bass Lake area must bring together the following structural information. These are: the detailed structural work done by Chase (1968, 1973) to the south, the detailed structural work done for this project, the frontal zone gneiss and the belt of anorthosites which exists to the east of the area mapped and extends south to the area mapped by Chase (1968, 1973). The anorthosites appear to be cylindrical bodies and extend across drainages (Berg, 1969). Cheney (1972) worked extensively in an anorthosite in the Bass Creek area and concluded it was intruded as a magma just prior to the last major episode of deformation. Since the last major episode of deformation is associated with the emplacement of the Idaho batholith, the anorthosite must be Cretaceous in age. If so, it represents a truly unique occurrence of anorthosite since post Precambrian anorthosites are more commonly associated with ultramafic intrusions.

Structures in the present study area have not been affected by the anorthosite to the east.

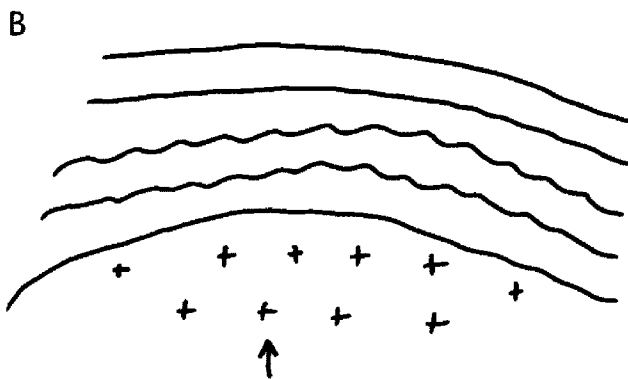
While direct evidence for the F_2 and F_3 events of Chase (1968, 1973) is obscured by later folding and related marginal granitization, there is no reason to believe that these fold episodes are absent in the Bass Lake area. As pointed out earlier, the diffuse maxima spread along the great



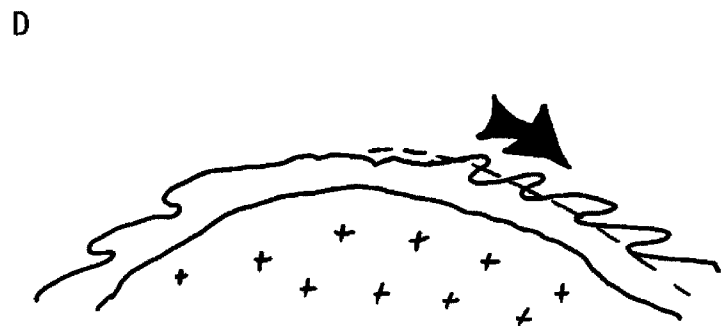
Idaho batholith in early stages of intrusion rising towards relatively undeformed Belt sediments.



Continued uplift causes some of the infrastructure to begin to move off the top of the batholith. This marks the most intense metamorphism and the development of nappe like structures.



With continued upward movement, the batholith begins to metamorphose the lower units of the Belt. These units will become part of the infrastructure.



A period of rapid uplift and cooling changes the style of deformation from plastic to a more brittle type. This is the formation of the frontal zone gneiss.

Fig. 10.--Model for Evolution of Structures

circle which approximates the foliation in the Bass Lake area (see Figures 5B and 5D) probably represents a transposition of these earlier folds. Combining structural work done by previous authors with structural work done for this project, it is possible to postulate the following structural events: F_1 is marked by a parallelism of mica schistosity and lithologic layering (Chase, 1968, 1973), F_2 folds show mica schistosity of the first episode parallel to lithologic layering around fold noses with some development of a new axial plane schistosity, F_3 folds are evidenced by deformation of F_2 folds and local development of incipient axial plane schistosity. Chase (1968, 1973) and Wehrenberg (1972) postulate an F_4 characterized by broad folding. A wide enough area was not studied in the Bass Lake area to confirm this. In the Bass Lake area, F_4 folding is characterized by the development of nappe type structures, as shown in Figure 8. F_5 folding represents the development of the frontal zone gneiss with rotation and smearing of earlier features. F_6 is a minor event marked by a small series of crenulations and folds transverse to the frontal zone movement direction. Following this, the frontal zone gneiss was cut by high angle normal faults which fixed the position of the front of the Bitterroot Range (Wehrenberg, 1972).

The exact sequence of metamorphic events is equally difficult to decipher. Norwick (1972) found evidence for Precambrian amphibolite grade load metamorphism in portions of the Prichard. In the high grade rocks surrounding the Idaho batholith, this evidence is undoubtedly obscured by later events. The presence of sillimanite within the schistosity indicates that the metamorphic grade probably attained amphibolite facies during the

F₁ event. The presence of folds outlined by sillimanite indicates that the metamorphic grade had certainly passed through the upper amphibolite facies sometime prior to the termination of F₄ folding. Micas which have formed polygonal arcs indicate a post strain thermal event, perhaps final emplacement of the Idaho batholith. Uneven extinction in these micas probably represents a later minor event. Combining the above with previous work, it is possible to postulate a sequence of events in the Bass Lake area.

During the early stages of the emplacement, the Idaho batholith was moving upwards towards relatively flat lying units of the Precambrian Belt Supergroup (see Figure 10A). Continued upward movement began to impart a gravitational potential to the Belt units, some of which by now represent infrastructure (Figure 10B); in addition, metamorphism was approaching sillimanite grade. With further rise, the Belt units began to move off the Idaho batholith as shown in Figure 10C. The maximum metamorphic intensity (sillimanite-orthoclase) was reached during this phase (F₄ folding). This phase also marked the development of the nappe type structures. There were at least two fold episodes prior to the development of the nappe type structures. Uplift continued in spite of a general decline in temperatures. In fact, the occurrence of cordierite and andalusite in the anorthosites in Bass Canyon may indicate that uplift become extremely rapid at this time (Cheney, 1972). With this uplift came a general decrease in temperatures and a change in the style of deformation. The style of deformation changed from a plastic type evidenced by the nappe type structures, to one or more zones of movement (Figure 10D), this being the formation of the frontal

zone gneiss. Associated with the formation of the frontal zone gneiss was a retrograde metamorphism which varied considerably within the frontal zone gneiss. Material slid off the top of the Idaho batholith to the east during this period. Further cooling and continued uplift was accommodated by faulting, these faults being the range front faulting and the Mormon Saddle fault. Some later alteration has developed along the range front faults.

CHAPTER V
SUMMARY AND CONCLUSION

Rocks of the Prichard and Ravalli formations of the Belt Supergroup are exposed to the northeast of the border of the Idaho batholith. Rocks of both units are metamorphosed to the sillimanite-orthoclase and sillimanite-muscovite zones of the amphibolite facies and are compatible with conditions expected adjacent to a catazonal granitic intrusion. Concordant and discordant pods of amphibolite and calc-silicate gneiss are present in the metamorphic units. Deformed anorthosites are also present. The rocks have been subjected to an extended period of prograde metamorphism followed by a period of rapid uplift which has produced some retrograde effects.

The rocks have undergone a very complex series of structural events which include at least two episodes of mesoscopic folding, one of macroscopic folding and the formation of a zone of intense shearing caused by the gravity induced removal of material off the top of the Idaho batholith.

Structural work shows that the mesoscopic folds have been transposed into the foliation during the macroscopic folding and now define only a weak maxima within the foliation plane. Considerable "marginal granitization" is associated with this macroscopic folding, granitic material tending to accumulate in the core zones of the macroscopic folds.

Following the formation of the macroscopic folds, continued uplift and a general decrease in temperatures caused a distinct change in the style

of deformation from a fairly plastic style of deformation to one characteristic of a more brittle environment. This change in style is marked by the development of the shear zone known as the frontal zone gneiss.

Structural work in the frontal zone gneiss shows that pre-frontal zone structures have been rotated by a rigid body rotation and subsequently smeared out along the movement plane which can be defined by lineations within the foliation plane. Following the development of the frontal zone gneiss, the front of the Bitterroot Range was cut by high angle normal faults. Later fluids migrating along these fault planes have altered the rocks near the fault zones.

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