1975

A section of the northern boundary of the Sapphire tectonic block

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A SECTION OF THE NORTHERN BOUNDARY

OF THE SAPPHIRE TECTONIC BLOCK

By

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A.B., University of California, Berkeley Campus, 1973

Presented in partial fulfillment of the requirements

for the degree of

Master of Arts

UNIVERSITY OF MONTANA

1975

Approved by:

Chairman, Board of Examiners

Dean, Graduate School

June 10, 1975

Date

Desormier, William L, M.A., Summer 1975 Geology

A Section of the Northern Boundary of the Sapphire Tectonic Block (65 pp.)

Director: James L. Talbot JLT

As a consequence of the rise of the Bitterroot dome of the Idaho batholith (an integral part of the Cordilleran orogenic belt) the Sapphire gravity slide block formed and now lies immediately to the east. The intersection of the northern boundary of the Sapphire block and the Lewis and Clark line (a broad zone of linear structures in northwestern Montana) lies within the study area. This study attempts to determine the precise structural relationships between the northern boundary and the Lewis and Clark line.

The study area, the Clinton-Rock Creek area, lies in Missoula and Granite Counties some thirty kilometers southeast of Missoula, Montana. A three-hundred and fifty square kilometer area was mapped during approximately 90 days spent in the field in the summer of 1974. The field work consisted of mapping the structures, delineating the stratigraphy, and measuring stratigraphic sections. The laboratory work consisted mainly of locating large scale structures on air photos and determining statistical structural relations.

The data collected during the study suggest that the Cretaceous Sapphire block overrode the Pre-existing northwest trending Lewis and Clark line structures in the Clinton-Rock Creek area, and was in turn cut and offset, during the Oligocene or Miocene (?), by the reactivated Lewis and Clark line. Although (in the Clinton-Rock Creek area) the northern boundary of the Sapphire block is an entire zone, greater than 18 km wide and consists of at least 6 reverse faults, the precise location of the northern boundary is defined as the northern-most fault, the Blackfoot-Cramer Creek fault. The dominant structures within the zone of the northern boundary are northwest-southeast trending high-angle southwest dipping reverse faults, and the subparallel gently plunging tight drag folds associated with these faults. The structures within the zone of the northern boundary indicate a dominant northeastward to east-northeastward movement direction and a minimum of 8 km of total stratigraphic separation in a northeastward direction.

ACKNOWLEDGEMENTS

The principal financial support was from a National Science Foundation Grant GA 14401 awarded to Dr. James L. Talbot of the University of Montana and Dr. Ronald B. Chase of Western Michigan University. Partial field expenses were furnished through a Grant-in-Aid of Research from Sigma XI, The Scientific Research Society of North America. Air photos and several necessary maps were provided by the United States Forest Service.

I would like to express my appreciation to Gary Morrison of the United States Forest Service, the Bob Wheeler family who sheltered me during part of the field season, Tim Lindsey and Dr. James A. Peterson who helped measure and describe the stratigraphic sections, Dr. Donald Winston for his constructive criticism on the stratigraphy chapter, the faculty, students, and staff of the University of Montana who contributed to the completion of this project, and the kind Montanans who gave access to their property.

I am especially indebted to Dr. James L. Talbot for his encouragement, valuable criticism, and untiring guidance, and to my wife, Patricia and my children, Shelly, Brandi, and Alisa for their many sacrifices.

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INTRODUCTION

REGIONAL SETTING

The Idaho batholith, a large catazonal pluton, and its related features are integral parts of the Cordilleran orogenic belt (Fig. 1). As a consequence of the rise of the Bitterroot dome of the Idaho batholith, the Sapphire gravity slide block formed and now lies immediately to the east (Fig. 2).

According to Hyndman, Talbot, and Chase (1975), the Sapphire block, a 100 km north-south by 75 km east-west block, moved approximately 25 km eastward. The block is internally coherent with deformation largely restricted to the boundaries. The western boundary of the block is essentially a 100 km north-south zone of cataclasis along the western edge of the Bitterroot Valley (Fig. 2). This zone dips 20-25^{o} east and is approximately 300-850 m thick. The southern boundary of the Sapphire block is largely concealed by syn- to post-tectonic plutonism, although the western section of this boundary is defined as the sillimanite isograd. The eastern boundary of the Sapphire block is expressed as a zone of north-south trending thrust faults and appressed folds lying within the Flint Creek Range. The northern boundary of the Sapphire block is the zone of east-west high-angle reverse faults just south and east of Missoula, Montana. A

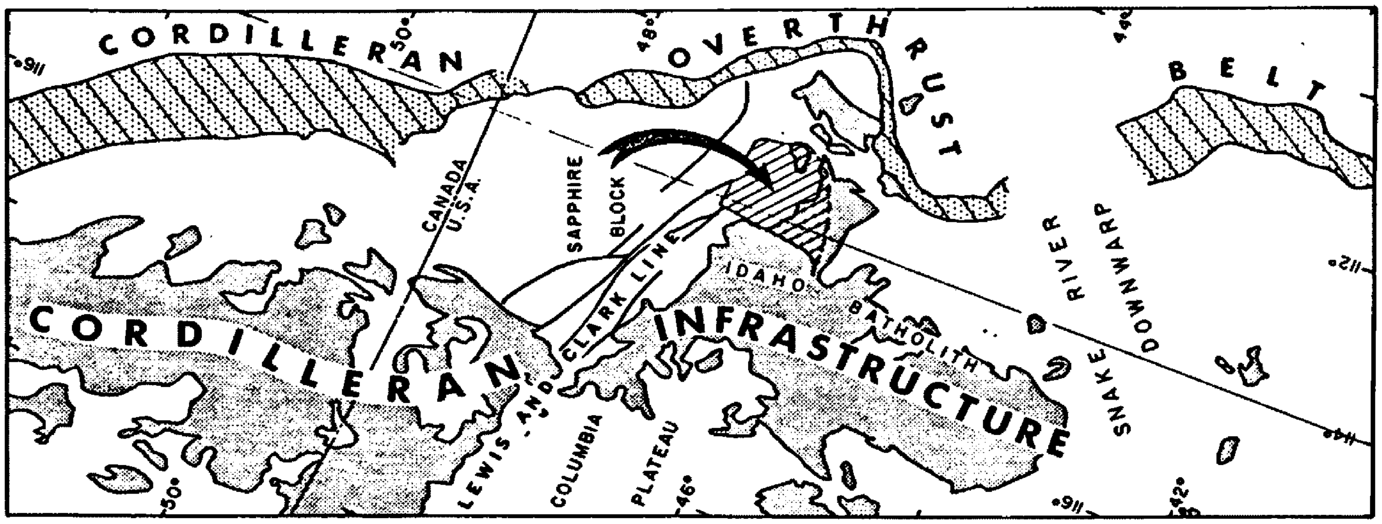
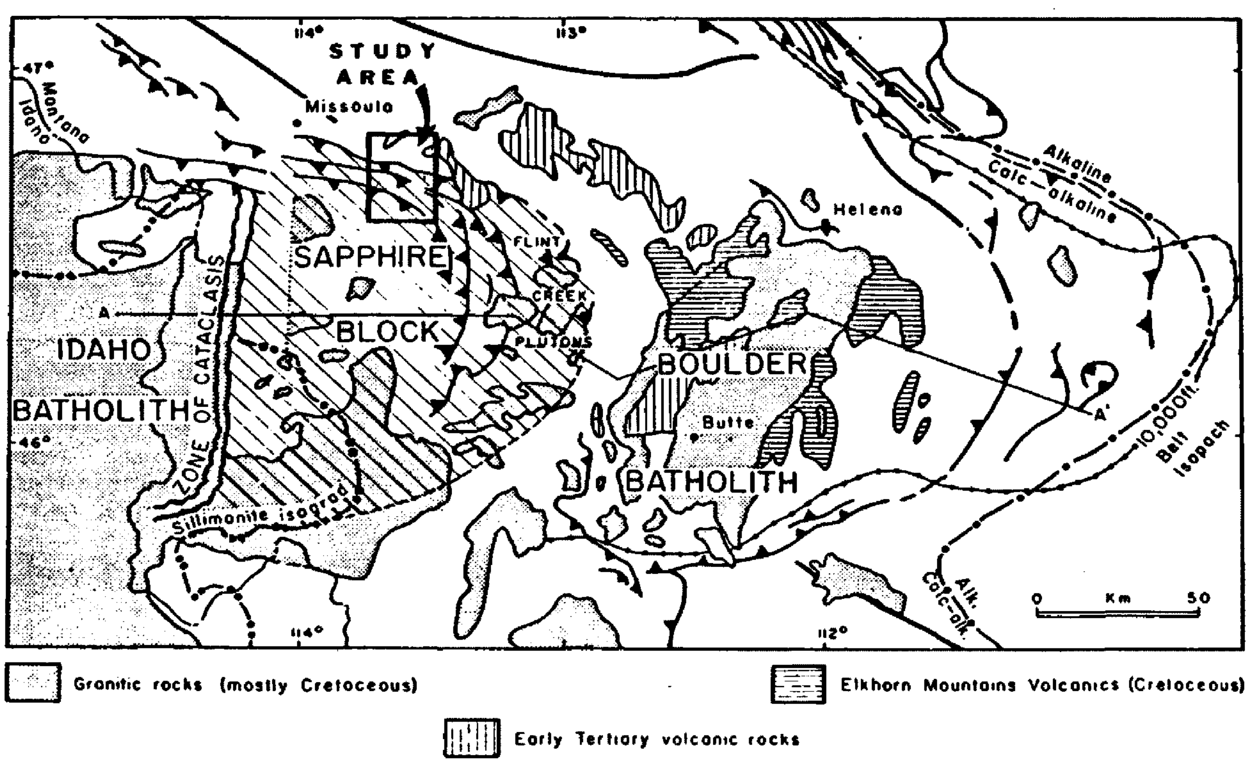


Figure 1. Location of the Sapphire block within part of the Cordilleran orogenic belt. From Hyndman, Talbot, and Chase (1975).

Figure 2. Index map (from Hyndman, Talbot, and Chase, 1975) with location of present study area.



section of the northern boundary lies within the study area (See inset Fig. 2).

The study area lies approximately 30 km southeast of Missoula, Montana and comprises some 350 km^2 in Missoula and Granite Counties (Fig. 3). The junction of the Clark Fork River and Rock Creek is approximately in the middle of the area. The main drainage of the area, the Clark Fork River, separates the Garnet Range in the north from the ranges in the south. In the south, Rock Creek trends north-south and separates the Sapphire Mountains on the west from the John Long Mountains on the east.

THESIS

The intersection of the Lewis and Clark line and the northern boundary of the Sapphire gravity slide block lies within the study area. The problem was to (1) precisely locate a section of the northern boundary of the Sapphire block, (2) determine the type of structures that form the boundary, (3) determine the direction, magnitude, and age of the movements, and (4) determine the precise relationship between the boundary and the Lewis and Clark line.

METHOD AND SCOPE

The problem was structural and stratigraphic, hence the greatest portion of the data was collected during approximately 90 days spent in the field in the summer of 1974. The field work consisted of mapping the structures and stratigraphy, collecting specimens, and measuring stratigraphic sections. Laboratory studies consisted mainly

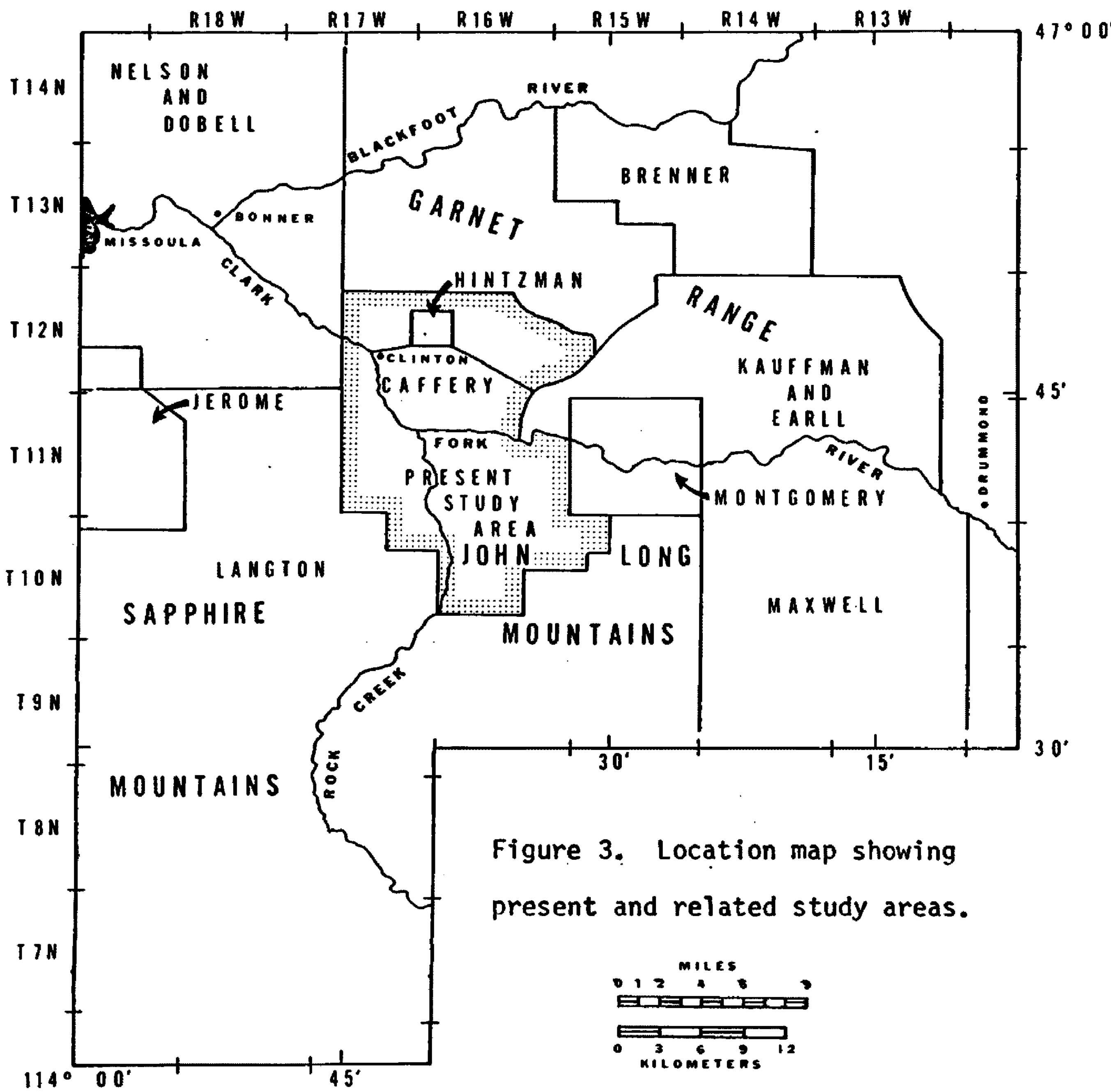


Figure 3. Location map showing present and related study areas.

of locating large scale structures on air photos and determining statistical structural relations.

RELATED LITERATURE

Related regional studies were conducted by Price and Mountjoy (1970) in the Canadian Rocky Mountains and by Mudge (1970, 1972) in northwestern Montana. The geometry, sedimentation, and copper occurrences of the Precambrian Belt basin were described by Harrison (1972), and the tectonic features of the Precambrian Belt basin were discussed by Harrison and others (1974). A model involving the rise of the Idaho batholith, development of the Sapphire block, and emplacement of the Boulder batholith and Flint Creek plutons has been proposed by Hyndman and others (1975).

The northeastern part of the Idaho batholith and adjacent region were described by Langton (1935), who also produced a reconnaisance geologic map for an area adjacent to and including part of the study area (Fig. 3). Parts of the Nimrod area described by Montgomery (1958) and the Garnet-Bearmouth area described by Kauffman and Earll (1963) were remapped during the present study. The 15' Bonner quadrangle, adjacent to the northwestern part of the study area, was mapped by Nelson and Dobell (1961). Within the present study area, previous work was conducted in the Clinton mining district by Hintzman (1964) and north of Rock Creek by Caffery (1973). Jerome (1968) mapped an area several kilometers south of Missoula, Maxwell (1965) mapped an area southwest of Drummond, and Brenner (1968) mapped the Lubrecht Experimental Forest.

Chapter II

STRATIGRAPHY

GENERAL STRATIGRAPHIC FEATURES

The bedrock in the Clinton-Rock Creek area consists of slightly metamorphosed sediments of Precambrian age, with minor Paleozoic sedimentary rocks (Pl. 1 and Table 1). The sequence consists of marine clastic and carbonate rocks with an aggregate thickness greater than 6 km. The rocks occur in northwest-southeast to east-west trending belts that dip gently to the southwest and south. Many of these belts are bounded by southwest dipping reverse faults or vertical faults.

The Precambrian rocks consisting of the "middle Belt carbonate" and the Missoula Group of the Belt Supergroup (Fig. 4) dominate the area and are largely separated from the Paleozoic rocks by the northwest trending Blackfoot-Cramer Creek reverse fault. The Paleozoic rocks occur only in the northern part of the study area and are mapped as two units. In some areas Cambrian Hasmark can be distinguished and is in contact with Precambrian Pilcher quartzite. In other areas various units of the Paleozoic are present but due to structural complexities the units were not differentiated.

Regional metamorphism has transformed the original sediments of the Precambrian Belt to chlorite-grade argillite, siltite, quartzite, and dolomite. Internal strain is low, as evidenced by a general lack

Table 1. Local stratigraphic nomenclature and thicknesses (meters)

	Missoula southwest Langton (1935)	Nimrod Montgomery (1958)	Missoula northeast Nelson and Dobell (1961)	Garnet-Bearmouth Kauffman and Earll (1963)	Alberton Hall (1968)	Clinton-Rock Creek (present study)
CAMBRIAN		Red Lion 90-110		Red Lion 110	Red Lion 110	
		Hasmark 150-180		Hasmark 370-550	Hasmark 570	Hasmark 400
		Silver Hill 30-60		Silver Hill 0-110	Silver Hill 140	
		Flathead 20-30				
PRECAMBRIAN		Sheep Mountain 610-760	Pilcher 300+	Pilcher 460	Pilcher 140	Pilcher 430-760
	Garnet Range 1980	Garnet Range 1680-1830	Garnet Range 550+	Garnet Range 910+	Garnet Range 910	Garnet Range 760
	McNamara* 910	McNamara 760-910	McNamara 1220	McNamara 850	McNamara 1220	McNamara 430-550
		Hellgate 610-760	Bonner 460	Bonner 790	Bonner 270-910	Bonner 240-460
	Hellgate 670 Miller Peak 880		Miller Peak 1830	Miller Peak 580 Base concealed	Miller Peak 820-1680	Miller Peak 1569+
	Helena 1220 Spokane 610 Newland 1220		Newland 1220+ Base concealed		Wallace 2740	Wallace 730-1590+ Base concealed

*Includes Bonner quartzite and upper Miller Peak strata.

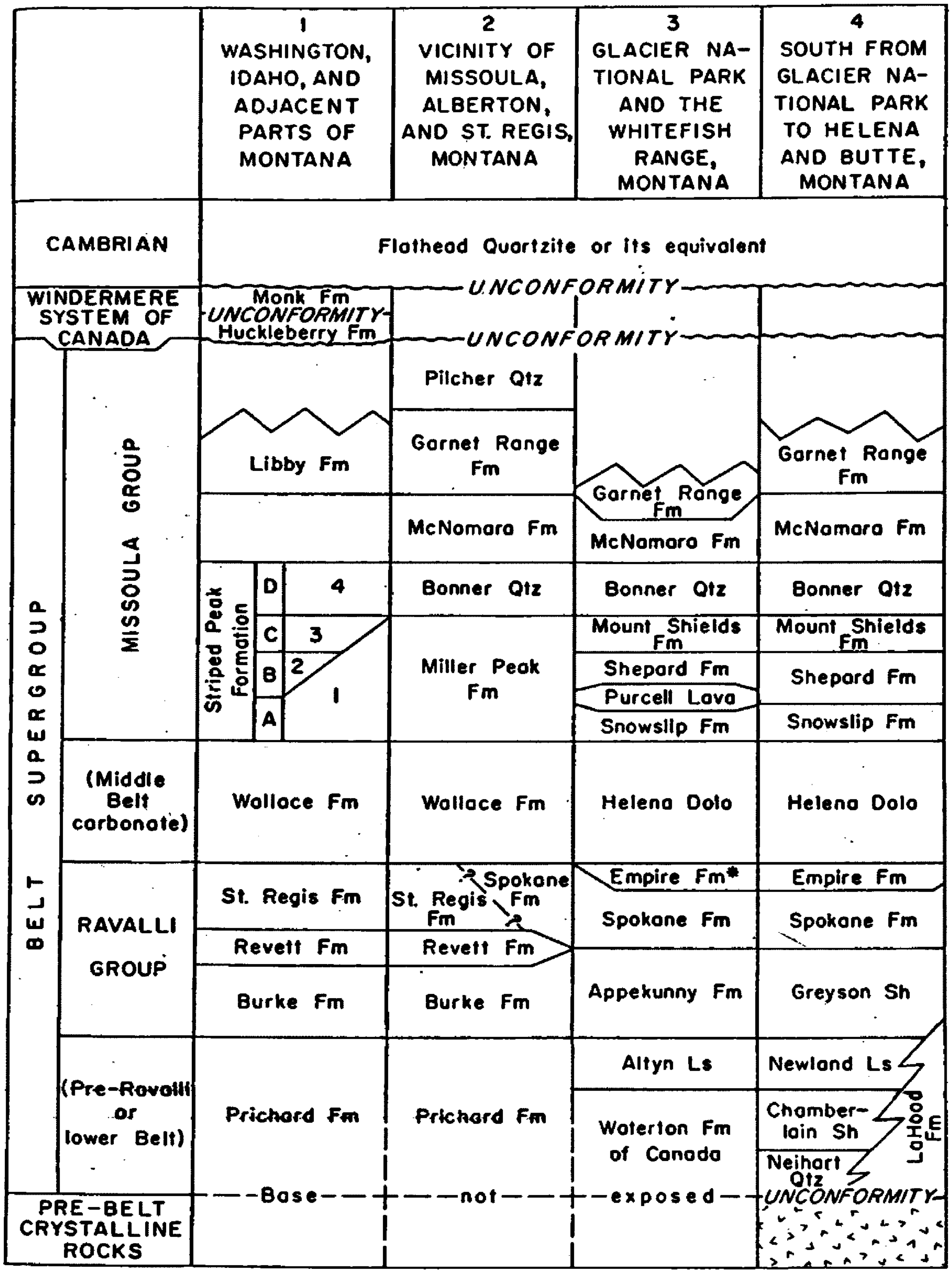


Figure 4. Recommended terminology for the Belt Supergroup. Numbers and letters in column 1 are informal members. Names in parentheses are used informally. *Possibly equivalent strata are called Werner Peak Formation of Smith and Barnes (1966) in the Whitefish Range. From Harrison (1972).

of cleavage, and the grade of metamorphism is also low, clearly preserving sedimentary structures such as load casts, cut and fill structures, sun cracks, water escape structures, rip up structures, ripple marks, and cross bedding. In many rocks, sedimentary textures such as overgrowths also are preserved.

PRECAMBRIAN BELT SUPERGROUP

Middle Belt Carbonate

The "middle Belt carbonate" is an informal name (Harrison, 1972) given to the group of rocks overlying the Ravalli Group and underlying the Missoula Group of the Precambrian Belt Supergroup (Fig. 4). It is a generally thick sequence of carbonates occurring in eastern Washington, southern Canada, northern Idaho, and western and central Montana. In the classification followed by this report (Harrison, 1972) the "middle Belt carbonate" is divided into two equivalent units; the Helena dolomite of southern Canada and northwestern and central Montana, and the Wallace Formation of eastern Washington, northern Idaho, and western Montana.

Wallace Formation. The Wallace Formation is the name given to the impure carbonates of eastern Washington, northern Idaho, and western Montana. The type locality is in the vicinity of Wallace, Idaho (Ransome and Calkins, 1908). In the region of Missoula, Montana these carbonates were called "Wallace limestone" by Clapp and Deiss (1931), and "Wallace Formation" by Hall (1968). Langton (1935) and Nelson and Dobell (1961) called these carbonates "Newland limestone", but Smith and Barnes (1966) showed that the "Newland" was older.

The Wallace Formation rocks occur only in the southern half of the study area (Pl. 1). In the largest and northern-most occurrence the unit is in fault contact with younger strata along its northeastern boundary and conformably overlain by the Miller Peak Formation along its southwestern boundary. The next largest occurrence is in the southwestern part of the area where it is in complete fault contact with surrounding Miller Peak strata. The only other occurrence is in the core of a small anticline in the extreme southern area where Wallace strata are conformably overlain by Miller Peak strata.

The base of the formation is not exposed and the calculated thicknesses of 730 and 1590 m are necessarily minima. Regionally the Wallace is considerably thicker (Table 1). The 3050 m by Langton (1935) and 2740 m by Hall (1968) are comparable, whereas the 1220 m given by Nelson and Dobell (1961) is not representative because the Wallace in the Bonner quadrangle has been "thinned" by thrusting in a manner similar to many units in the present study area. The detailed stratigraphy of the Wallace Formation has not yet been defined regionally so it is not known what proportion of the total unit is exposed in the study area. A distinctive unit near the middle of the Wallace is a rusty weathering limestone with abundant breccia (J. L. Talbot, personal communication, 1975). This unit is not seen in the Clinton-Rock Creek area so the strata present are tentatively correlated as upper Wallace.

In the study area the dominant lithology is banded or laminated tan, and medium and dark gray impure dolomite and limestone. Carbonate bearing argillite, siltite, and quartzite interbeds are common.

Calcite veins, sun cracks, and differential weathering of less resistant beds are common, whereas stromatolites and molar tooth structures are rare. The rocks commonly have caliche on weathered surfaces, generally weather gray or brown and tan, and rarely weather reddish-brown.

Good exposures that are typical of the Wallace Formation in the study area can be seen along Rock Creek Road in two different locations. One exposure is approximately 2 km south of the mouth of Rock Creek and the other exposure is approximately 3 km south of the first.

The boundary between the Wallace Formation and the Miller Peak Formation is in most places a zone approximately 30 m thick and is considered to be one of the most distinct contacts in all of the Belt Supergroup. The zone is characterized by an upward increase in clastics, decrease in carbonate, and a color change from tan and shades of dark gray to light green and light greenish gray. The contact was placed above the uppermost carbonate, which is just below or coincides with the lower red beds in the Miller Peak sequence.

Missoula Group

The Missoula Group (Clapp and Deiss, 1931) is the uppermost group within the Precambrian Belt Supergroup (Fig. 4). The Missoula Group is a thick sequence of clastic rocks occurring in eastern Washington, southern Canada, northern Idaho, and western Montana. The thickest sequence of the Missoula Group and type localities are well exposed near Missoula, Montana. The Missoula Group is divided into five component units (Fig. 4); the Miller Peak Formation, the Bonner quartzite, the McNamara Formation, the Garnet Range Formation, and the Pilcher quartzite.

<u>Miller Peak Formation</u>. The oldest unit in the Missoula Group, the Miller Peak Formation, is a thick sequence of clastic rocks and includes the "Hellgate member" of Nelson and Dobell (1961). The Miller Peak as described here was defined by Nelson and Dobell (1961) except that in the mapping of this study the "Hellgate member" is not distinguished from the remainder of the Miller Peak strata. This description includes the original "Miller Peak Formation" as named and described by Clapp and Deiss (1931). The type locality for this section of the formation is located on Miller Peak in the 15' Bonner quadrangle. The "Hellgate member" of the Miller Peak was named the "Hellgate Formation" by Clapp and Deiss (1931), and redefined as the "Hellgate member" by Nelson and Dobell (1961). The type locality for the "Hellgate member" is in Hellgate Canyon in the 15' Bonner quadrangle. In this report the upper Miller Peak is equivalent to the lower member of the "McNamara Formation" as named and described by Clapp and Deiss (1931). The type locality for this member is near McNamara's Landing east of Bonner, Montana.

Miller Peak strata occur mainly in the southern part of the study area where it occupies about one-third of the entire area of the map (Pl. 1). The largest occurrence is in normal and fault contact with Wallace strata and in fault contact with other strata. Other Miller Peak strata form a relatively large fault block in the south-eastern area, are part of a relatively large fault block west of the Rock Creek interchange, are in normal contact with Bonner quartzite in four small occurrences, and form a small fault block west of Schwartz Creek.

A complete section of Miller Peak Formation does not occur in the area, and due to structural complexities and lack of suitable marker beds, the partial sections have not been correlated, therefore, the thickness of 1569 m measured in the lower Miller Peak can only be a minimum. The 1569 m is a total thickness obtained from three stratigraphic sections described in the appendix. Other local thicknesses of Miller Peak strata are given (Table 1). The thicknesses are comparable except with the 580 m from Kauffman and Earll (1963) which is a minimum thickness since the base of the Miller Peak is not exposed in their area.

The dominant rocks of the formation are red and green argillite, siltite, and quartzite. The lower 790 m is dominantly red and green argillite and siltite with lesser amounts of variously colored quartzite. The next 460 m is dominantly red, fine- to medium-grained quartzite with lesser amounts of variously colored siltite and argillite. The upper part of the Miller Peak is dominantly argillite and siltite interbedded with lesser amounts of variously colored fine-grained quartzite. Some of the quartzite contains appreciable amounts of feldspar and resembles Bonner quartzite, although the latter is almost always coarser grained. In addition to the overall quartzose nature of the rocks and the abundant feldspar in the quartzite, detrital mica occurs throughout the section and carbonates and salt casts occur in certain horizons. Specular hematite and malachite rarely occur as surface mineralization.

Sedimentary structures such as sun cracks, cut and fill structures, load casts, ripple marks, and cross bedding are abundant and generally well preserved. The bedding ranges from fine horizontal laminations in the finer grained units to massive in the coarser grained units. Other sedimentary structures that rarely occur are water escape structures, argillite nodules, argillite and siltite intraclasts, and flat pebble chips.

Excellent exposures occur along the west side of Rock Creek 7-14 km south of the mouth of Rock Creek. The strata dip at low angles and form steep bold cliffs, but are accessible only by crossing Rock Creek. The quartzite member of the Miller Peak occurs in these cliffs but better exposures of this member occur on the east side of Rock Creek approximately 1 km above the mouth of Spring Creek. In these exposures the quartzite forms blocky outcrops of medium- to coarse-grained cross-bedded quartzite. The cross-beds are large and some of the quartzite resembles Bonner quartzite. Good exposures of upper Miller Peak strata can be seen along Dirty Ike Creek, where a distinctive 15 cm thick waxy green bed appears near the top of the section. A thin waxy green (bentonite?) bed occurs in upper Miller Peak strata in other parts of Montana and may be a good marker bed (Don Winston, personal communication, 1975).

The contact between the Miller Peak Formation and the Bonner quartzite is gradational and not well exposed in the study area. The contact zone is characterized by an upward increase in quartzite and decrease in argillite and siltite. The contact was placed at the appearance of the first thick sequence of massive medium-grained feldspathic quartzite.

Bonner Quartzite. Overlying the Miller Peak Formation is the Bonner quartzite which is one of the more distinctive units in the Missoula Group. It is generally a pink massive to cross-bedded feldspathic medium-grained quartzite that was described as a member of the McNamara Formation by Clapp and Deiss (1931) and later redefined as the Bonner quartzite by Nelson and Dobell (1961). The unit is widespread over most of western Montana; the thickest sections are in the vicinity of Missoula, and the type locality is near Bonner.

The Bonner quartzite occurs in the northwestern part of the study area (Pl. 1) where it is part of four small fault blocks and one large fault block. In the large fault block, the Bonner quartzite is apparently in normal contact with the Miller Peak and the McNamara Formations but has a calculated thickness of 240 m which appears abnormally low (Table 1). The fault block is cut by a northwest-southeast trending vertical fault and may be subject to other structural complexities. The Bonner quartzite in the block just west and north of the Rock Creek interchange is apparently in normal contact with the Miller Peak and the McNamara Formations, and has a calculated thickness of 230-460 m. As can be seen in the roadcut just north of the mouth of Rock Creek, it is heavily sheared and has several faults that are subparallel to bedding. The Bonner quartzite in the block along Schwartz Creek is largely bounded by faults and may have internal complexities. The section is probably repeated in this block and the calculated thickness of the Bonner is 1300 m, which is higher than other local values (Table 1). Although the 1300 m is high and the 230 and 240 m is low, the 460 m calculated for the strata north of the

Clark Fork River is comparable to local values.

The rocks are dominantly pink, massive to cross-bedded, feldspathic, medium-grained quartzites and commonly have interbeds and intraclasts of maroon argillite and siltite. The color varies in shades of red, purple, gray, and green, and the quartz and feldspar grains generally vary in size from very fine to very coarse and commonly to pebble size. In the Flint Creek section, approximately 175 km southeast of Missoula, Montana, facies of the Bonner are made up of quartzite and feldspar pebble and cobble conglomerate (Winston, 1973).

The Bonner is an arkosic quartzite and has a feldspar content of approximately 20 percent. The feldspar is dominantly microcline. The dominant pink color of the rocks is from a coating of hematite on the quartz and feldspar grains. Outcrops are generally very blocky and the bedding is usually massive, although cross bedding is common and sun cracks and ripple marks are rare. The Bonner quartzite is similar to some of the quartzite within the Miller Peak Formation but the former is consistently coarser grained and has ubiquitous feldspar while the latter is generally finer grained and usually has much less feldspar. Good exposures of the Bonner can be seen northwest of Clinton along Dirty Ike Creek.

The contact between the Bonner quartzite and the McNamara Formation is gradational and is a zone approximately 30 m thick. The zone is characterized by an upward color change from shades of pink to shades of gray and then to shades of purple, maroon, and green, as well as an upward decrease in grain size and feldspar content.

McNamara Formation. The McNamara Formation as described here was defined by Nelson and Dobell (1961) and is restricted to the upper member of the "McNamara Formation" as originally described by Clapp and Deiss (1931). The McNamara occurs over most of western Montana but the thickest sections are in the region of Missoula and the type locality is at McNamara's Landing east of Bonner.

McNamara strata occurs only in the northern part of the study area and generally as part of fault blocks. East of Clinton and south of the Bonita beacon appear to be the only locations with complete sections of McNamara (Pl. 1). In the section south of the Bonita beacon the contact between the McNamara and the Garnet Range Formations lies in the Clark Fork Valley and may be a fault, however, a thickness of 430 m was calculated for the McNamara in this section, and a thickness of 550 m was calculated for the McNamara in the section east of Clinton. These values are lower than other values obtained within the Missoula region (Table 1).

The strata are dominantly argillite and siltite with lesser amounts of quartzite. The dominant colors are maroon and light green but the colors vary in shades of red, purple, gray, green, and brown. The quartzites are generally very fine-grained, commonly fine-grained, and rarely medium-grained.

The dominant mineralogy is quartz with some feldspar. Detrital mica is common on some bedding planes and malachite rarely occurs as surface stains.

Sedimentary structures are generally well preserved and the abundant structures are bedding, sun cracks, cut and fill structures, load casts, ripple marks and argillite nodules. Bedding generally occurs as fine laminations less than 1 mm to 5 mm, commonly occurs as thicker layers on the order of 5 mm to several centimeters, and rarely occurs more massively in layers up to 1 m thick. Argillite and siltite intraclasts are common, cross-bedding is uncommon, and water escape structures and flat pebble chips are rare.

Some McNamara strata are very similar in appearance to some Miller Peak strata and it is often very difficult, if not impossible, to distinguish the formations. Generally, the quartzite in the McNamara does not occur in thick sequences and is not as abundant as in the Miller Peak, but the most distinctive difference between the two is the occurrence of argillite nodules. Argillite nodules rarely occur in Miller Peak strata but are common in the McNamara. The argillite nodules are dominantly light opalescent green in color but also occur in shades of pink, gray, and tan. The nodules are generally subrounded and rarely larger than 5 cm in diameter. These nodules can be seen in the good exposures on the dirt road along the south fork of Wallace Creek.

The contact between the McNamara Formation and the Garnet Range Formation is poorly exposed in the study area. The contact is a relatively thin gradational zone where detrital mica increases upward and color changes from maroon and gray to brown and green. The contact was placed at the first thick sequence of brownish-green quartzite beds.

Garnet Range Formation. The Garnet Range Formation was named by Clapp and Deiss (1931) and the type locality is along the northern side of Blackfoot Canyon approximately 3 km east of Bonner, Montana, although a thicker well exposed section occurs near Alberton, Montana. The Garnet Range was described by Nelson and Dobell (1961) for the exposures near Missoula and by Hall (1968) for the exposures near Alberton.

In the study area Garnet Range strata occurs in two belts, one in the northern region and one in the central region. Part of the east central exposures were described by Montgomery (1958) and part of the northeastern exposures were described by Kauffman and Earll (1963). These two belts are bounded in part by faults and in part by conformable contacts. A thickness of 760 m was calculated for the Garnet Range near the south fork of Wallace Creek. This thickness is approximately intermediate between the extreme values obtained for the Missoula region (Table 1).

This formation is one of the more distinctive units in the Missoula Group and is dominantly green interbedded quartzite, siltite, and argillite. The principal distinctive characteristics are ubiquituous detrital mica and a predominant rusty-brown color on the weathered surfaces of the rocks. The color is commonly medium to dark olive-green and greenish-gray but varies in shades of brown, green, and gray. Finer grained quartzites are common while coarser grained quartzites are relatively uncommon. Interbedded argillite and siltite occur in most sections.

In the Garnet Range Formation sedimentary structures are generally not well preserved; the only common sedimentary structure being horizontal bedding. The bedding is conspicuous in that quartzite beds several centimeters thick occur with interbeds of finely laminated, platy, and fissile argillite and siltite. The only other sedimentary structures are rare cross bedding and sun cracks.

The formation is readily recognized by the distinctive rusty-brown color on weathered surfaces, by the ubiquituous detrital mica, and by the conspicuous interbeds of quartzite, and argillite and siltite. Good exposures of Garnet Range strata occur approximately 8 km along the Gillespie Creek Road.

The contact between the Garnet Range Formation and the Pilcher quartzite is not well exposed in the study area. The contact appears gradational and is a relatively thin zone where there is an upward color change from green and brown to maroon, purple, and gray, increase in grain size, and decrease in the amount of detrital mica. The contact was placed at the first thick sequence of medium-grained quartzite which is neither green nor brown.

Pilcher Quartzite. The Pilcher quartzite is the upper unit of the Precambrian Belt Supergroup and of the Missoula Group, and is a relatively thin unit that is quite restricted in its regional extent. The unit was named the "Sheep Mountain Formation" by Clapp and Deiss (1931) and renamed Pilcher quartzite by Nelson and Dobell (1961). The type locality is along Pilcher Creek in the Bonner 15' quadrangle.

In the study area this unit is commonly fault bound. The largest and northern-most occurrence is completely fault bound, intruded by a small stock, and complexly faulted on a scale too small to be shown on the map (Pl. 1). The southern-most and western-most occurrences are completely fault bound along one boundary. The central occurrence of Pilcher conformably overlies the Garnet Range

Formation and appears to be unconformably overlain by Hasmark in the section along lower Cramer Creek. The thicknesses of 430 and 760 m calculated for the Pilcher along the unconformable contact is within the range of thicknesses obtained for Pilcher strata in the Missoula region (Table 1).

The quartzite is generally pink, purple, or gray, highly cross-bedded, and medium-grained. The color varies in shades of red, purple, gray, white, and green. The dominant quartzites are medium-grained but lesser amounts of very fine-grained quartzite commonly occur. Small pebbles, and argillite and siltite interbeds rarely occur. The grains are dominantly quartz with little or no feldspar, and detrital mica is common.

The most notable sedimentary structures are massive-bedding and cross-bedding. The cross-bedding is generally very conspicuous and consist of alternating bands in shades of purple and gray. Massively-bedded pink Pilcher commonly resembles Bonner quartzite but the latter characteristically contains feldspar.

In the study area the Precambrian Pilcher quartzite commonly is unconformably overlain by the Cambrian Hasmark Formation. The contact can be seen approximately 3 km along the road to the Bonita beacon from the West Fork of Cramer Creek, but the contact is merely a highly weathered zone approximately 20 m thick. The "typical" Pilcher is not well exposed in the study area but good exposures of Pilcher quartzite do occur 4-5 km along the above mentioned road.

PALEOZOIC ROCKS

Hasmark Formation

There are two distinct occurrences of Paleozoic rocks in the study area. In the first case, Cambrian Hasmark Formation is in contact with Precambrian Pilcher quartzite and is in fault contact with other rocks. In the second case, Paleozoic rocks are in fault contact with Precambrian rocks or the Cambrian Hasmark as described in the first case. The Hasmark Formation occurs in the northern part of the study area, and on the map (Pl. 1) has been differentiated from the other Paleozoic units. Subdivision of the Paleozoic units into the component formations was found to be beyond the scope of this study principally because of time limitations. In this study the classification followed for the Paleozoic rocks is that of Kauffman and Earll (1963).

In southwestern Montana the Middle Cambrian sequence unconformably overlies the Precambrian Belt rocks (Hanson, 1952). The Hasmark Formation is the upper unit of the Middle Cambrian sequence which consists of the Hasmark Formation, the Silver Hill Formation, and the Flathead quartzite (Kauffman and Earll, 1963). The Hasmark Formation conformably overlies the Silver Hill Formation, which in turn conformably overlies the Flathead quartzite. The Hasmark Formation was named by Emmons and Calkins (1913) in their study of the Philipsburg quadrangle and the type locality is southwest of Philipsburg, Montana. Middle Cambrian limestone was described and tentatively correlated as Hasmark Formation by Langton (1935) and as Meagher limestone by Nelson and Dobell (1961). According to the correlation chart of Hanson (1952), the Meagher Formation is equivalent to the lower section of the Hasmark Formation. Other studies in the Missoula region that include descriptions of Hasmark strata are by Montgomery (1958), Kauffman and Earll (1963), and Hall (1968).

Hasmark occurs in two discontinuous belts in the northern half of the study area. In the northern-most belt the outcrops are poor and the structural relations are far more complex than can be shown by the map (Pl. 1). In most places within the southern-most belt the Hasmark appears to unconformably overlie the Pilcher quartzite along one boundary and to be in fault contact with Precambrian units along the other. The thickness of 400 m calculated for the Hasmark along this southern belt is comparable to that obtained by Kauffman and Earll (1963) and Hall (1968), (Table 1).

The unit is characteristically light to medium gray dolomite with lesser amounts of limestone. The unweathered color is rarely dark gray, and the weathered color is generally light gray and commonly light brown and tan. Bedding is generally poor and varies from massive to finely laminated. Calcite veins are common, and chert and quartzite lenses are rare.

The outcrops are generally bold and well exposed. Good exposures of Hasmark occur along the west side of Cramer Creek and along the dirt road 3-4 km toward the Bonita beacon from the West Fork of Cramer Creek. In the study area the upper boundary of the Hasmark Formation is everywhere a fault contact.

Undifferentiated Paleozoic

The undifferentiated Paleozoic rocks occur only in three regions in the extreme northeastern and eastern part of the study area. The Paleozoic rocks east of Cramer Creek and adjacent to the northern-most occurrence of this study was mapped and described by Kauffman and Earll (1963). Kauffman and Earll mapped the units as Cambrian Hasmark and Red Lion Formations, and Devonian Maywood and Jefferson Formations. The Cambrian Hasmark Formation has been discussed above, and the Cambrian Red Lion, and the Devonian Maywood and Jefferson Formations will be briefly discussed below.

The Cambrian Red Lion Formation was named and described by Emmons and Calkins (1913) and the type locality is in the Philipsburg quadrangle. In the Missoula, Montana region the Red Lion was described by Pardee (1918), Montgomery (1958), Kauffman and Earll (1963), and Hall (1968). In the Garnet-Bearmouth area the Red Lion Formation unconformably overlies the Hasmark Formation. Within the Red Lion Formation the lower shale (Dry Creek) member is approximately 10 m thick, and the laminated limestone (Sage) member is approximately 110 m thick. Kauffman and Earll (1963) described the shale member as, "Red and yellow shale, calcareous siltstone, and dolomite. The red shale has abundant worm burrows and markings." and the laminated limestone member as, "... A light-gray crystalline limestone ...interbedded with fine yellow-red laminae of argillaceous and siliceous material..." In the Garnet-Bearmouth area the Cambrian Red Lion Formation is unconformably overlain by the Devonian Maywood Formation.

The Maywood Formation was named, described, and tentatively placed in the Silurian by Emmons and Calkins (1913), and the type locality is in the Philipsburg quadrangle. The Maywood was redefined as Devonian by Lochman (1950). The Devonian Maywood was also described by Sloss and Laird (1947), Montgomery (1958), and Kauffman and Earll (1963), and in the Garnet-Bearmouth area forms a unit that is approximately 120 m thick and consists mainly of yellowish-gray, light gray, and dark gray dolomites and limestones with lesser amounts of dolomitic clastic rocks. In the Garnet-Bearmouth area the contact between the Devonian Maywood and Jefferson Formations is a gradational zone approximately 30 m thick.

The Devonian Jefferson as named and described in the type locality near Three Forks, Montana by Peale (1893) included the Devonian Maywood strata. Lochman (1950) recommended that the name Maywood Formation be applied to the lower Devonian unit of Sloss and Laird (1947). The present division of the Jefferson and Maywood Formations follows that of Robinson (1963). The Jefferson was also described by Montgomery (1958) and Kauffman and Earll (1963), and in the Garnet-Bearmouth area consists of some 520 m of fossiliferous grayish-brown, light to dark gray, and black limestone and dolomite that is thick bedded to massive and commonly has a petroliferous odor.

In the largest occurrence of the study area the undifferentiated Paleozoic unit is well exposed and consists of a relatively thick sequence of limestone, dolomite, and clastic rocks that extends approximately 2 km northeast of the map area. The unit is separated from the other formations by the northwest-southeast trending Blackfoot-Cramer Creek reverse fault. The best exposures can be seen along the

Cramer Creek Road for several kilometers past the Linton Mine.

IGNEOUS ROCKS

The principal igneous rocks in the Clinton-Rock Creek area have been discussed by previous workers and presently were only cursorily examined. The principal igneous occurrences (Pl. 1) are the Wallace Creek stock, the Ashby Creek stock, the Nimrod volcanics and the Gillespie Creek and Beavertail Hill hypabyssal rocks. In addition to the larger occurrences, small hypabyssal bodies are seen throughout the area.

The Wallace Creek stock was mapped by Pardee (1918) and Hintzman (1964), and the Ashby Creek stock was mapped by Pardee (1918). During the present study the intrusions were mapped as separate bodies (Pl. 1) because in the area between them there are no outcrops and the float and soil are not igneous. The contacts of the Wallace Creek stock are from Hintzman (1964) and those of the Ashby Creek stock are not well exposed and less well known. The stocks intrude several of the reverse faults of the northern boundary of the Sapphire block and are necessarily younger in age. The structural relationship between the stocks and the vertical faults of the Lewis and Clark line is not apparent.

A diabase sill and numerous rhyodacite dikes occur in the area of the Wallace Creek stock but are not included due to the small scale of the final map. The reader is referred to Hintzman (1964) for details of these intrusions.

The principal volcanic rocks occur in the eastern part of the study area and were mapped by Pardee (1918) and Montgomery (1958). The main occurrences are south and west of the Nimrod tunnels (Pl. 1).

The volcanic rocks south of the Nimrod tunnels were described by Montgomery (1958) as Tertiary dacite porphyry. These rocks do not show any apparent relationship to the structures within the study area but do overlie the igneous rocks just west of the Nimrod tunnels (Montgomery, 1958).

The igneous rocks just west of the Nimrod tunnels were mapped as Late Cretaceous to Early Tertiary granodiorite by Pardee (1918) and as Tertiary andesite porphyry by Montgomery (1958). Although the western part of this occurrence appears hypabyssal, only the western part was examined during this study so the interpretation of Montgomery (1958) was assumed to be correct. These rocks do not show any apparent relationship to the structures within the study area, but are presumably post-thrusting in age. Post-thrusting volcanic rocks in the Bearmouth area, approximately 10 km to the east, have been radiometrically dated as 44.5 ± 2 m.y. and 44.9 ± 2 m.y. by R. L. Armstrong (Tom Williams, personal communication, 1975).

The main occurrence of hypabyssal rocks is the one along Gillespie Creek approximately 3-4 km south of Beavertail Hill (Pl. 1). The boundaries of this body were mapped during the present study and only the eastern portion was mapped by Montgomery (1958) who described the rocks as Tertiary dacite porphyry. The body appears to be intrusive and contains xenoliths of Precambrian Belt rocks. The hypabyssal nature of this occurrence, the Belt rock xenoliths, and the shape of the intrusion may imply that the body is the feeder plug for some of the volcanics in the area.

Chapter III

STRUCTURE

STRUCTURAL SETTING

The dominant structures of the study area are northwest-southeast trending faults and drag folds associated with some of these faults. This structural style is produced by two dominant regional structures: The northern boundary of the Sapphire gravity slide block and the Lewis and Clark line. The northern boundary of the Sapphire block (Fig. 2) is a zone of east-west trending reverse faults and the Lewis and Clark line (Fig. 1) is a northwest-southeast trending zone of vertical faults and tight folds.

REGIONAL STRUCTURES

Lewis and Clark Line

The Lewis and Clark line is a broad zone of linear structures that extends several hundred kilometers southeast from northern Idaho. The line has been discussed recently by Smith (1965), Weidman (1965), Harrison (1972), Talbot and Hyndman (1973), and Harrison and others (1974). The dominant structural features of the line are northwest-southeast trending vertical faults. The time and nature of displacement along the faults has been a topic of much debate. The interpretation of Harrison and others (1974) is that the displacement began in Late Precambrian and continued intermittently through Early Tertiary time. Harrison and others (1974) also interpret the displacement as right-lateral strike-slip along the major vertical faults with a dip-slip component on some of the faults.

One of these faults with an apparently large component of dip-slip is the Ninemile fault which is the northwest extension of the Clark Fork fault. The Clark Fork fault extends into the study area and is overridden by the northern boundary of the Sapphire gravity slide block.

Sapphire Block

The northern boundary of the Sapphire gravity slide block is a 75 km long zone of east-west trending high-angle reverse faults. The Sapphire block formed as a consequence of the rise of the Bitterroot dome of the Idaho batholith and now lies immediately to the east of the northern part of the batholith (Hyndman and others, 1975). The Sapphire block moved approximately 25 km eastward and is internally coherent with deformation restricted to the boundaries. The structures forming the northern boundary indicate a northward to eastward movement direction.

Structures along what is now recognized as the northern boundary (Hyndman and others, 1975) were described by Montgomery (1958), Nelson and Dobell (1961), Kauffman and Earll (1963), and Hall (1968). Within the zone of the boundary, the distance between faults and the age of the strata involved generally increase toward the south. A section of the northern boundary lies within the study area (Fig. 2).

STRUCTURES IN THE CLINTON-ROCK CREEK AREA

General Structural Relations

The study area is characterized by a general southwest dip of bedding and northwest-southeast trending faults (Pls. 2 and 3). Folding is relatively unimportant although kink folds and drag folds are associated with some of the faulting. The dominant southwest dip of bedding can be seen on the structure map (Pl. 2). The strike and dip symbols represent average bedding orientations obtained from computer plots of bedding pole diagrams. Several examples of these plots are shown as contour diagrams on Plate 3. The average orientations were obtained from over one-thousand bedding plane orientations which were separated by area and formation, and plotted on bedding pole diagrams; these diagrams were then contoured by hand.[1]

The dominant structures of the area are the northwest-southeast trending reverse and vertical faults (Pl. 2). The reverse faults, representing the northern boundary of the Sapphire gravity slide block, dip to the southwest at high angles, and indicate a general northeastward direction of movement. The reverse faults occur in two belts comprised of subparallel elongate blocks and through-going faults. These two belts of reverse faults are separated by vertical faults which are the local representations of the Lewis and Clark line.

[1]A map showing all of the primary structural data is on file in the Geology Department, University of Montana.

Lewis and Clark Line Vertical Faults

The main vertical faults within the study area are the Dirty Ike Creek fault, the fault along the West Fork of Cramer Creek, and the Wallace Creek fault (Pl. 2).

The Dirty Ike Creek fault is a vertical fault with a very straight trace trending N 50 W. The magnitude of the movement is relatively small with approximately 120 m of left-lateral strike-separation and approximately 60 m of dip-separation with the north-eastern block down-dropped relative to the southwestern block (Fig. 7). The fault has a shear zone several meters thick and can be seen in the field and on air photos along most of its trace. The fault extends approximately 6 km southeastward from the extreme northwestern part of the study area to near the Wallace Creek stock (Pl. 2). The fault extends more than 4 km west into the Bonner quadrangle. The fault is subparallel to the Clark Fork fault in the Bonner quadrangle and to the fault along the West Fork of Cramer Creek which is to be discussed below.

The fault along the West Fork of Cramer Creek is a vertical fault and has a straight trace trending N 60 W over most of its length. As can be seen from cross section A-A' (Fig. 5), there is a minimum of 330 m of dip-separation with the block on the southwest down-dropped relative to the block on the northeast. Drag folding consistent with the sense of slip is present and can be seen on both sides of the fault. The fault is not well exposed although it is apparently a thin zone, and can be seen on air photos along most of its trace. East of Cramer Creek the fault was not seen in the field and also is not

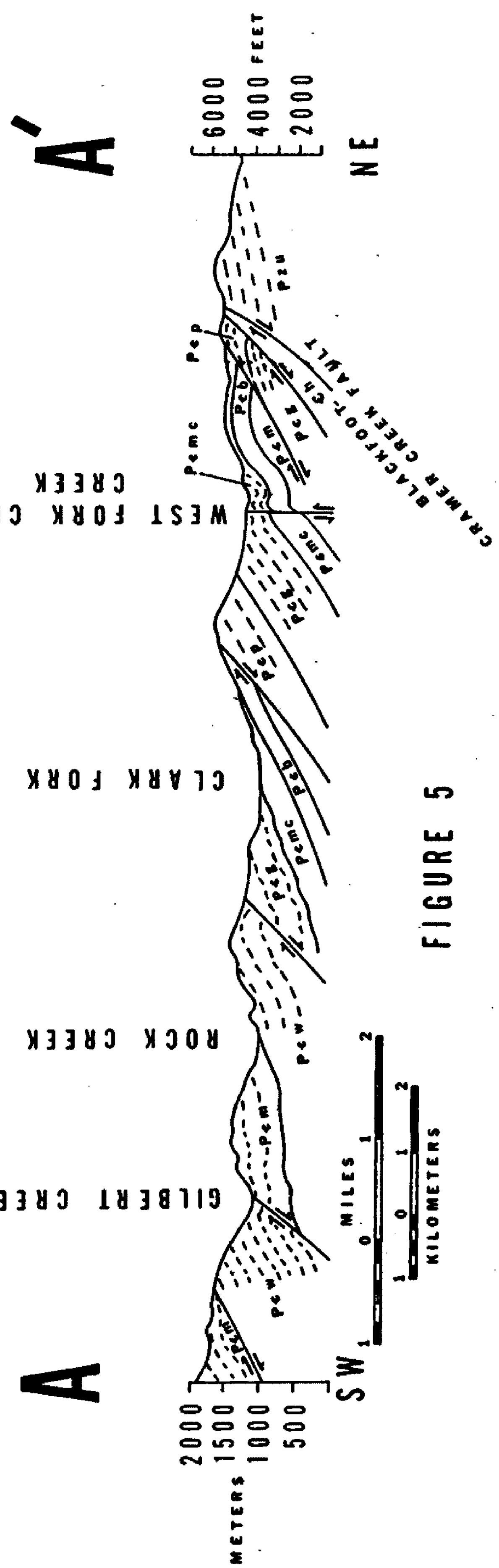

A
A'
SW
NE
METERS
2000
1500
1000
500
6000
4000
2000
FEET
GILBERT CREEK
ROCK CREEK
CLARK FORK VALLEY
WEST FORK CRAMER CREEK
CRAMER CREEK FAULT
MILES
KILOMETERS

FIGURE 5

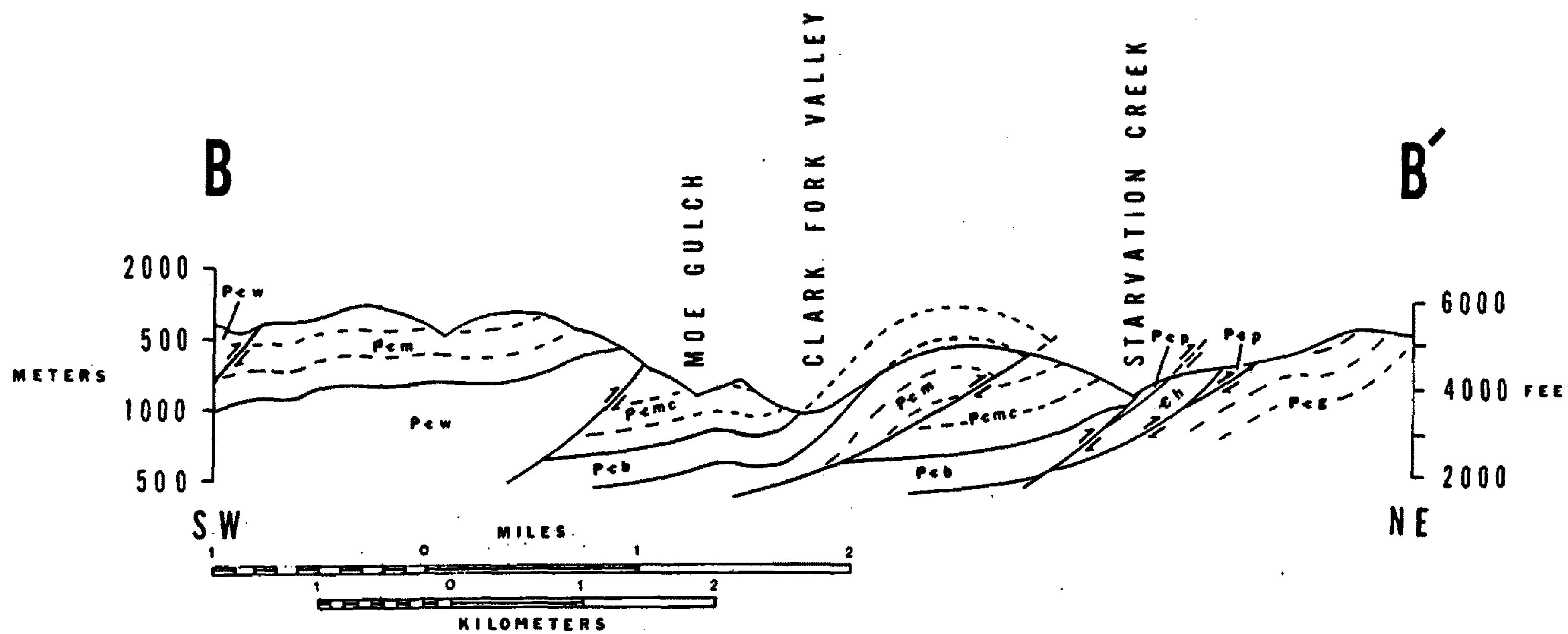
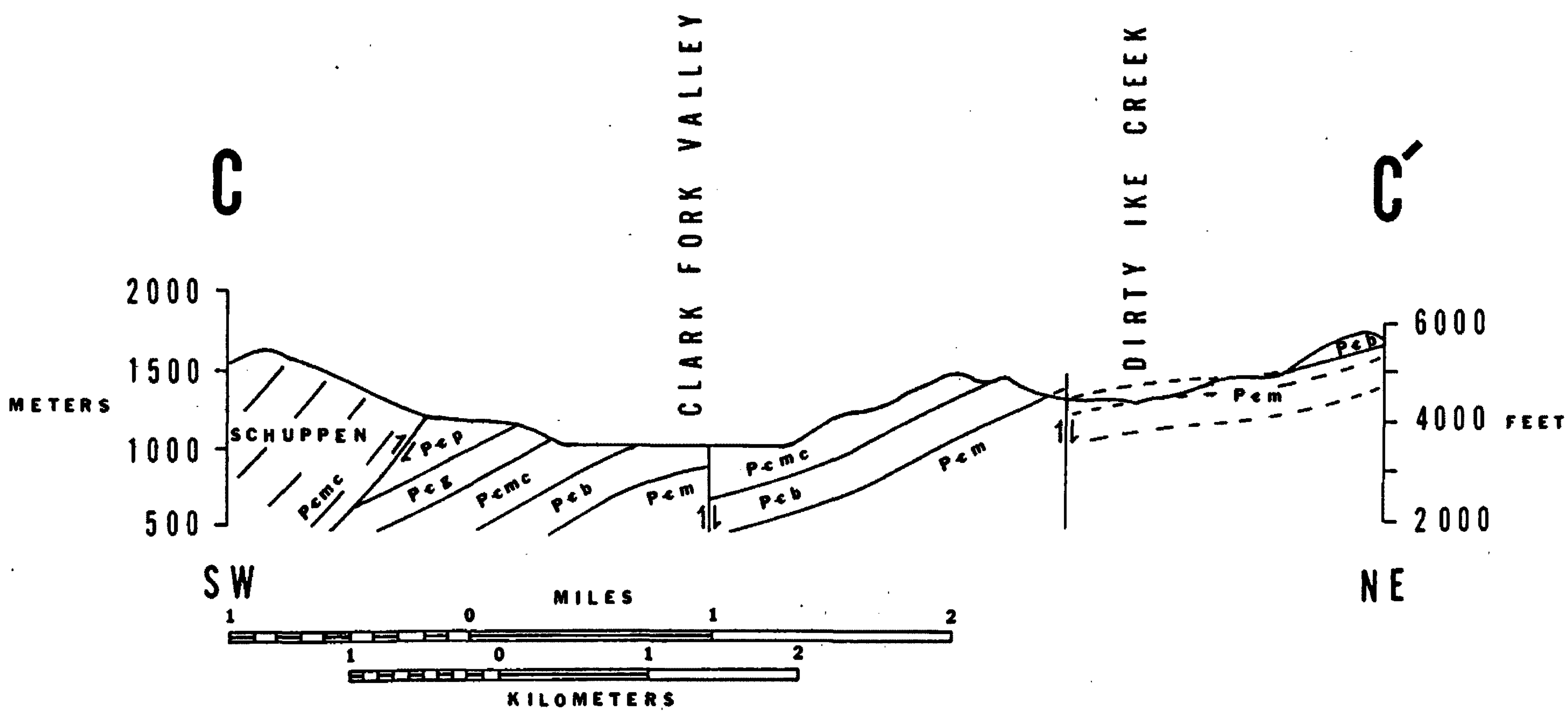

B
B'
MOE GULCH
CLARK FORK VALLEY
STARVATION CREEK
2000
500
1000
500
METERS
6000
4000 FEET
2000
SW
NE
P€w
P€m
P€w
P€mc
P€b
P€m
P€mc
P€b
P€p
P€p
€h
P€g
MILES
1
0
1
2
1
0
1
2
KILOMETERS

FIGURE 6



C
C′
CLARK FORK VALLEY
DIRTY IKE CREEK
METERS
2000
1500
1000
500
6000
4000 FEET
2000
SCHUPPEN
P¢mc
P¢p
P¢g
P¢b
P¢m
SW
NE
MILES
1
0
1
2
KILOMETERS

FIGURE 7

expressed on the air photos. West of Cramer Creek the fault has a straight northwestern trend for approximately 4 km toward Wallace Creek. Here, the trend of the fault becomes more westerly and on the air photos appears to intersect with the Wallace Creek fault.

The Wallace Creek fault is apparently a vertical fault with a trend that varies from northwest-southeast through east-west to northeast-southwest (Pl. 2). On cross-section C-C' (Fig. 7) the Wallace Creek fault is the vertical fault in the Clark Fork Valley. As can be seen on this cross-section there is approximately 400 m of dip-separation with the block on the northeast down-dropped relative to the block on the southwest. The fault can be seen to be a thick zone of shearing in the exposures along the gravel pit northeast of the entrance to the Wallace Creek Canyon. The fault zone is generally poorly exposed but the fault appears to bifurcate just south of the lake along Wallace Creek. One branch of the fault trends northeastward and appears to intersect with the fault south of Kamas Peak. The other branch appears to be the extension of the fault along the West Fork of Cramer Creek. To the west, the Wallace Creek fault begins to trend north of west and apparently connects with the Clark Fork fault mapped by Nelson and Dobell (1961). In the study area, the Wallace Creek fault, the Dirty Ike Creek fault, and the fault along the West Fork of Cramer Creek lie between two belts of reverse faults.

Sapphire Block Reverse Faults

The dominant structures within the study area are the reverse faults (Pl. 2). The faults generally trend northwest-southeast, dip at high angles to the southwest, and occur in two belts separated by the vertical faults described above. One belt occupies the central part of the area and the other occupies the northeastern part. The central belt is comprised of two moderately large fault blocks, and two long faults that extend through and out of the area. Within the central belt the two main fault blocks are the block along Gilbert Creek and the block just west of the Rock Creek interchange.

The southern-most fault block lies along Gilbert Creek and trends northwest-southeast (Pl. 2). The northern boundary of this block is a well-defined reverse fault that can be seen in the exposures along Rock Creek where the fault dips to the south and west at approximately 45-50^{o}. Along this boundary, Precambrian Wallace strata have been faulted northeastward onto Precambrian Miller Peak strata with a minimum stratigraphic throw of 2 km (Fig. 5).

The southern boundary of this block is a fault boundary, the nature of which is not well known. This boundary was mapped by Langton (1935) as a high-angle reverse fault dipping northeast with Wallace strata faulted southwestward onto Miller Peak strata. In several places along the boundary the strata of the two formations are either highly disturbed or abut against one another, but in at least one location, the younger Miller Peak strata are seen to override northeastward onto the Wallace strata. At this location the fault dips approximately 40^{o} to the south. One straight reverse fault associated with the northern boundary of this block extends approximately 4 km southeast to Spring Creek. West of the study area the block has been mapped by Langton (1935).

The other main fault block within the central belt of reverse faults is the one just west of the Rock Creek interchange. This block is unique in that it is not elongate in shape as other blocks in the area are, but is triangular in shape. The block is also unique in that it is comprised of strata that are tightly folded on a large scale (Pls. 2 and 3). These strata were thrust northward to northeastward on a relatively low dipping fault plane which gives an appearance of a large landslide block. From the trace of the northern and eastern faults of this block (Pl. 2), the dip of the fault north of the Clark Fork River was calculated to be approximately 30^{o} S and is much shallower south of the river (Fig. 6). Miller Peak, Bonner, and McNamara strata have been faulted northward to northeastward onto McNamara and some Garnet Range strata with a stratigraphic throw of approximately 1800 m.

The contacts within this block are shown on the map as normal contacts but as can be seen in the good exposures along the highway north of Rock Creek, there are several faults subparallel to bedding near the Bonner-McNamara contact. These strata are also moderately folded and just east of the above-mentioned contact, the McNamara strata are overturned to the east. This block is bounded on the south by one of the long through-going faults of the central belt of reverse faults.

The longest and most continuous fault within the central belt of reverse faults lies south of the Clark Fork River and trends generally northwest-southeast (Pl. 2). The movement is generally northeastward and along part of the fault Wallace strata has been faulted onto Pilcher strata which indicates a stratigraphic throw greater than 3 km (Pl. 1). The fault trace is mildly sinuous and in one location the dip of the fault was calculated to be 40^{o} S using the three-point method.

In the study area the fault extends from near Schwartz Creek to an area approximately 22 km southeastward and is continuous over most of its length (Pl. 2). The eastern portion of this fault is intruded by hypabyssal rocks, part of which were mapped by Montgomery (1958), (Pls. 1 and 2). The extreme western part of this fault is offset to the northeast by the relatively minor Schwartz Creek fault which appears to be post-thrusting. From this location the reverse fault trends west and connects with the extreme southeastern reverse fault mapped by Nelson and Dobell (1961).

The second longest and most continuous fault in the central belt of reverse faults lies mainly north of the Clark Fork River and trends generally somewhat north of west (Pl. 2). The movement was generally northeastward but there was some movement to the north and possibly to the east. In the area near the Bonita beacon, Bonner quartzite has been faulted northeastward onto Pilcher quartzite and the minimum stratigraphic throw is approximately 2 km (Fig. 5). The dip of the fault was measured as 45^{o} S in the exposures along the eastern side of Cramer Creek, and calculated to be approximately 45^{o} S in another location along the fault.

In the study area the fault extends from Cramer Creek in the east to the extreme western area near Clinton, and is nearly continuous along its length (Pl. 2). The reverse fault is offset by a minor fault in one location approximately 2 km northeast of the mouth of Starvation

Creek. The reverse fault connects with the Bearmouth thrust (Kauffman and Earll, 1963) in the east and with a reverse fault along Greenough Creek of the 15' Bonner quadrangle (Nelson and Dobell, 1961) in the west. This fault is the northern-most reverse fault of the central belt.

The northeastern belt of reverse faults is comprised of two subparallel reverse faults and a number of minor faults (Pl. 2). The southern-most of the two main faults trends generally northwest-southeast but varies from north-south to east-west. The movement direction is northeastward to eastward and as can be seen on cross-section A-A' (Fig. 5), where McNamara strata has been faulted onto Pilcher quartzite, the minimum stratigraphic throw is approximately 1 km. In this location the trace of the fault is sinuous (Pl. 2) and the dip of the fault plane has been calculated to be approximately 30^{o} to the southwest. Just south of Kamas Peak and a few kilometers west of the location where cross-section A-A' intersects the main reverse fault, there is a moderately straight east-northeast trending fault that intersects with the Wallace Creek fault, is sub-perpendicular to the main reverse fault, and offsets the main fault for a distance greater than 3 km. This sub-perpendicular fault appears to transform the dominantly reverse dip-slip movement into dominantly strike-slip movement (Pl. 2). West of this "tear" fault the movement again becomes dominantly reverse dip-slip in an eastward to northeastward direction. In the west, the main fault can be seen on air photos to continue several kilometers northwestward, and in the east, may continue for some distance into the area mapped by Kauffman and Earll (1963).

The northern-most fault is a northwest-southeast trending reverse fault that is subparallel to the above-mentioned fault (Pl. 2). Movement is to the northeast and, as can be seen on cross-section A-A' (Fig. 5), Precambrian Pilcher and Cambrian Hasmark strata have been faulted onto undifferentiated Paleozoic strata. The dip of the fault could not be measured or calculated but the trend is straight and the dip is assumed to be relatively high. Stratigraphic throw is uncertain but the fault is significant since it is the northern-most reverse fault in the region and so is the northern boundary of the Sapphire gravity slide block. In this region the strata north of this fault are relatively undisturbed (See, for example: Kauffman and Earll, 1963, and Brenner, 1968) while the strata to the south are highly faulted. This fault connects with the Cramer Creek fault (Kauffman and Earll, 1963) in the east and on air photos appears to connect in the west with the Blackfoot fault (Nelson and Dobell, 1961).

Folds

Although faults are the most important structures in the area, large open folds are present and are represented by the sinuous formation contacts seen on the map (Pl. 1). In addition, tight drag folds are associated with the main faults. The large scale folds representing the sinuous map patterns trend south-southwest, and plunge consistently at approximately 20-30^{o} to the south and southwest (Pls. 2 and 3).

The tight folds associated with the main faults are not expressed in the map patterns but can be seen on the cross-sections (Figs. 5, 6, and 7) and are generally smaller scale structures than the above-mentioned folds. The trend of these fault associated folds is commonly parallel to the faults and the plunge is generally low. The folds show consistent southwest over northeast asymmetry and as can be seen on the cross-sections, the degree of folding increases with proximity to the fault.

Minor structures that occur in the study area are (Pls. 2 and 3) the anticline in the extreme southern part, the syncline in the extreme southeastern part, doming of the Miller Peak strata around the periphery of the Wallace Creek stock, and small kink-folds whose rotation sense indicates the relative movement direction. The anticline plunges approximately 20^{o} to the northeast and the syncline plunges approximately 5^{o} to the southwest. As can be seen on the structure map (Pl. 2), out of the few kink-fold measurements represented, all but one were rotated in a manner that indicates north through east movement direction.

Problems

In the study area several problems were encountered that appear to be related to structure. The problems are the absence of certain stratigraphic units, abnormal stratigraphic thicknesses, ambiguous displacement along certain vertical faults, and structural correlation with the adjacent area. Below, each problem will be described, assumptions will be presented, and interpretations will be made.

In the Clinton-Rock Creek area, Middle Cambrian Hasmark strata is in contact with Precambrian Pilcher quartzite, hence Flathead quartzite and Silver Hill strata are missing. In several locations the contact between the Hasmark and Pilcher is shown to be faulted, but in two locations the nature of the boundary is not well known. One of these less well known boundaries is the eastern boundary between the Hasmark and Pilcher strata just southeast of Kamas Peak (Pls. 1 and 2) and this boundary is believed to be faulted. The other less well known boundary is the one between Hasmark and Pilcher strata along lower Cramer Creek. This contact is believed to be unconformable, but it is possible for it to be a fault.

Another problem encountered was abnormal stratigraphic thicknesses in certain locations. Some of the abnormally thick sections can be attributed to repetition of section by faulting. One such location is approximately 2 km southeast of Kamas Peak where the rocks have been represented simply as Pilcher quartzite on the map (Pl. 1) but, in fact, the area is complexly faulted and there is much repetition of section.

Repetition of section appears to be the reason Precambrian Bonner quartzite and McNamara strata are abnormally thick in the area approximately 3 km southwest of Clinton (Fig. 7 and Pl. 1). Nelson and Dobell (1961) mapped several reverse faults in the McNamara strata adjacent to this area, but these faults were not mapped during the present study. At least one fault not mapped during the present study was encountered in the Bonner quartzite in contact with this McNamara strata. The calculated thickness of this Bonner quartzite is 1300 m which is significantly greater than other values obtained in the study area and in the Missoula region (Table 1). The abnormally high value for the thickness of the Bonner in this area is attributed to repetition of section. The calculated thickness of the above-mentioned McNamara strata is 1200 m which is a minimum value, is approximately the same as the maximum value obtained in the Missoula region, and is significantly greater than other values obtained in the study area (Table 1). The apparently high value for the thickness of the McNamara in this area is also attributed to repetition of section.

Just north of this area where the McNamara and Bonner strata are abnormally thick is an area where the McNamara and Garnet Range strata are abnormally thin. The units may be stratigraphically thin or "thinned" by faulting between the Garnet Range and McNamara strata, but the correct interpretation is not known since the exposures are poor and many of the contacts are concealed by valley fill.

The nature of the displacement of the Lewis and Clark line faults has been a topic of much debate, and the Clark Fork fault mapped by Nelson and Dobell (1961) is one of the Lewis and Clark line faults. In the present study area the extension of the Clark Fork fault appears to be the Wallace Creek fault and the fault along the West Fork of Cramer Creek but there is an apparent conflict in the nature of the displacement. The Wallace Creek fault appears to be down-dropped to the north, which agrees with the sense of movement proposed by Nelson and Dobell (1961) for the Donovan Creek fault in the Bonner quadrangle. The conflict arises because the fault along the West Fork of Cramer Creek appears to be down-dropped to the south, which is also the dominant sense of movement for the Clark Fork fault in the Bonner quadrangle. No direct evidence for the sense of slip is available and it may be that the conflict arises because the fault has a strike-slip component of movement.

Another problem encountered is that some structures and stratigraphic units along Cramer Creek could not be correlated with those mapped by Kauffman and Earll (1963). The Bearmouth thrust and the Cramer Creek fault mapped by Kauffman and Earll (1963) correlate with structures in the present study area and are respectively the reverse faults (Pl. 2) just north of the mouth of Cramer Creek and just southwest of the Linton Mine.

The stratigraphic sequence between these two faults was mapped during the present study (Pl. 1) as units of Cambrian Hasmark and Precambrian Pilcher, Garnet Range, and McNamara. The Hasmark unit unconformably overlies a unit of Pilcher quartzite which in turn conformably overlies the Garnet Range unit. The Garnet Range strata are down-faulted against the McNamara unit which in turn is faulted northeastward onto a second unit of Pilcher quartzite. These stratigraphic units and their boundaries do not correlate with those mapped by Kauffman and Earll (1963). Kauffman and Earll (1963) mapped this area as Cambrian Hasmark strata down-faulted against Precambrian Garnet Range strata which in turn conformably overlies Precambrian McNamara strata.

Kauffman and Earll (1963) extended the Mount Baldy syncline to just east of Cramer Creek but this structure is not apparent in the exposures along the creek and, in fact, the McNamara strata just west of the creek are gently dipping and anticlinal. A traverse was made through the area east of Cramer Creek but the structure is complex and further work would be necessary to the east to resolve the structural problems.

DISCUSSION

Structural Style

The study area is characterized by reverse faults, with internal, plastic, deformation confined to the areas adjacent to the faults. Very little foliation is present, metamorphic grade is low, and for the most part gently folded beds dip at low angles to the southwest.

There is little metamorphism present beyond diagenesis except in the very fine-grained portions of the rocks where there is some sericite, and some recrystallization of the sedimentary grains. Strain shadows are commonly seen within quartz and feldspar grains and the degree of strain is higher in the specimens from locations closer to the faults. While the quartz and feldspar grains in the specimens from closer to the faults are heavily strained, the deformation can be seen to be plastic rather than by flow for there still is little recrystallization of the sedimentary grains. The metamorphic grade does increase in several locations where the sedimentary rocks are in contact with igneous rocks such as along the Wallace Creek stock (Pl. 1). There, the rocks can be seen in thin section to contain biotite and have a polygonal texture but no definite foliation.

Movement Picture of the Reverse Faults

The dominant structures within the study area are the northwest-southeast trending high-angle reverse faults of the northern boundary of the Sapphire gravity slide block. Within the zone of the northern boundary the distance between faults and the age of the strata involved generally increase toward the south (Pl. 1) which indicates a deeper sequence of faulting in this direction. The oldest strata involved in the reverse faulting are from the Wallace Formation and these strata occur only in the southern half of the area.

The structures within the zone of the northern boundary of the Sapphire block indicate direction and minimum magnitude of movement. The northwest-southeast trending reverse faults and associated drag folds as well as the southwest dipping fault planes are interpreted as indicating a dominant northeastward direction of movement. The drag folds show consistent southwest over northeast asymmetry and the small kink folds occurring throughout the area (Pl. 2) generally indicate northward through eastward direction of movement. Also, the one large "tear" fault south of Kamas Peak indicates movement toward the east and just north of east. The total stratigraphic separation on all of the faults has been calculated to be a minimum of 8 km to the northeast. The dominant movement of the Sapphire block was to the east (Hyndman and others, 1975) but the amount of eastward transport cannot be determined in the study area. The 8 km stratigraphic throw translates to a minimum of 14 km if the movement is eastward.

Lewis and Clark Line Faults

Within the study area the Lewis and Clark line is represented by the major northwest-southeast trending vertical faults. The major vertical faults are the Dirty Ike Creek fault, the fault along the West Fork of Cramer Creek, and the Wallace Creek fault. The Wallace Creek fault apparently connects with the Clark Fork fault (Nelson and

Dobell, 1961) and with the fault along the West Fork of Cramer Creek (Pl. 2). East of Cramer Creek this fault was not seen in the field and is not expressed on air photos. Since the Lewis and Clark line is not seen east of Cramer Creek but cuts and offsets the reverse fault blocks in the study area and to the west, the actual relationship between the Lewis and Clark line and the northern boundary of the Sapphire block is quite complex.

Time Relations

In the study area Cambrian Hasmark is the youngest strata involved in the reverse faulting but to the east near Bearmouth (Kauffman and Earll, 1963) Cretaceous strata have been affected by the reverse faulting. These reverse faults are thought to have developed in Late Cretaceous to Early Tertiary time (Hyndman and others, 1975). The interpretation of Harrison and others (1974) is that displacement along the Lewis and Clark line began in Late Precambrian and continued intermittently through Early Tertiary time. The Clark Fork fault (one of the Lewis and Clark line faults) cuts Oligocene (?) strata near Missoula (Hall, 1968) and cuts and disturbs Oligocene strata just north of Missoula in the Coal Mine Creek area (J. P. Wehrenberg, personal communication, 1975). According to Wehrenberg, the disturbed Oligocene strata in the Coal Mine Creek area is depositionally overlain by undisturbed Pliocene (?) strata placing time limits to the latest activity on this fault. The data collected in the present study suggest that the Late Cretaceous Sapphire block overrode the pre-existing Lewis and Clark line structures in the study area, and was in turn cut and offset in places by the reactivated Lewis and Clark line. The Lewis and Clark line is not seen to the east so although the most recent movement was along this line, it was of only small magnitude in the study area.

Chapter IV

SUMMARY AND CONCLUSIONS

The purpose of the investigation was to 1) precisely locate a section of the northern boundary of the Sapphire gravity slide block, 2) determine the type of structures that formed the boundary, 3) determine the direction, magnitude, and age of the movements, and 4) determine the precise relationship between the boundary and the Lewis and Clark line.

The reverse faults within the Clinton-Rock Creek area represent the northern boundary of the Sapphire block, and lie in a northwest-southeast trending zone within which the distance between the faults and the age of the strata involved generally increase toward the south indicating a deeper sequence of faulting in this direction. The northern-most reverse fault lies in the northeast portion of the study area and thrusts Precambrian Pilcher and Cambrian Hasmark strata onto undifferentiated Paleozoic strata (Pls. 1 and 2). This fault appears to connect with the Blackfoot fault (Nelson and Dobell, 1961) in the west and with the Cramer Creek fault (Kauffman and Earll, 1963) in the east. The strata north of this fault are relatively undisturbed while the strata to the south are highly faulted. While the entire zone of reverse faults represents the northern boundary of the Sapphire gravity slide block, there is a sharp change in structural style at the Blackfoot-Cramer Creek fault which is therfore chosen as the northern boundary.

In addition to the dominant fault structures, there are folds which are commonly associated with the faults. The folds plunge gently in directions subparallel to the faults and are more prominent close to the faults (Pls. 1 and 2, and Figs. 5, 6, and 7). Several of the long and continuous reverse faults extend through the area, while others form elongate fault blocks. The dip of the faults generally varies at the surface from 30-50^{o} to the southwest and is assumed to decrease with depth, but is believed to be higher along some of the faults having relatively straight traces (Figs. 5, 6, and 7).

The dominant southwest dip of the reverse faults and the consistent southwest over northeast asymmetry of the associated drag folds indicate a general northeastward direction of movement. The small kink folds occurring throughout the area (Pl. 2) generally indicate northward and eastward direction of movement and the one large "tear" fault south of Kamas Peak indicates movement to the east and to just north of east. The total stratigraphic separation is a minimum of 8 km to the northeast and the dominant direction of movement is northeastward to east-northeastward.

The reverse fault blocks of the northern boundary of the Sapphire block have been cut and offset by the Lewis and Clark line faults indicating that in the study area the latest movement was along the Lewis and Clark line, however, the Lewis and Clark line is not seen to the east, having been totally overridden by the Sapphire block. Displacement along the Lewis and Clark line began in Late Precambrian and continued intermittently through Early Tertiary time (Harrison and others, 1974) and the Sapphire block is thought to have developed in Late Cretaceous to Early Tertiary time (Hyndman and others, 1975).

In conclusion, the data collected in the present study suggest that the Late Cretaceous Sapphire gravity slide block overrode the pre-existing Lewis and Clark line structures in the study area, and was in turn cut and offset, during the Oligocene or Miocene (?), by the reactivated Lewis and Clark line. Although the northern boundary of the Sapphire block is actually an entire zone the precise location of this boundary in the Clinton-Rock Creek area is by definition, the northern-most fault, the Blackfoot-Cramer Creek fault. The dominant structures within this zone of the northern boundary are northwest-southeast trending high-angle reverse faults dipping to the southwest and the subparallel gently-plunging tight drag folds associated with these faults. The structures within the zone of the northern boundary indicate a dominant northeastward to east-northeastward movement direction and a minimum of 8 km of total stratigraphic separation in a northeastward direction.

APPENDIX

STRATIGRAPHIC SECTIONS

Three stratigraphic sections were measured and described in the Precambrian Belt rocks along the west side of Rock Creek near the cable crossing at Quigley (Pl. 1). These sections were measured and described in an attempt to subdivide the Miller Peak Formation into the Mount Shields, Shepard, and Snowslip Formations as other workers (Childers, 1963, McGill and Sommers, 1967, and Mudge, 1970, 1972) have done in other parts of Montana. Subdivision of the Miller Peak Formation was found to be beyond the scope of this study because of time limitations and structural complexities, but the knowledge obtained from the study of the three sections aided in distinguishing the Miller Peak strata from the similar appearing McNamara strata.

Although the Miller Peak strata are well exposed along Rock Creek, they are faulted, hence three offset sections were measured. The top of the third section is approximately 250 m below the peak of Solomon Mountain and the bedding is relatively flat-lying. Just beyond the map area approximately 2-3 km west of Solomon Mountain, Ravalli Group strata overthrust Miller Peak strata. The unmeasured thickness of this Miller Peak strata between the thrust fault and the top of the measured section is approximately 250 m thick. The 1569 m measured section of the Miller Peak strata is comparable to complete sections of Miller Peak Formation in the Missoula region (Table 1). The 1569 m and the 250 m is greater than most of the other thicknesses, hence it is assumed that the measured sections and the unmeasured strata nearly comprise the entire Miller Peak Formation.

Section 1

The base of the first section lies in Precambrian Wallace strata in the creek in the extreme southern part of the study area approximately 1 km south of the Quigley cable crossing (Pl. 1).

Unit	Description	Thickness (meters)	Cumulative Thickness
7.	Quartzite: Tan to pink quartzite with some siltite and argillite interbeds, low-angle cross-beds, and detrital mica; unit is partly covered.	67	468
6.	Siltite and argillite: Purple siltite and argillite with some purple quartzite and green argillite interbeds.	59	401
5.	Quartzite: Purple quartzite with some purple siltite and argillite interbeds, and detrital mica.	43	342
4.	Siltite and argillite: Purple siltite and argillite with some green platy argillite interbeds and abundant pink to purple very fine-grained quartzite interbeds; some detrital mica, argillite and siltite intraclasts, and low-angle cross-beds.	101	299
3.	Siltite and argillite: Greenish-gray, yellowish-gray, light gray, purple, and maroon siltite and argillite with some pink quartzite interbeds, sun cracks, ripple marks, and argillite and siltite intraclasts.	52	198

Section 1 —— Continued

Unit	Description	Thickness (meters)	Cumulative Thickness
2.	Siltite: Greenish-gray, gray, purplish-gray, and red siltite with some argillite and quartzite interbeds, detrital mica, cross-beds, argillite and siltite intraclasts; unit is partly covered.	93	146
1.	Dolomite: Tan, brown, and gray dolomite with some limestone, argillaceous dolomite, and quartzite interbeds, and cross-beds; unit is partly covered.	53	53
	Total measured Miller Peak strata	415	
	Total measured Wallace strata	53	
	Total measured strata	468	

Section 2

The first section was terminated because of poor exposures. The area between the first and second sections does not appear to be highly faulted, and the beds at the top of the first section were followed down-dip and northward, hence the base of the second section is approximately coincident with the top of the first. The base of the second section is just north of the Quigley cable crossing (Pl. 1).

Unit	Description	Thickness (meters)	Cumulative Thickness
7.	Siltite and argillite: Gray to green siltite and argillite with abundant sedimentary structures; unit is partly covered.	76	394

Section 2 —— Continued

Unit	Description	Thickness (meters)	Cumulative Thickness
6.	Siltite: Grayish-green siltite with some argillite interbeds, detrital mica, boudin-like structures, and load casts; some reddish-brown weathering; unit is partly covered.	58	318
5.	Covered: Unit largely covered; some thin green siltite and argillite beds.	40	260
4.	Siltite: Green siltite with some quartzite and red argillite interbeds, and sun cracks and other sedimentary structures; unit is partly covered.	34	220
3.	Quartzite: Green, purple, and tan quartzite with some green siltite interbeds, sun cracks, detrital mica, and argillite and siltite intraclasts.	58	186
2.	Quartzite and siltite: Purple quartzite and siltite with some argillite interbeds, detrital mica, sun cracks, ripple marks, cross-beds, load casts, and argillite and siltite intraclasts; some pink and tan quartzite and siltite; weathers rusty to yellowish-brown.	91	128
1.	Siltite and quartzite: Gray, tan, and light green siltite and quartzite with some argillite interbeds, detrital mica, sun cracks, ripple marks, and altered pyrite crystals; unit is partly covered.	37	37
	Total measured Miller Peak strata	394	

Section 3

The second section was terminated because of poor exposures. The area between the second and third section is faulted, and the beds at the top of the second section can not be followed to the base of the third. Because of the lack of suitable marker beds, it is not possible to determine exactly where the base of the third section is relative to the top of the second, but the top 207 m of the second section and the lower 137 m of the third section are dominantly green argillite and siltite, therefore it is assumed that these sections approximately comprise one continuous section. The base of the third section is approximately 2 km north of the Quigley cable crossing (Pl. 1).

Unit	Description	Thickness (meters)	Cumulative Thickness
10.	Quartzite: Tan and greenish-gray quartzite with gray and greenish-gray siltite interbeds, and some sun cracks; unit is partly covered.	44	760
9.	Covered: Unit largely covered; some grayish-green siltite and argillite.	55	716
8.	Quartzite: Tan, gray, and greenish-gray quartzite with some siltite interbeds, argillite and siltite interclasts, and low-angle cross-beds; unit is partly covered.	62	661
7.	Quartzite: Purple quartzite with some siltite and argillite interbeds, argillite and siltite intraclasts, ripple marks, and cross-beds.	194	599
6.	Siltite and quartzite: Greenish-gray, gray, tan, and purple siltite and quartzite with some ripple marks and boudin-like compaction structures.	79	405
5.	Quartzite: Brown, brownish-purple, and purple quartzite with some siltite interbeds and abundant low-angle cross-beds.	30	326
4.	Quartzite: Dominantly purple quartzite.	40	296
3.	Argillite: Purple, light gray, greenish-gray, and green argillite with some siltite, and quartzite interbeds.	43	256

Section 3 —— Continued

Unit	Description	Thickness (meters)	Cumulative Thickness
2.	Quartzite: Purple, purplish-gray, gray, tan, light green, and green quartzite with some siltite and argillite interbeds, low-angle cross-beds, ripple marks, and argillite and siltite intraclasts.	76	213
1.	Siltite: Green, greenish-gray, purple, and pink siltite with some quartzite and argillite interbeds, sun cracks, argillite and siltite intraclasts, cross-beds, detrital mica, ripple marks, and load casts.	137	137
	Total measured Miller Peak strata	760	

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Legend for Plate 1

Igneous rocks

Andesite and dacite

Granodiorite

Hypabyssal rocks

Sedimentary rocks

PALEOZOIC

Undifferentiated Paleozoic

Hasmark Formation

PRECAMBRIAN

Pilcher quartzite

Garnet Range Formation

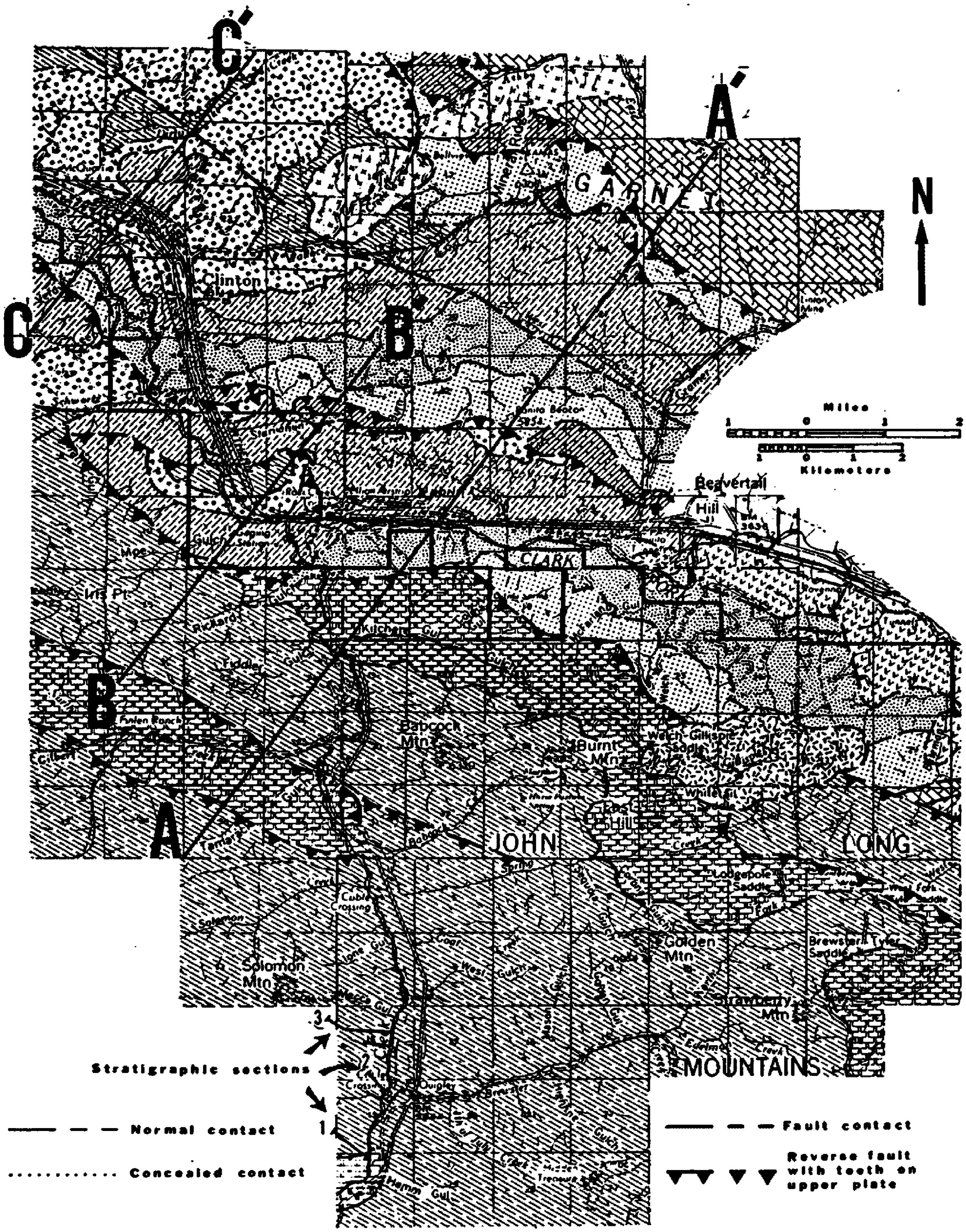
McNamara Formation

Bonner quartzite

Miller Peak Formation

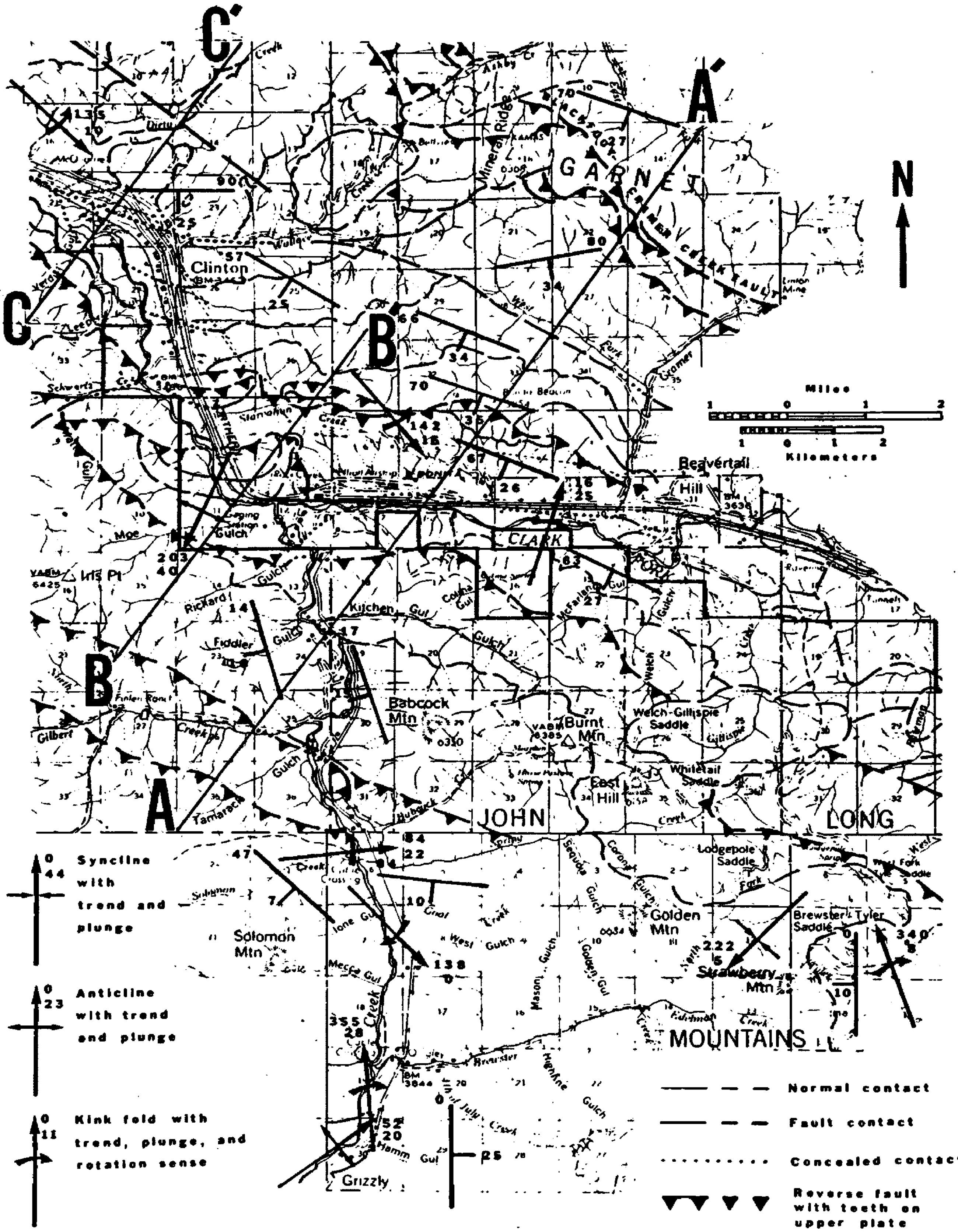
Wallace Formation

Plate 1. Geologic map of the Clinton-Rock Creek area*



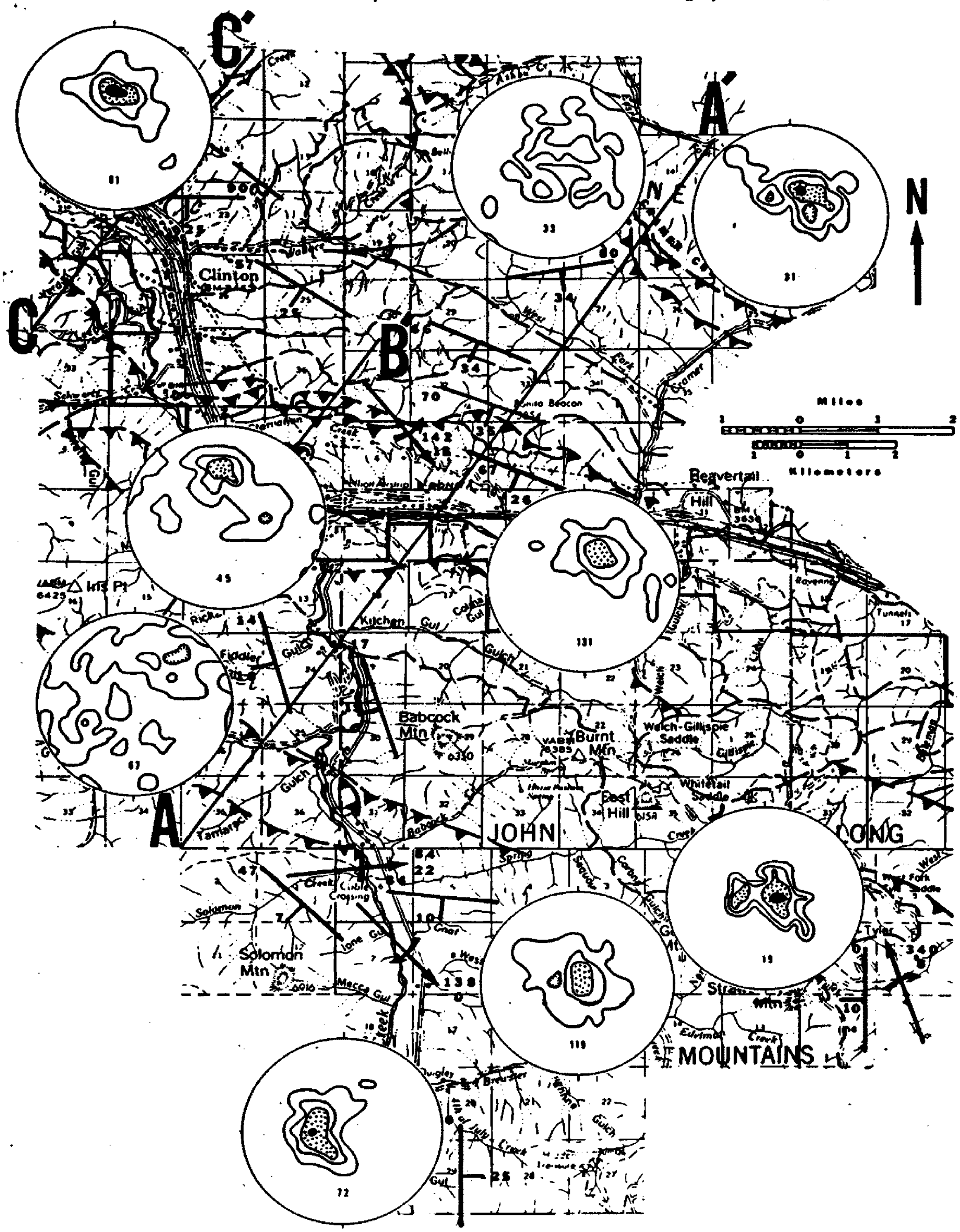
*A full scale detailed map of the area is on file in the Geology Department, University of Montana.

Plate 2. Structure map of the Clinton-Rock Creek area*



*A full scale detailed map of the area is on file in the Geology Department, University of Montana.

Plate 3. Structure map with contoured bedding pole diagrams



Contours are 1, 5, 10, and 20 percent per 1 percent area. Numbers within the diagrams represent number of readings. Hachured contours represent lower percent area.