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PETROLOGY AND STRATIGRAPHY OF THE FLATHEAD  
FORMATION PHILIPSBURG-DRUMMOND, MONTANA

By

HAROLD ALLEN ILLICH

B.Sc. University of Texas, 1963

Presented in partial fulfillment of the requirements for the degree of

Master of Science

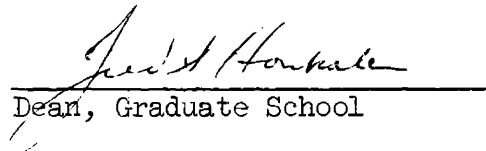
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## ABSTRACT

The Flathead Formation and the units bounding the Flathead were studied in the Philipsburg Drummond area, Montana. The Flathead is a transgressive Middle Cambrian marine sandstone, probably deposited by a beach. It unconformably overlies Belt units and grades upward into the Middle Cambrian Silver Hill shale. The Belt units are difficult to identify in terms of Bonner Quadrangle terminology because of the lack of sufficient stratigraphic work in the area.

Petrographically the Flathead is a bimodally moderately sorted medium and fine-grained sandstone; siliceous submature quartzarenite. The principal source of the quartz in the Flathead is interpreted to be the Belt strata over which the Flathead transgressed. This interpretation is supported by trace quantities of doubly overgrown quartz grains in all sections and an abundance of these grains in one section, and by the high rounding values of the non-doubly overgrown quartz grains in the Flathead.

The Flathead interval was traced westward into the Missoula-Bonner area. The Flathead lithology is absent as a mappable unit in this area and the Pilcher occupies its stratigraphic position. The unconformity is interpreted to die out to the west. The Flathead is interpreted to be a facies of the upper Pilcher. The Pilcher in the Missoula-Bonner area is interpreted to have been deposited continuously from the Precambrian to the Cambrian.



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## INTRODUCTION

The Flathead Formation is the lowest formally recognized unit in the Cambrian sequence in western Montana. Over much of western Montana the Flathead is interpreted to lie unconformably on Precambrian Belt strata and basement complexes. Where the Flathead is recognized it is relatively thin, measuring a few feet to 300 feet thick. The unit is generally unfossiliferous but considered to be Middle Cambrian because of its gradational contact with the overlying Middle Cambrian Silver Hill shale.

The Flathead quartzite was studied in the Philipsburg-Drummond area in the fall of 1964 and the summer of 1965. The area is located east of the John Long Range and on the west flank of the Flint Creek Range in the Flint Creek drainage (Figures 1a and 1b). This area roughly corresponds to the area included in the Philipsburg, Bearmouth, and Drummond Quadrangles.

The object of this study is to establish the stratigraphic relationships of the Flathead with the overlying Silver Hill and the underlying Belt strata, and also to furnish a petrographic description of the Flathead. A secondary problem is to interpret the petrogenesis of the Flathead and to attempt to delineate the Flathead interval to the west in the Missoula-Bonner area. Although the Flathead has long been recognized in western Montana (Peale, 1893), it has not been studied in detail petrographically. The Flathead is of paramount importance because of its proximity to the Cambrian-Precambrian boundary in these areas.

In the Flint Creek drainage the Flathead quartzite is a dis-

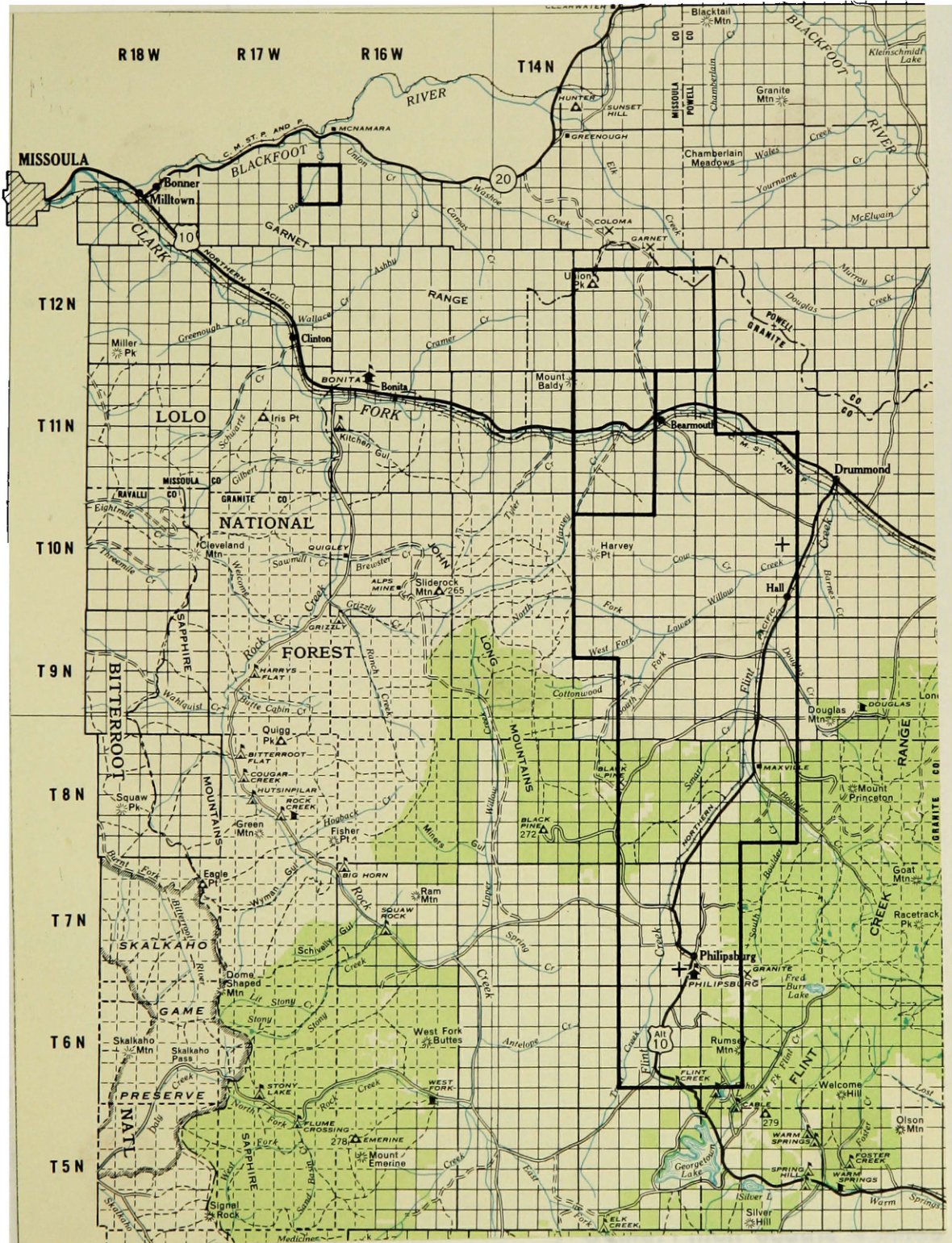


Figure 1a. Distribution of study areas in western Montana.

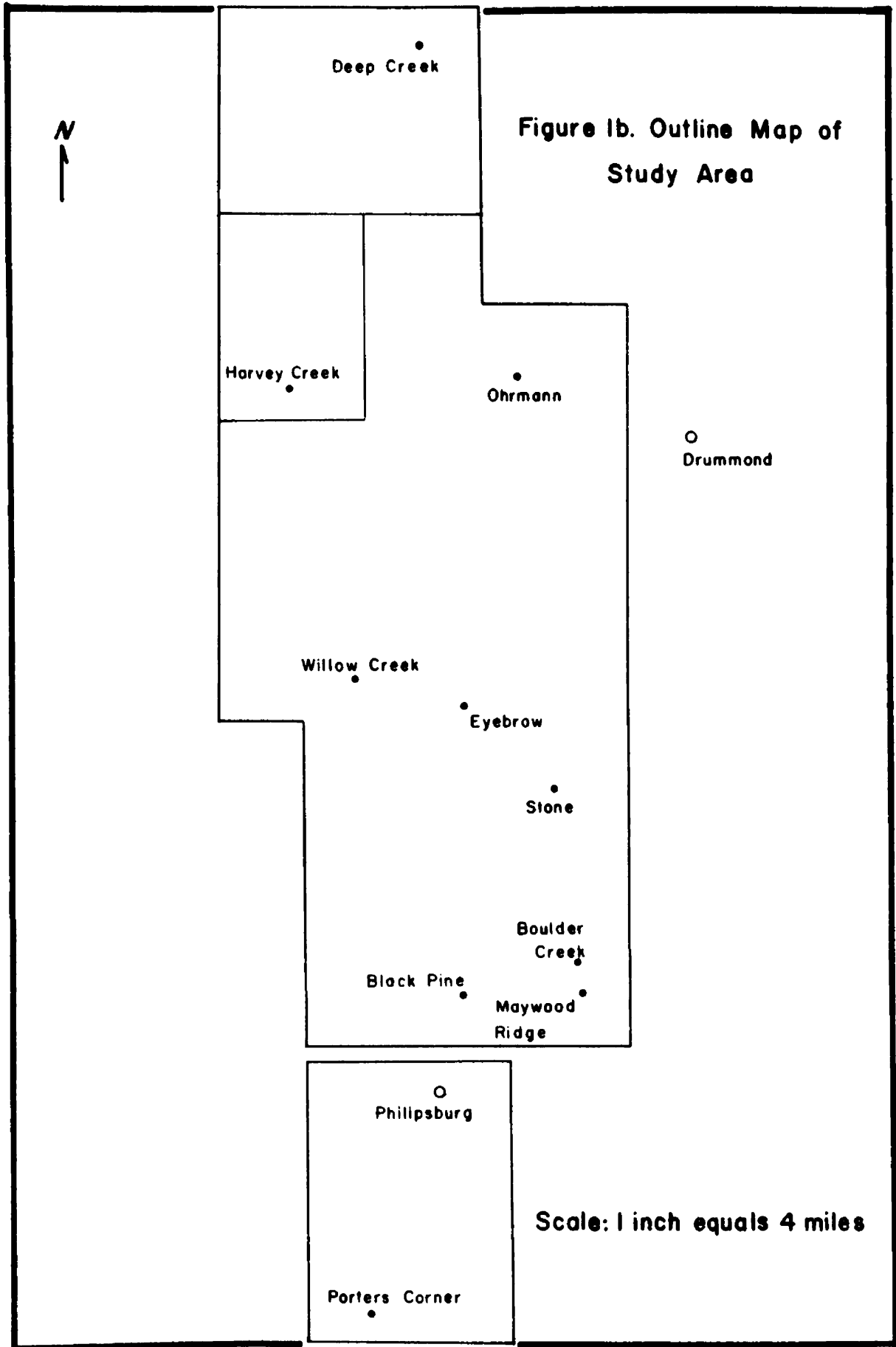


Figure 1b. Outline Map of Study Area

Scale: 1 inch equals 4 miles

tinative unit usually overlying Belt strata and underlying recessive Silver Hill shales. It is a white quartzite that contains little feldspar and few rock fragments. In the Missoula-Bonner area no Flathead lithology has clearly been demonstrated below the Silver Hill; rather, the Silver Hill apparently grades downward into the Pilcher quartzite. The Pilcher quartzite is the uppermost formation of the Missoula Group and hence Precambrian (?) in age. There is clearly a need for a stratigraphic and petrographic understanding of the Belt-Flathead contact, the Flathead Formation, and the Flathead-Silver Hill contact before the Belt-Cambrian relationships can be understood in the Missoula-Bonner area.

#### Acknowledgements

The author is deeply indebted to Dr. Donald Winston whose guidance and companionship in the field made this paper possible, to Dr. Don Hyndman, Dr. Chester Beaty, and David R. Pevear who helped in editing, to Polley McClure Illich who helped in photographing the thin sections, and to all of the ranchers whose kind permission allowed the author to work some of the measured sections.

#### Previous work

Calkins and Emmons (1915) were the first to map the Flathead quartzite in the Flint Creek area. They interpreted the Belt-Flathead contact as unconformable. Included in this classic paper is a photograph from the northwestern Anaconda-Pintlar Range of an angular discordance between the Belt strata and the Flathead. Poulter (1956), as



a result of mapping the Georgetown thrust area, states that the Flathead lies unconformably on Belt strata and that an angular discordance between these two units is observable west of Rainbow Mountain. McGill (1959) concurred with previous workers in finding the contact unconformable on the north-west flank of the Flint Creek Range. Ross (1963, p. 99) in his general survey of the Belt Series concludes that the relationship between the Flathead and the underlying Belt is unconformable in some areas of western Montana, but suggests that it may be conformable in others. Kauffman (1963, p. 6), working in the Garnet-Bearmouth area, states that "... a very slight angular discordance..." exists between the Flathead and the Belt strata. Maxwell (1965) indicates on his map of the Flint Creek drainage that the relationship between the Flathead and the Belt strata is unconformable. Maxwell indicates that regional beveling of the Belt is demonstrable particularly in the Willow Creek area, where he believes that the Flathead is represented by lenticular sand bodies on top of the Precambrian erosion surface. However, these are probably blocks of Flathead caught in a fault zone. Nelson and Dobell (1961, p. 210) find no Flathead in the Missoula-Bonner area and they suggest that the Pilcher, the uppermost formation of the Missoula Group, grades upward into a Middle Cambrian shale, which is probably correlative with the Silver Hill.

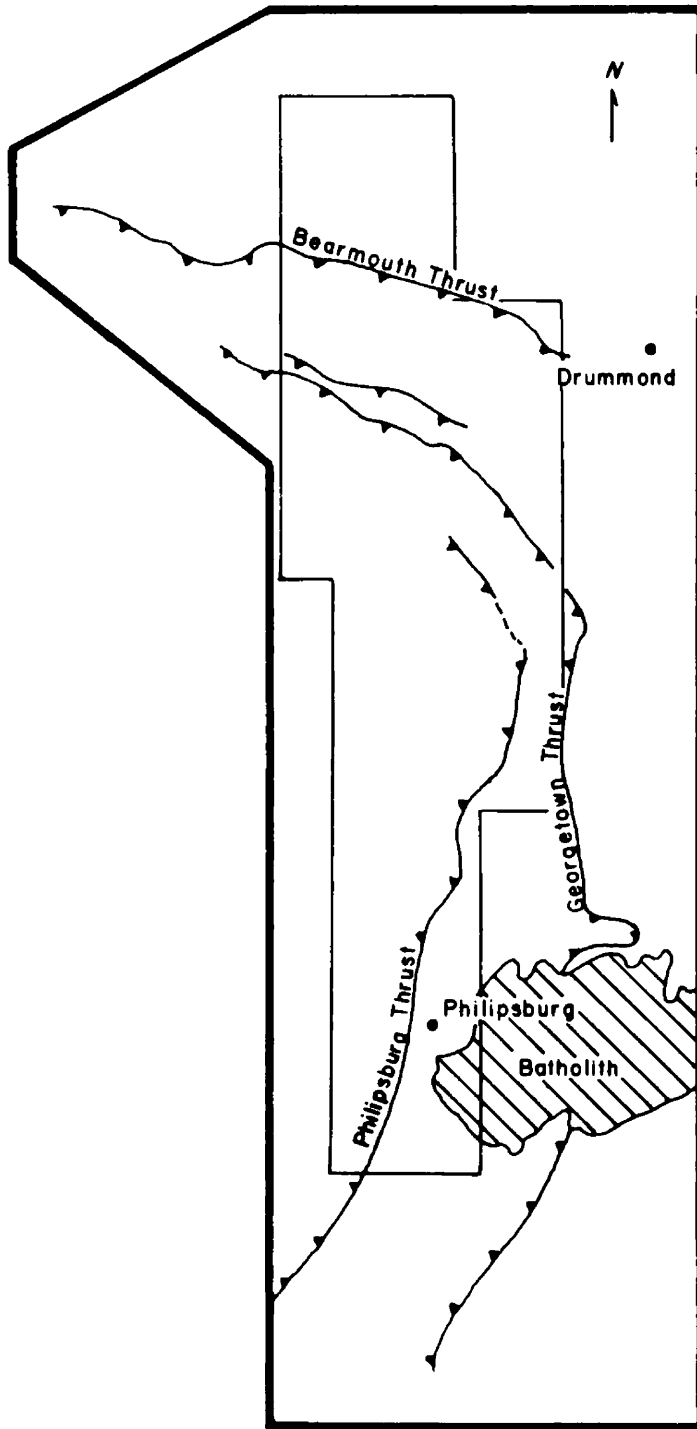
Thus, there is general agreement in the Flint Creek area that the Flathead is unconformable on Belt strata. It is also generally accepted that the Flathead is conformable with the Silver Hill in this area. To the west, however, no unconformity has been demonstrated either directly or indirectly between the Belt and the Middle Cambrian Silver Hill.



### Structural framework

The Philipsburg-Drummond area and the Missoula-Bonner area as well as much of western Montana owe their present topography to the dissection of rocks complexly folded and faulted during the Laramide. Poulter (1956), Gwinn (1960), Mutch (1961), McGill (1965), Maxwell (1965), and Weidman (1965) have published recent papers dealing with the description and interpretation of the structure of these areas. The principal interest in the structural complications and their relationship to the stratigraphy and petrology of the Flathead centers around the amount of crustal shortening that has occurred in the study area. It is important to know what the regional distribution of any stratigraphic unit was at the time of deposition and how that distribution has been altered by crustal shortening.

In the Flint Creek area the major structural features to which large scale crustal shortening can be attributed are the Montana Lineament, the Bearmouth thrust, the Philipsburg thrust, and the Georgetown thrust. Relatively large scale displacements (of the order of 10-15 miles) have not been demonstrated between Missoula and Drummond along the eastward extension of the Montana Lineament. It is quite obvious, however, that some crustal shortening has occurred with the development of the Bearmouth, Philipsburg, and Georgetown thrusts (Figure 2). Due to the problem of crustal shortening the majority of the measured sections are located on the Philipsburg thrust plate or to the west of the trace of the thrust. This effectively places most of the sections on a single structural plate. If the possibility of 'significant' crustal shortening is considered for the study area, the net result has been to



**Figure 2. Major Structural Features in the  
Philipsburg - Drummond Area**

(After Gwinn, 1960)

bring rocks of once separated depositional environments closer together. The shortening that has occurred is not obvious in the regional stratigraphic or petrologic relationships.

#### GENERAL STRATIGRAPHY

For purposes of describing the general stratigraphic relationships of the Flathead, the Philipsburg-Drummond area will be subdivided into three smaller areas. Each of the areas has certain features which distinguish it from the others. The areas are listed below and the sections in the Flint Creek area are listed. The Deep Creek and Harvey Creek areas have only one section each.

1. Flint Creek area
  - a. Porters Corner section (undescribed)
  - b. Maywood Ridge section
  - c. Boulder Creek section
  - d. Black Pine section (unmeasured)
  - e. Stone section
  - f. Eyebrow section
  - g. Ohrmann section
  - h. Willow Creek section.
2. Harvey Creek area
3. Deep Creek area

The sections are approximately located on figures 1a and 1b. They are more precisely located in appendix 1 along with the descriptions of the sections.

The stratigraphic section of the Missoula Group in the Missoula-Bearmouth-Bonner area is diagrammed in Figure 3. Formations in the Missoula Group will be referred to frequently in the discussions of the lower contact of the Flathead.

	Silver Hill	Interbedded green and red argillite and gray to gray-green glauconitic quartzite. Argillite becomes predominant higher in the unit.
		Gradational
Missoula Group	Pilcher 1000'	Red and white cross-bedded quartzite with minor amounts of interbedded red argillite.
		Gradational
	Garnet Range 1800'-2000'	Greenish-gray micaceous quartzite interbedded with green and gray argillite, moderate to light brown on weathered surface.
		Gradational
	McNamara 4000'	Green and red silty argillite and argillaceous siltite, ripple marks and mud cracks, minor amounts of quartzite.
		Gradational
	Bonner 1500'	Pink arkosic quartzite with minor amounts of interbedded argillite, cross-bedded.
		Gradational
	Miller Peak 5000'-6000'	Red and green silty argillite and argillaceous siltite, mud cracks and ripple marks, local quartzite beds and laminations.

Figure 3. Generalized description and thicknesses of the Missoula Group, Bonner Quadrangle. After Nelson and Dobell, 1961.

Stratigraphy in the Flint Creek area

The Flathead quartzite in the Flint Creek area is generally less metamorphosed than the Flathead to the east on the Georgetown thrust plate. For the most part, the Flathead sections in the Flint Creek area are incomplete. The Stone section is the only complete one. The Flathead is 80-120 feet thick. On the outcrop it is usually white to salmon colored and locally limonite stained. The very light color results from the almost complete lack of the red and green clay that is characteristic of the bounding formations. The Flathead in hand specimen appears to be medium to fine-grained pure quartz sandstone with rare altered feldspar grains and occasional quartz pebbles. A basal (?) pebble and cobble conglomerate has been observed in Flathead float at Cable Mountain on the Georgetown thrust plate. The Flathead in the Flint Creek area is mostly moderately sorted (terminology of Folk, 1954), and moderately to well indurated, with rare poorly indurated beds. The beds range considerably in thickness but average 4 to 36 inches; however, beds of 1 to 50 inches thick are common. The cross-laminations are common but are usually not obvious because of the more or less uniform light color of the Flathead; darker clay minerals do not mark the planes of lamination.

At the Stone section the Flathead rests on Belt redbeds that range from arkoses to subarkoses. These redbeds are mostly poorly sorted, contain traces to a few percent of mica flakes (muscovite and degraded muscovite), and moderate percentages of red 'hematitic' clay (5-20%). The contact between the Belt redbeds and the Flathead is

striking. The white, moderately to well indurated, quartzite of the Flathead in contact with the red clayey feldspathic Belt strata makes a contact easy to identify in the field. The measured section at Stone has a thickness of 311 feet, the upper 114 feet of which is Flathead. The unconformity at the Belt-Flathead contact at this section is interpreted from the following observations: the presence of a striking lithologic change from the Belt redbeds to the white Flathead without any observable gradation; the contact between these two units is marked by a very poorly indurated limonite stained sand that is interpreted to be a paleosoil; the striking mineralogical change from sandstone rich in mica and feldspar below to sandstone that is pure quartz above without noticeable gradation.

The Stone and Porters Corner sections are unique in the Flint Creek area because of the observable Belt-Flathead contact. The Porters Corner section is problematical and only included to report the presence of a Belt-Flathead contact. Because of the lack of data this section must be otherwise excluded from this paper.

The boundary between the Flathead and the Silver Hill can be seen at Maywood Ridge, Boulder Creek, Willow Creek, and Porters Corner sections. At this boundary there is a rather abrupt change upward from characteristic Flathead quartzite to red and green shale intercalated with clayey sandstone beds of the lowest Silver Hill. These clayey sandstones become progressively fewer as the Silver Hill grades totally upward to shale. Texturally and mineralogically the Silver Hill sandstone differs from the Flathead sandstone. The Silver Hill sandstone occasionally contains significant quantities of feldspar (5-15%),

glauconite (5-20%), and is mostly moderately sorted. The lower shale or argillite of the Silver Hill is mostly green. Green clay clasts, typical of the lowermost Silver Hill shale, are commonly found in the uppermost beds of the Flathead, leading the author to conclude that the Flathead and Silver Hill are conformable.

The Flathead in the Flint Creek drainage is not amenable at the present level of study to key bed stratigraphic study, and indeed, it is doubtful that such is possible megascopically.

#### Stratigraphy in the Harvey Creek area

The Harvey Creek section is northwest of the Flint Creek area (Figure 1b). It is pragmatic to describe this section from the Silver Hill stratigraphically downward.

The Silver Hill at this section is recessive, forming a covered interval. The shale beds themselves are only visible where the interval is trenched. The boundary between the Flathead and Silver Hill is not exposed but it is assumed to be gradational, similar to the Flathead-Silver Hill boundary in the Flint Creek area.

The Flathead at this section has a measured thickness of approximately 50 feet. The lower contact is covered by talus. The Flathead is an extremely uniform quartzose sandstone throughout the exposed thickness; it is white to salmon colored, locally limonite stained, medium to fine-grained, moderately to well indurated, with bedding ranging in thickness from 6 to 36 inches. It is locally cross-laminated. Because the lower portions of the Flathead at this outcrop are covered with talus its contact with the Belt could not be studied but the Belt


does crop out below and to the sides of the talus slope. The Belt unit exposed at this outcrop differs from the Belt redbeds found in the Flint Creek area. This Belt unit is a buff-tan to yellow-brown, medium to fine-grained, moderately indurated, micaceous and slightly feldspathic quartzarenite, with beds 1 to 6 inches thick. The lithology of this Belt unit closely corresponds to the lithology of the Garnet Range of the Missoula Group in the Missoula-Bonner area. Maxwell (1965) has mapped Garnet Range, Pilcher, Flathead and Silver Hill at this locality. Maxwell's stratigraphic succession at this locality is:

Silver Hill  


---

Flathead  



---

Pilcher  
  
Garnet Range

The author concurs with the observation that the Garnet Range is present but suggests that the stratigraphic sequence is:

Silver Hill  


---

Flathead  
  
Garnet Range

Maxwell apparently identifies part of the Flathead as Pilcher. No Pilcher lithology was observed in contact with the Flathead. Possibly the Pilcher is included in the covered section, but no Pilcher float was found.

The contact between the Garnet Range and the Flathead is interpreted to be unconformable but it is covered and no definite evidence can be offered in support of this conclusion.



Stratigraphy in the Deep Creek area

The two sections at Deep Creek represent the two most northern sections in the Philipsburg-Drummond area. When these two sections are combined they yield a complete Flathead section including the lower Belt contact and the upper Silver Hill contact.

The lower contact of the Belt with the Flathead is not well exposed and only a few feet of the underlying Belt can be observed. The Belt unit at this outcrop is buff-tan micaceous quartzarenite, medium to fine-grained, moderately indurated, with beds 1/2 to 2 inches thick. The unit contains relatively high quantities of mica (2-4%) and traces of feldspar. This lithology, like the Belt unit at Harvey Creek, most closely corresponds to the Garnet Range of the Missoula Group. The nature of the boundary between the Garnet Range-Flathead is unknown due to the lack of sufficient outcrop exposure, but it is interpreted to be conformable. Petrographically there is no break across the boundary. The mica content decreases upward to trace amounts and the clay content decreases upward. This apparently continuous change is interpreted to be characteristic of a gradational boundary.

The lower 30 feet of the Flathead at this section is atypical of the Flathead lithologies in the Flint Creek area. It is red and white cross-laminated, moderately to well indurated, medium to fine-grained, with beds 6 to 36 inches thick. In this respect the lower 30 feet of the Deep Creek section is similar to the Pilcher. The lower portion of this section may indeed be Pilcher, but the author hesitates to assign this name until the lateral relationship can be demonstrated by mapping. The red and white cross-laminated interval grades upward

into a more typical Flathead lithology and because of the gradation the lower unit is tentatively included in the Flathead. The upper 80 feet of the Deep Creek section is a white to salmon colored, locally limonite stained, medium to fine-grained, moderately to well indurated quartzarenite, with beds 6 to 36 inches thick. The upper 80 feet is locally cross-laminated.

The boundary between the Flathead and the Silver Hill is covered at the measured section but to the east this boundary can be seen. The boundary is interpreted to be gradational as in the two areas to the south of the Deep Creek area. The lowest Silver Hill is marked by green and red shale intercalated with clayey sandstone. The sandstone is most abundant near the base of the Silver Hill and becomes less abundant stratigraphically upward in the Silver Hill.

#### Tentative stratigraphic conclusions and suggestions

The stratigraphic observations are drawn together in this section into a group of conclusions and suggestions. There is need for much more work before these suggestions can be validated or rejected.

Conclusion. The Flathead lies unconformably on Belt redbeds in the Flint Creek area at the Stone section. These redbeds have been mapped as the Miller Peak by Maxwell (1965). Maxwell also indicates that the Flathead in this area is a lenticular sand body.

Suggestion. The Belt units in the Flint Creek area are considered to be too poorly known to identify with certainty any redbeds

in terms of Bonner Quadrangle terminology. Maxwell has produced an excellent reconnaissance map, but it seems unlikely that the redbeds at Stone are Miller Peak when one observes the Miller Peak to the east on the Georgetown thrust plate and to the west in the Clinton area. In these areas the Miller Peak does contain thin redbed intervals but the principal lithology is green and red silty argillite. Maxwell's indication that the Flathead is lenticular is considered invalid, for at no place in the Flint Creek area is it possible to demonstrate this conclusion as far as is known by the author.

Conclusion. The Flathead grades upward into the overlying Silver Hill shale. This relationship can be demonstrated at the Maywood Ridge, Boulder Creek, and Willow Creek sections. This agrees with the conclusions of the previous workers in the area.

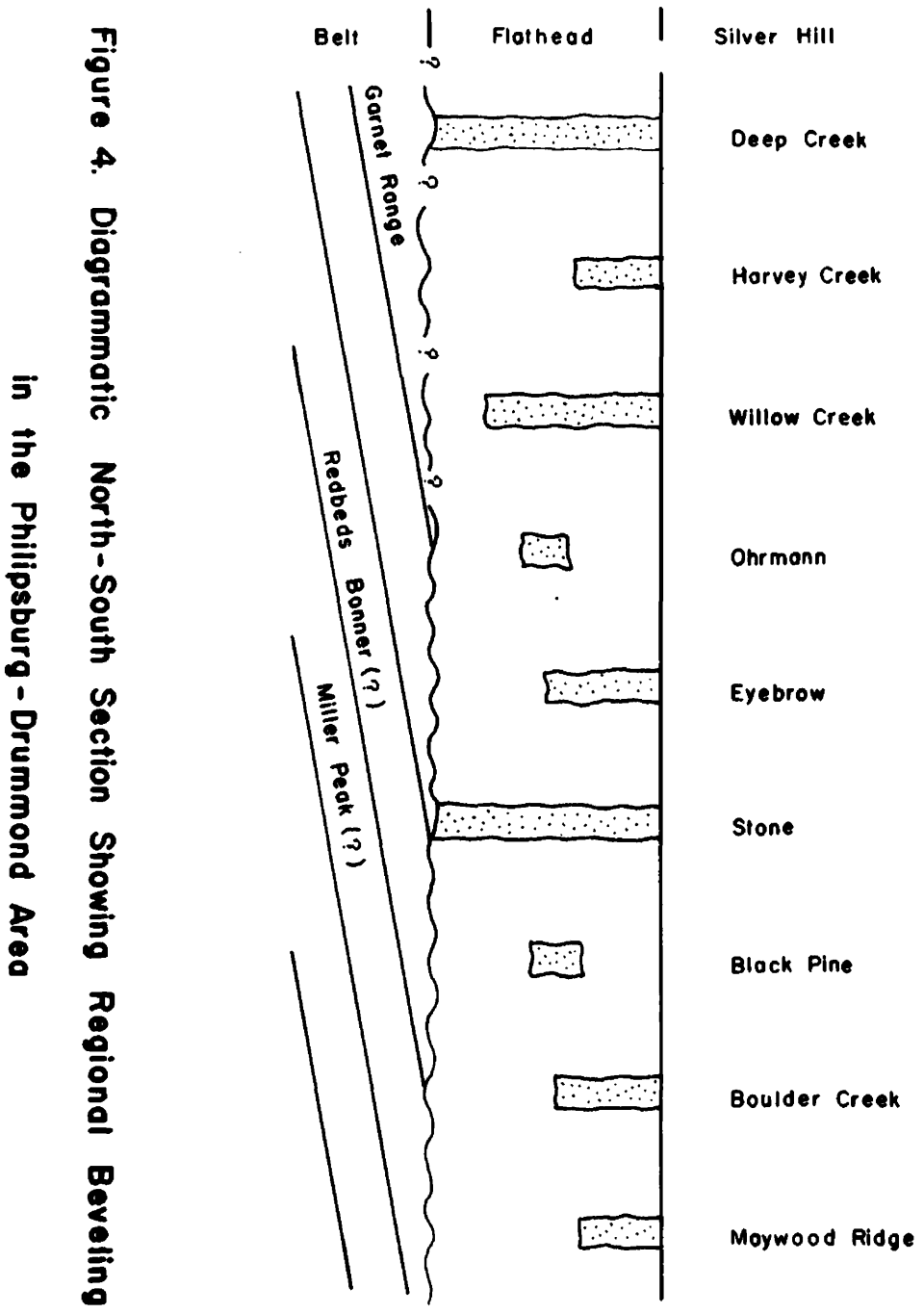
Suggestion. Although the boundary between the Flathead and the Silver Hill is interpreted to be gradational, there is a dramatic change in sandstone types in this interval. This interval offers an excellent opportunity for detailed petrologic study.

Conclusion. In the Harvey Creek area the Flathead lies on a lithology quite different from that found in the Flint Creek area. This lithology is interpreted to be the Garnet Range. If this interpretation is correct, then support is given to Maxwell's thesis that erosional beveling is demonstrable regionally.

Suggestion. Maxwell mapped Pilcher in the Harvey Creek area. No lithology was observed by the author in this area, however, that

North

South



**Figure 4. Diagrammatic North-South Section Showing Regional Beveling  
in the Philipsburg - Drummond Area**

suggests the Pilcher. Rather the Flathead lies directly on the Garnet Range. The contact relationship is unknown because of the lack of sufficient exposure. These two units are considered to be conformable.

Conclusion. In the Deep Creek area, the Flathead is interpreted to lie conformably on the Garnet Range. The lower 30 feet of the Deep Creek section may be Pilcher.

Suggestion. It is suggested that the lower portion of the Deep Creek section may be Pilcher. If this is so, a question arises concerning the thinness of the Pilcher at Deep Creek in comparison with the Pilcher in the Missoula-Bonner area. This is answered by considering the Pilcher to be a local unit having its greatest thickness in the Missoula-Bonner area and thinning to the east and the west. Further, the Flathead may be a facies of the upper Pilcher. If the Pilcher and the Flathead are facies related, then no systemic unconformity separates the Belt from the Middle Cambrian to the west. Nelson and Dobell (1961) have suggested that no systemic unconformity exists between the Pilcher and the Middle Cambrian shale (Silver Hill) in the Bonner Quadrangle, and thus, that the uppermost Belt in that area is Cambrian. This suggestion contradicts the regional relationship of the Pilcher-Flathead-Silver Hill as mapped by Kauffman (1963) in the Bearmouth area. Kauffman mapped Silver Hill and Hasmark overstepping the Pilcher and did not identify a Flathead-Pilcher contact. His map is the antithesis of the above suggestion since he recognized an angular unconformity between the Belt (Pilcher) and the Cambrian (Flathead, Silver Hill, and Hasmark) The author is of course in favor of his own suggestion and feels that Kauffman has made a mistake.

## INTRODUCTION TO PETROGRAPHY AND PETROLOGY

Approximately 130 thin sections are described from the Flathead and bounding units. The petrography and petrology is discussed formation by formation. The principal emphasis is placed on the Flathead. The percent of the various constituents in thin section was estimated visually. The Flathead thin sections are essentially monomineralic and the descriptions are very accurate. However, the units bounding the Flathead are mixtures of several grain types in moderate percentages. These descriptions are less accurate than those of the Flathead. The best method of determining relative percentages is by large number point counts, but due to time limitations this was not practical.

In order to follow a systematic nomenclature in this paper, a synthesis of classifications has been adopted. A slightly altered diagram of McBride (1963) has been used for the rock names, and the textural classification of Folk (1951, 1954, 1961) has been used for modification of the rock names. The basic triangular diagram proposed by McBride has been adopted by the author in preference to other published classifications because its polar members are considered to be objectively recognizable. The diagram is reproduced in Figure 5. McBride's original diagram has been altered in two ways. McBride places mica in "miscellaneous transported constituents" and quartzose sedimentary rock fragments at the quartz pole. In this paper, mica and sedimentary rock fragments are placed at the rock fragment pole. This deviation from McBride's original proposal is considered to be within the latitude of his classification and does not change it significantly.

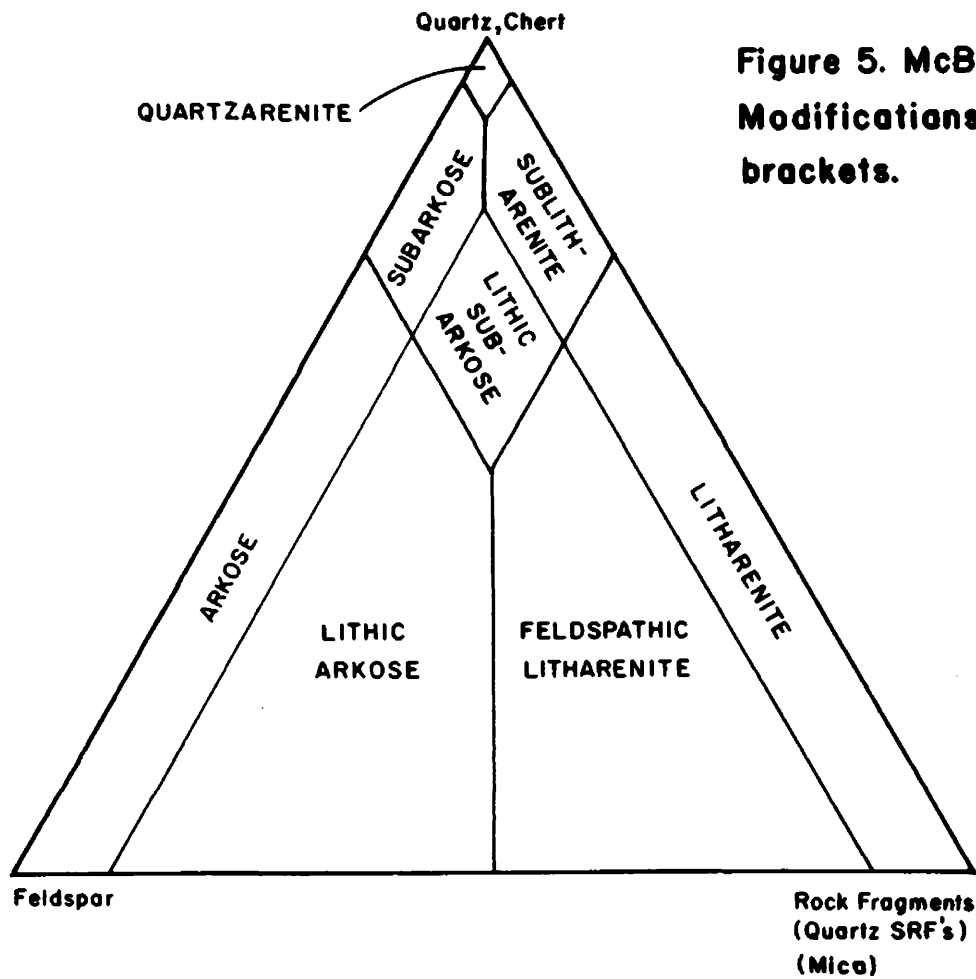


Figure 5. McBride's (1963) Classification. Modifications as used in this paper in brackets.

The textural terms are used as Folk has defined them. Photographs of the sorting values are in the appendix. Any deviation from the common use of Folk's terminology is explained in the text.

An attempt has been made to use all the terms objectively. No genetic implications are to be interpreted from the use of the textural terms, which have been defined by Folk on the basis of objective parameters.

### The Flathead lithology

The Flathead is generally a white quartzarenite in the Drummond-Phillipsburg area. Figure 6 is a plot of the mineralogy of the Flathead on a modified McBride diagram. Qualitatively the Flathead ranges from quartzarenite to litharenite. Quantitatively, however, over 90% of the thin sections are quartzarenites. The tail occupying the sublitharenite-litharenite field represents thin sections from the lower 30 feet of the Deep Creek section. The sedimentary rock fragments (SRF's) that are found in these Deep Creek thin sections are doubly overgrown quartz grains.

In thin section the Flathead is a medium to fine-grained sandstone; siliceous submature quartzarenite. In many samples the sandstone is bimodally sorted. The Flathead is composed of 99-100% quartz throughout the study area. It contains trace amounts of mica and chert and occasional intervals contain trace quantities of microcline and orthoclase. The quartzarenites, exclusive of the lower 30 feet of the Deep Creek section, contain a few doubly overgrown quartz grains. The grains that are not doubly overgrown are subround to round (3.5 to



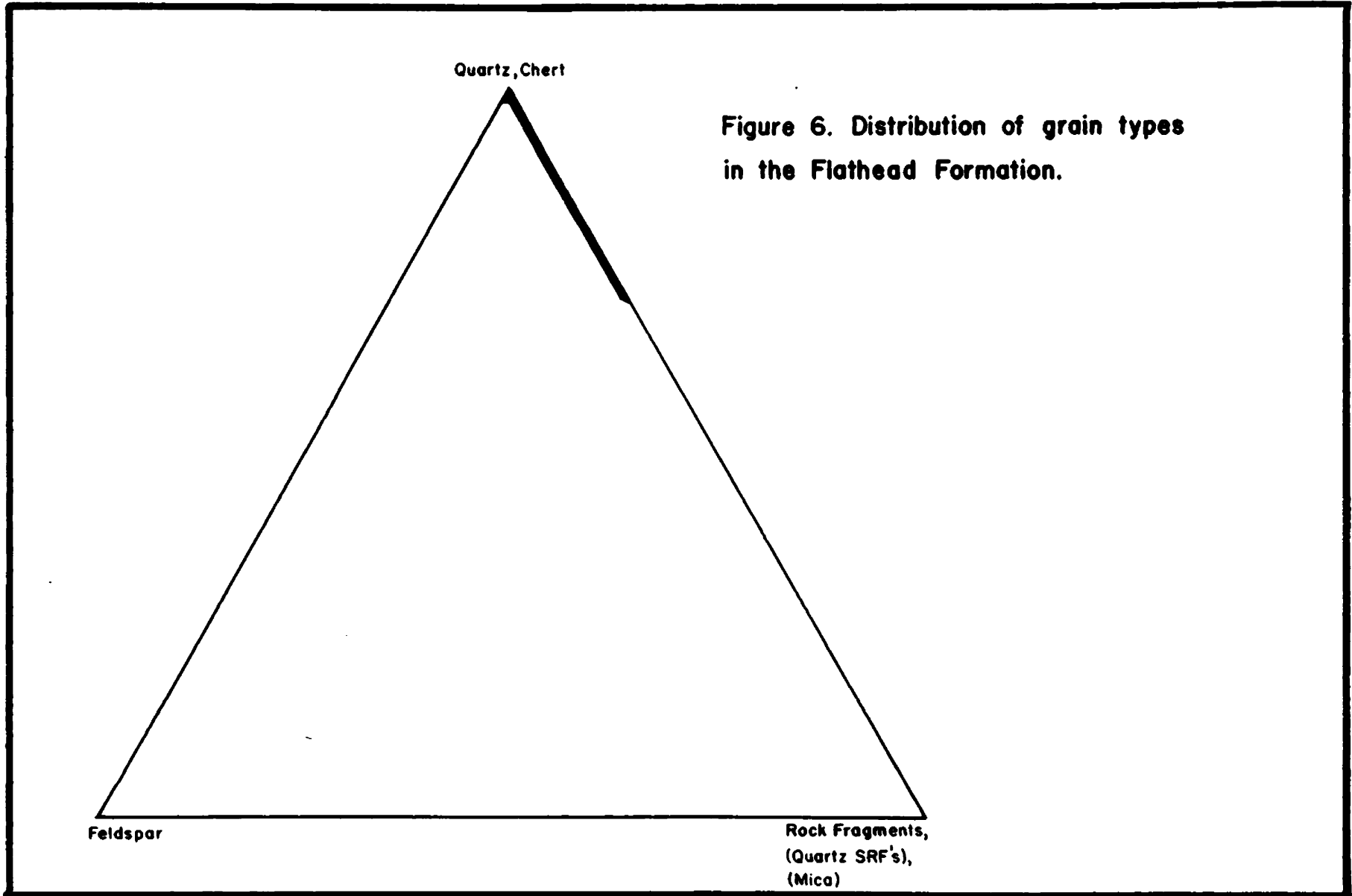


Figure 6. Distribution of grain types in the Flathead Formation.

4.5; Powers, 1953). The grains that are doubly overgrown are sub-angular to subround (2.5 to 3.5). The quartz grains are moderately to strongly welded and occasional grains are sutured. The median grain size is medium to fine but in the southern part of the area some of the beds contain coarse sand to pebble quartz grains. Moderate sorting is the rule throughout the Flathead. Quartz is the only cement found in the Flathead thin sections. The heavy minerals are zircon, tourmaline, and epidote. In many cases the tourmaline is overgrown. Clay minerals occur in trace quantities mostly as dust on the detrital quartz grains. Occasionally, however, upgraded clay minerals (illite?) are present in quantities of 1%. The clay minerals are usually iron stained.

The sedimentary structures are graded-laminations and cross-laminations. Graded-laminations occur in the bimodally sorted samples and are interpreted to be the result of rapid deposition without reworking of the sedimentary unit.

The high concentrations of doubly overgrown quartz grains in the lower 30 feet of the Deep Creek section and the relatively high concentrations of clay along planes of lamination in this section suggest that the lower part of this section was deposited in a calmer environment than was most of the Flathead.

The author believes that because of the clay dust surrounding core grains, quartz rims are rather delicately cemented to the core grain and would not suffer much abrasion or transportation.

Two possible source areas are known for the Flathead. Potential source areas for clastic grains are the basement complexes to the south

of the area and the Belt sediments present in the area and to the south. The quartz grains that are doubly overgrown obviously have been derived from a previous sedimentary source. The majority of the quartz in the Flathead, however, is not doubly overgrown but the rounding values are high (3.5 to 4.5). It is suggested that the apparent transportation distance is too short for such rounding to be achieved in quartz derived from the basement complexes. The quartz is therefore interpreted to be principally derived from the Belt sediments and to be second cycle material.

#### Belt-Flathead contact in the Philipsburg-Drummond area

The lower boundary of the Flathead is rarely exposed in the study area. Only at Stone and Deep Creek can a boundary between the Flathead and Belt be seen, and only at Stone can the contact be studied. At Harvey Creek the Belt strata below the Flathead contact can be examined. At Harvey Creek and Deep Creek the unit underlying the Flathead is interpreted to be Garnet Range. At Stone the Belt underlying the Flathead is a series of feldspathic redbeds much like the Bonner of the Missoula Group in outcrop appearance and in thin section. It is difficult to identify these Belt units because of the lack of sufficient stratigraphic work in the area. The author is prepared to say that the Belt unit at Deep Creek and Harvey Creek is Garnet Range but is unwilling to commit himself to naming the Belt unit at Stone. It is clear, however, that the Belt units underlying the Flathead at Deep Creek and Harvey Creek (Garnet Range) and Stone (Bonner-like) are distinct in thin section. In the following two portions

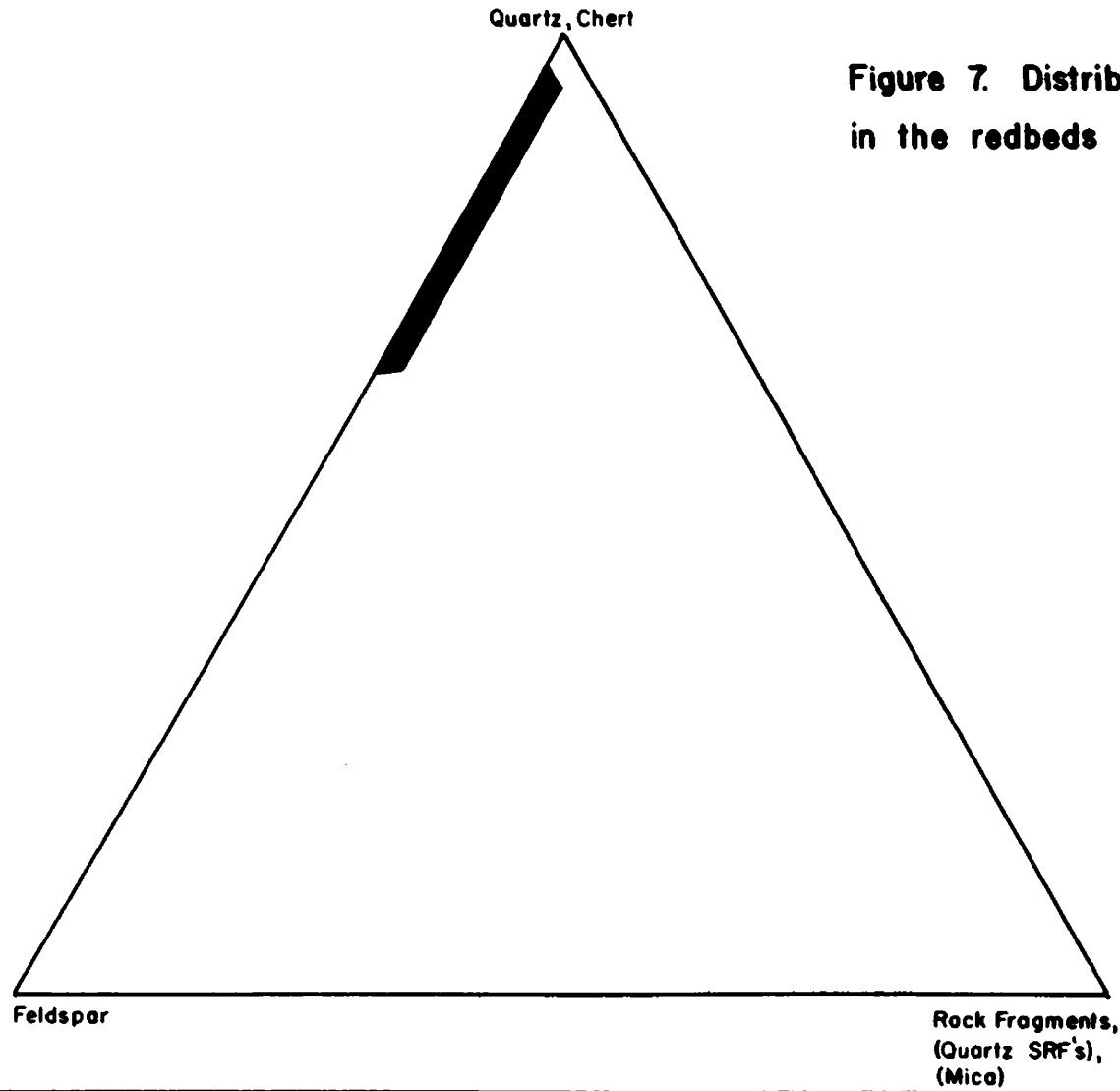
of the paper these units will be described to illustrate the differences between them

### Redbed lithology at Stone

The white quartzarenites of the Flathead are interpreted to lie unconformably on the sequence of feldspathic redbeds at Stone. Figure 7 is a plot of the thin section lithologies at Stone. The sandstones at this section are fine to medium-grained sandstone; siliceous and feldspathic submature to immature subarkoses. They contain 70-95% quartz and 5-30% feldspar. The feldspar is mostly microcline and orthoclase but occasional plagioclase grains are present. The feldspar grains range from fresh to deeply altered. The unit contains trace quantities of mica and chert. Fine and medium-grained clasts composed of upgraded clay (illite?) and sericite occur throughout the thin sections. Their genesis is difficult to determine but they can be objectively placed into two classes. G-4 grains are clasts in which the clay minerals are well oriented, and G-5 grains are clasts in which the clay minerals are poorly oriented. Some of the sericitic G-4 and G-5 grains are demonstrably alteration products of feldspar but the genesis of most of the clasts cannot generally be established and they are not included in the classifying mineralogy. The G-4, G-5 grains occur generally in quantities of less than 1%, but occasionally they are as abundant as 7-10%. When they form more than one percent of the slide they are included as miscellaneous transported constituents.

Grains that have been designated micropegmatitic occur in trace quantities. The most abundant heavy minerals are zircon, tourmaline,

**Figure 7. Distribution of grain types  
in the redbeds at Stone.**



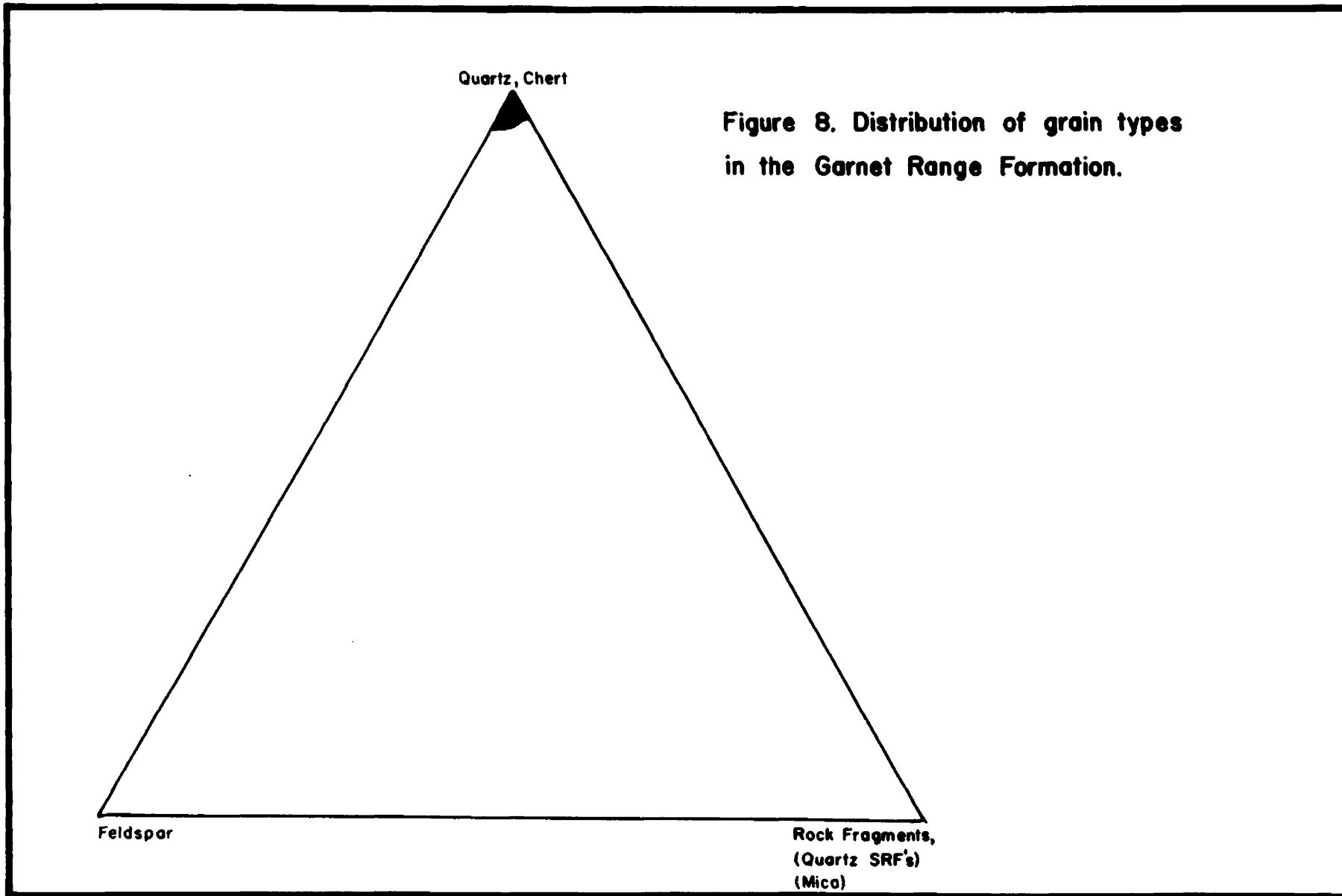
and epidote. The grains in thin section are moderately to strongly welded with rare suturing. The median grain size is fine to medium. The sandstone is mostly moderately sorted but some is poorly sorted. As in the Flathead, graded-laminations occur in conjunction with bimodal sorting but this texture is rarer in the redbeds than in the Flathead. The rounding values are 3.5 to 4.5, comparable to those of the Flathead. Quartz and feldspar overgrowths are universally present and cement the sandstone. It is important to note that this is the only unit in which the feldspars are overgrown. Tourmaline is usually overgrown as well. Red 'hematitic' illite matrix occurs in quantities of 1-2% but rarely as high as 10%.

The unit is petrographically distinct from the overlying Flathead, and the contact between the two units is a sharp plane. These two lines of evidence support the interpretation of an unconformity between the two units.

#### Garnet Range lithology

Very few thin sections were examined from the Garnet Range lithology. This unit underlies the Flathead at the Deep Creek and Harvey Creek sections. Figure 8 is a plot of the thin section lithologies.

In thin section this unit is fine to medium-grained sandstone; siliceous submature to immature slightly feldspathic and micaceous quartzarenite. The heavy mineral content, median grain size, sorting, and rounding values are comparable to those values obtained for the Flathead. Feldspar, mostly microcline and orthoclase, occurs in



**Figure 8. Distribution of grain types in the Garnet Range Formation.**

quantities of 1-3%. The feldspars are commonly fresh and they are not usually overgrown. The mica content is higher in this unit than in either the Flathead or the redbeds at Stone and ranges from 1-2%. Apparently the high mica content imparts the slabby parting to the Garnet Range on the outcrop. Quartz is the only cement in these thin sections. An 'illitic' matrix is usually present in quantities of 1-2% but occasionally as abundant as 10%.

Because of the slabby nature, mica concentrations along parting planes, and the buff-tan color (which may be caused by the weathering of mica), this formation is distinct from the Flathead and the redbeds in this area.

#### Silver Hill lithology

In most outcrops the lower Silver Hill is covered. Too few thin sections of the sandstone of this unit were examined to determine regional petrography. In thin section this unit is fine to medium-grained sandstone; siliceous submature to immature glauconitic quartzarenite. The values for median grain size, packing, heavy mineral content, sorting, and rounding are comparable to those values found for the Flathead. Glauconite occurs in some of the beds in quantities of 5-20%. A red 'hematitic' illitic matrix is present in quantities of 1-10%. Feldspar usually occurs in trace quantities but occasionally in quantities as high as 5-20%. Where it is present it is mostly fresh. The glauconite, fresh feldspar, and red 'hematitic' illite serve to distinguish the lower Silver Hill sandstone from the Flathead sandstone.

The boundary between the Flathead and the Silver Hill is re-



presented where exposed by red and green shale intercalated with sandstone beds. The lowest Silver Hill sandstone is chosen as the first sandstone above the lowest red or green shale interval.

### CONCLUSIONS

The conclusions are divided into two parts. The first part deals with the petrogenesis of the Flathead in the Drummond-Phillipsburg area and the second part deals with the westward extension of this interval in the Missoula-Bonner area. The petrogenesis of the Flathead is a first order interpretation supported by a detailed study. The extension of this interval to the west is a second order interpretation with limited support in data.

#### Petrogenesis of the Flathead

Conclusion. The Flathead of the Flint Creek and Harvey Creek areas is a transgressive Middle Cambrian sandstone over an erosion surface developed on pre-existing Belt strata.

Discussion. The sharp lithic break without noticeable gradation at the Stone section, the south and eastward overstepping of successively older Belt strata by the Flathead from Deep Creek and Harvey Creek to Stone, and the presence of a paleosol at Stone are evidence for an unconformity. The Flathead is interpreted to be Middle Cambrian because of its gradational contact with the Silver Hill. No fossils were found in the Flathead in the study area.

Conclusion. The Flathead is known to be unconformable on Belt

strata only in the southern part of the study area.

Discussion. The northward and westward extension of the unconformity beyond the Harvey Creek area is uncertain. The Belt and Cambrian strata may be conformable in these directions. An unconformity has not been clearly identified at Deep Creek and Harvey Creek.

Conclusion. The Flathead is interpreted to be a marine sandstone, probably a transgressive beach.

Discussion. The Silver Hill shale is marine on the basis of fossils and glauconite. No stratigraphic break has been observed between the Flathead and the Silver Hill that would indicate a major environmental change from non-marine to marine. The Flathead is a sheet sandstone. The cross-laminations, sorting, and lack of clay, plus its being transgressive over an unconformity appeals to the classic interpretation of a beach environment for the Flathead.

Conclusion. The sedimentary laminations that are preserved indicate that the Flathead was deposited rather rapidly.

Discussion. It is clear from the frequency of graded-laminations in thin section that this texture is common in the Flathead. Graded-lamination is the result of rapid deposition without reworking.

Conclusion. Much of the quartz present in the Flathead was derived from pre-existing sediments.

Discussion. The abundance of double overgrowths in the Deep Creek section and trace amounts of these grains throughout the Flathead

support this conclusion. The high rounding values of the grains in the Flathead can be explained by appealing to second cycle quartz.

#### Lateral extension of the Flathead interval

A study of the petrogenesis of the Flathead has primary value in the stratigraphic and petrologic understanding of the unit. The ultimate importance of such a study, however, is in interpretation of the regional stratigraphic relationships of the unit. Because of the importance of understanding the Flathead interval regionally, two sections were measured in the Bear Creek area to the northeast of Missoula (Figure 1).

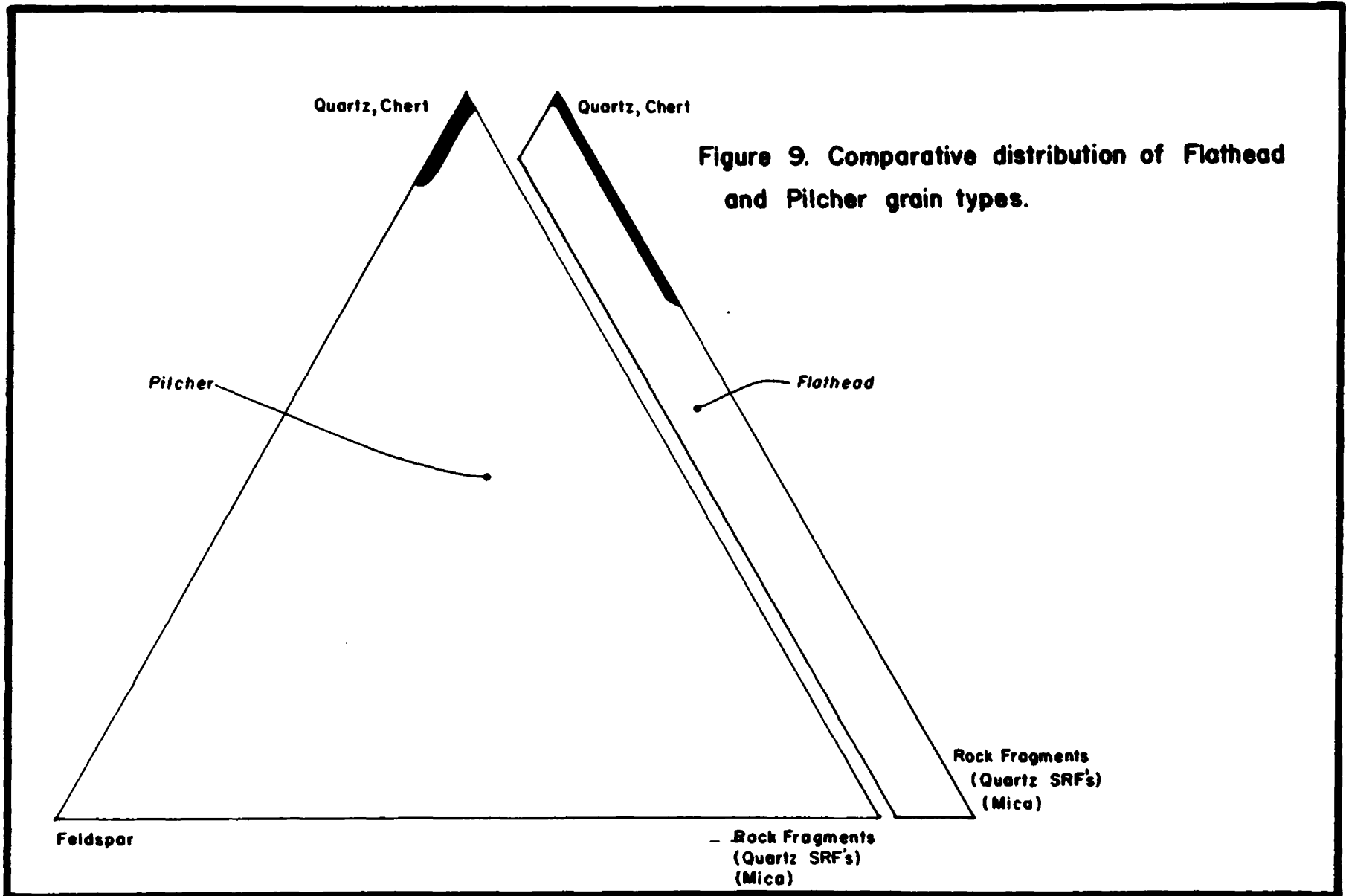
At Bear Creek the Garnet Range grades upward to Pilcher and the Pilcher grades upward to Silver Hill. If the Flathead is present, its stratigraphic position should be below the Silver Hill and in gradational contact with it. The characteristic Flathead lithology is absent at Bear Creek, and the Pilcher grades upward into the Silver Hill. The gradational boundary between these two units is similar to the Flathead-Silver Hill boundary in the Flint Creek area. The uppermost Pilcher sandstone beds contain green clay clasts similar to the green argillite of the lowest Silver Hill. Intercalated with the red and green argillite of the lowest Silver Hill are clean and clayey glauconitic sandstone beds that become less abundant higher in the Silver Hill. No unconformity has been demonstrated at the base of the Cambrian at this section. If the Pilcher is Precambrian and at the same time is in gradational contact with the Middle Cambrian Silver Hill, there appears to be a contradiction.

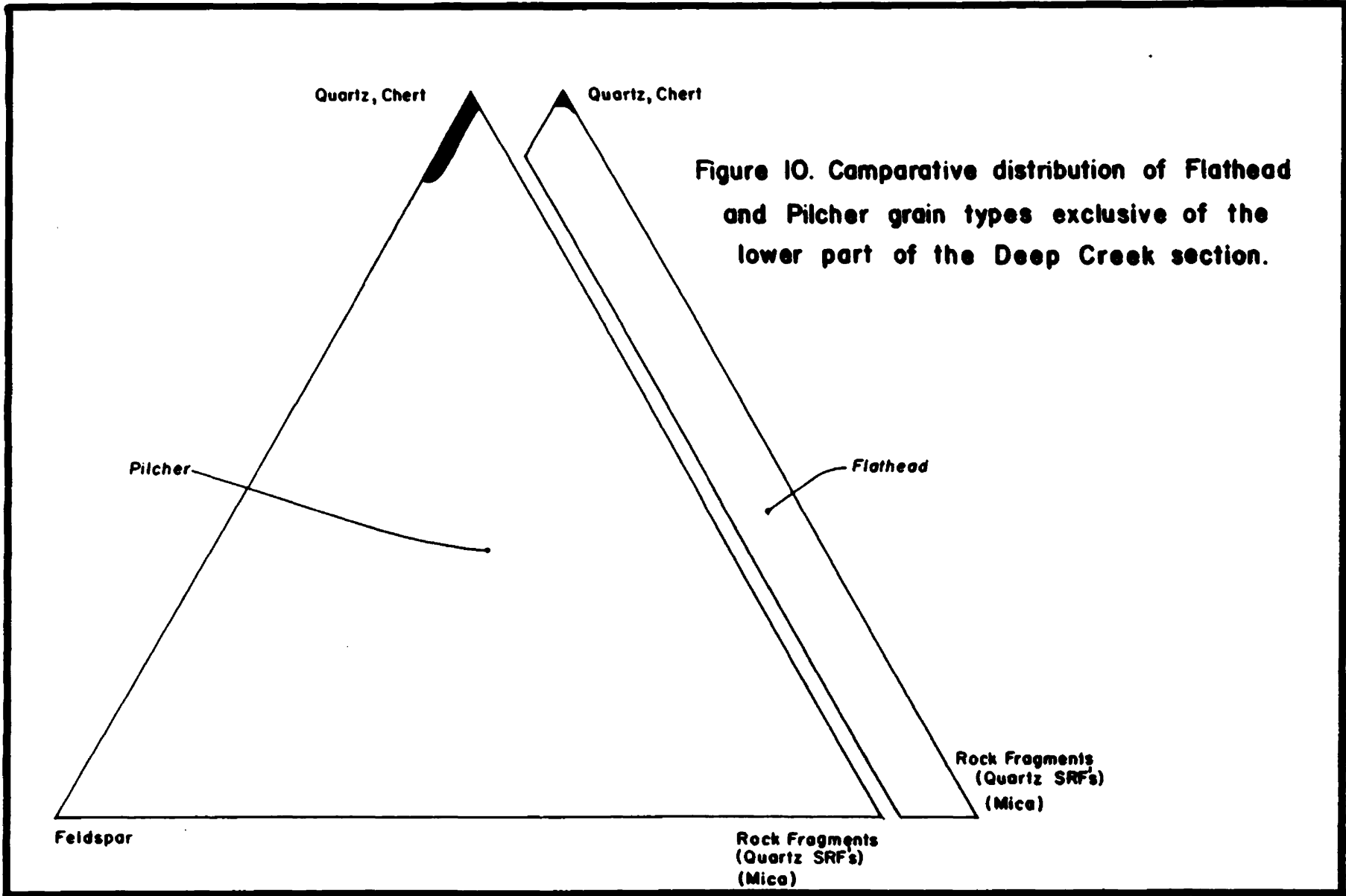
The Pilcher at Bear Creek has a measured thickness of approximately 600 feet. It is characteristically red, white, and red and white cross-laminated, moderately to well indurated, medium to fine-grained, with sandstone beds 2 to 36 inches thick. Interbedded with the sandstone are red argillite laminations and beds. The Pilcher is somewhat more argillaceous toward its base at this outcrop. On the outcrop, it appears to lack feldspar and is chiefly composed of quartz. The Pilcher at Bear Creek generally has the appearance of a dirty red and white sandstone.

In thin section the Pilcher is medium to fine-grained sandstone; siliceous submature to immature slightly feldspathic quartzarenite. Figure 9 is a comparison of the Flathead lithologies in the Drummond-Philipsburg area and the Pilcher lithologies at Bear Creek. The Bear Creek Pilcher is mostly feldspathic quartzarenite and tails to subarkose. The Flathead is mostly quartzarenite and tails to sublitharenite and litharenite. If the tail of litharenite and sublitharenite is discounted and the principal lithology of the Flathead is considered, Figure 10 is the resulting comparative plot of the Flathead with the Pilcher. It can be seen that the two plots differ very little. The principal differences between the two units are:

<u>Pilcher</u>	<u>Flathead</u>
1. 1-5% feldspar	1. Traces of feldspar
2. Traces to 1% mica	2. Occasional mica grains
3. 1-5% 'hematitic' clay content	3. Traces of clay
4. Sorting moderate to poor	4. Sorting moderate to well

The feldspars in both units are usually smaller than the median grain size and they are usually moderately to heavily altered and/or in-





cluded. Differences of sorting, mica content, and clay content are attributable to the energy of the depositional environment. The difference in feldspar content is also believed to be attributable to the energy of transportation and deposition. Feldspar in low energy environments is less mechanically abraded than feldspar in high energy environments.

From the trend of the comparison, particularly in view of the stratigraphic relationships, the upper portion of the Pilcher and the Flathead are believed to be facies of one another. Two possible interpretations based on this belief seem most reasonable to the author.

#### Case 1

Because of the thickness of the Pilcher at Bear Creek and because of its gradational contact with the underlying Garnet Range and overlying Silver Hill, the Pilcher deposition probably extended from the Precambrian to the Cambrian. In the Bear Creek area, the Pilcher was being deposited in a marine environment west or north of a strand line while to the south or east of the strand line in the Drummond-Philipsburg area the Belt was being eroded. The Pilcher was a slightly offshore facies of the beach that deposited the Flathead during the Middle Cambrian transgression. This interpretation requires a regression limit of the Precambrian sea between Bear Creek and the Harvey Creek, Stone areas. The essential differences between the Pilcher and the Flathead are due to the energy of the environment of deposition.

#### Case 2

The second hypothesis considers the Pilcher to be a continental

sandstone. The Pilcher represents, perhaps, a local and discontinuous alluvial deposit adjoining an erosional surface. During the Middle Cambrian the sea transgressed over the continental Pilcher and over the adjoining erosional surfaces. It is believed that the Pilcher represents net deposition and not net removal. Therefore the transgression over the Pilcher lithotope did not create an unconformity. The characteristic Flathead lithology is probably not present at Bear Creek because of reworking of the Pilcher and the ensuing mixing of the constituents of the two units.

### Case 3

A third possibility can be considered. An unconformity may exist between the Pilcher and the Silver Hill that has not been recognized by the author. It is necessary to say that a great deal of regional stratigraphy and petrography must be done before a definite conclusion can be made about the petrogenesis of the Garnet Range-Pilcher-Silver Hill in this area.



Appendix I

Descriptions of measured sections

Maywood Ridge section

Location: This section is located approximately 2.5 miles southeast of Maxville in the southwest quarter of the northeast quarter of section 22, T.8 N., R.13 W. It lies on the divide between South Boulder Creek and Boulder Creek. Two sections were measured and painted in this area. The description applies to the most northwesterly one. The best approach is from the South Boulder Creek road starting from a point one half mile north of the junction of this road with the Wyman Gulch road. Several Flathead exposures are present in the area and all are cliffs that face to the south. In order to find this section one should approach from the south examining each until the painted sections are found.

Description.

- 60'-66' Dark red, moderately to well indurated, fine-grained, bedding 1" to 5", argillaceous quartzarenite.
- 53'-60' Dark red to salmon, moderately to well indurated, medium to fine-grained, bedding 1" to 4", quartzarenite.
- 43'-53' Dark red, moderately to well indurated, medium to fine-grained, bedding 1" to 12", argillaceous quartzarenite interbedded with dark red argillite.
- 41'-43' Covered section.
- 40'-41' Salmon, moderately to well indurated, cross-laminated, medium to coarse-grained, quartzarenite.
- 31'-40' Covered section.

Top of Flathead.

- 7'-31' White to pink to salmon, moderately to well indurated, medium to coarse-grained, occasional pebbles, locally cross-laminated, bedding 6" to 36", quartzarenite.
- 6'-7' White to salmon, moderately indurated, medium to coarse-grained, bedding 6", quartzarenite.
- 0'-6' White to pink to salmon, moderately to well indurated, medium to coarse-grained, occasional pebbles, locally cross-laminated, bedding 6" to 36", quartzarenite.

Boulder Creek section

Location: This section is located in the northwest quarter of the southeast quarter of section 15, T.8 N., R.13 W., approximately 2 miles southeast of Maxville. It is in a road cut on the Maxville-Princeton road. The section is located on the north side of Boulder Creek approximately one eighth of a mile southeast of the road that crosses the creek and leads to Wyman Gulch.

Description

- 77'-80' Red, moderately to well indurated, fine to medium-grained, bedding 6" to 18", hematitic quartzarenite.
- 72'-77' Red sandy argillite containing thin laminations of quartzarenite.
- 70'-72' Red, well indurated, fine to medium-grained, bedding 1" to 4", hematitic quartzarenite.
- 54'-70' Red thinly laminated argillite containing occasional thin laminations of quartzarenite.

Top of Flathead.

- 47'-54' White, limonite stained, moderately to well indurated, medium to coarse-grained, bedding 6" to 36", quartzarenite.
- 46'-47' White to cream or tan, limonite stained, poorly indurated, medium to coarse-grained, bedding 1" to 2", quartzarenite.
- 37'-46' White to cream or tan, limonite stained, moderately to well indurated, medium to coarse-grained, bedding 6" to 24", quartzarenite.
- 36'-37' White, limonite stained, moderately indurated, medium to fine-grained, bedding 2", quartzarenite.
- 31'-36' White to tan, moderately to well indurated, limonite stained, medium to fine grained, bedding 6" to 12", quartzarenite.
- 30'-31' White to cream or tan, limonite stained, poorly indurated, medium to coarse-grained, bedding 1" to 2", quartzarenite.
- 27'-30' White to tan, moderately indurated, limonite stained, medium to fine-grained, bedding 3" to 6", quartzarenite.
- 26'-27' White to cream or tan, limonite stained, poorly indurated, medium to coarse-grained, bedding 1" to 2", quartzarenite.
- 0'-26' White to tan, limonite stained, moderately to well indurated, medium to fine-grained, bedding 6" to 50", locally cross-laminated, quartzarenite.

Stone section

Location: This section is in the northeast quarter of the southwest quarter of section 27, T.9 N., R.13 W. It is located on the Norris Ranch a few yards east of highway 10A at the community of Stone. This section is located on a small hill the south side of which has been quarried for building stone.

Description

- 305'-311' No description, quartzarenite.
- 300'-305' Covered section.
- 295'-300' White to tan, moderately to poorly indurated, medium to coarse-grained, bedding 3" to 12".
- 277'-295' No description, quartzarenite.
- 260'-277' White to tan, limonite stained, well indurated, medium to coarse-grained, bedding 6" to 36", occasional pebbles and granules, cross-laminated, quartzarenite.
- 259'-260' Limonite stained, poorly indurated, medium to fine-grained, bedding 1/4" to 1/2", quartzarenite.
- 252'-259' White to tan, limonite stained, moderately to well indurated, medium to fine-grained, bedding 6" to 36", cross-laminated, quartzarenite.
- 243'-252' White to tan, limonite stained, moderately to poorly indurated, medium to fine-grained, bedding 2" to 10", occasional pebbles, quartzarenite.
- 225'-243' White to salmon, areas of limonite stains, well indurated, medium to fine-grained, bedding 6" to 36", cross-laminated, occasional pebbles, quartzarenite.
- 205'-225' White to salmon, areas limonite stained, well indurated, medium to fine-grained, bedding 6" to 30", quartzarenite.
- 197'-205' White to tan, limonite stained, well indurated, medium to coarse-grained, bedding 6" to 30", occasional pebbles, quartzarenite.

Top of Belt Redbeds

- 195'-197' Strongly limonite stained, very poorly indurated, medium to coarse-grained, bedding 1" to 3", contains pebbles and granules.
- 187'-195' Covered section.

- 185'-187' Limonite stained, moderately to well indurated, medium to fine-grained, bedding 2" to 6", occasional clasts of red argillite, subarkose.
- 180'-185' Covered section.
- 176'-180' Red, moderately to poorly indurated, medium to fine-grained, bedding 1/2" to 2", containing red argillite.
- 175'-176' Limonite stained, moderately indurated, medium to fine-grained, bedding 6" to 8", subarkose.
- 170'-175' Red to pink, poorly indurated, medium to fine-grained, bedding 1/2" to 2".
- 164'-170' Covered section, subarkose.
- 162'-164' Limonite stained, moderately indurated, medium to fine-grained, bedding 6" to 15".
- 156'-162' Red, poorly indurated, medium to fine-grained, bedding 1/2" to 1", subarkose.
- 154'-156' Limonite stained, moderately indurated, medium to fine-grained, bedding 1" to 6".
- 151'-154' Red, poorly indurated, medium to fine-grained, bedding 1/2" to 2", subarkose.
- 146'-151' Limonite stained, moderately indurated, medium to fine-grained, bedding 6" to 12", thin laminations of red argillite.
- 143'-146' Red, poorly indurated, medium to fine-grained, bedding 1/2" to 2", thin laminations of red argillite.
- 141'-143' Limonite stained, moderately to well indurated, medium to fine-grained, bedding 6" to 12", containing red argillite clasts.
- 134'-141' Red, poorly indurated, medium to coarse-grained, bedding 1/2" to 2", thin laminations of red argillite.
- 132'-134' Covered section.
- 130'-132' Red, limonite stained, moderately to poorly indurated, medium to fine-grained, bedding 1/2" to 12", containing red argillite clasts, subarkose.
- 120'-130' Covered section.

- 114'-120' Red and white, limonite stained, moderately to poorly indurated, medium to fine-grained, bedding 2" to 20", thin red argillite laminations, subarkose.
- 80'-114' Covered section, subarkose.
- 75'-80' Red to salmon, limonite stained, moderately to well indurated, bedding 6" to 12", thin red argillite laminations, subarkose.
- 72'-75' Red, moderately to poorly indurated, medium to fine-grained, bedding 1" to 8", subarkose.
- 56'-72' Covered section, subarkose.
- 35'-56' Red, limonite stained, moderately to poorly indurated, bedding 1/4" to 6", medium to coarse-grained, thin laminations of red argillite, arkose.
- 28'-35' Salmon to tan, moderately to well indurated, medium to coarse-grained, bedding 6" to 24", thin red argillite laminations, subarkose.
- 18'-28' Red, limonite stained, poorly indurated, medium to coarse-grained, bedding 1/4" to 2", thin red argillite laminations, subarkose.
- 15'-18' Covered section.
- 14'-15' Red to tan, limonite stained, moderately to well indurated, medium to coarse-grained, bedding 6" to 12".
- 10'-14' Covered section.
- 8'-10' Red to tan, moderately to poorly indurated, medium to coarse-grained, bedding 6" to 10", thin laminations of red argillite, arkose.
- 3'-8' Covered section.
- 0'-3' Red, moderately to poorly indurated, medium to coarse-grained, bedding 1/4" to 2", thin laminations of red argillite, arkose.

Eyebrow section

Location: This section is located on the <sup>Haugstman</sup>~~Hoffman~~ Ranch in the northwest quarter of the southwest quarter of section 17, T.9 N., R.13 W. This section is labeled as The Eyebrow on the 15 minute Bearmouth Quadrangle. The Eyebrow is a crescent-shaped hill trending northwest-southeast. The section is located approximately one-half mile north of the access road on the southwestern slope of the hill.

Description

- 65'-75' White to salmon, moderately indurated, medium to very coarse-grained, bedding 6" to 18", containing pebbles, quartzarenite.
- 60'-65' White to salmon, well indurated, medium to very coarse-grained, bedding 6" to 18". containing pebbles in the lower few inches, quartzarenite.
- 55'-60' White to tan, moderately to well indurated, medium to coarse-grained, bedding 6' to 12', containing pebbles, thin laminations of argillite, quartzarenite.
- 50'-55' White to tan, well indurated, medium to coarse-grained, bedding 6' to 18', thin laminations of argillite, quartzarenite.
- 45'-50' White to tan, well indurated, medium to coarse-grained, bedding 6' to 18', cross-laminated, thin argillite laminations, quartzarenite.
- 40'-45' White to tan, moderately to well indurated, medium to coarse-grained, bedding 1" to 2", cross-laminated (?), quartzarenite.
- 34'-40' White to tan, moderately indurated, medium to coarse-grained, thin laminations of argillite, quartzarenite.
- 30'-34' White to tan, moderately to well indurated, medium to coarse-grained, thin laminations of argillite, quartzarenite.
- 28'-30' Covered section.
- 20'-28' Light red to salmon, moderately indurated, thin laminations of argillite, quartzarenite.
- 5'-20' White to salmon, moderately to well indurated, occasional beds being medium to dark red, medium to coarse-grained, bedding 2" to 8", cross-laminations, quartzarenite.
- 0'-5' White irregularly banded dark red, well indurated, bedding 6" to 18", medium to coarse-grained, quartzarenite.

Willow Creek Reservoir section

Location: This section is located in the northeast quarter of the southeast quarter of section 2, T.9 N., R.14 W. The painted section is on south facing cliffs above the spillway on the east of the reservoir. It is cautioned that this section is hazardous because of an unstable talus slope at the base of the cliffs and loose debris.

Description

116'-120' Covered section.

Top of Flathead

105'-116' White, locally limonite stained, moderately to poorly indurated, medium to coarse-grained, bedding 3" to 12", rarely containing green clay clasts that are typical of the lower shales of the Silver Hill Formation, quartzarenite.

104'-105' White, limonite stained, moderately to well indurated, medium to coarse-grained with occasional pebbles, bedding 1" to 4", cross-laminated, quartzarenite.

85'-104' White, locally limonite stained, moderately to poorly indurated, medium to coarse-grained, bedding 3" to 12", locally cross-laminated, quartzarenite.

84'-85' White, limonite stained, moderately to well indurated, medium to coarse-grained with occasional pebbles, bedding 1" to 4", cross-laminated, quartzarenite.

71'-84' White, locally limonite stained, moderately to poorly indurated, medium to coarse-grained, bedding 3" to 12", locally cross-laminated, quartzarenite.

70'-71' White, limonite stained, moderately to well indurated, medium to coarse-grained, bedding 1"-4", cross-laminated, quartzarenite.

57'-70' White, locally limonite stained, moderately to poorly indurated, medium to coarse-grained, bedding 3" to 18", locally cross-laminated, quartzarenite.

55'-57' White, limonite stained, moderately to well indurated, medium to coarse-grained, occasional pebbles, bedding 1" to 4", cross-laminated, quartzarenite.

0'-55' White, locally limonite stained, moderately to poorly indurated, medium to fine-grained with rare coarse grains and pebbles, bedding 3" to 18", locally cross-laminated, quartzarenite.



Ohrmann section

Location: This section is located on the Bill Ohrmann Ranch in the southwest quarter of the northeast quarter of section 3, T.10 N., R.13 W. The painted section is approximately 2 miles west of the point where the Allendale Ditch crosses the access road. The Allendale Ditch is located on the Drummond Quadrangle. It is on the north side of the road on a south-southwest facing slope. This slope is part of a low ridge that parallels the road.

Description

106'-110'	Covered section.
81'-106'	White, limonite stained, moderately to poorly indurated, medium to fine-grained, badly brecciated, quartzarenite.
45'-81'	Covered section.
42'-45'	White, limonite stained, moderately to poorly indurated, medium to fine-grained, badly brecciated, quartzarenite.
36'-42'	Covered section.
32'-36'	White, limonite stained, moderately to poorly indurated, medium to fine-grained, badly brecciated, quartzarenite.
6'-32'	Covered section.
0'-6'	White, limonite stained, moderately to poorly indurated, medium to fine-grained, badly brecciated, quartzarenite.

Harvey Creek section

Location: This section is located in the northwest quarter of the southwest quarter of section 32, T.11 N., R.14 W. The painted section is on cliffs that face to the west. These cliffs are on the ridge that forms the divide between Welch Gulch and Harvey Creek. The simplest way of finding the painted section is to walk up Welch Gulch until the first outcrop of Flathead is found. This outcrop is then followed up the slope until the section is encountered.

Description

188'-190' Covered section.

Top of Flathead

145'-188' White to salmon, locally limonite stained, moderately to well indurated, medium to fine-grained, bedding 6" to 36", locally cross-laminated, quartzarenite. This interval is very uniform in its appearance on the outcrop.

72'-145' Covered section, in this covered section lies the contact between the Flathead and the underlying Belt strata.

68'-72' Buff-tan to yellow-brown, limonite stained, moderately indurated, medium to fine-grained, micaceous, bedding 1" to 6", quartzarenite to subarkose.

15'-68' Covered section.

0'-15' Buff-tan to yellow-brown, limonite stained, moderately to poorly indurated, medium to fine-grained, bedding 1/4" to 3", micaceous, quartzarenite to subarkose.

Deep Creek sections #1 and #2

Location: These two sections are located in the northeast quarter of the northeast quarter of section 12, T.12 N., R.14 W, north of Bearmouth. They can be reached by taking the Garnet road north from highway 90 (State 10, 12) about nine miles until the Deep Creek road is reached. Turn east on the Deep Creek road at old Beartown and go approximately 3.5 miles. The two sections are located on the north side of the road on south facing cliffs. The lower section is #1 and the upper section is #2.

Description. Deep Creek section #1.

- 15'-30' Red and white, limonite stained, moderately to well indurated, medium to fine-grained, bedding 6" to 36", cross-laminated, soft sediment deformation ?, thin laminations of red argillite, quartzarenite.
- 2'-15' Red and white, limonite stained, moderately to well indurated, medium to fine-grained, bedding 6" to 36", cross-laminations, quartzarenite.

Top of Garnet Range

- 0'-2' Buff-tan to yellow-brown, moderately indurated, medium to fine-grained, bedding 1/2" to 2", micaceous, quartzarenite. There is a question whether this buff-tan Garnet Range is conformable with the overlying Flathead.

Description. Deep Creek section #2.

- 100'-105' Covered section. Green shale or argillite ?
- 98'-100' Red, moderately to well indurated, medium to coarse-grained, bedding 2" to 6", rarely green shale or argillite clasts, quartzarenite.
- 95'-98' Covered section. Green shale or argillite ?
- 94'-95' White, limonite stained, well indurated, medium to coarse-grained, bedding 6" to 8", green shale or argillite clasts, quartzarenite.
- 91'-94' Covered section. Shale or argillite ?
- 90'-91' White, limonite stained, well indurated, medium to fine-grained, bedding 6" to 8", green shale or argillite clasts, quartzarenite.
- 86'-90' Covered section. Shale or argillite ?

- 85'-86' White, moderately to well indurated, medium to fine-grained, bedding 6" to 8", contains green shale or argillite clasts, quartzarenite.
- 82'-85' Covered section. Green shale or argillite ?
- Top of Flathead
- 60'-82' White to salmon, occasional beds of red and white cross-laminated, well indurated, medium to fine-grained, locally limonite stained, quartzarenite.
- 0'-60' White to salmon, locally limonite stained, commonly beds of red and white cross-laminated sandstone, well indurated, medium to fine-grained, bedding 6" to 36".

Bear Creek section

Location: This section is located in the southwest quarter of the northwest quarter of section 18, T.13 N., R.16 W., on Bear Creek. Bear Creek is a north flowing tributary of the Blackfoot River. The section can be reached by taking the Bonner-Potomac road to the Bear Creek-Game Creek access road, approximately one-half mile east of McNamara's landing. The Bear Creek road is followed for approximately 3.8 miles. The section is on the south side of the road on a north facing slope. Parallel to the measured section is a steel irrigation pipe. The lower portion of the section can be seen immediately above the point where the irrigation pipe empties into a wooden flume.

Description

- 365'-370' Red, moderately to well indurated, medium to fine-grained, shaley, thinly laminated, quartzarenite.
- 362'-365' Green shale or argillite.
- 360'-362' Sandstone, no description.
- 355'-360' Green shale or argillite.
- 350'-355' Gray to gray-green, moderately to well indurated, medium to fine-grained, bedding 2" to 6", glauconitic quartzarenite.
- 346'-350' Green shale or argillite.

Top of Pilcher

- 343'-346' White, moderately to well indurated, medium to fine-grained, bedding 2" to 4", quartzarenite.
- 339'-343' Red, moderately to well indurated, medium to fine-grained, bedding 2" to 36", quartzarenite. At 343' there is a sharp contact between the red sandstone below and the white sandstone above. This is interpreted to be due to secondary bleaching because bedding crosses the color contact. At 340' is found a bed containing cobble sized sandstone clasts in a fine to medium-grained matrix.
- 315'-339' Covered section.
- 300'-315' White, and red and white cross-laminated, moderately to well indurated, medium to fine-grained, locally limonite stained, bedding 2" to 36", quartzarenite.

- 270'-300' Red and white cross-laminated, and red and pink horizontal-laminations, moderately to well indurated, occasional beds poorly indurated, medium to fine-grained with a few beds having coarse-grains, bedding 1" to 36", quartzarenite.
- 240'-270' Covered section.
- 170'-240' Red and white cross-laminations alternating with red, and red and white horizontally-laminated, moderately to well indurated with occasional beds poorly indurated, medium to fine-grained, bedding 2" to 36", quartzarenite.
- 140'-170' Red and white cross-laminated, red, and red and white horizontally-laminated, moderately to well indurated, medium to fine-grained, bedding 2" to 36", quartzarenite. Locally there are medium to coarse-grained beds and laminations that are moderately to poorly indurated and cross-laminated. In some cases the poor induration is due to outcrop weathering.
- 120'-140' Red and white cross-laminations, red, and red and white horizontally-laminated, limonite stained, moderately to well indurated, medium to fine-grained, bedding 2" to 36", quartzarenite.
- 103'-120' Red and white cross-laminated, red, and red and white horizontally-laminated, moderately to well indurated, fine to medium-grained with some beds having coarse-grains, bedding 2" to 36", quartzarenite.
- 102'-103' Same as 103'-120' but poorly indurated, probably due to outcrop weathering.
- 95'-102' Covered section.
- 75'-95' White with occasional red and white cross-laminations, limonite stained, moderately to well indurated, medium to fine-grained, bedding 6" to 36", quartzarenite. The whole interval is generally cross-laminated but the cross-laminations are not obvious unless some clay content is present to mark the planes of lamination.
- 65'-75' White to pink, moderately to well indurated, medium to fine-grained, cross-laminated, bedding 6" to 30", quartzarenite.
- 60'-65' Red, limonite stained, cross-laminated, moderately to well indurated, medium to fine-grained, quartzarenite.

- 54'-60' Covered section.
- 22'-54' White and salmon, limonite stained, moderately to well indurated, locally cross-laminated, medium to fine-grained, occasional partings of red argillite, occasional red argillite clay clasts, quartzarenite.
- 19'-22' Red, moderately to well indurated, medium to fine-grained, bedding 1" to 18", quartzarenite.
- 18'-19' Red argillite, thinly laminated.
- 17'-18' Red to salmon, moderately to well indurated, medium to fine-grained, limonite stained, cross-laminated, bedding 4" to 8", quartzarenite.
- 16'-17' Red argillite, thinly laminated.
- 0'-16' Red to salmon, moderately to well indurated, medium to fine-grained, limonite stained, cross-laminated, bedding 4" to 24", quartzarenite.

Appendix 2

Petrographic descriptions



## Introduction to Petrographic Descriptions

The thin section descriptions are given by measured section. Each thin section carries a letter and number (i.e. S-116 or E-50). The letter is a symbol for the measured section and the number is the footage from which the sample was collected.

Each thin section is described by a five or six part name which is consistent with Folk's and McBride's classifications. It was found that the Flathead sandstones are characteristically bimodally sorted. Folk's scheme is modified to indicate this texture.

### Example:

Bimodally moderately sorted fine and medium-grained sandstone; siliceous submature quartzarenite.

The example has two prominent modes both moderately sorted, one medium-grained and the other fine-grained.

In each measured section at least one thin section has been described in greater detail than given above. These thin sections are thought to be characteristic of the lithology present at the measured section and they are marked with the letter 'C'. The abbreviations given below are used in the detailed descriptions.

Q	quartz
F	feldspar
Ch	chert
SRF	sedimentary rock fragments
M	mica
Hv	heavy minerals
Oth	miscellaneous detrital constituents
Pk	packing
MS	median grain size
UE	upper grain size extreme
S	sorting
TxN	textural name
R	rounding
Cm	cement
Am	authigenic minerals
Mx	clay matrix
St	sedimentary structures and textures

Tourmaline is a common heavy mineral in the thin sections. The pleochroic colors were systematically recorded after a slightly modified scheme of Krynine (1946). This data is presented at the end of the thin section descriptions.

Maywood Ridge sectionX<sub>2</sub>-1

Bimodally moderately sorted very fine and medium-grained graded sandstone; siliceous submature quartzarenite. Traces of G-5 grains. (Flathead).

X<sub>2</sub>-10.5 C

Q 99-100%; F none; Ch traces; M none; SRF none; Fv zircon, epidote, tourmaline; Oth traces of G-5 grains; Pk moderate to strongly welded; MS bimodal, 0.28 mm. and 0.12 mm.; UE 1.14 mm.; S moderate; TxN bimodally moderately sorted very fine and medium-grained graded sandstone; R 3.5-4.5; Cm quartz; Am euhedral hematite grains; Mx traces of hematitic stained clay; St graded-laminations.

Bimodally moderately sorted very fine and medium-grained graded sandstone; siliceous submature quartzarenite. (Flathead).

X<sub>2</sub>-23

Bimodally moderately sorted very fine and medium-grained graded sandstone; siliceous submature slightly feldspathic quartzarenite. (Flathead).

X<sub>2</sub>-30

Bimodally moderately sorted fine and coarse-grained graded sandstone; siliceous submature quartzarenite. (Flathead).

X<sub>2</sub>-40

Well sorted fine-grained sandstone; siliceous supermature quartzarenite. A single clay clast, traces of G-4, G-5 grains. (Silver Hill).

X<sub>2</sub>-47

Moderately sorted very fine-grained sandstone; siliceous submature feldspathic, containing clay clasts, quartzarenite. Traces of doubly overgrown quartz, traces to 1% G-4, G-5 grains. (Silver Hill).

X<sub>2</sub>-59

Bimodally moderately to poorly sorted silt and fine-grained sandstone; siliceous submature slightly glauconitic, slightly feldspathic, G-4, G-5 bearing, quartzarenite. (Silver Hill).

X<sub>2</sub>-64

Moderately to well sorted very fine-grained sandstone; siliceous immature feldspathic, glauconitic, quartzarenite. Traces to 1% G-5 grains. (Silver Hill).

Boulder Creek section

## M-1

Moderately sorted medium to fine-grained sandstone; siliceous submature quartzarenite. (Flathead).

## M-10 C

Q 99-100%; F none; Ch traces; M none; SRF none; Hv tourmaline, epidote, zircon; Oth none; Fk moderate to strong welding; MS 0.19-0.20 mm.; UE 0.48-0.50 mm.; S moderate; TxN moderately sorted medium-grained sandstone; R 3.5-4.5; Cm quartz; Am none; Mx traces of 'hematitic' clay material as dust around the detrital quartz grains; St horizontally-laminated; Moderately sorted medium-grained sandstone; siliceous submature quartzarenite. (Flathead).

## M-16

Poorly to moderately sorted fine-grained sandstone; siliceous submature quartzarenite. (Flathead).

## M-20

Bimodally moderately sorted fine and very fine-grained graded sandstone; siliceous submature quartzarenite. Traces of G-5 grains. (Flathead).

## M-25

Bimodally moderately sorted fine and very fine-grained graded sandstone; siliceous submature quartzarenite. (Flathead).

## M-29

Moderately sorted medium-grained sandstone; siliceous submature quartzarenite. (Flathead).

## M-35

Bimodally moderately sorted fine and very fine-grained sandstone; siliceous submature quartzarenite. The bimodal nature of this thin section is due to coarser grains floating in a matrix of finer material. (Flathead).

## M-41

Moderately to poorly sorted medium-grained sandstone; siliceous submature quartzarenite. (Flathead).

## M-50

Bimodally moderately sorted medium and very fine-grained graded sandstone; siliceous submature quartzarenite. (Flathead).

## M-64

Well sorted very fine-grained sandstone; siliceous supermature feldspathic, glauconitic, quartzarenite. Traces of G-4, G-5 grains, altered glauconite?. (Silver Hill).

Stone section

S-2

Moderately to poorly sorted medium-grained sandstone; siliceous and feldspathic submature G-4, G-5 bearing arkose. Traces of VRF's? Feldspar overgrowths form a secondary cement in this slide and therefore the cement is described as siliceous and feldspathic. (Redbeds).

S-10

Bimodally moderately to poorly sorted medium and fine-grained graded sandstone; siliceous and feldspathic immature to submature G-4, G-5 bearing subarkose to arkose. Traces of muscovite, and traces of VRF's?. (Redbeds).

S-20

Bimodally poorly sorted medium and very fine-grained graded sandstone; siliceous and feldspathic submature G-4, G-5 bearing subarkose. Traces of micropegmatitic grains, muscovite, and VRF's?. (Redbeds).

S-29

Moderately sorted medium-grained sandstone; siliceous and feldspathic submature G-4, G-5 bearing subarkose. Traces of muscovite, traces of VRF's?. (Redbeds).

S-41

Poorly sorted fine-grained sandstone; siliceous and feldspathic submature to immature G-4, G-5 bearing subarkose to arkose. Traces of muscovite and chert. This slide may be bimodally sorted. (Redbeds).

S-50

Bimodally moderately to poorly sorted medium and fine-grained graded sandstone; siliceous and feldspathic submature G-4, G-5 bearing arkose. Traces of muscovite, chert, and micropegmatitic grains. Traces of VRF's? (Redbeds).

S-56

Bimodally moderately to poorly sorted medium and fine-grained graded sandstone; siliceous and feldspathic submature G-4, G-5 bearing subarkose. Traces of muscovite, chert, and micropegmatitic grains. Traces of VRF's? (Redbeds).

S-72

Moderately to well sorted fine-grained sandstone; siliceous and feldspathic immature G-4, G-5 bearing subarkose. Traces of chert, muscovite, and VRF's?. (Redbeds).

## S-82 C

Q 88-93%; F 5-10% microcline/orthoclase; Ch traces; M traces of muscovite; SRF traces of doubly overgrown quartz and traces of siltite fragments; Hv tourmaline; Oth traces of micropegmatitic grains, G-4, G-5 grains, and VRF's?; Pk moderate to strong welding; MS 0.210 mm.; UE 0.44 mm.; S moderately; TxN moderately sorted fine-grained sandstone; R 2.5-3.5; Cm quartz and feldspar overgrowths with quartz predominating; Mx 3-8% illitic clay matrix usually iron stained; St horizontally-laminated.

Moderately sorted fine-grained sandstone; siliceous and feldspathic immature G-4, G-5 bearing subarkose. (Redbeds).

## S-100

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous and feldspathic submature G-4, G 5 bearing, clay clast bearing subarkose. Traces of chert, muscovite, micropegmatitic grains and VRF's?. (Redbeds).

## S-116

Moderately sorted fine-grained sandstone; siliceous and feldspathic submature G-4, G 5 bearing, micaceous, subarkose. Traces of chert and micropegmatitic grains. (Redbeds).

## S-130

Moderately sorted fine-grained sandstone; siliceous and feldspathic immature G-4, G-5 bearing subarkose. Traces of chert and micropegmatitic grains. (Redbeds).

## S-153

Moderately sorted fine-grained sandstone; siliceous and feldspathic immature G-4, G-5 bearing subarkose. Traces of chert, muscovite, and micropegmatitic grains. (Redbeds).

## S-160

Moderately sorted fine-grained sandstone; siliceous and feldspathic submature G-4, G-5 bearing subarkose. Traces of muscovite, chert, siltite fragments, doubly overgrown quartz grains, micropegmatitic grains, and clay clasts. (Redbeds).

## S-165

Moderately sorted fine-grained sandstone; siliceous and feldspathic submature G-4, G-5 bearing, clay clast bearing subarkose. Traces of chert, muscovite, doubly overgrown quartz grains, and micropegmatitic grains. (Redbeds).

## S-175

Moderately sorted fine-grained sandstone; siliceous and feldspathic immature G-4, G-5 bearing subarkose. Traces of chert, muscovite, micropegmatitic grains, and VRF's?. (Redbeds).

## S-185

Moderately sorted fine-grained sandstone; siliceous and feldspathic submature G-4, G-5 bearing subarkose. Traces of chert, muscovite, siltite fragments, micropegmatitic grains and VRF's?. (Redbeds).

## S-202

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz grains. Traces of siltite and chert. (Flathead).

## S-210

Bimodally moderately sorted medium and coarse-grained graded sandstone; siliceous submature quartzarenite. Traces of chert, siltite, muscovite, and doubly overgrown quartz grains. (Flathead).

## S-220

Well sorted fine-grained sandstone; siliceous supermature quartzarenite. Traces of chert, siltite, and VRF's?. (Flathead).

## S-230

Bimodally moderately to well sorted medium-grained graded sandstone; siliceous submature to supermature quartzarenite. Traces of siltite fragments and chert. (Flathead).

## S-240

Moderately sorted fine to medium-grained sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz grains. (Flathead).

## S-251

Poorly sorted medium to coarse-grained sandstone; siliceous submature quartzarenite. This slide may be bimodally sorted. Traces of chert. (Flathead).

## S-260 C

Q 99-100%; F none; Ch traces; M none; SRF traces of doubly overgrown quartz grains; Hv tourmaline and zircon; Oth traces of G-5 grains; Pk moderate to strong welding; MS bimodal, 0.23 mm. and 0.15 mm.; UE 1.1 mm.; S moderate; TxN bimodally moderately sorted fine-grained graded sandstone; R 3.5-4.5; Cm quartz; Mx traces quantities of upgraded clay; St graded-laminations. Bimodally moderately sorted fine-grained graded sandstone; siliceous submature quartzarenite. (Flathead).

## S-270

Bimodally moderately sorted coarse and very fine-grained graded sandstone; siliceous submature quartzarenite. Traces of chert and doubly overgrown quartz. (Flathead).

S-280

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of muscovite and chert. (Flathead).

S-311

Bimodally moderately to poorly sorted medium and coarse-grained graded sandstone; siliceous submature quartzarenite. Traces of muscovite. (Flathead).



Eyebrow section

E-2

Moderately sorted medium-grained sandstone; siliceous submature quartzarenite. Traces of mica and badly altered feldspar. Traces of doubly overgrown quartz. (Flathead).

E-10

Moderately sorted fine-grained sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz. (Flathead).

E-20 C

Q 99-100%; F none; Ch none; M none; SRF traces of siltite fragments; Hv zircon, tourmaline; Oth traces of heavily included grains, quartz?; Pk moderate welding; MS bimodal, 0.35 mm. and 0.15 mm.; UE 0.90 mm.; S moderately; TxN bimodally moderately sorted medium and fine-grained graded sandstone; R 3.5-4.5; Cm quartz; Mx traces of clay as dusting on detrital quartz grains; St graded-laminations; Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. (Flathead).

E-32

Bimodally moderately to well sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz. (Flathead).

E-40

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of G-4, G-5 grains. (Flathead).

E-50

Bimodally moderately to poorly sorted coarse and fine-grained graded sandstone; siliceous submature slightly feldspathic quartzarenite. Traces of doubly overgrown quartz and G-4, G-5 grains. (Flathead).

E-62

Bimodally moderately sorted coarse and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of G-4, G-5 grains. (Flathead).

E-70

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature slightly feldspathic quartzarenite. Traces of G-4, G-5 grains. (Flathead).

Willow Creek Reservoir section

## WCR-0

Bimodally moderately to well sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. Zircon overgrowth? (Flathead).

## WCR-10

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz. (Flathead).

## WCR-22

Bimodally moderately sorted coarse and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz. (Flathead).

## WCR-30 C

Q 99-100%; F trace quantities of microcline and orthoclase, smaller than median grain size; Ch none; M traces of muscovite; SRF traces of siltite grains, traces of doubly overgrown quartz grains; Hv epidote, tourmaline; Oth traces of heavily included and/or altered unidentified grains; Fk moderate to strong welding traces of suturing; MS bimodal, 0.60 mm. and 0.18 mm.; UE 1.20 mm.; S moderately; TxN bimodally moderately sorted coarse and fine-grained graded sandstone; R 3.5-4.5; Cm quartz; Am trace quantities of feldspar overgrowths?; Mx traces of upgraded clay matrix. Bimodally moderately sorted coarse and fine-grained graded sandstone; siliceous submature very slightly feldspathic quartzarenite. (Flathead).

## WCR-39

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature very slightly feldspathic quartzarenite. Traces of G-4, G-5 grains. (Flathead).

## WCR-50

Bimodally moderately to poorly sorted medium and coarse-grained sandstone; siliceous submature very slightly feldspathic quartzarenite. The bimodal nature is the result of the coarse mode floating in a matrix of the finer mode. Traces of doubly overgrown quartz. (Flathead).

## WCR-60

Bimodally moderately sorted coarse and fine-grained graded sandstone; siliceous submature feldspathic quartzarenite. (Flathead).

## WCR-70

Bimodally moderately sorted coarse and fine-grained graded sandstone; siliceous submature very slightly feldspathic quartzarenite. (Flathead).

## WCR-80

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature very slightly feldspathic quartzarenite. Traces of green clay clasts. (Flathead).

## WCR-90

Bimodally moderately sorted medium and very fine-grained graded sandstone; siliceous very slightly feldspathic quartzarenite. Traces of glauconite. (Flathead).

## WCR-100

Moderately to poorly sorted medium-grained sandstone; siliceous submature very slightly feldspathic quartzarenite. Traces of doubly overgrown quartz. (Flathead).

## WCR-115

Moderately to well sorted medium-grained sandstone; siliceous submature very slightly feldspathic quartzarenite. (Flathead).

Ohrmann section

This section is badly brecciated and covered. Because of the difficulty of obtaining undisturbed samples only three thin sections were cut.

Or-33

Moderately sorted medium-grained sandstone; siliceous submature quartzarenite. Traces of feldspar and muscovite. (Flathead).

Or-90

Moderately to well sorted medium-grained sandstone; siliceous submature quartzarenite. Traces of feldspar and muscovite. (Flathead).

Or-95

Bimodally moderately sorted medium and coarse-grained graded sandstone; siliceous submature quartzarenite. Traces of muscovite, feldspar and siltite fragments. (Flathead).

Harvey Creek section

## Hv-2 C

Q 80-90%; F 3-5% microcline/orthoclase/plagioclase, mostly fresh; Ch traces to 1%; M traces to 1% muscovite; SRF traces of doubly overgrown quartz grains; Hv zircon, tourmaline, epidote; Oth 3-5% G-4, G-5 grains; Pk moderate welding; MS 0.125 mm.; UE 0.225 mm.; S moderate; TxN poorly sorted fine-grained sandstone; R 3.5-4.5; Cm quartz; Mx 5-7% upgraded clay matrix; St horizontally-laminated;

Moderately sorted fine-grained sandstone; siliceous immature feldspathic, micaceous, G-4, G-5 bearing quartzarenite. (Garnet Range).

## Hv-10

Poorly sorted fine-grained sandstone; siliceous submature feldspathic, micaceous, G-4, G-5 bearing quartzarenite. Traces of doubly overgrown quartz. (Garnet Range).

## Hv-15

Poorly sorted fine-grained sandstone; siliceous submature feldspathic, micaceous, G-4, G-5 bearing quartzarenite. (Garnet Range).

## Hv-68

Moderately to poorly sorted fine-grained sandstone; siliceous submature feldspathic, micaceous, G-4, G-5 bearing quartzarenite. Traces of doubly overgrown quartz. (Garnet Range).

## Hv-72

Moderately to poorly sorted fine-grained sandstone; siliceous submature feldspathic, micaceous, G-4, G-5 bearing quartzarenite. Traces of doubly overgrown quartz grains. (Garnet Range).

## Hv-145

Moderately sorted fine-grained sandstone; siliceous submature quartzarenite. Traces of double overgrowths. (Flathead).

## Hv-150

Moderately to well sorted fine-grained sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz. (Flathead).

## Hv-160

Moderately sorted fine-grained sandstone; siliceous submature quartzarenite. (Flathead).

## Hv-170

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz grains, traces of clay clasts. (Flathead).

## Hv-182

Moderately sorted fine-grained sandstone; siliceous submature quartzarenite. (Flathead).

## Hv-186 C

Q 99-100%; F none; Ch traces; M none; SRF traces of doubly overgrown quartz grains, traces of siltite fragments; Hv zircon, tourmaline; Oth traces of heavily included and/or altered unidentified grains; Pk moderate to strong welding traces of suturing; MS 0.20-0.22 mm.; UE 0.70-0.71 mm.; S moderate; TxN moderately sorted fine-grained sandstone; R 3.5-4.5; Cm quartz; Mx traces to 1% upgraded clay; St horizontally-laminated; Moderately sorted fine-grained sandstone; siliceous submature quartzarenite. (Flathead).

Deep Creek section #1DC<sub>1</sub>-0

Poorly sorted fine-grained sandstone; siliceous immature feldspathic, micaceous, G-4, G-5 bearing quartzarenite. Traces of doubly overgrown quartz grains and traces of siltite fragments. (Garnet Range).

DC<sub>1</sub>-3

Moderately to poorly sorted fine-grained cross-laminated sandstone; siliceous submature sublitharenite. This sample contains 5-10% doubly overgrown quartz grains. (Flathead).

DC<sub>1</sub>-8 C

Q 75-80%; F none; Ch traces; M traces of muscovite; SRF 20-25% doubly overgrown quartz grains, traces of siltite fragments; Hv zircon, tourmaline, epidote?; Oth traces of heavily included and/or altered unidentified grains; Pk moderate welding; MS 0.22-0.24 mm.; UE 0.54-0.60 mm.; S moderate; TxN moderately sorted fine-grained sandstone; R 3.5-4.5 for the non-doubly overgrown quartz grains, 2.5-3.5 for the doubly overgrown quartz grains; Cm quartz; Am tourmaline; Mx traces to 1% clay dust around the detrital quartz grains;

Moderately sorted fine-grained sandstone; siliceous submature sublitharenite to litharenite. (Flathead).

DC<sub>1</sub>-20

Moderately sorted fine-grained sandstone; siliceous submature litharenite. Approximately 30% of the grains in this slide are doubly overgrown quartz, traces of siltite fragments. (Flathead).

DC<sub>1</sub>-30

Moderately sorted fine-grained sandstone; siliceous submature sublitharenite to quartzarenite. Traces of clay clasts, traces of siltite fragments. (Flathead).

Deep Creek section #2DC<sub>2</sub>-0

Moderately sorted fine-grained sandstone; siliceous submature litharenite. Approximately 30% of this slide is composed of doubly overgrown quartz grains. The non-doubly overgrown quartz grains have rounding values of 3.5-4.5. The doubly overgrown quartz grains have rounding values of 2.5-3.5. (Flathead).

DC<sub>2</sub>-9

Bimodally moderately sorted fine and very fine-grained cross-laminated sandstone; siliceous submature to immature quartzarenite. Traces of doubly overgrown quartz grains and traces of siltite fragments. 4-6% clay matrix. (Flathead).

DC<sub>2</sub>-20

Moderately sorted fine-grained sandstone; siliceous submature sublitharenite. 15-20% of the slide is composed of doubly overgrown quartz grains whose rounding is 2.5-3.5. The rounding of the non-doubly overgrown quartz grains is 3.5-4.5. (Flathead).

DC<sub>2</sub>-32

Moderately sorted medium-grained sandstone; siliceous submature SRF bearing quartzarenite. 1-2% doubly overgrown quartz grains. (Flathead).

DC<sub>2</sub>-40

Moderately to well sorted fine-grained sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz grains. (Flathead).

DC<sub>2</sub>-48

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. (Flathead).

DC<sub>2</sub>-60

Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. (Flathead).

DC<sub>2</sub>-70 C

Q 99-100%; F none; Ch traces; M traces of muscovite; SRF traces of doubly overgrown quartz grains; Hv zircon, tourmaline, epidote?; Oth traces of heavily included and/or altered unidentified grains; Pk moderately to strongly welded, traces of suturing; MS 0.15 mm.-0.16 mm.; UE 0.57 mm.; S moderate; TxN moderately sorted fine-grained sandstone; R 3.5-4.5; Cm quartz; Mx traces to 1% clay; St horizontally laminated;  
Moderately sorted fine-grained sandstone; siliceous submature quartzarenite. (Flathead).



DC<sub>2</sub>-80

Bimodally moderately sorted coarse and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz grains and traces of siltite fragments. (Flathead).

DC<sub>2</sub>-90

Moderately sorted fine-grained sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz grains. 2-3% limonite stained clay matrix. (Silver Hill).

Bear Creek section

The thin sections from this section represent the Pilcher lithology that grades upward into the Silver Hill shales. No Flat-head lithology is recognizable in this area and areas to the west.

BC<sub>1</sub>-1

Moderately sorted medium-grained sandstone; siliceous submature to immature micaceous, feldspathic quartzarenite. (Pilcher).

BC<sub>1</sub>-9.5

Moderately sorted medium-grained sandstone; siliceous submature very slightly feldspathic quartzarenite. Traces of doubly overgrown quartz and traces of siltite fragments. (Pilcher).

BC<sub>1</sub>-21

Poorly sorted fine-grained sandstone; siliceous immature micaceous feldspathic quartzarenite. Traces of chert, doubly overgrown quartz grains, siltite fragments, and heavily included and/or altered unidentified grains. (Pilcher).

BC<sub>1</sub>-30

Moderately to poorly sorted fine-grained sandstone; siliceous submature very slightly feldspathic quartzarenite. Traces of muscovite, chert, and heavily included and/or altered unidentified grains. (Pilcher).

BC<sub>1</sub>-40

Bimodally moderately to poorly sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. Traces of chert and muscovite. (Pilcher).

BC<sub>1</sub>-50

Bimodally moderately to poorly sorted medium and very fine-grained graded sandstone; siliceous immature feldspathic quartzarenite. Traces of chert and muscovite. (Pilcher).

BC<sub>1</sub>-62

Poorly sorted fine-grained sandstone; siliceous immature micaceous feldspathic quartzarenite. Traces of chert, doubly overgrown quartz grains, and siltite fragments. (Pilcher).

BC<sub>1</sub>-71

Moderately sorted medium-grained sandstone; siliceous submature quartzarenite. Traces of chert, muscovite, doubly overgrown quartz grains, and siltite fragments. (Pilcher).

BC<sub>1</sub>-81

Bimodally moderately sorted medium and fine-grained poorly graded sandstone; siliceous submature slightly feldspathic quartzarenite. Traces of chert and muscovite. (Pilcher).

BC<sub>1</sub>-90 C

Q 97-98%; F 2-3%; Ch traces; M traces of muscovite; SRF traces of siltite fragments; Hv tourmaline; Oth traces of heavily included and/or altered unidentified grains; Ek moderately to strong welding traces of suturing; MS 0.22 mm. to 0.25 mm.; UE 0.47 mm.; S moderately; TxN moderately sorted fine-grained sandstone; R 3.5-4.5; Cm quartz; Mx 1-3% upgraded clay matrix; St horizontally laminated;  
Moderately sorted fine-grained sandstone; siliceous submature feldspathic quartzarenite. (Pilcher).

BC<sub>1</sub>-109

Bimodally moderately sorted fine and very fine-grained graded sandstone; siliceous immature feldspathic quartzarenite. Traces of muscovite, chert, and siltite fragments. (Pilcher).

BC<sub>1</sub>-118

Bimodally moderately to poorly sorted medium and fine-grained graded sandstone; siliceous submature to immature feldspathic quartzarenite. Traces of chert, muscovite, siltite fragments, doubly overgrown quartz grains, and heavily included and/or altered unidentified grains. (Pilcher).

BC<sub>1</sub>-130

Moderately sorted fine-grained sandstone; siliceous immature quartzarenite. Traces of feldspar, muscovite, chert, doubly overgrown quartz grains, and siltite fragments. (Pilcher).

BC<sub>1</sub>-140

Bimodally moderately to poorly sorted fine and very fine-grained poorly graded sandstone; siliceous submature to immature feldspathic quartzarenite. Traces of chert, muscovite, siltite fragments, and clay clasts. (Pilcher).

BC<sub>1</sub>-150

Bimodally poorly sorted fine and very fine-grained graded sandstone; siliceous immature feldspathic quartzarenite. Traces of muscovite, chert, siltite fragments, and clay clasts. (Pilcher).

BC<sub>1</sub>-160

Bimodally moderately sorted medium and very fine-grained poorly graded sandstone; siliceous immature feldspathic quartzarenite. Traces of chert, muscovite, siltite fragments, and heavily included and/or altered unidentified grains. (Pilcher).

BC<sub>1</sub>-170

Poorly sorted fine-grained sandstone; siliceous immature feldspathic quartzarenite or subarkose?. Traces of chert, muscovite, siltite fragments, and clay clasts. (Pilcher).

- BC<sub>1</sub>-180  
Moderately to poorly sorted medium-grained sandstone; siliceous submature feldspathic quartzarenite. This slide may be bimodally sorted. Traces of chert, muscovite, doubly overgrown quartz grains, siltite fragments, and heavily included and/or altered unidentified grains. (Pilcher).
- BC<sub>1</sub>-200  
Bimodally moderately to poorly sorted medium and fine-grained poorly graded sandstone; siliceous submature feldspathic quartzarenite. Traces of chert, muscovite, doubly overgrown quartz grains, and siltite fragments. (Pilcher).
- BC<sub>1</sub>-210  
Moderately to poorly sorted medium-grained sandstone; siliceous submature feldspathic quartzarenite. Traces of chert, muscovite, and siltite fragments. (Pilcher).
- BC<sub>1</sub>-220  
Bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature feldspathic quartzarenite to subarkose? Traces of chert, muscovite, doubly overgrown quartz grains and clay clasts. (Pilcher).
- BC<sub>1</sub>-230  
Bimodally moderately sorted coarse and fine-grained sandstone; siliceous submature feldspathic quartzarenite. Traces of chert, muscovite, and siltite fragments. (Pilcher).
- BC<sub>1</sub>-275  
Moderately sorted medium to fine-grained sandstone; siliceous submature subarkose. Traces of muscovite and chert. (Pilcher).
- BC<sub>1</sub>-291  
Bimodally moderately to poorly sorted medium to very fine-grained poorly graded sandstone; siliceous immature feldspathic quartzarenite. Traces of chert, muscovite, and siltite fragments. (Pilcher).
- BC<sub>1</sub>-302  
Bimodally moderately sorted medium and very fine-grained poorly graded sandstone; siliceous feldspathic quartzarenite. Traces of chert, muscovite, and siltite fragments. (Pilcher).
- BC<sub>1</sub>-311  
Bimodally moderately to poorly sorted fine and very fine-grained graded sandstone; siliceous immature feldspathic quartzarenite or subarkose?. Traces of chert, muscovite, and siltite fragments. (Pilcher).
- BC<sub>1</sub>-339  
Moderately to poorly sorted medium-grained sandstone; siliceous submature quartzarenite. Traces of chert, clay clasts, and doubly overgrown quartz grains. (Pilcher).

BC<sub>1</sub>-340

Poorly sorted fine-grained sandstone; siliceous immature feldspathic quartzarenite. Traces of chert, muscovite, clay clasts, and siltite fragments. (Pilcher).

BC<sub>1</sub>-343

Moderately to poorly sorted medium-grained sandstone; siliceous submature quartzarenite. Traces of doubly overgrown quartz and siltite fragments. (Pilcher).

BC<sub>1</sub>-351

Moderately sorted medium-grained sandstone; siliceous submature glauconitic sublitharenite. 7-10% doubly overgrown quartz grains. Traces chert, muscovite, and clay clasts. (Silver Hill).

Tourmaline types

SLIDE NUMBER	COLORLESS			BLACK non-pleochroic	BROWN				GREEN		BLUE		VARI-COLORED	PINK		OVERGROWN
	with inclusions	without inclusions	faint brown pleochroism		rutile inclusions	golden orange-brown	many inclusions	few inclusions	many inclusions	few inclusions	mauve to blue	pale blue		many inclusions	few inclusions	
X2-1							X	X	X	X						X
X2-10.5							X	X	X	X						X
X2-23							X	X	X	X						X
X2-30							X									X
X2-40																
X2-47							X		X	X						X
X2-59																
X2-64							X		X	X						X
M-1																
M-10			X				X		X	X						
M-16							X		X							X
M-20							X		X	X						X
M-25									X	X						
M-29									X	X						
M-35									X	X						X
M-41									X	X						X
M-50							X									
M-64									X							
S-2								X								X
S-10								X	X	X						?
S-20								X	X	X						X
S-29								X	X	X						X
S-41								X	X	X						X
S-44								X	X	X						X
S-50								X		X						X

SLIDE NUMBER	COLORLESS			BLACK non-pleochroic	BROWN			GREEN		BLUE		VARI-COLORED	PINK		OVERGROWN
	with inclusions	without inclusions	faint brown pleochroism		rutile inclusions	golden orange-brown	many inclusions	few inclusions	many inclusions	few inclusions	mauve to blue		pale blue	many inclusions	
S-56															X
S-72								X	X	X					X
S-77								X	X	X					X
S-82									X	X	X				X
S-100								X							
S-102															
S-116									X	X					X
S-130									X	X	X				X
S-135									X	X	X				X
S-153									X	X	X				X
S-160											X				
S-165									X	X					X
S-175									X	X	X				X
S-185									X	X	X				X
S-202									X	X					
S-210									X	X	X				X
S-220									X	X					
S-230									X						X
S-240	X														X
S-251															
S-260									X	X	X				X
S-270									X	X	X		X		X
S-280									X		X				
E-2									X	X					X
E-10									X						
E-20									X						



SLIDE NUMBER	COLORLESS			BLACK non-pleochroic	BROWN				GREEN		BLUE		VARI-COLORED	PINK		OVERGROWN
	with inclusions	without inclusions	faint brown pleochroism		rutile inclusions	golden orange-brown	many inclusions	few inclusions	many inclusions	few inclusions	mauve to blue	pale blue		many inclusions	few inclusions	
E-32							X	X					X			X
E-50							X	X								
E-62							X									
E-70				X												
WCR-0							X	X								X
WCR-10							X	X								
WCR-30							X	X								
WCR-39		X					X	X								
WCR-50							X	X								
WCR-60							X	X								
WCR-70							X	X								
WCR-80							X	X								
WCR-90							X	X								
WCR-100							X	X								
HV-2							X	X								
HV-10							X	X								X
HV-15							X	X								
HV-68		X					X	X								X
HV-72							X	X								
HV-145							X	X								
HV-150							X	X								X
HV-160							X	X								X
HV-170							X	X								
HV-182							X	X								
HV-186							X	X								

SLIDE NUMBER	COLORLESS			BLACK non-pleochroic	BROWN				GREEN		BLUE		VARI-COLORED	PINK		OVERGROWN	
	with inclusions	without inclusions	faint brown pleochroism		rutile inclusions	golden orange-brown	many inclusions	few inclusions	many inclusions	few inclusions	mauve to blue	pale blue		many inclusions	few inclusions		
DC1-0																	X
DC1-3									X	X	X	X					X
DC1-8									X	X	X	X					X
DC1-20									X	X	X	X					X
DC1-30									X								X
DC2-0									X								
DC2-9									X	X	X						
DC2-20									X	X	X			X			X
DC2-30									X	X	X						
DC2-40									X								
DC2-48									X							X	
DC2-60									X	X							
DC2-70									X	X						X	
DC2-80									X								X
DC2-90									X							X	
BC1-1									X	X							X
BC1-9.5									X	X	X						X
BC1-21			X						X	X	X						X
BC1-30									X	X							X
BC1-40									X	X							X
BC1-50									X	X	X						X
BC1-62									X	X	X						X
BC1-71									X	X	X						X
BC1-81									X	X	X						X
BC1-90									X	X	X						X



Photographs

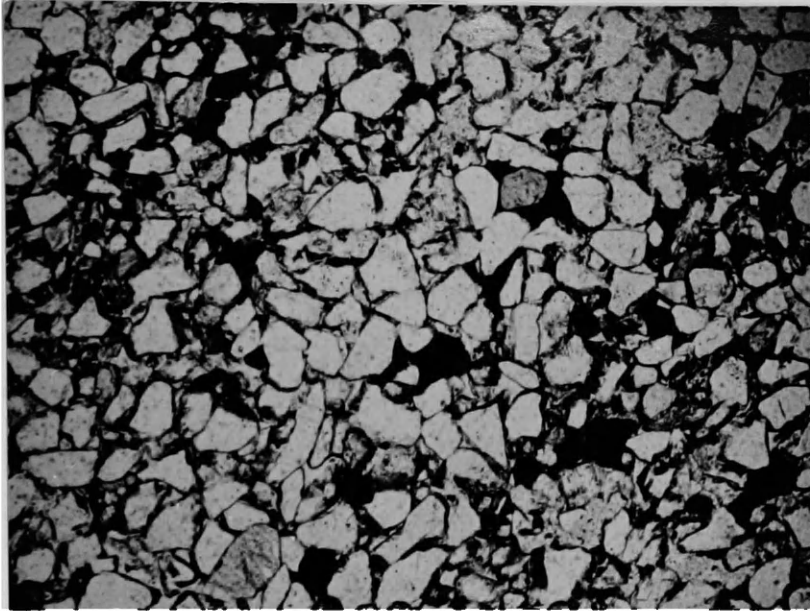


Figure 11. X<sub>2</sub>-64, moderately to well sorted fine-grained sandstone; siliceous immature feldspathic, glauconitic, quartzarenite. Note concentrations of hematitic clay. Silver Hill, X40, nicols uncrossed.

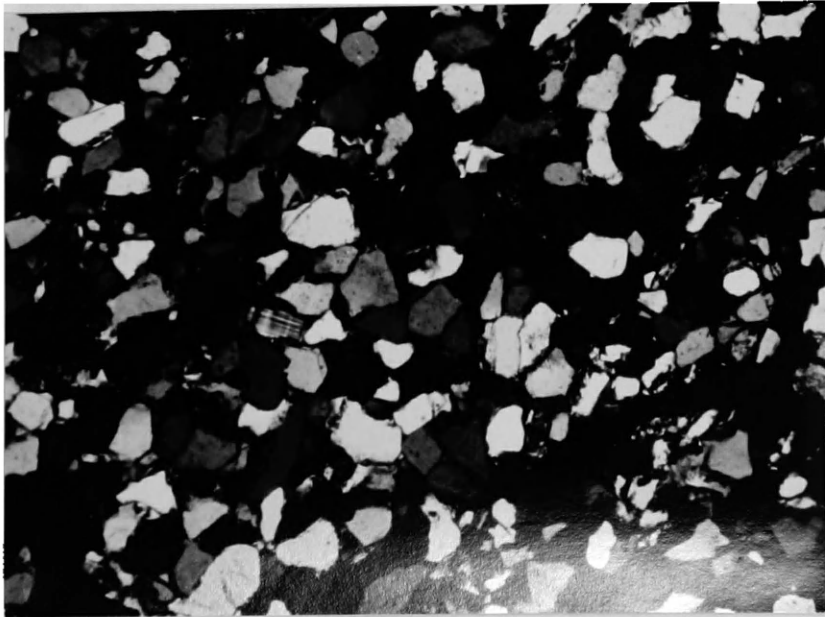


Figure 12. Same field as Figure 11, nicols crossed.

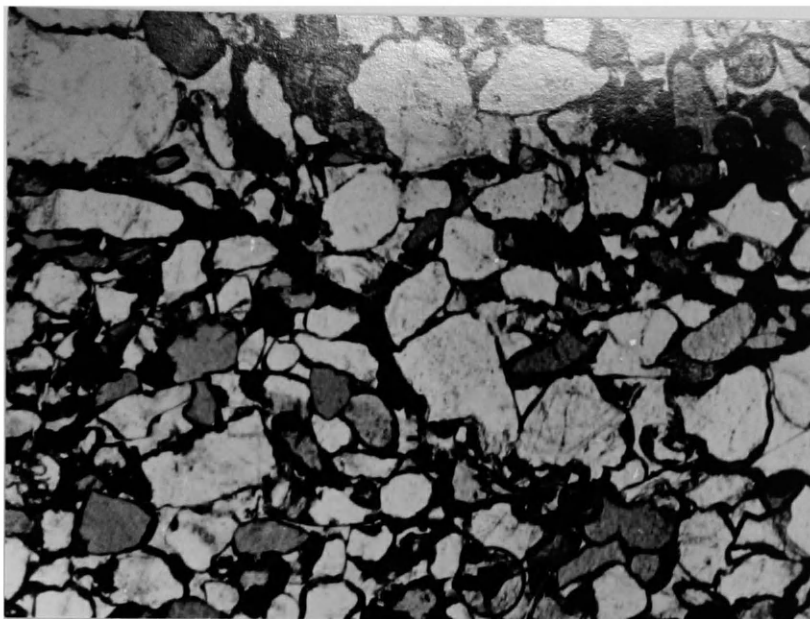


Figure 13. BC<sub>1</sub>-368, glauconitic quartzarenite (undescribed in appendix), the glauconite grains are the gray grains scattered over the field. Silver Hill, X40, nicols uncrossed.



Figure 14. DC<sub>2</sub>-60, bimodally moderately sorted medium and fine-grained graded sandstone; siliceous submature quartzarenite. Note the moderate to strong grain boundary welding, the graded laminations are not shown in this photograph, Flathead, X40, nicols crossed.

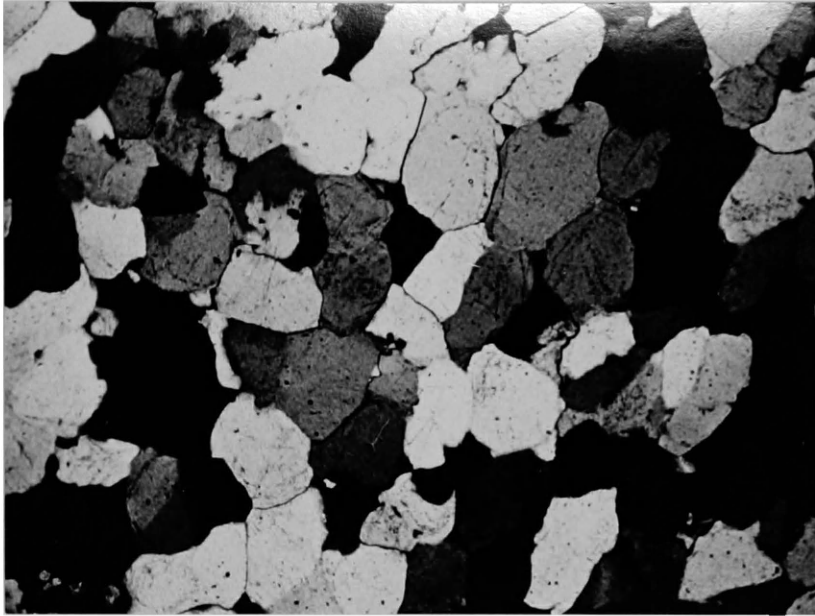


Figure 15. Well sorted fine-grained sandstone; siliceous supermature quartzarenite. Flathead, X40, nicols crossed.

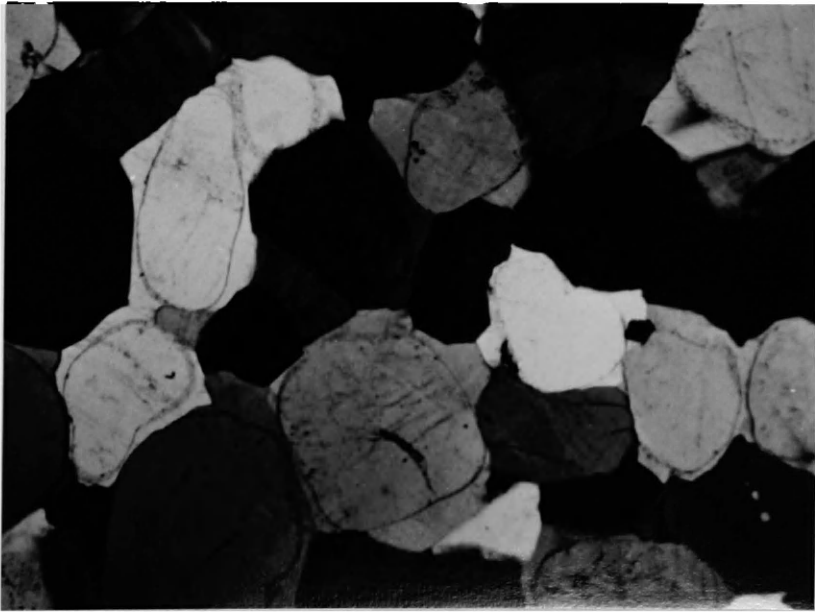


Figure 16. Hv-145, moderately to well sorted fine-grained sandstone; siliceous submature quartzarenite. Note excellent rounding and dark dust between core and overgrowth, Flathead, X60, nicols crossed.

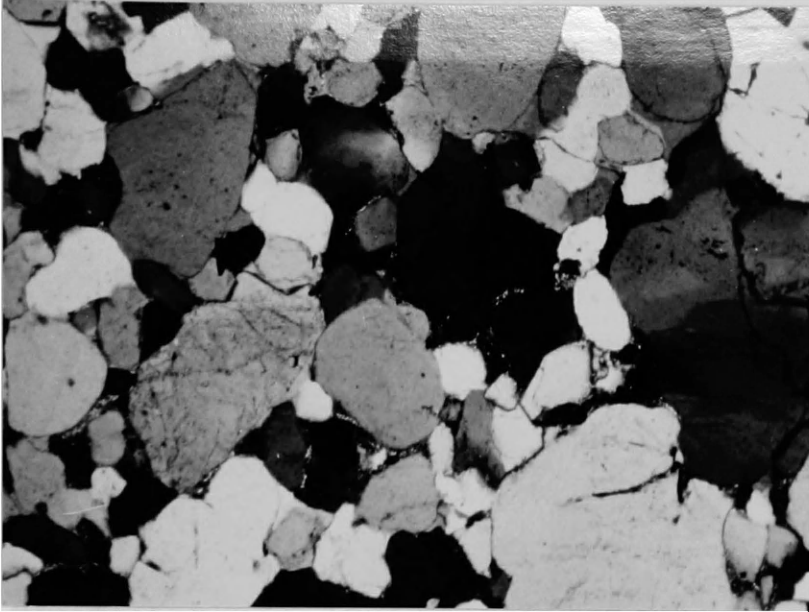


Figure 17. X<sub>2</sub>-23, bimodally moderately sorted very fine and medium-grained graded sandstone; siliceous submature slightly feldspathic quartzarenite. Flathead, X40, nicols crossed.

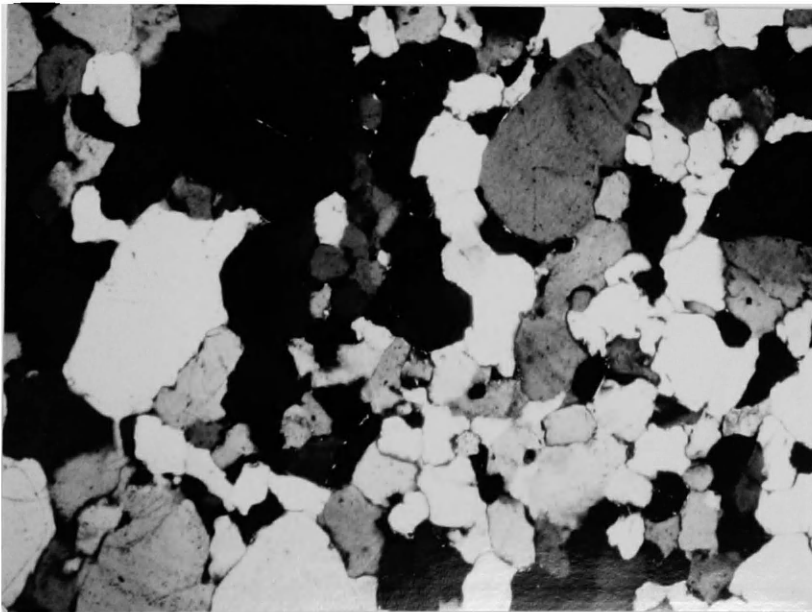


Figure 18. S-270, bimodally moderately sorted coarse and very fine-grained graded sandstone; siliceous submature quartzarenite. Flathead, X40, nicols crossed.



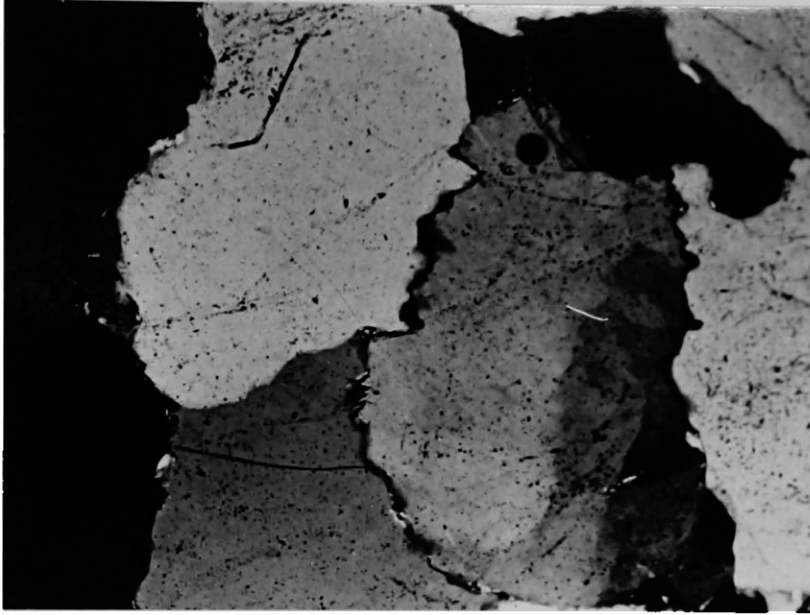


Figure 19. E-40, sutured grain boundary, Flathead, X150, nicols crossed.

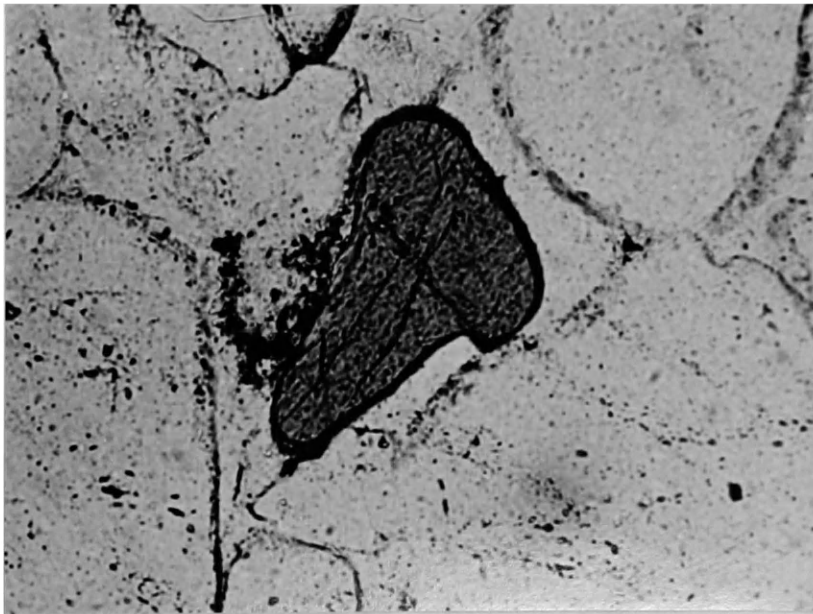


Figure 20. X<sub>2</sub>-23, pleochroic blue overgrown tourmaline, Flathead, X165, nicols uncrossed.

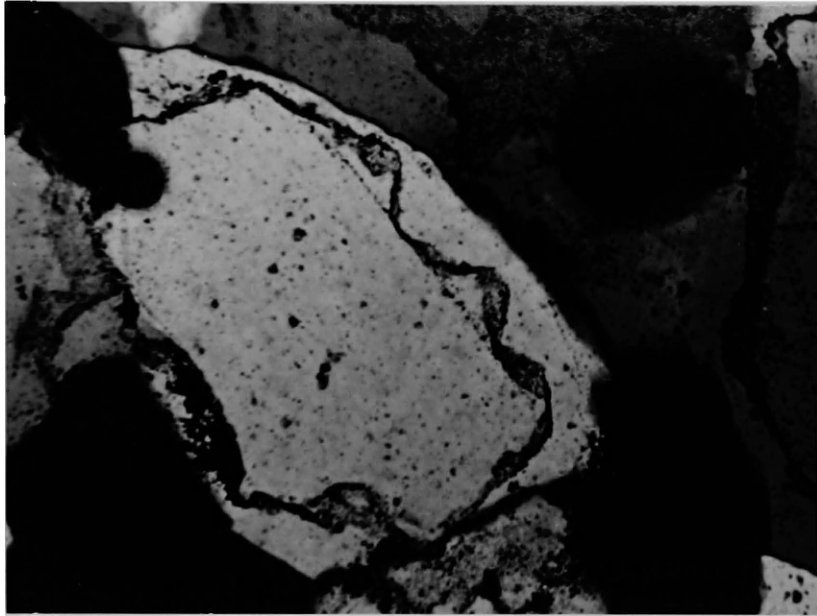


Figure 21.  $DC_1-8$ , doubly overgrown quartz grain, Flathead, X180, nicols crossed.



Figure 22.  $DC_2-0$ , doubly overgrown quartz grain, Flathead, X130, nicols crossed.

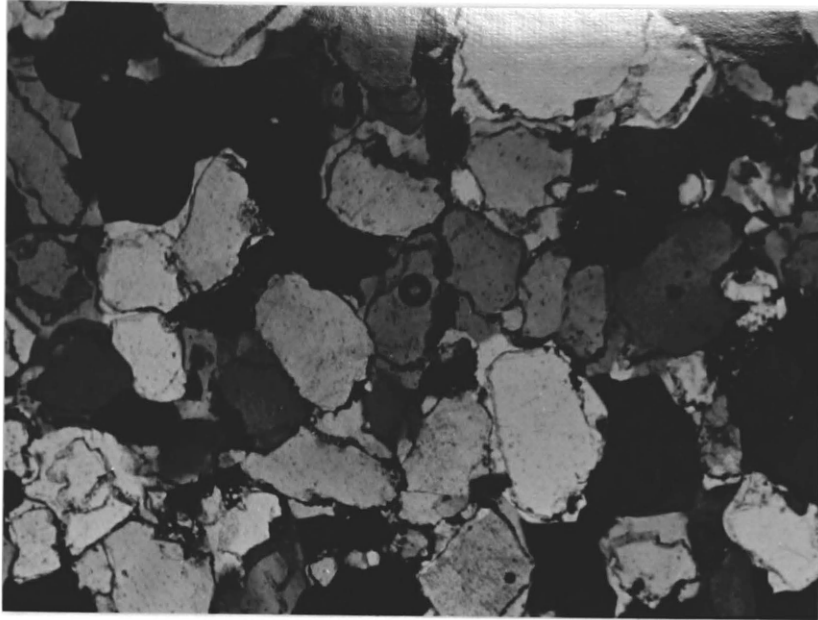


Figure 23. DC<sub>2</sub>-0, moderately sorted fine-grained sandstone; siliceous submature litharenite. General field, Flathead, X50, nicols crossed.



Figure 24. DC<sub>7</sub>-0, poorly sorted fine-grained sandstone; siliceous immature feldspathic, micaceous, G-4, G-5 bearing quartzarenite. Garnet Range, X40, nicols crossed.



Figure 25. S-165, moderately sorted fine-grained sandstone; siliceous and feldspathic submature, G-4, G-5 bearing subarkose. Redbeds at Stone, X40, nicols crossed.

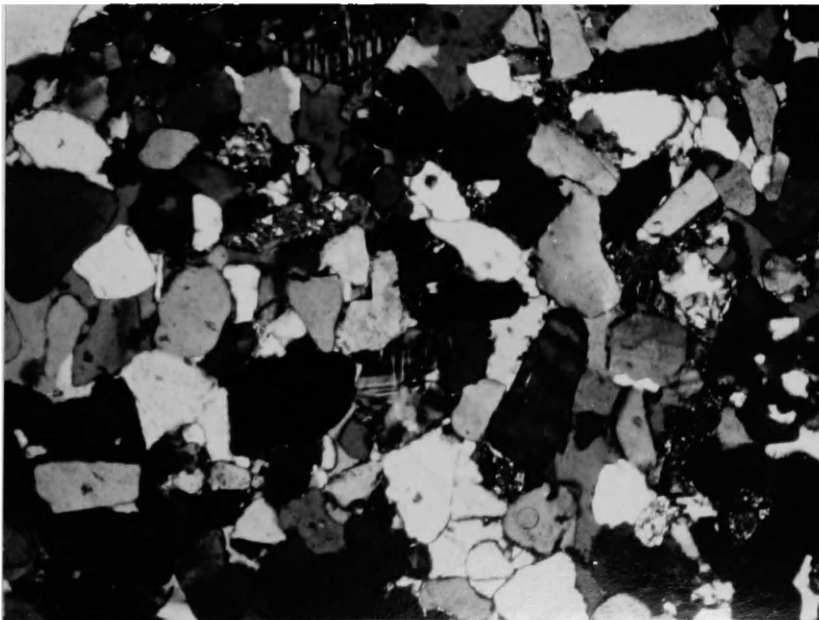


Figure 26. S-102, moderately sorted fine-grained subarkose (undescribed in appendix). Redbeds at Stone, X40, nicols crossed.

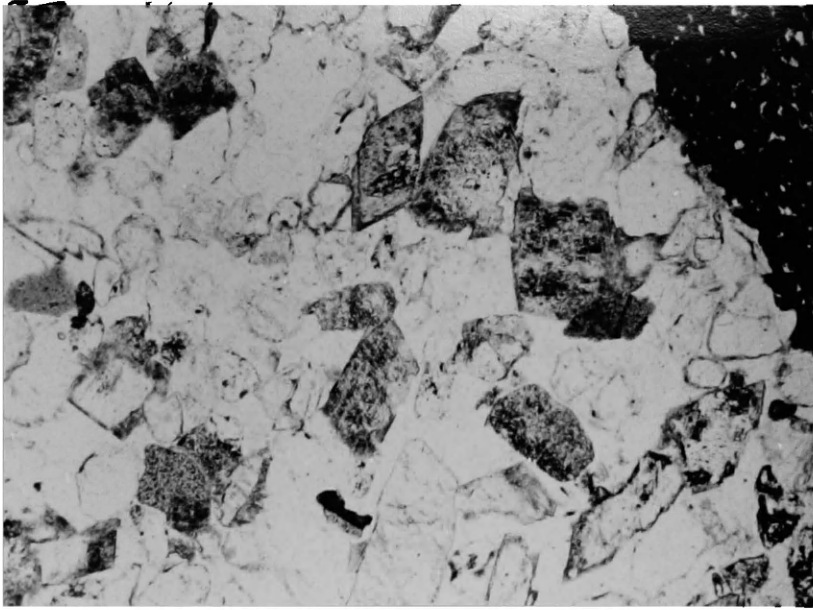


Figure 27. S-165, clouded feldspar overgrowths, dark area in the northeast is a clay clast. Redbeds at Stone, X40, nicols uncrossed.



Figure 28. S-116, dark feldspar overgrowth over a lighter core grain. Redbeds at Stone, X155, nicols crossed.

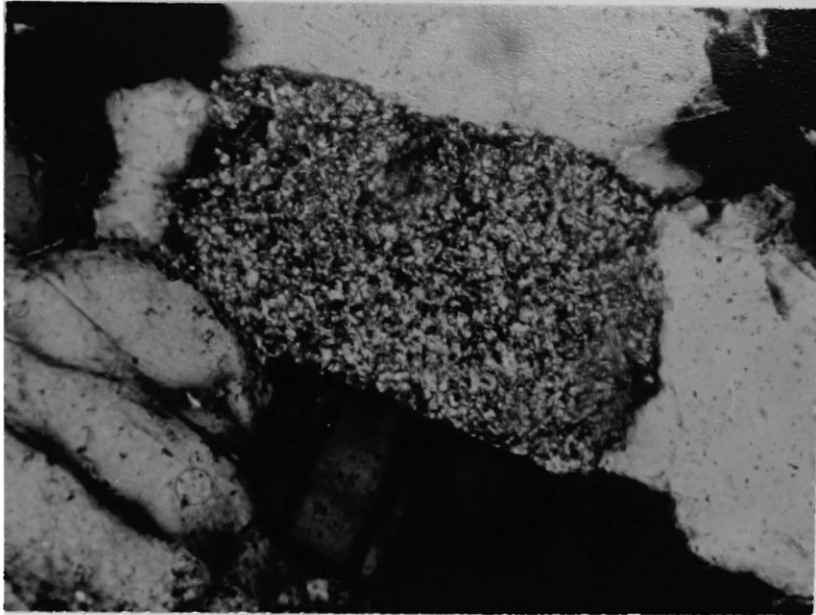


Figure 29. S-185, G-5 grain. Redbeds at Stone, X300, nicols crossed.

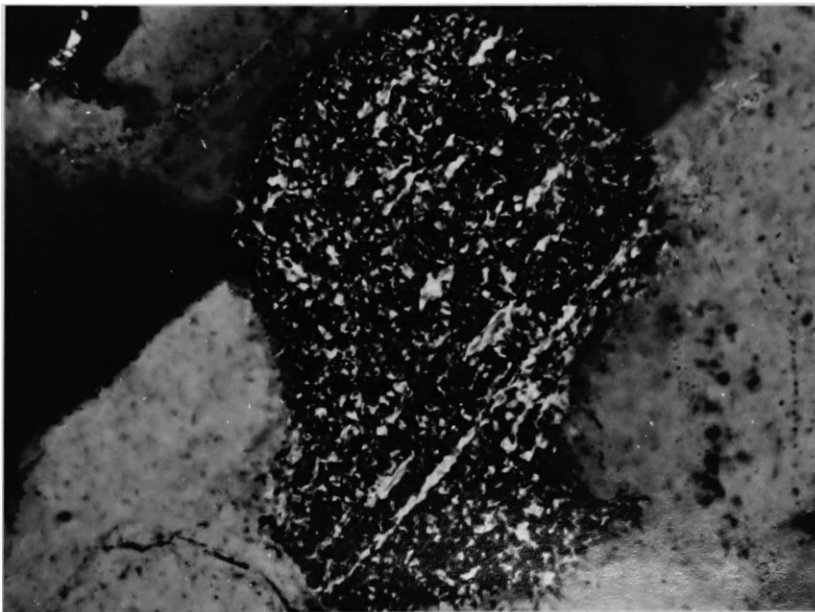


Figure 30. S-185, G-4 grain. Redbeds at Stone, X270, nicols crossed.

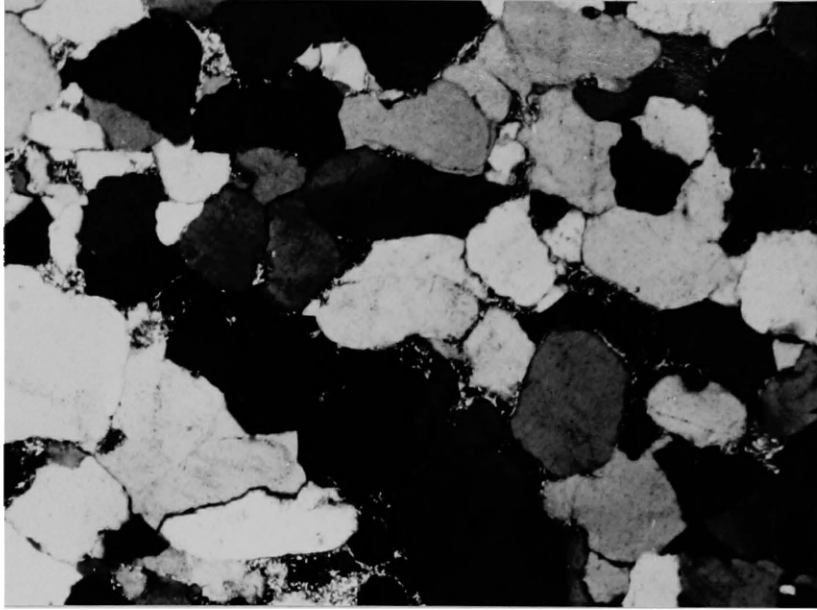


Figure 31. BC<sub>1</sub>-30, moderately to poorly sorted fine-grained sandstone; siliceous submature slightly feldspathic quartzarenite. Pilcher, X40, nicols crossed.

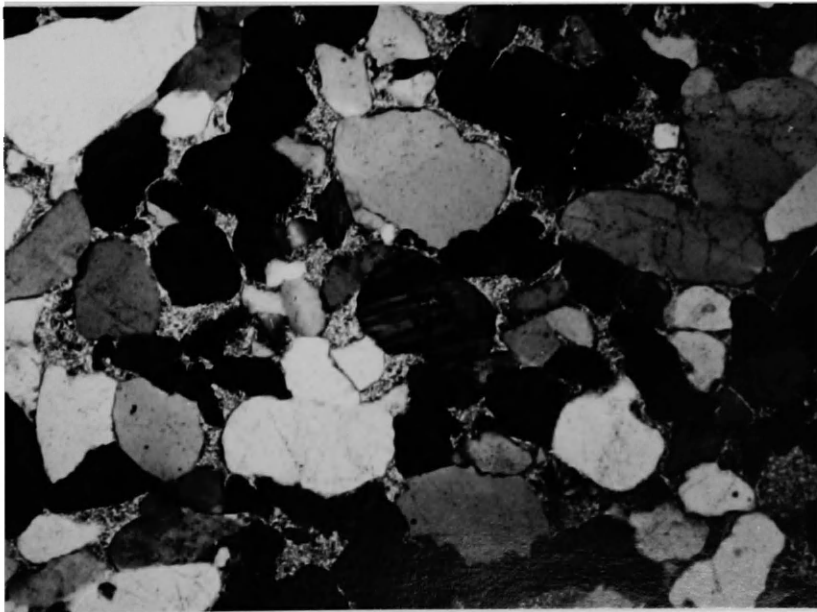


Figure 32. BC<sub>1</sub>-311, bimodally moderately sorted fine and very fine-grained graded sandstone; siliceous immature feldspathic quartzarenite. Pilcher, X40, nicols crossed.

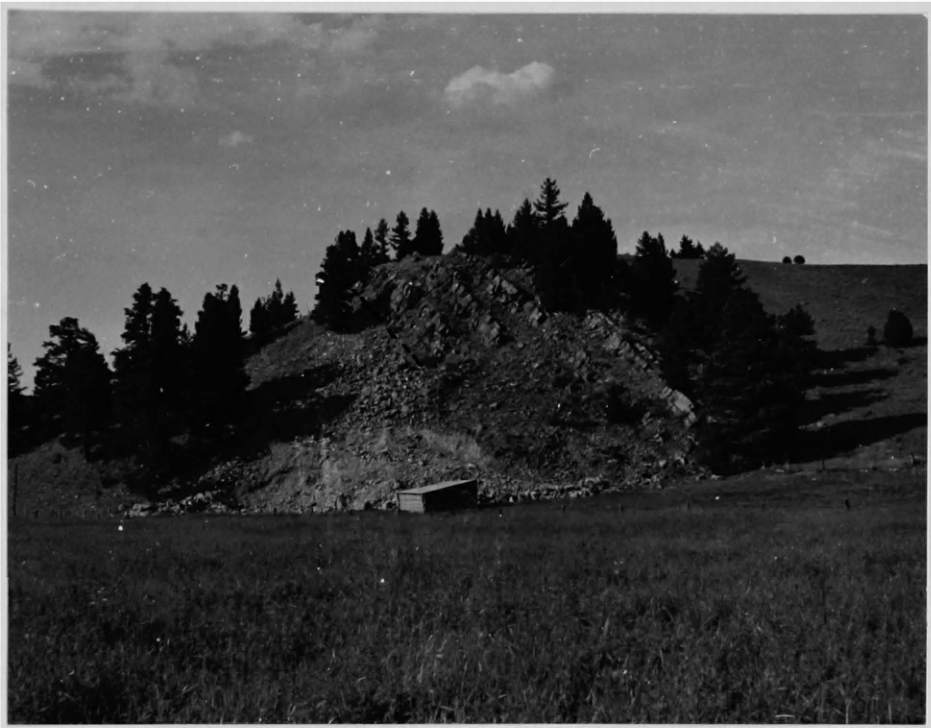


Figure 33. Stone section, looking north, the unconformity is marked by a dashed line.



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