



Tectono-sedimentary evolution of a Late Cretaceous alluvial fan, Beaverhead Group, southwestern Montana  
by Paul Alex Azevedo

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences  
Montana State University  
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**Abstract:**

The lower conglomeratic member of the Late Cretaceous Beaverhead Group east of Bannack, Montana contains a progressive unconformity which provides a direct link between sedimentation and deformation in the leading edge of the Cordilleran fold and thrust belt of southwest Montana. The recognition of a progressive unconformity within the lower Beaverhead conglomerate along Grasshopper Creek directly ties the deposition of the strata to uplift of the Madigan Gulch anticline. In addition, it provides an alternate interpretation for the structural configuration of the Beaverhead strata in the study area.

Along Grasshopper Creek, the lower Beaverhead conglomerate consists of approximately 354 m of synorogenic pebble/cobble conglomerate with subordinate sandstone and minor volcanic rocks. Consideration of lithofacies types, bed geometries, and facies associations suggests deposition on an alluvial fan characterized by cohesionless debris flows, hyperconcentrated flows, and proximal, braided gravel-bed river processes. The preserved remnants of a large fanhead channel is evidence that the surface of the fan actively went through periods of fanhead entrenchment which probably occurred in response to a tectonic stimulus.

Paleocurrent and clast composition data suggest the source area for the lower Beaverhead conglomerate was the east limb of the Madigan Gulch anticline. Formation of this eastward-verging asymmetrical fold may be related to movement of the Ermont thrust over a subsurface ramp. The progressive unconformity records the kinematic evolution of the fold.

The progressive unconformity is defined by the existence of three wedge-shaped packages of sediment. Each package of sediment formed in response to basinward rotation of the proximal part of the fan during uplift of the Madigan Gulch anticline. The rotative offlap geometry of the progressive unconformity indicates that the rate of uplift was episodic and exceeded the rate of sedimentation.

**TECTONO-SEDIMENTARY EVOLUTION OF A LATE CRETACEOUS  
ALLUVIAL FAN, BEAVERHEAD GROUP,  
SOUTHWESTERN MONTANA**

by

**Paul Alex Azevedo**

A thesis submitted in partial fulfillment  
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**APPROVAL**

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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**ABSTRACT**

The lower conglomeratic member of the Late Cretaceous Beaverhead Group east of Bannack, Montana contains a progressive unconformity which provides a direct link between sedimentation and deformation in the leading edge of the Cordilleran fold and thrust belt of southwest Montana. The recognition of a progressive unconformity within the lower Beaverhead conglomerate along Grasshopper Creek directly ties the deposition of the strata to uplift of the Madigan Gulch anticline. In addition, it provides an alternate interpretation for the structural configuration of the Beaverhead strata in the study area.

Along Grasshopper Creek, the lower Beaverhead conglomerate consists of approximately 354 m of synorogenic pebble/cobble conglomerate with subordinate sandstone and minor volcanic rocks. Consideration of lithofacies types, bed geometries, and facies associations suggests deposition on an alluvial fan characterized by cohesionless debris flows, hyperconcentrated flows, and proximal, braided gravel-bed river processes. The preserved remnants of a large fanhead channel is evidence that the surface of the fan actively went through periods of fanhead entrenchment which probably occurred in response to a tectonic stimulus.

Paleocurrent and clast composition data suggest the source area for the lower Beaverhead conglomerate was the east limb of the Madigan Gulch anticline. Formation of this eastward-verging asymmetrical fold may be related to movement of the Ermont thrust over a subsurface ramp. The progressive unconformity records the kinematic evolution of the fold.

The progressive unconformity is defined by the existence of three wedge-shaped packages of sediment. Each package of sediment formed in response to basinward rotation of the proximal part of the fan during uplift of the Madigan Gulch anticline. The rotative offlap geometry of the progressive unconformity indicates that the rate of uplift was episodic and exceeded the rate of sedimentation.

## INTRODUCTION

Synorogenic conglomerates have long been recognized as a valuable tool in deciphering the tectonic history of their source area (Ryder and Scholten, 1973; Haley, 1985; Lawton, 1986; DeCelles and others, 1987, 1991a, Haley and Perry, 1991). However, incomplete exposures and lack of accurate chronologic markers often make direct links between sedimentation and deformation difficult (Holl and Anastasio, 1993). Recent studies (Riba, 1976; Anadon and others, 1986; DeCelles and others, 1987, 1991a;b) have suggested that synorogenic conglomerates produced in compressional tectonic settings may contain suites of structures that are characteristic of contractional deformation and are directly attributable to deformation of their adjacent source terranes. These structures include intraformational thrust faults, folds, and progressive unconformities.

Progressive unconformities develop as wedge-shaped packages of sediment deposited on the flanks of growing structures such as anticlines, high angle faults and nappe fronts. The geometry of a progressive unconformity is usually interpreted to be directly controlled by the interplay between the rate of tectonic uplift and the rate of sediment accumulation along the flank of the structure (Riba, 1976).

The recognition of progressive unconformities is important because the geometry or stacking characteristics of successive depositional wedges may provide insight into the kinematic evolution of the adjacent source terrane (DeCelles and others, 1991a; Verges and Burbank, 1992; Holl and Anastasio, 1993). However, descriptions of syntectonic sediments containing progressive unconformities are scarce in the geological literature (Riba, 1976; Anadon and others, 1986; DeCelles and others, 1987, 1991a;b; Holl and Anastasio, 1993). Those that have been described are found in alluvial fan deposits adjacent to foreland basin margins and intrabasinal uplifts. These studies suggest that progressive unconformities may be an important characteristic of thrust generated conglomerates that have been widely overlooked. One stratigraphic unit in the North American Cordillera which might be expected to contain progressive unconformities is the Late Cretaceous Beaverhead Group of southwestern Montana.

Strata of the Beaverhead Group comprise the synorogenic Upper Cretaceous to lower Tertiary (?) stratigraphic sequence in southwestern Montana. Beaverhead Group strata are dominated by conglomerates that are thought to have been shed from structural elements which rose in response to contractional deformation in the Rocky Mountain foreland to the east and the fold and thrust belt to the west (Ryder and Scholten, 1973, Haley, 1985). Lithofacies analysis of the Beaverhead Group conglomerates suggest they were deposited on alluvial fans and



in the proximal portions of braided gravel-bed fluvial systems (Ryder and Scholten, 1973; Haley, 1985; Haley and Perry, 1991). Although the depositional environment and structural setting are favorable for the development of progressive unconformities no structures of this type have been described to date in the Beaverhead strata.

East of Bannack, Montana synorogenic strata of the Late Cretaceous Beaverhead Group crop out along Grasshopper Creek. Previous work by Goodhue (1986), Johnson and Sears (1988) and Coryell and Spang (1988) suggests that the lower conglomerate member of the Beaverhead Group in this area may be a promising location to look for progressive unconformities. In this area the lower conglomerate member is dominated by framework-supported limestone-clast conglomerate with interbeds and lenses of sandstone and minor volcanic rocks (Goodhue, 1986; Johnson, 1986; Johnson and Sears, 1988). By analogy with other Beaverhead Group strata in southwestern Montana, Goodhue (1986) hypothesized that the lower conglomerate unit east of Bannack represented deposition on the surface of small alluvial fans and in the proximal portions of braided gravel-bed stream systems. The uplifted structural elements which shed these deposits resulted from compressional deformation in the frontal fold and thrust zone of the Cordilleran fold and thrust belt in southwestern Montana (Johnson and Sears, 1988; Coryell and Spang, 1988).

Purpose of study

The purpose of this study is to explore the question, "Does the lower Beaverhead conglomerate east of Bannack, Montana contain a progressive unconformity?" In testing this hypothesis the following questions were addressed:

1) What depositional environment(s) characterized the lower conglomeratic unit? To date, progressive unconformities have only been recognized in proximal alluvial fan environments adjacent to compressional uplifts. Therefore it is important to establish the depositional environment of the lower Beaverhead strata. Alluvial fan deposits can be recognized by a distinctive association of lithofacies (Miall, 1978; Rust, 1978).

2) What is the provenance of the lower conglomeratic unit? Knowledge of the sediment provenance is important for determining the location and composition of the source area. Paleocurrents from an individual alluvial fan deposit should have a flow pattern radiating outward from the fan apex (Nilsen, 1982). However, this radial pattern may become hard to detect if the fan apex is not preserved. Coalescing of adjacent fan sequences may produce complex paleoflow patterns. Possible paleoflow indicators include channel orientation, cross-stratification in sandstones and conglomerates, and conglomerate clast long-axis orientation. Measurement of the largest clast sizes in alluvial fan sequences may also be a

useful paleoflow indicator. There is generally a rapid decrease in the maximum and average clast size downfan from the fan apex (Bluck, 1964; Lustig, 1965; Bull, 1972; Nilsen, 1982). However, the uniformity of particle size decrease may be greatly affected by the amount of temporary channel entrenchment during the history of the fan (Bull, 1972). Compositional trends in the <sup>a</sup>course-grained and fine-grained fractions of the sediments may provide additional insight into the structural evolution of the source area. The character of clast compositional trends may be indicative of the structural setting of the source area (Steidtmann and Schmitt, 1988).

3) What evidence can be found in the lower Beaverhead strata which might suggest the existence of a progressive unconformity? Determining the depositional environment and provenance will not in itself document the existence of a progressive unconformity within the lower Beaverhead deposits. Progressive unconformities are recognized in proximal alluvial fan deposits of the Tertiary Ebro Basin, Spain by a series of overlapping, wedge-shape sedimentary packages which thin in an upfan direction (Riba, 1976). Such sedimentary wedges might be documented in the lower Beaverhead conglomerate by recording bedding attitudes throughout the stratigraphic section. It is hypothesized here that uplift of the source terrane, which is integral to the development of a progressive unconformity, should cause the initial sedimentary packages to be deformed to a greater degree than later deposits. However, each

sedimentary package should contain an internally consistent set of bedding attitudes. Plotting bedding attitudes on a photomosaic of the outcrops may also serve to highlight the existence and geometry of individual sedimentary packages. It may also be possible to distinguish individual packages based on lithology and association of lithofacies.

4) If a progressive unconformity is present in the lower Beaverhead conglomerate does its geometry reveal any information regarding the kinematic evolution of the source terrain? When the rate of uplift exceeds the rate of sedimentation along the flanks of the structure the individual sedimentary-wedge packages will offlap each other in a basinward direction (Riba, 1976, Anadon and others, 1986). If the rate of sedimentation exceeds the rate of deformation the sedimentary wedges will onlap each other towards the hinterland (Riba, 1976, Anadon and others, 1986).

#### Location

The study area is located along Grasshopper Creek in the northern portion of the Armstead Hills approximately 3 km east of Bannack State Park in Beaverhead County, Montana (Figure 1 and 2). The study area covers approximately 6 km<sup>2</sup> (Sections 8, 9, 16, and 17 T8S; R11W) of the U.S. Geological Survey Bannack 7.5 minute topographic quadrangle.

Beaverhead strata in this area crop out in a north-south trending arcuate band for several kilometers on either side of

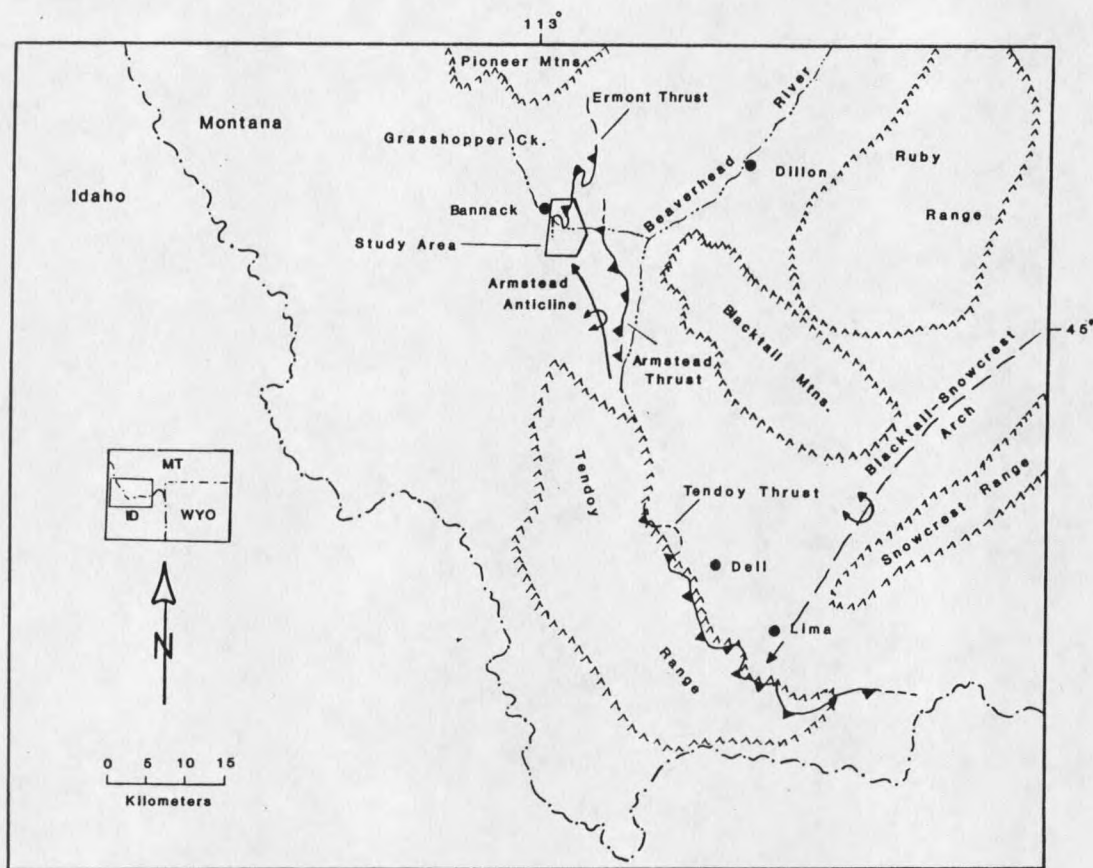


Figure 1. Generalized map of southwestern Montana showing location of study area and major regional structures. Modified from Johnson (1986).

Grasshopper Creek. In general, good to fair out crops are limited to several of the northeast-southwest trending gulches which bisect the area. The most prominent outcrops are located immediately adjacent to Grasshopper Creek where up to 354 m of strata are exposed. These outcrops adjacent to Grasshopper Creek were chosen for the focus of this study because they offered the greatest extent of high quality exposures.

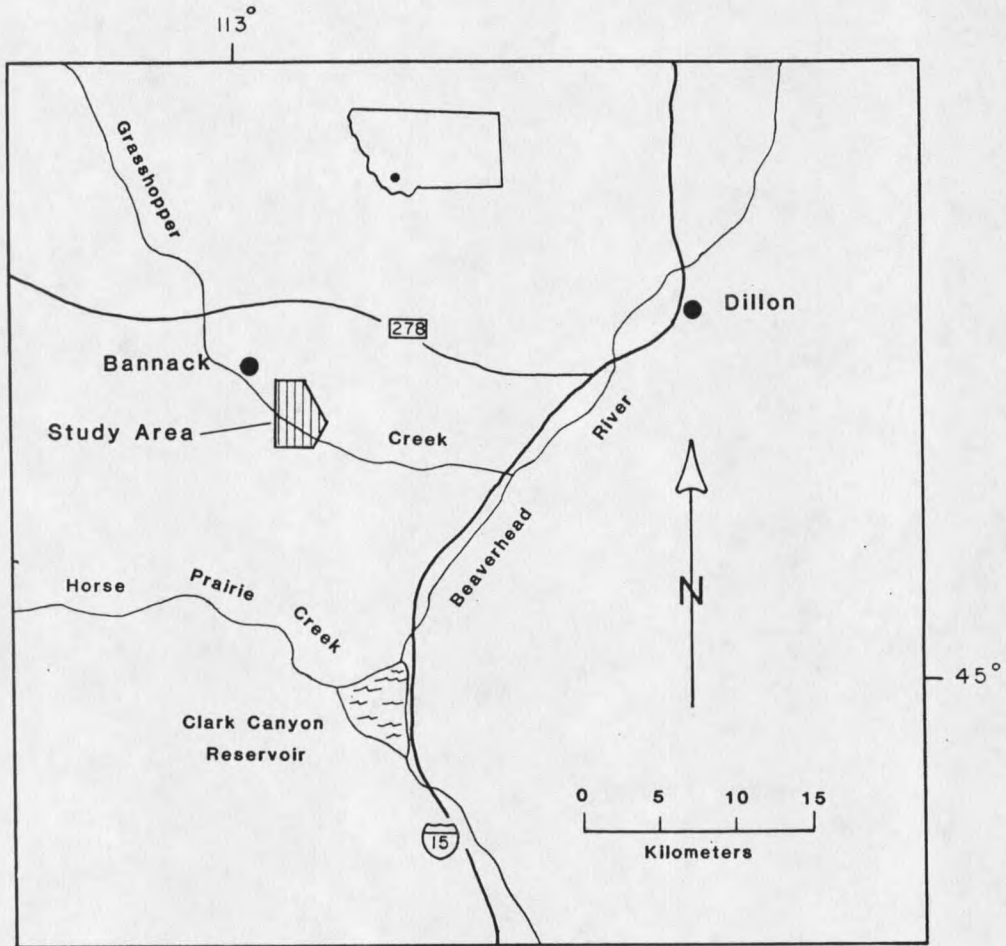


Figure 2. Study area location map.

## METHODS

### Field Procedures

The lower conglomerate member of the Beaverhead Group in the study area was measured using a Brunton Pocket Transit, Jacob's staff and a 30 m (100 ft) steel tape (Compton, 1962). Seven partial sections were measured and described (Figure 3) (Plate 1). The partial sections were combined by determining their approximate stratigraphic positions relative to each other to form a nearly complete section through the lower conglomerate (Figure 4). The location of each section was chosen as a balance between accessibility and quality of exposures. Descriptions of depositional units within each section included lithology, texture (clast size, clast shape, and sorting), fabric, grading, stratification, bed thickness, lateral continuity of beds, nature of bounding surfaces, bed geometry, and sedimentary structures. A lithofacies classification system based on the system developed by Miall (1977, 1978) and appended by Rust (1978) was used to classify the lithofacies present.

Clast counts were performed on pebble-cobble conglomerates to ascertain the composition of strata exposed in the source area and to illuminate any stratigraphic compositional trends.

A



B

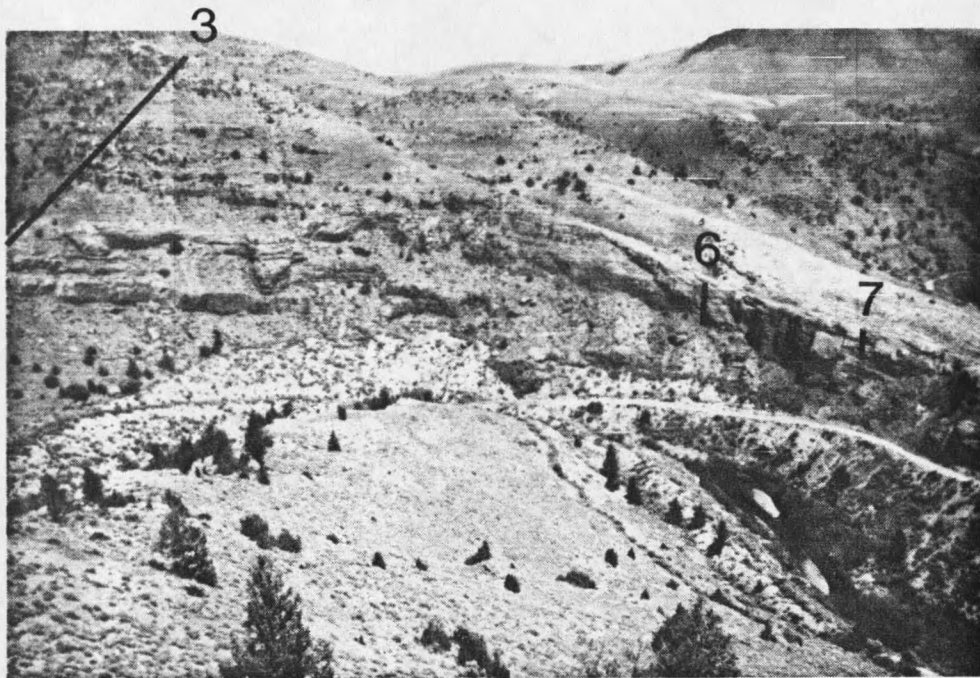


Figure 3. Overview of field area and location of measured sections. A) Outcrops on south side of Grasshopper Creek. East limb of Madigan Gulch anticline is just out of view to right. View S20W. B) Outcrops on north side of Grasshopper Creek. View N50E. Measured sections numbered as follows: 1=NG01; 2=NG02; 3=NG03; 4=NG04; 5=NG05; 6=CH1; 7=CH2.



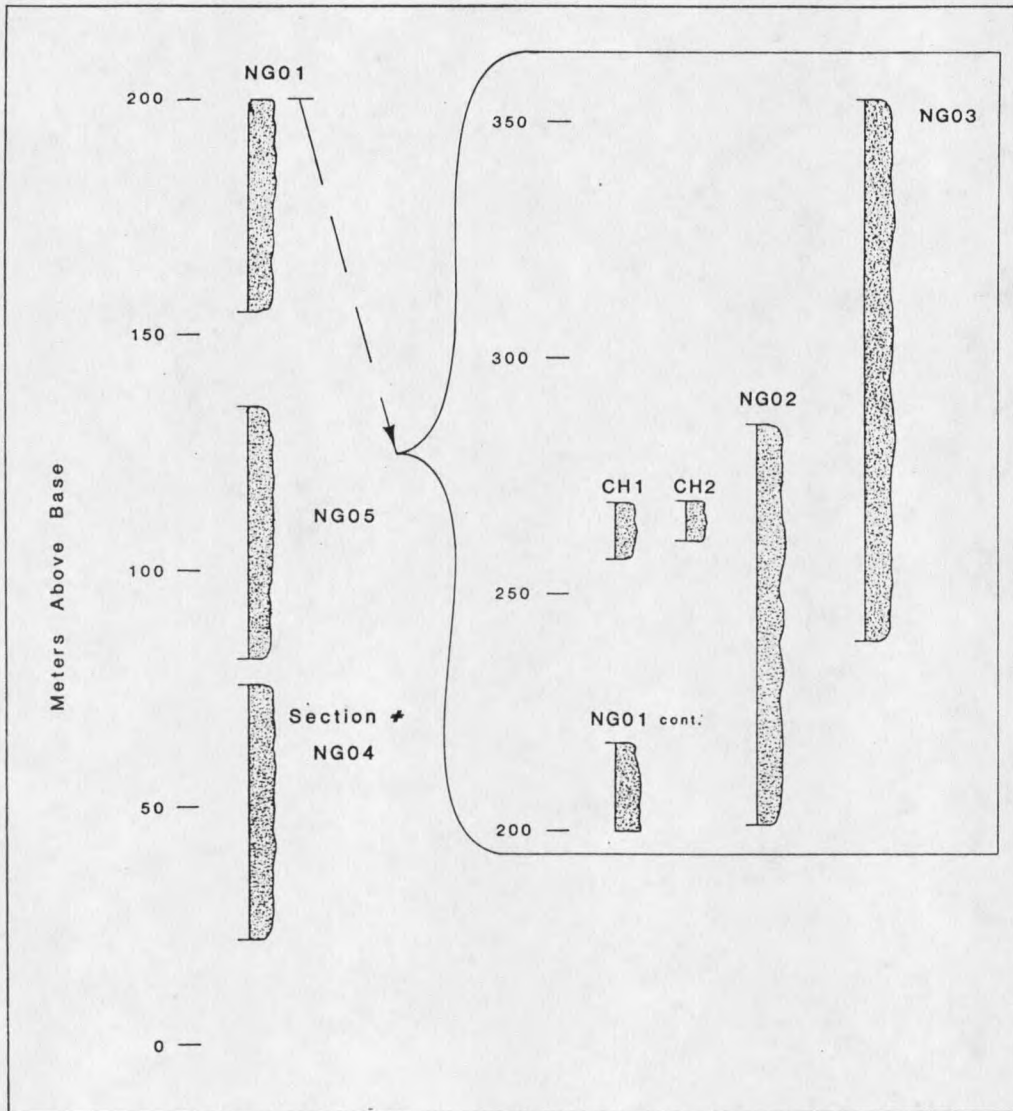


Figure 4. Relative stratigraphic position of measured sections in the lower Beaverhead conglomerate.

The lithology of a minimum of 250 clasts was recorded at 12 different locations using a fixed grid system designed to exceed the mean observed clast size. At two locations less than 250 clasts (142 minimum) were counted due to limited exposures. Qualitative estimates of clast composition modes

were also made in order to detect clast types present in trace amounts. At each clast count locality the maximum diameter of the 15 largest clasts was recorded in order to illuminate any trends in maximum particle size. Samples of Beaverhead sandstone lenses, conglomerate matrix, and volcanic units were collected for petrographic analysis.

Paleoflow data were gathered from measurements of the orientation of clast imbrication, trough axes and sole marks where possible. Additional insight into the tectono-sedimentary evolution of the Beaverhead strata was achieved by plotting apparent bedding attitudes onto a photomosaic of outcrops on the south side of Grasshopper Creek. Outcrops on the north side of the creek are of poor quality and were not photographed in detail.

#### Laboratory Methods

Seven Beaverhead sandstone samples and one conglomerate matrix sample were thin-sectioned, stained for potassium feldspar, and examined under a petrographic microscope. Point counts were done on the sandstone thin sections in order to: 1) determine the composition of the sandstones; 2) distinguish any compositional trends which occur vertically through the lower beaverhead section based on the fine-grained component; and 3) integrate sandstone composition data into an interpretation of provenance. Sandstones selected for point counting were chosen as representative samples from different

stratigraphic levels throughout the section. In addition, four volcanic rock samples from the lower conglomerate member were also thin-sectioned, stained for potassium feldspar, and examined petrographically to determine composition and mode of emplacement.

Modal composition of each sandstone sample was determined by identifying the composition of a minimum of 250 framework grains per sample. Point counts were performed using a fix-grid spacing that exceeded the visually estimated mean grain size of each sample. To petrologically classify the sandstones and to discern possible petrofacies, sandstone compositional data were plotted on a on a QFL ternary diagram (Folk, 1980, p. 127). To discern possible source area provenance, the sandstone compositional data were also plotted on a QmFLt ternary diagram (Dickinson and others, 1983). The conglomerate matrix sample was examined qualitatively to determine the composition of the fine-grained component of the matrix. Compositional data from both sandstone thin-sections and conglomerate clast counts were plotted stratigraphically to determine compositional trends within the stratigraphic section.

All paleocurrent orientation data were rotated about structural strike on an equal-area net to determine paleocurrent trends. Vector orientation and magnitude were calculated using the methods of Potter and Pettijohn (1977, p. 374-377) and Tucker (1989, p. 95-96).

## REGIONAL STRUCTURAL AND STRATIGRAPHIC SETTING

Ruppel and Lopez (1984) recognized three divisions of the Cordilleran fold and thrust belt in southwest Montana and central Idaho. These include the Medicine Lodge thrust plate, Grasshopper thrust plate, and frontal fold and thrust zone (Figure 5). Each of the thrust plates, as well as the frontal fold and thrust zone, are characterized by a discrete sequence of sedimentary rocks and differences in structural style.

The frontal fold and thrust zone is the leading part of the Cordilleran fold and thrust belt in southwest Montana and fringes the eastern edge of the Grasshopper and Medicine Lodge thrust plates (Figure 5). Rocks within the frontal fold and thrust zone consist of Paleozoic and Mesozoic sedimentary rocks of the cratonic shelf along with Archean crystalline rocks incorporated in some imbricate thrusts (Ruppel and Lopez, 1984). Deformation in the zone is characterized by tight, partly overturned folds and multiple imbricate thrust faults that commonly cut through the limbs of the overturned folds. Within the frontal fold and thrust zone, thrust-related folding and faulting gradually become less intense and pervasive eastward, dying out against the crystalline rocks of the craton (Ruppel and Lopez, 1984). The study area lies within the frontal fold and thrust zone.

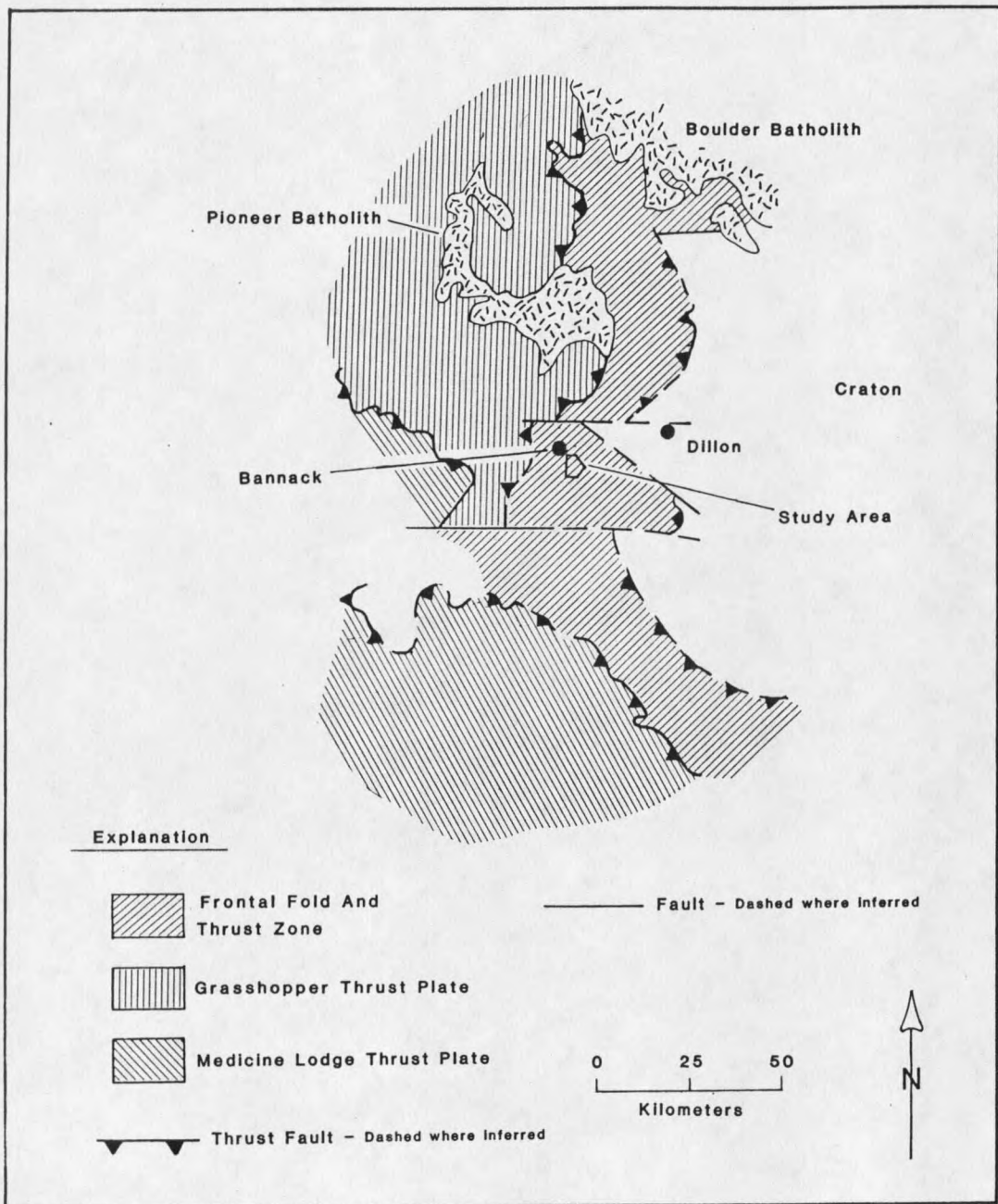


Figure 5. Major divisions of the Cordilleran fold belt in southwest Montana and east-central Idaho. Modified from Ruppel and Lopez (1984).

The Grasshopper plate lies structurally above the frontal fold and thrust zone (Figure 5). This plate carries a thick sequence of quartzite and finer-grained clastic rocks belonging to the upper part of the Proterozoic Belt Supergroup (Missoula Group). The Missoula Group rocks are locally underlain by carbonates of the middle part of the Belt Supergroup and are locally overlain by Cambrian and Devonian rocks. Upper Paleozoic and Mesozoic rocks are not known to be preserved on the Grasshopper plate. The Grasshopper plate is gently folded and cut by multiple imbricate thrusts that appear to sole into the basal decollement (Ruppel and Lopez, 1984).

The Medicine Lodge plate lies structurally above the Grasshopper plate and frontal fold and thrust zone and consists of a thick sequence of Proterozoic Y quartzite overlain by Ordovician through Triassic miogeoclinal rocks. It is deformed by tight, locally isoclinal, east-verging folds and cut by multiple interlacing imbricate thrusts that appear to dip down into the basal decollement (Ruppel and Lopez, 1984).

## GENERAL GEOLOGY OF THE STUDY AREA

### Local Stratigraphy

The study area is underlain by approximately 2,100 m of unmetamorphosed Paleozoic and Mesozoic sedimentary rocks deposited with angular unconformity over Archean metamorphic and intrusive igneous rocks (Coryell, 1983) (Figure 6). No Proterozoic strata are present in the study area. Along Grasshopper Creek, strata of the Upper Cretaceous Beaverhead Group are deposited on strata of the Mississippian Lombard Formation. The Beaverhead rocks are locally overlain by Tertiary volcanic rocks and Quaternary alluvial deposits.

A brief synopsis of the local stratigraphic sequence is shown in Table 1. A more complete discussion of the local Beaverhead Group stratigraphy is presented in a later section. Descriptions of the Precambrian through Early Cretaceous units are compiled from work done by Coryell (1983), Clark (1986), and Goodhue (1986) in the Armstead Hills, immediately south of the field area and Thomas (1981) in the Badger Pass area, immediately north of the field area. Descriptions of the Beaverhead Group and later rocks are compiled from my own work as well as from work done by Coryell (1983), Johnson (1986), Ivy (1989), Pearson and Childs (1989), and Gonnermann (1992).

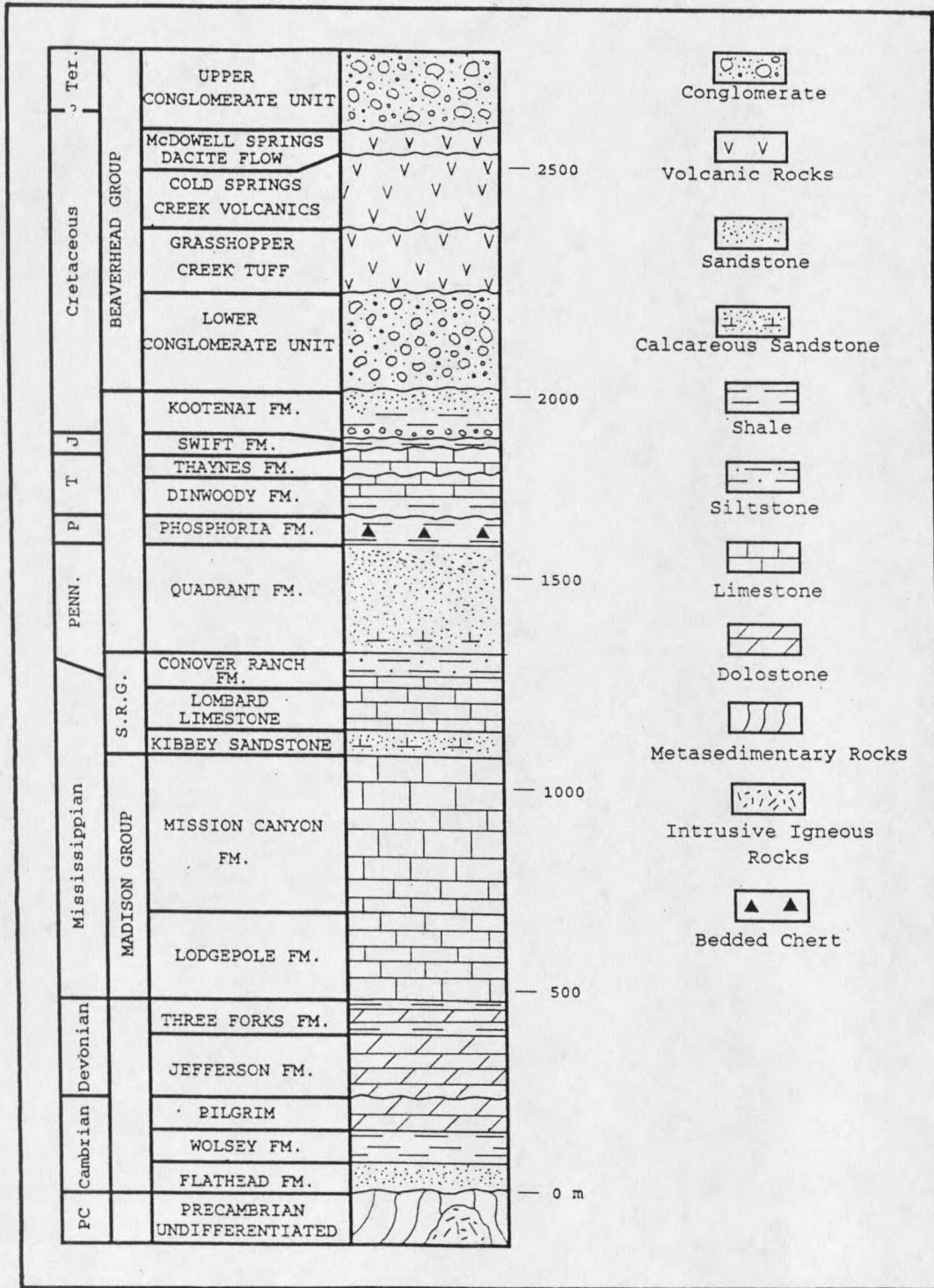


Figure 6. Generalized stratigraphic column of study area and northern portion of the Armstead Hills. S.R.G.=Snowcrest Range Group. Compiled from Coryell (1983) and Goodhue (1986).



Table 1. Summary descriptions of lithologic units.

Formation Name	Thickness (Range in m)	Lithologic Description
<u>Lower Tertiary-Upper</u>		
<u>Cretaceous</u>		
Beaverhead Group Upper conglomerate unit	0-396	Quartzite and limestone pebble/cobble conglomerate; clast supported; minor interbeds of carbonate cemented sandstone and siltstone.
McDowell Springs Dacite flow	165	Dacite flow. Basal monolithic breccia grades upwards into massive columnar-jointed dacite capped by flow ridges.
Cold Springs Creek volcanics	30-488	Heterogeneous assemblage of volcanic breccias, ash-flow tuffs, lava flows and volcanoclastic strata of intermediate composition.
Grasshopper Creek tuff	30-304	Pyroclastic-flow and fallout-tuff deposits; very slightly porphyritic; siliceous, feldspathic, and zeolitic.
Lower conglomerate unit	0-357	Limestone pebble/cobble conglomerate; clast supported; minor interbeds of carbonate cemented sandstone.
<u>Cretaceous</u>		
Kootenai Fm.	0-366	Basal chert pebble conglomerate overlain by fine-grained siltstone capped by coarse-grained, moderately sorted sandstone.
<u>Jurassic</u>		
Swift Fm.	13	Interbedded marl and conglomerate; glauconitic; conglomerate contains black elongate chert and quartz chips.
<u>Triassic</u>		
Thaynes Fm.	75-122	Limestone with small interbeds of argillaceous and sandy material; may become glauconitic toward top.
Dinwoody Fm.	30-274	Shale and limestone. Shale, thin-bedded, flaggy, calcareous. Limestone, thin to med.-bedded pelecypod-bearing biomicrites and biosparites; characteristic chocolate brown color on weathered surfaces.

Table 1. - continued

Formation Name	Thickness (Range in m)	Lithologic Description
<u>Permian</u> Phosphoria Fm.	80-110	Dolomite, cherty dolomite, bedded chert, phosphatic mudstone, and sandstone.
<u>Pennsylvanian</u> Quadrant Fm.	190-366	Sandstone, fine- to med.-grained, supermature, quartzarenite; massive to thick-bedded; extremely hard when silica cemented; friable and poorly indurated when calcite cemented.
<u>Pennsylvanian/Mississippian</u> Conover Ranch Fm.	45	Limestone, silty limestone, dolomite, siltstone, and shale.
<u>Mississippian</u> Lombard Limestone	129	Limestone, thin- to thick-bedded, micrite, and biomicrite; chert nodules and chert stringers found in upper part.
Kibbey Sandstone	27	Sandstone, siltstone, dolomitic siltstone; sandstone calcareous, fine- to med.-grained, thin- to med.-bedded.
Mission Canyon Fm.	180-700	Limestone, massive- to very thickly-bedded; bioclastic; nodules and stringers of chert found throughout formation; solution breccia present in the upper 20 m.
Lodgepole Fm.	200-384	Limestone, thin- to medium-bedded, micrite and biomicrite; contains nodules and lenses of chert.
<u>Devonian</u> Three Forks Fm.	50-111	Interbedded limestone, dolomitic siltstone, and silty shale.
Jefferson Fm.	0-200	Dolomite, med.- to thick-bedded; distinctive petroliferous odor on freshly broken surfaces; zones of dolomite breccia.
<u>Cambrian</u> Pilgrim Fm.	0-94	Dolomite, thickly bedded, sucrosic texture.

Table 1. - continued

Formation Name	Thickness (Range in m)	Lithologic Description
Wolsey Fm.	18-69	Finely fissile shale with interbeds of fine-grained sandstone; sandstone rich in hematite and glauconite.
Flathead Fm.	5-91	Sandstone, thin- to thick bedded, med.- to coarse-grained, silica cemented, supermature quartzarenite; thin beds and lenses of pebble conglomerate common.
<u>Precambrian</u> Precambrian undifferentiated		Quartzo-feldspathic gneiss, schist, amphibolite, marble, quartzite, and pegmatite.

### Local Structural Geology

In a broad sense, the structural geology of the Bannack area resulted from hanging wall deformation along the leading edge of the frontal fold and thrust belt (Coryell, 1983). Structural features within and surrounding the study area include three large-scale folds and three major faults (Figure 7).

#### Folds

The Madigan Gulch anticline is an eastward-verging, southward plunging asymmetrical anticline cored by Mississippian carbonate rocks. Steeply dipping to overturned strata exposed in the east limb of this anticline range in age from Upper Cretaceous Beaverhead conglomerates to Lower Mississippian Lodgepole Limestone. The fold has a sinuous

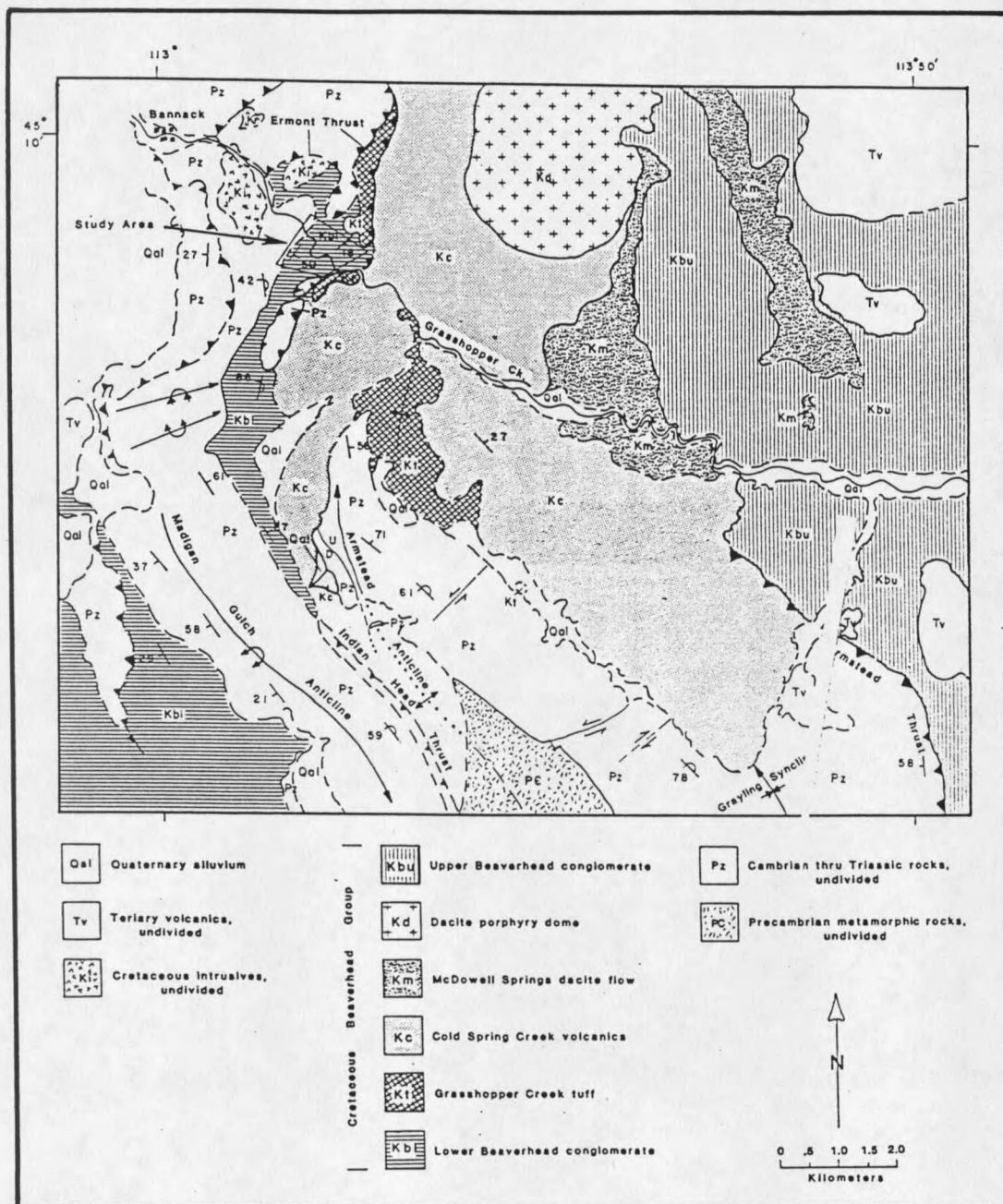


Figure 7. Generalized geologic map of study area. Adapted from Johnson and Sears (1988) and Gonnermann (1992).

trace but generally trends southeast (Coryell, 1983). The northern part of the fold has been cut by a possible southern extension of the Ermont thrust.

The Armstead anticline is an north plunging, east-verging, arcuate, asymmetric fold cored by Archean metamorphic rocks. Consistent north- to northwest- striking foliation in the metamorphic rocks of the core of the anticline (Lowell, 1965) suggests they were folded concordantly with the overlying sedimentary strata (Goodhue, 1986). The axial surface has a sinuous trace with the southern part of the fold trending north, central part trending northwest, and northern part swinging abruptly to the north and northeast (Figure 7). Just south of the field area, Paleozoic strata wrap around the nose of anticline where it plunges beneath strata of the Upper Cretaceous Cold Springs Creek volcanics. The southern extension of the fold is covered by the Clark Canyon Reservoir. Strata exposed on the east limb are steeply dipping to overturned and range in age from Cambrian through Pennsylvanian. The Armstead anticline is bounded to the west by a fault that places Paleozoic rocks against the Archean core.

Adjacent to the east flank of the Armstead anticline is a broad synclinal structure termed the Grayling syncline by Lowell (1965). This eastward-verging fold is asymmetric with a steep west limb and shallow east limb. Trend and plunge of the fold mimics that of the neighboring Armstead anticline

(Goodhue, 1986). Strata exposed in the limbs of the syncline range in age from the Upper Mississippian Conover Ranch Formation to the Lower Triassic Dinwoody Formation. The broad east limb of the fold is truncated by the Armstead thrust. The Grayling syncline plunges to the north and is buried beneath the Upper Cretaceous Cold Spring Creek Volcanics (Figure 7). The syncline is truncated by thrusting to the south (Coryell, 1983).

### Faults

The Ermont thrust was named by Myers (1952) and is the western most and structurally highest thrust in the study area. Along this fault, Mississippian and upper Paleozoic rocks have been brought over Upper Cretaceous conglomerates and volcanic rocks of the Beaverhead Group. Thomas (1981) mapped the north-northeast trend of the surface trace of the fault 24 km from the north side of Grasshopper Creek to its disappearance under Tertiary strata north of Badger Pass. He suggested that the thrust may die out in a series of fold structures north of the Tertiary cover. On the north side of Grasshopper Creek the trace of the fault is lost in a series of complex structures and intrusions. The westward dip of the fault plane gradually steepens as one proceeds south from less than  $15^{\circ}$  north of Badger Pass (Thomas, 1981) to  $35^{\circ}$ - $40^{\circ}$  near Bannack (Johnson, 1986). This change in the dip of the fault plane may indicate the presence of a subsurface ramp. Thomas

(1981) and Johnson (1986) have suggested that the Ermont thrust is the source for what they have interpreted to be klippen of Madison Limestone resting on top of the lower limestone conglomerate of the Beaverhead Group on the north and south sides of Grasshopper Creek (Secs. 9 and 17, T8S, R11W).

Johnson (1986) mapped a possible southern extension of the Ermont thrust south of Grasshopper Creek. This fault places Upper Mississippian and Pennsylvanian rocks over Lower to Middle Mississippian rocks and Beaverhead conglomerate. Further south, Coryell (1983) mapped a west dipping thrust fault that places Pennsylvanian rocks over strata of the lower Beaverhead conglomerate. He hypothesized that this fault may be the southern most extension of the Ermont thrust.

The Armstead thrust (Johnson, 1986) is the eastern most and structurally lowest thrust in the Bannack area where the fault is exposed for approximately 8 km (Johnson, 1986). Along its generally northwest trending surface trace, the fault places Mississippian carbonate, Pennsylvanian sandstone, and Upper Cretaceous volcanic rocks over strata belonging to the upper conglomerate member of the Beaverhead Group. Previous workers (Lowell, 1965; Coryell, 1983; Goodhue, 1986) have mapped this fault as a northern extension of the Tendoy thrust which places Mississippian rocks over Late Cretaceous to early Paleocene(?) Beaverhead conglomerates in the region of Dell and Lima, Montana. However, Johnson (1986) reported that

structural complications associated with the McKenzie thrust system of Perry and others (1985) south of Bannack do not permit the northward extension of the Tendoy thrust into the Armstead Hills.

Displacement along the thrust decreases from south to north (Gonnermann, 1992). Two kilometers south of Grasshopper Creek in Section 31 (T8S, R10W) displacement along the thrust dies out in a zone of fractured and sheared quartzite clasts within the Beaverhead conglomerate (Gonnermann, 1992). Maximum displacement is unknown, but Goodhue (1986) suggests it is greater than 500 m.

The east flank of the Madigan Gulch anticline is separated from the east flank of the Armstead anticline by a fault of ambiguous origin. This fault was termed the Indian Head thrust by de La Tour-du-Pin (1983; in Goodhue, 1986). The fault plane dips southwest at  $60^{\circ}$ - $80^{\circ}$  and the fault trace is subparallel to the axial surface trace of the major folds (Coryell, 1983). There are several interpretations of fault style which include normal faulting (Brant and others, 1949 in Johnson, 1986; Kupsch, 1950 in Johnson, 1986); younger-over-older thrust faulting (Lowell, 1965; Goodhue, 1986; Johnson, 1986); and listric normal faulting over a subsurface ramp (Coryell, 1983). Schmidt (personal communication in Coryell, 1983) has suggested that the fault was a west-directed high angle reverse fault that was later rotated to the east by thrusting. Along the south and central parts of the Armstead anticline



this fault juxtaposes Mississippian and older rocks against the Archean metamorphic rocks of the anticlinal core. To the north where the fault cuts the nose of the Armstead anticline the Mississippian Mission Canyon Formation has been faulted over progressively younger rocks from Archean metamorphic rocks to Mission Canyon Formation in a down plunge direction.

### STRATIGRAPHY AND AGE OF THE BEAVERHEAD GROUP

Strata of the of Upper Cretaceous to lower Tertiary (?) Beaverhead Group crop out over an area of approximately 1,700 km<sup>2</sup> in southwestern Beaverhead County, Montana and adjacent Clark County, Idaho (Figure 8). In general, Beaverhead Group strata are dominated by complexly interfingering limestone and quartzite clast conglomerate and sandstone with minor amounts of lacustrine limestone, mudstone, volcanic rocks, and exotic limestone blocks. The deposits exhibit marked changes in facies and thickness. Locally the deposits may be up to 4,500 m thick (Ryder and Scholten, 1973). Structural elements which acted as source areas for the terrigenous clastic deposits are thought to have been located in both the Rocky Mountain foreland to the east and the fold and thrust belt to the west (Ryder and Scholten, 1973; Haley, 1985; Haley and Perry, 1991).

The Beaverhead Group in the study area east of Bannack, Montana is divided into: 1) a lower limestone-pebble/cobble conglomerate with minor volcanic rocks; 2) an intermediate volcanic unit of ash flow tuffs, lava flows, volcanic breccias, a dacite dome, and associated shallow level intrusions; and 3) an upper quartzite-limestone pebble/cobble conglomerate (Figures 6 and 9). The lower unit consists of

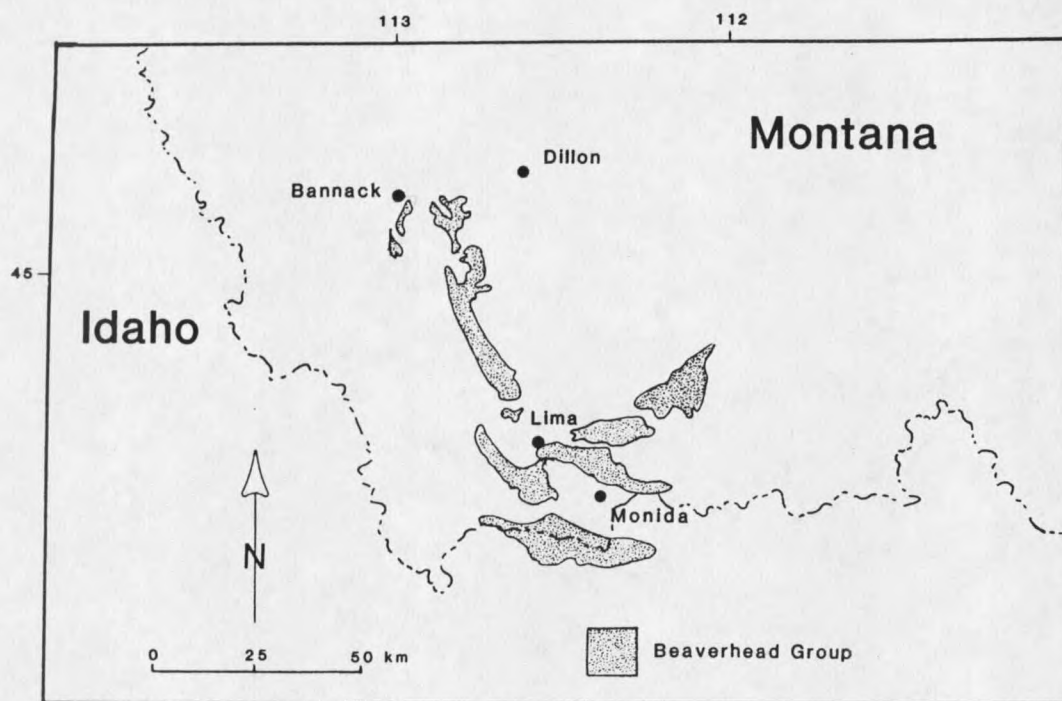


Figure 8. Distribution of Beaverhead Group rocks in southwestern Montana and east-central Idaho. Modified from Wilson (1967).

approximately 354 m of clast-supported limestone-clast conglomerates with lenses of fine- to coarse-grained sandstone and minor mudstone. Approximately 21 m above the basal contact of the Beaverhead Group is a 6 m thick sequence of fine- to medium-grained tuffs. Poor exposures of these greenish-grey to purple bedded tuffs crop out in the prominent northeast-southwest trending gulch just above the basal contact on both sides of Grasshopper Creek.

The lower most conglomerate unconformably overlies folded Mississippian Lombard Limestone (Figure 10). To the south, the



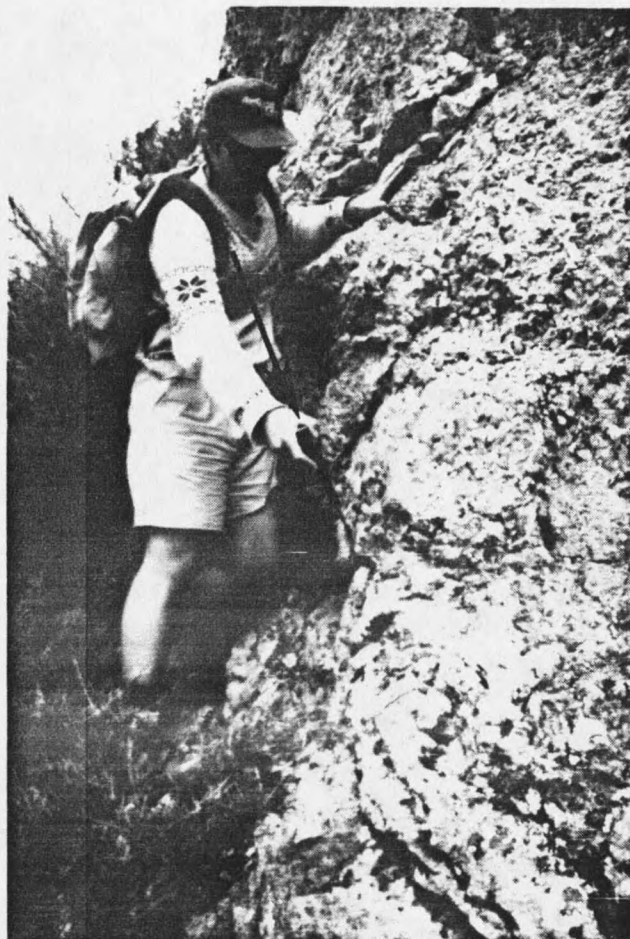


Figure 10. Contact between the lower Beaverhead conglomerate and Lombard Limestone on the east limb of the Madigan Gulch anticline. Hammer is in line with the depositional surface which is dipping approximately  $65^{\circ}$ . Dr. Schmitt's left hand is on a large boulder of Lombard Limestone. When depositional surface is projected skyward, this clast is in the lower Beaverhead conglomerate.

the basal Beaverhead and top of the Lombard. These pods are interpreted to be remnants of scree deposits that collected in low areas of the pre-Beaverhead surface.

Above the lower conglomerate unit (Figures 6 and 9) is a volcanic sequence which Ivy (1989) informally divided into the

Grasshopper Creek tuff and the Cold Springs Creek volcanics. The nature of the relationship between the volcanic rocks and conglomerates of the Beaverhead Group in this area was ambiguous until Gonnermann (1992) recognized that the "McDowell Springs intrusive sheet" (part of the Cold Springs Creek volcanics) of Pearson and Childs (1989) and Ivy (1989) was actually a dacite flow underlying the upper quartzite-limestone-clast conglomerate. Gonnermann (1992) based this interpretation on the recognition of a basal monolithic breccia which grades upward through a transition zone into massive, columnar-jointed dacite, capped by prominent flow ridges. Recognition of the McDowell Springs dacite as a lava flow establishes the volcanic rocks as part of the Beaverhead Group (Gonnermann, 1992).

The upper conglomeratic unit consists of up to 396 m (Pearson and Childs, 1989) of clast-supported quartzite-limestone conglomerate. The quartzite clasts were probably derived from Proterozoic quartzites of the thrust belt to the west (Ryder and Scholten, 1973; Ruppel and Lopez, 1984). The unit also contains highly weathered andesite clasts derived from the underlying Cold Springs Creek volcanic unit (Johnson and Sears, 1988). The remainder of the clasts are limestone, white quartzite, and chert probably derived from Paleozoic formations (Johnson and Sears, 1988; Gonnermann, 1992).

Contact relationships between rocks of the Beaverhead Group and the underlying strata vary by location. In the study

area and south of Lima, Montana, near the Lima Peaks (Haley, 1985; Haley and Perry, 1991) an angular unconformity separates the Beaverhead Group rocks from underlying strata of Paleozoic age. South and east of Monida, Montana, the Beaverhead rocks may rest disconformably or conformably on strata of the Late Cretaceous Frontier Formation (Dyman and others, 1991).

Because of its synorogenic nature, the Beaverhead Group consists of a number of spatially isolated, individually-mappable units which differ in lithology, thickness, and age (Haley, 1985; Haley and Perry, 1991) (Figure 11). Determining the temporal relationships between individual depositional units is difficult because few datable palynomorphs or other fossils have been recovered from Beaverhead strata. Thus, relative ages must be established by indirect methods such as stratigraphic correlation.

On the basis of lithological similarities, Johnson (1986) correlated the lower Beaverhead conglomerate in the study area with the Lima Conglomerate of the Beaverhead Group of Nichols and others (1985). The Lima Conglomerate, which crops out east of Lima, Montana, 70 km southeast of the study area, was dated palynologically as mid-Campanian (78-81 Ma) by Nichols and others (1985). If Johnson's (1986) correlation is correct, a similar age is inferred for the lower limestone conglomerate in the study area. Radiometric dating ( $^{40}\text{Ar}/^{39}\text{Ar}$ ) of the overlying volcanic rocks of the Cold Springs Creek unit

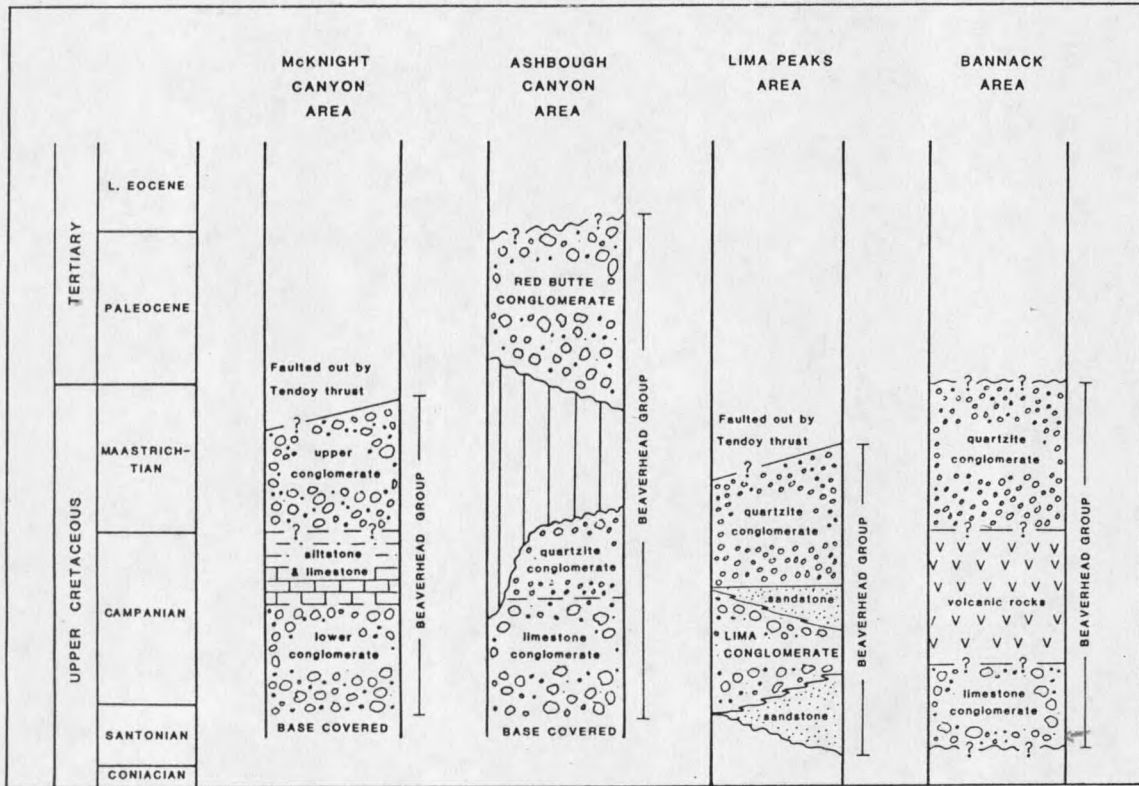


Figure 11. Ages and stratigraphic relationships of formal and informal units within the Beaverhead Group. Adapted from Haley and Perry (1991).

demonstrate that this phase of volcanism began approximately 80 Ma (analysis by L.W. Snee in Ivy, 1989). The age of the underlying Grasshopper Creek tuffs is unknown. Thus, the minimum age of the lower limestone conglomerate is no younger than middle Campanian but its maximum age is uncertain. The existence of the thin sequence of volcanic rocks within the lower conglomerate was unrecognized by previous workers. Radiometric dating of these tuffs could help to constrain the age of the lower conglomerate unit.



The upper quartzite-limestone conglomerate unit was mapped as part of the informal "Kidd quartzite conglomerate" of the Beaverhead Group by Ryder and Scholten (1973). Haley (1985) included these rocks in his "Kidd outcrop belt of undifferentiated quartzite conglomerates of the Beaverhead Group". Southeast of the study area these conglomerates are unconformably overlain by the Red Butte Conglomerate of the Beaverhead Group which Haley and Perry (1991) have suggested is probably no older than Maastrichtian and no younger than middle Eocene in age. West of the study area the upper quartzite-limestone conglomerate stratigraphically overlies the McDowell Springs dacite flow and a portion of the dacite dome (Figure 9) (Gonnermann, 1992). Radiometric dating ( $^{40}\text{Ar}/^{39}\text{Ar}$ ) of the dome indicates extrusion occurred approximately 75.8 Ma (analysis by L.W. Snee *in* Ivy, 1989). Thus, the upper quartzite conglomerate of the Beaverhead Group in the Bannack area is probably Maastrichtian in age.

## LITHOFACIES

Lithofacies analysis of the lower Beaverhead Group conglomerate involved establishment of the lithofacies present and detailed recording of their lateral and vertical distribution. The major lithofacies present in the study area include; conglomerate (G), sandstone (S), fine-grained units (F), and volcanic rocks (V). Each lithofacies is discussed below and is summarized in Table 2.

### Conglomerate Lithofacies (G)

#### Introduction

Conglomerate lithofacies are clast-supported with both organized or disorganized fabrics. Framework clasts are subrounded to angular and are generally equidimensional making recognition of preferred orientations difficult. Conglomerate lithofacies are divided into five subfacies which together make up approximately 85% of the lower Beaverhead strata in the study area.

#### Massive, Disorganized, Polymodal Conglomerate (Gcd)

Description. Lithofacies Gcd is characterized by polymodal framework gravels with a poorly- to very poorly-sorted matrix of calcite-cemented quartz-rich sand and

Table 2. Summary of lithofacies. Lithofacies codes modified from Miall (1977) and Rust (1978).

Lithofacies Code	Description	Sedimentary Structures	Interpretation
Gcd	Clast-supported, very poorly sorted, disorganized, cobble-boulder conglomerate	Massive, some crude inverse grading	Cohesionless debris flows, hyper-concentrated flood flows
Gcm	Clast-supported, moderately-to poorly-sorted, pebble-cobble conglomerate	Massive, some crude normal to inverse grading and imbrication	Longitudinal gravel bars; high-density gravelly traction carpets
Gch	Clast-supported, moderately- to well-sorted, horizontally stratified, pebble-cobble conglomerate	Horizontal stratification, imbrication	Longitudinal gravel bars
Gcp	Clast-supported, well-sorted, well-packed, pebble conglomerate	Imbrication, normal grading	Waning-stage minor channel fills and bar flank accretions
Gct	Clast-supported, moderately- to well-sorted, cross-stratified, pebble-cobble conglomerate	Cross-stratification parallel to lower bounding surface	Infilling of shallow channels and bar top scours by migrating gravel sheets
Sm	Fine- to coarse-grained, very poorly- to well-sorted sand, gravel as isolated clasts or stringers	Massive, some inverse grading, bioturbation	Sandy debris flows; sheet flood deposits; waning-stage channel and bar-top deposits; overbank deposits
Sh	Very-fine- to medium-grained, moderately- to well-sorted sand	Horizontal lamination	Waning-stage channel and bar-top deposits
Sr	Very-fine- to medium-grained, well-sorted sand	Ripple cross-lamination	Waning-stage channel and bar-top deposits, overbank deposits
Fm/F1	Massive to finely laminated mud	massive, bioturbation, fine laminations	Overbank deposits
V	Purple to greyish-green, fine-grained to aphanitic tuffs	Massive, some units have slaty partings	Tuff deposits

granular to small pebble size clasts of chert and limestone. Due to the poor organization and textural polymodality of this facies, formal delineation of a boundary between matrix and framework clasts is difficult. Facies Gcd contains abundant clasts that are significantly larger than the visually estimated mean clast size. The largest of these "outsized" clast may exceed 2.4 meters in diameter. Where present, elongated or platy clasts have random orientations, including vertical. Clasts often protrude from the tops of beds. Typically, the deposits are ungraded to inversely graded although some units exhibit coarse-tail normal grading. Deposits of facies Gcd range in thickness from less than 0.3 to 2 m and are found as lobes or thin sheets with sharp, slightly erosive to nonerosive bases, or as channel-filling bodies (Figure 12). The upper surface of this facies may be capped by lenses of massive (Sm) sandstone which infiltrate between the clasts in the upper part of the unit. Additionally, units of Gcd may grade laterally and vertically into gravels of facies Gcm.

Interpretation. The poor organization, ungraded to inversely graded texture of the polymodal framework gravels, the very poorly sorted matrix, and the presence of abundant "outsized" clasts suggest that units of facies Gcd represent the deposits of clast-rich, cohesionless debris flows. The term "cohesionless" is used here in the sense of Nemec and Steel (1984) to emphasize the relative unimportance of matrix

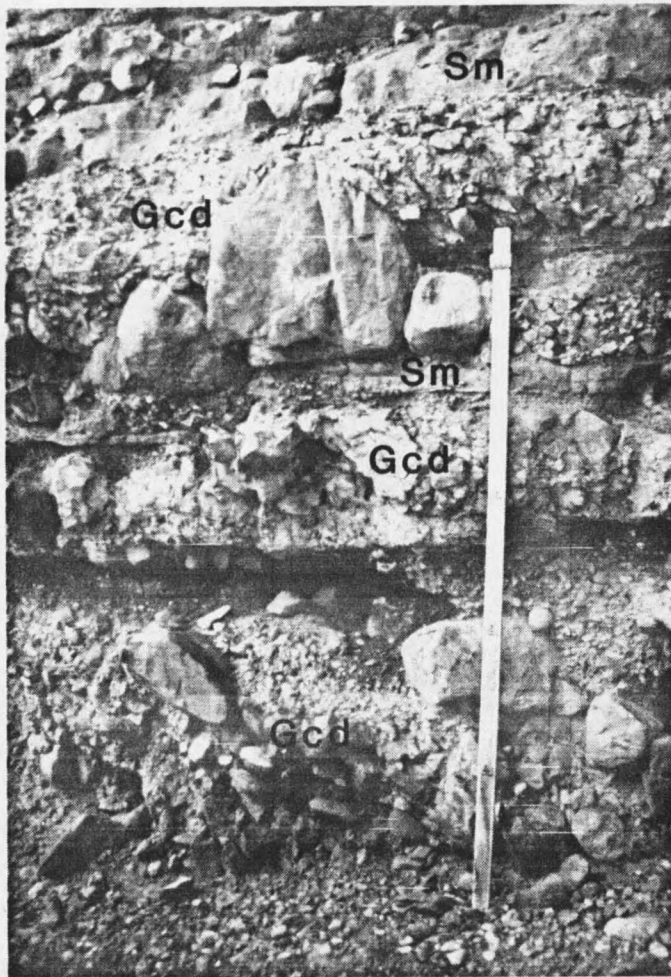


Figure 12. Facies Gcd interbedded with thin, discontinuous beds of massive sandstone (Sm). Jacob's staff is 1.5 m long.

cohesion in controlling flow behavior, particularly yield strength, mode of clast support, and mode of en masse deposition (cohesive freezing versus frictional freezing). The absence of a clay-rich matrix and the framework-supported nature of the deposits suggest that viscous debris flows could not have been the principal mechanism of clast transport (e.g. Schultz, 1984).

The flows probably consisted of a dense heterogeneous combination of boulders, cobbles and pebbles mixed with a fluid phase consisting of sand, silt, and water. Yield strength was controlled by internal friction originating from particle interlocking and sliding friction in the poorly sorted materials rather than cohesion of the matrix. Blair (1987a) described modern cohesionless debris flows on the Roaring River alluvial fan in Colorado containing 12.5% sand and 0.5% silt and clay. Clast support in these flows was provided by both turbulence and dispersive pressure. Pierson (1981) showed that in virtually cohesionless debris flows (4% clay), boulder size particles are readily held suspended by varying combinations of buoyancy, inertial dispersive pressure, turbulence, and grain-to-grain contact. Similar clast-supported debris flow deposits have been reported by Schultz (1984), Nemeč and Steel (1984), Wells (1984), DeCelles and others (1987), and Waresback and Turbeville (1990).

Thin sheet geometries were produced as the flows spread out unconfined across the depositional surface. Lobate geometries probably represent levees on the side of the flows while channel-filling geometries represent flows within pre-existing alluvial channels. Inversely graded beds are probably the result of flows where the forces of buoyancy, and inertial dispersive pressure acted in concert to keep the large particles on top of the flow. Normally graded beds may be the

result of the settling of clast within the flow during transport (Schultz, 1984; Denlinger and others, 1984).

On first inspection, some of the channel-filling deposits appear to resemble deposits of longitudinal bars (facies Gm of Miall, 1977). However, the polymodal distribution of grain sizes and poor sorting suggest the conglomerates were formed by mass immobilization rather than selective deposition. Furthermore, the matrix is too coarse-grained and poorly sorted to have infiltrated between the larger clasts after gravel framework deposition (Smith, 1986).

Massive, Disorganized  
Conglomerate (Gcm)

Description. Lithofacies Gcm is typically a bimodal clast-supported conglomerate having a unorganized to poorly organized fabric of pebble to cobble size framework clasts in a sandy matrix (Figure 13). Framework clasts are moderately- to poorly-sorted with a closed framework packing. Rarely, some units exhibit a local open framework packing. Although the deposits are essentially internally unstratified, abrupt lateral and vertical variations in grain size do occur. Grading is generally absent although, crude inverse or normal grading is apparent in some units. "Outsized" clasts are distributed irregularly, either as isolated individuals or in clusters. Elongated or platy clasts may have a weakly-developed imbrication. Matrix is generally poorly- to well-sorted, fine- to medium-grained, calcite cemented, quartz-rich

sand. Locally the matrix may be very poorly-sorted, very coarse-grained sand with granule to small pebble size clasts. Areas of poorly-sorted matrix are associated with the presence of "outsized" clasts.

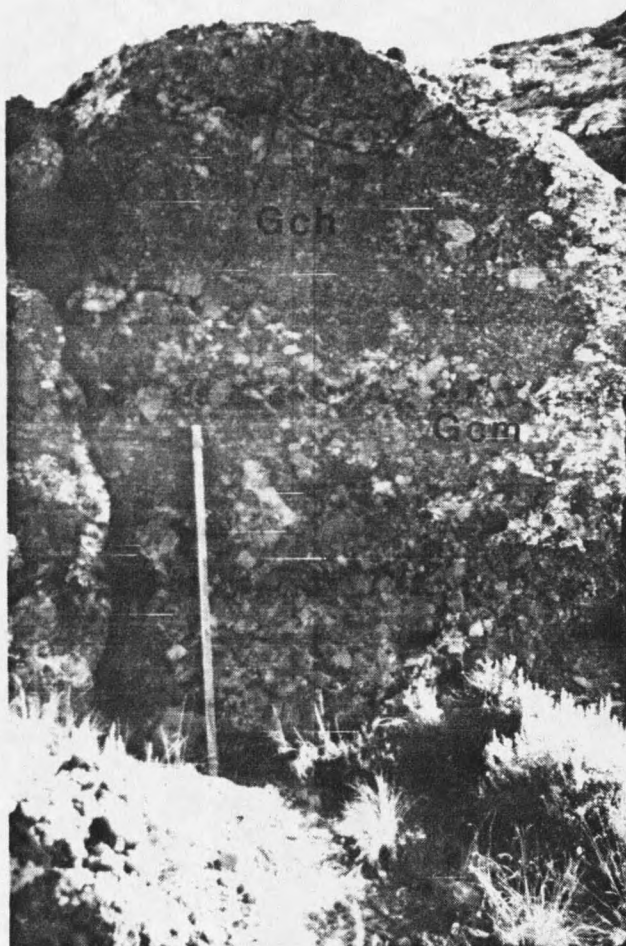


Figure 13. Facies Gcm overlain by facies Gch. Jacob's staff is 1.5 m long.

Bedding planes are indistinct to distinct and range from planar to irregularly concave-upward. Indistinct bedding planes often make it difficult to determine bed thickness and



lateral continuity. Individual beds, where visible, range in thickness from 0.5 to 2 m and extend laterally for up to 45 m. Some of these units have well-defined planar to slightly scoured bounding surfaces while in others, the bounding surfaces may be locally deeply scoured. Amalgamated stacked beds of facies Gcm, separated by thin, discontinuous lenses of sandstone, may reach 10 m in thickness.

Lithofacies Gcm may grade laterally into gravels of lithofacies Gcd and Gch or vertically into conglomerates of facies Gch or sandstones. Where sandstones cap units of facies Gcm, they typically form discontinuous lenses less than 0.25 m thick and generally do not extend laterally for more than 1.5 m before being truncated by the overlying conglomerates. These sandstone lenses are composed of medium-to very coarse-grained sand that may be massive (Sm), or horizontally stratified (Sh). The sandstones have sharp bases that drape the irregular topography formed by clasts projecting from the top of the underlying conglomerate unit.

Interpretation. Deposits of lithofacies Gcm are the most abundant in the study area. This lithofacies also shows the greatest variation in texture and fabric of framework clasts and matrix. Because the variations between deposits were frequently gradational and the gradations subtle, the deposits were not broken into subfacies. The interpretations that follow cover a range of possible depositional processes that may have led to these deposits.

Clast-supported, poorly organized gravel deposits with a poorly sorted coarse-grained sandy matrix and a general lack of reverse grading similar to deposits of facies Gcm have been interpreted by Smith (1986) to be the product of high-density sheet floods or hyperconcentrated flood flows. Smith (1986) uses the term "hyperconcentrated flood flow" to describe high-density flows intermediate in sediment/water ratio between fully turbulent dilute stream flow and viscous debris flows. The texture and fabric of these poorly-sorted sediments suggest rapid traction and suspension deposition from high-concentration dispersions in which turbulence and grain interactions are the primary support mechanisms (Smith 1986). Although deposition is rapid it does not occur en masse (Smith, 1986). Deposits with similar inferred modes of transport and deposition were described by Ballance (1984), Wells (1984), Wells and Harvey (1987), and Waresback and Turbeville (1990). These authors inferred the flows to be deposited on the surface of alluvial fans.

Todd (1989) interpreted sheet-like deposits in the Early Devonian Trabeg Conglomerate Formation of the Dingle Group (Lower Old Red Sandstone) in southwest Ireland that are similar to lithofacies Gcm to be the deposits of stream-driven, high-density gravelly traction carpets. These high-density bedload carpets move as high density dispersions along the bottom of channels during high magnitude floods and are thought to be somewhat analogous to the traction carpets

driven by high-density turbidity currents (Lowe, 1982). Todd (1989) suggests that these traction carpets are driven by tangential shear stress exerted by the overflowing turbulent portion of the sediment-laden stream flow under peak flow conditions. This shear stress is transmitted downwards and converted to dispersive pressure which supports much of the weight of the clasts within the flow. Additional support is derived from the buoyant lift enhanced by the dense nature of the interstitial fluid of watery sand (Todd, 1989). Variable types of grading are thought to be controlled by differences in the apparent viscosity of the traction carpets. Lack of sorting and internal stratification suggests that deposition occurred en masse by frictional freezing during waning of the stream flood (Todd, 1989). As the floods dissipated, sand was deposited on top of the gravel sheets. Conglomerate deposits of this type, up to 3 m thick, are found on stream-dominated, 'flashy' (ephemeral) alluvial fans (Todd, 1989).

Massive, moderately-sorted, pebble and cobble conglomerates similar to some deposits of lithofacies Gcm have been widely recognized and interpreted as the result of deposition by longitudinal bars in gravel-dominated braided streams (Smith, 1970, 1974; Rust, 1972, 1978; Boothroyd and Ashley, 1975; Miall, 1977; Hein and Walker, 1977;). These bedforms develop and grow during periods of moderate to high stage discharge. Typical dimensions for individual gravel bars range up to 1 m in thickness although superimposed units may

reach 4 m or more in thickness (Miall, 1977). Bar lengths of several hundred meters are possible, but these larger examples probably represent composite or coalesced forms (Miall, 1977).

Hein and Walker (1977) suggested that these bedforms grow from the emplacement of channel lag deposits as diffuse gravel sheets during maximum flow stages. These lag deposits, which initially may be only a few clasts thick (Boothyrod and Ashley, 1975; Hein and Walker, 1977), act as nuclei for subsequent development of longitudinal bars. Bars with massive or horizontally stratified internal structures develop when water and sediment discharges are high and the rate of downstream bar migration exceeds the rate of vertical aggradation (Hein and Walker, 1977). These conditions are most often met in the proximal reaches of braided streams (Hein and Walker, 1977).

Rust (1975, 1978) suggests that longitudinal gravel bars are primary bedforms that are stable under flood conditions when all bed material is in motion. The resulting deposits are characteristically massive to horizontally stratified because the low ratio of water depth to mean particle diameter suppresses the development of slip faces and the development of cross-stratification on the lee side of the bar (Rust, 1975, 1978).

Massive conglomerates above trough-shaped scour surfaces were deposited as channel lags (Miall, 1977). The bimodal clast population is the result of infiltration of finer grains

into an open gravel framework as flow strength decreased (Enyon and Walker, 1974; Miall, 1977). Scoured bounding surfaces between individual units and the discontinuous sand lenses indicate modification by subsequent high stage flows (Rust, 1978). Abrupt changes in clast size reflect varying discharge and discontinuous accretion (Nemec and Steel, 1984). The clusters of large clasts may be the remnants of cohesionless debris flows (Gcd) which were later modified by fluvial processes so that their initial origin is now obscured. The presence of very poorly-sorted sand to pebble matrix, similar to that found with lithofacies Gcd in association with the clast clusters, lends to support this view.

#### Horizontally Stratified Conglomerate (Gch)

Description. Units of lithofacies Gch consist of organized, moderately- to well-sorted pebble to cobble conglomerate with a crude to well-developed horizontal stratification (Figure 13). Stratification is defined by changes in clast size or sorting. Fining-upward sequences are the dominant textural trend although in many units there is no apparent change in clast size. One example of a crudely developed coarsening-upward sequence was observed. When present, elongate clasts have a moderate to well-developed imbrication. Matrix is fine- to medium-grained, moderate to well-sorted, calcite cemented, quartz-rich sand.

Units of lithofacies Gch display several different geometries. Thin, discontinuous sheets up to 0.5 m thick and 3.0 m wide with flat or concave-upward bases are normally found within units of facies Gcm. Broad channel-shaped or apparently tabular bodies up to 2 m thick and 10 m wide form distinct beds with planar to slightly irregular bounding surfaces. Discontinuous lenticular bodies of sand may be interbedded with these larger units.

Interpretation. Moderately-sorted, pebble and cobble conglomerates with crude- to well-developed horizontal stratification have been widely recognized and interpreted as the result of deposition by longitudinal bars in gravel-dominated braided streams (Smith, 1970, 1974; Rust, 1972, 1978; Hein and Walker, 1977; Boothroyd and Ashley, 1975; Miall, 1977). The genesis and evolution of the longitudinal gravel bars that gave rise to lithofacies Gch is envisioned to be the same as that for those deposits of lithofacies Gcm interpreted as longitudinal bars as discussed above. The thin discontinuous beds of Gch found within beds of Gcm were deposited on top of or within shallow channels incised into the surface of the Gcm beds. The thicker and more laterally extensive beds of Gch were deposited within larger channels.

The bimodal clast population is the result of infiltration of finer grains into an open gravel framework as flow strength decreased (Enyon and Walker, 1974; Miall, 1977). Scoured bounding surfaces between individual units and the

discontinuous sand lenses indicate modification by subsequent high stage flows (Rust, 1978). The one example of a coarsening-upward sequence is probably the result of deposition during rising-stage flow (Enyon and Walker, 1974).

Organized, Pebble  
Conglomerate (Gcp)

Description. Facies Gcp consists of organized, stratified, bimodal, well-sorted, tightly packed pebble conglomerate. Beds of Gcp fine upwards and have well-defined lenticular or wedge shaped geometries, generally less than 0.5 m thick and 2 m wide with concave-up erosional bases. Matrix is fine- to medium-grained, moderately- to well-sorted quartz-rich sand. Units of facies Gcp usually occur within or on top of beds of Gcm or Gch.

Interpretation. Fluvial gravels similar to facies Gcp have been described in the deposits of modern gravelly braided streams (Smith, 1970, 1974; Rust, 1972, 1978; Hein and Walker, 1977). Units of Gcp are interpreted to be waning stage flood deposits that accumulated within channels that developed on the tops and margins of larger bars made up facies Gcm and Gch. The bimodal clast population is the result of infiltration of finer grained sediments into an open gravel framework as flow strength decreased (Enyon and Walker, 1974; Miall, 1977). Deposits analogous to these were reported by DeCelles and others (1991b) in the Paleocene Beartooth conglomerate in Wyoming and Montana.

Trough Cross-Stratified  
Conglomerate (Gct)

Description. Units of Gct are rare in the lower Beaverhead conglomerate. Four units of this lithofacies were recorded; three of these were poorly exposed. Lithofacies Gct consists of trough cross-stratified pebble conglomerate that fines upward and is similar to facies Gch in texture and matrix. Individual troughs appear to be broad, shallow features up to 1 m deep and have a concave-up erosional base. The largest lateral dimension measured was 1.5 m; however, poor outcrop exposures likely obscured the true dimensions. Trough-filling strata generally appear to conform to the shape of the basal scour surface, but some merge tangentially with the lower bounding surface (Figure 14). Trough-filling strata dip at angles of less than  $10^{\circ}$ .

Interpretation. Lithofacies Gt is interpreted to represent deposition in shallow channels and bar top scours by migrating gravel sheets during flood and waning flow stages in braided streams (Miall, 1977). Larger channels developed by avulsion during high-stage flow (Miall, 1977) while the smaller channels and scours were produced by waning flow modification of bar surfaces and margins (Williams and Rust, 1969). Stratification parallel to the lower bounding surface of the channels and scours suggests deposition under upper flow regime conditions (Miall, 1977).



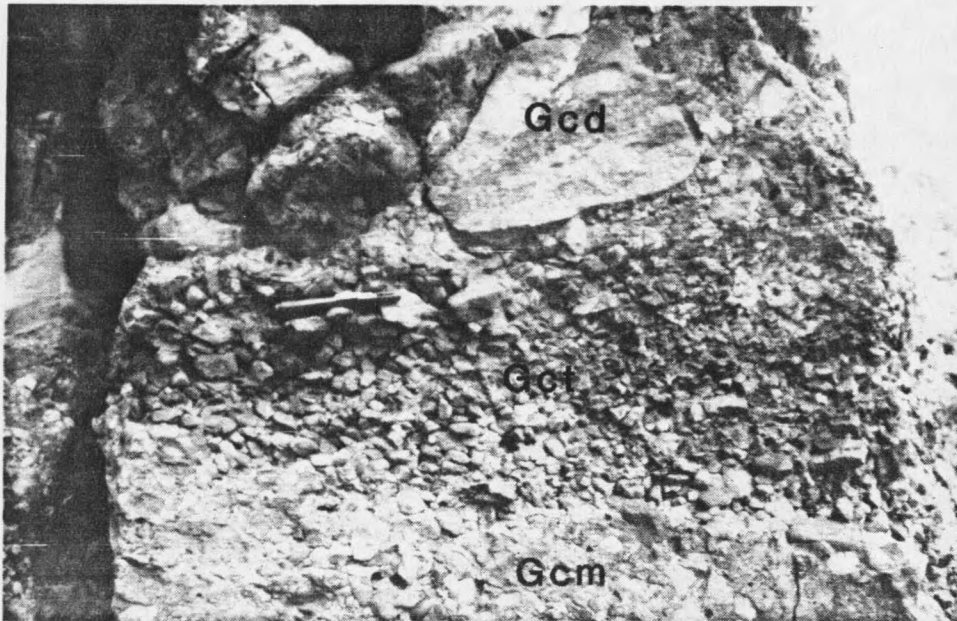


Figure 14. Facies Gct overlain by facies Gcd and underlain by facies Gcm. Pen is 13 cm long.

### Sandstone and Mudstone Lithofacies (S/F)

#### Introduction

Sandstones and mudstones account for approximately 15% of the overall volume of the lower Beaverhead conglomerate. The rarity of these lithofacies suggests low preservation potential during subsequent flood events (Rust, 1984). These fine-grained rocks are most commonly preserved as discontinuous lenses or trough-shaped bodies between or within stacked conglomerate beds. The highest percentage of sandstones and mudstones are found in the lower part of the section where the beds have apparently tabular geometries that extend laterally for approximately 60 m. Basal contacts are

generally sharp and slightly irregular with the sand filling in around the clasts at the top of the underlying conglomerates. Upper bounding surfaces are planar or contain irregularly scoured troughs. Scours are infilled by conglomerates of lithofacies Gcd, Gcm, or Gch. Sandstone and mudstone beds are generally truncated by conglomerates of lithofacies Gcm and Gch. Any combination of the three sandstone lithofacies recorded (Sm, Sh, and Sr) can be found adjacent to each other within a single sandstone unit.

#### Massive Sandstone (Sm)

Description. Deposits of lithofacies Sm are quite variable ranging from well- to very poorly-sorted, fine- to very coarse-grained quartz-rich sand. In some units, abundant granule- to small cobble-sized clasts are scattered randomly throughout or arranged in stringers or clusters while other units contain only occasional clasts. Clast concentrations vary widely both vertically and horizontally within different parts of the same unit. Sm units generally have lenticular, trough-shaped, or tabular geometries. Beds of Sm range in size from a few centimeters thick by tens of centimeters wide up to 3.5 m thick with a lateral extent of approximately 60 m. The lower bounding surfaces are generally sharp and irregular with clasts from underlying conglomerates extending up into the base of the beds.

Deposits with lenticular or trough-shaped geometries generally are more poorly-sorted and have higher

concentrations of gravel-size clasts. Sand-filled burrows are visible in some of the tabular units near the base of the section. Lithofacies Sm often grades vertically into sandstones of facies Sh. Where it is not capped by other sandstones, beds of Sm are overlain along an irregularly scoured surface by conglomerates.

Interpretation. The presence of sand-filled burrows in some the Sm units indicate that bioturbation is in part responsible for the massive, structureless sandstones. Faint, discontinuous patches of horizontal lamination (Sh) and ripple cross-lamination (Sr) within the sandstones suggest that the massive beds originally contained sedimentary structures. Direct evidence of bioturbation is limited to the tabular sandstones found near the base of the section. Similar sandstones described by DeCelles and others (1987, 1991b) were interpreted to be ephemeral flood deposits on inactive areas of an alluvial fan.

Deposits of lithofacies Sm containing abundant granule to small cobble clasts are interpreted to result from deposition by sandy debris flows or fluidal sediment flows (Nemec and Steel, 1984). In flows of this type, turbulence are considered to be the main particle support mechanism. Stringers of clasts are interpreted to be the result of traction transport along the base of the bed. Waresback and Turbeville (1990) interpreted similar units (their facies Gmsu) in the Plio-Pleistocene Puye Formation of north-central New Mexico to be

the deposits of clast-poor sandy debris flows. DeCelles and others (1991b) interpreted deposits of massive pebbly sands in the Paleocene Beartooth conglomerate of southwest Montana that are similar to facies Sm to be the deposits of sandy mudflows. Wells (1984) suggested that deposits of this nature may have been formed by waning sheetfloods, dewatering of debris flows, or reworking of surficial deposits by sheetwash during storms.

Blatt and others (1980, p. 118) suggest massive bedding of primary origin may result from processes lacking a tractional phase during deposition such as very rapid sedimentation from suspension or deposition from highly concentrated sediment dispersions. Some of the apparently massive sandstones may actually contain sedimentary structures, but the structures are not evident in the outcrops.

#### Horizontally Laminated Sandstone (Sh)

Description. Lithofacies Sh is a horizontally laminated, fine- to medium-grained, moderately- to well-sorted quartz-rich sand. Facies thickness ranges from a few millimeters to 20 cm and units are generally laterally discontinuous. Thin (<1 cm) interbeds of siltstone are periodically found in the upper parts of the facies. When present, facies Sh is always found overlying sandstones of facies Sm. Units of facies Sh is either conformably overlain by fine-grained sediments of

lithofacies Fl/Fm or conglomerates along a planar or irregularly scoured surface.

Interpretation. The horizontally laminated sandstones of lithofacies Sh are interpreted to have been deposited under upper plane bed conditions during falling stage flow over bar tops or in shallow channels. Harms and others (1975, 1982) note that horizontally laminated sandstones can form under both lower and upper flow regimes conditions. Lower flow regime plane beds are limited to sands coarser than that observed (Harms and others, 1982) so this interpretation is rejected. Upper plane bed conditions may be inferred if current or parting lineations are present or if lithofacies Sh is associated with trough cross-stratified sandstones (Harms and others, 1982). Unfortunately, neither of these potentially diagnostic relationships were observed. However, shallow flow in channels or over bar tops during falling stage could maintain upper flow regime conditions favorable for the transport and deposition of fine sand by traction processes (Harms and Fahnestock, 1965). The thin lenticular nature of the Sh sandstones and their association with lithofacies Fl/Fm also suggests shallow flow conditions (DeCelles and others, 1987).

Ripple Cross-laminated  
Sand (Sr)

Description. Lithofacies Sr is characterized by ripple cross-laminated, very fine- to fine-grained, moderately- to

well-sorted quartz-rich sand. Units of Sr are laterally very discontinuous and generally 2 to 6 cm thick. This lithofacies is usually found in the upper portions of the same beds containing lithofacies Sm and Sh. Asymmetric ripple crests are preserved only locally. Lithofacies Sr is either overlain by fine-grained sediments of facies Fl/Fm or conglomerates along a planar or irregularly scoured surface.

Interpretation. The ripple cross-laminated sandstones of lithofacies Sr are interpreted to be generated under lower flow regime conditions by the migration of asymmetric ripples across the surfaces of bars or within bar top channels during late stage, shallow waning flow (Harms and Fahnestock, 1965; Miall, 1977). The association of lithofacies Sr with lithofacies Sm suggests occurrences of Sr may have at one time been more prevalent, but were subsequently destroyed by bioturbation.

#### Fine-Grained Lithofacies (Fm/Fl)

Description. Fine-grained lithofacies include red and brown massive mudstone (Fm) and laminated siltstone and mudstone (Fl). Interbedding of fine-grained sand, silt, and mud on a small scale is common. Bioturbation, small scale ripples and undulatory bedding may be present. Units of this facies may reach up to 0.5 m in thickness in the lower part of the section. Facies Fm/Fl are found either overlying the

sandstone lithofacies or interbedded with them on a small scale.

Interpretation. The siltstone and mudstones of lithofacies Fm/F1 are interpreted to represent deposition of fines from suspension during very low velocity flow conditions in shallow bar top swales, inactive channels, and overbank areas (Miall, 1977).

### Volcanogenic Lithofacies (V)

#### Introduction

Volcanic rocks make up less than 1% of the lower Beaverhead strata. Outcrops of this lithofacies are sparse. Contact relationships with the underlying and overlying Beaverhead strata are uncertain. The basal contact is covered while the upper contact, where it is exposed, appears to be gradational with the overlying sandstones and conglomerates.

#### Volcanic Rocks (V)

Description. The volcanic rocks form a series of six interbedded units divisible primarily by color. Units range from 0.8 to 1.5 m thick and have apparently tabular geometries. Contacts between units appear to be sharp or slightly gradational. Units are purple, purplish-green to grayish-green, massive to platy or flaggy, fine-grained to aphanitic with phenocrysts of quartz, feldspar, and mafic

fragments. Sedimentary rock fragments of limestone, chert, and sandstone may be present in pods or as individual clasts.

Interpretation. The fine-grained to aphanitic texture of hand samples and the massive to platy or flaggy bedding characteristics of the outcrops suggests the deposits are tuffs. The presence of sedimentary rock fragments suggest that some of the deposits may have been reworked. However, an unequivocal interpretation of the genesis of these deposits is not possible due to the high degree of weathering and limited outcrop extent.



### LOWER BEAVERHEAD STRATIGRAPHY

Detailed measurement of the lower Beaverhead section began approximately 21 m above the Lombard/Beaverhead contact. Steep, rugged terrain prevented a careful lithofacies analysis of the basal deposits. However, cursory examination suggest that they were dominated by conglomerates of facies Gcm and Gch. Conglomerate lithofacies make up approximately 85% of the lower Beaverhead conglomerate in the study area (Figure 15). Sandstone (15%) and volcanic rocks (less than 1%) make up volumetrically minor components of the deposits.

The basal conglomerate is overlain by approximately 6 m of volcanic rocks which are in turn overlain by 32 m of interbedded sandstone and mudstone of facies Sm, Sr, and Fm/Fl. The sandstone beds range from 0.5 to 3.5 m thick while the mudstone beds range from less than 0.25 to 0.5 m thick. These interbedded fine-grained units are in turn overlain by 10 m of interbedded sandstone (Sm and Sr) and conglomerate (Gcm and Gcd). The sandstones found in the first 48 m of the measured section account for the vast majority of sandstone in the lower Beaverhead. These lower sandstones have apparent tabular geometries. The remaining approximately 300 m of section is almost completely dominated by conglomerates. Sandstones, primarily Sm, in the remainder of the section are

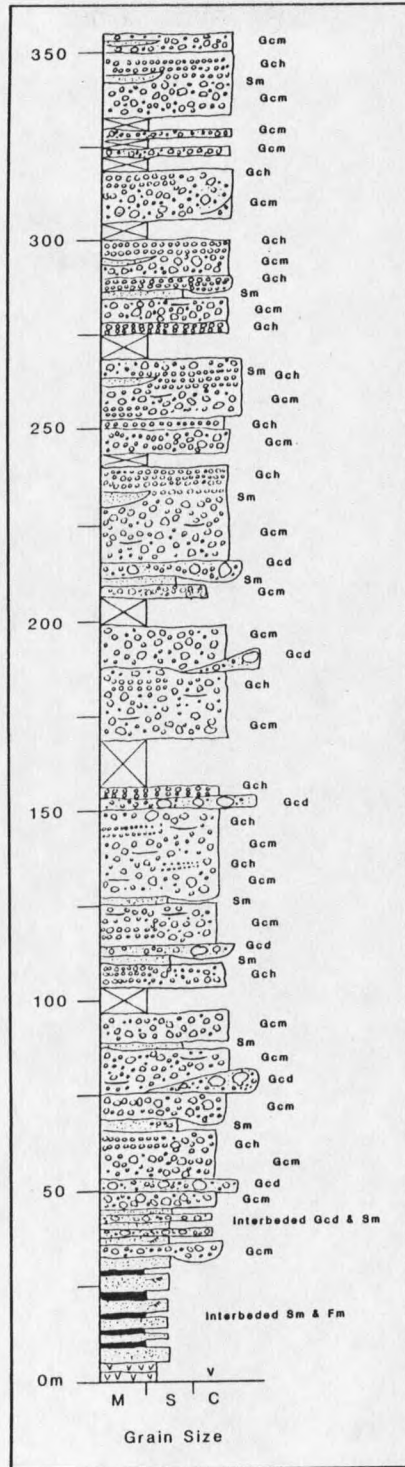


Figure 15. Generalized vertical lithofacies profile of the lower Beaverhead conglomerate. Note the dominance of lithofacies Gcm.

found only as lenses that are often laterally truncated or have scoured upper surfaces.

Conglomerates of lithofacies Gcm are by far the most dominant conglomerate lithofacies found throughout the lower Beaverhead strata. Deposits of lithofacies Gcd, although never prominent, are most often found in the interval from approximately 69 to 220 m above the basal contact. Conglomerates of lithofacies Gch are most prevalent in the interval between 200 and 322 m. This same interval also contains the largest and most abundant sandstone lenses. Lenses may be up to 1.5 m thick and 60 m wide. Deposits of facies Gch are most often present as discontinuous beds less than 1 m thick within amalgamated units of Gcm. Thick units, up to 2 m, have lenticular shapes and fill channels scoured into deposits of facies Gcm or into the tops of sandstone lenses.

## DEPOSITIONAL SYSTEMS

The suite of facies present in the lower Beaverhead conglomerate indicates deposition by channelized and nonchannelized high energy alluvial systems. The deposits which characterized these systems include the products of cohesionless debris flows (Gcd), hyperconcentrated flood flow (Gcm), longitudinal bar formation (Gcm and Gch), and waning stage accretion on bar tops and in interbar channels (Gcp, Gct, Sm, Sh, Sr, Fm/Fl) (Plate 1). The facies assemblages present are characteristic of alluvial fans and proximal gravel-bed braided river depositional systems (Hooke, 1967; Bull, 1972; Miall 1977, 1978; Rust, 1978) and are analogous to Rust's (1978) facies assemblages  $G_I$  and  $G_{II}$ . The facies assemblages present in the lower Beaverhead conglomerate of the study area are interpreted to be the deposits of the proximal portion of a single alluvial fan. This alluvial fan will be referred to as the Grasshopper Creek alluvial fan.

Other observations which support a proximal alluvial fan interpretation are the dominance of conglomerate facies over sandy facies (Boothroyd and Ashley, 1975; Miall, 1977, 1978), presence of deeply incised, vertical walled channels (Haley, 1985) (Figure 16), and locally high degree of clast angularity (Nilsen, 1982). Another characteristic of alluvial fans is the

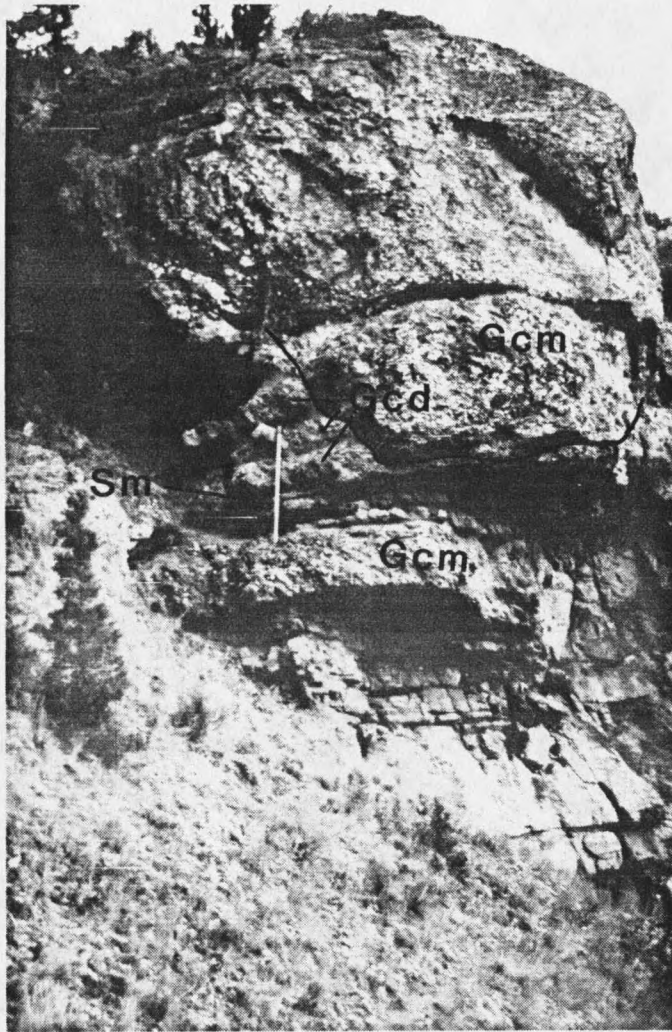


Figure 16. Steep walled channel incised into conglomerates (Gcm and Gcd) and sandstones (Sm). Channel is filled with gravels of facies Gcm and is approximately 2 m deep. Jacob's staff is 1.5 m

relatively rapid downfan decrease in both average and maximum clasts size (Nilsen, 1982). Tracing of the proximal conglomerate deposits into more distal deposits was not possible due to faulting and burial by Upper Cretaceous volcanic rocks. Thus the relationship between grain size and distance from source area is uncertain. This lack of

significant lateral exposure also prevented any documentation of a fan-like distribution of paleocurrents. Nevertheless, the types and distribution of facies present are similar to that reported in other modern and ancient alluvial fan deposits.

Debris flow facies are characteristic of deposits found on the proximal part of alluvial fans (Hooke, 1967; Bull, 1972; Harvey, 1984). The development of debris flows is favored in areas where abundant loose debris is temporarily stored in the source drainage basin and subject to short periods of intense rainfall (Blissenbach, 1954; Bull, 1972; Blair and McPherson, 1992). Thus, the proximal portions of fans developed in semiarid regions should be dominated by debris flow deposition (Blissenbach, 1954; Bull, 1972). Graham and others (1986) have suggested that during the Late Cretaceous the climate in southwestern Montana was seasonally temperate. If this is true, debris flow deposits appear to be under represented in the lower Beaverhead conglomerate.

The relative paucity of debris flow deposits may have several explanations. Blair (1987a) and Blair and McPherson (1992) showed that post depositional events on fan surfaces may completely obscure evidence of the depositional process primarily responsible for fan formation. Blair and McPherson (1992) showed that gravel deposits previously interpreted by Hooke (1967) to be of fluvial origin are actually the result of post-depositional winnowing of fines from debris flow deposits. The localized areas in some massive conglomerates

(Gcm) that contain "outsized" clasts in a poorly sorted matrix suggests some of these deposits may have a debris flow origin. If so, debris flows may have been a more important process in delivering sediment to the fan than is suggested by the volume of their preserved deposits. Alternatively, uplift of the source area may have led to cannibalization of the most proximal portions of the fan and the reworking and redistribution of gravels initially deposited by debris flows to medial or distal portions of the fan.

Conglomerates of facies Gcm and Gch were deposited on the surface of the fan by hyperconcentrated flood flow and proximal gravel-bed braided stream flow processes (Miall, 1978; Rust, 1978; Ballance, 1984; Harvey, 1984; Wells, 1984). Hyperconcentrated flood flow sediments (facies Gcm) were deposited when high concentration flood flows within fluvial channels spread out over the fan surface. Deposition was probably caused by a widening of the flow due to loss of confinement and a concurrent decrease in depth and velocity of flow (Bull, 1972).

Deposits of facies Gch and some deposits of facies Gcm are interpreted to represent longitudinal bars formed in the proximal portion of a braided gravel-bed fluvial system on the fan surface (Rust, 1978; Miall, 1978). The dominance of massive (Gcm) and horizontally stratified (Gch) gravels to the almost total exclusion of cross-bedded gravels (Gct) supports

the interpretation that deposition took place in the proximal reaches of the system (Rust, 1978).

Interbedded sandstones and mudstones with tabular geometries found near the base of the Beaverhead strata were deposited on the fan surface by ephemeral sheet floods outside of areas subject to active channel migration and scouring (Heward, 1978; Mack and Rasmussen, 1984; DeCelles and others, 1987). Evidence of bioturbation indicates deposition in these area was sporadic enough to allow for colonization of the deposits by burrowing organisms.

One of the most salient features of the lower Beaverhead conglomerate in the study area is a very large channel-shaped structure incised into deposits of conglomerate and sandstones approximately 249 m above the Lombard/Beaverhead contact (Figure 17). This structure is approximately 200 m across and 20 m deep and has a highly erosive lower bounding surface with up to several meters of relief. The deposits within this structure consist of interbedded conglomerate and sandstone of facies Gcm, Gch, Sm, and Sr. This facies association is interpreted to represent deposits of a gravelly braided stream system. Based on the size, geometry and internal lithofacies association, this structure is interpreted to be a major fanhead trench that was incised into the fan surface and subsequently backfilled. Fanhead trenches of similar size and geometry have been described on modern fans by Bull (1964) and Lustig (1965). Decelles and others (1991b) described a similar







































































































































































