Depositional environments and provenance of arkosic sandstone, Park shale, middle Cambrian, Bridger Range, southwestern Montana
by Jenny Christine Fryxell

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Earth Science
Montana State University
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Abstract:
Middle Cambrian strata of southwestern Montana are a transgressive regressive package of rocks consisting of fine-grained elastics and carbonates. The rocks represent the Sauk sequence and in ascending order are: The Flathead Sandstone, Wolsey Shale, Meagher Limestone, Park Shale, Pilgrim Limestone and Snowy Range Formation. Quartz/feldspar-rich zones occur in the Flathead, Wolsey, Meagher, and Park Shale.

Quartz/feldspar-rich zones in the upper third of the Meagher, a flat-pebble conglomerate with a coarse, detrital, silt-sized matrix at the top of the Meagher, and abrupt increases in the stratagraphic thickness of the Meagher and Hasmark Formations near the Idaho/ Montana border, reflect increasing tectonic instability and shallowing of the sea during late Meagher/early Park time. The arkosic interval of the Park represents the culmination of tectonic instability and disruption of the marginal-shelf environment. Renewed tectonic instability most likely occurred along pre-existing zones of structural weakness.

The arkosic sandstones of the Park are restricted to the northern half of the Bridger Range and to the lower 30 m of the Park shale. The arkosic interval of the Park consists of two major facies: a quartz/orthoclase-rich facies with locally developed flat-pebble conglomerate, and a calcareous, fossiliferous, arkosic, glauconite-rich sandstone.

The arkosic sandstones of the Park Shale were deposited in a shallow-water near-shore island complex. The abrupt, sporadic occurrence, and lateral discontinuity of the quartz/orthoclase-rich facies indicates catastrophic sedimentation followed by a rapid return to mud sedimentation. The abundance of glauconite, carbonate and fossils in the glauconite-rich facies suggests deposition in a stable, quiet, shallow-water, marginal-shelf environment.

The sporadic occurrence of sandstone throughout the arkosic interval suggests periodic rejuvenation of a granite gneiss source rock. During subaerial exposure of the source rock, a weathered zone or profile developed. This weathered zone was a source of clastic detritus for both arkosic sandstone facies.

By latest Park/earliest Pilgram time, erosion of the source area, increasing tectonic stability and an effective rise in eustatic sea level had re-established stable, marginal-shelf conditions.

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DEPOSITIONAL ENVIRONMENTS AND PROVENANCE OF

ARKOSIC SANDSTONE, PARK SHALE, MIDDLE CAMBRIAN,

BRIDGER RANGE, SOUTHWESTERN MONTANA

by

JENNY CHRISTINE FRYXELL

A thesis submitted in partial fulfillment
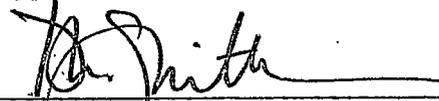of the requirements for the degree

of

MASTER OF SCIENCE

in

Earth Science

Approved:

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Chairperson, Graduate Committee

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Head, Major Department

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Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

May, 1982

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ABSTRACT

Middle Cambrian strata of southwestern Montana are a trans-
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The sporadic occurrence of sandstone throughout the arkosic
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By latest Park/earliest Pilgram time, erosion of the source
area, increasing tectonic stability and an effective rise in eustatic
sea level had re-established stable, marginal-shelf conditions.

INTRODUCTION

Location

The study area is located in the Bridger Range, directly north of Bozeman, Montana (Fig. 1). The Bridger Range, which is an asymmetric, eastward verging, anticlinal uplift bounded on the west by a normal fault, trends north-south for 26 miles. The Park Shale crops out along the western flank of the Bridgers, the southeastern limb of the Horseshoe Hills, and to the south along the northwestern flank of the Gallatin Range (Fig. 1).

Purpose

The arkosic sandstones of the Park represent an interesting stratigraphic-sedimentologic problem which has not been previously addressed. Middle Cambrian rocks in the study area are dominated by fine-grained clastic and carbonate rocks which total 498 m. Feldspar-rich sandstone and siltstone beds occur in the Flathead Sandstone, Wolsey Shale, and Park Shale. Quartz/feldspar sandstone stringers are present in the Meagher Limestone. The occurrence of these arkose-rich intervals, in a stratigraphic section consisting of fine-grained clastic and carbonate material, represents a local disruption of the stable, marginal-shelf environment. This study was a: (1) description of the stratigraphy and areal distribution
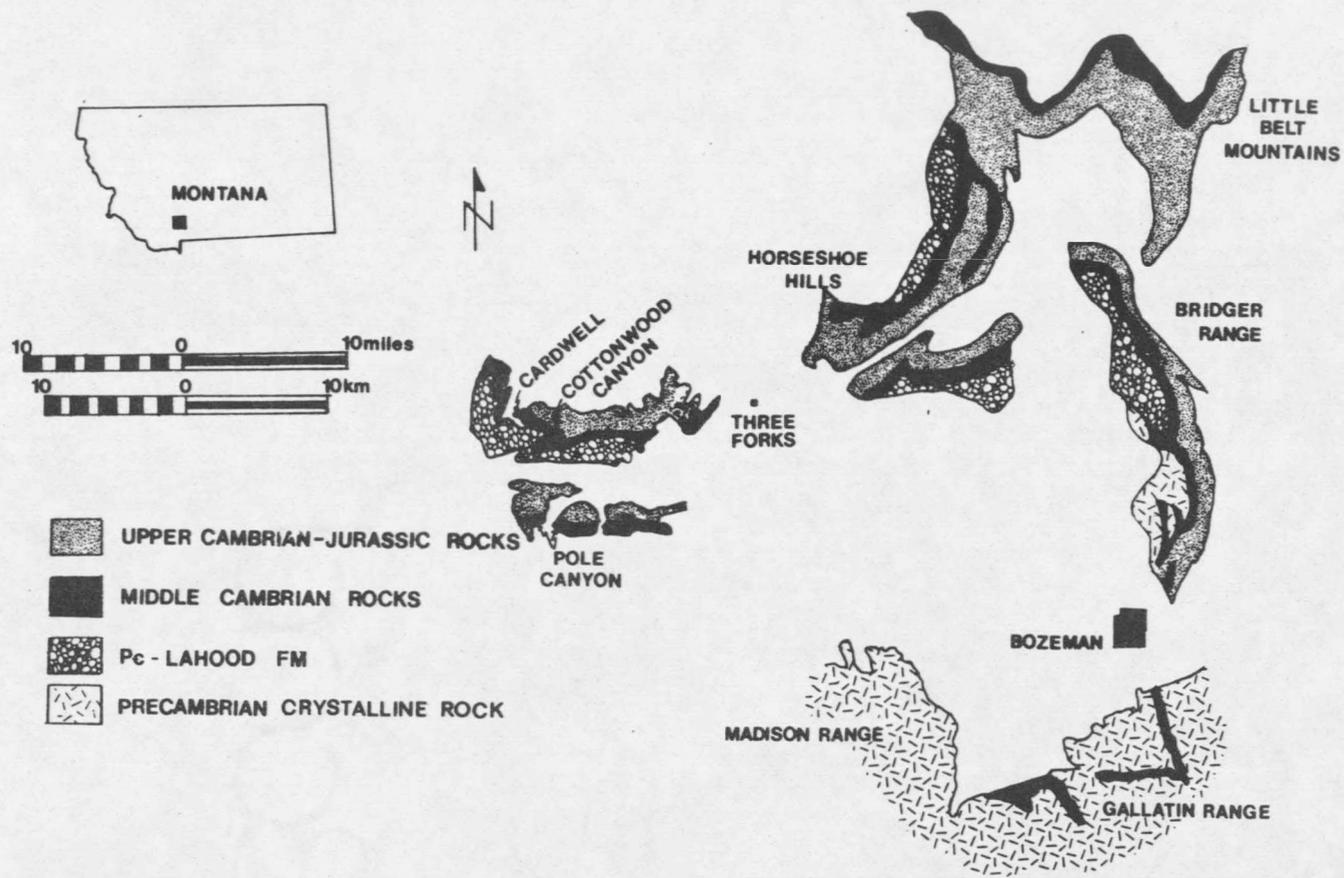
Figure 1. Distribution of Middle Cambrian rocks referred to in the text. Author's measured sections lie along strike in the northern half of the Bridger Range, and in the Horseshoe Hills. Section locations shown in Figure 7.

of the arkose, (2) details petrographic characteristics of the arkoses and (3) develops a depositional model that explains the occurrence of arkose in a stratigraphic sequence consisting of fine-grained clastic and carbonate rocks.

Procedure

Field studies of the Park arkosic interval were conducted during the summers of 1980 and 1981. Field work entailed locating, measuring, and sampling arkosic sandstone outcrops. Exposures are poor as the shale tends to slump badly. As a result, the best outcrops are in very steep, southeast-facing or northwest-facing slopes. In addition, interpretation of field data was hampered by the sporadic occurrence of outcrops along strike in the Bridger Range, the total lack of Cambrian outcrops to the east, and the lack of outcrops for seven miles to the west.

Later, representative handsamples and thin sections were studied using binocular and petrographic microscopes. Samples from selected areas of Precambrian crystalline rock, Flathead Sandstone, Wolsey shale and Meagher Limestone were also examined in thin section. Estimates of mineral percentages were obtained both petrographically and by staining samples using the method proposed by Bailey and Stevens (1960) for selective staining K-feldspar and plagioclase.

REGIONAL SETTING

Sedimentary Tectonics

The structural and stratigraphic framework of western Montana evolved in Precambrian Y time during Belt sedimentation (McMannis, 1965). Sediments were deposited in the Belt Basin, a large epicratonic trough, which formed a northwest-southeast trending reentrant along the eastern margin of the Cordilleran miogeosyncline (Fig. 2). The basin swung inland at its southeasternmost extent, forming the east-west trending Belt Embayment. The embayment was bounded on the north by the North American craton and on the south by the Dillon Block (Hartison and others, 1974). The Dillon Block is essentially the same tectonic province as the Paleozoic Wyoming shelf of Sloss (1950).

The northern margin of the Block is coincident with the Paleozoic shelf break and is defined by the east-west trending Willow Creek fault zone. This zone is thought to represent a major Precambrian structural discontinuity which is still active today and which probably influenced Paleozoic and Mesozoic sedimentation patterns as well (Sloss, 1950; Bonnet, 1979).

Depositional patterns of Cambrian through Mississippian formations, Jurassic formations, and parts of Cretaceous sections are thicker in east-west zones. These depositional patterns closely
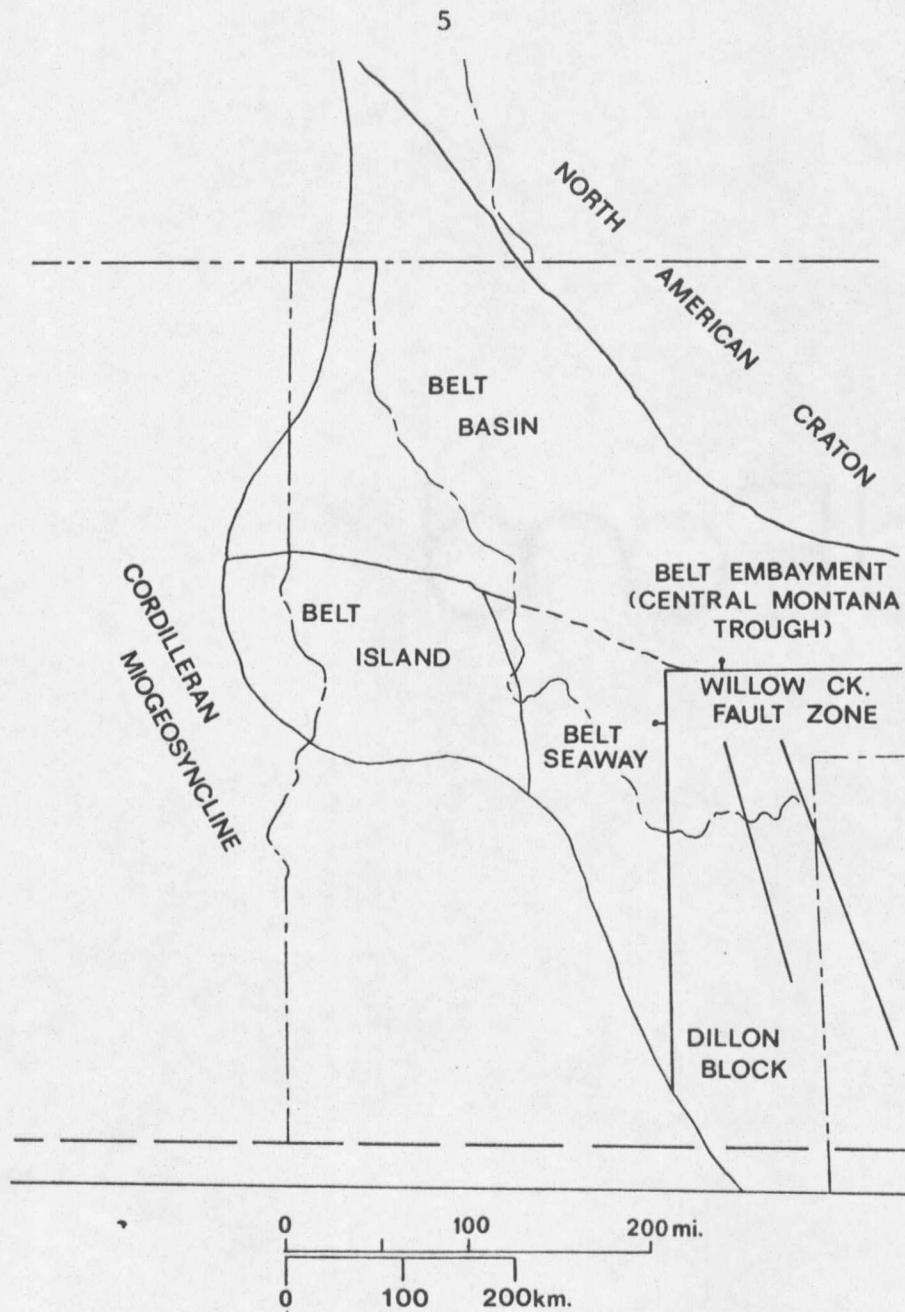
Figure 2. Tectonic elements of the Belt Basin and pre-Belt
crystalline rocks. Bar and ball indicate the down-
dropped side of a normal fault. Modified from
Bonnet (1979).

parallel the trend of the Belt embayment and the Willow Creek fault zone, suggesting that reactivation of major Precambrian zones of weakness controlled Paleozoic sedimentation (Fig. 3)(Sloss, 1950; McMannis, 1965; D. Winston, in press).

Based upon similarities in structural trends, various authors (Sloss, 1950; McMannis, 1965) have postulated that major faults and fault zones in the area of the Tobacco Root Mountains and the Bridger Range are related to the Nye-Bowler lineament of Wilson (1936). Roberts (1972) has postulated that the Nye-Bowler line-ament, and other lineaments such as the Lake Basin-Huntley trends, are Laramide structural features that may represent reactivated Precambrian structures.

Stratigraphy

The Sauk sequence (Sloss, 1963) was deposited on the shelf and western edge of the North American craton during the eastward transgression of the Cambrian sea. The sequence is a transgressive-regressive package of rocks consisting of a basal sandstone and three shale/ limestone repetitions with minor interbedded siltstone and sandstone. In the Bridger Range, these rocks are represented by the Flathead Sandstone, Wolsey Shale, Meagher Limestone, Park Shale, and the Snowy Range Formation which consists of the Dry Creek Shale and the Sage Pebble Conglomerate (Figs.4 and 5).
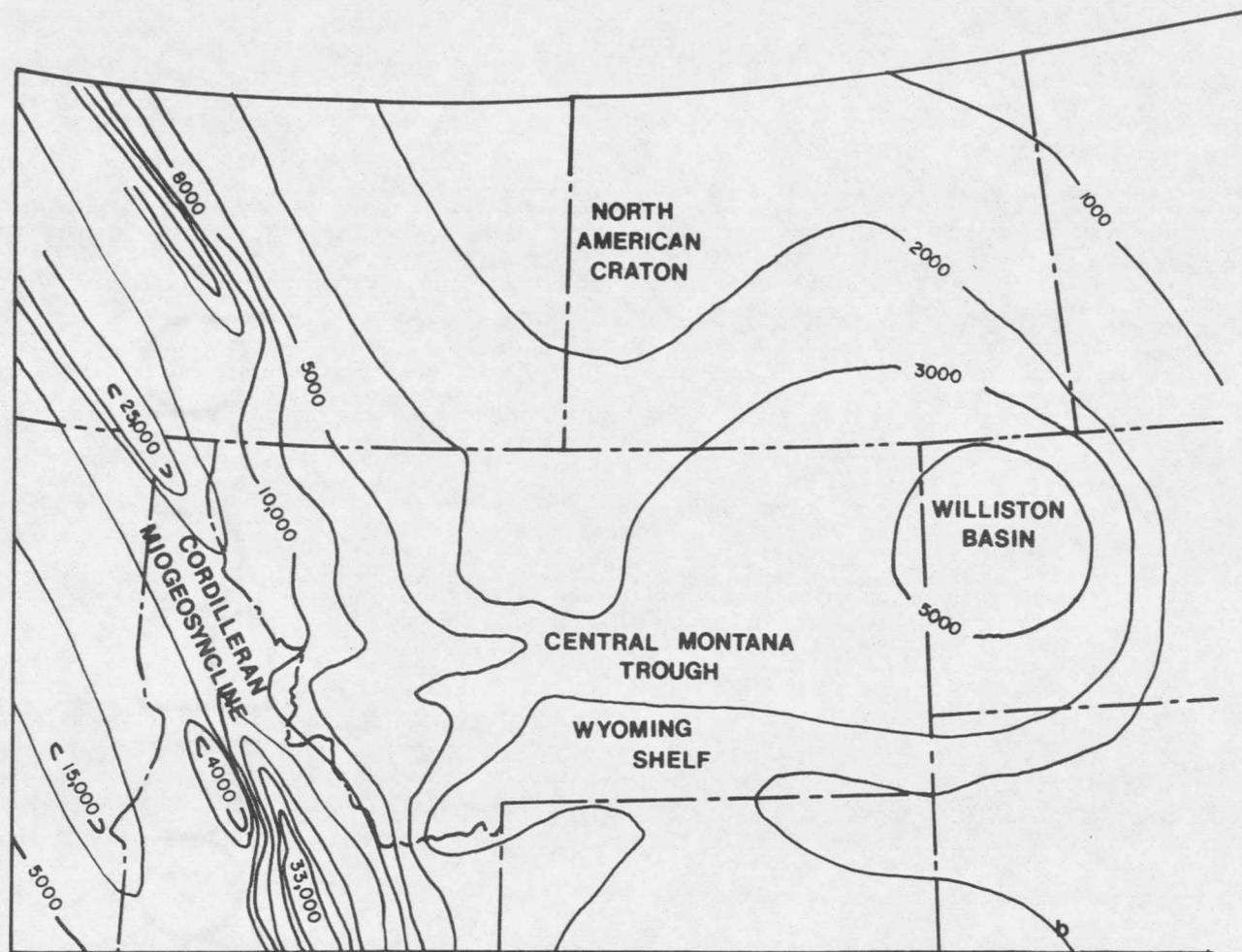
Figure 3. Thickness of Paleozoic strata, shown by generalized isopachs.
Modified from Sloss, 1950.
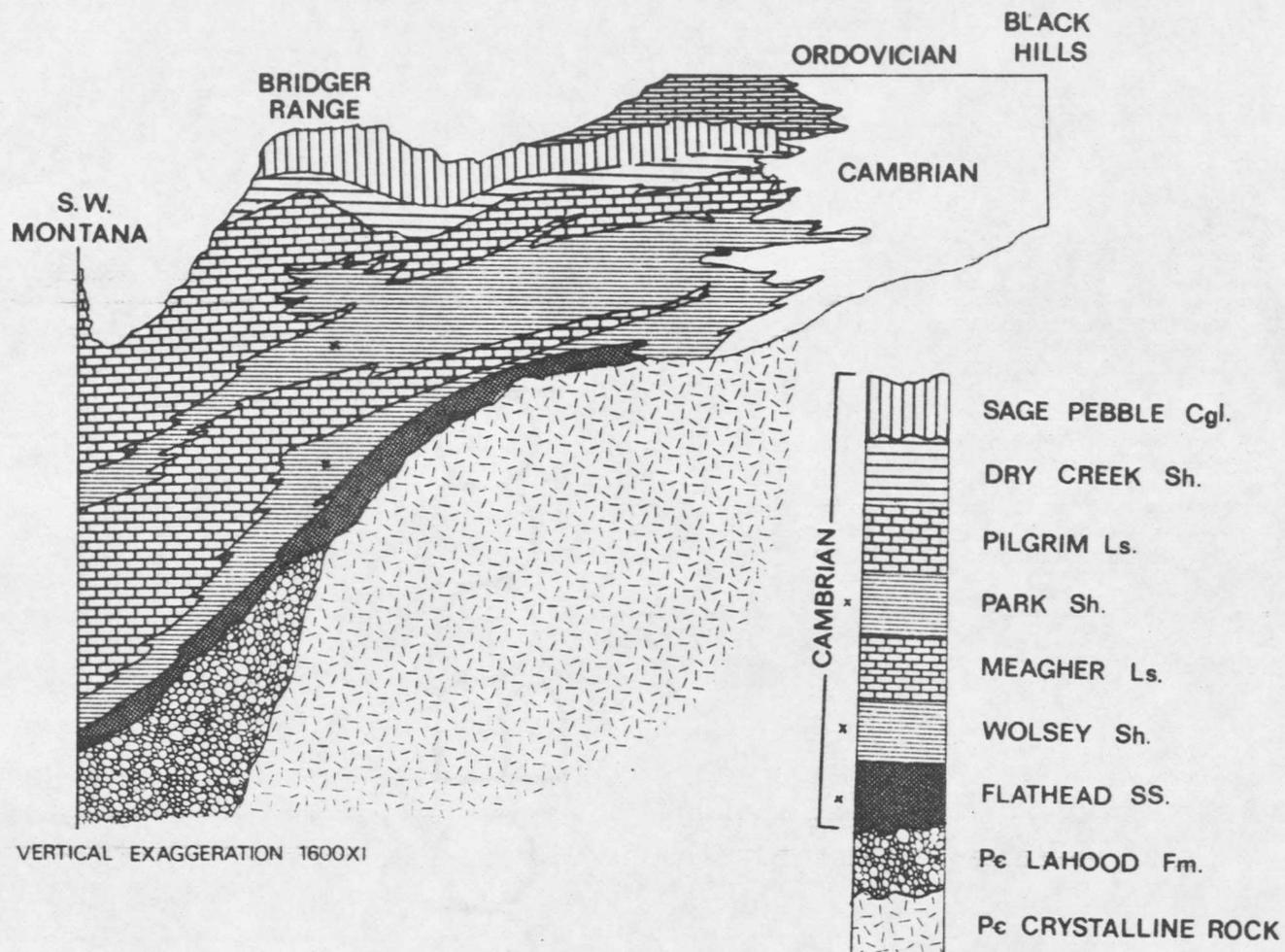
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            feldspar-rich intervals. Modified from Lochman-Balk, 1972.
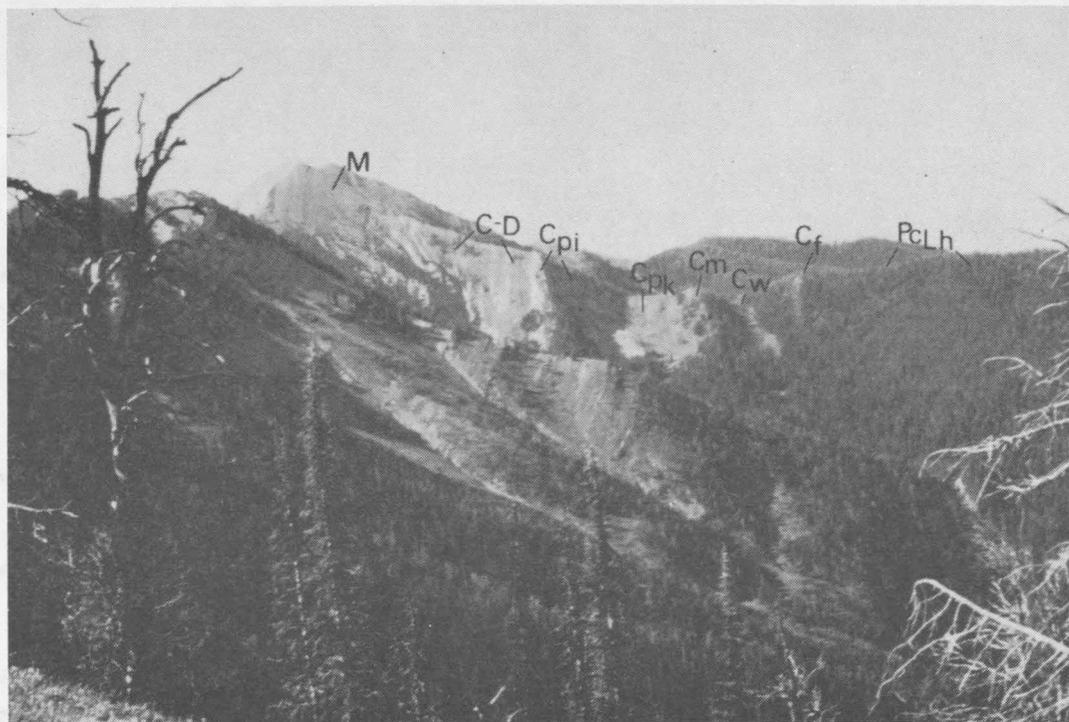
Figure 5. Stratigraphic units exposed on the west flank of the Bridger
Range. View is to the south at Saddle Peak.

$P_{\epsilon lh}$: LaHood Fn ϵ_m : Meagher Limestone
ϵ_f : Flathead Sandstone ϵ_{pk} : Park Shale
ϵ_w : Wolsey Shale ϵ_{pi} : Pilgrim Limestone
                                        D/M: Devonian-Mississippian rock

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The Cambrian sea transgressed over an irregular post-Belt/pre-Flathead erosional surface (Lochman-Balk, 1972). Topographic highs became islands, generating point sources of clastic detritus and greatly influencing local sedimentation. The influence of the islands on sedimentation is seen in the stratigraphic record as abbreviated or thickened sections, or as lithologic variations such as arkosic sandstone occurring within a shale.

Graham and Suttner (1974) have documented such lithologic and thickness variations in the Flathead Sandstone and the Wolsey Shale near Three Forks, Montana, about 64 km west of the study area (Fig. 1). The Three Forks island complex is a group of at least three islands composed of Belt arkose. The most prominent of the group is the Milligan Canyon island; the Jefferson Canyon and Highway 10 islands are smaller and of lesser relief (Graham and Suttner, 1974). Stratigraphic relations at Milligan island best demonstrate the islands' influence on sedimentation during Middle Cambrian time. Here, the Flathead Sandstone is absent at the crest of the island and thickens progressively west and east. The Flathead is also absent at the Jefferson Canyon and Highway 10 islands. At the Highway 10 island, the Meagher/Wolsey contact is less than 3 m above the middle limestone of the Wolsey, indicating a dramatically thinned section (Graham and Suttner, 1974).

When not directly adjacent to an island in this area, the Flathead Sandstone and Wolsey Shale lack arkosic sandstone. In the Three Forks area, the Flathead is a moderately well-sorted, medium-to coarse-grained, silica-cemented sandstone. The Wolsey is a grey-green, fossiliferous, fissile, micaceous shale. Silty and intraclastic limestone occurs in the upper Wolsey and a thin, basal quartz arenite associated with siltstone beds is common. A prominent, thinly bedded, silty limestone occurs in the middle of the formation and varies in thickness from 2-30 m. This is the Silver Hill limestone of the Wolsey Shale (Hanson, 1952; Graham and Suttner, 1974).

Adjacent to the islands, the Flathead is arkosic and conglomeratic and Wolsey limestone beds contain abundant feldspar and quartz. Graham and Suttner (1974) identified three genetic types of sandstone: (1) products of incomplete reworking of a residual soil which developed on the Belt arkoses during post-Belt/pre-Flathead weathering and erosion, (2) products of limited transport, and (3) winnowed lag deposits.

The influence of islands or topographic "highs" on Cambrian sedimentation has also been described by Hanson (1952), Alexander (1951), Mann (1950), Robinson (1963), McMannis (1963), and LeBauer (1964). LeBauer, in his study of the Wolsey Shale, postulated the presence of small, topographically low islands composed of Belt

sedimentary rock, Precambrian gneiss and marble. The islands were located in or near the Bridger Range, Pole Canyon, and Cottonwood Canyon areas (Fig. 1). Other Cambrian islands have been described in Wisconsin by Dott (1974) and in Arizona by McKee (1945).

STRATIGRAPHY OF THE PARK ARKOSIC INTERVAL

The arkosic sandstones of the Park Shale are restricted to the lower 30 m of the formation (Fig. 6). Arkosic sandstone beds occur sporadically throughout this interval with the stratigraphic separation between beds or lentils increasing upsection. Grain size and ratio of detrital grains to carbonate cement also decreases upsection. This results in a lithologic change from a calcareous, arkosic sandstone near the bottom of the interval to feldspathic limestone near the top. The arkosic sandstone interval of the Park Shale consists of two major facies: (1) a quartz/orthoclase-rich facies with locally developed flat-pebble conglomerate, and (2) a calcareous, fossiliferous, arkosic, glauconite-rich sandstone (Figs. 7 and 8).

The arkosic interval of the Park is limited to the northern half of the Bridger Range, extending from Morrison Canyon to Dry Creek Canyon (Fig. 8). Outcrops of both facies occur sporadically along strike due to a combination of poor exposure and original areal distribution. In Fig. 7, Sections 14 and 15 represent the northern and southernmost occurrences of arkosic sandstone. Section 1 is the "type location" of the Park arkosic sandstone.

Major beds (5-17 cm thick) of the quartz/orthoclase-rich facies occur at North Cottonwood Creek, Mill Creek, Hardscrabble, and

Calcareous, fossiliferous, arkosic glauconitic sandstone; weak cross-stratification formed by clastic component; composite pebbles common; fossils are found in large carbonate blocks.

Massive, poorly sorted, calcarous quartz-orthoclase-rich sandstone with very minor interbeds of shale and calcareous arkosic glaucontic siltstone, symmetrical ripple marks and "burrow"-like structures occur locally on upper surface of bed.

Figure 6.   Composite stratigraphic profile of the Park Shale arkosic interval.
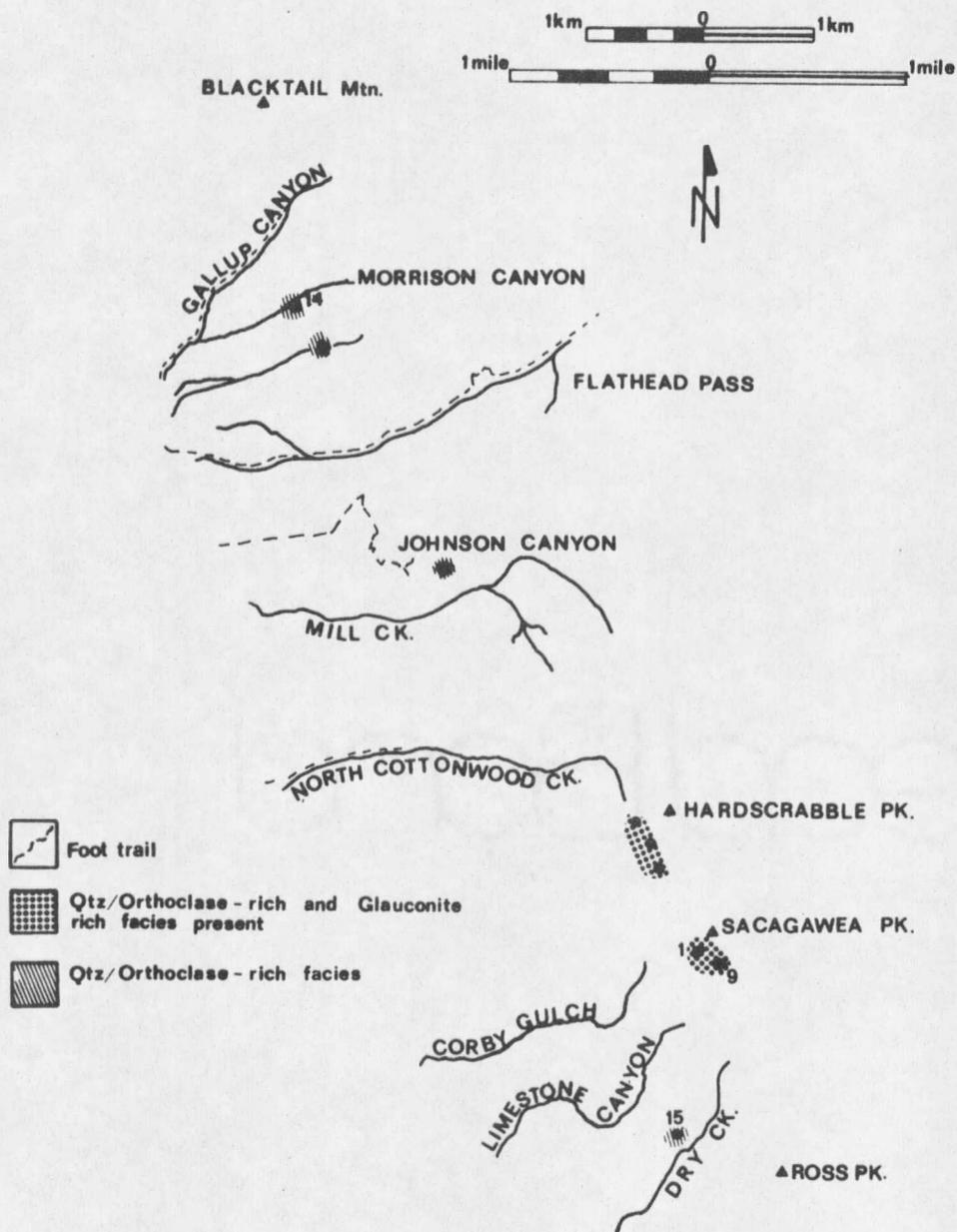
Figure 7.   Distribution of th quartz/orthoclase-rich and glauconite-
rich sandstone in the northern Bridger Range. Dots repre-
sent measured sections or areas of arkosic sandstone
float.
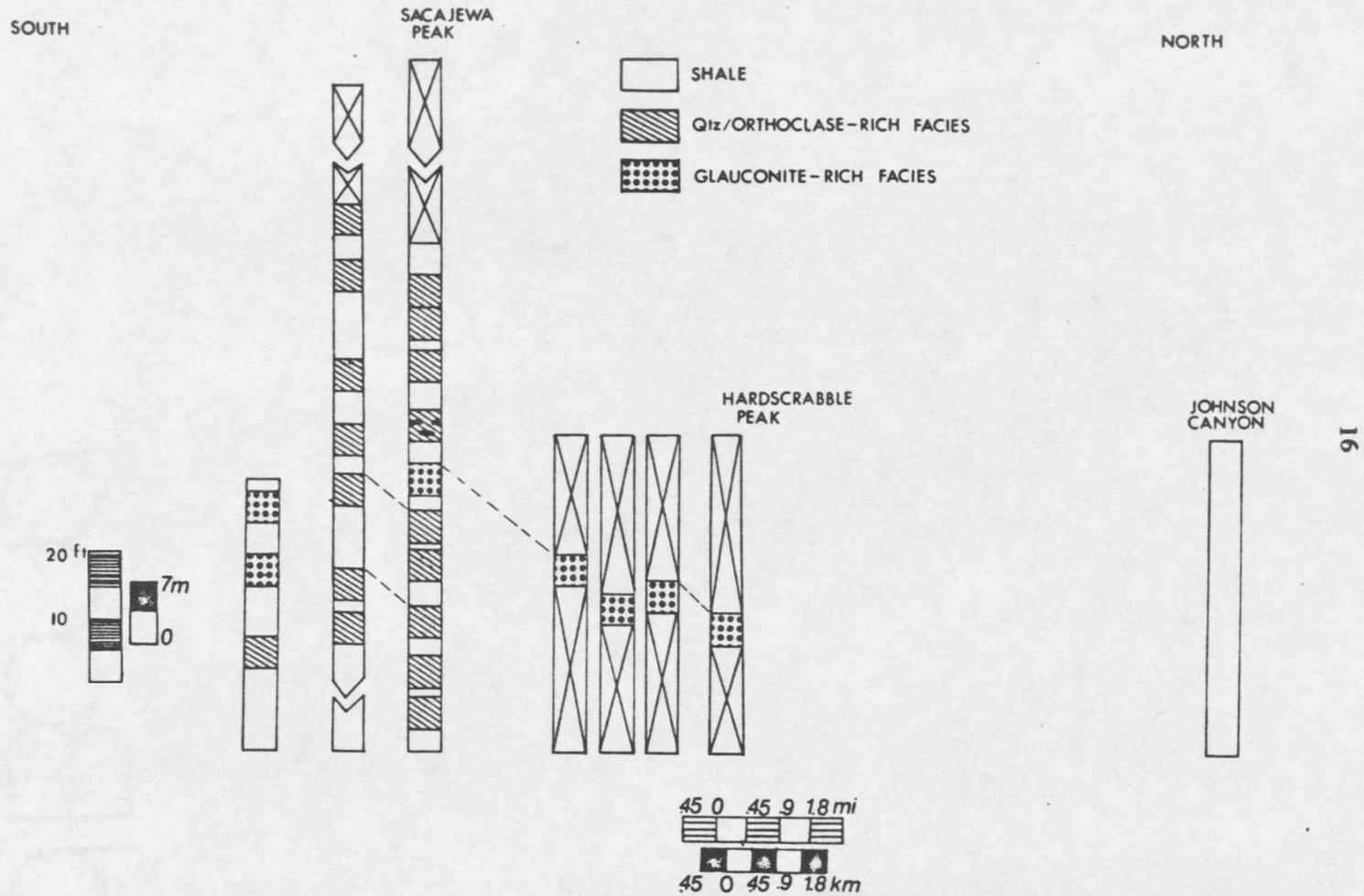
Figure 8. Location and correlation of sections, northern Bridger Range.

Sacajawea peaks. South of Sacajawea Peak, the quartz/orthoclase-rich facies, which is characterized by bright, salmon-pink feldspar, seems to pinch-out and disappear. At the South Meadow section (Section 9, Fig. 7), the arkose is characterized by large, white grains of feldspar, quartz, and an abundance of chlorite-rich matrix. This section is designated as subfacies A and will be discussed in conjunction with the general part of the facies.

In contrast to the quartz/orthoclase-rich facies, the glauconite-rich facies occurs only between Hardscrabble and Sacajawea peaks and is restricted to the lower portion of the arkosic interval. The exact stratigraphic position of the facies is undetermined due to poor exposures. Glauconite-rich intervals, however, are found to the south in the Gallatin Range and to the west in the Horseshoe Hills (Verrall, 1952; McMannis, 1964; McMannis and Chadwick, 1964). Although the clastic component of the facies is absent in both of these locations, the greater areal distribution of glauconite suggests that the depositional environment of the facies was fairly widespread.

In both cases, the basal contact of an individual sandstone bed or lentil with the underlying shale is generally abrupt and planar to undulatory. However, the base of the glauconite facies is usually characterized by a basal lime layer which varies in thickness from 1-5 cm and which is restricted to this facies. The limestone is

cream-colored and may show faint laminations or cross-stratification. The contact between the limestone and the glauconite-rich part of the facies is sharp and abrupt, even though local channeling occurs (Plate 1, A). The upper contact of a bed or lentil in either facies is abrupt. Upper surfaces of beds may or may not have a very thin coating of olive-green, micaceous shale. This coating is pervasive in the glauconite facies and poorly preserved in the quartz/ orthoclase-rich facies.

A. Handsample of the glauconite-rich facies collected by C. Lochman-Balk and W. J. McMannis, 1949. Note the slight imbrication of carbonate intraclasts in the upper half of the sample. Also note the abrupt contact at the top of the basal lime layer and the truncation of the burrow on the right hand side of the sample.

B. Handsample of the quartz/orthoclase-rich facies. Note the large vein-quartz grain in the lowermost right hand corner of the sample and the angularity and very poor sorting of the laminated, silty carbonate intraclasts and detrital grains.

C. Ovate and fragmented burrows on the upper surface of an arkosic, fossiliberous carbonate lens. Sample from the upper part of the arkosic interval, Park Shale, Sacajawea Peak section.

D. Fragmented, branched burrows associated with feldspar, and vein quartz, and fossil debris. Sample from the upper part of the arkosic interval, Park Shale, Sacajawea Peak Section.

E. Laminated, micaceous, "U-shaped" load structure in the quartz/orthoclase-rich facies at the North Cottonwood section. Note the displacement of shale due to loading and the fissile character of the siltstone at the bottom and top of the structure.

F. Quartz/orthoclase-rich lens at the North Cottonwood section. Note the "ripple-like" basal contact of the lens due to loading and displacement of the underlying shale. The lens has become segmented due to soft sediment boudinage.

PLATE 1

A

B

C
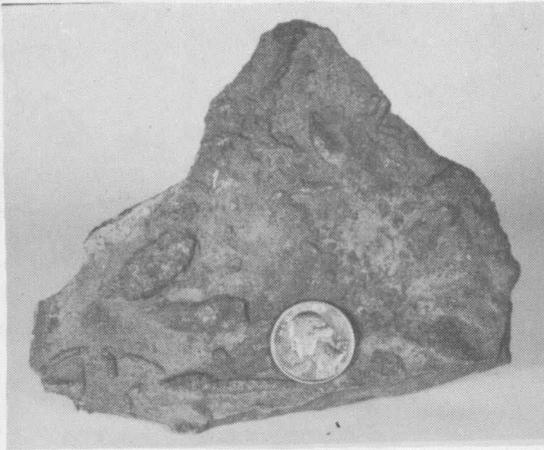
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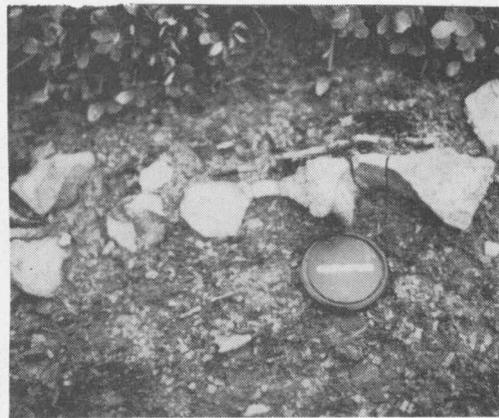
LITHOLOGY OF THE PARK ARKOSIC INTERVAL

The relative percentages of mineral constituents in each facies were estimated in thin section using grain percentage charts from Compton (1962). Several assumptions were used in estimating mineral percentages. These are: (1) grains with well developed, pervasive iron oxide-clay coats, exhibiting a definely biaxial interference figure, without twinning, were counted as orthoclase, (2) if a grain seemed to exhibit a biaxial interference figure, but had moderate to strongly undulose extinction and lacked cleavage, it was counted as a quartz grain, (3) if a grain was 1 mm or larger, and composed of quartz, chlorite and feldspar stained by iron oxide, it was counted as a composite grain. These composite grains were distinguished from other lithiclasts due to their mineralogical similarity with composite pebbles (2 mm - 2 cm), (4) If a composite grain consisted of quartz, unstained feldspar, and lacked chlorite, it was counted as a lithiclast.

Estimates of mineral percentages were double-checked by using the staining technique proposed by Bailey and Stevens (1960) which stains K-feldspar yellow and plagioclase red. The percentage of lithiclasts and intraclasts, in both facies, was based on combined field and petrographic estimates. Field estimates of these percentages may have been low as the majority of the lithiclasts were

A. "Burrow-like" structures present on the upper surface of a quartz/orthoclase-rich bed at the Sacajawea Peak section. These might possibly be burrow systems such as Tholassinoides.

B. Handsample of the glauconite-rich facies. Note the small channel in the basal lime layer and very faint cross-stratification.

C. Photomicrograph of the glauconite-rich facies in thin section, plane light, 1x magnification. A: glauconite, B: Girvanella, C: quartz grain.

D. Photomigrograph of the quartz/orthoclase-rich facies in thin section, crossed nicols, 1x magnification. Note the angularity and poor sorting of grains. A: quartz, B: perthitic microcline, C: orthoclase grain with iron oxide-clay coating.

E. Photomicrograph of composite pebble #1, plane light, 1.2 x magnification. Note the angularity and poor sorting of grains. Darker interstitial grains are chloritized mafic minerals.

F. Composite pebble #5, plane light, 1.2 x magnification. Note lineation of quartz grains.

PLATE 2

A
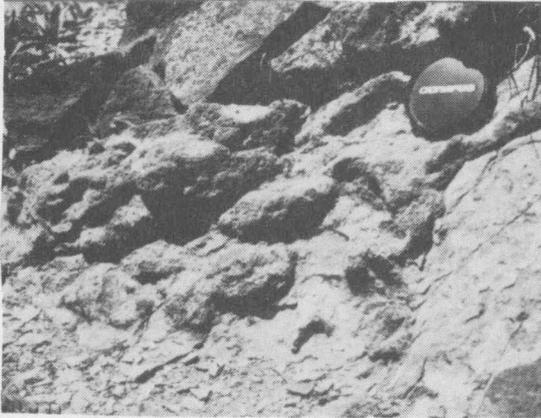
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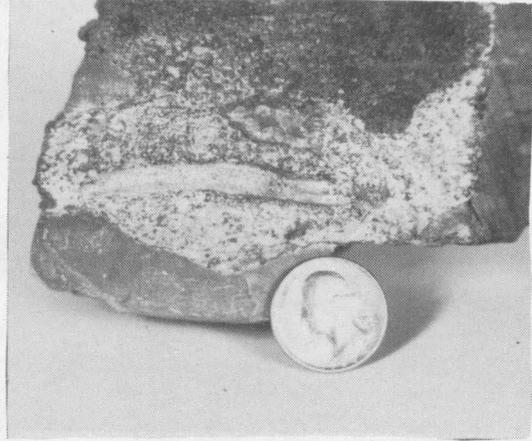
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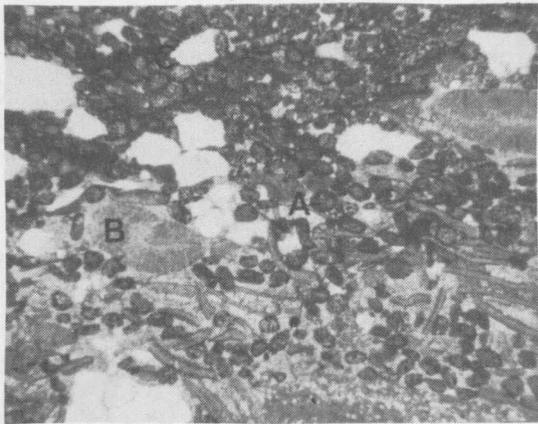
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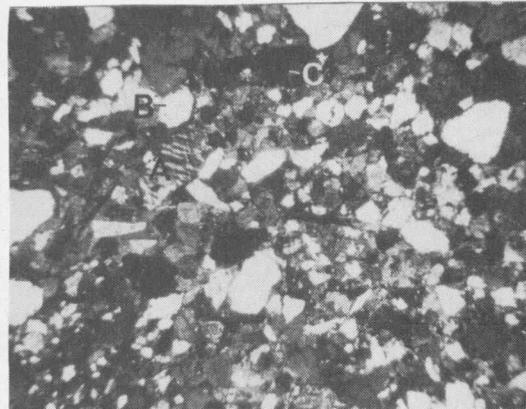
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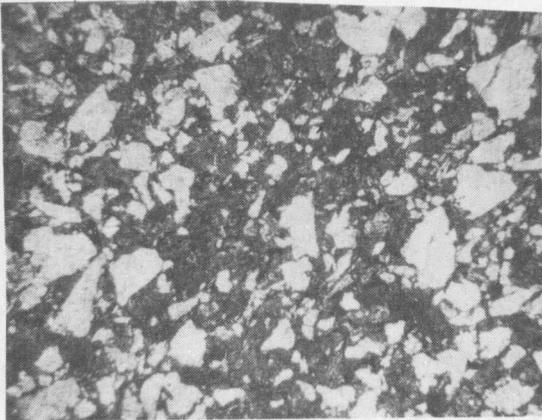
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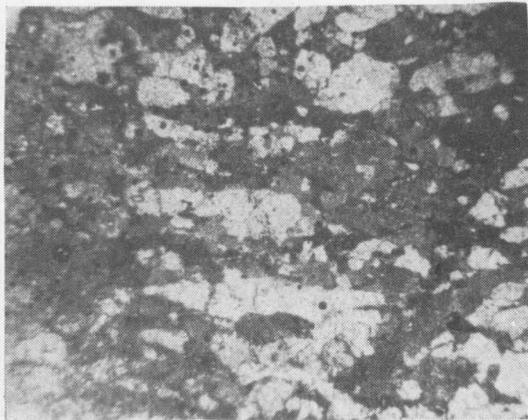
small and most easily recognized in thin section. In addition, poor field exposures of bth facies hindered accurate estimations of lithiclast and intraclast percentages. As a result, the percentages for both of these constituents may be low.

Due to poor exposures of both facies, the reader should bear in mind that the lines of evidence for each facies must be viewed collectively in order to support each interpretation.

The lithology of the Park arkosic sandstones will be discussed in two sections. The first section describes the quartz/orthoclase-rich facies, the second describes the glauconite-rich facies. Each section consists of five main parts: (1) constituents, (2) sedimentary structures, (3) soft sediment deformation, (4) facies geometry and (5) interpretation of facies characteristics.

Quartz/Orthoclase-Rich Facies Description

General

Constituents. On the average, the quartz/orthoclase-rich facies is composed of 36% sparry calcite cement, 3% fossil debris, 7% carbonate intraclasts, 14% composite grains, 5% lithiclasts, 10% matrix and glauconite, and 34% detrital grains. Of the total detrital percentage, quartz averaged 56%, orthoclase 25%, microcline 8%, plagioclase 6%, and chlorite 5% (Plate 2, D). Mafic minerals, occurring as free detrital grains, are rare.

Quartz grains range in size from less than 0.3 mm to 3 mm, averaging 0.8 mm in diameter. Rounding and sorting of grains is fairly poor. Rounded to well-rounded grains are present. Undulose extinction is common and varies from slight to strong. Pitted, fractured, and gouged grains are common. Light grey, amorphous clay (?) coatings are often found on grain surfaces. More rarely, iron oxide and chlorite patches or rims occur on quartz grains.

Of the feldspar grains present, orthoclase is by far the most abundant. Grains average 0.7 mm in diameter and are angular to subangular. Sorting is fair. Large, individual grains of orthoclase are less common than quartz or microcline grains of the same size. Perthitic microcline ranges from less than 0.3 mm to 6 mm, averaging 0.8 mm. Grains are irregular to subrounded and sorting is moderately poor.

Plagioclase grains are moderately sorted, average 0.8 mm in diameter and are angular to subangular. Untwinned grains are common, and twinning, when present, is poorly developed. Due to poor twinning, few estimates of anorthite content were made. However, estimates that were made ranged from 10-28% AN, indicating albite and oligoclase.

The feldspars of this facies show three major types of alteration: (1) iron oxide staining associated with a clay coating, (2)

clay coatings unassociated with iron oxide, and (3) embayment and replacement of grains by calcite. Orthoclase grains usually show the greatest degree of alteration and are characterized by strongly developed iron oxide-clay "coats." The clay coating itself is dark gray and speckled in appearance. In thin section the iron oxide is typically a deep, dark red and forms a second coat on top of the clay coating. Small "windows" or patches where iron staining is absent may be present towards the interior of the grain. In several thin sections, a second generation of iron oxide staining may be represented by small, red-gold flecks. The flecks occur on top of the dark red clay coats and are, in turn, covered by a lighter coating of iron oxide. The gold, sparkly color may be due to calcium carbonate occurring as a later alteration product.

Plagioclase and microcline, in comparison to orthoclase, are relatively free of well developed iron oxide-clay "coats." These grains are characterized by iron oxide halos which occur around grain edges or as patches concentrated on fracture or cleavage planes in the grains. Poorly developed iron oxide coats are present on some plagioclase grains and well developed coats on plagioclase grains are rare. In general, plagioclase and microcline grains have a cloudy appearance due to weakly developed, light gray clay coatings.

The dark, speckled clay coats, which are characteristically associated with orthoclase grains, are absent. The genesis of the iron oxide coatings and possible sources of iron will be discussed under provenance of the arkosic sandstones.

Calcite usually occurs as small flecks on a grain surface, as veinlets exploiting cleavage planes or fractures in a grain, embayments along a grain margin, or as cement. Total replacement of grains by calcite is not common.

Limestone intraclasts and lithiclasts are minor constituents of the facies. The intraclasts occur at North Cottonwood Creek, Hardscrabble Peak and Sacajawea Peak. The major constituents of the intraclasts are angular, silt-sized quartz and feldspar grains, sparry calcite cement, iron-stained, comminuted trilobite debris and mica grains. Meta-quartzite rock fragments comprise the bulk of the lithiclasts in the facies. These fragments show little alteration and often display well developed lineation of quartz grains. Fragments of marble and siltstone are rare.

Composite grains average 1.4 mm in diameter. Sorting is fair and grains are angular to subangular. The alteration characteristics of quartz and feldspar in these composite grains are the same as those discussed earlier. Chlorite occurs as a rim, patch or as a replacement of iron-magnesium silicates.

Sedimentary Structures. Symmetrical and interference ripple marks, imbrication of intraclasts, groove casts, and burrows are the characteristic sedimentary structures of the quartz/orthoclase-rich facies. Symmetrical ripple marks range in wavelength from 1-45 cm and in amplitude from 4 mm-5 cm. The amplitude and wavelength of the interference ripples were not measured because ripple crests were eroded (Plate 3, E and F).

Intraclasts are found either in an edge-wise fashion or slightly imbricated and occur at all four major outcrops of the facies. Weakly developed groove casts and other unidentifiable sole markings are present on the bottom of fissile, silty, micaceous siltstone beds, which occur as small interbeds or lenses in the upper part of the arkosic interval.

Burrows are branched or ovate in form (Plate 1, C and D). The burrows, which are associated with trilobite debris and silt-to sand-sized grains, occur as fragments on tops of beds. They also occur in lenses which are often found as pieces of float. The Sacajawea section is the only location where these burrows occur and they appear to be restricted stratigraphically, in the vertical sense, between 9.6 - 11.3 m. The burrows are associated with a decrease in the size of detrital constituents and increases in fossil debris and carbonate content.

A. Composite pebble 7. 1.2 x magnification, crossed nicols.
   Note the clastic texture of the pebble. Smaller grains
   form a matrix which occurs between the larger grains.

B. Composite pebble #11, crossed nicols, 1.2 x magnification.
   A: perthitic microcline, B: quartz, C: carbonate cement.

C. Subfacies A of the quartz/orthoclase-rich facies, south
   Meadow section. Note arkosic sandstone interbeds.

D. Subfacies A of the quartz/orthoclase-rich facies. Note
   the lenticular and wavy bedding composed of quartz and
   unstained feldspar. Note deformed pod in upper left
   hand corner of the photograph.

E. Eroded symmetrical ripple from the North Cottonwood section.
   Note cross-stratification in overlying, calcareous silt-
   stone.

F. End on view of eroded symmetrical ripple (Fig. E). Note
   smaller symmetrical ripples and overlying cross-stratified,
   calcareous siltstone.

PLATE 3

A
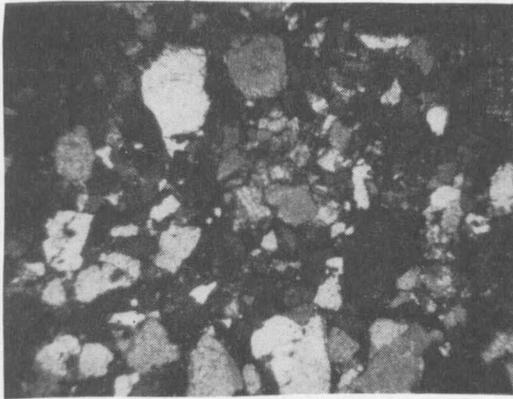
B
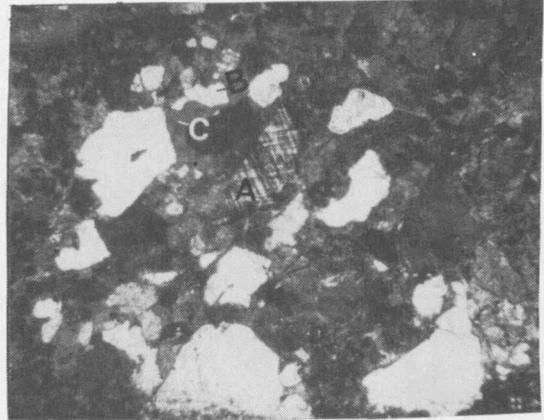
C

D

E

F
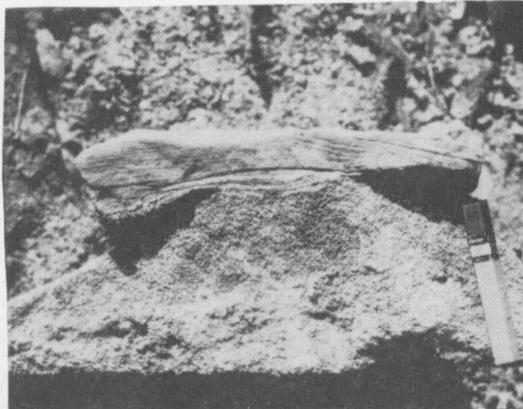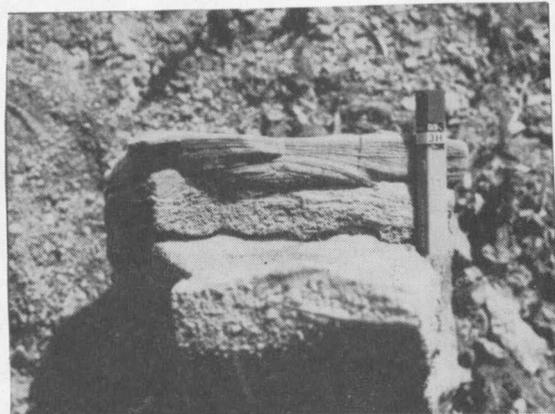
<u>Soft-Sediment Deformation Structures</u>. Soft-sediment deforma-
tion structures are not abundant in the facies but are present in
both the arkosic sandstone and associated micaceous siltstone. Soft
sediment deformation was due to loading as the weight of the silt or
sand displaced the underlying shale. These structures are present
only at the North Cottonwood Creek section.

Load structures in the micaceous siltstones are "U"-shaped or
of a chevron fold style. "U"-shaped load structures are up to 12 cm
wide and 7 cm deep (Plate 1, D). Fold structures are rare and may
contain shale trapped between fold limbs.

Structures in arkosic sandstone beds differ from those in
micaceous siltstone. Basal contacts of load structures in several
lenses of arkosic sandstone are very undulatory, producing a "ripple-
like" structure (Plate 1, F). Similar "ripple-like" structures
occur in the glauconite facies and their origin will be discussed
under interpretation of glauconite facies characteristics.

"Burrow-like" structures are present in both facies. However,
in the quartz/orthoclase-rich facies, these structures are present
only at the Sacajawea Peak section. Burrows are up to 18 cm long,
5 cm wide, and .6-1.3 cm in height (Plate 1, A). C. W. Bradley
(1981 pers. comm.) thought these structures might <u>possibly</u> be burrow
systems such as <u>Tholassinoides</u>, but expressed some doubt as to

whether or not the structures were truly organic in origin. The main argument against an inorganic origin is that the "burrows" occur on the top of the arkose bed. This eliminates the possibility that these "burrows" are actually load structures. However, trilobite of the size required to make such large burrows are not known from the Park Shale. Perhaps these "burrows" were made by soft bodied organisms which have not been preserved.

Facies Geometry. Beds of the quartz/orthoclase-rich facies generally are lenticular. The largest (5-17 cm) and laterally most persistent beds eventually pinch-out along strike. The laterally most persistent bed in the facies was traced 26.5 cm. Smaller lentils are common, especially in the upper part of the arkosic interval at the Sacajawea Peak section. These smaller lentils vary from .5-6.8 cm in thickness and vary in length.

Subfacies A

Subfacies A is found only in the South Meadow area, south of Sacajawea Peak (Plate 3, C). The subfacies is recognized on the basis of: (1) a decrease in the percentage of salmon-pink feldspar, (2) the fairly regular occurrence of arkosic beds in the section, (3) a significant decrease in the percentage of carbonate cement, resulting in a grain-supported sandstone, (4) the presence of chloritic matrix, and (5) tidal and lenticular bedding.

Constitutents. Estimates, based on stained handsamples, aver-
aged 53% quartz, 37% K-feldspar, 2% plagioclase, 5% matrix, and 3%
carbonate cement. Sorting of the grains is very poor and they are
slightly larger and more angular in comparison to the clastic com-
ponent of the two major facies.

Sedimentary and Soft Sediment Deformation Structures. Wavy and
lenticular bedding, and soft sediment deformation structures are
present only in the lower 3 m of the measured section (Plate 3, D).
The ripples and sand lenses consist of angular to subrounded quartz
and feldspar grains which lack iron-staining. Individual lenses may
be laminated. Deformed lenses and pods are fairly common, indi-
cating that slumping and soft-sediment boudinage occurred soon after
deposition.

Interpretation of the Quartz/Orthoclase-
rich Facies

Seven major characteristics summarize the petrologic and strati-
graphic relations of the quartz/orthoclase-rich facies. These are:

(1) general paucity of broken fossil debris

(2) trace amounts of glauconite

(3) paucity of sedimentary structures

(4) weakly stratified, imbricated intraclasts

(5) lateral discontinuity of arkose beds

(6) abrupt and sporadic occurrence of arkose

(7) abrupt contact with enclosing shale.

These characteristics suggest deposition in a shallow-water, current-agitated, near-shore island (point source) complex (Fig. 9). The abrupt contacts of the arkosic sandstone with the enclosing shale, their lateral discontinuity and sporadic occurrence suggest periods of catastrophic sedimentation. These periods were followed by a rapid return to conditions favoring mud sedimentation.

The general lack of glauconite and fossil debris, and the presence of sparry calcite cement suggest deposition in a current-agitated environment. Glauconite forms in an environment where there is an abundant source of organic matter, little or no influx of clastic debris and carbonate sedimentation is dominant (Bentor and Kastner, 1965; and McRae, 1972). A slightly reducing environment is thought to enhance the development of glauconite (Cloud, 1955; McRae, 1972). The near absence of glauconite in itself does not imply current-agitated conditions in the depositional environment. However, the comminuted fossil debris that is present suggests that, in the area of the point source, biologic communities were poorly developed and that the current and/or wave energy was high. In such an agitated environment any organic matter or fine-grained sediment being transported by currents would not have been deposited. In

ARKOSE

PARK SHALE

FLATHEAD, WOLSEY, MEAGHER

MIDDLE CAMBRIAN (FLATHEAD-PARK)

PRECAMBRIAN CRYSTALLINE ROCK

WEATHERED ZONE
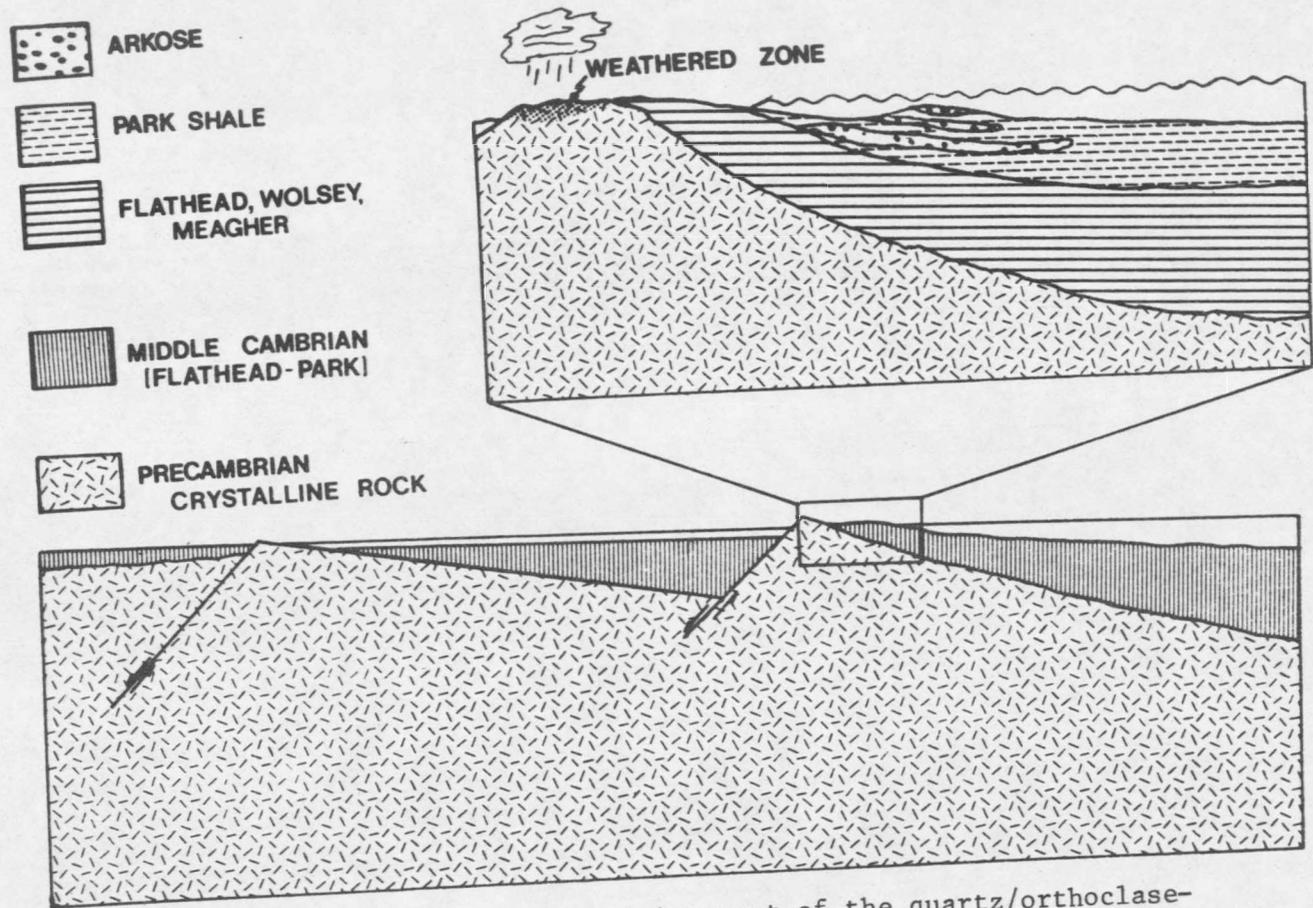
Figure 9. Hypothesized depositional environment of the quartz/orthoclase-rich facies.

addition to keeping fine-grained sediments and organic matter in
suspension, current agitation would have maintained oxygenated
waters, prohibiting the development of reducing conditions and the
formation of glauconite.

A glauconite forming environment associated with, but located
at some distance from, the shoal-intershoal complex during the
deposition of the lower part of the facies, is indicated by traces
of glauconite in several samples. In addition, a thin interbed of
glauconite occurs in association with a major quartz-orthoclase
sandstone bed at Sacajawea Peak. At some distance from the shoal-
intershoal complex or complexes,the current/wave energy would have
been less and the influx of clastic debris little or absent, gener-
ating environments favoring glauconite formation. Erosion and trans-
portation of the glauconite into the clastic sedimentary environment
may have been due to storm generated currents.

The presence of ripple marks, intraformational conglomerate, in
addition to tidal and lenticular bedding, support the hypothesis of
a shallow-water depositional environment and demonstrate the influ-
ence of tides and other currents (Lochman-Balk, 1970; Reineck and
Singh, 1975; Sepkoski, 1981). The laminations of the intraclasts,
which are formed by trilobite debris and micas stained by iron
oxides, are similar to those found in beach sands (Reineck and

Singh, 1975). Reineck (1963) proposed that the laminations were due to the swash and backwash of waves on a beach. The borders of the intraclasts are relatively undeformed and, in some cases, may be partially armored by grains of quartz and feldspar.

The lack of strongly deformed intraclasts suggests that partial lithification of the sediment took place prior to erosion and rede position. Such flat-pebble conglomerates are very common in early Paleozoic strata and are thought to have formed when major storms eroded and re-deposited partially lithified sediments (Lochman-Balk, 1970; Pettijohn, 1975; Sepkoski, 1981).

The wavy and lenticular bedding, is perhaps, the best evidence of wave and current energy alternating with slack water conditions in the vicinity of the shoal-intershoal complexes and are representative of bed types found in mixed tidal flats (Reineck and Wunderlich, 1968; Reineck and Singh, 1975). After the first 4 m in the South Meadow section, the outcrop is characterized by arkosic sandstone beds which occur at 4.3 m, 6 m and 7.6 m. In comparison to a typical outcrop of the facies at other locations, these beds occur at fairly regular intervals. In conjunction with the tidal and lenticular bedding, this sequence may represent a mixed tidal flat over which a channel later migrated. The regular occurrence of arkosic sandstone beds may indicate that this area was, for a period

of time, one of the major channels or mixed tidal flats dissecting the shoal-intershoal complex or complexes.

Similar situations occur at Sacajawea Peak, Hardscrabble Peak and the North Cottonwood sections (Fig. 8). At these locations the quartz/orthoclase-rich beds exhibit significant thickness, and lateral continuity, and dominate the arkosic interval of the Park. This suggests that these areas may have been key sediment dispersal routes. It is important to note that only lentils or very small, discontinuous beds occur between major outcrops.

The abrupt and sporadic appearance of the arkosic sandstones, their abrupt contacts with the enclosing shale, and the lateral discontinuity of the beds are the result of catastrophic and rapid sedimentation. During Park time, mud was the dominant mode of sedimentation, representing quiet water deposition in a tectonically stable, marginal-shelf environment. The sporadic occurrence of arkose denotes spasmodic tectonism, disruption of the stable, marginal-shelf environment, and the rejuvenation of a clastic point source.

The abrupt, flat to slightly undulose basal contacts, lateral discontinuity of beds, and locally wave-rippled tops of beds are characteristic of storm-deposited, sublittoral sheet sandstones (Goldring and Bridges, 1973; and Kreisa, 1981). According to J. Parrish (1981 pers. comm.), southwestern Montana was located near

20°N latitude in Middle Cambrian time, placing it in the trade winds belt (Fig. 10). Seasonal storms were major sediment movers in this belt as documented by Dott (1974) and Kreisa (1981). During such storms, the strong surge currents and waves needed to transport sand out onto the shallow, open marine shelf are generated. Sand suspended in these currents would be transported seaward by the return flow of the current, far past the usual depositional environment. These mechanisms of sediment transport have been invoked by Reineck and Singh (1972) to explain thin, laminated sheet sands in the North Sea and by Hayes (1967) in his work on Gulf coast sediments. Hayes described sands up to 9 cm thick which were deposited on homogeneous muds in water depths between 16-23 m. The grossly lenticular arkosic sandstone beds of the Park may have been deposited in this manner.

The abrupt upper contact of the sandstone beds represents a relatively rapid return to mud sedimentation, following deposition of the arkosic sands. Symmetrical ripple marks at North Cottonwood Creek and Sacajawea Peak indicate reworking of the sands soon after deposition and may help explain the lack of upward fining sequences. This situation is analogous to that described in Kreisa's work on the Martinsburg Formation of Southwestern Virginia (1981). The lack of sand and fine silt grains in the shale beds overlying the individual arkose beds indicates that each bed represents a single
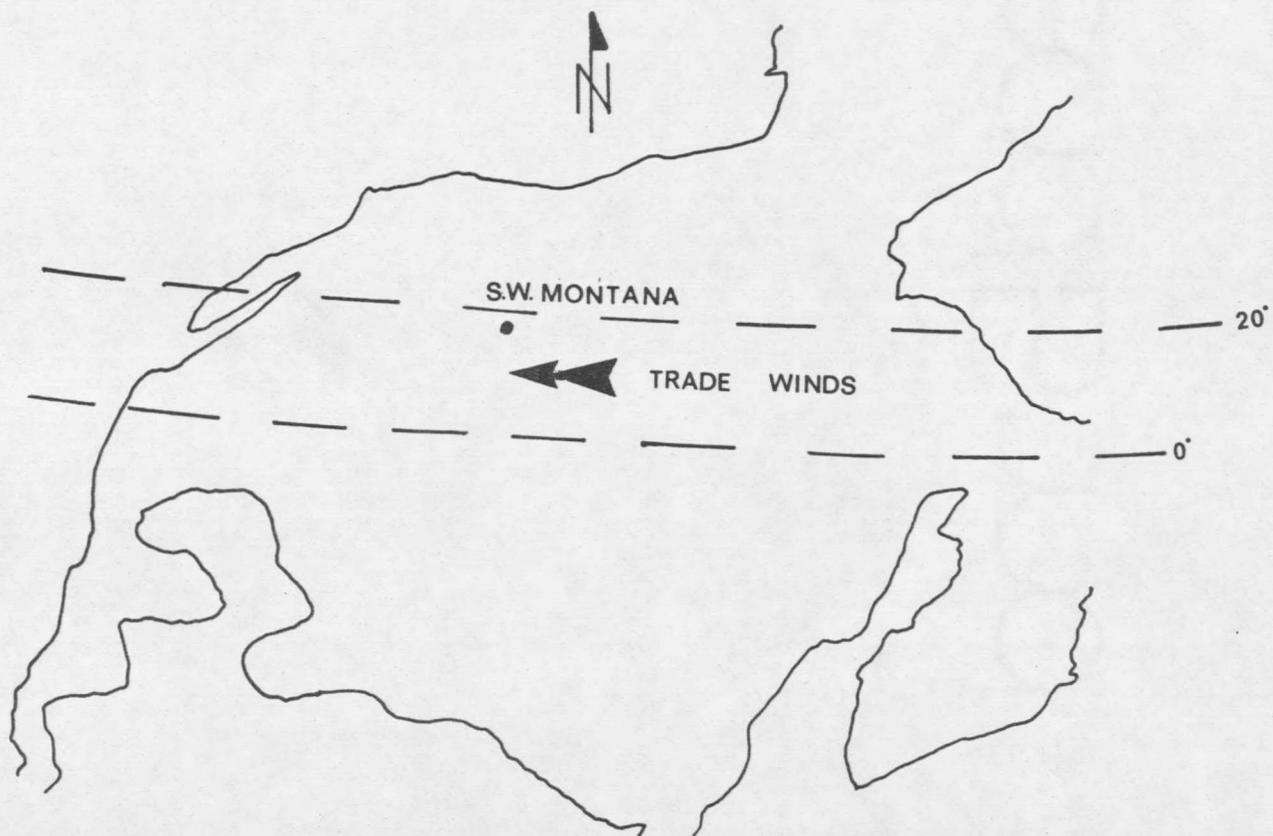
Figure 10. Location of southwestern Montana during Middle Cambrian time with respect to the Paleoequator (J. T. Parrish, 1982, pers. comm.).

depositional event, such as a storm, and that mud sedimentation was

re-established soon after the bed was deposited.

GLAUCONITE-RICH FACIES DESCRIPTION

General

Constituents

The major constituents of the facies are 33% glauconite, 13% biomicrite intraclasts, 21% detrital grains, 3% lithoclasts, 21% cement, and 9% fossils, exclusive of the biomicrite intraclasts (Plate 2, C). Minor constituents include composite pebbles and iron-magnesium silicates such as hornblende. Mafic minerals rarely occur as free, discrete grains.

Glauconite occurs as oval to elliptical pellets and very rarely as test or fossil fillings. Pellets average 0.5 mm in diameter. In thin section, unweathered glauconite grains are bright green and are characterized by limonitic rims. Interstices between these grains are often filled with dark iron oxide. Weathered grains are orange-yellow and have been replaced by calcite, limonite or both. Darker iron oxide rims and speckles define pellet boundaries.

Biomicrite intraclasts occur as discreet blocks and tabular shaped clasts that average 5 cm by 11 cm. Smaller clasts are occasionally slightly imbricated. The large blocks exhibit internal cross-stratification. The blue-green algae, Girvanella, inarticulate

brachiopod-trilobite debris, and micritic cement are the principal constituents of the intraclasts. _Girvanella_ occurs as small, oval to elliptical, individual grains that range in size from 0.5-5 mm. Coarse crystalline calcite, with unit extinction, indicates complete recrystallization of the algae. Trilobites and inarticulate brachiopods occur as comminuted fossil debris in the intraclasts. The trilobite debris consists primarily of fractured spines. Occasionally several whole spines or pieces of thorax, filled with mud, are present. Iron staining of the fossil debris is absent.

Detrital grains are the third major constituent of the facies. Of the grains counte, quartz averaged 37%, orthoclase 42%, plagioclase 11%, microcline 5%, and chloritized mafic minerals and mica 5% of the total detrital percentage. Quartz grains are angular to subrounded and poorly sorted. Amorphous, light gray clay coatings and rarely, iron oxide rims, are the major types of alterations. Pitting, gouged, and micro-fractured grains are common. Grains exhibit moderate to strongly undulose extinction.

Orthoclase, the dominant feldspar present, averages 0.9 mm in diameter. Sorting and rounding are moderately poor. Pitted, gouged, and fractured grains are common. Grains of perthitic microcline average 1 mm in size. Sorting is fair and grains are irregular to subrounded. Plagioclase grains are similar to those

described in the quartz/orthoclase-rich facies and average 0.8 mm
in size. Sorting is fair and rounding poor. Anorthite content
ranged from 10-27% AN, indicating albite and oligoclase. The
alteration of orthoclase, microcline and plagioclase is essentially
the same at that described in the quartz/orthoclase-rich facies.

Important but minor constituents are composite pebbles ranging
in diameter from 2 mm-2 cm. The major constituents are quartz 45%,
K-spar 41%, plagioclase 3%, and 7% unrecognizable, chloritized
mafics and mica (Plate 2 E). Altered, but recognizable mafic
minerals are rare. In composite pebble #2 (Wolsey Shale, Bridger
Range) several grains of orthopyroxene (diopside?) were identified.
These grains compose about 1% of the composite pebble.

The alteration associations exhibited in the composite pebbles
are the same as those observed in the composite and single grains
of both facies. The iron oxide-clay-chlorite association is especi-
ally well developed in these pebbles. The coatings of the ortho-
clase grains usually lack any of the "windows" described earlier
under the quartz/orthoclase-rich facies.

At first glance, grains of the pebble seem to exhibit inter-
locking texture. In thin section, however, the texture varies
greatly from "true" interlocking texture to "psuedo" interlocking
texture to clastic texture (Plate 2E, 2F). In thin section,

gradation of textures may or may not be observed.

In "pseudo" interlocking texture, grain to grain contacts are broad, dark and diffuse. This texture is the result of the grain to grain contacts being exploited by a clay film, with or without iron oxide, and/or chlorite. Displacement of adjacent grains along these contacts occur in several composite pebbles. In these cases, individual grains seem to have shifted slightly, relative to adjacent grains, producing offset along the grain to grain contact. These characteristics suggest that this texture is the product of incipient weathering and disintegration of grain to grain contacts.

In spite of extensive alteration and incipient loss of interlocking texture, relicit metamorphic fabrics are recognized in pebbles 5a, 5b, and 8b and in many of the metamorphic lithiclasts. In Plate 2F, pebbles 5a and 5b, from the Sacajawea Peak area, exhibit lineation and crenulated quartz grain boundaries. Pebble 8a has very weakly developed schistosity.

Pebbles 7 and 9a exhibit the greatest textural variations of the composite pebbles studied in thin section (Plates 3,A and B). Pebble 7 contains an abundance of matrix which occurs between larger composite and single grains. Pebble 9a is the most interesting. In this composite pebble, the grains "float" in carbonate cement. Pebbles 9b, 8a, and 11 show similar cement-grain relationships. However, the majority of the composite pebbles are silica

cemented and the occurrence of several carbonate-cemented pebbles is an interesting anomoly. Silica-cemented pebbles display "true" interlocking to clastic texture whereas in the carbone cemented pebbles, the grains are distinctly separate from one another. Pebbles of both types of cement have the same mineralogy, alteration associations, and display well-defined composite pebble boundaries.

In the pebbles, the origin and diagenetic history of the two types of cements is problematic. Two possible explanations for the co-existence of the cements are: (1) co-precipitation in a source rock profile, where physical and chemical controls produced a zonation of two cement types or (2) the replacement of silica cement by carbonate cement or vice versa. The co-precipitation of these cements is constrained by Eh/pH relationships, temperature, and the saturation of the medium with respect to calcium carbonate and orthosilicic acid (Blatt, et al., 1972). The occurrence of a natural environment where such physical and chemical requirements are met is probably rate (Custer, 1982, pers. comm.).

Sedimentary Structures

Sedimentary structures present in the glauconite-rich facies are weakly developed cross-stratification, very weak imbrication of smaller biomicrite intraclasts, and vertical burrows in, and local

channeling of, the basal limestone layer. Structures are not
common in this facies, though in part, this may be due to poor
exposure. The weakly developed cross-stratification is defined by
the clastic component of the facies. Grains do not form continuous
laminae, but form a "sand train" which is roughly continuous along
a bedding plane. The only sedimentary structures definitely due to
organic activity are vertical burrows found in the basal lime layer
at Sacajawea Peak. The rock sample, containing the burrows, was
collected in 1949 by W. J. McMannis and Christina Lochman-Balk. The
burrows range in height from 3.2-3.8 cm and vary in width from
2 mm-1.1 cm. Calcareous siltstone fills the burrows. The siltstone,
which is more resistant than the surrounding carbonate, forms small
bumps at the top of the burrows. One of the burrow tops has been
truncated. The contact between the glauconite and the carbonate is
abrupt and planar and no mixing of the constituents occurs
(Plate 1,A).

The presence and truncation of the burrow, local channeling of
the basal carbonate, and the abrupt contact between the glauconite
and carbonate indicate that partial lithification of the basal lime
layer occured prior to the deposition of the facies. Christina
Lochman-Balk (1981 pers. comm.) stated that:

McMannis was much interested in this contact since pre-
viously we had thought that Park deposition had been
continuous after the Meagher, whereas this specimen sug-
gested that there was a break in deposition, or in a more
modern interpretation, at least time for the limestone
surface to form a hardground.

Soft-Sediment Deformation Structures

Soft-sediment deformation structures are not common in the

glauconite-rich facies, a situation similar to that in the quartz/

orthoclase-rich facies. In general, the features are the same:

i.e., "ripple-like" load and "burrow-like" structures. The "ripple-

like" structures present in the glauconite-rich facies differ from

those previously described as internal stratification is present.

The "burrow-like" features are essentially the same as those

described in sedimentary structures of the quartz/orthoclase-rich

facies. The tops of the "burrows" lack the green micaceous shale

which always occurs at the top of the facies. This shale "coating"

is very distinct from the overlying shale and may represent the

final stages of deposition in the glauconite facies. If "burrowing"

had taken place prior to deposition of the green shale coating,

these "burrows" should have been covered as the shale was deposited.

This relationship suggests that these features developed sometime

after the facies was deposited.

The "ripple-like" structures were found only in large pieces of float immediately adjacent to the outcrop. The rippled appearance is produced by finger-like channels which originate at a common point. These structures are often characterized by a basal lag consisting of sand sized, salmon pink and vein quartz grains smaller than 1.5 mm. The lag grades upward into silt-sized grains of similar composition, which form very faint, steeply dipping laminations. The laminations are slightly concave upward, fill the channels asymmetrically, and become parallel bedded at the top of the structure (Fig. 11).

The internal stratification, lack of chaotic internal structure, and the relief of the finger-like channels suggest that these structures may be erosional channels modified by loading. The internal stratification of the "ripple-like" structures is similar to that of erosional channels found in the intertidal zone and described by Reineck and Singh (1975). Such channels are produced by the erosion of soft sediment surfaces. Diagonally passing currents fill the channels with sediment, producing asymmetric, concave upwards laminae. These currents are common in intertidal zones during high water where the current patterns are controlled by differing water levels and not the surface morphology of the sea floor (Reineck and Singh, 1975).
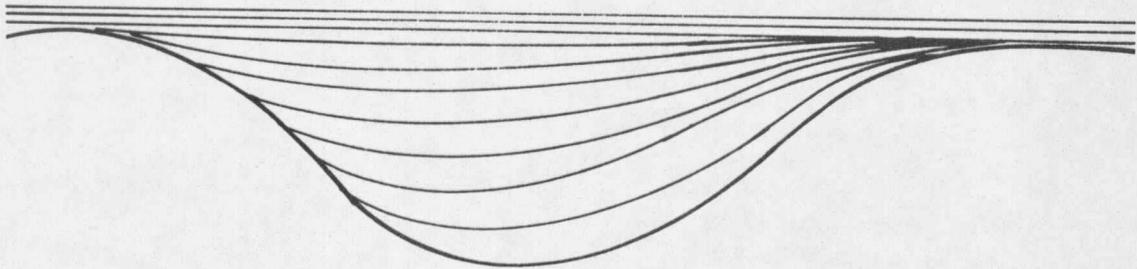
Figure 11. Channel filled asymmetrically by
steeply inclined laminae. (From
Reineck and Singh, 1972).

Facies Geometry

The geometry of the glauconite-rich facies was not determined
due to extremely poor exposure along strike.

Interpretation of the Glauconite-rich Facies

There are eight major characteristics of the glauconite-rich
facies. These are:

(1) abundant glauconite

(2) abundant fossil debris, locally concentrated in shelly

lag deposits

(3) biomicrite intraclasts

(4) greater areal distribution of facies and greater lateral

occurrence of float in areas where the facies does occur.

(5) abundance of composite pebbles

(6) absence of glauconite from the rest of the Park

(7) increased carbonate content of the facies

(8) presence of detrital grains.

The abundance of glauconite, fossil debris, and increased
carbonate content of the facies suggest deposition in a quiet
shallow water, stable, marginal-shelf environment. Disruption of
stable shelf conditions is indicated by locally developed shelly
lag concentrations, the presence of detrital grains, and weakly de-
veloped cross-stratification (Fig. 12).
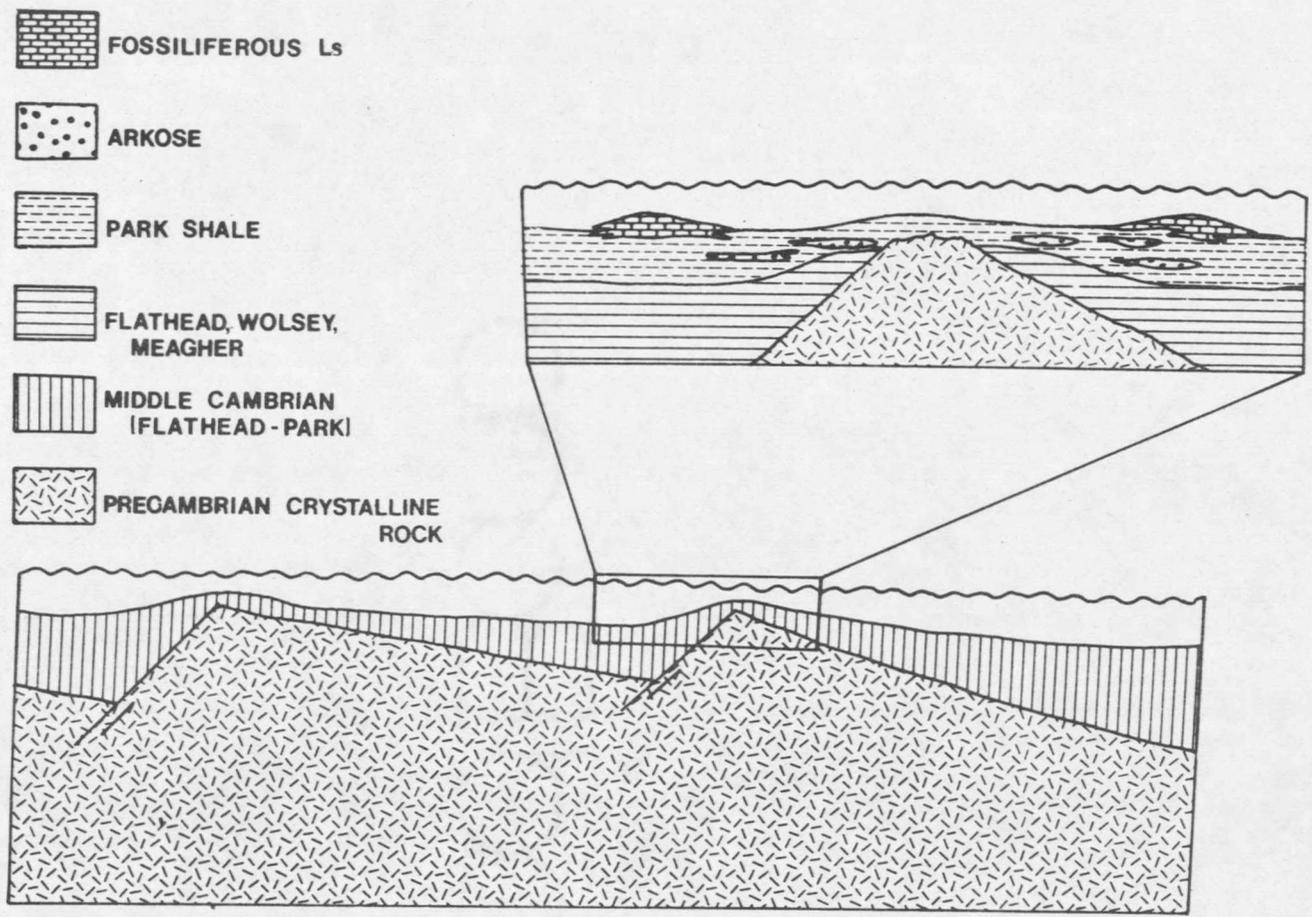
Figure 12. Hypothesized depositional environment of the glauconite-rich facies.

The carbonate-glauconite association is characteristic of a shallow marine environment (Benton and Kastner, 1965). This association and the other characteristics indicating shallow water conditions, represent major changes in intrabasinal factors controlling sedimentation. These factors are the rate and type of clastic detritus being introduced into the depositional environment, and the tectonic setting which controlled that environment.

Quiet, shallow-water shelf conditions, very low rates of clastic sedimentation, and decreased turbidity, enhance carbonate sedimentation and the formation of glauconite. These conditions also favored the development of biostromal build-ups and local shoaling. The shoals and intershoal areas supported abundant biotic communities composed of trilobites, small inarticulate brachiopods, and the blue-green algae Girvanella. This algae is typically found in shallow water (50 m) carbonate shelf facies formed in lagoons or behind reefs (Ginsburg, et al., 1971; Wray, 1977). The abundant Girvanella, in association with micritic carbonate cement, indicates deposition in a shallow, quiet-water environment, perhaps in an intershoal setting. Here, current energy would be weak, allowing carbonate muds to accumulate and Girvanella communities to develop and flourish.

The requirements of glauconite formation may have been best met in topographic lows between shoal-intershoal complexes or in

areas seaward of the complexes where sedimentation rates would be low and turbulence minimal. Glauconite pellets develop very slowly along the water-sediment interface and rapid sedimentation would have buried developing grains (McRae, 1972). Glauconite forms at depths as shallow as 15 m (McRae, 1972; Pettijohn, 1975). At shallower depths, the environment is subject to turbulence too great for glauconite formation. The lack of turbulence at depths greater than 15 m, both between and seaward of the shoal-intershoal complexes, would have favored the development of reducing "pockets" in topographic lows on the sea floor. The large amount of fossil debris indicates that an adequate supply of organic matter was present. The accumulation and decay of organic matter in these topographic lows would have enhanced development of oxygen-poor conditions (McRae, 1972; Graham and Suttner, 1974). Degraded alumino-silicate lattices, which provide the required layer structure, and a supply of iron and potassium ions, could easily have been derived from both regional and local sources (Lochman-Balk, 1972; McRae, 1972; Graham and Suttner, 1974).

Regionally, fine-grained clastic material was derived from the northeast. Lochman-Balk (1972) noted an increase in the percentage of fine-grained clastics in a northeasterly direction in Middle and Upper Cambrian rocks of western Montana, suggesting that parts of

the Canadian Shield were exposed. Locally, Fe/K rich, fine-grained

clastic sediments could have been derived from weathered crystalline

and Belt rocks. The total absence of glauconite from the biomicrite

intraclasts, and the presence of clastics in the glauconite-

carbonate association, indicates that the glauconite formed in an

environment which was separate but spatially associated with the

shoal-intershoal complexes.

The biomicrite intraclasts of the glauconite facies may have

formed in tidal channels and fissures similar to those described by

Wilson (1977) in his discussion of early Paleozoic carbonate build-

ups. In the field, the large biomicrite intraclasts seem to occur

at the same stratigraphic position within the facies and show

little to moderate amounts of rotation from the horizontal. These

characteristics suggest that the clasts may have developed when an

algal bank or banks collapsed. Early cementation is indicated by

the rectangular shape and undeformed boundaries of the intraclasts.

These intraclasts may have been generated in the following manner.

With increasing development and cementation of the biostromal

build-ups, the underlying shale would gradually compact. Compac-

tion and possible soft sediment deformation of the shale would

eventually reduce the support given to the overlying build-ups.

Structurally, the partially cemented build-ups would have acted as

a "competent" beam in comparison to the shale. The lack of support from the shale would have decreased the stability of the build-ups, increasing their susceptibility to damage by slumping and/or wave and current energy.

Scour and traction features indicate that strong currents were an influence in the deposition of the facies. A small, but well developed channel 4.8 by .6 cm occurs in the basal lime layer of the facies north of Sacajawea Peak. Other scour features may be present but were not observed because exposures of this layer were very poor. Traction features such as imbricated carbonate intraclasts and locally developed shelly lag deposits are slightly more common. The shelly lag deposits are composed of dark, fragmented, inarticulate brachiopod valves, glauconite and carbonate cement. Whole, convex upward valves are rare.

The concentration of hard skeletal parts may develop in regions where large surfaces are undergoing strong erosion or where channels are eroding and migrating laterally. Such shell concentrations presently occur on beaches, near mollusk colonies, or on the bottom of channels as lag deposits. Lag deposits are characterized by disarticulated and fragmented shells due to reworking by waves and currents (Reineck and Singh, 1975). The local shell concentrations in the glauconite facies are interpreted to be small channel

lag deposits. The currents, which generated the traction and scour features, probably occurred in topographic lows between the shoal-intershoal areas and in tidal channels and fissures.

The clastic component of the facies, the lack of glauconite in the rest of the Park and the significant lack of limestone, until the last 3 m of the formation, indicate a disruption of the stable shelf environment. The presence of current-generated structures and channel lag deposits support this hypothesis. Renewed influence of the clastic sediment source is indicated by the presence of detrital quartz, feldspar, and composite pebbles in these dominantly chemical rocks.

The renewed influence of the clastic sediment source, during deposition of the glauconite facies, may have been due to some other factor than tectonism. Two possible alternative explanations for the clastic component of the facies are: (1) a change in current regime due to increasingly shallow conditions and the increasing influence of sea floor topography. Dott (1974) noted that currents on modern, shallow-water shelves are controlled by wind directions and topographic obstructions. A change in current regime could introduce clastic detritus into an allocthonous depositional environment, or (2) the minor percentage of clastics represent the "fine" portion of clastic detritus derived from the island-shoal complex during a storm, and later deposited at some distance

from the complex with decreasing wave energy (Dott, 1974; Reineck
and Singh, 1972; Hayes, 1967).

SOURCE ROCK OF THE PARK ARKOSIC INTERVAL

Provenance

In summary, petrographic data suggest that the arkosic sand-
stones of the Park Shale were derived from a weathered zone or
profile developed on granitic gneiss. The weathered zone may have
developed during periods of subaerial exposure of the source rock
and possible concomitant shallowing of the surrounding depositional
environment. The presence of the weathering zone is inferred from
textural relationships, the presence of composite grains and
gneissic pebbles, and alteration associations. The occasional
occurrence of rounded-to-well rounded quartz grains, limestone and
siltstone lithiclasts, and metamorphic rock fragments represent
minor contributions of lower Middle Cambrian Strata and other
Precambrian crystalline rocks to the influx of clastic detritus.

The Park arkosic sandstones were derived from a quartz/
orthoclase-rich gneiss as indicated by (1) average mineralogy
(Table 1) and (2) the presence of relict metamorphic textures in
the larger individual and composite grains. The mineralogy of
composite grains in both facies and that of individual grains in
the glauconite-rich facies are very similar. Quartz/orthoclsae
ratios vary from 37:42 to 35:41. The ratio of quarts to plagio-
clase, and to chloritized, mafic minerals are relatively high,

ranging from 37:11 to 35:5. The similarity between these ratios
suggest that the individual grains of the glauconite-rich facies
were probably derived from composite grains.

The quartz/orthoclase ratio (56:25), estimated for individual
grains of the quartz/orthoclase-rich facies, is higher than the
same ratio for composite grains in either facies and for individual
grains of the glauconite-rich facies (Table 1). Four possible
explanations for this anomaly are: (1) exposure of a quartz-rich
zone in the granitic gneiss, (2) exposure of other quartz-rich
Precambrian crystalline rock, perhaps similar to the medium grained,
gray gneiss described by Tysdal (1966) (Table 1), located to the
south in the northern Gallatin Range, (3) differential weathering
and elimination of orthoclase, and (4) derivation of quartz from
exposed sections of Flathead Sandstone and Wolsey arkosic sandstone.
The most probable explanation for the high quartz/orthoclase ratio
is a combination of exposure of other Precambrian quartz-rich rock
and exposure of Flathead and Wolsey sandstone.

The composite pebbles have a higher quartz/orthoclase ratio
(45:36) and lower percentage of plagioclase (3%) than the composite
grains of either facies or the individual grains of the glauconite-
rich facies (Table 1). The variation in average mineralogy and the
presence of relict metamorphic fabrics (weakly developed schistosity

Table 1. Comparison of average mineral percentages of the Park Arkose (quartz/
orthoclase-rich and glauconite-rich facies), LaHood Arkose (adapted
from McMannis, 1963), and a Gallatin Range gneiss (taken from Tysdal,
1966).

	Quartz	Ortho-clase	Micro-cline	Plagio-clase	Chloritized Mafic Minerals	Biotite	Muscovite
Glauconite-rich facies, individual grains	37	42	5	11	6	–	–
Glauconite-rich facies, composite grains	35	41	7	10	5	–	–
Quartz/orthoclase-rich facies, individual grains	56	25	8	6	5	–	–
Quartz/orthoclase-rich facies, composite grains	37	42	6	9	5	–	–
Composite pebbles (2 mm – 2 cm)	45	36	6	3	7	–	–
LaHood Arkose, Bridger Range *	47	2	14	37	–	–	–
LaHood Arkose, Horseshoe Hills*	47	0	12	41	–	–	–
LaHood Arkose, Caverns Area*	50	15	23	15	–	–	–
LaHood Arkose, Jefferson Canyon*	43	3	9	43	–	–	–
Medium-gray, medium grained gneiss, Gallatin Range	40–50	–	15–30	–	–	10–15	5–10

*Average mineral composition of the LaHood was re-adjusted to show only percentages of detrital minerals.

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clastic texture) suggest that the pebbles were probably derived from a more quartz-rich area of the granitic gneiss.

Precambrian crystalline rock, other than the granitic gneiss source rock, and Cambrian sedimentary rock were minor sources of clastic detritus during the deposition of both facies. Meta-quartzite rock fragments are the most common type of lithiclast found in either facies. These rock fragments, which are character-ized by strongly crenulated grain-to-grain contacts and undulose extinction, were probably derived from a Precambrian meta-quartzite and are not lithiclasts derived from the Flathead or the Wolsey arkosic sandstones. Fragments of marble are rare and a single, small amphibolite lithiclast was found at the South-Meadow section. Sedimentary lithiclasts are also rare. In part, their rarity may be due to the difficulty in recognizing grains or rock fragments derived from pre-existing sedimentary rocks, such as the Flathead or Wolsey arkosic sandstones. In addition, lithiclasts derived from carbonate rocks, such as the Meagher limestone, would not have withstood any significant amount of transport. These factors bias any estimation of the contribution of lower Middle Cambrian rocks to the influx of clastic detritus. Sedimentary lithiclasts that could be identified consisted almost entirely of siltstone rock fragments. In thin section, these fragments were recognized on the basis of undeformed and unarmored clast margins. Although no

sedimentary quartzite rock fragments were found, rounded-to-well-rounded quartz grains in both facies were most likely derived from pre-existing sandstones such as the Flathead.

Comparison of estimated percentages of quartz, plagioclase, microcline and orthoclase in the Park arkosic sandstones, with those of the LaHood, reveal some significant differences in mineralogy (Table 1). The differences between the two lie in the sharply contrasting percentages of microcline, orthoclase and plagioclase. In Table 1, the average mineralogy of the LaHood at four major outcrops (McMannis, 1963), within and adjacent to the study area are listed. In comparison, orthoclase percentages in the LaHood (36-0) are much lower than those of the Park Sandstones (42-25) (Table 1). Microcline, and especially plagioclase, were more abundant in the LaHood. Much of the plagioclase in the LaHood is not twinned. Where twinning is present, the twins are usually well developed and of the albite type (McMannis, 1963). In contrast, twinned plagioclase grains in the Park are characterized by poorly developed, broad, diffuse twins. The differences in mineralogy between the Park and the Precambrian sedimentary rock of the LaHood suggest that the LaHood was <u>not</u> the source of the arkosic sandstone.

Source Area

The arkosic sandstones of the Park were probably derived from a localized source of clastic detritus, such as an island or island complex. Subaerial exposure of the granitic gneiss and subsequent development of a regolith or weathered zone, would generate a source of easily erodable clastic detritus. In addition, overlying lower Middle Cambrian strata would also be weathered and eroded, generating a source of sedimentary lithiclasts. However, if these overlying strata lapped onto the crystalline source rock at relatively shallow dips, exposures would be limited, restricting the contributions of these rocks to the influx of clastic detritus. This may be an additional explanation for the paucity of recognizable sedimentary lithiclasts.

There are three main lines of evidence for the existence of a weathered zone in the source rock. These are: (1) an iron oxide-clay-chlorite association, (2) the presence of composite pebbles and grains which may be analogous to composite grains and pebbles found in the lower part of the Beartrap paleosol, (3) the presence of matrix in several composite pebbles, and (4) the wide range of grain size within the composite pebbles and grains, which is characteristic of recomposed granites (Pettijohn, 1978).

Conditions for iron oxide development were defined by Walker
(1967), as: (1) the presence of iron-magnesium silicates, (2) con-
ditions favoring the intrastratal solution of these minerals, and
(3) oxidation of ferrous to ferric iron, resulting in the pre-
cipitation of iron oxides. The intrastratal solution of iron-
magnesium silicates and precipitation of ferric hydroxides is
favored by a basic, oxidizing environment. In addition, the
hydraulic gradient of the system must be sufficient to prevent
oversaturation of the water with respect to the cations being
leached from the iron-magnesium silicates (Walker, 1967; Birkeland,
1972).

In a weathering profile, especially in the vadose zone, these
criteria could be satisfied. Downward percolation of sea water,
combined with subaerial exposure of the gneissic source rock, would
favor hydrolysis of quartz, feldspar and iron-magnesium silicates.

Hydrolysis of these minerals would result in the development
of clays, iron oxides and chloritization of the iron-magnesium
silicates. The iron oxide-clay coating association, which is
characteristic of orthoclase grains in both facies, may have de-
veloped in such a manner.

The apparent selective staining of orthoclase by iron oxides
represents a puzzling diagenetic problem to which there may be
several answers. Two possible explanations are: (1) the orthoclase

grains of the source rock were initially iron-rich, and the selective staining of the grains is due to the exsolution of iron from the crystal lattice during hydrolysis (G. Thompson, 1981, pers. comm.), (2) The greater degree of disorder of the crystal lattice in the monoclinic system increased the susceptibility of orthoclase to weathering and alteration (Huang, 1977). If orthoclase grains weathered more easily, clay coatings would develop more readily, and be more extensive than coatings developed on plagioclase and microcline. Well developed clay coatings would be able to absorb more of the iron released into solution by the hydrolysis of iron-magnesium silicates. The result would be the more pervasive iron-clay coatings characteristic of orthoclase grains.

With continued development of a weathered zone, a vertical variation in grain size would gradually evolve. The uppermost part of the profile would be characterized by intense alteration and disintegration of the source rock. Increasing grain size and decreasing intensity of alteration would be expected down-profile with increasing distance from the surface.

This vertical variation in grain size is excellently displayed in the preserved Precambrian paleosol at the Beartrap recreation area, 40 km west of Bozeman on Highway 289. The uppermost part of the Beartrap profile is composed of very fine-grained silt and clay, and represents the end product of a weathered biotite gneiss.

The silt and clay grade downward into an increasingly micaceous, sand-sized grus. Small granules and pebbles become more common as the intensity of weathering decrease with depth in the profile. Eventually, the grus grades into moderately weathered gneiss. The small composite grains and pebbles of the arkosic sandstones may be analogous to the composite pebbles and grains found in the lower part of the Beartrap paleosol. The broad, diffuse grain-to-grain contacts which characterize these pebbles and grains may represent the initial effects of weathering at depth within the inferred regolith.

The textural variation within the composite pebbles and grains is an additional line of evidence indicating the existence of a weathered zone. Composite pebbles 11, 7, and 1 (Plate 3A, B, and 2E) exhibit a distinctly clastic texture, and a wide variety of grain sizes (Plate 3A, 3B, and Plate 2C, respectively). In thin section, Pettijohn (1975) cites the absence of an even-grained appearance and a wide range of grain sizes as definitive character- istics of recomposed granite, that is a granite which underwent some weathering and distintegration, but so little reworking prior to lithification that it is similar to the granite itself. Pettijohn's concept of a recomposed granite can be extended to a granitic gneiss and explains the gradation of texture seen in some composite pebble thin sections. The variation in composite pebble texture

from true "interlocking texture (quartz ribbons in composite pebble 5a, Plate 2F) to clastic (composite pebble #1, Plate 3A) may be the result of differing original locations in the weathered source rock profile and concomitant variations in weathering intensity.

In summary, the arkosic sandstones of the Park were derived from a weathered zone of granitic gneiss. The existance of this weathered zone is based on the presence of an iron oxide-clay-chlorite association, composite pebbles and grains and the wide range of grain sizes within the composite pebbles. In addition, the broad, dark, diffuse grain-to-grain contacts and apparent displacements along these contacts suggest that the detrital grains of the arkose were derived from a weathered zone or profile.

SEDIMENTARY TECTONIC SETTING OF MIDDLE CAMBRIAN

DEPOSITIONAL ENVIRONMENTS

Whatever model is generated to explain the arkosic sandstone of the Park Shale, it must take into account the stratigraphically "high" occurrence of feldspar in the section, and the localized occurrence of arkose. These observations may be explained by a possible combination of local tectonism, eustatic sea-level changes and storms. The sedimentary tectonic setting for Middle Cambrian rocks of the Bridger Range will be discussed in three sections: (1) post-Belt/pre-Flathead time, (2) Flathead to earliest Park time, and (3) early Park to earliest Pilgrim time. Under each section the progressive evolution of the sedimentary tectonic setting will be discussed, as well as any modifications required to explain stratigraphic and sedimentologic anomalies.

The Sauk Sequence (Sloss, 1963) was deposited on a stable shelf platform in an Afro-trailing-edge setting during Middle to Late Cambrian time (Shearer, 1980). The trailing-edge setting which evolved during a late Precambrian rifting event, 850 m.y.b.p., created or reshaped the western continental margin of North America (Steward and Suczek, 1977). Rifting was followed by erosion of the thermal bulge and subsidence of the shelf due to thermal contraction,

resulting in the gradual eastward migration of the Cambrian strand-
line.

Epeirogenic uplift and exposure of the craton in early
Ordovician time produced the bounding unconformity between the Sauk
and Tippecanoe sequences. However, the passive margin setting
persisted into middle Ordovician time, when a convergent plate
margin developed off the coast of western North America, creating
the Klamath-Sierran arc (Burchfiel and Davis, 1975).

Post-Belt/Pre-Flathead Time

The Belt/Flathead contact is a major unconformity representing
an undetermined amount of time (Verrall, 1955; McMannis, 1955)
Regionally, the contact is unconformable in that the Flathead trun-
cates all Belt units and older Archean metamorphic rocks. Locally,
the contact is an angular unconformity (Deiss, 1935).

Shortly after the end of Belt sedimentation, Beltian strata and
older, metamorphic rocks were tilted and uplifted forming the Helena
Mountains. The principal centers of uplift were located in the area
of the present day Beartooth, Big Snowy and Little Belt Mountains
(Deiss, 1935). The regional continuity of the Flathead Sandstone,
its uniformity of thickness, and lithology indicate that these
mountains had been eroded to a near peneplain. In addition, these
characteristics suggest that the Beltian trough was no longer sub-
siding and was acting as a stable shelf prior to the transgression

of the Flathead Sea (Verrall, 1952). However, locally the topo-
graphy was irregular with a relief of 100-133 m (Lochman-Balk, 1972).

The inclusion of pieces of Belt argillite, pebbles of Belt
arkose, holocrystalline granitic rock in the Flathead, and the local
preservation of a bleached or weathered zone at the Belt/Flathead
contact indicate that physical and chemical weathering of the ero-
sional surface occurred prior to the transgression of the Cambrian
Sea (Deiss, 1935; Verrall, 1955; Tysdal, 1965; Lochman-Balk, 1972;
Graham and Suttner, 1974). This weathered zone or "paleosol" occurs
locally in both Wyoming and Montana and ranges in thickness from
0-9 m (Kennedy, 1980).

Flathead to Earliest Park Time

The Flathead Sandstone is a calcareous, poorly-to-moderately-
well sorted, medium-to coarse-grained sandstone. Locally, the lower
Flathead is arkosic and conglomeratic. In the study area, the
sandstone varies from as little as 17 m in parts of the Gallatin
Range, to 77 m in the Bridger Range and 46 m in the Horseshoe Hills
(Hanson, 1952; McMannis, 1952; Verrall, 1955; McMannis and Chadwick,
1964). The basal Flathead is in erosional contact with underlying
Belt or Archean crystalline rock. The upper contact is gradational
with the overlying Wolsey Shale (McMannis, 1952; Verrall, 1955)
(Fig. 1).

The Wolsey Shale is a transitional, tripartite unit between the Flathead Sandstone and the Meagher Limestone (LeBauer, 1964, Fig. 4). The lower unit consists of shale with interbedded sandstone and locally occurring arkosic limestone. The middle unit is characterized by green, fissile, micaceous, silty shale with minor, intercalated, burrowed, calcareous siltstone. This unit is often followed by a limestone which varies considerably in thickness. West of the study area in the vicinity of the Three Forks island complex, this limestone is known as the Silver Hall Member of the Wolsey (Hanson, 1952). The third unit consists of brown, fissile shale, and minor interbeds of calcareous siltstone and silty limestone. The Wolsey varies in thickness from 47 m in the Gallatin Range to 100 m in the Horseshoe Hills (Verrall, 1955; McMannis and Chadwick, 1964) (Fig. 1). The upper contact of the Wolsey is gradational with the overlying Meagher Limestone.

The Meagher, like the Wolsey, is divided into three basic units (Verrall, 1955; McMannis, 1955; LeBauer, 1965). The lowermost unit is a locally argillaceous, thinly bedded, fossiliferous, blue-and-gold mottled micrite and microsparite. The middle unit of the Meagher is thinly bedded but weathers massively, and is a persistent ledge-former. The unit is composed of an oolitic, pelletoidal, intrasparite. The upper unit consists of a thinly bedded, blue- and gold-mottled biosparite. Upsection, there are increasing amounts of

silt-sized detrital grains, intraformational conglomerate, and fragmental limestone (McMannis, 1952; LeBauer, 1965).

The Meagher varies in thickness from an average of 123 m in the Bridger Range to 99 m in the Horseshoe Hills, and 153 m to the south in the Gallatin Range (Fig. 1). The upper contact is placed at the top of the last major "Meagher-type" limestone and is gradational with the overlying Park Shale (McMannis, 1952).

The progressive downwarping of the shelf and relative rise of eustatic sea level during early Middle Cambrian times is represented by the Flathead-Wolsey-Meagher transgressive sequence (Sloss, 1963; Lochman-Balk, 1972). During earliest Middle Cambrian time, rapid subsidence of the unstable western North America shelf resulted in a relatively rapid initial marine transgression (Lochman, 1957). Subsidence continued at a slow rate until middle Middle Cambrian time, shifting the littoral-sublittoral Flathead-Wolsey facies eastward. In late Middle Cambrian time, the Meagher Limestone was deposited during the maximum downwarping of the shelf (Verrall, 1955; Lochman-Balk, 1972). After deposition of the Meagher, gradual epeirogenic upwarping of the shelf and westward progradation of the shoreline resulted in the progressive shallowing of the sea until early Upper Cambrian time (Lochman, 1957; Lochman-Balk, 1972). However, the sporadic occurrence of arkosic sandstone and quartz/feldspar stringers throughout Middle Cambrian strata demonstrate

that topographic highs continued to influence local sedimentary environments until early Upper Cambrian time.

Stratigraphic and lithologic evidence of Central Montana strongly suggest that the stable shelf setting was periodically disrupted by local tectonism during late Middle Cambrian time (Beutner and Schulten, 1967; Lochman-Balk, 1972). First, there is an abrupt increase in thickness of the Hasmark and Meagher formations just east of the Idaho/Montana border. In this area, the Hasmark and Meagher consist of dolomites, dolomitic and stromatolitic reefs (Lochman-Balk, 1972). This increase in the thickness is accompanied by an abrupt lithofacies change from the Hasmark and Meagher to clastics consisting of conglomerate and coarse-grained sandstone (Lochman-Balk, 1972). Tysdal (1969), in a personal communication to Lochman-Balk, suggested the presence of a growth fault to explain the facies change. Second, Beutner and Schulten (1967) recognized a large Cambrian to Ordovician tectonic element, located along the Idaho/Montana border.

The third line of evidence indicating tectonic instability during late Middle Cambrian time are quartz/feldspar-rich zones in the Meagher. The quartz/feldspar-rich zones occur in the Bridger Range near the head of Limestone Canyon and to the north near Morrison Canyon (Fig. 7). Mineralogically, the quartz/feldspar-rich zones are identical to the sandstones in the Park. However, in the

Meagher, the grains are more angular and better sorted. In most cases, the detritial grains and especially the feldspars, are fresh and lack any iron-staining, chloritization, and calcite replacement. Only near a faulted outlier of Meagher limestone, south of Sacajawea Peak, did a few salmon-pink (iron-stained) feldspar grains occur. A single very small, composite quartz/feldspar pebble was also found at this locality. At Limestone and Morrison canyons, the exact stratigraphic location of the quartz/feldspar-rich zones, with respect to the middle or upper third of the Meagher, is unknown due to both structural complexities and poor exposure. The sand-sized detrital matrix of the flat-pebble conglomerate, which occurs at the top of the Meagher, and the silty, micaceous shale of the lowermost Park, reflect the increasing tectonic instability and shallowing of the sea during latest Meagher/earliest Park time. Increased tectonic instability may have been due to incipient reactivation of a pre-existing structural zone of weakness, such as the Willow Creek fault zone, or to the development of a local fault, or fault system.

Early Park to Earliest Pilgrim Time

Lochman (1957) postulated that the change in sedimentation style from carbonates of the Meagher to the fine-grained clastics of the Park was due to slow and sporadic subsidence of the shelf. McMannis (1955) stated that "simple regression of the seas could not

account for the increased volume of clastics in Park time," implying
an epeirogenic uplift of the craton to the last. McMannis' infer-
rence of epeirogenic upwarping may explain the increased volume of
fine-grained clastic rocks, but it does not explain the occurrence
of arkosic sandstone in the Park. The presence of arkosic sandstone
beds in the Park shale strongly suggest that the area north of the
Wyoming shelf was unstable during the first half of Park time.

Several lines of reasoning suggest that the abrupt and sporadic
occurrence of arkosic sandstone in the Park is unexplainable by a
simple drop in eustatic sea level. The localized occurrence of the
arkosic sandstones and their stratigraphic separation (especially
that between the Wolsey and Park sandstones) requires local tecton-
ism and rejuvenation of the source of clastic sediments, greatly
modifying local depositional environments.

In order to influence sedimentation throughout early Middle
Cambrian time (in a tectonically stable setting), an island with at
least 259 m of relief would be required (Fig. 13). An island with
this relief would have produced significant variations in the thick-
ness of Middle Cambrian Strata (in this case, Flathead-Park rocks)
and in the lithologic types adjacent to the island or islands. In
addition, feldspathic sandstone or arkose should have been generated
from Flathead to Park time, producing a dominantly clastic sequence.
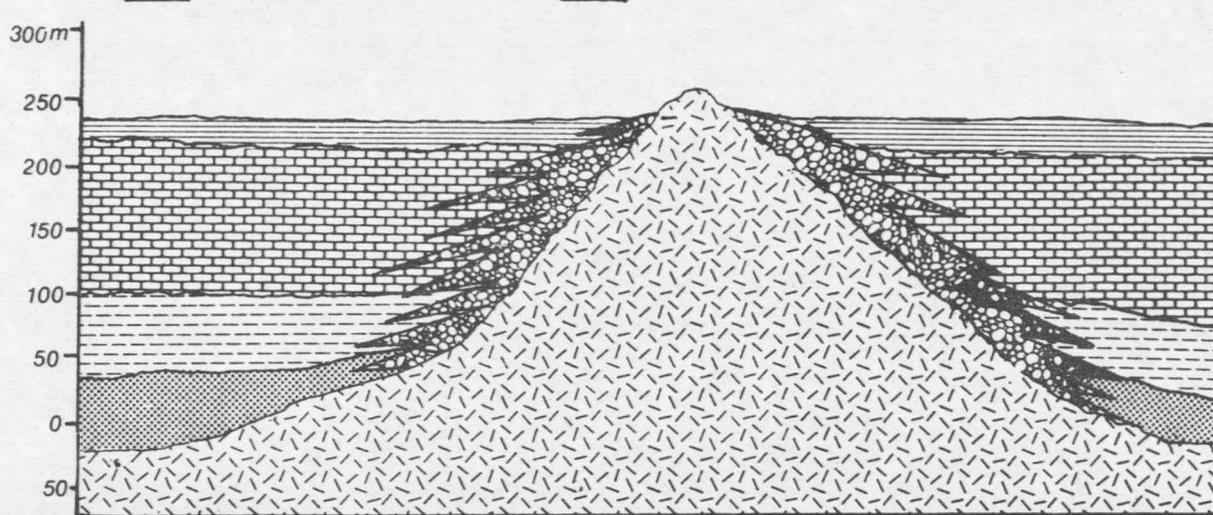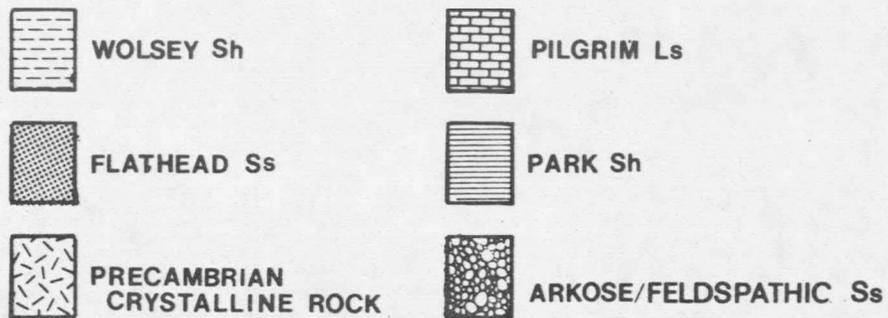Instead, stratigraphic and lithologic evidence indicates that the

Figure 13. Hypothetical facies relationships between a clastic point
source and a transgressive sequence of strata in a tectoni-
cally stable, marginal shelf setting.

depositional environment alternated between carbonate and fine-grained clastic sedimentation, and that the island or islands were not usually within the range of effective wave base.

Stratigraphic evidence in Middle Proterozoic Belt rocks indicate a series of horsts and grabens defined by three east/west fault zones and a single northwest trending fault zone. This fault zone, known as the Townsend Line, extends from the Bridger Range to Scapegoat Mountain (Fig. 14) (Winston, 1982). A dramatic increase in thickness of Belt strata in the Ovando block and the concentration of soft sediment deformation structures such as intrastratal folding, indicate differential uplift and subsidence, and tectonic instability along these lineaments (D. Winston, 1982, pers. comm.).

Several lines of evidence suggest that modification of the marginal shelf environment, and generation of a clastic sediment point source, may have been due to renewed tectonic instability along the Townsend Line (Fig. 14). These lines of evidence are: (1) restriction of the arkosic sandstones to the northern half of the Bridger Range (Fig. 1), (2) the absence of detrital quartz and feldspar in the Horseshoe Hills and the Gallatin Range sections (Fig. 1), and (3) the proximity of the arkoses to the Townsend Line. Reactivation along the Townsend Line, or the development of a fault or fault zones, may have resulted in a small scale horst and graben structural setting. Differential uplift and subsidence of these
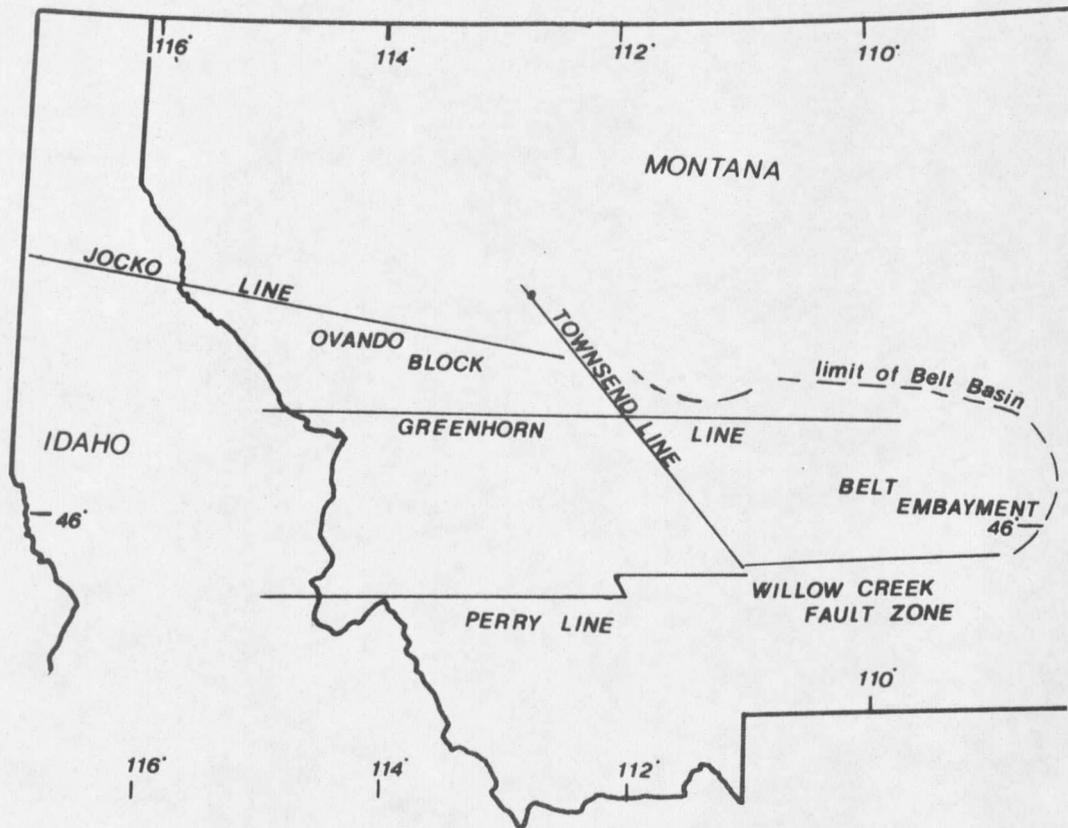
Figure 14. Location map of major Precambrian line-
aments, horsts, and grabens within the
Belt Basin and embayment. Modified from
Winston (1982, in press).

small "blocks" would be analogous to "floorboards" on a porch of differentially rising and lowering. Such "floorboard" type tectonism would generate a point source of clastics. During periods of "uplift" the granitic gneiss source rock would be exposed and weathered. Consequently, an easily erodable source of clastics would be generated. The association of the inferred island or point source with the Townsend Line is similar to the setting at the Three Forks island complex. Structural control of these islands is indicated by the parallel trends of island distribution and the Willow Creek fault zone, and the restriction of the islands to the north side of the fault zone.

The arkosic sandstones of the Park, which are most abundant between Hardscrabble and Sacajawea peaks, thin and pinch out to the south, towards the Willow Creek fault zone. This trend is contrary to what would be expected if the former source area of the LaHood arkose was also the source for arkosic sandstones of the Park. If the source area for the Park Arkosic sandstones was south of the Willow Creek fault zone, then the thickness of the arkose beds should increase in a southerly direction, as should the percentage of clastics in the Flathead-Park sequence. The restriction of the sandstone to the northern half of the Bridger Range, and the increased abundance of arkose between Sacajawea and Handscrabble peaks, suggest that the source area was to the north and east of the

present day Bridger Range. The lack of arkose to the west and south
(Horseshoe Hills and Gallatin Range, respectively), lend support to
this hypothesis.

The arkosic interval of the Park represents sporadic differ-
ential uplift and subsidence of the island or islands and surrounding
depositional environment. The islands were areas of local shoaling
and sources for coarse feldspar, quartz grains, and rock fragments.
The dominance of the quartz/orthoclase-rich facies throughout the
arkosic interval suggests that "floorboard" tectonism dominated
early to middle Park time. The glauconite-rich facies probably
accumulated during a period of tectonic stability, possible eustatic
sea level rise, and/or shelf subsidence. Turbidity was greatly
reduced as a result of tectonic stability and the concurrent decrease
in both the energy of the depositional environments and the influx
of clastic sediments. The reduction of clastic sedimentation and
turbidity enhanced both carbonate sedimentation and growth of bio-
stromal build-ups.

The greater areal distribution of the glauconite-rich facies
suggests that the depositional environment was more widespread, and
the sedimentary tectonic setting more stable, in comparison to that
of the quartz/orthoclase-rich facies.

Upsection in the arkosic interval, the stratigraphic separation
between arkosic beds increases and is accompanied by both a decrease

in grain size and an increase in carbonate cement. These character-
istics suggest the gradual reduction of the source area by erosion,
and/or an effective eustatic sea level rise.

Gradual downwarping of the shelf and craton resulted in the
transgression of the latest Middle/earliest Upper Cambian sea. This
transgressive phase of the Sauk sequence is represented by the
increasing abundance of limestone in the Park and gradational con-
tact with the overlying Pilgrim Limestone (Lochman, 1975; McMannis,
1952).

SUMMARY

The evolution of the sedimentary tectonic setting and deposition of Middle Cambrian rocks, in the study area, are summarized in Figures 15, 16, and 17. During post-Belt/pre-Flathead time, an irregular weathered erosional surface developed prior to the transgression of the Flathead sea. Topographic highs on this surface consisted of more resistant Precambrian metamorphic and Belt sedimentary rock (Deiss, 1935; Verrall, 1955; LeBauer, 1964; Lochman-Balk, 1972; Kennedy, 1980)(Fig. 15.) Reworking of weathered Belt and Precambrian crystalline rock resulted in the locally arkosic and conglomeratic character of the Flathead (Verrall, 1955; McMannis, 1952; Graham and Suttner, 1974)(Fig. 15).

During deposition of the lower Wolsey Shale, arkosic debris continued to be shed into a relatively shallow water, nearshore-island environment (Fig 15). Arkosic sandstones occur in Wolsey Shale at the Pole Canyon, Cottonwood Canyon and Bridger Range sections (Fig. 2) (McMannis, 1952; LeBauer, 1964). Continued transgression of the sea eventually submerged the islands, eliminating them as a source of both fine-grained and coarse-grained clastic sediments in Late Wolsey time (Fig. 15).

The lower and middle thirds of the Meagher Limestone were deposited on a stable, marginal-shelf, dotted with banks and shoals,
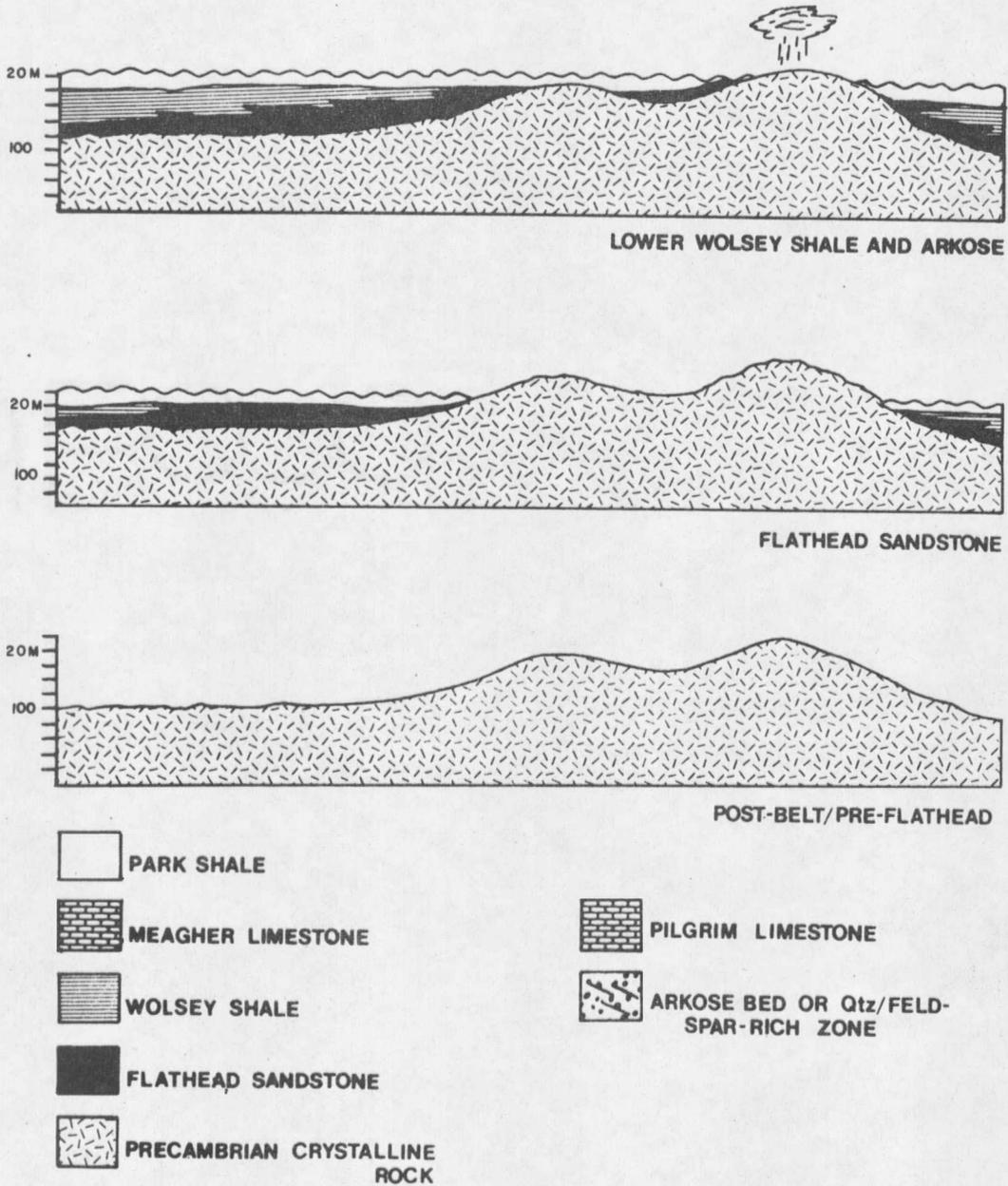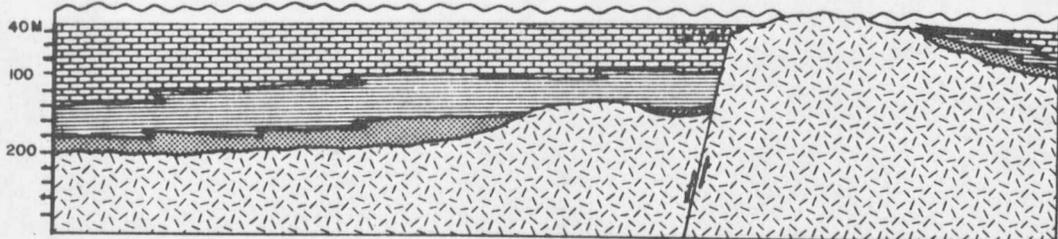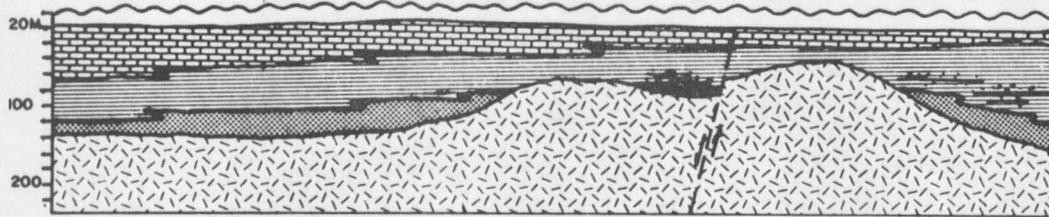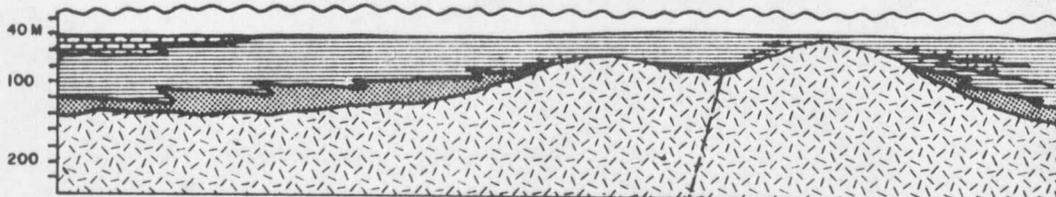
Figure 15. Summary of the sedimentary tectonic setting for
post-Belt/pre-Flathead to lower Wolsey time and
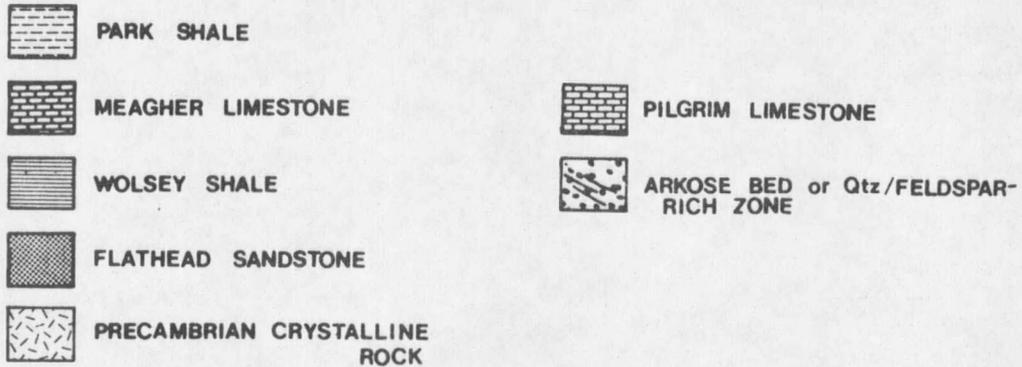the influence of topographic highs on sedimen-
tation.

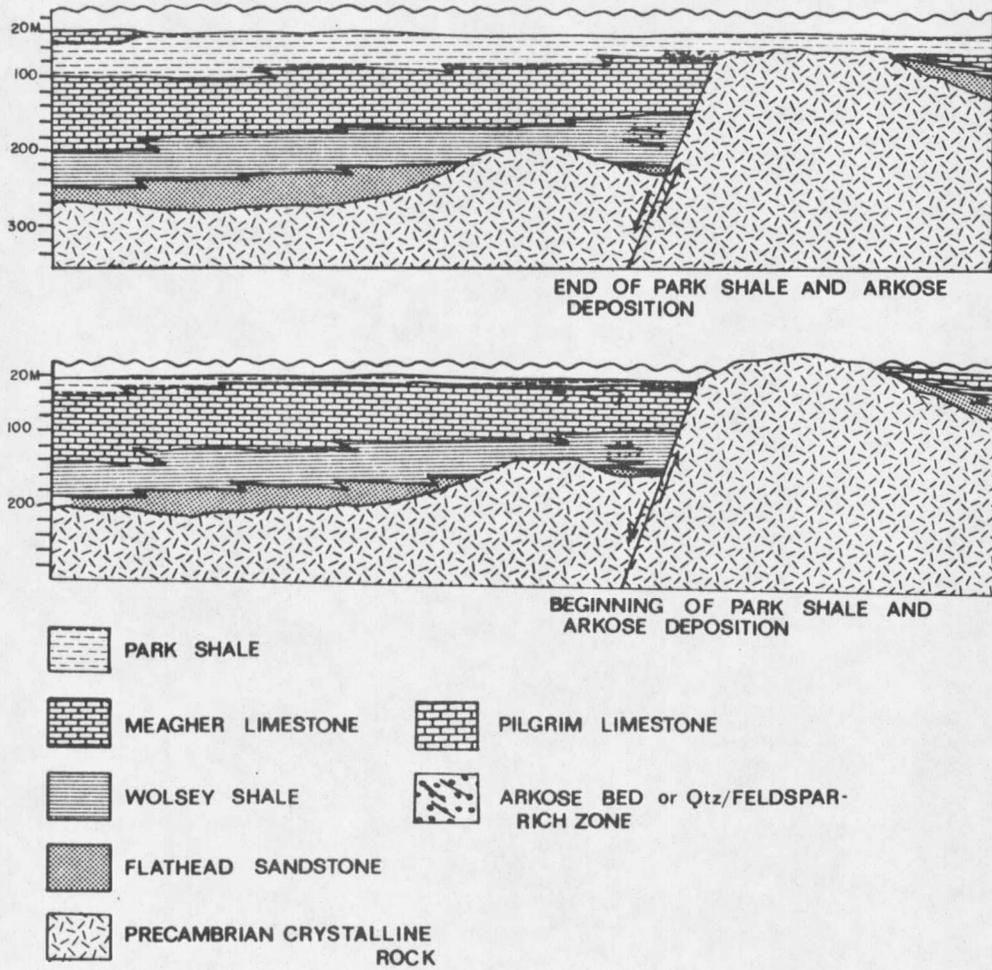Figure 16.   Summary of the sedimentary tectonic setting for late Wolsey to latest Meagher time.

Figure 17. Summary of the sedimentary tectonic setting for Middle
Park to earliest Pilgrim time and deposition of the
Park arkose.

with no apparent local source of siliceous clastic sediments ex-
posed. Lack of clastic detritus, and the presence of intraforma-
tional conglomerate, oolitic limestone and cross-stratification
characterize the middle third of the Meagher (McMannis, 1955;
LeBauer, 1965). During deposition of the upper third of the Meagher,
the marginal-shelf area became increasingly unstable and shallow,
resulting in locally occurring flat-pebble conglomerate and exposure
of a siliceous clastic point source. Erosion of the clastic point
source produced the quartz/feldspar-rich zones of the upper Meagher.

Differential uplift and subsidence of the island or islands
and surrounding depositional environment occurred sporadically
throughout the deposition of the lower Park. During periods of
uplift and subaerial exposure, a weathered granitic gneiss source
area developed. Erosion of the weathered profile most likely
occurred during periodic storms. A period of tectonic stability,
possible eustatic sea level rise and/or shelf subsidence is indi-
cated by the occurrence of the glauconite-rich facies (Fig. 15).

Reduction of the source area by erosion, combined with an
effective rise in eustatic sea level, eliminated the islands as
clastic point sources (Fig. 17). The increasing limestone/shale
ratio in the uppermost Park and the gradational contact with the
overlying Pilgrim Limestone, reflect continued transgression of the
Cambrian sea and reduction in the rate and amount of clastic

detritus being introduced into the depositional environment. These

characteristics represent the re-establishment of stable shelf

conditions in the study area during earliest Pilgrim time (Fig. 17).

CONCLUSIONS

(1) The arkosic interval of the Park Shale represents a period of tectonic instability and disruption of the stable, marginal-shelf environment. Renewed tectonic instability most likely occurred along pre-existing zones of structure weakness such as the Townsend Line. The proximity of the arkose to the trend of the Townsend Line, the restriction of the arkose to the northern half of the Bridger Range, and the absence of detrital quartz and feldspar in the glauconite-rich zones of the Park, to the west and south of the Bridgers, support this hypothesis. Sloss (1950) and McMannis (1965) suggested that reactivation of major Precambrian zones of weakness controlled or strongly influenced Paleozoic sedimentation.

(2) The quartz/orthoclase-rich facies was derived from a weathered zone of granitic gneiss. The general lack of glauconite, and the occurrence of comminuted fossil debris suggest desposition in a shallow water, current-agitated environment. The abrupt contacts of sandstone beds and lentils, their lateral discontinuity and sporadic occurrence, and wave-rippled tops suggest catastrophic and rapid sedimentation. These characteristics are typical of storm deposited, sublittoral sheet sandstones. The presence of the weathering zone is inferred on the basis of an iron oxide-clay-chlorite association, composite pebbles and grains of re-constituted

granitic gneiss, and the wide range of grain sizes within the composite pebbles.

(3) The three main constituents of the glauconite-rich facies (glauconite, fossil debris, and carbonate cement) indicates deposition in a shallow water, stable, marginal-shelf environment. The absence of glauconite and large biomicrite intraclasts from the rest of the Park Shale, suggest that the intrabasinal factors controlling sedimentation during deposition of the glauconite-rich facies were unique to Park time. The facies probably reflects a period of tectonic stability, a decreased rate of clastic sedimentation and a lack of coarse, clastic sediment being introduced into the depositional environment. These changes enhanced carbonate sedimentation and the development of biostromal build-ups. Disruption of stable, marginal-shelf conditions is indicated by locally developed shelly lag concentrations, the clastic component of the facies, and weakly developed cross-stratification. The detrital quartz and feldspar grains of the facies indicates renewed influence of the clastic point source.

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