Stratigraphy of Mid-Cretaceous Blackleaf and Lower Part of the Frontier Formations in Parts of Beaverhead and Madison Counties, Montana

U.S. GEOLOGICAL SURVEY BULLETIN 1773

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By THADDEUS S. DYMAN and DOUGLAS J. NICHOLS

Description of Albian and Cenomanian to Turonian Strata in Blacktail, Snowcrest, Tendoy, and Gravelly Ranges, and Pioneer and McCartney Mountains, Southwest Montana

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DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U. S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE: 1988

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center
Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Dyman, T. S.
Stratigraphy of Mid-Cretaceous Blackleaf and Lower Part of the Frontier Formations in Parts of Beaverhead and Madison Counties, Montana

(U.S. Geological Survey bulletin ; 1773)
Bibliography: p.
Supt. of Docs. no.: I 19.3:1773
1. Geology, Stratigraphic—Cretaceous. 2. Blackleaf Formation (Mont.) 3. Frontier Formation. 4. Geology—Montana—Beaverhead County. 5. Geology—Montana—Madison County. I. Nichols, Douglas J. II. Title. III. Series
QE75.B9 no. 1773 557.3 s 87-600054
[QE687] [551.7′7′0978669]

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By Thaddeus S. Dyman *and* Douglas J. Nichols

Abstract

The Albian Blackleaf Formation and the Cenomanian to Turonian lower part of the Frontier Formation in Madison and Beaverhead Counties, Montana, were deposited within or east of the southwestern Montana fold-and-thrust belt prior to thrusting, near the western depositional edge of the foreland basin.

The Blackleaf Formation ranges from 425 to 600 m in thickness and is subdivided into four mappable lithofacies units: lower clastic (unit 1), lower mudstone-shale (unit 2), upper clastic (unit 3), and volcaniclastic (unit 4). Unit 1 conformably overlies the upper carbonate member (gastropod limestone) of the Lower Cretaceous Kootenai Formation. This basal unit ranges from 13 to 87 m in thickness and consists of mudstone, quartz- and chert-rich sandstone, and limestone. Unit 2 ranges from 17 to 73 m in thickness and consists predominantly of thin-bedded mudstone, shale, and siltstone. Unit 3 ranges from 4 to 76 m in thickness and consists of thin- to thick-bedded quartz-rich sandstone and interbedded mudstone. Unit 4 ranges from 270 to 378 m in thickness and consists of porcelanitic mudstone, shale, and subordinate lithic sandstone. The Albian Age for the Blackleaf Formation was determined from fossil bivalves and palynomorphs.

The Blackleaf Formation is overlain by the Cenomanian to Turonian lower part of the Frontier Formation. The lower part of the Frontier, which attains a thickness of at least 300 m is composed of lithic sandstone, conglomerate, and subordinate mudstone and shale.

INTRODUCTION

The depositional history of the Cretaceous foreland basin in western Montana is represented by a westward thickening sedimentary sequence that attains a maximum cumulative thickness of nearly 7,000 m near Drummond (Gwinn, 1960; 1965). This sequence of interbedded marine and nonmarine clastic and carbonate rocks reflects both Sevier- and Laramide-style tectonism along the western margin of the Cretaceous seaway. Because this sequence exhibits extensive lateral and vertical facies variations, it poses complex sedimentologic and stratigraphic problems. Few detailed studies of this sequence have been undertaken; in some areas of southwest Montana it has not even been adequately described. Furthermore, stratigraphic nomenclature in the region is confusing, and several names have been applied to the same rocks even within the same area.

The Lower and lower Upper Cretaceous sequence in the Lima Peaks region and in parts of the Tendoy, Gravelly, and Snowcrest Ranges (Beaverhead and Madison Counties, Montana), and Pioneer Mountains is unique (fig. 1). The sequence lies within or near the easternmost frontal thrust sheets of the southwest Montana fold-and-thrust belt, along the western depositional edge of the foreland basin.

The sequence has been a source of interest to petroleum exploration companies. Borehole data in Madison and Beaverhead Counties are limited. As of December 1986, seven dry holes have penetrated the Cretaceous in southern Beaverhead County, Montana, and northern Clark County, Idaho (fig. 2; table 1). Seismic exploration parties have been active within the area.

Mid-Cretaceous formations in Madison and Beaverhead Counties include the Aptian to Albian Kootenai Formation, the Albian Blackleaf Formation, both of Early Cretaceous age, and the Cenomanian to Turonian or Late Cretaceous lower part of the Frontier Formation. This sequence is underlain by clastic and carbonate rocks of the Jurassic Morrison Formation and Ellis Group and is overlain by synorogenic conglomerate, limestone, and sandstone of the Upper Cretaceous Beaverhead Group (table 2).

The purpose of this report is to describe the Blackleaf and lower part of the Frontier Formations in parts of Beaverhead and Madison Counties, Montana, to establish lithostratigraphic subdivisions of these formations, and to describe their paleontologic and biostratigraphic characteristics and age relationships.

The study area (figs. 2 and 3) includes the (1) Lima Peaks region south of Lima, near Sawmill and Little Sheep Creeks; (2) Snowcrest and Gravelly Ranges in eastern Beaverhead and southern Madison Counties; (3)

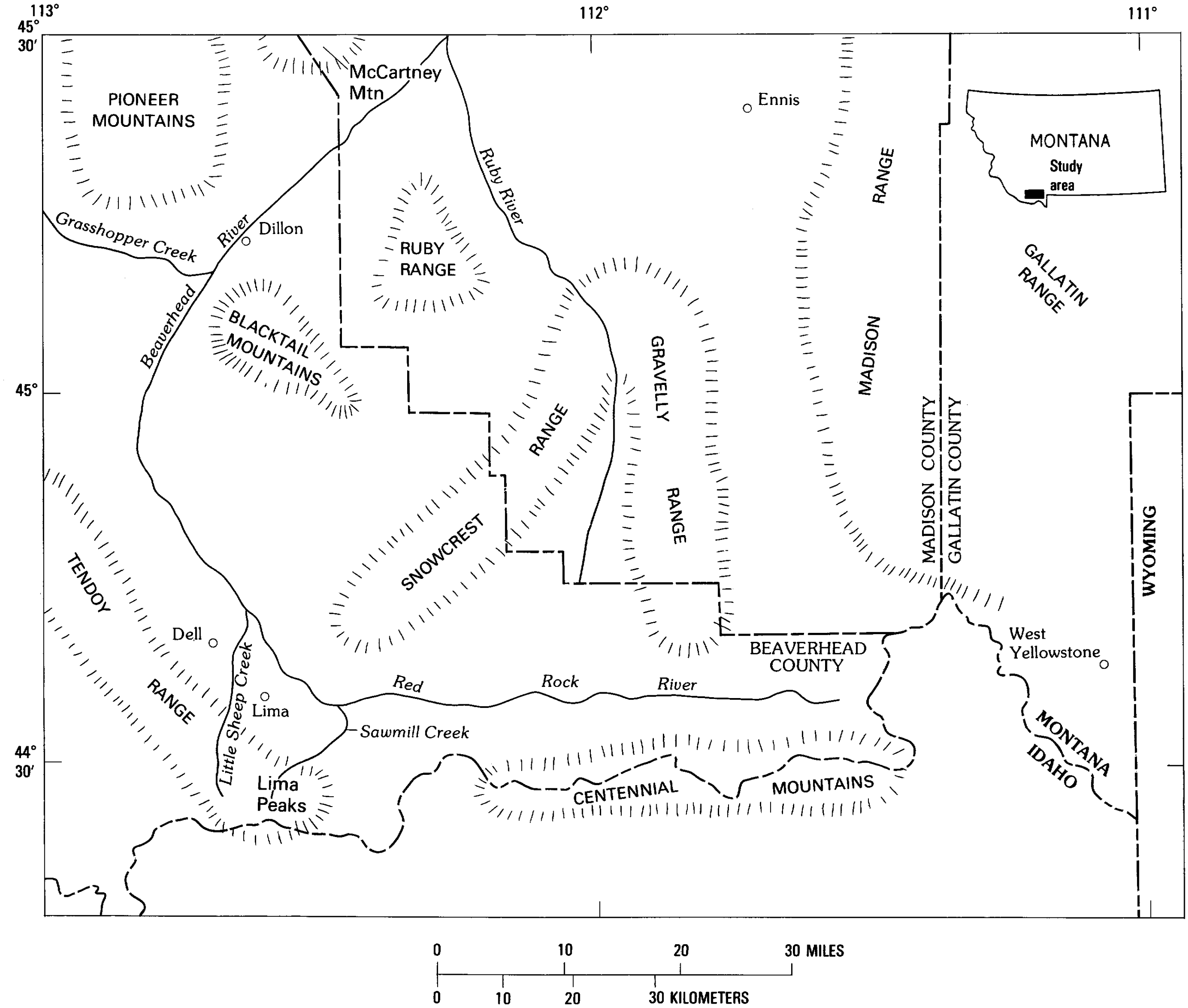


Figure 1. Mountain ranges in parts of Beaverhead, Madison, and Gallatin Counties, southwestern Montana.

Centennial Mountains along the border of Idaho and Montana; (4) northern Blacktail and eastern Pioneer Mountains north and south of Dillon; and (5) McCartney Mountain area north of Dillon, in southern Madison County. A list of measured sections and sample localities described in this study is given at the end of the report in the Appendix. The list includes codes, locations, and sources of information.

The Blackleaf-Frontier contact was established for this report at the base of the first significant sandstone or shale bed above mudrocks of the upper Blackleaf Formation. The Blackleaf-Kootenai contact was established as being at the last appearance of gastropod-rich limestone at the top of the Kootenai Formation.

The study was undertaken originally to include only the Blackleaf Formation. However, strata suggested to belong to the Frontier Formation are included in order to establish an upper Blackleaf contact, to define tectonic controls during the mid-Cretaceous, and to determine variations in provenance between the Blackleaf and Frontier Formations.

STRATIGRAPHY

The Blackleaf and lower part of the Frontier Formations outcrop in narrow belts along the margins of present-day ranges in southwestern Montana (fig. 3). Outcrop quality varies from excellent to poor. The best exposed sections are located in the Pioneer and McCartney Mountains area; composite sections were measured south of Lima and in the Snowcrest Range (Antone Peak and

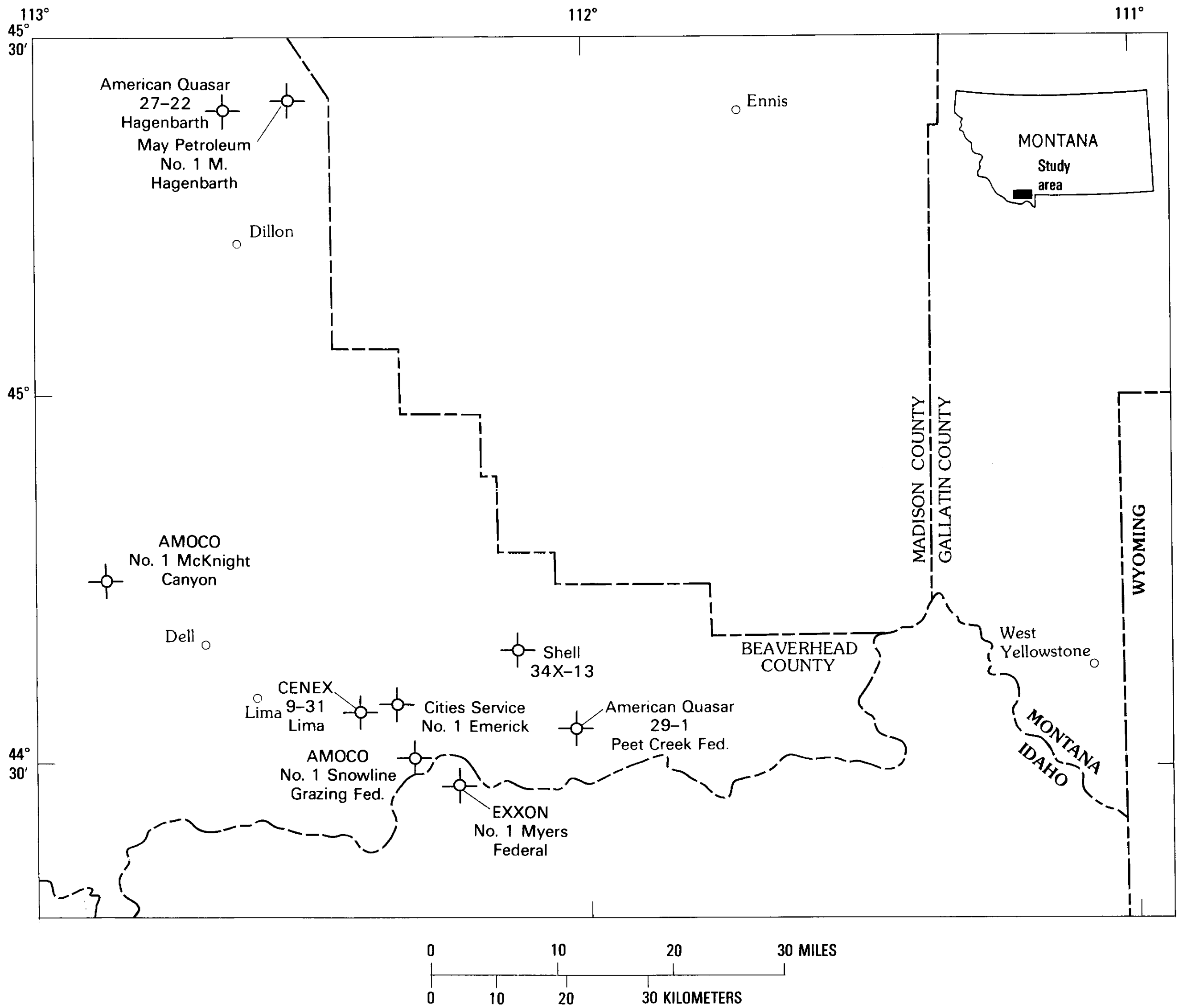


Figure 2. Boreholes that penetrate Cretaceous strata in parts of Beaverhead and Madison Counties, Montana, and adjacent northeastern Idaho. See table 1 for borehole descriptions and geologic data.

Lima Peaks sections, Appendix) where rocks are poorly exposed.

The Blackleaf and lower part of the Frontier Formations in the study area are composed of a predominantly clastic sequence of sandstone, siltstone, mudstone, and shale with much lateral and vertical variation. The formations are herein subdivided into five informal lithofacies units from bottom to top: (1) Blackleaf lower clastic (unit 1), (2) Blackleaf mudstone-shale (unit 2), (3) Blackleaf upper clastic (unit 3), (4) Blackleaf volcaniclastic (unit 4), and (5) Frontier lower clastic (unit 5). These lithofacies units are readily identifiable on the basis of field observations and can be traced throughout the study area (fig. 4). The lithofacies units will be referred to by number in the following paragraphs.

Dyman (1985a) has provided graphic lithology logs, sample numbers and lithofacies identification, grain size, porosity, and paleocurrent direction for sections measured in this study. Data presented in the following pages summarize and update the detailed descriptions of Dyman and others (1984), and Dyman (1985b).

NOMENCLATURE

Table 3 summarizes stratigraphic names used within or near the study area. Many different names have been used and no consistent pattern of nomenclature has been established, in part because of local lithologic and facies changes and the long distance from type localities. The

Table 1. Description of boreholes that penetrate mid-Cretaceous rocks in Beaverhead County, Montana and northern Clark County, Idaho (see fig. 2).

Well name/location	Total depth in meters (feet) and formation at total depth	Comments
May Petroleum Co. No. 1 Margaret Hagenbarth, C NE 1/4 NW 1/4 sec. 12, T. 5 S., R. 8 W., Beaverhead Co.	1,230 (4,039)	Penetrated part of the Blackleaf Formation.
American Quasar Co. 27-22 Hagenbarth, penetration SW 1/4 SW 1/4 sec. 27, T. 5 S., R. 9 W., Beaverhead Co.	3,672 (12,048) Precambrian.	Possibly penetrated the Blackleaf Formation.
Shell Oil Co. 34X-13 Unit, SW 1/4 SE 1/4 sec. 13, T. 13 S., R. 5 W., Beaverhead Co.	3,122 (10,244) Lodgepole Limestone, cored Quadrant, 1 drill-stem test, no shows.	Penetrated the Backleaf Formation. Possible faulting.
CENEX 9-31 Lima SW 1/4 NE 1/4 SE sec. 31, T. 14 S., R. 7 W., Beaverhead Co.	4,790 (15,715) Blackleaf Formation.	Penetrated the top of the Blackleaf Formation at 8,400 feet (2,560 m). Stratigraphic sequence probably faulted.
Cities Service Co. No. 1 Emerick, W 1/2 NW 1/4 NE 1/4 sec. 33, T. 14 S., R. 7 W., Beaverhead Co.	4,240 (13,909) Cretaceous.	Redrilled as CENEX 2-33 Lima
Amoco Oil Co. No. 1 Snowline Grazing Fed., NE 1/4 SE 1/4 sec. 10, T. 15 S., R. 7 W., Beaverhead Co.	4,392 (14,410) Cretaceous.	Penetrated the Blackleaf Formation. Stratigraphic sequence probably faulted.
Exxon Co. No. 1 Myers Federal Unit, SW 1/4 NE 1/4 sec. 14, T. 14 N., R. 35 E., Clark Co., Idaho	5,650 (18,540) Flathead Sandstone, drill-stem test in Madison Limestone, gas show.	Penetrated the Blackleaf Formation. Stratigraphic sequence probably faulted.
American Quasar Co. 29-1 Peet Creek Federal Unit, SW 1/4 NE 1/4 sec. 29, T. 14 S., R. 4 W., Beaverhead Co.	3,711 (12,177) Precambrian, 7 drill-stem tests, no shows.	Penetrated the Blackleaf Formation.
Amoco Oil Co. No. 1 McKnight Canyon Unit, SE 1/4 NW 1/4 sec. 21, T. 12 S., R. 10 W., Beaverhead Co.	Unknown	

Table 2. Generalized stratigraphic sequence for southwestern Montana.
[Thicknesses are averages for the region]

Stratigraphic unit	Chronologic units	Average thickness of chronologic units meters (feet)
Undifferentiated	Cenozoic	(5000)
Beaverhead Gp. Frontier Fm.	Upper Cretaceous	3962 (13000)
Blackleaf Fm. Kootenai Fm.	Lower Cretaceous	610 (2000)
Morrison Fm. Swift Fm. Rierdon Fm.	Jurassic	133 (400)
Thaynes Fm. Woodside Fm. Dinwoody Fm.	Triassic	360 (1200)
Phosphoria Fm.	Permian	(800)
Quadrant Ss. Amsden Fm.	Pennsylvanian	884 (2900)
Big Snowy Gp. Mission Canyon Ls. Lodgepole Ls.	Mississippian	1007 (3500)
Three Forks Fm. Jefferson Fm.	Devonian	274 (900)
Kinnikinic Qtzite.	Ordovician	350
Pilgrim Ls. Park Sh. Meagher Ls. Wolsey Sh. Flathead Ss.	Cambrian	350 (1000)

decision to apply the names Blackleaf and Frontier to Cretaceous strata in Madison and Beaverhead Counties, Montana, was made after reviewing the literature (table 3) and carefully examining the area near Blackleaf Creek, Montana, the type area of the Frontier at Cumberland Gap, Wyoming, and additional outcrops.

The Blackleaf Formation in the study area is similar to the Blackleaf Formation on Blackleaf Creek (Cobban and others, 1976) northwest of Great Falls. The term "Colorado Group" is not used in this study because it includes both Lower and Upper Cretaceous rocks. The stratigraphy of the Upper Cretaceous Frontier Formation has not been worked out in southwestern Montana, and facies relationships between the Frontier Formation and the Colorado Group in northwestern Montana are unknown. The terms "Mowry" and "Thermopolis" Shales are not used because they represent more marine facies to the east. "Aspen" Formation is a useful term but is generally used in conjunction with the underlying Bear River Formation to the south in Idaho. Lithofacies described in this study resemble the Blackleaf Formation in northwest Montana more than they resemble the Bear River Formation of eastern Idaho. Figure 5 summarizes Blackleaf-Frontier equivalents in the region.

For northwest Montana Cobban and others (1959) named four members of the Blackleaf Formation, from bottom to top: Flood, Taft Hill, Vaughn, and Bootlegger. Because these members cannot be readily mapped in Madison and Beaverhead Counties, the names were not used. In the course of developing Blackleaf stratigraphy in southwestern Montana, Dyman (1985a, b, d) and Dyman and others (1984) developed preliminary names for Blackleaf lithofacies (for example, the lower

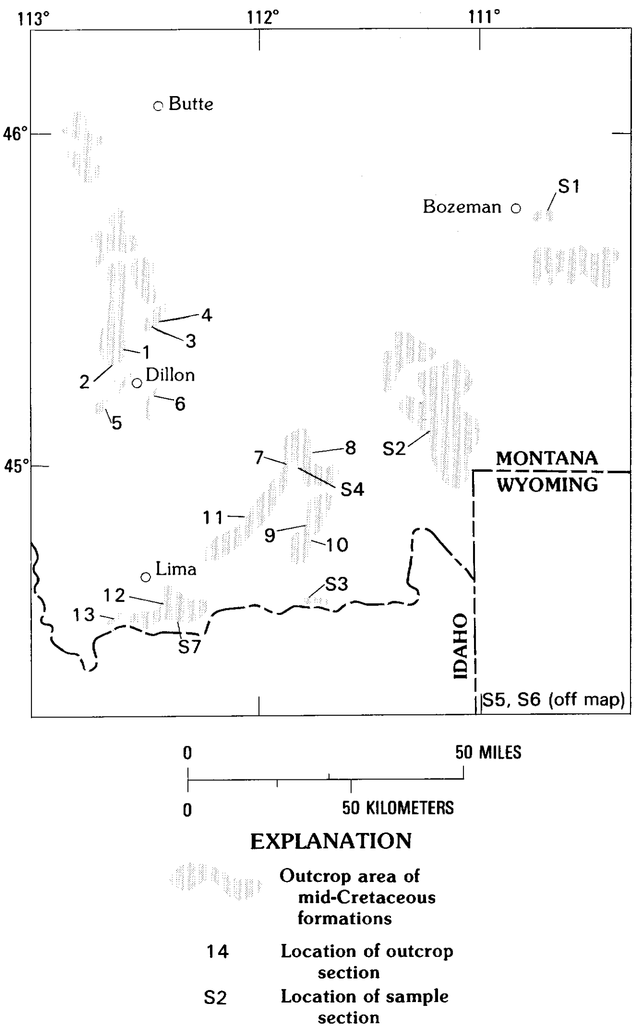


Figure 3. Map of southwestern Montana and adjacent areas showing outcrops of the Blackleaf and Frontier Formations and the location of outcrop sections and sample localities (see Appendix).

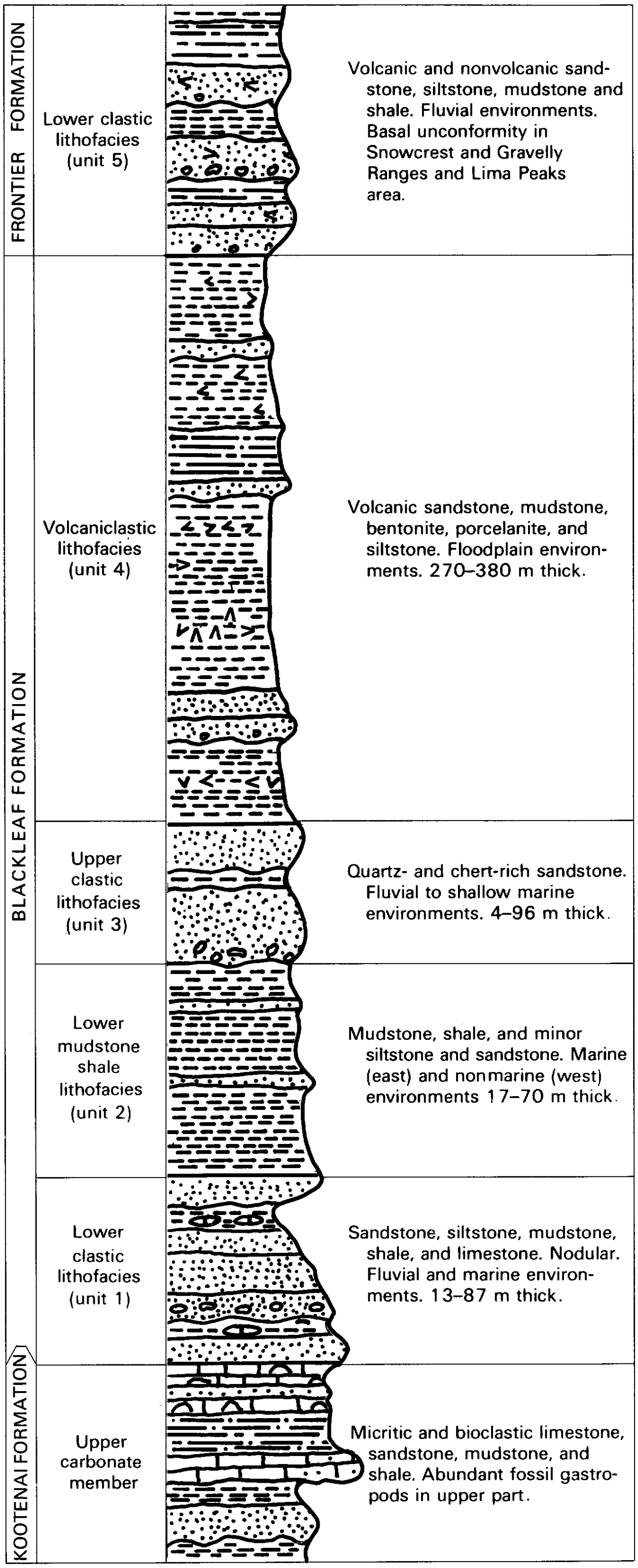


Figure 4. Stratigraphic description of the upper part of the Kootenai Formation, the Blackleaf Formation, and lower part of the Frontier Formation, Beaverhead and Madison Counties, Montana.

clastic lithofacies of this report was first called the lower transitional clastic lithofacies). Formal member names are not used with the Blackleaf Formation in this report because much work remains to be completed before lithofacies relationships can be fully worked out. Additional measured sections must be described and the pre-thrust-faulting spatial relationships of sections in different areas must be established. The Blackleaf Formation may be raised to group rank within the next few years as the stratigraphy of the Lima to Drummond area becomes better known, and some of the informal lithofacies names used here may become formations within the group. Other lithofacies may assume member names now used in the Drummond area.

The part of the Frontier Formation described in this study area is similar to the sandstone-rich lower Frontier (Veatch, 1907) near Kemmerer, Wyoming; whereas, the lower part of the Marias River Formation (Cobban and others, 1959) in northwest Montana that overlies the Blackleaf there contains more shale.

BLACKLEAF FORMATION

The Kootenai-Blackleaf contact is conformable and is defined in this study as the top of the last gastropod-rich limestone of the upper carbonate member of the Kootenai Formation (fig. 4). Although probably diachronous, the contact is well defined in the field. Discontinuous beds of micritic limestone and mudstone, rich in limestone nodules, occur above this contact, but these units contain no gastropods.

The Blackleaf-Frontier contact is conformable in the Pioneer and McCartney Mountains area but may be unconformable in the Snowcrest and Gravelly Ranges and in the Lima Peaks area. The top of the Blackleaf Formation is defined in this study at the base of the first thick sandstone, conglomerate, or dark-gray shale bed above the volcaniclastic lithofacies unit. The contact is best exposed in the Lima Peaks area where it is recognized by a sharp color change and lithologic break and by an erosional surface and a lag conglomerate. This contact is probably diachronous, and correlation was best made where palynologic data were available.

Thickness data for the total Blackleaf Formation are available from four surface sections and one exploratory well in the study area (fig. 6). The Blackleaf Formation varies in outcrop thickness from a minimum of 425 m south of Lima to a maximum of 600 m north of Dillon. Subsurface data within the Lima anticline are difficult to interpret because of possible structural complications (W. J. Perry, Jr., oral commun., 1984). Comparable apparent thickness values for the Blackleaf are available from wells (1) American Quasar 29-1 Peet Creek Federal (490 m); (2) Shell Oil Company 34X-13

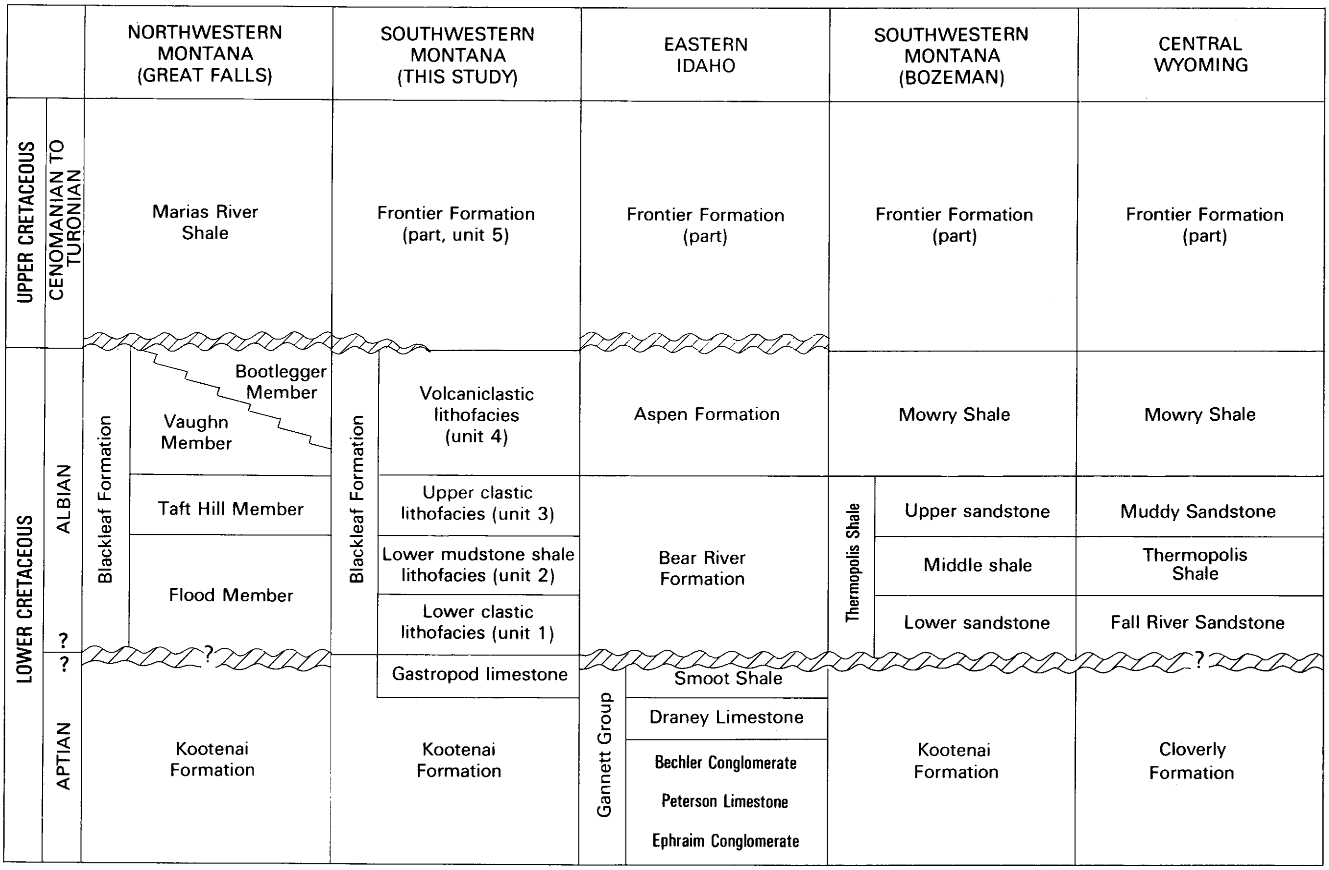


Figure 5. Stratigraphic nomenclature for strata of mid-Cretaceous age in western Montana, northeastern Idaho, and central Wyoming. Data from Gwinn (1960), Roberts (1972), McGookey and others (1972), Schwartz (1972), Cobban and others (1976), and Vuke (1984).

(580 m); and (3) CENEX 9-31 Lima (594 m) (fig. 2; table 1). Dipmeter data corrections (W. J. Perry, Jr., oral commun., 1985) suggest a true thickness of 465 m for the Blackleaf in the Peet Creek Federal well, a value comparable to the Lima Peaks surface section (425 m). Thickness variations from the Shell Oil Company 34X-13 borehole and the CENEX 9-31 Lima borehole are affected by steep dips and faulting (Perry and others, 1983, p. 734). The two dry holes near Dillon (May Petroleum No. 1 Margaret Hagenbarth and American Quasar 27-22 Hagenbarth boreholes) did not penetrate all of the Lower Cretaceous sequence.

Published thickness variations for the Blackleaf Formation are in part related to placement of the Blackleaf upper contact. Schwartz's (1972, 1983) Blackleaf Formation north of Dillon in the Pioneer Mountains (Apex section in this report; see Dyman, 1985a) was measured as more than 1,200 m (3,800 ft) thick. The upper part of the same section in this present report was considered part of the Frontier Formation.

Because of poor exposures and structural complications, a complete Blackleaf section could not be measured in the northern Snowcrest and Gravelly Ranges. The Ruby River section is faulted and does not represent a true Blackleaf thickness (Dyman, 1985a).

Lower Clastic Lithofacies (Unit 1)

Lithology and Thickness

Lower clastic lithologies include quartz- and chert-rich sandstone (quartzarenite, sublitharenite, and litharenite of Folk, 1968), siltstone, mudstone, and subordinate limestone, shale, and conglomerate. The sandstone is (1) generally gray or brown, (2) fine to medium grained, (3) thin to thick bedded, (4) very calcareous and iron stained, (5) commonly bioturbated, (6) horizontally laminated (fig. 7) to trough cross stratified, and (7) commonly ripple-laminated with well-developed symmetric ripples.

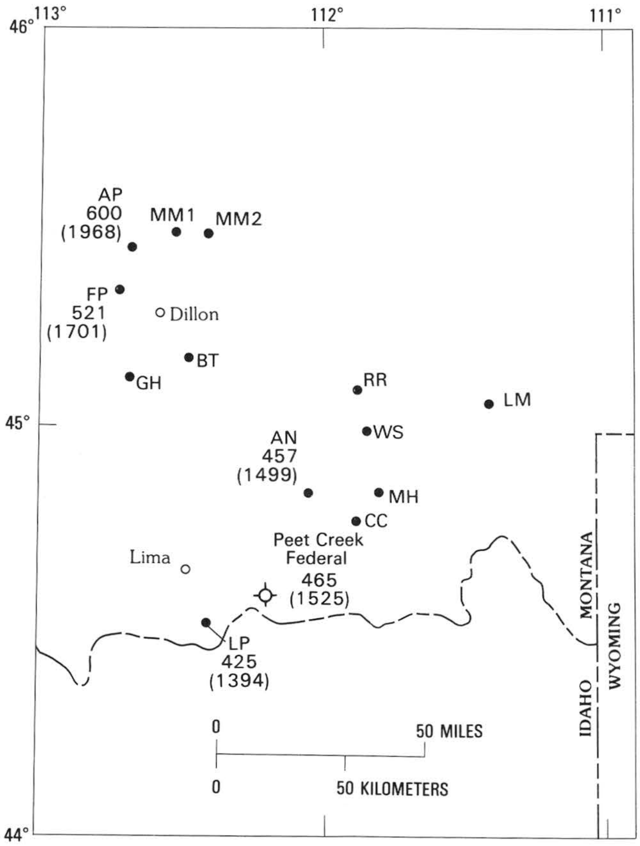
Siltstone is found above unit 1 sandstone in fining upward sequences that reach a maximum thickness of 7 m. The siltstone is gray to brown, finely laminated or

Table 3. Historical review of stratigraphic nomenclature for Cretaceous strata in parts of Madison and Beaverhead Counties, Montana.

Author and date of publication	Unit name	Type and location of study	Comments
Klepper (1950).	Frontier Formation Aspen Formation Bear River Formation Kootenai Formation	Reconnaissance in the Snowcrest Range.	Recognized each formation but mapped only Kootenai and overlying undifferentiated Upper Cretaceous strata.
Myers (1952).	unnamed units Kootenai Formation	Mapping in the Pioneer Mountains.	Mapped 4 unnamed units, one equivalent to Aspen Formation.
Ziegler (1954).	Thermopolis Formation Kootenai Formation	Mapping in the Snowcrest Mountains.	Mapped undifferentiated Upper Cretaceous strata.
Scholten and others (1955).	Aspen Formation Kootenai Formation	Mapping, and interpretations of the Lima Peaks area.	
Mann (1954, 1960).	Colorado Formation Kootenai Formation	Mapping, and interpretations of the Snowcrest Range.	Recognized 6 informal units above the Kootenai Formation.
Lowell (1965).	Colorado Shale	Mapping near Dillon, Montana.	
Roberts (1965, 1967, 1972).	Frontier Formation Mowry Shale Thermopolis Shale Kootenai Formation	Stratigraphy near Livingston, Montana.	
Hadley (1969, 1980).	Frontier Formation Thermopolis Shale Kootenai Formation	Mapping and interpretations in the northern Snowcrest Range.	
Moran (1971).	Thermopolis Shale	Mapping in the Centennial Range.	

Table 3. Continued

Author and date of publication	Unit name	Type and location of study	Comments
James (1977)	Blackleaf Formation Kootenai Formation	Sedimentology, stratigraphy, regional study in southwest Montana.	Described transitional beds between the formations.
Witkind (1977), Witkind and Prostka (1980).	Thermopolis Shale Kootenai Formation	Mapping in the Centennial Range.	Recognized a lower sandstone member and an upper shale member.
Peters (1970)	Colorado Group undifferentiated	Mapping in the Pioneer Mountains.	
Sharp (1970)	Colorado Group undifferentiated	Mapping in the Pioneer Mountains.	
Schwartz (1972, 1983).	Blackleaf Formation Kootenai Formation	Stratigraphy, sedimentology, and regional study in southwest Montana.	Subdivided the Blackleaf Formation into 4 formal litho-facies intervals.
Skipp and others (1979).	sandstone-claystone unit Kootenai Formation	Mapping in the Lima Peaks area.	Sandstone-claystone unit equvalent to Aspen Formation of Scholten and others (1955).
Sadler (1980)	Colorado Shale Kootenai Formation	Mapping in the Lima Peaks area.	
Achuff (1983)	Colorado Group Kootenai Formation	Mapping and structure in the Blacktail Range.	
Perry and others (1983).	Frontier Formation Blackleaf Formation	Structure in the southern Tendoy Mountains.	Recognized members of Blackleaf of Cobban and others (1976).



EXPLANATION

• LP 425 (1394)	**Location of outcrop section**—Letters designate section name, number represents thickness of unit in meters, m designates minimum thickness. Thickness in feet in parentheses
⌖ 465 (1525)	**Borehole**—Number designates thickness of formation in meters. Thickness in feet in parentheses

Figure 6. Map showing thickness of the total Blackleaf Formation in part of southwestern Montana. See Appendix for names and locations of outcrop sections. Missing data values due to incomplete sections.

structureless, and commonly bioturbated with variably oriented burrows. It commonly contains carbonaceous matter and wood fragments and is variably calcareous. Calcareous beds laterally grade into silty limestone.

Mudstone and shale are gray to red or green and often silty. They are variably calcareous, commonly nodular, and iron stained. Shale is relatively rare; however, interbedded fossiliferous mudstone and black shale are found at the base of unit 1 at the Ruby River section. Finely disseminated carbonaceous matter is present in some mudstone and most shale beds.

Subordinate gray limestone is micritic with well-developed laminations and algal(?) coatings. The limestone is generally silty and unfossiliferous and contains variable amounts of finely disseminated carbonaceous matter. Limestone beds are commonly nodular with nodules as much as 10 cm in diameter. Nodules are micritic and iron stained; they make up more than 50 percent of some beds (fig. 8). Limestone beds attain a maximum thickness of 1.8 m.

Conglomerate beds within unit 1 are uncommon; where present, they include basal-lag rip-up zones, and limestone-channel deposits that reach a maximum thickness of 1.5 m. Basal-lag deposits contain angular to subrounded mudstone, siltstone, and limestone rip-up clasts up to 2.5 cm (rare) in diameter, and occur at the bases of discontinuous sandstone beds. Rip-up zones are less than 5 cm thick and discontinuous. Limestone-channel deposits include clasts up to 10 cm in diameter that vary from 60 to 100 percent micritic limestone (fig. 9). Subordinate lithologies include mudstone, siltstone, and chert.

Unit 1 thicknesses range from 87 m at the McCartney Mountain and Apex sections north of Dillon to 13 m in the Gravelly Range east of Dillon (fig. 10). There is a marked eastward thinning of the unit.

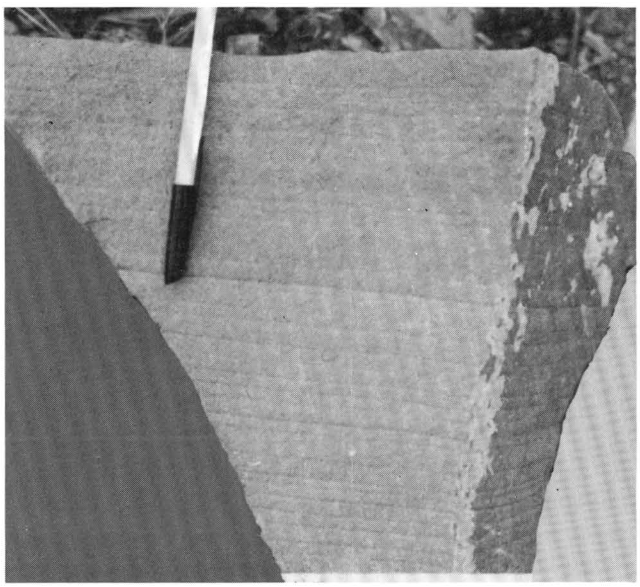


Figure 7. Flatbedded, iron-stained lithofacies unit 1 sandstone Blackleaf Formation, McCartney Mountain I section. Pen approximately 10 cm long.

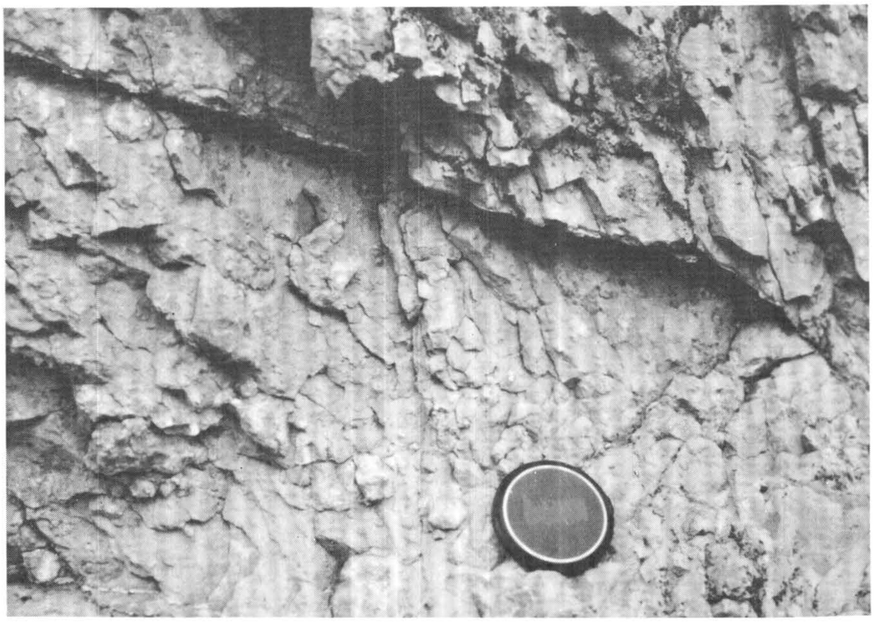


Figure 8. Nodular mudstone bed in lower part of lithofacies unit 1, Blackleaf Formation, McCartney Mountain I section. Lens cap approximately 6 cm in diameter.

Stratigraphic Relations, Age, and Correlation

The basal Blackleaf contact is conformable in the study area but is considered unconformable for equivalent rocks in parts of northwest Montana (Cobban and others, 1976; Mudge, 1972) and west-central Montana (Roberts, 1972). James (1977) considered the contact conformable in southwest Montana although he identified local fluvial channel scours at the contact.

The upper contact of unit 1 is established at the base of the first thick gray shale bed above the upper carbonate lithofacies of the Kootenai Formation (fig. 4). This contact is difficult to define in parts of the study area because unit 2 gray shale varies significantly in thickness, and unit 1 also contains such beds. The contact in this study is established arbitrarily but does define a major change in lithostratigraphic and sedimentologic character. Poor exposures at the Lima Peaks and Antone Peak sections prevented easy recognition of the upper contact.

Table 4 illustrates sample identification and location, genera and species, lithofacies, age determinations, and environments of deposition for 14 bivalve specimens from Blackleaf and Frontier samples. Three *Inoceramus comancheanus* Cragin molds (fig. 11) were found in the upper part of unit 1 at the Monument Hill section in the Gravelly Range. A similar Albian fauna was described by Cobban (1951) from the Skull Creek Shale and Fall River Sandstone in the Black Hills, and by Mudge (1972) from the Blackleaf Formation in Sun River Canyon. Cobban and others (1976) in part based an Albian Age for the Blackleaf Formation in northwestern Montana on the presence of the late Albian *Inoceramus comancheanus* Cragin Faunal Zone in the Flood Member.

Table 5 presents sample identification and location, genera and species, lithofacies, age determinations, and proposed environment of deposition for palynomorph assemblages in the study area. An assemblage near the base of unit 1 (Lima Peaks section, uppermost Kootenai Formation) exclusively provides a late Albian age (sample LP-7A-1). This uppermost Kootenai sample includes the species *Appendicisporites jansonii*, which ranges into the upper (but not uppermost) Albian (Nichols and others, 1982) and provides a maximum age for the overlying Blackleaf Formation.

Unit 1 is in part lithostratigraphically correlative with the lower sandstone of the Thermopolis Shale near Bozeman, and the Flood Member of the Blackleaf Formation near Great Falls, which Roberts (1972) and Rice (1976) correlated with the Fall River Sandstone.

Sedimentologically, unit 1 sandstone is predominantly fluvial and deltaic, especially to the west in the Pioneer Mountains.

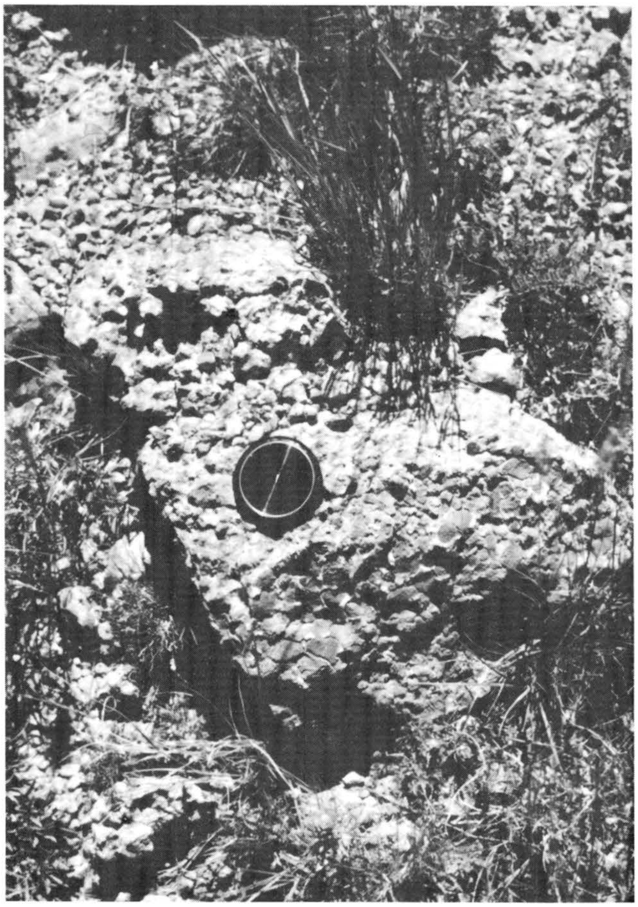


Figure 9. A limestone conglomerate, lithofacies unit 1, Blackleaf Formation, Lima Peaks section. Looking south with lower part of channel on left. Lens cap approximately 6 cm in diameter.

Lower Mudstone-Shale Lithofacies (Unit 2)

Lithology and Thickness

Lower mudstone-shale lithologies include mudstone, shale, siltstone, and subordinate chert- and quartz-rich sandstone (quartzarenite, sublitharenite, and litharenite of Folk, 1968). The shale is gray to black, is moderately to strongly fissile, and contains finely disseminated carbonaceous matter, wood fragments, coal, and rare bivalve fragments. Bioturbation is common and burrows and trails are well developed. Calcareous nodules up to 5 cm in diameter are abundant but limited to discrete intervals. Shale is variably calcareous and may be stained by hematite or limonite; it is usually interbedded with gray mudstone that is less bioturbated and contains less carbonaceous matter.

Sandstone is fine to very fine grained, brown to gray and light blue, variably calcareous, and parallel laminated. The sandstone contains generally straight-crested symmetric ripples, the tops of which may be strongly bioturbated.

Sandstone and siltstone at McCartney Mountain and in the Pioneer Mountains (Apex section) form the thickest unit 2 beds in the study area and may be up to 5 m thick. Black shale is the dominant lithology in the Gravelly Range, where interbedded siltstone and sandstone are rare (fig. 12).

Unit 2 thicknesses increase to the east and north (fig. 13). The high values in the McCartney Mountain and Frying Pan Gulch sections may reflect the transitional nature of the upper contact.

The lower mudstone-shale lithofacies in the Lima Peaks area and central Snowcrest Range is poorly

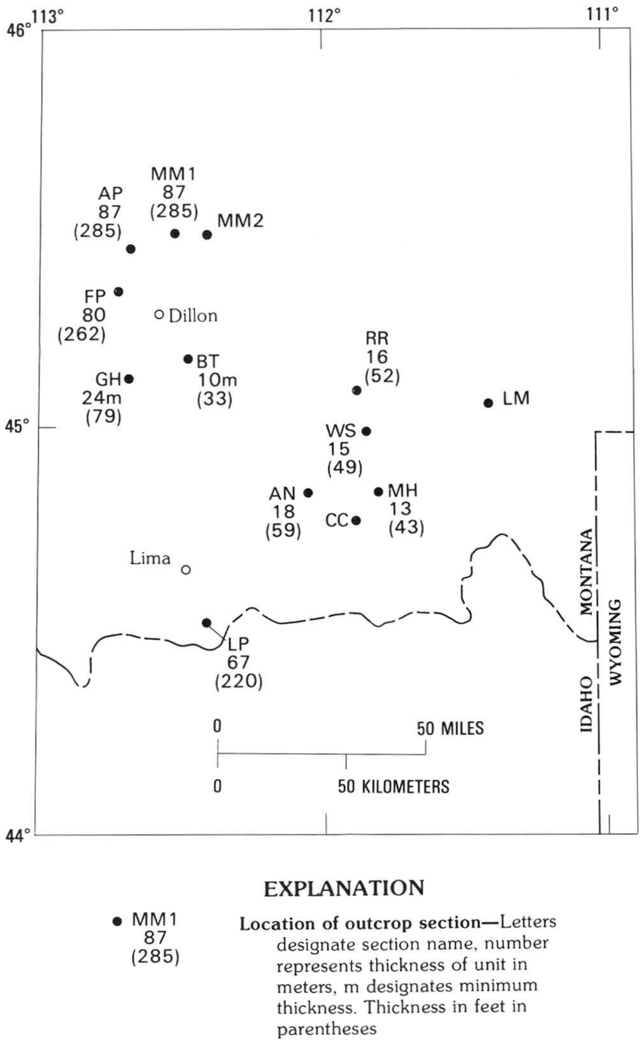


Figure 10. Thicknesses of lithofacies unit 1, Blackleaf Formation in parts of southwestern Montana. Missing data values due to incomplete sections. See Appendix for detailed section locations.

Table 4. Descriptions of molluscan fossils and associated strata in the Blackleaf and Frontier Formations, Beaverhead and Madison Counties, Montana.
[See Dyman (1985b) for additional stratigraphic information. Fossils identified by W. A. Cobban, U.S. Geological Survey. Leaders, no information]

Sample number and locality (see Appendix 1)	Name or description of fossils	Range span of fossil	Stratigraphic unit	Depositional environment
LP-A-1, LP-A-2, Lima Peaks section.	Small, poorly preserved bivalves, unidentifiable	---	Unit 1, Blackleaf Formation (near top of unit)	---
AP-166, Apex section.	*Tellina(?)*	---	Unit 5, Frontier Formation	Shallow marine to brackish(?)
RR-50, Ruby River section	*Pleurocardia pauperculum* (Meek).	Cenomanian and Turonian	Unit 5, Frontier Formation	Shallow marine, nearshore, sandy or silty environments.
AN-2, Antone Peak section.	Unidentified molds of bivalves and gastropods.	---	Unit 1, Blackleaf Formation	Brackish(?).
MH-4, (USGS Mesozoic locality D12625), Monument Hill section.	*Ostrea anomioides* Meek and an unidentified thick-shelled bivalve.	late Albian	Unit 3, Blackleaf Formation	Marine.
MH-6, Monument Hill section.	*Inoceramus comancheanus* Cragin.	late Albian	Unit 2, Blackleaf Formation	Marine.
WS-7, Warm Springs Creek section.	*Ostrea anomioides* Meek.	late Albian	Unit 3, Blackleaf Formation	Marine.

exposed. Lithology and electric logs from the Exxon Company No. 1 Myers Federal well southeast of Lima (fig. 2) suggest the presence of approximately 14 m of mudstone and shale in this interval.

Stratigraphic Relations, Age, and Correlation

The lower contact of unit 2 is established at the base of the first thick gray shale bed above the sandstone of unit 1. This contact is gradational with unit 1 and is difficult to define, particularly in the Pioneer Mountains, where unit 2 is thin. The upper contact is established at the base of the first thick sandstone bed (minimum thickness 5 m) of the upper clastic lithofacies. The upper boundary is also difficult to establish in the Pioneer Mountains because of interbedded sandstone and shale; however, the number and thickness of shale beds decrease significantly in this interval.

The lower boundary of unit 2 is also difficult to establish at the Warm Springs Creek and Ruby River sections. Here, unit 1 sandstone is rare, and dark-gray shale is the dominant lithology above the Kootenai Formation.

A single *Inoceramus comancheanus* Cragin mold (fig. 11) was found near the top of unit 2 at the Monument Hill section in the Gravelly Range supporting a late Albian age for the unit at this locality. Unit 2 palynomorph assemblages at both the McCartney Mountain

Table 5. Palynomorphs in the Blackleaf and lower Frontier Formations, Beaverhead and Madison Counties, southwest Montana
[See Dyman 1985a for additional stratigraphic information]

Sample number and locality (see Appendix 1)	Genera and species	Range span of fossils	Stratigraphic unit	Depositional environment
LP-7A-1, Lima Peaks section (USGS paleobotany locality D6586-A)	*Appendicisporites jansonii* *Cicatricosisporites* spp. *Concavissimisporites variverrucatus* *Cyathidites minor* *Pityosporites* sp.	late Albian	Uppermost Kootenai Formation (near base of unit 1)	Nonmarine.
LP-64-1, Lima Peaks section (USGS paleobotany locality D6586-B)	*Cicatricosisporites* sp. *Cyathidites minor* *Gleicheniidites senonicus* *Laevigatosporites* sp. *Taxodiaceaepollenites hiatus*	mid-Cretaceous	Unit 4, Blackleaf Formation	Nonmarine.
LP-102-1, Lima Peaks section (USGS paleobotany locality D6586-C)	*Araucariacites australis* *Cicatricosisporites* sp. *Cyathidites minor* *Gleicheniidites senonicus* *Laevigatosporites* sp. *Pityosporites* spp. *Taxodiaceaepollenites hiatus* *Tricolpites* sp.	mid-Cretaceous	Unit 4, Blackleaf Formation	Nonmarine.
LP-131-1, Lima Peaks section (USGS paleobotany locality D6586-D)	*Appendicisporites* sp. *Cicatricosisporites* spp. *Cupuliferoidae-pollenites* sp. *Cupuliferoipollenites* sp. *Cyathidites minor* *Densoisporites* sp. *Foveotriletes* sp. *Laevigatosporites* sp. *Microreticulati-sporites* sp. *Podocarpidites* sp. *Pseudoschizaea* sp. *Rugubivesiculites* sp. *Taxodiaceapollenites hiatus* *Tricolpites* sp. *Triporoletes reticulatus* *Vitreisporites pallidus* isoetalean microspores.	Cenomanian	Unit 5, Frontier Formation	Nonmarine aquatic.

Table 5. Continued

Sample number and locality (see Appendix 1)	Genera and species	Range span of fossils	Stratigraphic unit	Depositional environment
SRC-5-1, Antone Peak section (USGS paleobotany locality D6735)	*Araucariacites australis* *Callialasporites* sp. *Cicatricosisporites* sp. *Corollina* sp. *Costatoperforosporites foveolatus* *Cupuliferoidaepollenites* sp. *Cyathidites minor* *Foveotriletes* sp. *Gleicheniidites senonicus* *Laevigatosporites* sp. *Pityosporites* sp. *Rugubivesiculites* sp. *Taxodiaceaepollenites hiatus* *Vitreisporites pallidus*	Albian to Turonian	Unit 5, Frontier Formation	Nonmarine.
MM-33-1, McCartney Mountain section (USGS paleobotany locality D6737)	*Appendicisporites* sp. *Corollina* sp. *Cyathidites minor* *Gleicheniidites senonicus* *Stereisporites* sp. *Vitreisporites pallidus*	mid-Cretaceous	Unit 2, Blackleaf Formation	Nonmarine.
MH-8-1, Monument Hill section (USGS paleobotany locality D6738)	*Appendicisporites* sp. *Cicatricosisporites* sp. *Corollina* sp. *Cupuliferoidaepollenites* sp. *Gleicheniidites senonicus* *Taxodiaceaepollenites hiatus* *Pityosporites* sp. *Vitreisporites pallidus* dinoflagellate cysts, unidentified.	Albian and Cenomanian	Unit 2, Blackleaf Formation	Marine.
RR-17-1, Ruby River section (USGS paleobotany locality D6739-A)	*Cicatricosisporites* sp. *Costatoperforosporites foveolatus* *Cupuliferoidaepollenites* sp. *Cyathidites minor* *Gleicheniidites senonicus* *Laevigatosporites* sp. *Lycopodiumsporites* sp. *Pityosporites* sp. *Taxodiaceaepollenites hiatus* *Vitreisporites pallidus*	Albian to Turonian	Unit 2, Blackleaf Formation	Nonmarine.

Table 5. Continued

Sample number and locality (see Appendix 1)	Genera and species	Range span of fossils	Stratigraphic unit	Depositional environment
RR-46-1, Ruby River section (USGS paleobotany locality D6739-B)	*Arecipites*? sp. *Cupuliferoidaepollenites* sp. *Cyathidites minor* *Eucommiidites minor* *Laevigatosporites* sp. *Nyssapollenites albertensis* *Pityosporites* spp. *Rugubivesiculites* sp. *Vitreisporites pallidus*	Cenomanian	Unit 5, Frontier Formation	Nonmarine.
P 3736-54, Lima Peaks section (collected by W. J. Perry, Jr.; identified by A. D. Williams, written commun., 1982; confirmed by D. J. Nichols).	*Cicatricosisporites* sp. *Liliacidites* cf. *peroreticulatus* *Foraminisporis wonthaggiensis* *Ephedripites* sp. *Quadripollis krempii* tricolpate pollen *Michrystridium* sp. *Veryhachium* sp.	Probably Cenomanian to Turonian	Unit 5, Frontier Formation	Nonmarine or brackish.
P 3736-83, near Lima Peaks section, collected by W. J. Perry, Jr., from beds south of Sawmill Creek on north flank of Shine Hill, sec. 17, T. 15 S., R. 7 W.; identified by A. D. Williams, written commun., 1982; confirmed by D. J. Nichols; see also Nichols and others, 1985, locality D6600)	*Eucommiidites minor* *Krauselisporites* cf. *linearis* *Echinatisporis varispinosus* *Foveosporites subtriangularis* *Cicatricosisporites* sp. *Quadripollis krempii* *Triporoletes* sp. *Corollina* sp. *Cyathidites* sp. *Pityosporites* sp. *Taxodiaceaepollenites hiatus*	Albian to Turonian	Unit 5, Frontier Formation	Nonmarine.

(sample MM-33-1) and Monument Hill sections (sample MH-8-1) were not adequate to provide detailed ages.

Table 6 illustrates sample identification and location, genera and species, lithofacies, age determinations, and proposed environment of deposition for megafloral specimens in the study area. Two specimens of *Anemia fremonti* Knowlton (sample AP-X-1) were found in unit 2 at the Apex section in the Pioneer Mountains. Brown (1933) recognized *Anemia fremonti* Knowlton as common to both the Aspen and Frontier Formations in southwest Wyoming.

The lower mudstone-shale lithofacies is in part lithostratigraphically correlative with the middle shale member of the Thermopolis Shale near Bozeman, and the upper shale unit of the Flood Member of the Blackleaf Formation near Great Falls.

Unit 2 sandstone and siltstone may be marine, lagoonal, or deltaic in origin. Paleontologic data suggest a nonmarine environment of deposition in the west and a marine environment of deposition in the east.

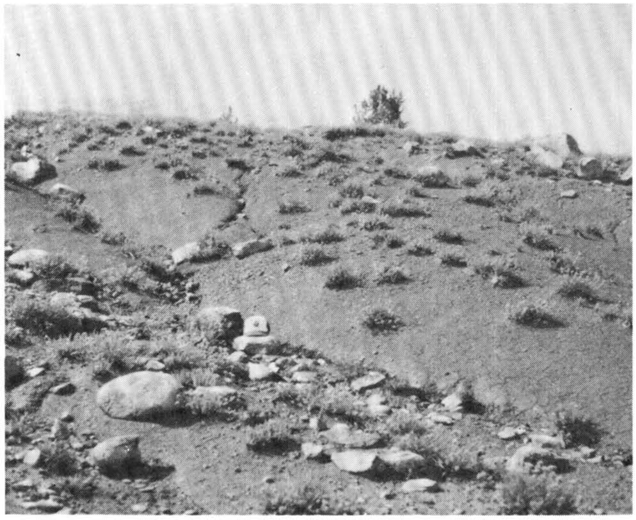


Figure 12. Outcrop of black shale in gully, lower part of lithofacies unit 2 Blackleaf Formation, Monument Hill section, Gravelly Range. View is north. Photo approximately 6 m across at base.

Figure 11. External mold of *Inoceramus comancheanus* Cragin, lithofacies unit 2, Blackleaf Formation, Monument Hill section, Gravelly Range. Pencil approximately 10 cm long.

Upper Clastic Lithofacies (Unit 3)

Lithology and Thickness

Upper clastic lithologies include quartz- and chert-rich sandstone (sublitharenite and litharenite of Folk, 1968) and subordinate mudstone, siltstone, shale, and conglomerate. Sandstone is gray to yellow brown, fine to coarse grained, variably calcareous, and medium to thick bedded (fig. 14). It contains abundant carbonaceous matter and wood fragments and is ripple laminated, trough cross-stratified, or horizontally laminated. In the east (Warm Springs Creek and Monument Hill sections), unit 3 sandstone is locally fossiliferous and contains rare glauconite grains.

Subordinate mudstone and shale are olive gray to dark gray, variably fissile, usually silty, weakly to moderately calcareous, bioturbated, and limonite stained. Carbonaceous matter and root structures are present in places. Dark-gray shale is locally present at the base of the unit. Mudstone beds up to 7 m thick occur in the Pioneer Mountains (Dyman, 1985b).

Subordinate siltstone is interbedded with unit 3 mudstone and shale or lies above unit 3 sandstone in fining-upward sequences. Siltstone is gray to brown, limonite stained, moderately calcareous, and commonly burrowed and bioturbated. Abundant carbonaceous matter and wood fragments are present. Siltstone in the lower part of unit 3 is rippled and occurs as thin (less than 5 cm) discontinuous beds. Individual fining upward cycles may exceed 10 m in thickness.

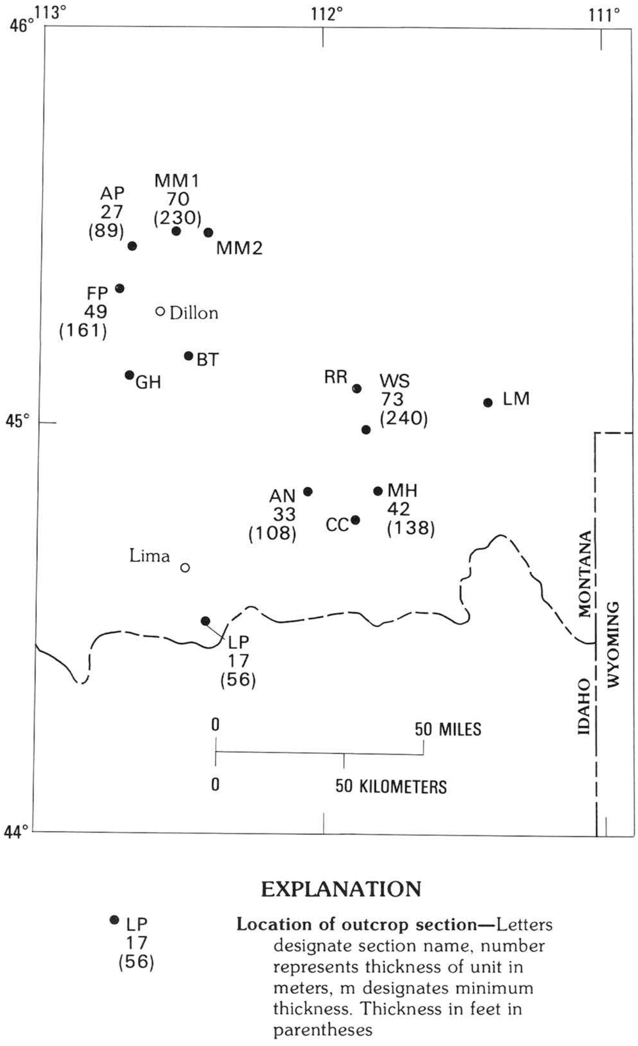


Figure 13. Thicknesses of lithofacies unit 2, Blackleaf Formation, in parts of southwestern Montana. Missing data values due to incomplete sections. See Appendix for detailed section locations.

Unit 3 conglomerate is locally abundant and occurs within sandstone beds as both intraformational rip-ups and exotic clasts. Intraformational deposits include angular-to-subangular mudstone, porcelanitic mudstone, and shale clasts (fig. 15). Exotic clasts include rounded to subrounded chert, quartzite, and argillite. Clasts may exceed 5 cm in diameter.

Unit 3 thickness data are presented in figure 16. Thicknesses range from a maximum of 76 m in the Pioneer Mountains (Apex section) to a minimum of 4 m at the Ruby River section in the Gravelly Range. The unit appears to thin eastward. The 36 m thickness at Frying Pan Gulch may be in part due to the gradational nature of the lower contact at that location.

Subsurface thicknesses for unit 3 range from a maximum of 135 m (Exxon Co. No. 1 Myers Federal Unit) to a minimum of 90 m (American Quasar Co. 29–1 Peet Creek Federal Unit) (figs. 2, 16). The Myers-Federal Unit section is structurally thickened (Perry and others, 1983).

Stratigraphic Relations, Age, and Correlation

The lower contact of unit 3 is at the base of the first thick sandstone bed (minimum thickness 5 m) above the shale and mudstone beds of unit 2 (fig. 4). The lower contact is locally unconformable because of the fluvial nature of unit 3 sandstone; it may be difficult to establish because of gradational change in lithologies from unit 1 to unit 2.

The upper contact is placed at the base of the first thick shale or mudstone bed above unit 3 sandstone. The character of this contact varies within the study area. In the Pioneer Mountains (Apex section), a thick sequence of unit 4 olive-green to brown mudstone lies above the

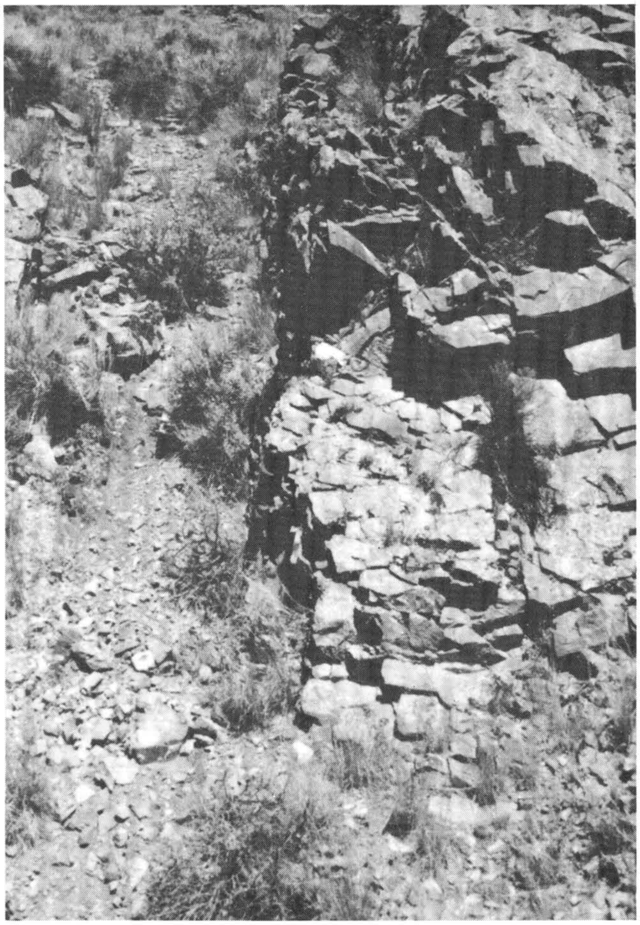


Figure 14. Sandstone and interbedded yellow-brown mudstone near middle of lithofacies unit 3, Blackleaf Formation, Apex section, Pioneer Mountains. Upsection is to the right. Photo approximately 3 m across at base.

Table 6. Descriptions of paleobotanical megafossils, Blackleaf and lower Frontier Formations, Beaverhead and Madison Counties, southwest Montana.
[Samples identified by C. J. Smoleu and W. Rember, University of Idaho, Moscow. See Dyman 1985a for additional stratigraphic information]

Sample number and locality (see Appendix 1)	Genera and species	Range span of fossils	Stratigraphic unit	Depositional environment
AP-X-1, Apex section.	*"Anemia fremonti"* Knowlton	Identified in Frontier Formation in Wyoming.	Unit 2, Blackleaf Formation	Nonmarine.
LP-138, Lima Peaks section.	*"Vitis(?)"* *"Populites"* *"Aralia veatchi"* Knowlton	Identified in Frontier Formation in Wyoming.	Unit 5, Frontier Formation	Nonmarine.
SRC-8, Antone Peak section.	Small, unidentified dicot leaf, wood and bark.		Unit 5, Frontier Formation	Nonmarine.
AN-C, Four miles west of Antone Peak section, on Clover Divide.	*Vitis*, unidentified dicot leaf base.		Unit 5, Frontier Formation	Nonmarine.
AP-181, Apex section.	*Tempskya* sp.	Albian or Cenomanian (?).	Unit 5, Frontier Formation	Nonmarine.
LP-X-1, Lima Peaks section.	Unidentified log		Unit 5, Frontier Formation	Nonmarine.
LP-114, Lima Peaks section.	Bone fragments and fish scales.		Unit 4, Blackleaf Formation	
Observation only (no sample).	*Tempskya* sp.	Albian or Cenomanian (?).	Unit 4, Blackleaf Formation	Nonmarine.

contact. In the Lima Peaks, Gravelly Range, and McCartney Mountain sections, gray mudstone is interbedded with dark-gray shale and subordinate sandstone. With the exception of local channeling at the base of sand bodies, this contact is considered conformable. West of the Boulder batholith Schwartz (1972) placed the upper contact of his interval C at the base of the stratigraphically lowest "volcaniclastic" bed. The method was not used for this study because a significant stratigraphic variation exists in the first appearance of volcanic detritus in unit 4 sandstone, and the volcanic lithic content of sandstone is difficult to determine in the field.

Ostrea anomioides Meek was identified from both the Warm Springs Creek and Monument Hill sections in a coquina bed at the base of unit 3 (table 4). Mann (1954) found similar specimens at Warm Springs Creek, and Cobban and others (1976) identified *O. anomioides* in the Taft Hill Member of the Blackleaf Formation near Great Falls. Cobban (in Hadley, 1980) identified additional specimens in the Varney quadrangle in the northern

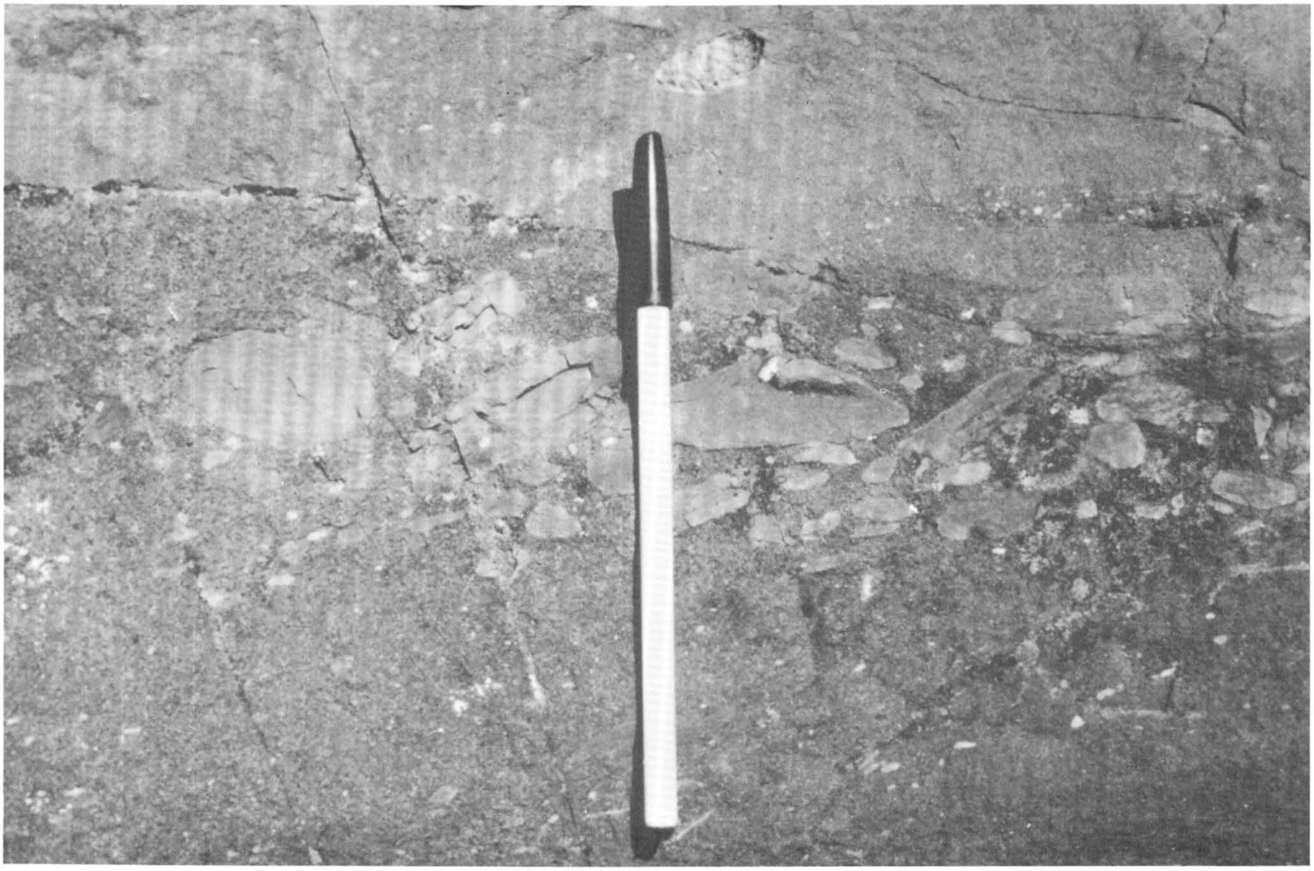


Figure 15. Conglomeratic bed near top of lithofacies unit 3, Blackleaf Formation, McCartney Mountain II section. Angular-to-subrounded mudstone clasts, imbricated. Pen approximately 10 cm long.

Gravelly Range. *Ostrea anomioides* is a marine bivalve of late Albian age (W. A. Cobban, oral commun., 1985). Neither palynomorphs or megafloral specimens were found in unit 3.

The upper clastic lithofacies is in part lithostratigraphically correlative with the upper sandstone member of the Thermopolis Shale near Bozeman, the upper sandstone unit of the Taft Hill Member of the Blackleaf Formation near Great Falls, and the Muddy Sandstone in Wyoming.

Unit 3 sandstone is fluvial, especially to the west in the Pioneer Mountains. However, the presence of a brackish water to marine bivalve coquina bed and rare glauconite grains at the base of unit 3 in the Gravelly Range suggest some marine to shoreface influence (table 4).

Volcaniclastic Lithofacies (Unit 4)

Lithology and Thickness

Unit 4 is the thickest and most heterogeneous lithofacies unit in the study area; it marks the first significant influx of volcanic detritus during Blackleaf deposition.

Unit 4 lithologies include mudstone, porcelanitic mudstone, siltstone, volcanic-rich sandstone (litharenite, lithic arkose, and feldspathic litharenite of Folk, 1968), tuff(?), limestone, and conglomerate (fig. 4). Mudstone is the dominant lithology. Lower unit 4 mudstone is generally olive green to gray, variably calcareous, weakly fissile, and structureless. Fossils are rare.

Porcelanitic mudstone is abundant in the middle and upper parts of unit 4, but uncommon in the lower part. Porcelanitic mudstone is highly variable in color with shades of red, gray, and green being dominant; it is in part hard and dense, weakly to strongly calcareous, and locally bentonitic. Bentonitic beds exhibit well-developed "popcorn texture" on exposed slopes (fig. 17). Mudstone may contain intraformational mud rip-ups and contorted bedding. Strongly calcareous nonporcelanitic mudstone laterally grades into micritic limestone. Ovular-shaped lithophysae (accretionary lapilli) up to 3 mm in diameter (Ross and Smith, 1961, p. 27) are abundant locally in tuffaceous(?) unit 4 mudstone beds in the Pioneer Mountains. Lithophysae were observed by Schwartz (1972) in equivalent beds, and by Wanless and others (1955) at the Willow Creek section near Alpine, Wyoming, in the upper part of the Aspen Formation.

Locally, upper unit 4 porcelanitic mudstone is very finely laminated with individual laminations less than 1 mm thick.

Unit 4 siltstone occurs as thin, discontinuous beds within unit 4 mudstone and above sandstone beds in discontinuous lenticular bodies. The siltsone is commonly tan or gray, rippled, micaceous, bioturbated, and variably calcareous. Pyrite crystals up to 1 cm in diameter are locally present.

Unit 4 sandstone is highly variable in color but is most commonly red or brown to gray. The sandstone is thin to medium bedded, generally fine grained, lithic-rich in the middle and upper part of the unit, variably calcareous, and hematite stained. Sandstone is subordinate to mudstone at all localities, especially in the Pioneer Mountains (Apex section), where the sand to shale ratio is 1:6. Sandstone is most commonly ripple laminated or flat bedded. Unit 4 conglomerate occurs as quartzite- and chert-pebble channel fills and as rounded to angular mudstone, shale, siltstone, and chert-pebble lag deposits.

Unit 4 thickness data are illustrated in figure 18. Data are sparse, and structural complications due to faulting exist at the Ruby River section. Thicknesses range from a maximum of 378 m in the Snowcrest Range (Antone Peak section) to a minimum of 271 m at the Lima Peaks section. Subsurface data near the Lima Peaks section vary in quality. Unit 4 is 270 m thick in the American Quasar 29-1 Peet Creek Federal well; however, a thickness of more than 600 m at the Exxon Co. No. 1 Myers Federal Unit is considered suspect and may be due to faulting or folding. Total unit 4 thicknesses are not available for other sections in the study area due to surface cover or erosion.

Stratigraphic Relations, Age, and Correlation

The lower contact of unit 4 is established at the base of the first thick mudstone and shale bed (minimum thickness 10 m) above unit 3 sandstone (fig. 4). The contact is considered conformable and is readily identifiable in the field.

In the Pioneer Mountains the upper contact is established at the first thick sandstone or conglomerate bed of the lower clastic lithofacies of the Frontier Formation. In the Lima Peaks area, however, the upper contact may be unconformable because of a sharp color and lithologic change, the presence of lag gravels above the contact, and palynologic, petrographic, and vitrinite data (Dyman, 1985c).

Sharp color and lithologic changes were also observed in the Snowcrest and Gravelly Ranges (Ruby River, Warm Springs Creek, and Antone Peak sections) within the same stratigraphic interval. The upper contact of unit 4 at Frying Pan Gulch is defined as at the base of a distinctive conglomerate bed 350 m above the base of the unit (fig. 19). This bed can be traced for more than a kilometer north of the measured section. Other conglomerate and sandstone beds occur within unit 4 at the Frying Pan Gulch, McCartney Mountain, and Apex sections, but they are laterally discontinuous (less than 50 m in length) and are thin (less than 2 m thick). The upper unit 4 contact at the Apex section is less dramatic but occurs at the base of a similar conglomeratic sandstone bed.

Two palynomorph assemblages from the Lima Peaks section (samples LP-64-1 and LP-102-1) indicate a mid-Cretaceous age for unit 4 at this locality (table 5).

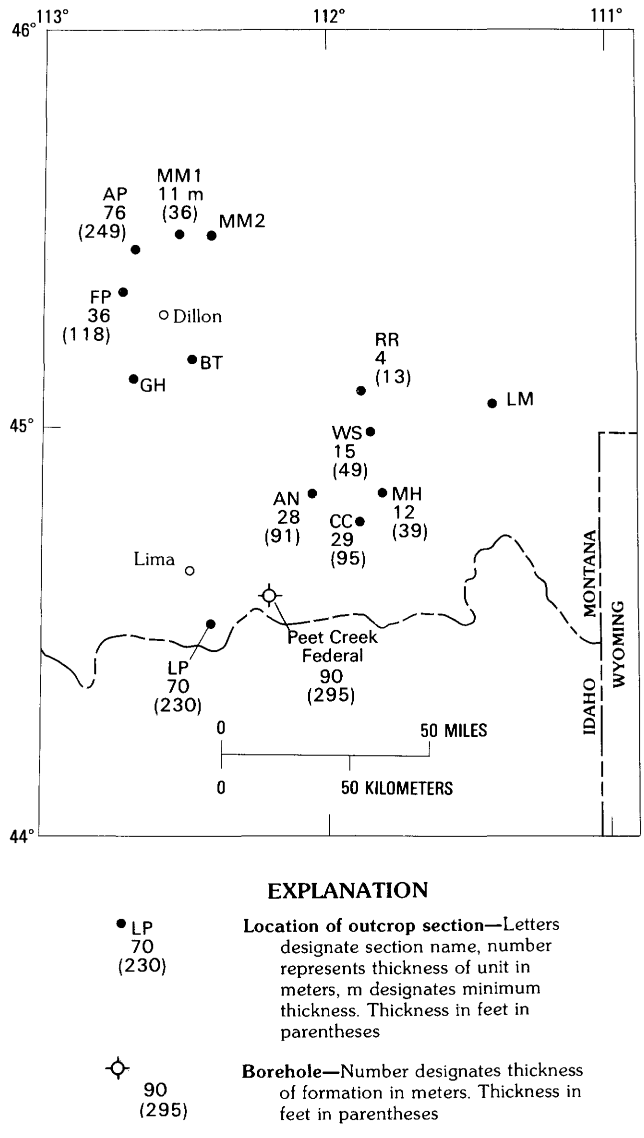


Figure 16. Thicknesses of lithofacies unit 3, Blackleaf Formation in parts of southwestern Montana. Missing data values due to incomplete sections. See Appendix for detailed section locations.

Figure 17. Mudstone beds with "popcorn" texture (left), lithofacies unit 4, Blackleaf Formation, Lima Peaks section. Photo approximately 10 m across at base.

An additional assemblage from the Ruby River section (sample RR-17-1) was limited in useful specimens and a more detailed age date is not available. A single specimen of *Tempskya* sp. was identified from unit 4 at the Lima Peaks section (table 6). Read and Ash (1961) recognized *Tempskya* only from the Albian of the Western United States, but C. J. Smiley (oral commun., 1985) indicated that it may in fact extend into the Cenomanian.

The volcaniclastic lithofacies is in part lithostratigraphically correlative with the Mowry Shale in central Montana and Wyoming, the Vaughn Member of the Blackleaf Formation near Great Falls, and the Aspen Formation of western Wyoming and southeastern Idaho.

Unit 4 was probably deposited on a broad floodplain. Fluvial channels are present but are relatively small. Periodic flooding resulted in the deposition of dark-gray mudstone. Finely laminated porcelanitic mudstone may have been deposited in low-energy lacustrine or lagoonal settings. Periodically, influx of volcanic detritus from nearby sources resulted in the deposition of bentonite and tuffaceous sediments.

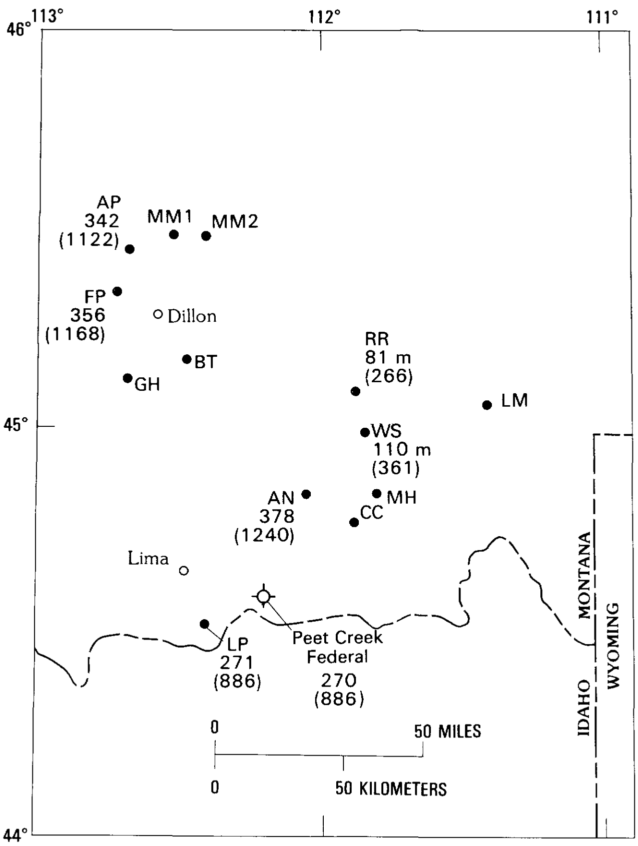
FRONTIER FORMATION

Lower Part, Lower Clastic Lithofacies (Unit 5)

Lithology and Thickness

Unit 5 records the first significant influx of coarse clastic detritus following unit 3 deposition. Volcanism, initiated with deposition of unit 4, continued during initial deposition of the Frontier Formation in Cenomanian time.

Unit 5 lithologies include sandstone (litharenite, lithic arkose, and feldspathic litharenite of Folk, 1968), conglomerate, shale, mudstone and porcelanitic mudstone, limestone, siltstone, and bentonite (fig. 4). Unit 5 sandstone is heterogeneous, varying from quartz- and chert-rich to lithic-rich beds upward in each section. Sandstone is gray to brown, medium to coarse grained, medium to thick bedded, generally cross stratified, moderately calcareous, and iron stained. Unit 5 conglomerate contains (1) quartzite-, chert-, and porcelanitic-rich, generally rounded to subrounded clasts in channels; or (2) angular to subangular rip-up clasts of porcelanitic mudstone at the base of small isolated channels. Clasts generally attain a maximum diameter of 0.3 m. Rare sandstone beds exceed 3 m in thickness. Unit 5 mudstone and shale are olive green to dark gray but are locally highly variable in color. They are weakly to strongly calcareous and bentonitic. Mudstone is locally porcelanitic (Pioneer Mountains sections) and contains beds rich in ovular lithophysae similar to those encountered in unit 4. Dark-gray shale occurs at the base or within the lower Frontier Formation as thin, discontinuous beds. Dark-gray shale may contain root



EXPLANATION

• AP 342 (1122) — **Location of outcrop section**—Letters designate section name, number represents thickness of unit in meters, m designates minimum thickness. Thickness in feet in parentheses

270 (886) — **Borehole**—Number designates thickness of formation in meters. Thickness in feet in parentheses

Figure 18. Thicknesses of lithofacies unit 4, Blackleaf Formation in parts of southwestern Montana. Missing data values due to incomplete sections. See Appendix for detailed section locations.

structures, leaf and wood impressions, bivalves, and isseminated coal. Concretions composed of micritic limestone as much as 0.4 m in diameter occur locally at the Apex section in the Pioneer Mountains.

Subordinate siltstone is found interbedded with unit 5 mudstone and shale or above unit 5 sandstone in fining upward sequences. Individual fining upward cycles may exceed 10 m in thickness. Siltstone is olive brown to gray, moderately calcareous, commonly burrowed and bioturbated, and contains abundant carbonaceous matter and leaf and wood impressions.

Unit 5 calcareous mudstone locally grades into micritic limestone in the Pioneer Mountains sections. Limestone is gray, thin-bedded, in part silty, and occurs as discontinuous beds. Unit 5 bentonite occurs as thin (less than 10 cm thick) gray beds within unit 5 mudstone or shale.

The basal sandstone of the Frontier Formation is easily identified in the subsurface near Lima (Exxon Co. No. 1 Myers Federal Unit and American Quasar Co. 29–1 Peet Creek Federal), but a Frontier thickness value is impossible to determine objectively because of structural complications, poor outcrop condition, and uncertainties as to where to place the upper contact.

Stratigraphic Relations, Age, and Correlation

The lower contact of unit 5 is established at the base of the first thick conformable sandstone or conglomerate bed (minimum thickness 5 m) above the base of unit 4 or at the suspected unconformity in the Snowcrest and Gravelly Ranges and in the Lima Peaks area. At both the Apex and Frying Pan Gulch sections, more than 300 m of lithic-rich sandstone, mudstone, and siltstone are exposed above the base of the Frontier Formation. Sandstone and conglomerate are the dominant lithologies at or near the base of the unit at these sections, but they decrease in abundance upward in the section.

In the Lima Peaks area, more than 150 m of sandstone, shale, mudstone, and conglomerate are exposed in a series of discontinuous outcrops above unit 4. In the Lima Peaks area and in the Snowcrest and Gravelly Ranges, 10–20 m of olive-gray to dark-gray shale and subordinate siltstone and mudstone lie immediately above the suspected unconformity at the base of the Frontier Formation. Sandstone increases in abundance above these beds. R. G. Tysdal (oral commun., 1985) observed dark-gray shale beds above the color-variant Blackleaf equivalents in the Madison Range to the east but considered them part of the Mowry Shale. These dark-gray shale beds are not correlative with the basal Frontier beds

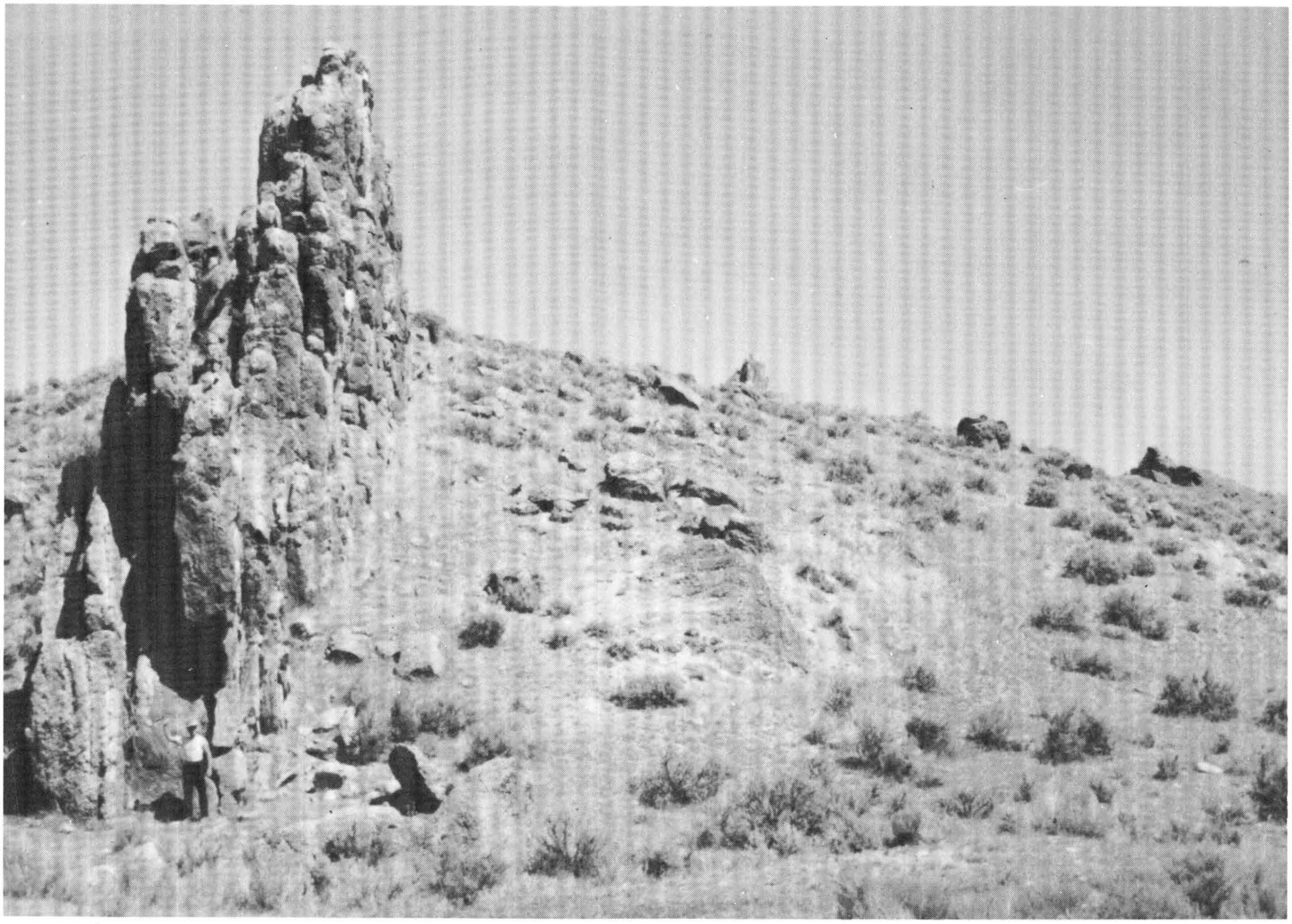


Figure 19. Basal conglomerate beds, lithofacies unit 5, Frontier Formation, Frying Pan Gulch section, Pioneer Mountains. Upsection is to the right. Conglomerate bed approximately 6 m thick. Person at base of conglomerate bed approximately 2 m tall.

in this study area (Tysdal and others, in press). More than 100 m of lower Frontier clastic rocks are exposed at the Ruby River section in the northern Snowcrest Range.

A single specimen of *Pleurocardia pauperculum* (Meek) was identified from the lower Frontier Formation at the Ruby River section in the northern Snowcrest Range (table 4). The species is found in sandy and silty nearshore marine environments of either Cenomanian or Turonian age (W. A. Cobban, oral commun., 1985). Other specimens could not be conclusively identified.

Palynomorph data also support a Cenomanian to Turonian Age for the lower part of the Frontier Formation (table 5). Sample LP-131-1 was collected 5 m above the upper Albian sample LP-102-1 at the base of the Frontier Formation. Sample LP-131-1 has a younger aspect than samples below in the Blackleaf Formation and resembles samples previously observed in the lower Frontier Formation in Wyoming.

Ryder and Ames (1970) considered conglomerate in the Lima Peaks area (Shine Hill sample locality; Dyman, 1985b) to be part of their Upper Cretaceous to Paleocene synorogenic Beaverhead Formation (Upper Cretaceous Beaverhead Group of Nichols and others, 1985), based in part on a palynomorph assemblage similar to sample P3736-83 (table 5). Sample P3736-83 was considered part of the Frontier Formation by Nichols and others (1985) based on a reinterpretation of the age significance of the assemblage and field observations from this study that suggest continuity with lower Frontier beds nearby.

Palynologic samples from the McCartney Mountain area and Pioneer Mountains were not useful because of extensive destruction due to thermal alteration associated with batholith intrusion. An assemblage from both the Apex and Frying Pan Gulch localities would have been valuable in correlating these sections with those to the south and east. Without these data, the lithostratigraphic correlations used to determine the Blackleaf-Frontier boundary in this area are considered tentative.

A single specimen of *Tempskya* sp. identified from the Frontier Formation at the Apex section (table 6) may represent an occurrence stratigraphically younger than previously recognized for the genus.

SUMMARY

The Blackleaf and lower Frontier Formations can be subdivided into five easily recognized lithofacies: (Blackleaf) lower clastic (unit 1), lower mudstone-shale (unit 2), upper clastic (unit 3), volcaniclastic (unit 4), and (lower Frontier) lower clastic (unit 5). The Blackleaf Formation reaches a maximum thickness of 600 m in the Pioneer Mountains.

The lower clastic lithofacies (unit 1) is conformable with the underlying Kootenai Formation; varies from 87 m (west) to 13 m (east) in thickness; includes quartzarenite, litharenite, mudstone, micritic limestone, siltstone, and limestone conglomerate; and was deposited in fluvial, deltaic, and lagoonal settings.

The lower mudstone-shale lithofacies (unit 2) is conformable with unit 1; varies from 73 m (east) to 17 m (southwest) in thickness; includes mudstone, shale, siltstone, and subordinate sandstone; and was deposited in shallow marine (east) to lagoonal and floodplain (west) settings.

The upper clastic lithofacies (unit 3) is conformable with unit 2; varies from 76 m (west) to 4 m (east) in thickness; includes litharenite, and subordinate siltstone and mudstone; and was deposited in fluvial and deltaic (west) to shallow marine (east) settings.

The volcaniclastic lithofacies (unit 4) is conformable with unit 3; varies from 378 m to 270 m in thickness; is lithologically heterogeneous and includes mudstone, shale, bentonite, porcelanite, lithic- and chert-rich sandstone, and conglomerate; and was deposited in a floodplain setting.

The Frontier Formation, lower clastic lithofacies (unit 5) is in part unconformable with unit 4; includes chert- and lithic-rich sandstone, conglomerate, mudstone, and shale; and was deposited in fluvial to shallow marine(?) brackish water environments.

The Blackleaf Formation is late Albian in age and the lower part of the Frontier Formation is Cenomanian to Turonian in age based on analysis of bivalve and palynomorph data. The Cenomanian or Turonian Shine Hill conglomerate unit in the Lima Peaks area is not equivalent to the Upper Cretaceous Beaverhead Group but is equivalent to or should be placed in the Frontier Formation on the basis of palynomorph data.

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★ **U.S. GPO:** 1988 573-047/66,062

APPENDIX

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CODES, LOCATIONS AND SOURCE FOR SECTIONS AND SAMPLE LOCALITIES DESCRIBED IN THIS STUDY

1.	AP:	Apex section. Lithofacies units 1–5 present. SE½ section 7, S½ section 6, T. 5 S., R. 8 W., Twin Adams Mountain Quadrangle, Beaverhead County, Montana (Dyman, 1985b).
2.	FP:	Frying Pan Gulch section. Lithofacies units 1–5 present. Section 30, T. 6 S., R. 9 W., Bond Quadrangle, Beaverhead County, Montana (Dyman, 1985b).
3.	MM:	McCartney Mountain I section. Lithofacies units 1–4 present. E½ sections 21 and 28, S½ section 16, T. 4 S., R. 8 W., Block Mountain Quadrangle, Madison County, Montana (Dyman, 1985b).
4.	MM2:	McCartney Mountain II section. Lithofacies units 1–3 present. NE¼ section 35, T. 4 S., R. 8 W., Block Mountain Quadrangle, Madison County, Montana (Dyman, 1985b).
5.	GC:	Grasshopper Creek section. Lithofacies unit 1 present. SE¼ section 26, T. 8 S., R. 10 W., Dalys Quadrangle, Beaverhead County, Montana (Dyman, 1985b).
6.	BT:	Blacktail Creek section. Lithofacies unit 1 present. NE¼ section 15, T. 9 S., R. 9 W., west of Crampton Ranch, Gallagher Mountain Quadrangle, Beaverhead County, Montana. (Dyman, 1985b).
7.	RR:	Ruby River section. Lithofacies units 1–5 present. SE¼ section 18, T. 9 S., R. 3 W., Home Park Ranch Quadrangle, Madison County, Montana (Dyman, 1985b).
8.	WS:	Warm Springs Creek section. Lithofacies units 1–5 present. E½ section 15, and NE¼ section 22, T. 9 S., R. 3 W., Varney Quadrangle, Madison County, Montana (Dyman, 1985b).
9.	CC:	Cottonwood Iron Creek section. Lithofacies units 1–3 present. N½ section 25, T. 10 S., R. 3 W., Monument Ridge Quadrangle, Madison County, Montana (Dyman, 1985b).
10.	MH:	Monument Hill section. Lithofacies units 1–5 present. Unsurveyed area about ½ mile west of Gravelly Range Road along southwest flank of Monument Hill, Monument Ridge Quadrangle, Madison County, Montana (Dyman, 1985b).
11.	AN and SRC:	Antone Peak section. Lithofacies units 1–5 present. NW¼ section 22, SW¼ section 11, T. 12 S., R. 5 W., Antone Peak Quadrangle, Beaverhead County, Montana (Dyman, 1985b).
12.	LP:	Lima Peaks section. Lithofacies units 1–5 present. Sections 13, 14, and 18, T. 15 S., R. 8 W., Lima Peaks Quadrangle, Beaverhead County, Montana (Dyman, Niblack, and Platt, 1984).

13\. LS: Little Sheep Creek sample locality. Lithofacies units 1-4 present. N½ section 26, T. 15 S., R. 9 W., Gallagher Gulch Quadrangle, Beaverhead County, Montana (Dyman, unpub. data, 1985).

S-1\. RC: Rocky Creek Canyon sample locality. Lithofacies units 1-5 present. SW¼ section 20, T. 2 S., R. 7 E., north side highway I-90, Gallatin County, Montana (Roberts, 1972, p. C 61).

S-2\. LM: Lincoln Mountain sample locality. Lithofacies units 1-5 present. Section 7, T. 9 S., R. 4 E., along south flank of Lincoln Mountain, Gallatin County, Montana (Hall, 1961).

S-3\. CR: Centennial Range sample locality. Lithofacies unit 5 present. W½ section 30, T. 14 S., R. 37 E., west side Price-Peet road, Corral Creek Quadrangle, Beaverhead County, Montana (Dyman, unpub. data, 1985).

S-4\. WS: Warm Springs Creek sample locality. Lithofacies unit 1 present. Section 21, T. 9 S., R. 3 W., junction Warm Springs road and Ruby River road, Varney Quadrangle, Madison County, Montana (Dyman, unpub. data, 1985).

S-5\. SR: Snake River sample locality. Lithofacies units 1-3 present. Section 4, T. 37 N., R. 117 W., (unsurveyed) north side of highway 89 east of Wolf Creek, Lincoln County, Wyoming (Durkee, 1980).

S-6\. WC: Willow Creek sample locality. Lithofacies units 1-5 present. Sections 6 and 7, T. 38 N., R. 116 W., West side of Willow Creek, Teton County, Wyoming (Wanless and others, 1955).

S-7\. SH: Shine Hill sample locality. Lithofacies unit 5 present. E½ section 17, T. 15 S., R. 7 W., Snowline Quadrangle, Beaverhead County, Montana (Dyman, unpub. data, 1985).