

CORRELATION CHART OF LOWER CRETACEOUS ROCKS, MADISON RANGE TO LIMA PEAKS AREA, SOUTHWESTERN MONTANA

By

R.G. Tysdal, T.S. Dyman, and D.J. Nichols

Abstract

Lower Cretaceous strata in southwestern Montana were deposited in a nonmarine facies of the Cordilleran foreland in the west and in a marine shelf facies of the foreland in the east. Some of the strata represent time-equivalent sediments deposited in different environments, and different names have been applied previously to the same strata even within the same area. The four measured sections presented here are in sequences of strata that have been telescoped by thrust faults of Late Cretaceous to early Tertiary age, and facies represented in the measured sections originally were deposited farther apart than they are now. Strata described herein are underlain by the Aptian to Albian(?) Kootenai Formation and are overlain by the Cenomanian to Turonian lower part of the Frontier Formation.

In the Snowcrest Range and Lima Peaks area, strata represented by the two westernmost measured sections are assigned to the Albian Blackleaf Formation, which contains the Flood Member and the overlying volcanoclastic-rich Vaughn Member. The Taft Hill and Bootlegger Members of the Blackleaf Formation, in their type sections near Great Falls, are not recognized by us in southwestern Montana. The two easternmost measured sections represent strata in the Madison, Gravelly, and Greenhorn Ranges, where Albian rocks are assigned to the Thermopolis Shale, Muddy Sandstone, and Mowry Shale. In southwestern Montana the Thermopolis Shale and overlying Muddy Sandstone are lithically equivalent to the Flood Member of the Blackleaf Formation, whereas the Mowry Shale is equivalent to the Vaughn Member. Strata in the Snowcrest Range have characteristics in common with both the eastern and western facies. The geographic location for the

change in nomenclature is arbitrary, but is placed along the axis of the Ruby River valley, which separates the Snowcrest Range from the Greenhorn and Gravelly Ranges.

INTRODUCTION

Lower Cretaceous rocks in southwestern Montana represent strata that were deposited in the foreland basin of the Cordilleran thrust belt in the west and in a shelf facies of the foreland in the east. The strata record cyclic sedimentation during a succession of marine transgressions and regressions, which were caused by an interaction of source-area tectonism, basin subsidence, and varied rates of sedimentation. The four measured sections are in sequences of strata that have been telescoped by thrust faults of Laramide age, thus facies represented in the measured sequences were originally deposited farther apart than they are now. Some of the strata represent time-equivalent sediments deposited in very different environments, and several names have been applied to the same strata within the same area. Hence, nomenclatural problems of the region represented by the sections are addressed in this report.

Strata equivalent to several formations present on the shelf also can be recognized in the basinal sequences to the west. Facies changes occur from east to west, but the rock units are recognized as broadly similar. The purpose of this report is to review stratigraphic relationships and nomenclature in the region, and to present a revision of the correlations for the units. These goals are accomplished through the presentation of new data, including measured sections, and reinterpretation of existing data.

MEASURED SECTIONS

The locations of the four measured sections are shown on figure 1. The two westernmost measured sections, Lima Peaks and Antone Peak, and the lower part (Warm Springs Creek) of the Greenhorn composite section in the valley between the Greenhorn and Gravelly Ranges, were selected from twelve original descriptive sections released in Open-File reports by Dyman and others (1984), Dyman (1985a, b), and additional data of Dyman. The upper part (Cow Camp) of the Greenhorn composite section, and the Lincoln Mountain section in the Madison Range, are previously unpublished sections of Tysdal. These four sections record the most diverse strata that we know of in the region. The Lincoln Mountain section is nearly completely exposed, but the Antone Peak section in the southern part of the Snowcrest Range is poorly exposed. The lower and upper parts of the Greenhorn composite section lie within 1.5 mi (2.5 km) of one another.

The four measured sections and their stratigraphic correlations are presented here using the SRG (Stratigraphic Report Graphic). The SRG is a stratigraphic applications computer program developed by the U.S. Geological Survey and Petroleum Information Corporation of Denver, Colo. The SRG accepts sedimentologic, paleontologic, lithologic, paleoecologic, and nomenclatural data for outcrop sections and cores, and displays these data in a scale-variant format (see "Explanation of measured sections") (Petroleum Information Corporation, 1984; Dyman and others, 1985). The SRG is proprietary to Petroleum Information Corporation, but is available by contract to the U.S. Geological Survey for a variety of research applications.

STRATIGRAPHY

The eastern two measured sections represent strata of the Madison, Gravelly, and Greenhorn Ranges (fig. 1). The Lower Cretaceous rocks in these areas are assigned to the Aptian to Albian(?) Kootenai Formation and the Albian Thermopolis Shale, Muddy Sandstone, and Mowry Shale; lowermost Upper Cretaceous rocks are assigned to the Cenomanian to Turonian lower part of the Frontier Formation. In the Snowcrest Range and Lima Peaks area, represented by the western two measured sections, strata correlative with those formations previously named are assigned to the Aptian to Albian(?) Kootenai Formation, the Albian Blackleaf Formation, and the Cenomanian lower part of the Frontier

Formation. Several different names had been used previously for strata that here are called Blackleaf Formation, but no consistent pattern of nomenclature had been established, in part because of local lithologic and facies changes and the great distance between outcrops and type localities. The decision by Dyman and others (1984) and Dyman (1985a, b, c) to apply the names Blackleaf and Frontier to Cretaceous strata in Beaverhead County and the southwestern part of Madison County, Mont., was made after reviewing the literature and carefully examining the area near Blackleaf Creek, Mont., the type area of the Frontier at Cumberland Gap, Wyo., and additional outcrops (Dyman and Nichols, 1988).

The measured sections bridge areas where different shelf and foreland basin terminology are used currently. The lithic character of the Lower Cretaceous stratigraphic units is very much the same in the Madison, Greenhorn, and Gravelly Ranges. In the Lima Peaks area, however, the lithic equivalents of the eastern units are different and use of the Blackleaf name is appropriate. Strata of the Snowcrest Range, represented by the poorly exposed Antone Peak section, seem to have characteristics more like those of the Lima Peaks section than those of the Greenhorn composite section. Reconnaissance data suggest that the Lower Cretaceous rocks of the Snowcrest Range may change character gradually along the length of the range. Hence, the geographic location for the change in nomenclature is somewhat arbitrary, but is here placed along the axis of the Ruby River valley, which separates the Snowcrest Range from the Greenhorn and Gravelly Ranges (fig. 1). This placement is respectful of historical usage of nomenclature in the Greenhorn and Lima Peaks areas, as well as the differing lithic character of the Lower Cretaceous units in different parts of the region. Lower Cretaceous strata of the eastern part of the Centennial Mountains are judged to have characteristics more in common with the eastern strata than with the Blackleaf rocks. Post-Kootenai Lower Cretaceous strata present in the Exxon and American Quasar boreholes near the western part of the Centennial Mountains (fig. 1) were assigned to the Blackleaf Formation by Perry (1986), but Perry (oral commun., 1987) now believes that strata of the American Quasar borehole (the eastern of the two boreholes) are more representative of facies recognized within the eastern part of the region considered in this report.

Stratigraphic relationships and regional correlations are illustrated in figure 2. In discussing stratigraphic relationships, we generally proceed from east to west, from shelf to foreland basin.

All megafossils reported here, including those in cited references, were identified by W.A. Cobban except where otherwise noted. Palynomorphs were identified by D.J. Nichols and are shown in tables 1 and 2.

PREVIOUS WORK

Early works concerned with the Lower and Upper Cretaceous rocks in southwestern Montana commonly were mapping studies, and they generally left the sequence separated into the Kootenai Formation and an undivided unit of overlying strata. In the general area of the measured sections, strata above the Kootenai were assigned to the "Colorado and Montana formations" (Peale, 1896), "Colorado formation" (Mann, 1954, 1960), "Colorado Shale" (Lowell, 1965), Colorado Group (Klepper, 1950; Christie, 1961; Becraft and others, 1970; Garihan and others, 1983), Blackleaf and Frontier Formations undivided (McBride, 1988), or were neither divided nor named (Swanson, 1950; Brasher, 1950; Sheedlo, 1984). In the Lima area, the Aspen Formation (Scholten and others, 1955; Ryder, 1968; Ryder and Ames, 1970; Skipp and others, 1979), and "Colorado Shale" (Sadler, 1980) also have been used for these strata. The term Colorado Group is not used here. The stratigraphy of the Upper Cretaceous Frontier Formation and correlative strata has not been worked out in the western part of southwestern Montana; hence, facies relationships between the Frontier and Upper Cretaceous rocks of the Colorado Group in northwestern Montana are unknown. The Aspen Formation (Veatch, 1907) is geographically restricted to eastern Idaho and western Wyoming, where it is used in conjunction with the underlying Bear River Formation. Strata described here resemble the Blackleaf Formation in northwestern Montana more than they resemble the Bear River Formation.

The post-Kootenai Lower Cretaceous strata on the eastern side of the Pioneer Mountains, northwest of the area of our sections, were assigned to the "Colorado formation" (Richards and Pardee, 1925; Karlstrom, 1948), left unnamed (Myers, 1952), and later placed in the Colorado Group (Ruppel and others, 1983; Pearson and Zen, 1985; Zen, 1988). We cite these studies because they include some of the earliest work undertaken on Lower Cretaceous strata in southwestern Montana, and indicate that the strata do not readily lend themselves to subdivision. In addition, the Pioneer Mountains area contains strata that were studied in detail by other workers

(cited, where appropriate, in following section of this report) who were specifically concerned with Lower Cretaceous rocks, and who also examined rocks in part of the region of the four measured sections presented in this report.

Many studies divided strata above the Kootenai into lithofacies, members, or formations. Because the names and the strata that workers included differed from one area to the next, other studies are cited and discussed where applicable in the following sections. We have attempted to cite all relevant university theses, but others of which we were unaware may exist.

KOOTENAI FORMATION

The Kootenai Formation is discussed briefly in this report because it underlies all of our measured sections, and contact relationships with overlying rocks require an understanding of the upper part of the Kootenai. The basal part of each of the measured sections shown represents strata of the uppermost part of the Kootenai Formation. In southwestern Montana the Kootenai has been divided into as many as six units (for example, DeCelles, 1986). It typically contains a basal conglomeratic sandstone, a variety of medial sandstone and mudstone strata, and carbonate strata in the upper part. Two units of carbonate strata have been recognized regionally, the upper of which contains an abundance of gastropods (Holm and others, 1977). The gastropod limestone is commonly considered to mark the top of the formation in southwestern Montana and is used in this report.

In the shelf area of southwestern Montana, gastropods are absent locally from the uppermost carbonate strata, as shown by our studies and the graphic sections of Vuke (1984) in the Madison Range. The overlying lower sandstone member of the Thermopolis Shale, or equivalent lithofacies, lacks carbonate beds in the sections examined by us in the Madison, Greenhorn, and Gravelly Ranges. Klepper (1950) previously had used the gastropod limestone to mark the top of the Kootenai in the Snowcrest Range. The contact is sharp, marks an upward change from nonmarine to marine strata, and is disconformable. In the Lima Peaks area, non-gastropod-bearing limestone occurs upsection of the gastropod limestone. Discontinuous lenses of nodular micritic limestone and calcareous mudstone are interbedded with sandstone and siltstone that are typical of the lower sandstone member of the

Thermopolis. These strata were assigned to the lower part of the Blackleaf Formation by Dyman and Nichols (1988) because (1) the gastropod limestone is a widespread marker unit that is readily identifiable, (2) the gastropod limestone is readily mappable, and (3) the carbonate beds above the uppermost gastropod limestone are discontinuous and thus do not represent a reliable marker unit.

A late Albian palynomorph assemblage was identified in the uppermost part of the Kootenai Formation in the Lima Peaks section, providing a maximum age for the Blackleaf Formation at this locality (table 1). The assemblage was obtained from dark-gray shale below the uppermost gastropod limestone bed.

BLACKLEAF FORMATION

The Blackleaf name previously had been used for Lower Cretaceous rocks in southwestern Montana (including the area of the four sections presented here) by Schwartz (1972, 1983), James (1977), and Suttner and others (1981); and in the Lima Peaks area by Perry and others (1983) and Perry (1986). In addition, Dyman and others (1984), Dyman (1985a, b, c), and Dyman and Nichols (1988) used Blackleaf for the western three of the measured sections presented in this report.

In northwestern Montana, Cobban and others (1959) named four members of the Blackleaf Formation, from bottom to top: Flood, Taft Hill, Vaughn, and Bootlegger (fig. 2). Detailed measured sections of these members were presented in Cobban and others (1976). The Flood(?) name has been used in southwestern Montana by Perry and others (1983). Dyman (1985a, b, c), Dyman and Nichols (1988), and Schwartz (1972, 1983) used informal names for lithic intervals or units of the Blackleaf Formation. We follow Perry and others (1983) in using the name Flood Member to encompass the lowermost strata of the Blackleaf Formation, consisting of two sandstone units separated by a unit of black shale (the lithic equivalent of the shale member of the Thermopolis Shale). We recognize that the sandstone units of this tripartite member differ in character from those in the type section near Flood Siding in Cascade County, Mont. Preliminary study of correlative sandstone units between Lima Peaks and the Drummond area of central western Montana indicate that their character differs areally, although the tripartite nature still exists. We have not recognized the Taft Hill and Bootlegger Members in southwestern Montana. The

Vaughn Member consists predominantly of nonresistant beds of nonmarine bentonitic mudstone in pastel shades of gray, green, pink, orange, and brown in the area of our measured sections, although nonbentonitic mudstone is present in the Madison Range. Porcellanitic mudstone, volcanoclastic sandstone and siltstone, and tuff are also present in the study area but are more abundant and form part of a much thicker Vaughn sequence west and northwest of the area of this study.

Lithic units of the Blackleaf Formation of this report are similar to the four lithofacies intervals (designated A, B, C, D) of Schwartz (1972, 1983). But, because Schwartz did not publish his measured sections or present them in his dissertation, precise correlation with his lithofacies intervals is difficult. On the other hand, some major differences exist between his descriptions of the four intervals and our observations. For example, descriptive material in Schwartz (1972) makes clear that, as defined by him, the upper part of the Blackleaf Formation in some areas in the Greenhorn Range includes Upper Cretaceous strata that we consider part of the Frontier Formation.

The Blackleaf Formation in the area of the western two sections varies in thickness from a maximum of 1,500 ft (457 m) at the Antone Peak section in the Snowcrest Range to a minimum of 1,394 ft (425 m) at the Lima Peaks section. Similar thicknesses have been reported in the subsurface near the Lima Peaks section (Perry and others, 1983). Corrected dip-meter data (W.J. Perry, Jr., oral commun., 1985) for the American Quasar Peet Creek Federal 29-1 borehole (fig. 1) suggest a thickness of 1,525 ft (465 m), a value comparable to the thickness exposed near Lima Peaks.

The lithology, thickness, and other geologic properties of the members and (or) lithic units of the Blackleaf Formation are discussed below with correlative strata of the Thermopolis Shale, Muddy Sandstone, and Mowry Shale.

THERMOPOLIS SHALE

The name Thermopolis Shale is used in the Livingston area of southwestern Montana (figs. 1, 2) for a sequence of strata that is composed of three informal members: a lower sandstone, a middle shale, and an upper sandstone (Roberts, 1965, 1972). Roberts recognized these members as lithic equivalents of the Fall River Sandstone, the Skull Creek Shale, and the Muddy Sandstone, respectively.

The lower sandstone also is the lithic equivalent of the "rusty beds" that make up the upper part of the Cloverly Formation in Wyoming; and the middle shale is the lithic equivalent of the Thermopolis Shale. For the southern part of the Madison Range, Witkind (1969) had tentatively made correlations with the rocks of the Livingston area and used the Thermopolis name. In this report, and in Tysdal (in press), we follow the usage for contiguous strata in northwestern Wyoming and use the name Muddy Sandstone for the upper sandstone in the Madison, Greenhorn, and Gravelly Ranges. We follow Roberts (1972) in using the informal name lower sandstone member of the Thermopolis Shale for the lithic equivalent of the Fall River Sandstone and the rusty beds, and shale member of the Thermopolis Shale for the correlative of the Thermopolis Shale in Wyoming. Using either the Fall River or Skull Creek names would entail transposing names across areas of southern Montana for which the Wyoming-derived nomenclature now is widely used.

Lower sandstone member of the Thermopolis Shale, and Flood Member of the Blackleaf Formation

The lower sandstone member of the Thermopolis Shale in the Madison Range is composed of pale-brown to rusty colored, fine-grained, crossbedded quartz arenite, and characteristically displays abundant oscillatory ripple marks. The upper few feet of the unit at Lincoln Mountain is composed of maroon to dark-brown siltstone, separated by mudstone layers. The lower contact is sharp and probably is unconformable. Vuke (1984) reported the unit to be almost entirely quartz arenite at some localities. According to Vuke (1984) for the Madison Range, and Schwartz (1972) for the entire region, the sandstone member is marine and was deposited in a shoreface environment. In the Flood Member of the Blackleaf Formation in the two western sections, the lithic equivalent of the lower sandstone member of the Thermopolis consists of green to gray and red calcareous mudstone, quartz- and chert-rich sandstone, and micritic and nodular limestone; these strata were deposited in fluvial, lacustrine, and near-shore marine environments (Dyman and Nichols, 1988).

The lower sandstone member is 121 ft (37 m) thick at the Lincoln Mountain measured section, and ranges from 55 to 120 ft (17 to 37 m) thick within the Madison Range (Vuke, 1984; Witkind, 1969). At the composite Greenhorn section the lower sandstone

member is 50 ft (15 m) thick, and its lithic equivalent in the lower part of the Flood Member of the Blackleaf Formation at the Lima Peaks section increases to a thickness of 220 ft (67 m).

In the Madison Range, the lower sandstone member of the Thermopolis Shale was assigned to the lower part of the Bear River(?) Formation by Austin and Stoeber (1950); Hall (1961) used the name "upper sandstone member" of the Kootenai Formation; Hadley (1969a, 1980) used "shale unit" of the Kootenai Formation; Lauer (1967), Ray (1967), Rose (1967), and Bolm (1969) also placed the sandstone in the upper part of the Kootenai; Wilson (1970) subdivided the unit into a silty sandstone member and an overlying rusty beds member and placed both in the Kootenai; Witkind (1969) designated the rocks the "sandstone member of the Thermopolis(?) Shale"; Kehew (1971) and Walsh (1971) mapped it with the Thermopolis Shale; Vuke (1984) used the named "rusty beds member of the lower Thermopolis Formation"; and Tysdal and Simons (1985) referred to the unit as the lower half of the Thermopolis Shale.

In the Greenhorn Range and the northernmost part of the contiguous Gravelly and Snowcrest Ranges, Mann (1954, 1960) included sandstone here assigned to the lower sandstone member in the "upper sandstone member" of the Kootenai Formation, and Hadley (1960, 1969b, 1980) used the term "shale unit" of the Kootenai Formation. In the central part of the Snowcrest Range, Gealy (1953) and Zeigler (1954) recognized these clastic rocks as equivalents of the rusty beds and mapped them as part of the Thermopolis Shale. In the southern part of the Snowcrest Range, Keenmon (1950) assigned the sandstone unit to the basal sandstone member of the Bear River(?) Formation. In the southern part of the Gravelly Range, Christie (1961) and Sonderegger and others (1982) mapped the sandstone as the top unit of the Kootenai. In the Centennial Mountains and the southern part of the Gravelly Range, Honkala (1969) apparently placed the lower sandstone member in the "Colorado shale." Also in the Centennial Mountains, Kennedy (1947) assigned the sandstone immediately above the gastropod limestone of the Kootenai to the Bear River Formation; Witkind (1975, 1982) and Witkind and Prostka (1980) placed this sandstone unit in the Thermopolis(?) Shale. In the Lima area, Dillon (1949) included this sandstone in the Bear River Formation.

Three molds of *Inoceramus comancheanus* Craigin, a species of late Albian age, were found in the upper part of the lower sandstone member of the Thermopolis near Monument Hill in the Gravelly

Range, about 10 mi (16 km) south of the Greenhorn composite section (Dyman and Nichols, 1988). Three species of lacustrine ostracods (identified by I.G. Sohn) were reported by Hadley (1980, p. 71-72) from the lower part of the lower sandstone member near the Greenhorn composite section. They are Cypridea wyomingensis Jones sensu Peck 1941, Cypridea anomala Peck 1941, and Eupera onestae (McLearn).

Shale member of the Thermopolis Shale, and shale unit of the Flood Member of the Blackleaf Formation

In the Madison, Gravelly, and Greenhorn Ranges and the Centennial Mountains, the shale member of the Thermopolis Shale is a marine unit that is composed mainly of black fissile shale, but contains thin beds of sandstone in the uppermost part. The equivalent lithofacies of the Flood Member of the Blackleaf Formation in the Snowcrest Range and Lima Peaks area consists predominantly of mudstone, shale, siltstone, and subordinate fine-grained sandstone and limestone; these strata were deposited in lagoonal to shallow-marine environments (Dyman and Nichols, 1988). The shale member is 39 ft (12 m) thick at the Lincoln Mountain section, and ranges from about 30 to 300 ft (10 to 90 m) thick in the Madison Range (Vuke, 1984; Witkind, 1969). In the area from the Greenhorn and Snowcrest Range sections to the Lima Peaks section, the shale lithofacies ranges from 56 to 240 ft (17 to 73 m) thick. At the Lima Peaks section, the shale interval of the Blackleaf is poorly exposed. Dyman and others (1984) originally considered this interval part of their upper clastic lithofacies. Lithology and electric logs from the Exxon Company No. 1 Myers Federal well, located about 8 mi (11 km) east of the Lima Peaks section (fig. 1), indicate the presence of 46 ft (14 m) of mudstone and shale in this interval.

Albian palynomorphs have been reported from the shale member in the central part of the Madison Range (Vuke, 1982) and in the area of the Greenhorn Range section (Hadley, 1980). Tysdal (in press) collected the bivalve Inoceramus bellevuensis Reeside from the black shale at several localities within the central part of the Madison Range, and Dyman and Nichols (1988) reported a single mold of Inoceramus comancheanus Cragin (late Albian) at the top of the lithofacies near Monument Hill in the Gravelly Range.

In the Madison Range the shale member was assigned to the upper part of the Bear River(?)

Formation by Austin and Stoeber (1950); the name Thermopolis(?) Shale was used by Hall (1961) and the "dark-shale member" by Hadley (1969a, 1970), both of whom equated it with the black shale unit of the Thermopolis Shale of Wyoming. Lauer (1967), Ray (1967), Rose (1967), Bolm (1969), Kellogg (1971), and Walsh (1971) placed the shale unit in the Thermopolis Shale; and Wilson (1970) used the name Thermopolis Shale for the black shale unit only. Other workers recognized its equivalence to the Skull Creek Shale of Montana, but applied different names: basal strata of the upper part of the Thermopolis(?) Shale (Witkind, 1969); upper member of the Thermopolis Formation (Vuke, 1984); and upper part of the Thermopolis Shale (Tysdal and Simons, 1975).

In the Greenhorn Range and the northernmost parts of the contiguous Gravelly and Snowcrest Ranges, Mann (1954, 1960) described the black shale unit and assigned it questionably to the "Colorado Formation." Hadley placed the same unit in the Thermopolis Shale, variously calling it the "middle shale member" (Hadley, 1960) and later the "dark-shale member" (Hadley, 1980), and recognized its lithic correlation with the Skull Creek Shale. In the central part of the Snowcrest Range, Gealy (1953) and Zeigler (1954) mapped these strata as the Thermopolis Shale. In the southern part of the Snowcrest Range, Keenmon (1950) included these strata within the Bear River(?) Formation. In the southern part of the Gravelly Range, this lithofacies was called "Cretaceous Shale, unnamed" (Sonderegger and others, 1982), and "Colorado shale" (Honkala, 1949). In the Centennial Mountains, Kennedy (1947) mapped the shale as part of the Bear River Formation; Witkind (1975, 1976) mapped it as the Bear River(?) Formation, but recognized its correlation with the Thermopolis Shale; Witkind and Prostka (1980) and Witkind (1982) called it the shale member of the Thermopolis(?) Shale. In the Lima Peaks area, Dillon (1949) placed equivalent strata in the Bear River Formation.

MUDDY SANDSTONE, AND UPPER SANDSTONE OF THE FLOOD MEMBER OF THE BLACKLEAF FORMATION

The Muddy Sandstone at Lincoln Mountain in the Madison Range is composed of two yellowish-green, crossbedded, thin-bedded sandstone units that are separated by a unit of mudstone. In a detailed sedimentological study of the Muddy in the Madison

Range, Vuke (1984) concluded that the strata were deposited, from base to top, in distal delta front, delta-front sheet sand, and distributary channel environments. The Muddy at the Greenhorn composite section, and its lithic equivalent in the Flood Member of the Blackleaf Formation in the western two sections, consists of quartz- and chert-rich sandstone and interbedded mudstone deposited in fluvial, deltaic, and nearshore marine environments (Dyman and Nichols, 1988).

The Muddy Sandstone is 115 ft (35 m) thick at the Lincoln Mountain section. Vuke (1984) did not give thicknesses for this unit in the Madison Range, but we calculated a maximum thickness of about 85 ft (26 m) from her cross sections. Witkind (1969) estimated a thickness of 50 ft (15 m) for the Muddy(?) Sandstone in the southern part of the Madison Range, and it is 49 ft (15 m) thick at the Greenhorn composite section. In the area of the western two sections, the lithic equivalent of the Muddy ranges from 92 to 230 ft (28 to 70 m) thick.

To our knowledge, no fossils have been identified from the Muddy in the Madison Range, but the shallow-water marine bivalve Ostrea anomioides Meek was reported by Hadley (1980) and Dyman and Nichols (1988) from the Greenhorn Range.

In the Madison Range, Austin and Stoeber (1950) considered this unit to be part of the Aspen(?) Formation; Hall (1961) mapped the unit as the Muddy(?) Sandstone; Witkind (1969) mapped it as the Muddy(?) Sandstone Member of the Thermopolis(?) Shale; Hadley (1969a, 1980) considered it the upper unit of the Thermopolis Shale; Bolm (1969) considered the sandstone to be the Muddy Sandstone Member of the Thermopolis Formation; Lauer (1967), Ray (1967), Rose (1967), Wilson (1970), Kehew (1971), Walsh (1971), Vuke (1984), Tysdal and Simons (1985), and Tysdal (in press) used the formation name Muddy Sandstone.

In the Greenhorn Range and the northernmost parts of the contiguous Gravelly and Snowcrest Ranges, Mann (1954, 1960) described the stratigraphic unit here called Muddy and questionably assigned it to the "Colorado Formation." Hadley (1960, 1969b, 1980) assigned the sandstone to the Thermopolis Shale, referring to it as the upper sandstone member in his early paper, but leaving it unnamed in his latter two publications. In the central Snowcrest Range, Gealy (1953) and Zeigler (1954) placed the sandstone in the upper part of the Thermopolis Formation. In the southern part of the Snowcrest Range, Keenmon (1950) did not describe a sandstone unit at the stratigraphic horizon of the unit, stating that rocks at the contact of the Bear River(?)

and overlying Aspen(?) strata were poorly exposed. In the southern part of the Gravelly Range, clastic rocks of the Muddy Sandstone were included with the Aspen Formation by Sonderegger and others (1972). In the Centennial Mountains, Kennedy (1947) did not distinguish a sandstone unit correlatable with the Muddy lithofacies. A sandstone that Witkind (1975, 1976) included with the Aspen(?) Formation may be the lithic equivalent of the Muddy Sandstone; Witkind (1982) stated that beds which he previously assigned to the Aspen(?) Formation may have been mapped as Beaverhead(?) Formation. Honkala (1949) probably included this lithofacies within the Aspen Formation. In the Lima Peaks area, Dillon (1949) measured strata that he assigned to the Bear River Formation; we consider a sandstone unit in the upper part of his section to be the upper sandstone of the Flood Member of the Blackleaf Formation.

MOWRY SHALE

The Mowry Shale is a bipartite formation in part of the region being considered in this report. It consists of a lower unit of pastel-colored bentonitic strata, called the Vaughn Member, and an upper unit of dark-gray mudstone. The Vaughn Member pinches out eastward in southwestern Montana and likely intertongues with strata not readily discerned from Mowry strata that overlie the Vaughn. Where the Vaughn Member is present such time-equivalent strata occur within the informal unit called the upper part of the Mowry; where the Vaughn is absent the time-equivalent rocks and strata of the upper part of the Mowry are grouped together as Mowry Shale undivided. The upper unit is present only in the Madison Range, although it may have been deposited farther west and subsequently eroded.

Vaughn Member of Mowry Shale, and of Blackleaf Formation

A sequence of light-colored bentonitic strata overlies the Muddy Sandstone, and its lithic equivalent in the Blackleaf Formation, over a large area of southwestern Montana. In the Madison Range, Hall (1961) assigned the name "Albino" to the sequence of pastel beds and recognized that it was lithically similar to the Vaughn Member of the Blackleaf Formation in the area near Great Falls, Mont. The Albino name was never used beyond the range, however. Vaughn strata in the area of the type

section are a lithic correlative of the Mowry Shale (Cobban and others, 1959). Tysdal and others (in press) assigned the name Vaughn Member to these strata in the Madison Range, and throughout a large area of southwestern Montana, and made the Vaughn a member of the Mowry Shale. Thus defined, the Vaughn is a member of both the Blackleaf Formation and the Mowry Shale.

In the Madison Range the Vaughn strata were deposited in a marsh environment according to Wilson (1970) and Vuke (1984); Wilson reported the brachiopod *Lingula* in the uppermost pastel strata, indicating some marine influence. In the area of the western two sections, Dyman and Nichols (1988) considered the pastel beds of the Vaughn Member as deposited in lacustrine to flood plain environments. The Vaughn Member is 270 ft (82 m) thick at Lincoln Mountain in the Madison Range, but it is absent from some other areas of the Madison Range. At the Lima Peaks section the unit is 885 ft (271 m) thick. The member has a maximum thickness of 1,240 ft (378 m) at the Antone Peak section, but poor exposures characterize the section; covered intervals could conceal a fault or faults that caused repetition of strata.

The name Mowry Shale was used by Reeside and Cobban (1960, p. 21, 48) to describe beds in the Madison Range that yielded pelecypod and fish fragments, but no description of a stratigraphic unit was given. Swanson was cited as providing the data, although post-Kootenai strata had not been subdivided by Swanson (1950). Austin and Stoeber (1950) assigned these strata to the Aspen(?) Formation and, as noted above, Hall (1961) proposed the name "Albino" for the sequence of pastel beds. Lauer (1967), Ray (1967), Rose (1967), Kehew (1971), and Walsh (1971) used the name "Albino" for the pastel beds. Bolm (1969) used "Albino" for the pastel beds, and Wilson (1970) and Crabtree (1988) used "Albino" as a member of the Mowry Shale. Hadley (1969a, 1980) assigned the pastel beds to the Frontier Formation. Schwartz (1972) considered the pastel beds to be in the lower part of his lithofacies interval D. Vuke (1984), Tysdal and Simons (1985), and Tysdal (in press) assigned the pastel strata to the lower part of the Mowry Shale.

In an area about 10-12 mi (16-19 km) north of the Lincoln Mountain section, Vuke (1984) reported that a lithic equivalent of the pastel beds in the Lincoln Mountain area is represented by a light-colored, 10-ft (0.3-m) thick volcanoclastic sandstone unit, which she placed in the uppermost part of the Muddy Sandstone. We agree that the two volcanoclastic sequences are correlative, but consider the light-colored sandstone in

the northern exposures to be part of the Vaughn. The thickness of the light-colored volcanoclastic unit varies greatly throughout the range.

In the Greenhorn Range and the contiguous northern part of the Gravelly and Snowcrest Ranges, Mann (1954, 1960) assigned the pastel beds to the Colorado Formation. Klepper (1950, p. 69) assigned them to the Colorado Group and clearly recognized the possibility that they were a lateral equivalent of the Mowry Shale or perhaps the lower part of the Frontier Formation. Hadley (1960, 1969b, 1970) assigned the pastel beds to the Frontier Formation. In the central part of the Snowcrest Range, Gealy (1953) and Zeigler (1954) included the pastel beds in a unit called "undivided rocks of the Colorado and Montana groups" and "undifferentiated Colorado and Montana groups," respectively. In the southern part of the Snowcrest Range, Keenmon (1950) included the pastel lithologies within the Aspen(?) Formation. In the central part of the Gravelly Range, Sonderegger and others (1982) placed the pastel beds and overlying rocks (below the Upper Cretaceous Beaverhead Conglomerate) within the Aspen Formation. In the Centennial Mountains, Kennedy (1947) assigned all Cretaceous strata younger than the Bear River Formation to the Mesaverde Formation; such an assignment would include the pastel beds. Honkala's (1949) descriptions show that he assigned the pastel beds and immediately overlying rocks to the Aspen Formation, although he indicated that strata younger than the pastel beds may be included within the unit as well. Witkind (1975, 1976) included the pastel beds and overlying strata within the Aspen(?) Formation; Witkind (1982) later stated that he may have mapped strata as Beaverhead(?) Formation that are beds which he previously assigned to the Aspen(?) Formation. Near Lima Peaks, Dillon (1949) placed the pastel beds within the Aspen Formation.

Pastel beds in the Madison Range have yielded a Cretaceous megafloral assemblage, component identifications of which have been presented in Hall (1961), Wilson (1970), Vuke (1982), and Crabtree (1988). Smiley (in Wilson, 1970, p. 50) assigned an Albian age to this floral assemblage and Crabtree (1988) assigned a late Albian age to it. Wilson (1970, p. 50) reported the marine brachiopod *Lingula* from the uppermost pastel beds. The Albian to Cenomanian(?) seed fern *Tempskya* was collected from the pastel beds at the Lima Peaks section (Dyman and Nichols, 1988). Two palynomorph assemblages from the pastel beds at the Lima Peaks section yielded forms indicative of Cretaceous age (table 1). Although no further age refinement was possible, these assemblages are consistent with

assemblages in the Madison Range that are Albian in age.

Upper part of Mowry Shale

At Lincoln Mountain in the Madison Range, the Vaughn Member is overlain by 274 ft (84 m) of dark-gray mudstone and silty mudstone that contain a few minor interbeds of sandstone, bentonite, and coal. These strata represent marine and marginal-marine deposits; marsh, stream channels, and overbank deposits are present according to Vuke (1984). No time-equivalent dark-gray mudstone strata are known in the area of the western three sections, although such strata may have been deposited and subsequently eroded prior to deposition of the Frontier Formation. The top of the Mowry in the Madison Range was chosen at the base of a sequence of chert-rich sandstone beds that aggregate about 50 ft (15 m) thick and which are placed in the Frontier Formation (Tysdal and Simons, 1985).

Strata of the upper part of the Mowry Shale, or Mowry undivided where pastel beds are absent in the Madison Range, were assigned to the Aspen(?) Formation by Austin and Stoeper (1950). Hall (1961), Lauer (1967), Ray (1967), Kehew (1971), and Walsh (1971) mapped these rocks as Upper Cretaceous strata undivided. Bolm (1969) assigned the post-Vaughn strata to a unit of undifferentiated Cretaceous rocks, and Rose (1967) used "Albino" for them. Wilson (1970) assigned them to the Mowry Shale. Hadley (1969a, 1980) assigned strata of the upper member to the Frontier Formation. Schwartz (1972) considered them as part of his lithofacies interval D. Vuke (1984), Tysdal and Simons (1985), and Tysdal (in press) assigned the strata to the upper part of the Mowry Shale.

At Lincoln Mountain in the Madison Range, we obtained Albian palynomorphs from lower and upper beds of the upper member of the Mowry Shale, and Albian dinoflagellates from the upper beds (table 1). Wilson (1970, p. 50) reported dinoflagellates from the basal strata of the upper member, immediately above the pastel beds.

FRONTIER FORMATION

Strata assigned to the Frontier Formation differ in lithology and thickness from one section to the next. Lower strata of the Frontier are composed of lithic sandstone, conglomerate, bentonitic mudstone, and

shale, and were deposited in fluvial and shallow-marine(?) environments. The lower strata contain palynomorphs of Cenomanian to Turonian age (table 1).

The base of the Frontier Formation was placed at the base of the first sandstone unit above the dark-gray mudstone of the Mowry Shale in the Madison Range, and at the base of the first sandstone or conglomeratic bed above the Vaughn Member in the area of the other sections. At the Lima Peaks section, about 30 ft (9 m) of dark-gray nonvolcanic shale of Cenomanian age occurs above the Vaughn Member of the Blackleaf Formation and below sandstone of the Frontier. Because lower Frontier sandstone and conglomerate beds are laterally discontinuous in the Lima Peaks area, it is appropriate to place the base of the Frontier at the base of the shale, which also is a regional unconformity (Dyman and Nichols, 1988). The contact is probably diachronous, and correlation was best made where palynomorph data were available.

The long-ranging marine brachiopod Lingula subspatulata Hall and Meek was found in the basal sandstone of the Frontier Formation at the Lincoln Mountain section in the Madison Range and was associated with an unidentifiable juvenile ammonite. Basal strata of the Frontier in the Greenhorn composite section yielded the marine bivalve Pleurocardia pauperculum (Meek) (Dyman and Nichols, 1988).

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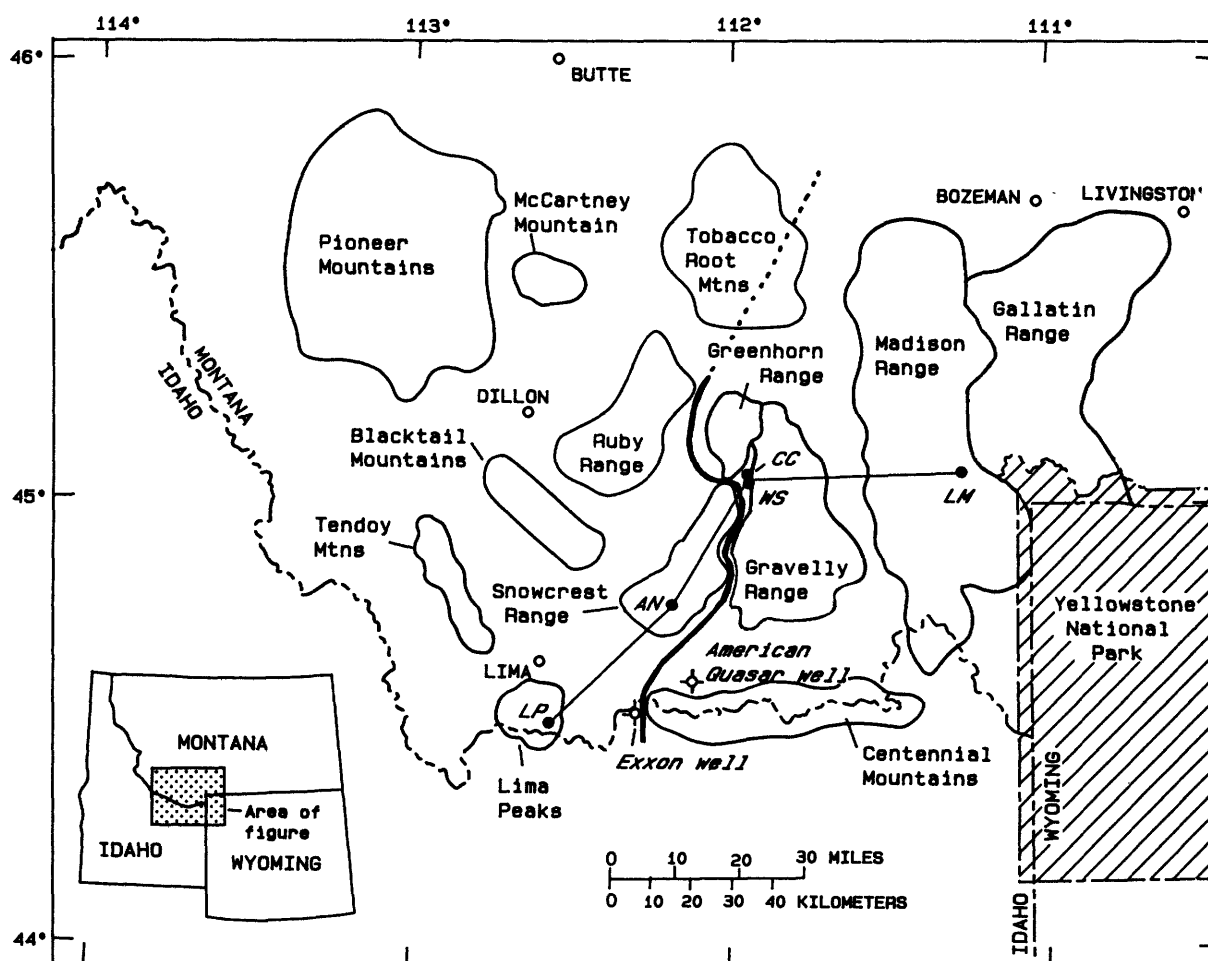


Figure 1.--Index map of southwestern Montana showing mountain ranges, locations of measured sections, and line (bold) marking geographic position of change in nomenclature of Lower Cretaceous rocks. Bold line is dotted where no Cretaceous rocks are preserved. Abbreviations for measured sections are as follows: AN, Antone Peak; CC, Cow Camp; LM, Lincoln Mountain; LP, Lima Peaks; WS, Warm Springs Creek.

AGE		NORTHWESTERN MONTANA	SOUTHWESTERN MONTANA (THIS REPORT)		NORTHWESTERN WYOMING	
			Western area	Eastern area		
Late Cretaceous	Cenomanian and Turonian	Marias River Shale (part)	Frontier Formation (part)	Frontier Formation (part)	Frontier Formation (part)	
Early Cretaceous	Albian	Blackleaf Formation	Blackleaf Formation	Bootlegger Member	Vaughn Member	Mowry Shale
				Vaughn Member	Upper part	Vaughn Member
				Taft Hill Member	Muddy Sandstone	Muddy Sandstone
				Flood Member	Shale member	Thermopolis Shale
					Sandstone member	Cloverly Formation
	Aptian	Kootenai Formation	Kootenai Formation	Kootenai Formation	Kootenai Formation	

Figure 2.--Correlation chart of Lower Cretaceous rocks in western Montana and northwestern Wyoming.

Table 2.--*Alphabetized list of species. Index number corresponds to row number in table 1*

Number	Species
28	Acanthotriletes sp. D
38	Aequitriradites spinulosus
11	Appendicisporites jansonii
23	Appendicisporites spp.
19	Araucariacites australis
3	Baltisphaeridium? sp.
21	Callialasporites sp.
29	Camarozonsporites insignis
4	Chichauadinium vestitum
12	Cicatricosisporites spp.
7	Cleistosphaeridium multispinosum
13	Concavissimisporites variverrucatus
30	Corollina sp.
31	Costatoperforosporites foveolatus
8	Cribooperidinium edwardsii
35	Cupuliferoideaepollenites spp.
41	Cupuliferoipollenites sp.
14	Cyathidites minor
24	Cycadopites sp.
9	Cyclonephelium sp.
32	Deltoidospora sp.
42	Densoisporites sp.
1	Dinoflagellate cysts, unidentified
39	Echinatisporis varispinosus
22	Eucommiidites minor
34	Foraminisporis wonthaggiensis
36	Foveotriletes sp.
16	Gleicheniidites senonicus
17	Laevigatosporites sp.
25	Leptolepidites sp.
33	Lycopodiumsporites sp.
43	Microreticulatisporites sp.
5	Nyktericysta sp.
10	Oligosphaeridium pulcherrimum
2	Oligosphaeridium sp.
40	Phyllocladidites inchoatus
15	Pityosporites sp.
44	Podocarpidites sp.
45	Pseudoschizaea sp.
6	Pterospermella sp.
26	Retimonocolpites peroreticulatus
37	Rugubivesiculites sp.
18	Taxodiaceaeipollenites hiatus
20	Tricolpites sp.
46	Triporoletes reticulatus
27	Vitreisporites pallidus
47	isoetalean microspores