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Chronostratigraphic Cross Section of Cretaceous Formations in Western Montana, Western Wyoming, Eastern Utah, Northeastern Arizona, and Northwestern New Mexico, U.S.A.

Pamphlet to accompany

Open-File Report 2015–1087

U.S. Department of the Interior
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SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors

Inch/Pound to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)

Divisions of Cretaceous time as used in this report[1]

Period	Stage	Age Estimates (Ma)
Upper Cretaceous	Maastrichtian	72–66
	Campanian	84–72
	Santonian	86–84
	Coniacian	90–86
	Turonian	94–90
	Cenomanian	100–94
Lower Cretaceous	Albian	113–100
	Aptian	126–113

[1]Ages were assigned mainly by means of associated molluscan fossils and the molluscan fossil zones of Cobban and others (2006); Gradstein and others (2012); and Singer and others, written commun., 2012. Fossils of zone 29 (mainly *Collignoniceras woollgari*) in the middle Turonian (Cobban and Hook, 1979; Cobban, 1991) provide the stratigraphic datum for the cross section

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Abstract

The chronostratigraphic cross section presented herein is a contribution to the Western Interior Cretaceous (WIK) project of the Global Sedimentary Geology Program. It portrays the Cretaceous formations at 13 localities in a south-trending transect from northwestern Montana through western Wyoming, eastern Utah, and northeastern Arizona, to northwestern New Mexico. The localities are in the Rocky Mountains and on the Colorado Plateau and contain strata that were deposited along the western margin of the Cretaceous Interior Seaway of North America. These strata are marine and nonmarine, mainly siliceous and calcareous, and of Aptian through Maastrichtian ages. They range in thickness from nearly 19,000 feet (ft) in southwestern Montana to about 1,500 ft thick in northeastern Arizona and northwestern New Mexico.

Lower Cretaceous formations in western Montana, western Wyoming, and eastern Utah disconformably overlie Jurassic rocks and locally include beds of either Aptian and Albian ages or Albian age. The Aptian beds consist of various lithologies of nonmarine origin. Albian beds consist of various nonmarine and marine lithologies. The Lower Cretaceous strata range in thickness from 4,300 ft in northern Utah to 180 ft in southern Utah and are absent at localities in Arizona and New Mexico.

Upper Cretaceous strata at most localities in the transect include beds of Cenomanian through Maastrichtian ages, although at five of the localities in Montana, Wyoming, Utah, Arizona, and New Mexico, younger strata are missing. Beds of Cenomanian, Turonian, Coniacian, Santonian, and Campanian ages in the region are siliceous, calcareous, or bentonitic and were deposited in marine and nonmarine environments. In the following Maastrichtian, siliceous lithologies accumulated in nonmarine environments. Thicknesses of the Upper Cretaceous strata range from more than 17,000 ft in southwestern Montana to nearly 6,000 ft in northwestern New Mexico.

In this transect for time-stratigraphic units of the Cretaceous, lateral changes in lithologies, regional differences in thicknesses, and the abundance of associated disconformities possibly reflect local and regional tectonic events. Examples of evidence of those events follow: (1) Disconformities and the absence of strata of lowest Cretaceous age in western Montana, western Wyoming, and northern Utah indicate significant tectonism and erosion probably during the Late Jurassic and earliest Cretaceous; (2) Stages of Upper Cretaceous deposition in the transect display major lateral changes in thickness, which probably reflect regional and local tectonism.

Introduction

This cross section of Cretaceous strata from western Montana to northwestern New Mexico is a contribution to the Western Interior Cretaceous (WIK) project of the former Global Sedimentary Geology Program (GSGP), which was established by The International Union of Geological Sciences. The WIK project was initiated in the early 1990s by R.J. Weimer of the Colorado School of Mines, supported by W.A. Cobban and J.D. Obradovich of the U.S. Geological Survey, and described by T.S. Dyman and others (1994). Subsequent contributions to the WIK project include the following east-trending biostratigraphic cross sections of Cretaceous strata: (1) across Montana and South Dakota by Dyman, Porter and others (1995); (2) across Wyoming and western South Dakota by Merewether and others (1997); (3) from eastern Utah, across Colorado, to western Kansas by Anna (2012); and (4) from eastern Arizona across New Mexico and southern Colorado to western Oklahoma by Molenaar and others (2002). A south-trending chronostratigraphic cross section of Upper Cretaceous formations extending from northeastern Wyoming, across eastern Colorado, to northeastern New Mexico, was contributed by Merewether and others in 2011.

The primary purposes of this latest cross section are to provide stratigraphic and chronological data and related interpretations for Cretaceous sedimentary rocks that were deposited in nearshore environments along the western margin of the Cretaceous Interior Seaway of North America. This cross section details marine and nonmarine strata in western Montana, western Wyoming, eastern Utah, northeastern Arizona, and northwestern New Mexico and supplements the cross sections published for other regions in the western interior.

This report is a compilation of information detailing Cretaceous strata at 13 localities in a south-trending transect between western Montana and northwestern New Mexico in the Rocky Mountains and the Colorado Plateau (fig. 1). These strata were deposited in various marine and nonmarine environments within the approximate time of 126–66 Ma (Gradstein and others, 2012). Relevant data for outcrops near the western margin of the Cretaceous Western Interior Seaway were obtained from publications by many Earth scientists and include descriptions and interpretations of lithologies, thicknesses, ages, fossil content, depositional environments, and stratigraphic contacts. Most of these strata were interpreted in terms of sedimentologic and tectonic events.

The localities recorded in this cross section are usually near communities (table 1). In western Montana, they are near East Glacier Park, Drummond, Lima, and Gardiner (section numbers 1–4). In western Wyoming, the localities are in the vicinity of Jackson and Kemmerer (section numbers 5 and 6). In eastern Utah, localities are near the communities of Coalville, Price, Harley Dome, and Henrieville (section numbers 7–10). The locality in northeastern Arizona, at Yale Point, is about 35 miles southeast of the town of Kayenta (section number 11); and in New Mexico, the localities are near the towns of Farmington and Gallup (section numbers 12 and 13).

Strata at the 13 localities consist of limestone, shale, siltstone, sandstone, conglomerate, coal, and bentonite, and their ages were assigned mainly by means of associated molluscan fossils and the molluscan fossil zones of the following: Cobban and others (2006); Gradstein and others (2012); and Singer and others, written commun., 2012. Fossils of zone 29 (mainly *Collignoniceras woollgari)* in the middle Turonian (Cobban and Hook, 1979; Cobban, 1991) provide the stratigraphic datum for the cross section. Chronological data define the locations and boundaries of the Cretaceous stages (Aptian through Maastrichtian, in ascending order) in the measured sections. Thicknesses of the 13 sections range from nearly 19,000 feet (ft) in southwestern Montana (section 3) to about 1,500 ft in northeastern Arizona and northwestern New Mexico (sections 11 and 13). The thicknesses presented herein are approximated. The sources of most of the descriptive and interpretive data and the locations of the principal outcrop areas are shown on table 1. These Cretaceous strata disconformably overlie beds of Jurassic age at most localities and commonly are overlain disconformably by Cenozoic strata.

Stratigraphy

Lower Cretaceous Strata in Ascending Order: Aptian and Albian Stages

Sedimentary rocks of the Aptian Stage (126–113 Ma) and the Albian Stage (113–100 Ma) have been identified in Montana, Wyoming, and Utah. Undivided Aptian and Albian strata in the Kelvin and Cedar Mountain Formations are exposed at the sections in localities 7, 8, and 10 in Utah, where they are overlain disconformably by Upper Cretaceous beds. The Aptian and lower Albian Kootenai Formation at localities 2 and 3 in Montana and the Gannett Group at locality 6 in Wyoming are disconformably overlain by Albian beds in the Blackleaf and Bear River Formations, respectively.

Lower Cretaceous strata range in thickness from about 4,300 ft at locality 7 in Utah to about 2,990 ft at locality 2 in Montana. They are as thin as 180 ft at locality 10 in Utah and are absent at localities 11–13 in Arizona and New Mexico. The basal contacts of the Lower Cretaceous sequences are disconformities, except at locality 2. The upper contacts of these strata are disconformities at localities 7, 8, and 10.

Aptian

Strata of the Aptian Stage are present at localities 2–4 in southwestern Montana and at localities 6–8, and 10 in southwestern Wyoming and eastern Utah, where they were deposited in nonmarine environments. They range in thickness from about 970 ft in the Morrison and Kootenai Formations at locality 2 to 270 ft in the Gannett Group at locality 6. Aptian strata have not been reported at localities 1, 5, 9, and 11–13.

Albian

Strata of the Albian Stage were identified at localities 1–10 in Montana, Wyoming, and Utah. In Montana, they are assigned to the upper part of the Kootenai and the overlying Blackleaf Formations and to the Thermopolis Shale. In Wyoming, they are assigned to the Cloverly Formation and the overlying Thermopolis Shale and to the upper part of the Gannett Group and the overlying Bear River Formation. In Utah, Albian strata are upper parts of the Kelvin and Cedar Mountain Formations. They have not been identified at localities 11–13 in Arizona and New Mexico. The Albian beds at localities 1, 3, and 7–10 are nonmarine. At locality 2, Albian strata consist of interstratified marine and nonmarine beds. At localities 5 and 6, the Albian includes nonmarine and overlying marine strata. At locality 4, Albian beds were deposited in marine environments. Fossils of early Albian age (zone 1) were projected by authors of relevant reports, from the nearest fossiliferous outcrops into the upper part of the Kootenai at locality 2, into a lower part of the Blackleaf at locality 3, into the Thermopolis at localities 4 and 5, and into the Bear River at locality 6.

The Albian strata range in thickness from about 2,020 ft in the upper part of the Kootenai and in the Blackleaf Formations at locality 2 in Montana to an estimated 100 ft in the Cedar Mountain Formation at locality 9 in Utah (Kirkland and Madsen, 2007). Thicknesses have not been reported for Albian strata at localities 7–10. The upper contacts of the Albian rocks are disconformities at localities 7, 8, and 10 in Utah and could be disconformities at locality 9 in Utah and at locality 2 in Montana, but the stratigraphy is uncertain at these localities.

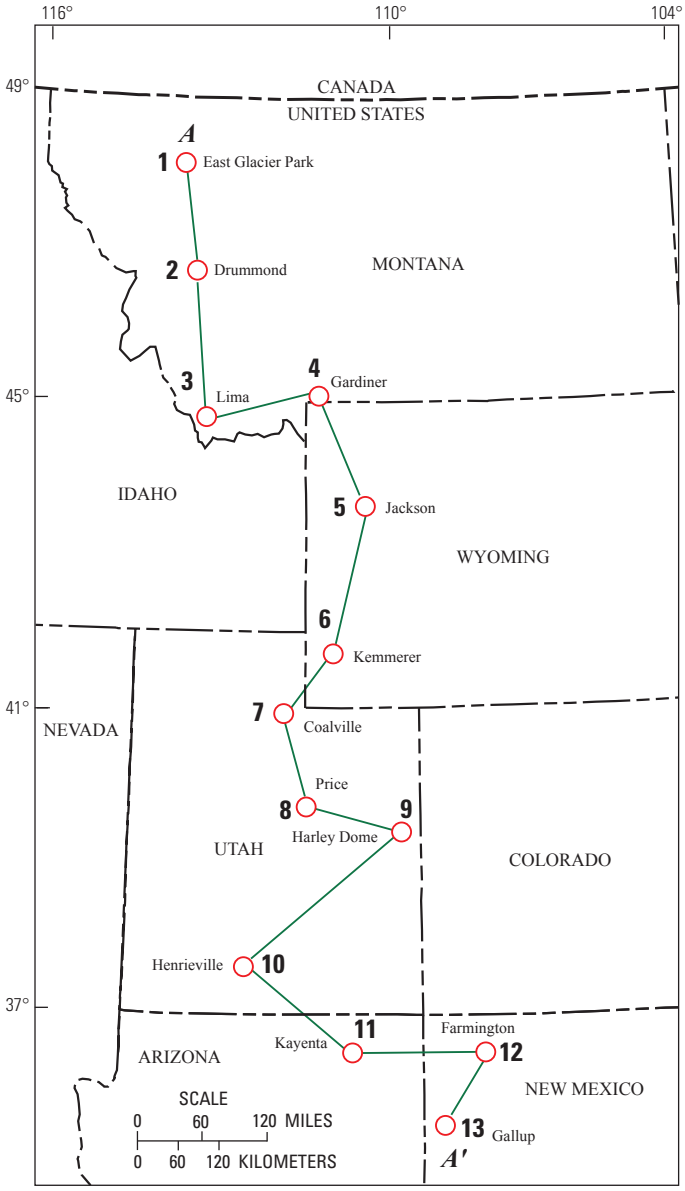

Figure 1. Map of selected Rocky Mountain States showing locations of main outcrop sections.

Upper Cretaceous Strata in Ascending Order: Cenomanian, Turonian, Coniacian, Santonian, Campanian, and Maastrichtian Stages

Sedimentary rocks of the Cenomanian (100–94 Ma), Turonian (94–90 Ma), and Coniacian (90–86 Ma) Stages have been identified at every locality in the cross section. The Santonian (86–84 Ma) Stage occurs at localities 1–12. Campanian (84–72 Ma) strata are present at localities 1–10 and 12. Maastrichtian (72–66 Ma) rocks are recognized at localities 1–3, 5, 7–9, and 12. The six stages of the Upper Cretaceous are represented by strata as much as 17,200 ft thick at locality 3 in southwestern Montana and by strata as thin as about 5,700 ft at locality 12 in northwestern New Mexico.

Cenomanian

Strata of the Cenomanian Stage in western Montana and northwestern Wyoming are assigned mainly to the upper part of the Blackleaf Formation at localities 1 and 2, to the upper Blackleaf and the lower part of the overlying Frontier Formations at locality 3, and to the Mowry Shale and the lower part of the overlying Frontier Formation at localities 4 and 5. In southwestern Wyoming and northern Utah (localities 6 and 7), Cenomanian rocks are within the Aspen Shale and a lower part of the overlying Frontier. At localities 8 and 9 in Utah, Cenomanian beds are within the Dakota Sandstone and the Dakota Formation. At locality 10 in Utah, the Cenomanian is represented by the Dakota Formation and a lower part of the Tropic Shale. In northeastern Arizona and northwestern New Mexico (localities 11–13), Cenomanian strata include the Dakota and lower parts of the overlying Mancos Shale.

Cenomanian rocks were deposited mainly in nonmarine environments at localities 1–3 in Montana and at localities 6–10 in Wyoming and Utah, and primarily in marine environments at localities 4 and 5 in Montana and Wyoming and at localities 11–13 in Arizona and New Mexico. Molluscan fossils of zones 4–7 in the lower Cenomanian were found in the Mowry Shale, the Aspen Shale, and the basal Frontier in Montana, Wyoming, and Utah (localities 4–7). Molluscan fossils of zones 20 and 21 of the upper Cenomanian occur in the Coberly Formation at locality 2, in the Dakota Sandstone and Dakota Formation at localities 8–10, and in the Mancos Shale at localities 11 and 13 (Kirkland, 1991).

In western Montana, Cenomanian strata range in thickness from as much as 3,450 ft at locality 3 to 660 ft at locality 1. In western Wyoming (localities 5 and 6), they are 1,000 ft thick and 1,220 ft thick, respectively. In Utah, Cenomanian beds range in thickness from 3,700 ft at locality 7 to 130 ft at locality 8. In northeastern Arizona (locality 11), they are about 290 ft thick. Strata in northwestern New Mexico at localities 12 and 13 are 370 ft thick and 300 ft thick, respectively. The basal contacts of Cenomanian strata at localities 7, 8, and 10–13 are disconformities. The contact of the Cedar Mountain Formation and the overlying Dakota Sandstone at locality 8 is also a disconformity (Fouch and others, 1983). Disconformities were also found either within or at the top of Cenomanian strata at localities 1–5, 8, 9, and 13.

Turonian

Strata of the Turonian Stage in western Montana are within the Marias River Shale at locality 1, within the upper part of the Coberly and the overlying Jens Formations at locality 2, and within the upper part of the Frontier Formation at localities 3 and 4. Turonian beds in western Wyoming and in north-central Utah (localities 5–7) are also within the Frontier. However, in eastern Utah at localities 8 and 9, Turonian strata are part of the Mancos Shale. At locality 10, they are within the Tropic Shale and the overlying Straight Cliffs Formation. In northeastern Arizona (locality 11), Turonian beds are an upper part

of the Mancos Shale and a lower part of the overlying Toreva Formation. In northwestern New Mexico, Turonian strata are within the Mancos Shale at locality 12, and are within the Mancos and the overlying Gallup Sandstone and lower beds of the Crevasse Canyon Formation at locality. 13.

Turonian nonmarine beds and overlying marine beds crop out in Montana, Wyoming, and Utah at localities 2, 6, and 7. Marine and overlying nonmarine Turonian strata were reported in Wyoming, Utah, Arizona, and New Mexico at localities 6, 7, 11, and 13. Only marine beds comprise outcrops of Turonian Age at localities 1, 4, 5, 8–10, and 12 in Montana, Wyoming, Utah, and New Mexico.

Fossils of early Turonian age (either zones 26, 27, or 28) occur in western Montana, in the lowermost Marias River Shale at locality 1 and were projected to the middle of the Coberly Formation at locality 2. They occur in the Frontier at locality 6 in southwestern Wyoming and at locality 7 in north-central Utah. They are also found in eastern Utah in basal beds of the Mancos at locality 8 and in a lower part of the Tropic Shale at locality 10. In Arizona and New Mexico at localities 11 and 13, respectively, they occur in the Mancos Shale.

Middle Turonian fossils of zone 29, which constitute the datum in the cross section, were found in the Coberly Formation at locality 2 (*Actinocamax manitobensis*?) and in the Frontier Formation (Collignoniceras woollgari) at locality 4. Beds containing fossils of zone 29 are absent at locality 1. These fossils occur in the Frontier at localities 5–7. They are also found in the Mancos at localities 8 and 9, and in the Tropic Shale at locality 10. They also occur in the Mancos at localities 11–13.

Turonian strata in western Montana range in thickness from 3,130 ft at locality 3 to 40 ft at locality 4. The strata in western Wyoming are 350 ft thick at locality 5 and 1,020 ft thick at locality 6. In Utah, the Turonian beds range in thickness from as much as 2,280 ft at locality 7 to 550 ft at locality 9. Turonian rocks in Arizona at locality 11 are 590 ft thick, while those in New Mexico at localities 12 and 13 are nearly 600 ft and 780 ft thick, respectively. Turonian strata disconformably overlie various older rocks at localities 4, 5, 8, 9, and 13. Turonian strata enclose disconformities at localities 1, 6, 7, 11, and 12, and are topped by disconformities at localities 1, 3–5, and 10–12.

Coniacian

Sedimentary rocks of Coniacian Age crop out at all localities shown on the cross section. They occur within the Marias River Shale at locality 1, within the Jens and the overlying Carten Creek Formations at locality 2, within the Beaverhead Group at locality 3, and within the Cody Shale and a lower part of the overlying Telegraph Creek Formation at locality 4. At locality 5, from oldest to youngest, Coniacian rocks were identified in the upper part of the Frontier Formation, the Cody Shale, and the Bacon Ridge Sandstone. At locality 6, Coniacian strata are within the uppermost Frontier and the lower part of the overlying Hilliard Shale. At locality 7, in ascending order, Coniacian strata are within the upper part of the Frontier, the Henefer Formation, and the lower part of the Echo Canyon Conglomerate. Coniacian beds at localities 8 and 9 are identified in the Mancos Shale. At locality 10, Coniacian rocks are a component of the Straight Cliffs Formation. At locality 11, they are assigned to the upper part of the Toreva Formation and the overlying Wepo Formation. Coniacian beds are within the Mancos Shale at locality 12 and within the Crevasse Canyon Formation at locality 13.

Coniacian strata in the cross section were deposited in nonmarine environments at locality 3, in mixed nonmarine and marine environments at localities 2, 7, 11, and 13, and in marine environments at localities 1, 4–6, 8–9, and 12. Fossils of early Coniacian age (zones 39–43) occur in the Marias River Shale at locality 1, in the Jens Formation at locality 2, and in the Cody Shale at locality 4. Early Coniacian fossils are in the upper Frontier at locality 5 and in beds of the upper Frontier and the lower Hilliard at locality 6. Early Coniacian occur in the upper Frontier at locality 7, in the Mancos at localities 8 and 9, and in the Straight Cliffs Formation at locality 10. Early Coniacian fossils are also in the Toreva Formation at locality 11, in the Mancos at locality 12, and in the Crevasse Canyon Formation at locality 13.

In Montana, fossils of middle and late Coniacian age (zones 44 and 45) are in the Marias River Shale at locality 1, are projected into the Jens and the overlying Carten Creek Formation at locality 2, and are in the Cody Shale at locality 4. In Wyoming, they are in the Cody Shale and in the overlying Bacon Ridge Sandstone at locality 5, and in the Hilliard Shale at locality 6. In Utah and New Mexico, the fossils occur respectively in the Straight Cliffs Formation at locality 10 and in the Crevasse Canyon Formation at locality 13.

Coniacian sequences in western Montana range in thickness from 930 ft at locality 2 to 380 ft at locality 3. In western Wyoming, they are 3,260 ft thick at locality 5 and as much as 1,500 ft thick at locality 6. In Utah, they range in thickness from 4,680 ft at locality 7 to about 250 ft at locality 10. The Coniacian rocks in Arizona at locality 11 are 330 ft thick. Those in New Mexico at localities 12 and 13 are about 390 ft thick and 400 ft thick, respectively. The basal contacts of the Coniacian sequences are disconformities at localities 1, 3–5, and 10–12. Disconformities also occur within the Coniacian strata at localities 2 and 10, and at the top of the Coniacian strata at locality 1.

Santonian

Strata of Santonian Age in the cross section were identified at localities 1–12. In Montana at locality 1, they comprise an upper part of the Marias River Shale and the entire overlying Telegraph Creek Formation. At locality 2, Santonian strata form most of the Carten Creek Formation. At locality 3, Santonian beds are in the lower part of the Beaverhead Group and at locality 4 they are within, from oldest to youngest, the Telegraph Creek Formation, the Eagle Sandstone, and the Everts Formation. In Wyoming at locality 5, Santonian beds are assigned to the upper part of the Bacon Ridge Sandstone and to the overlying coaly sequence of Love (1956). At locality

6, Santonian strata are a major part of the upper portion of the Hilliard Shale. In northern Utah at locality 7, they occur as a major part of the upper Echo Canyon Conglomerate. In northeastern Utah, at localities 8 and 9, Santonian beds are within the Mancos Shale. In southern Utah at locality 10, they occur as the upper part of the Straight Cliffs Formation. At locality 11 in Arizona, Santonian strata comprise an upper part of the Wepo Formation and the overlying Yale Point Sandstone. In New Mexico at locality 12, they form, in ascending order, an upper part of the Mancos Shale, the Point Lookout Sandstone, and basal beds of the Menefee Formation.

Santonian strata were deposited in nonmarine environments at localities 2, 3, and 7; in nonmarine and marine environments at localities 4, 5, and 10–12; and in marine environments at localities 1, 6, 8, and 9. Fossils of Santonian Age (zones 46–50) were collected at locality 1 from the Marias River Shale and the overlying Telegraph Creek, and at locality 4 (Tysdal and Nichols, 1991) from the Telegraph Creek and the overlying Eagle Sandstone and Everts Formation. Santonian fossils may also occur at locality 5 in the Bacon Ridge Sandstone and the coaly sequence of Love (1956) and at locality 6 in the upper part of the Hilliard Shale. Santonian fossils are in the Mancos Shale at localities 8 and 9, and in the Straight Cliffs Formation at locality 10. Santonian fossils at locality 11 are in the Yale Point Sandstone and at locality 12 are in an upper part of the Mancos.

Santonian beds in western Montana range in thickness from 4,530 ft at locality 2 to 400 ft at locality 1. Santonian strata in western Wyoming are 1,060 ft thick at locality 5 and as much as 3,880 ft thick at locality 6. Santonian beds in Utah range in thickness from 2,450 ft at locality 8 to 870 ft at locality 10. Santonian strata are 340 ft thick at locality 11 in Arizona and about 1,030 ft thick at locality 12 in New Mexico. At locality 1, Santonian strata are separated from underlying Coniacian strata by a disconformity, whereas at localities 2, 4, 7, and 10, disconformities separate the Santonian strata from overlying Campanian strata.

Campanian

Beds of Campanian Age (zones 51 through 64) have been identified in the cross section at localities 1–10 and 12. At locality 1, in ascending order, Campanian strata are assigned to the Virgelle Sandstone, Two Medicine Formation, Bearpaw Shale, and Horsethief Sandstone. Campanian beds are within the Golden Spike Formation at locality 2 and within the Beaverhead Group at locality 3. At locality 4, the Landslide Creek Formation is entirely in the Campanian Stage. At locality 5, the Campanian comprises, from oldest to youngest, the lenticular sandstone and shale sequence of Love (1956), the Mesaverde Formation, and the Meeteetse Formation. Campanian rocks at locality 6 are assigned to the Adaville Formation. At locality 7, they occur within the Evanston Formation, and at locality 8 they have been assigned, in ascending order, to the Mancos Shale, the Star Point Sandstone, the Blackhawk Formation, the Castlegate Sandstone, and the Price River Formation. At locality 9, the Campanian strata comprise, from oldest to youngest, the upper part of the Mancos Shale, the Castlegate Sandstone, the Sego Sandstone, the Neslen Formation, and the Price River Formation (Hettinger and Kirschbaum, 2002). At locality 10, they form, in ascending order, the upper part of the Straight Cliffs Formation, the Wahweap Formation, and the Kaiparowits Formation. Marine beds laterally equivalent to the upper part of the Straight Cliffs at locality 10 contain molluscan fossils of zones 52–55 (Fred Peterson, USGS, written commun., 2014). At locality 12, Campanian beds are within, from oldest to youngest, the Menefee Formation, the Cliff House Sandstone, the Lewis Shale, the Pictured Cliffs Sandstone, the Fruitland Formation, and the Kirtland Shale.

Campanian strata at localities 2–5, 7, and 10 were deposited in nonmarine environments. Lower beds of the Campanian sequences at localities 1, 6, 8, and 9 were deposited in marine environments. Beds in the middle of the Campanian sequence at locality 12 also originated in marine environments. At locality 1, marine strata are near the top of the Campanian sequence. Fossils of early Campanian age (zones 51–56) were found at localities 1, 8, and 9. Fossils of middle Campanian age (zones 57–64) have been projected to locality 4, and have been collected at locality 9. Fossils of late Campanian age (zones 65–73) were identified at locality 1 and were projected to localities 3, 9, and 12.

Campanian strata at localities in Montana range in thickness from about 4,000 ft at locality 2 to 2,000 ft at locality 4. In Wyoming, they are 3,160 ft thick at locality 5 and 2,970 ft thick at locality 6. Campanian rocks in Utah range in thickness from 3,740 ft at locality 10 to about 330 ft at locality 7. In New Mexico at locality 12, they are about 3,100 ft thick. The basal contact of Campanian strata is a disconformity at localities 2 and 4 in Montana and at localities 7 and 10 in Utah. Disconformities are present near the middle of the Campanian sequences at localities 8 and 9 in Utah. Contacts at the tops of these strata are disconformities at localities 4, 5, 6, and 10 in Montana, Wyoming, and Utah.

Maastrichtian

Strata of Maastrichtian Age were identified at localities 1–3, 5, 7–9, and 12. In western Montana, these strata were assigned to the Willow Creek and St. Mary River Formations at locality 1, to the upper part of the Golden Spike Formation at locality 2, and to the upper part of the Beaverhead Group at locality 3. In western Wyoming at locality 5, they comprise the Harebell Formation. In Utah, Maastrichtian beds form part of the Evanston Formation at locality 7, and parts of the North Horn Formation at localities 8 and 9. Maastrichtian rocks in New Mexico at locality 12 are an upper part of the Kirtland Shale which was deposited in nonmarine environments. Mollusks of early Maastrichtian age (zone 77) were projected from nearby marine strata into the nonmarine beds at locality 1.

The Maastrichtian strata in western Montana range in thickness from 4,160 ft at locality 3 to 700 ft at locality 2 and are absent at locality 4. In western Wyoming, they are

3,600 ft thick at locality 5 and are absent at locality 6. The Maastrichtian rocks in Utah range in thickness from 470 ft at locality 8 to 110 ft at locality 7, and are absent at locality 10. In New Mexico at locality 12, they are 220 ft thick. These strata disconformably overlie Campanian beds at locality 5 and enclose disconformities near the base of the Maastrichtian sequences at localities 8 and 9. At most localities in the cross section, the upper contacts of these strata have been described as disconformities.

Interpretations

In this cross section of outcropping Cretaceous rocks that extends irregularly from northwestern Montana to northwestern New Mexico, the strata were deposited during the Aptian through Maastrichtian Stages (sheet 1). The lower Neocomian Stage of the Lower Cretaceous is absent in the transect, but is represented by the hiatus between underlying Jurassic strata and the base of the Aptian Stage.

The 13 sequences of Cretaceous beds vary in lithology, depositional environment, thickness, and age, but portions of them can be correlated. At localities 4 and 5 in southwestern Montana and at 7 in north-central Utah, the Cretaceous strata are more than 17,000 ft thick, primarily nonmarine, and include thick sequences of conglomerate. In contrast, strata of the same age at locality 8 in northeastern Utah are nearly 8,400 ft thick, and include thick sequences of marine beds. Disconformities have been found at each of the 13 localities, but more have been identified at localities 1 and 2 in Montana and at locality 8 in Utah, which could indicate more Cretaceous tectonic activity in those areas than in adjacent areas.

Several regional sedimentological and structural events are evident in the Cretaceous strata. The disconformity at the contact of Jurassic rocks and Lower Cretaceous strata at localities 1 and 3–10 reflects tectonism and widespread erosion during the Late Jurassic and the early ages of the Early Cretaceous.

Lower Cretaceous strata are thickest in western Montana and in northern Utah, which indicates either more crustal subsidence and deposition or less truncation at disconformities in those areas during the Early Cretaceous. The southward decrease in the thickness from locality 2 in Montana to locality 6 in Wyoming, the subsequent increase in the thickness at locality 7 in Utah, and the southern decrease in the thicknesses of those rocks from locality 7 to locality 10 in Utah, and to localities in Arizona and New Mexico, may reflect penecontemporaneous tectonic events as well as differences in the amount of truncation at the tops of these strata. Aptian strata in the transect have a maximum thickness of 970 ft at locality 2 in Montana, which possibly indicates an area of more localized crustal subsidence. For Albian rocks, the maximum thicknesses along the transect are at localities 1, 2, and 3 in Montana which also suggests an area of more crustal subsidence.

The abundance of disconformities within Aptian and Albian rocks in western Montana could indicate intermittent Early Cretaceous tectonism in that area. Disconformities at and near the base of Albian strata and changes in lithologies at localities 1–4 in Montana and at localities 5 and 6 in Wyoming may represent a marine regression, subsequent erosion, followed by a marine transgression during late Aptian and early Albian time. The regression may have occurred or been caused by local uplift. Albian marine beds in Montana and Wyoming indicate a marine transgression during the Albian. The absence of Aptian and Albian rocks in the vicinity of localities 11–13 in Arizona and New Mexico could reflect crustal arching and erosion in that area during the Cenomanian.

Outcrops in Montana, Wyoming, and Utah (localities 4–7) reflect marine deposition during the Early Cenomanian. Offshore marine and overlying shallow marine and nonmarine Cenomanian strata at localities 4–7 indicate a marine transgression, followed by a regression in southwestern Montana, western Wyoming, and northern Utah. Disconformities within Upper Cenomanian strata at localities 1 and 2, and at the top of the Cenomanian strata at localities 4, 5, 8, 9, and 13 might indicate marine regressions and the erosion of nonmarine and nearshore marine strata.

The oldest Cenomanian beds overlie Lower Cretaceous strata in Montana, Wyoming, and Utah, and overlie Jurassic rocks locally in Arizona and New Mexico. They contain Cenomanian fossils from zones 5 and 7 at locality 4 in Montana, at localities 5 and 6 in Wyoming, and at locality 7 in Utah. In contrast, the oldest Cenomanian beds at localities 8 and 9 in northeastern Utah and at locality 11 in Arizona contain fossils from zones 20 and 21 of the upper Cenomanian. Comparable strata at locality 10 in southern Utah contain fossils from zones 15 or 16 of the middle or upper Cenomanian. At locality 13 in New Mexico, the middle or upper Cenomanian strata contain fossils from zone 10 of the middle Cenomanian. The basal contacts of the Cenomanian sequences could have formed a surface of irregular topography or could have been affected by penecontemporaneous tectonic events. The youngest Cenomanian beds contain fossils most likely from zone 21 of the upper Cenomanian.

Cenomanian strata are thickest in southwestern Montana and northern Utah, perhaps indicating areas of more crustal subsidence or accommodation. The sequences are much thinner elsewhere in Utah and in Arizona and New Mexico. However, disconformities at the base of the Cenomanian sequences in Utah, Arizona, and New Mexico could reflect tectonic activity that affected original deposition and thickness.

The disconformable contact of Cenomanian and Turonian strata in Montana at locality 4 and probably at locality 5 in Wyoming, at localities 8 and 9 in Utah, and at locality13 in New Mexico indicates marine regressions, erosion, and subsequent transgressions during the late Cenomanian and the early Turonian in several areas along the transect.

Outcrops of early and middle Turonian ages contain fossils from zone 26 at localities 8 and 10 in Utah, from zone 28 at localities 1 and 2 in Montana and locality 13 in New Mexico, and from zone 29 at locality 4 in Montana and at locality 5 in Wyoming. Beds of late Turonian age contain fossils from zone 37 at locality 8 in Utah and from zone 38 at locality 1 in

Montana. At locality 4 in Montana and locality 5 in Wyoming, where the Turonian strata are thin and bounded by disconformities, the enclosed fossils are from zone 29. These variations in the age of the Turonian rocks probably are related to penecontemporaneous tectonic events and associated erosion.

Thicknesses of Turonian strata in the transect exceed 2,000 ft at locality 3 in southwestern Montana and at locality 7 in northern Utah and are less than 400 ft thick at locality 4 in Montana and at locality 5 in Wyoming. The greater thickness might indicate areas of major crustal subsidence during the Turonian. Minimal thickness of the Turonian strata as well as associated disconformities at localities 1 and 4 in Montana and at locality 5 in Wyoming probably indicates tectonic uplift and erosion in those areas during the Turonian. Disconformities at or near the base of Turonian strata as well as the lithologies of the overlying beds in Montana, Wyoming, Utah, and New Mexico, at localities 1, 4, 5, 8, 9, and 13, indicate a marine regression followed by a marine transgression. Disconformities at the top of Turonian sequences in Montana and Wyoming, at localities 1, 3–5, and in Utah, Arizona, and New Mexico, at localities 10–12, also reflect a marine regression. Several of these disconformities, particularly those in Montana, Wyoming, Arizona, and New Mexico, at localities 1, 4, 5, 11, and12 could reflect Turonian tectonic events.

The disconformity between Turonian and Coniacian beds in Montana, Wyoming, Utah, Arizona, and New Mexico indicates, in ascending order, a marine regression, erosion, and a transgression across much of the region of the transect during middle and late Turonian and early Coniacian time. In Montana and Wyoming at localities 4 and 5, the lacuna between Turonian and Coniacian strata spans most of middle and late Turonian time and could reflect Turonian tectonism in that area.

Lowermost Coniacian strata contain fossils of zone 39 in Wyoming at localities 5 and 6 and probably elsewhere. Fossils of zone 40 are in the basal Coniacian at localities 11 and 12 in Arizona and New Mexico, respectively. Many of the outcrops in the cross section contain evidence of a regional marine transgression in early Coniacian time. Differences in the ages of the basal Coniacian beds could indicate that the disconformable basal contact was affected by Turonian or Coniacian tectonism. Disconformities within the Coniacian sequences at locality 2 in Montana and at locality 10 in Utah could reflect Coniacian tectonism and attendant marine regressions. Uppermost Coniacian beds contain fossils of zone 45 at localities 1, 2, and 4 in Montana, at localities 5 and 6 in Wyoming, at locality 10 in Utah, and at locality 13 in New Mexico.

Coniacian strata are more than 3,000 ft thick at locality 5 in Wyoming and at locality 7 in Utah, and about 1,500 ft thick at locality 6 in Wyoming. They are about 900 ft thick at localities 2 and 4 in Montana, and are nearly 700 ft thick at locality 8 in Utah. They are less than 500 ft thick at the remaining localities in Montana, Utah, Arizona, and New Mexico. The maximum thickness of Coniacian strata in the cross section, nearly 3,260 ft at locality 5 and as much as 4,660 ft at locality 7, could indicate two areas of anomalous crustal subsidence during the Coniacian. For Coniacian time, the thickness could reflect crustal uplifts and erosion in western Montana, crustal subsidence in western Wyoming and northern Utah, and less subsidence at other localities in Utah, and in Arizona and New Mexico.

The basal Santonian beds at locality 4 in Montana may contain fossils from zone 46. Younger beds at locality 4 and at locality 1 in Montana, at localities 5 and 6 in Wyoming, at localities 8–10 in Utah, and at locality 12 in New Mexico contain fossils from zone 47. The youngest Santonian strata contain fossils from zone 50 at localities 1 and 4 in Montana and at locality 8 in Utah. However, the youngest Santonian strata at locality 10 in Utah and at locality 11 in Arizona contain older fossils, from zone 48, which could indicate uplift and erosion in those areas during the Santonian.

Santonian rocks range in thickness from about 4,500 ft at locality 2 in Montana to 340 ft at locality 11 in Arizona. These strata exceed 2,000 ft in thickness at localities 2–4 in Montana, at locality 6 in Wyoming, and at localities 7 and 8 in Utah, which could indicate areas of major crustal subsidence during the Santonian. The Santonian strata are 340 ft thick at locality 11 in Arizona, 870 ft thick at locality 10 in Utah, and 1,040 ft thick at locality 12 in New Mexico, which might reflect crustal uplift centered in northeastern Arizona during the Santonian. The contact of Coniacian and overlying Santonian strata is a disconformity at locality 1 and reportedly is conformable elsewhere in the transect. Lithologies of upper Santonian strata at localities 1, 4, 6, 9, and 12 in Montana, Wyoming, Utah, and New Mexico, could indicate a regional marine regression.

Strata at locality 1 in Montana contain fossils of zone 51 near the base of the Campanian and of zone 71 near the top of that stage. Fossils from zones 51–71 are sparse at other localities in the transect. Marine and overlying nonmarine strata of early Campanian age at localities 1, 6, and 8 and of early and middle Campanian age at locality 9 indicate a marine regression in those areas in the early and middle Campanian. Basal disconformities overlain by nonmarine conglomerates at localities 2 and 7 and by nonmarine sandstone at locality 4 may also reflect a marine regression. At locality 12, Campanian nonmarine strata, overlain by marine strata of middle and late Campanian age, and overlain in turn by nonmarine strata seems to indicate a marine regression, a subsequent marine transgression, followed by a marine regression during the Campanian. However, the upper Campanian at locality 1 includes, in ascending order, marine and nonmarine strata that reflect a transgression and a following regression.

Campanian strata at localities 1–3 in Montana and at localities 5 and 6 in Wyoming range in thickness from 2,470 ft to 4,000 ft. In Utah at locality 7, they are the lower part of a conglomeratic unit and might be only about 300 ft thick. At localities 8–10 in Utah, they range in thickness from 2,840 ft to 3,740 ft. They are 3,100 ft thick at locality 12 in New Mexico. Disconformable basal contacts of the Campanian rocks at localities 2 and 4 in Montana and at localities 7 and 10 in Utah might indicate areas of crustal arching and erosion. The age of the basal Campanian at locality 4 corresponds to the age of the inception of volcanism in southwestern Montana (M.W. Reynolds, USGS, written commun., 2014). Disconformities were found near the

middle of the Campanian sequences at localities 8 and 9 in Utah. Contacts at the tops of these strata are disconformities at localities 4, 5, and 6 in Montana and Wyoming, and at locality 10 in Utah, and possibly at localities 8 and 9 in Utah.

Campanian strata are more than 3,000 ft thick at locality 2 in Montana, at locality 5 in Wyoming, at locality 10 in Utah, and at locality 12 in New Mexico may indicate areas of more crustal subsidence during the Campanian. However, at locality 7 in northern Utah the strata are less than 400 ft thick, which indicates an area of either less subsidence or uplift and erosion. Thickness of Campanian strata along the transect could have been reduced by erosion at disconformities within the sequences and at the tops of them.

Maastrichtian strata at localities in the cross section are nonmarine and were deposited during a widespread marine regression in the latest Cretaceous. They do not contain molluscan index fossils, although lower Maastrichtian marine beds containing fossils of zone 77 that can be traced laterally into nonmarine strata at locality 1 in Montana.

In Montana and Wyoming at localities 1, 3, and 5, the Maastrichtian strata range in thickness from 1,400 ft to 4,140 ft. In northeastern Utah, the thickness is 460 ft at locality 8, 450 ft. at locality 9, and 100 ft at locality 7. In northwestern New Mexico at locality 12, Maastrichtian beds are about 200 ft thick. However, disconformities at and near the base of the Maastrichtian sequences at localities 5, 8, and 9 and at the top of those sequences at localities 1–7 and 12 reflect periods of erosion that would have reduced total thicknesses. The thickness values could indicate that the maximum crustal subsidence during the Maastrichtian along the transect was in areas of western Montana and western Wyoming. The lesser thicknesses in northeastern Utah might reflect little subsidence or an area of crustal uplift and erosion.

Summary

During the Cretaceous Aptian through Maastrichtian Stages, the following probably indicate tectonic events: (1) regionally contrasting thickness of age-equivalent strata; (2) the relative abundance of disconformities in outcrops of the transect; and (3) lateral and vertical changes in lithologies. The most evident Cretaceous events along the transect probably include the following:

1. The absence of a sedimentary record for much of Early Cretaceous time at outcrops in the cross section reflects a lengthy period of widespread tectonism and erosion in the region, between the Jurassic Morrison Formation and Aptian strata (McGookey, 1972). However, the uppermost Morrison near locality 2 in Montana contains Early Cretaceous palynomorphs (Reynolds and Brandt, 2005).
2. Crustal subsidence and tectonism in western Montana during the Aptian and Albian may be indicated by greater thicknesses of Lower Cretaceous strata and the number of disconformities.
3. The absence of Aptian and Albian rocks locally in Arizona and New Mexico, in the vicinity of localities 11–13, might reflect uplift and erosion in that area during the Cenomanian.
4. Greater thickness of Cenomanian and Turonian strata in southwestern Montana and northern Utah indicates more crustal subsidence in those areas. The absence of middle and late Turonian fossils at localities 5 and 6 in Montana and Wyoming, respectively, might reflect a marine regression during the middle and late Turonian.
5. During Coniacian time, the thicknesses of comparable strata reflect more subsidence in western Wyoming and northern Utah and a major uplift in southwestern Montana. Fossils of early Coniacian age (zones 39–43) in outcrops of the cross section apparently indicate a widespread marine transgression slightly before that time.
6. The thicknesses of Santonian strata along the transect are greater at locality 2 in western Montana and at locality 6 in southwestern Wyoming, indicating more subsidence in those areas at that time. However, erosion at unconformities at the base or top of the Santonian at localities 1, 2, 4, 7, and 10 might have reduced the overall thickness. The various ages of the uppermost strata might reflect crustal arching in southern Utah and northeastern Arizona during the Santonian.
7. The apparent reduced thickness of the Campanian strata at locality 7 in northern Utah suggests tectonic uplift in that area. At localities 8 and 9, vertical changes in the lithologies of Campanian strata indicate local marine regressions and transgressions.
8. Variations in the thickness of the Maastrichtian strata along the transect suggest crustal arching in northeastern Utah during latest Cretaceous time.

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References

Anna, L.O., 2012, West-east lithostratigraphic cross section of Cretaceous rocks from central Utah to western Kansas: U.S. Geological Survey Open-File Report 2012–1074, 2 sheets, http://pubs.usgs.gov/of/2012/1074/.

Beaumont, E.C., and Dixon, G.H., 1965, Geology of the Kayenta and Chilchinbito quadrangles, Navajo County, Arizona: U.S. Geological Survey Bulletin 1202–A, 28 p. [Available at http://pubs.er.usgs.gov/publication/b1202A.]

Cobban, W.A., 1991, Occurrence and significance of the Middle Turonian (Upper Cretaceous) Belemnite *Actinocamax* in central western Montana, chap. C *of* Contributions to Late Cretaceous stratigraphy and paleontology, western Montana: U.S. Geological Survey Bulletin 1962, p. 21–26.

Cobban, W.A., and Hook, S.C., 1979, *Collignoniceras woollgari woollgari* (Mantell) ammonite fauna from Upper Cretaceous of Western Interior, United States: New Mexico Bureau of Mines & Mineral Resources Memoir 37, 51 p.

Cobban, W.A., and Reeside, J.B., Jr., 1952, Frontier formation, Wyoming and adjacent areas: American Association of Petroleum Geologists Bulletin, v. 36, no. 10, p. 1913–1961.

Cobban, W.A., Walaszczyk, Ireneusz, Obradovich, J.D., and McKinney, K.C., 2006, A USGS zonal table for the Upper Cretaceous middle Cenomanian-Maastrichtian of the Western Interior of the United States based on ammonites, inoceramids, and radiometric ages: U.S. Geological Survey Open-File Report 2006–1250, 45 p., http://pubs.usgs.gov/of/2006/1250/.

Dyman, T.S., Cobban, W.A., Davis, L.E., Eves, R.L., Pollock, G.L., Obradovich, J.D., Titus, A.L., Takahashi, K.I., Hester, T.C., and Cantu, D., 2002, Upper Cretaceous marine and brackish water strata at Grand Staircase-Escalante National Monument, Utah, Geological Society of America field trip road log, May 2002, *in* Lund, W.R., ed., Field guide to geologic excursions in southwestern Utah and adjacent areas of Arizona and Nevada: U.S. Geological Survey Open-File Report 02–172. [Available at http://pubs.usgs.gov/of/2002/0172/.]

Dyman, T.S., Merewether, E.A., Molenaar, C.M., Cobban, W.A., Obradovich, J.D., Weimer, R.J., and Bryant, W.A., 1994, Stratigraphic transects for Cretaceous rocks, Rocky Mountains and Great Plains regions, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., eds., Mesozoic systems of the Rocky Mountain region: The Rocky Mountain Section SEPM (Society for Sedimentary Geology), p. 365–391.

Dyman, T.S., Porter, K.W., Tysdal, R.G., Cobban, W.A., Fox, J.E., Hammond, R.H., Nichols, D.J., Perry, W.J., Jr., Rice, D.D., Setterholm, D.R., Shurr, G.W., Haley, J.C., Lane, D.E., Anderson, S.B., and Campen, E.B., 1995, West-east stratigraphic transect of Cretaceous rocks in the northern Rocky Mountains and Great Plains regions, southwestern Montana to southwestern Minnesota: U.S. Geological Survey Miscellaneous Investigations Series Map I–2474–A.

Dyman, T.S., Tysdal, R.G., Porter, K.W., and Thompson, G.A., 1995, Measured sections and correlations of mid-Cretaceous rocks near the Lombard thrust of the Helena salient in southwestern Montana: U.S. Geological Survey Open-File Report 95–841.

Fouch, T.D., Lawton, T.F., Nichols, D.J., Cashion, W.B., and Cobban, W.A., 1983, Patterns and timing of synorogenic sedimentation in Upper Cretaceous rocks of central and northeast Utah, *in* Reynolds, M.W., and Dolly, E.D., eds., Mesozoic paleogeography of the west-central United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Rocky Mountain Paleogeography Symposium 2, p. 305–336.

Fraser, G.D., Waldrop, H.A., and Hyden, H.J., 1969, Geology of the Gardiner area, Park County, Montana: U.S. Geological Survey Bulletin 1277, 118 p. [Available at http://pubs.er.usgs.gov/publication/b1277.]

Gardner, M.H., and Cross, T.A., 1994, Middle Cretaceous paleogeography of Utah, *in* Caputo, M.V., Peterson, J.A., and Franczyk, K.J., eds., Mesozoic systems of the Rocky Mountain region: The Rocky Mountain Section SEPM (Society for Sedimentary Geology), p. 471–502.

Gradstein, F.M., Ogg, J.G., Schmitz, Mark, and Ogg, Gabi, eds., 2012, The geologic timescale 2012: Elsevier Publishing Company, 1,176 p.

Gwinn, V.E., 1961, Geology of the Drummond area, central-western Montana: Montana Bureau of Mines and Geology Special Publication no. 21, table and map.

Gwinn, V.E., 1965, Cretaceous rocks of the Clark Fork Valley, central western Montana: Billings Geological Society 16th Annual Field Conference, p. 34–57.

Hettinger, R.D., and Kirschbaum, M.A., 2002, Stratigraphy of the Upper Cretaceous Mancos Shale (upper part) and Mesaverde Group in the southern part of the Uinta and Piceance Basins, Utah and Colorado: U.S. Geological Survey Geologic Investigations Series I–2764.

Kirkland, J.I., 1991, Lithostratigraphic and biostratigraphic framework for the Mancos Shale (late Cenomanian-middle Turonian) at Black Mesa, northeastern Arizona, *in* Nations, D.J., and Eaton, J.G., eds., Stratigraphy, depositional environments, and sedimentary tectonics of the western margin, Cretaceous Western Interior seaway: Geological Society of America Special Paper 260, p. 85–111.

Kirkland, J.I., and Madsen, S.K., 2007, The Lower Cretaceous Cedar Mountain Formation, eastern Utah—The view up an always interesting learning curve: Geological Society of America Rocky Mountain Section Annual Meeting, St. George, Utah, May 4–6, 2007: Utah Geological Association Publication 35, 108 p.

Love, J.D., 1956, Cretaceous and Tertiary stratigraphy of the Jackson Hole area, northwestern Wyoming, *in* Berg, R.R., and Strickland, J.W., eds., Jackson Hole: Wyoming Geological Association 11th Annual Field Conference Guidebook, p. 76–94, http://archives.datapages.com/data/wga/data/012/012001/76_wga0120076.htm.

Love, J.D., Duncan, D.C., Bergquist, H.R., and Hose, R.K., 1948, Stratigraphic sections of Jurassic and Cretaceous rocks in the Jackson Hole area, northwestern Wyoming: The Geological Survey of Wyoming, Bulletin 40, 48 p.

McGookey, D.P., compiler, 1972, Cretaceous System, *in* Mallory, W.W., editor-in-chief, Geologic atlas of the Rocky Mountain region: Rocky Mountain Association of Geologists, Denver, Colorado, p.190–211.

Merewether, E.A., Blackmon, P.D., and Webb, J.C., 1984, The mid-Cretaceous Frontier Formation near the Moxa Arch, southwestern Wyoming: U.S. Geological Survey Professional Paper 1290, 29 p. [Available at http://pubs.er.usgs.gov/publication/pp1290.]

Merewether, E.A., Cobban, W.A., and Obradovich, J.D., 2011, Biostratigraphic data from Upper Cretaceous formations—Eastern Wyoming, Central Colorado, and Northeastern New Mexico: U.S. Geological Survey Scientific Investigations Map 3175, 10 p., 2 sheets, http://pubs.usgs.gov/sim/3175/.

Merewether, E.A., Dolson, J.C., Hanson, W.B., Keefer, W.R., Law, B.E., Mueller, R.E., Ryer, T.A., Smith, A.C., Stilwell, D.P., and Wheeler, D.M., 1997, Cretaceous stratigraphy in a northeast-trending transect, northern Utah to south-central South Dakota: U.S. Geological Survey Geologic Investigations Map I–2609.

Molenaar, C.M., Cobban, W.A., Merewether, E.A., Pillmore, C.L., Wolfe, D.G., and Holbrook, J.M., 2002, Regional stratigraphic cross sections of Cretaceous rocks from east-central Arizona to the Oklahoma panhandle: U.S. Geological Survey Miscellaneous Field Investigations Series MF–2382.

Molenaar, C.M., Nummedal, Dag, and Cobban, W.A., 1996, Regional stratigraphic cross sections of the Gallup Sandstone and associated strata around the San Juan Basin, New Mexico, and parts of adjoining Arizona and Colorado: U.S. Geological Survey Oil and Gas Investigations Chart OC–143.

Repenning, C.A., and Page, H.G., 1956, Late Cretaceous stratigraphy of Black Mesa, Navajo and Hopi Indian Reservations, Arizona: American Association of Petroleum Geologists Bulletin, v. 40, no. 2, p. 255–294.

Reynolds, M.W., and Brandt, T.R., 2005, Geologic map of the Canyon Ferry Dam 30' × 60' quadrangle, west-central Montana: U.S. Geological Survey Scientific Investigations Map 2860, 32 p., 3 pl., scale 1:100,000, http://pubs.usgs.gov/sim/2005/2860/.

Rice, D.D. and Cobban, W.A., 1977, Cretaceous stratigraphy of the Glacier National Park area, northwestern Montana: Canadian Petroleum Geology Bulletin , v. 25, no. 4, p. 828–841.

Ryer, T.A., 1977, Age of Frontier Formation in north-central Utah: American Association of Petroleum Geologists Bulletin, v. 61, no. 1, p. 112–116.

Titus, A.L., Powell, J.D., Roberts, E.M., Sampson, S.D., Pollock, S.L., Kirkland, J.I., and Albright, L.B., 2005, Late Cretaceous stratigraphy, depositional environments, and macrovertebrate paleontology of the Kaiparowits Plateau, Grand Staircase–Escalante National Monument, Utah, *in* Pederson, J., and Dehler, C.M., eds., Interior Western United States: Geological Society of America Field Guide 6, p. 101–128, doi:.10.1130/2005.fld006(05).

Tysdal, R.G., Dyman, T.S., Nichols, D.J., and Cobban, W.A., 1990, Correlation chart of Frontier Formation from Greenhorn Range, southwestern Montana, to Mount Everts in Yellowstone National Park, Wyoming: U.S. Geological Survey Miscellaneous Field Studies Map MF–2116, pamphlet.

Tysdal, R.G., and Nichols, D.J., 1991, Biostratigraphic correlation of Santonian and Campanian formations in the northwestern part of Yellowstone National Park, and the Madison Range and Livingston area of southwestern Montana, chap. B *of* Contributions to Late Cretaceous stratigraphy and paleontology, western Montana: U.S. Geological Survey Bulletin 1962, p. 9–19.

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