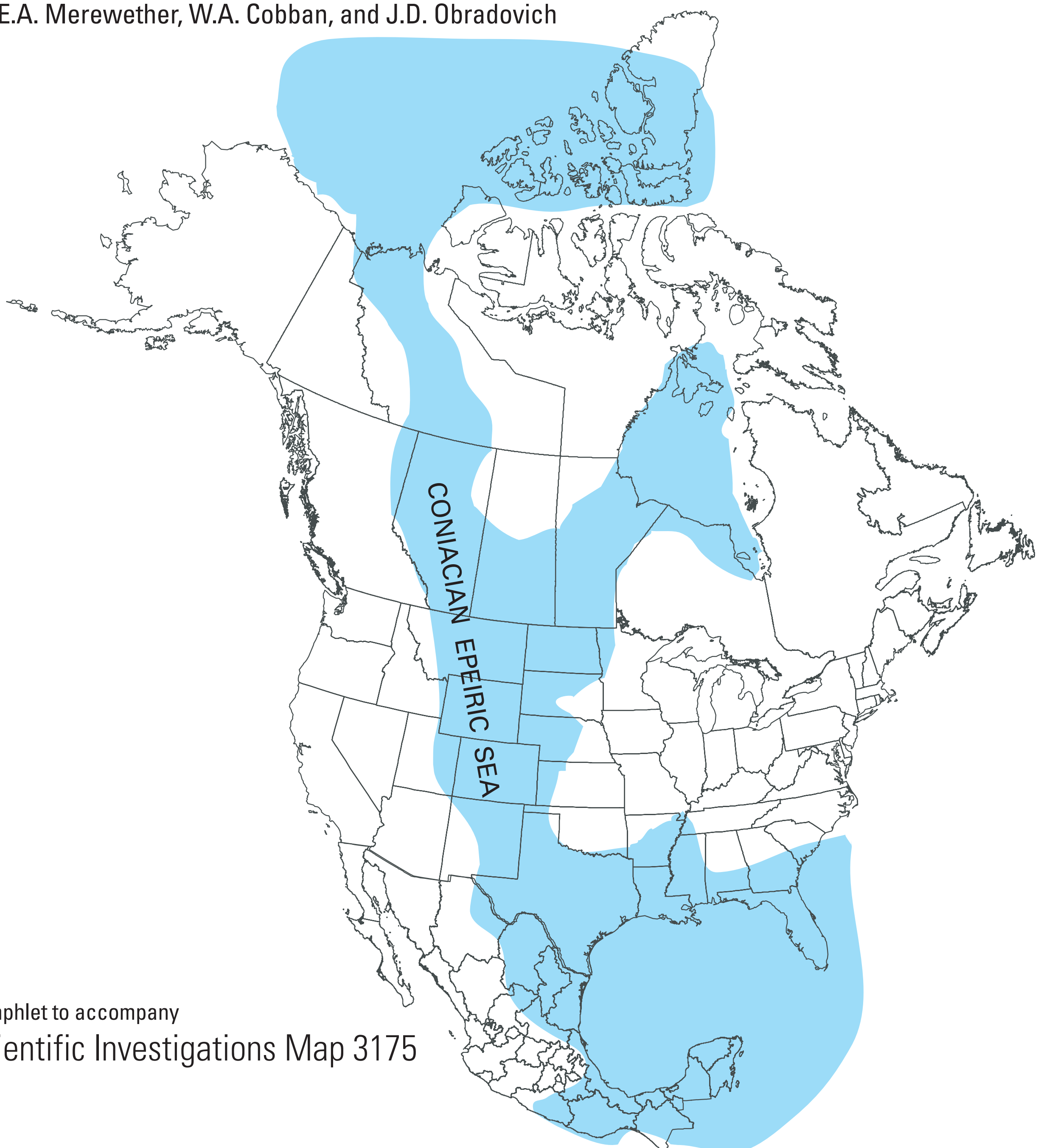
Biostratigraphic Data from Upper Cretaceous Formations—Eastern Wyoming, Central Colorado, and Northeastern New Mexico

By E.A. Merewether, W.A. Cobban, and J.D. Obradovich



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Biostratigraphic Data from Upper Cretaceous Formations—Eastern Wyoming, Central Colorado, and Northeastern New Mexico

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Abstract

Lithological and paleontological studies of outcrops of Upper Cretaceous formations were conducted at 12 localities in eastern Wyoming, central Colorado, and northeastern New Mexico. The sequence extends upward from the top of the Mowry Shale, or age-equivalent rocks, through the Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, Pierre Shale, and Fox Hills Sandstone, or age-equivalent formations, to the top of the Laramie Formation, or laterally equivalent formations. The strata are mainly siliciclastic and calcareous, with thicknesses ranging from about 3,300 ft in northeastern New Mexico to as much as 13,500 ft in eastern Wyoming. Deposition was mainly in marine environments and molluscan fossils of Cenomanian through Maastrichtian ages are common. Radiometric ages were determined from beds of bentonite that are associated with fossil zones.

The Upper Cretaceous formations at the 12 study localities are herein divided into three informal time-stratigraphic units based on fossil content and contact relations with adjacent strata. The basal unit in most places extends from the base of the Graneros to the top of the Niobrara, generally to the horizon of the fossil *Scaphites hippocrepis*, and spans a period of about 14 million years. The middle unit generally extends from the top of the Niobrara to the approximate middle of the Pierre, the horizon of the fossil *Baculites gregoryensis*, and represents a period of about 5 million years. The upper unit includes strata between the middle of the Pierre and the top of the Upper Cretaceous Series, which is the top of the Laramie Formation or of laterally equivalent formations; it represents a period of deposition of as much as 11 million years.

Comparisons of the collections of fossils from each outcrop with the complete sequence of Upper Cretaceous index fossils can indicate disconformable contacts and lacunae. Widespread disconformities have been found within the Carlile Shale and between the Carlile Shale and the Niobrara Formation. Less extensive disconformities are within the Greenhorn Formation, the Niobrara Formation, and the Pierre Shale.

Introduction

Biostratigraphic descriptions of outcropping Upper Cretaceous strata are presented herein for 12 localities in a south-trending transect from northeastern Wyoming to northeastern New Mexico (fig. 1), a distance of some 550 miles. The descriptions were obtained mainly from the publications listed at the end of this report. In regional cross sections (sheets 1 and 2), occurrences of the latest Campanian fossil *Baculites eliasi* are used as a reference plane. This study is related to the Western Interior Cretaceous (WIK) program, a cooperative investigation by geologists representing academia, commercial organizations, and State and Federal governments. It supplements east-trending stratigraphic cross sections in (1) Montana, South Dakota, and Minnesota by Dyman and others (1995); (2) Utah, Wyoming, and South Dakota by Merewether and others (1997); (3) Arizona, New Mexico, Colorado, and Oklahoma by Molenaar and others (2002); and (4) Utah, Colorado, and Kansas by Anna (in preparation).

The sedimentary rocks considered in this investigation consist of siliciclastic, calcareous, carbonaceous, and bentonitic strata of Cenomanian through Maastrichtian ages. They include rocks between the top of the Mowry Shale or age-equivalent beds and the top of the youngest Cretaceous formations. In eastern Wyoming, these strata have been assigned, in ascending order, to the Belle Fourche Shale, Greenhorn Formation, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone, and Lance Formation (see NW Black Hills section, sheet 1); or alternatively, to the Frontier Formation, Sage Breaks Shale, Niobrara Formation, Steele Shale, Rock River Formation, Pine Ridge Sandstone, Lewis Shale, Fox Hills Sandstone, and Medicine Bow Formation (see Rock River section, sheet 1). Laterally equivalent formations in central Colorado and northeastern New Mexico are, from oldest to youngest, the Graneros Shale, Greenhorn Limestone, Carlile Shale, Niobrara Formation, Pierre Shale, Fox Hills Sandstone (or Trinidad Sandstone), and Laramie Formation (or Vermejo Formation and Raton Formation) (see Pueblo and Trinidad-Aguilar sections, sheet 2).

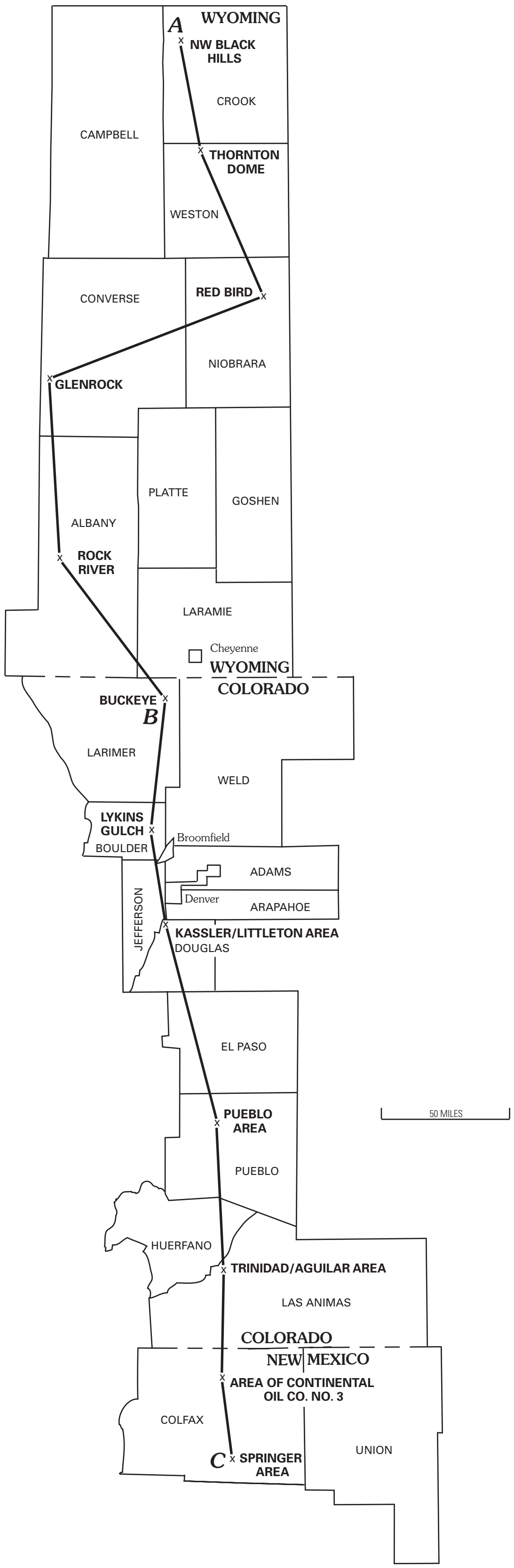

Figure 1. Location of cross section in counties of eastern Wyoming, central Colorado, and northeastern New Mexico (click here for large version of figure).

In the 12 outcrop sections, the thicknesses of the Upper Cretaceous strata range from about 13,500 ft in Albany County, southeastern Wyoming, to about 3,300 ft in Colfax County, northeastern New Mexico. Most of the strata were deposited in marine environments although some members, as well as the uppermost Cretaceous beds, accumulated in continental environments. Molluscan fossils from the marine beds and the associated informal zone numbers (fig. 2) are listed with lithologic symbols on the cross sections. The numbered zones generally include several fossil species in addition to those listed in figure 2. Sequences of fossils from the outcrops, when compared to the complete sequence of index fossils [fig. 2; Ireneusz Walaszczyk (written commun., 2011), Cobban and others, 2006], are evidence for correlations of lithofacies, as well as for periods of nondeposition and erosion. Lacunae in the outcrop sections (fig. 3) are indicated by local discontinuities in the fossil sequence. The duration of several lacunae was estimated from the radiometric ages of fossil zones (fig. 2; Cobban and others, 2006).

Chronostratigraphy

The sequences of Upper Cretaceous formations shown in this north-trending transect (fig. 1; sheet 1, 2) include strata that were deposited in continental, nearshore marine, and offshore-marine environments. Outcrop sections near Glenrock and Rock River in eastern Wyoming (fig. 1, sheet 1) contain continental and nearshore-marine beds, and are about 10,000 ft and 13,400 ft thick, respectively. The sequences in eastern Wyoming that originated mainly in offshore-marine environments are about 7,300 ft thick at Red Bird, 5,900 ft thick at Thornton Dome, and 4,500 ft thick near NW Black Hills. In central Colorado (fig. 1, sheet 2), outcrops of nearshore-marine and offshore-marine strata range from 9,500 ft thick at Buckeye to about 6,800 ft thick near Pueblo. Near Trinidad/Aguilar in south-central Colorado and near the Continental Oil Co. borehole and Springer in northeastern New Mexico, the outcrop sections consist mainly of offshore-marine strata and are 3,300 ft to 3,400 ft thick. Shorelines of the north-trending epicontinental seaway in which the offshore-marine beds were deposited were located far to the west (Cobban and others, 1994).

Strata in most of the outcrop sections of the transect are, herein, separated into the following three informal time-stratigraphic units: a basal unit that extends generally from the base of the Graneros to the top of the Niobrara (fossil zones 6 to 53); a middle unit that extends mostly from the top of the Niobrara to near the middle of the Pierre (fossil zones 53 to 61); and an upper unit that extends from the approximate middle of the Pierre (fossil zone 61) to the top of Upper Cretaceous strata (fossil zones younger than 75).

The basal unit is Cenomanian to early Campanian in age, represents a period of about 14 million years (m.y.), and contains more calcareous beds and disconformities than the

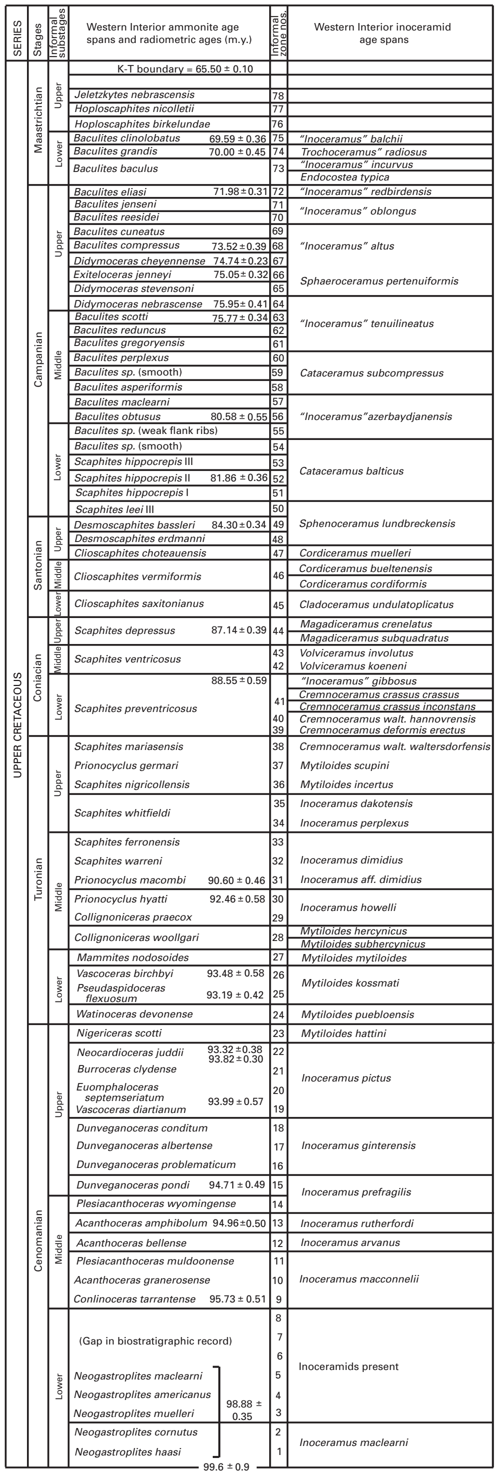

Figure 2. Molluscan fossil zones, informal zone numbers, fossil ranges, and radiometric ages for marine strata of Cenomanian, Turonian, Coniacian, Santonian, Campanian, and Maastrichtian Stages (Upper Cretaceous) in the Western Interior of the United States [modified after Ireneusz Walaszczyk (written commun., 2011); Cobban and others, 2006; Kennedy and others, 1996; Cobban, 1977]. m.y., millions of years (click here for large version of figure).

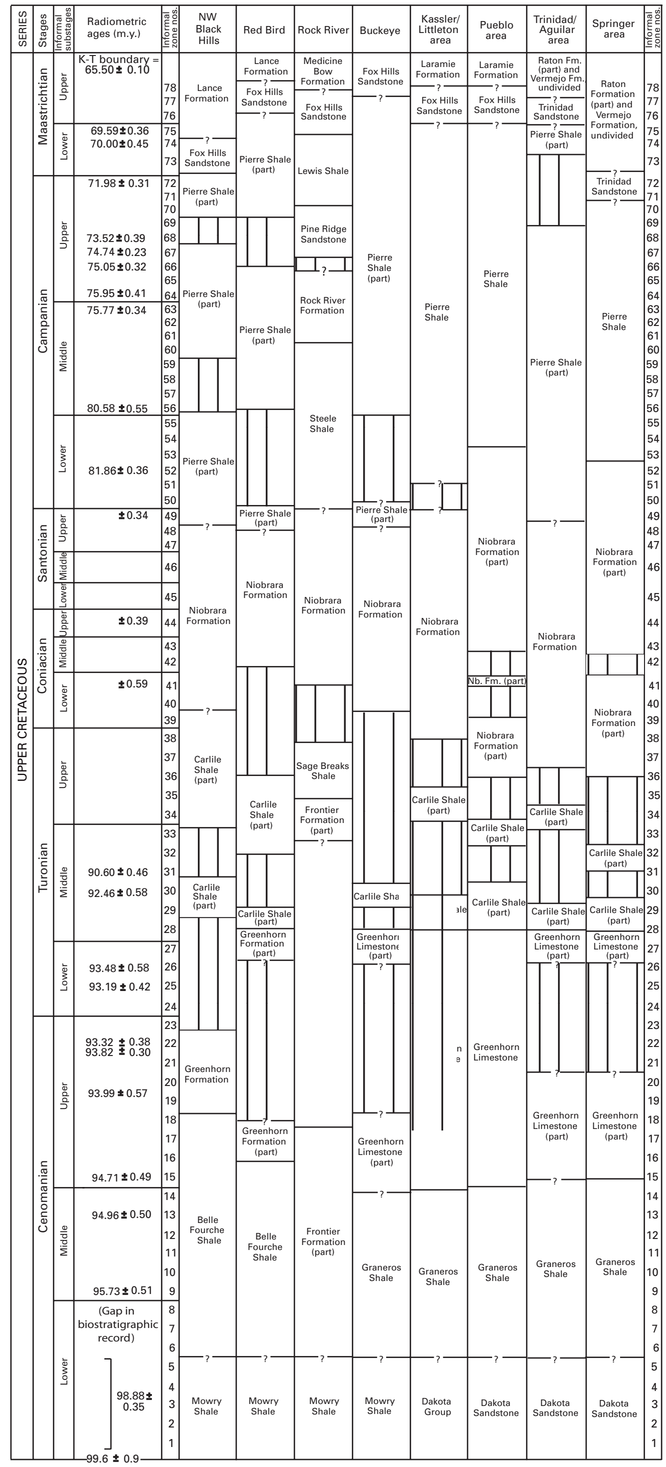

Figure 3. Lacunae (lined pattern) in Upper Cretaceous formations in eastern Wyoming, central Colorado, and northeastern New Mexico with informal fossil zone numbers and radiometric ages. m.y., millions of years (click here for large version of figure).

younger units. It is as much as 2,200 ft thick near NW Black Hills (23 percent of that outcrop section) and as little as 770 ft thick at Lykins Gulch (10 percent of that outcrop section). However, the ages of the tops of the underlying Mowry Shale or Dakota Sandstone in the 12 outcrop sections are probably not always the same. The apparent rates of deposition for the basal unit, which were affected by periods of erosion and non-deposition, as well as by differential crustal subsidence, range from 157 ft/m.y. near NW Black Hills to 54 ft/m.y. at Lykins Gulch (table 1).

The middle unit is of early to middle Campanian age, records deposition during about 5 m.y., consists generally of siliciclastic beds, and encloses a few apparently local disconformities. It is as much as 2,740 ft thick near Glenrock (28 percent of that outcrop section) and as little as 460 ft thick near NW Black Hills (11 percent of that outcrop section). Apparent rates of deposition for the middle unit are as much as 548 ft/m.y. near Glenrock to as little as 92 ft /m.y. near NW Black Hills (table 1).

The youngest unit, between fossil zone 61 and the top of the Cretaceous sequence, is of middle Campanian through Maastrichtian ages, and records about 11 m.y. of deposition. It is comprised generally of marine siliciclastic beds overlain by continental siliciclastic and carbonaceous beds, and it encloses several unconformities. This unit is 1,200 ft thick at Springer (36 percent of the outcrop section), 1,100 ft thick at the Continental Oil Co. borehole (33 percent of the total section), and thickens to 9,680 ft to the north near Rock River (72 percent of the total section). Northward from Rock River, thicknesses are 4,700 ft at Red Bird (65 percent of the total section), 3,000 ft at Thornton Dome (51 percent of the total section), and 1,700 ft near NW Black Hills (30 percent of the total section). Rates of deposition for the upper unit range from 880 ft/m.y. near Rock River, to 155 ft/m.y. near NW Black Hills, and to 100 ft/m.y. at the Continental borehole (table 1).

Cenomanian and Turonian Strata

Strata of Cenomanian age in eastern Wyoming (fig. 3, sheet 1) are assigned to the Belle Fourche Shale and to the overlying Greenhorn Formation (as young as fossil zone 20) or to the Belle Fourche Member of the Frontier Formation (as young as fossil zone 17). The Frontier can include, in ascending order, the Belle Fourche Member and the Wall Creek Member (Merewether, 1996). At Thornton Dome and Red Bird (fig. 1, sheet 1, and fig. 3), Cenomanian beds in the lower part of the Greenhorn (fossil zone 17) are disconformably overlain by beds of early Turonian age (fossil zone 27) in the upper part of the Greenhorn.

At NW Black Hills, Cenomanian beds (containing fossils as young as zone 22) in the Greenhorn are disconformably overlain by middle Turonian beds (fossil zone 29) of the Pool Creek Member of the Carlile Shale (fig. 3). The Carlile in eastern Wyoming consists, from oldest to youngest, of the Pool Creek, Turner Sandy, and Sage Breaks Members (see NW Black Hills section, sheet 1). Near Rock River, Cenomanian strata (fossil zone 17) in the Belle Fourche Member of the Frontier Formation are overlain, possibly disconformably, by upper Turonian beds (fossil zones 34 or 35) in the Wall Creek Member of the Frontier Formation. The Marker (gray-red) bentonite bed of middle Cenomanian age (fossil zone 13) is recognized at NW Black Hills, Thornton Dome, and Red Bird (sheet 1).

In central Colorado and northeastern New Mexico, strata of Cenomanian age (fossil zone 9 to as young as zone 23) are within the Graneros Shale and in the overlying Greenhorn Limestone, which consists, from oldest to youngest, of the Lincoln, Hartland Shale, and Bridge Creek Members (see Pueblo section, sheet 2, fig. 3). The age of the Bridge Creek Member near Pueblo is late Cenomanian and lower and middle Turonian (fossil zones 19 to 28; Kennedy and others, 2005). In that area, the Hartland Member is conformably overlain by the Bridge Creek Member. Incomplete sequences of Cenomanian and Turonian fossils probably indicate a disconformity and a hiatus within the Greenhorn and within strata of equivalent ages at other outcrop sections in central Colorado (sheet 2), as well as in outcrops near Thornton Dome and Red Bird in Wyoming (sheet 1).

Turonian Strata

In eastern Wyoming (sheet 1), lower and middle Turonian beds of fossil zones 27–30 are near the top of the Greenhorn and in the overlying Pool Creek Member of the Carlile Shale. They are disconformably overlain by middle and upper Turonian strata within fossil zones ranging from 32 to 37 in the Turner Sandy Member of the Carlile and in the Wall Creek Member of the Frontier. An unconformity at the contact of the Pool Creek and Turner Sandy Members of the Carlile in a borehole near Thornton Dome in eastern Wyoming was shown by Weimer and Flexer (1985). The Turner is conformably overlain by the Sage Breaks Member of the Carlile, which is late Turonian in age (fossil zones 36 and 37). The Wall Creek is conformably overlain by the Sage Breaks Member of the Cody Shale, which is an age-equivalent unit of the Sage Breaks Member of the Carlile.

In central Colorado and northeastern New Mexico, strata of early and middle Turonian ages in the Bridge Creek Member of the Greenhorn and in the overlying Fairport Member of the Carlile Shale contain fossils of zones 27 and 28. The Carlile in this region can include the following members, from oldest to youngest: Fairport, Blue Hill, Codell Sandstone, Juana Lopez, and Montezuma Valley (sheet 2). In the vicinity of Continental Oil Co. borehole No. 3, in northeastern New Mexico (fig. 1, sheet 2), the Fairport reportedly is overlain disconformably by the Blue Hill Member, which contains fossils of zone 30 (Molenaar and others, 2002). The Blue Hill and overlying Codell in central Colorado (sheet 2) are of middle Turonian age (fossil zone

Table 1. Thicknesses (ft) and approximate rates of deposition (ft/m.y.) for three informal stratigraphic units of Late Cretaceous age at localities in eastern Wyoming, central Colorado, and northeastern New Mexico.

Location	NW Black Hills	Thornton Dome	Red Bird	Glenrock	Rock River	Buckeye	Lykins Gulch	Kassler/ Littleton	Pueblo	Trinidad/ Aguilar	Continental Oil Co.	Springer
UPPER UNIT												
Thickness	1,700	3,050	4,660	5,700	9,680	6,400	5,600	5,170	4,800	?	1,100	1,200
Rate of deposition	155	277	424	518	880	585	509	470	436	?	100	109
MIDDLE UNIT												
Thickness	460	?	1,500	2,740?	2,440	2,160	1,650	1,320	700	?	1,140	900
Rate of deposition	92	278?	300	548?	488	432?	330	264	140	?	228	180
LOWER UNIT												
Thickness	2,200	?	1,130	1,500	1,310	890	770	1,170	1,260	1,200	1,070	1,250
Rate of deposition	157	104?	81?	107?	94?	64	54	84	90	86	76	90

30) and the age-equivalent strata of the Pool Creek Member in Wyoming.

The Codell Sandstone Member or the Blue Hill Member of the Carlile Shale are disconformably overlain by the Juana Lopez Member, which contains middle and upper Turonian fossils (zones 32–35) and is correlative with strata in the Turner Sandy Member of the Carlile Shale and in the Wall Creek Member of the Frontier Formation in Wyoming. At several outcrops in south-central Colorado and northeastern New Mexico, the Juana Lopez is conformably overlain by the Montezuma Valley (Leckie and others, 1997; Merewether and others, 2007), which is probably of late Turonian age.

Turonian and Coniacian Strata

At localities near Red Bird and Rock River in eastern Wyoming (fig. 3), the Sage Breaks Member of the Carlile and the Sage Breaks Shale, respectively, are of late Turonian age (fossil zone 36) and apparently are disconformably overlain by the Niobrara Formation of middle Coniacian age. Weimer and Flexer (1985) depicted an unconformity between the Sage Breaks and Niobrara in a borehole near Thornton Dome. The lower beds of the Niobrara at Red Bird contain fossils that represent zone 43. At other localities in this area, however, evidence is lacking for disconformities separating the Carlile and the Niobrara.

In northeastern New Mexico near Springer (fig. 3, sheet 2), the Montezuma Valley Member of the Carlile Shale is probably of late Turonian age and could be disconformably overlain by the Fort Hays Limestone Member of the Niobrara Formation of late Turonian age (fossil zone 36). The Niobrara in this region includes the Fort Hays Limestone Member and the overlying Smoky Hill Member. In central Colorado, near Trinidad/Aguilar, Pueblo, and Kassler/Littleton, the Juana Lopez is of middle and late Turonian ages (fossil zones 33 and 34) and is disconformably overlain by the Fort Hays Member of late Turonian age (fossil zones 37 and 38). Near the Continental Oil Co. No. 3 borehole and at Buckeye (fig. 3), the middle Turonian Codell Member (fossil zone 30) is disconformably overlain by the Fort Hays Member of late Turonian and early Coniacian ages (fossil zones 36 to 40).

Coniacian, Santonian, and Campanian Strata

The Niobrara Formation in eastern Wyoming and north-central Colorado is of Coniacian and probable Santonian ages. It is conformably overlain by the Pierre Shale or the Steele Shale, the lower beds of which are either Santonian or Campanian (fig. 3). Near Glenrock, Wyoming, the Niobrara is a member of the Cody Shale and is conformably overlain by the Steele Member of the Cody. At outcrops in central Colorado near Kassler/Littleton, the Niobrara is latest Turonian, Coniacian, and Santonian, and is conformably overlain by lower Campanian strata of the Pierre Shale. In south-central Colorado and northeastern New Mexico, the Niobrara is late Turonian, Coniacian, Santonian, and early Campanian, and is conformably overlain by lower Campanian beds of the Pierre. Gaps in the sequence of lower and middle Coniacian Inoceramids (fig. 2) at outcrops near Pueblo and Springer indicate hiatuses within the Smoky Hill Member of the Niobrara (Walaszczyk and Cobban, 2006) which could extend to other outcrops in central Colorado (sheet 2).

Coniacian, Santonian, Campanian, and Maastrichtian Strata

In eastern Wyoming, the Pierre Shale consists of the following units, in ascending order: Gammon Member, Ardmore Bentonite Bed, Sharon Springs Member, Mitten Member, Red Bird Silty Member, lower unnamed shale, Kara Bentonitic Member, and upper unnamed shale (see Red Bird section, sheet 1). Age-equivalent strata near Glenrock are assigned to the following formations, from oldest to youngest: Cody Shale, Mesaverde Formation, and Lewis Shale. The Gammon at NW Black Hills (sheet 1) is probably of late Santonian and early Campanian ages (fossil zones 49–55) and is overlain, possibly disconformably, by the Mitten Member of middle Campanian age (fossil zones 58–60). Lowermost strata of the Mitten in that area have been assigned to the Sharon Springs Member (Robinson and others, 1964). To the south near Red Bird and near Buckeye in north-central Colorado, the Gammon is much thinner and is disconformably overlain by the Sharon Springs of middle Campanian age (fossil zone 56). The sedimentology and southward thinning of the Gammon Member of the Pierre, at outcrops from the NW Black Hills to Red Bird, were interpreted and recorded by Asquith (1970). The Ardmore Bentonite Bed in the lower part of the Pierre was deposited during the middle Campanian (fossil zone 56) and is widespread in eastern Wyoming and central Colorado.

The lower unnamed shale member of the Pierre in eastern Wyoming encloses a disconformity within upper Campanian strata that separates beds containing fossils of zones 66 or 67 from beds containing fossils of zone 70. This disconformity has also been identified near Glenrock at the base of the Teapot Sandstone Member of the Mesaverde Formation and near Rock River at the base of the Pine Ridge Sandstone. Fossils of latest Coniacian and Santonian ages have not been found in outcrop sections in eastern Wyoming.

The Pierre and Lewis Shales of eastern Wyoming are conformably overlain by the Fox Hills Sandstone; the lowest beds of which have an apparent age range from early Maastrichtian at NW Black Hills (fossil zone 72), Thornton Dome (fossil zone 74), Glenrock (fossil zone75), and Rock River (fossil zone 75) to late Maastrichtian at Red Bird (fossil zone 75).

The Pierre Shale in north-central Colorado contains the following units, from oldest to youngest: (1) Gammon, Sharon Springs, Mitten, and Hygiene Sandstone Members; (2) a sequence of shales and sandstones that includes the Terry

Sandstone, Rocky Ridge Sandstone, Larimer Sandstone, and Richard Sandstone Members; (3) unnamed sequence of shales and sandstones; and (4) an upper sandy transition member (see Buckeye section, sheets 1, 2). In the vicinity of Pueblo, the Pierre includes the following, in ascending order: transition member, Apache Creek Sandstone, Ardmore Bentonite Bed, Sharon Springs, Rusty zone of Gilbert, Tepee zone of Gilbert, Cone-in-cone zone of Lavington (1933), and a transition member (see Pueblo section, sheet 2). The lowest beds of the Pierre could be late Santonian (fossil zone 49, fig. 3) at Buckeye and Lykins Gulch and early Campanian near Pueblo (fossil zone 54) and in the area of Springer (fossil zone 53) (sheet 2). The age of the uppermost Pierre in central Colorado and northeastern New Mexico ranges probably from late Campanian near Springer to early Maastrichtian near Pueblo and Kassler/Littleton to late Maastrichtian at Buckeye (fig. 3). Disconformities within the Pierre in this region probably are between the Gammon and Sharon Springs Members at Buckeye, and possibly within the lowermost Pierre at Lykins Gulch and Kassler/Littleton. A disconformity and lacuna near the top of the Pierre in the area of Trinidad/Aguilar are between beds of late Campanian age (fossil zone 68 or slightly younger) and early Maastrichtian age (fossil zone 74 or slightly older).

In central Colorado and northeastern New Mexico, the Pierre is conformably overlain by the Fox Hills Sandstone at Buckeye, Lykins Gulch, Kassler/Littleton, and Pueblo, and by the Trinidad Sandstone at Trinidad/Aguilar, Continental Oil Co. No. 3 borehole, and Springer (sheet 2). In this region, the age of the basal Fox Hills probably is late Maastrichtian and the age of the basal Trinidad probably is late Maastrichtian at Trinidad/Aguilar, early Maastrichtian at the Continental Oil Co. No. 3 borehole, and late Campanian at Springer.

Interpretations

Outcrop sections of Upper Cretaceous strata near Glenrock and Rock River In eastern Wyoming (sheet 1), include continental and nearshore-marine beds with thicknesses of about 10,000 ft and 13,400 ft, respectively. To the northeast and south (fig. 1), continental, nearshore-marine, and offshore-marine sequences are about 7,300 ft thick at Red Bird, 9,500 ft thick at Buckeye, 6,800 ft thick near Pueblo, and 3,300 ft thick near Springer. For all outcrop sections in the transect, it was assumed that the tops of the underlying Mowry Shale or Dakota Sandstone are nearly the same age. The regional thinning and lateral changes in dominant depositional environments of the Upper Cretaceous Series probably reflect different distances from shorelines and sources of sediments, as well as the number and duration of lacunae and regional variations in rates of crustal subsidence. Shorelines of the north-trending Late Cretaceous seaway that correspond to many of the offshore-marine beds in the transect were located far to the west (Cobban and others, 1994).

Within the outcrop sections in the transect, the three informal time-stratigraphic units vary in thickness, percentage of each total section, dominant depositional environment, apparent rate of deposition, and distances from correlative shorelines. The calcareous basal unit is overlain by the siliciclastic middle unit, which suggests deposition while laterally equivalent shorelines were prograding generally eastward.

Thicknesses of the lower and middle units vary laterally and have an inverse relation at several localities (table 1). At Buckeye, for example, the basal unit is comparatively thin (890 ft) and the middle unit is relatively thick (2,160 ft), whereas at Springer, Pueblo, and NW Black Hills, the basal unit is comparatively thick (1,250–2,200 ft) and the middle unit is relatively thin (460–900 ft). Apparent rates of deposition for the basal unit are largest at NW Black Hills, Thornton Dome, and Glenrock (104–157 ft/m.y.), and least at Buckeye and Lykins Gulch (54–64 ft/m.y.). For the overlying middle unit, the rates of deposition are greatest at Glenrock and Rock River (488–548? ft/m.y.) and least at NW Black Hills (92 ft/m.y.) and Pueblo and Springer (140–180 ft/m.y.). These thicknesses and rates of deposition suggest that either the tops of the basal unit in the region of the transect formed an irregular wavy surface or that the rates of subsidence of the sea floor varied locally during deposition of the basal and middle units.

The upper informal unit thickens northward almost uniformly from 1,100 ft at the Continental Oil Co. borehole, to 9,680 ft near Rock River, and thereafter thins northward to 1,700 ft near the NW Black Hills. Corresponding rates of deposition for the upper unit at those localities are 100 ft/m.y. at the borehole, 880 ft/m.y. near Rock River, and 155 ft/m.y. near NW Black Hills. These thicknesses and depositional rates probably reflect different distances from the main source of sediments, but could also indicate that the highest rates of crustal subsidence along the transect during late middle Campanian through Maastrichtian time were in the area between Pueblo and Red Bird.

The proposed lacunae in the outcrop sections (sheets 1, 2; fig. 3), which are indicated by interruptions in the established sequence of fossil zones (figs. 2, 3), apparently have local and regional distributions. A disconformity and the associated lacuna within the Greenhorn extend southward from Thornton Dome and Red Bird in Wyoming and probably to localities in central Colorado and northeastern New Mexico. They are between beds containing fossils of zones 18–20 and overlying beds containing fossils of zone 27. The age of the eroded surface of the lower parts of the Greenhorn is irregular. The age of upper parts of the Greenhorn is more consistent. This lacuna reflects a marine regression, widespread erosion, and a transgression, all of which happened during about 0.5 million years in the late Cenomanian and early Turonian.

The Carlile Shale in eastern Wyoming, central Colorado, and northeastern New Mexico encloses disconformities and variable lacunae that reflect events in the middle Turonian (fig. 3). At outcrop sections in the region (sheets 1, 2; fig. 3), ages of lower and upper parts of the Carlile are not uniform. The apparent duration of the lacunae is least near Springer, most near Kassler/Littleton and Trinidad/Aguilar, and intermediate elsewhere (sheet 2). Variations in the ages of the Carlile and in the durations of the enclosed lacunae might represent contrasting rates of local crustal subsidence or lateral changes in depositional and erosional events.

The lacuna at the contact of the Carlile or Sage Breaks and the overlying Niobrara also varies in duration, which is longest, as much as 2 m.y., in the outcrops near Buckeye (fig. 3). Strata in the upper part of the Carlile (or Sage Breaks) range in age from middle to late Turonian (fossil zones 32 to 38); they become progressively younger from Springer to Pueblo, Kassler/Littleton, and Rock River, possibly reflecting a northward decrease in the amount of erosion. Overlying beds in the lowermost part of the Niobrara transgress consistently northward from late Turonian (fossil zone 36) near Springer to middle Coniacian (fossil zone 42) near Red Bird. The ages of these strata suggest that the top of the Carlile/Sage Breaks was an irregular erosional surface that was buried by onlapping beds of the northward transgressing basal Niobrara (Merewether and Cobban, 1985).

Lacunae of lower and middle Coniacian ages are within the Niobrara near Pueblo and Springer and probably at nearby localities. The erosion of strata in this offshore marine environment might indicate local uplifts of the sea floor and powerful submarine currents.

Lower parts of the Pierre Shale at NW Black Hills, Thornton Dome, and Red Bird in eastern Wyoming, and probably at Buckeye, Lykins Gulch, and Kassler/Littleton in north-central Colorado, include a lacuna of variable durations. The temporal extent of this lacuna is represented by the length of time that elapsed between fossil zones 56 to 59 (middle Campanian) at NW Black Hills, between fossil zones 50 to 55 at Red Bird and Buckeye (early Campanian), and possibly between fossil zones 50 to 51 (early Campanian) at Kassler/Littleton.

Another lacuna was recognized in upper Campanian strata in eastern Wyoming but it has not been recognized in central Colorado or in northeastern New Mexico. It is located in the upper part of the Pierre Shale at NW Black Hills and Red Bird, at the base of the Teapot Sandstone Member of the Mesaverde Formation near Glenrock, and probably is at the base of the Pine Ridge Sandstone near Rock River. The temporal extent of this lacuna at NW Black Hills is represented by the length of time that elapsed between fossil zones 68 and 69, near Red Bird it is between fossil zones 67 to 69 (about 2 m.y.), and near Glenrock it might be between fossil zones 66 to 70. It is indeterminate at the outcrops near Rock River.

The uppermost lacuna in the Pierre is located in south-central Colorado, in the area of Trinidad/Aguilar, and apparently is a local feature. It is bounded by beds of late Campanian age (fossil zone 68 or slightly younger) and beds of early Maastrichtian age (fossil zone 74 or slightly older) and represents as much as 3.5 m.y.

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