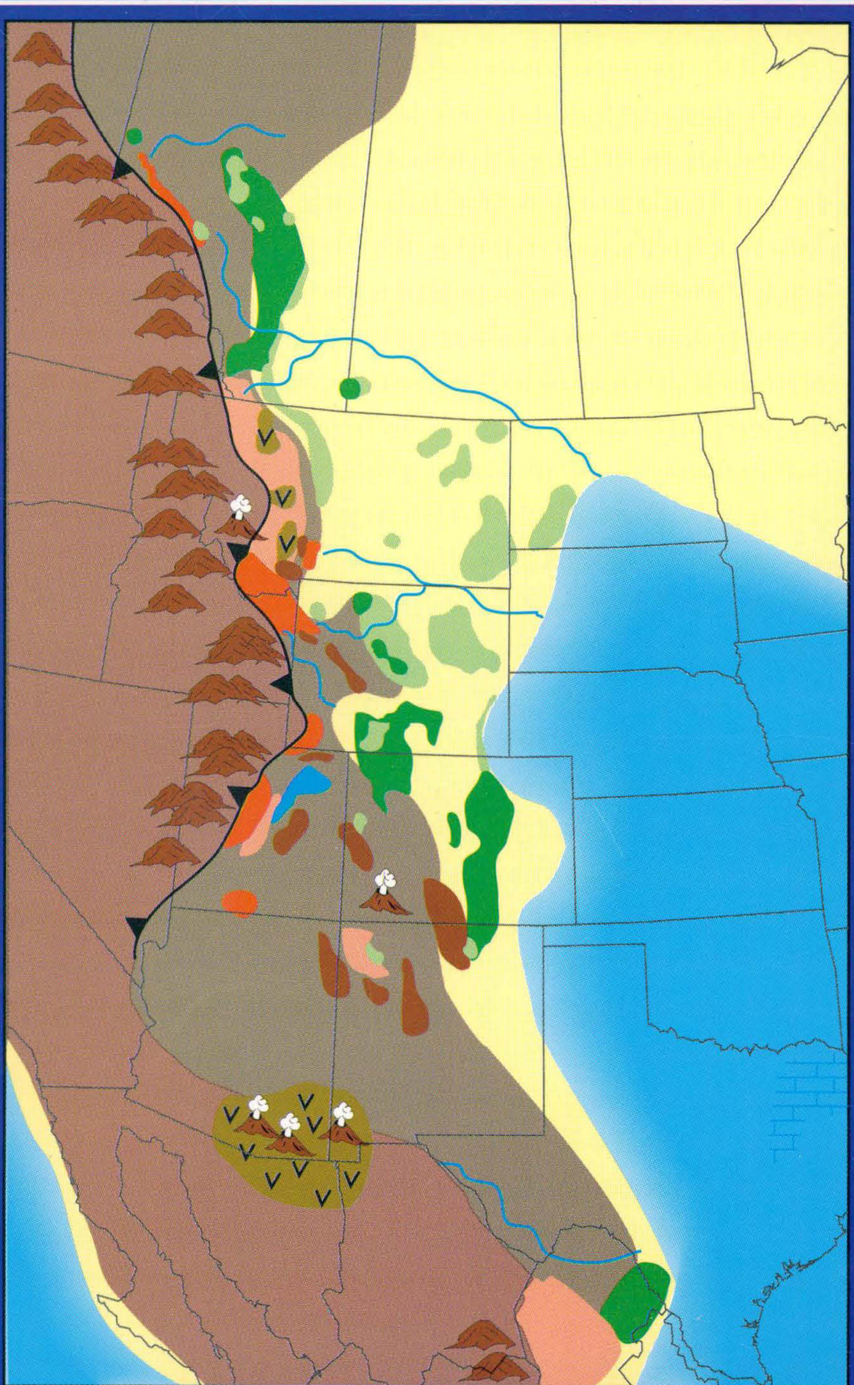
Paleogeography of the Late Cretaceous of the Western Interior of Middle North America—Coal Distribution and Sediment Accumulation



U.S. Geological Survey Professional Paper 1561

Paleogeography of the Late Cretaceous of the Western Interior of Middle North America—Coal Distribution and Sediment Accumulation

By Laura N. Robinson Roberts *and* Mark A. Kirschbaum

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Paleogeography of the Late Cretaceous of the Western Interior of Middle North America—Coal Distribution and Sediment Accumulation

By Laura N. Robinson Roberts *and* Mark A. Kirschbaum

ABSTRACT

A synthesis of Late Cretaceous paleogeography of the Western Interior, from Mexico to southwestern Canada, emphasizes the areal distribution of peat-forming environments during six biostratigraphically constrained time intervals. Isopach maps of strata for each interval reveal the locations and magnitude of major depocenters. A comparison of coal distribution and sediment accumulation within an overall paleogeographic framework provides insight into the relative importance of tectonism, eustasy, and climate on the accumulation of thick peats and their preservation as coals.

The thickest, most extensive Upper Cretaceous coals of the Western Interior of North America formed during the latest Cenomanian to middle Maastrichtian. This time interval is characterized by folding and thrusting related to Sevier-style deformation in the Western Cordillera, and associated development of a foreland basin along the eastern edge of the deformation front. It was a time of overall high eustatic sea level during which shorelines fluctuated over a wide area, but over time, gradually prograded eastward, filling in the seaway. The majority of peat in the study area accumulated on coastal plains in the more actively subsiding parts of the foreland basin, and in middle paleolatitudes between 35° and 55° N.

Less significant amounts of peat accumulated during the early part of the Cenomanian and the later part of the Maastrichtian. These two intervals of time have characteristics that are different from those of the majority of the Late Cretaceous. Unlike the coastal plain setting of later coals, Cenomanian coals accumulated as peats well inland in low-gradient alluvial plains during rises in relative sea level. The late Maastrichtian, by contrast, was characterized by the rapid retreat of the Western Interior seaway and, in the central United States, by the predominance of Laramide-style deformation. Peats that formed in the Maastrichtian were confined to rapidly subsiding intermontane basins or scattered over the retreating coastal plain environments.

INTRODUCTION

This report is a synthesis of the paleogeography and sediment accumulation patterns within the Western Interior foreland basin, from northern Mexico to southwestern Canada (fig. 1), during the Late Cretaceous with particular reference to the location of coal deposits. This study was undertaken as part of the U.S. Geological Survey's Cretaceous Coals of North America project, which was implemented to assess the relative importance of tectonism, sea-level variation, and climate in controlling the distribution of Upper Cretaceous coal. The amount of coal of Cretaceous age on the North American continent is greater than that of any other geologic period with over 2 trillion short tons contained in Upper Cretaceous rocks (not including Alaska; Wood and Bour, 1988).

The maps presented here will form the basis of future studies on such issues as the effects of sediment accumulation on paleogeography and evolution of foreland basin development. In a broad context, these maps will be valuable to the many other workers who are interested in the Cretaceous from the point of view of oil, gas, and coalbed methane resources. On the more academic side, the study is an important resource for those trying to understand basin development, paleoclimate, and sequence stratigraphy. Advances in all these fields will ultimately help the economic geologists as well.

WESTERN INTERIOR SEAWAY

A vast seaway occupied the Western Interior of North America during the Late Cretaceous, connecting the Circum-Boreal sea with the proto-Gulf of Mexico (fig. 1). This seaway formed during a time of maximum eustatic sea level for the Phanerozoic (Vail and others, 1977; Haq and others, 1987), when water levels flooded the stable cratonic areas of the world. At its maximum extent, the seaway extended for 4,800 km from the North Slope of Alaska to northern Mexico and was approximately 1,620 km wide from central Utah to

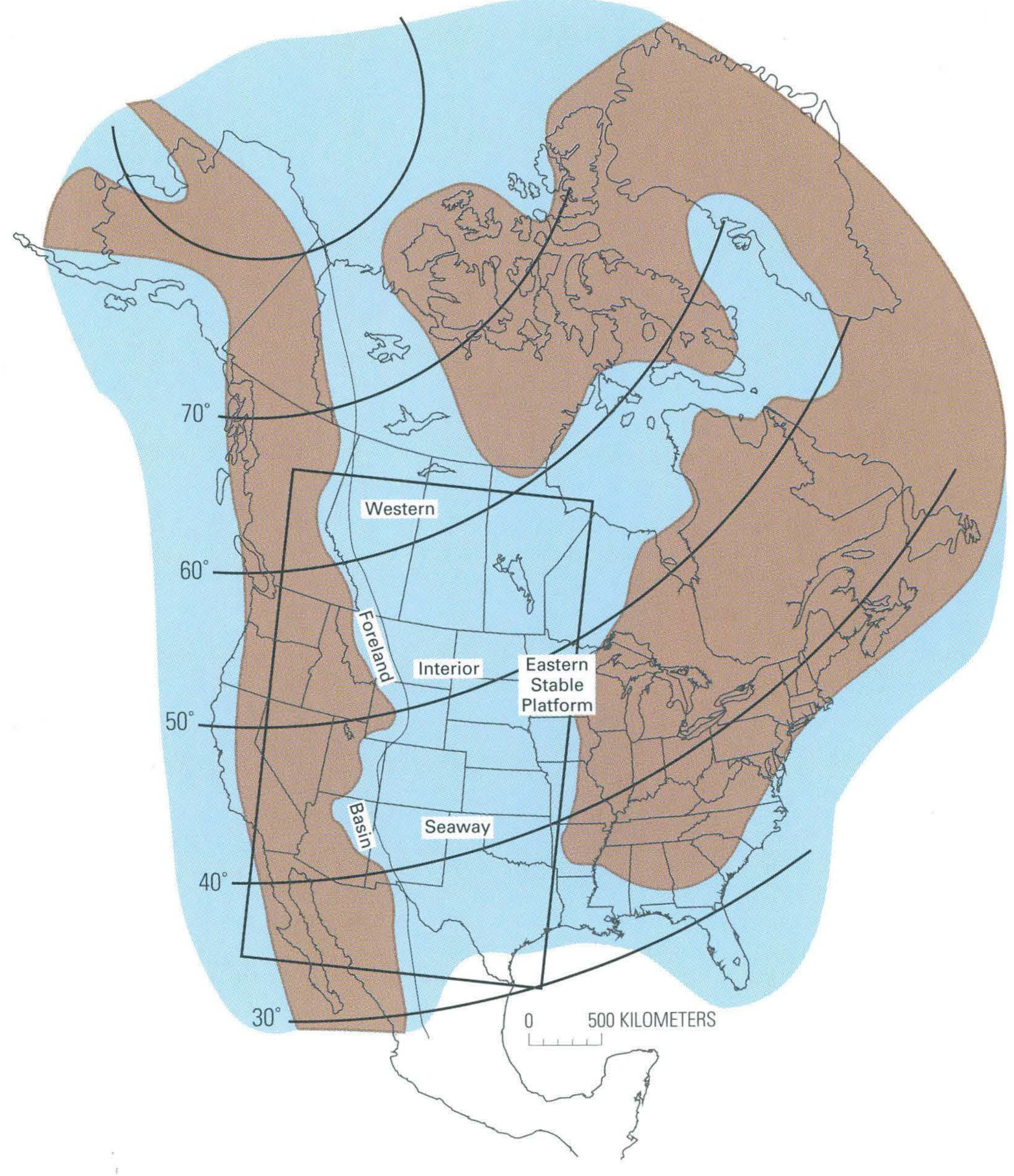


Figure 1. Extent of Western Interior seaway during peak late Turonian transgression (*Watinoceras* time) (Williams and Stelck, 1975, fig. 5). Also shown are general locations of the Foreland Basin and the Eastern Stable Platform (Kauffman, 1984, fig. 1). Paleolatitudes are averages from about 90 m.y. to 60 m.y. (Irving, 1979, fig. 14). Rectangle defines the study area covered by isopach and paleogeographic maps presented in this report.

Minnesota (fig. 1) (Kauffman, 1984). The seaway existed within an asymmetric foreland basin bordered on the west by the Columbian-Sevier orogen and flanking foredeep and on the east by the stable cratonic platform (fig. 1). The structural basin originated as the result of pre-Cretaceous tectonic processes. The thrusting and resulting crustal loading are related to the subduction of the Farallon plate (Keith, 1978) and the accretion of numerous terranes to the North American craton (Coney, 1981; Cant and Stockmal, 1989). At various times during the Late Cretaceous, these plate tectonic movements resulted in magmatic activity in western Canada, Idaho and Montana, Arizona and New Mexico, and the Sierra Nevadas of California. A transition from Sevier-style deformation (thin-skinned thrusting with associated forelands) to Laramide-style deformation (thick-skinned thrusting with associated uplifts and intermontane basins) took place in the Late Cretaceous as a result of a shallowing of the angle of the subducting slab and compressional stresses in the lithosphere (Keith, 1978; Erslev, 1993).

During phases of uplift in the Columbian-Sevier orogen, great volumes of coarse-grained terrigenous sediments were deposited as clastic wedges in the western side of the basin. Lithofacies grade, west to east, from coarse-grained sandstone facies, through interbedded sandstone and shale, to shale, chalk, and ultimately to limestone. These generalized facies patterns were interrupted by effects on sedimentation caused by major movements along the thrust belt, growth of arches, increase in subsidence rate, periodic subaerial exposure and erosion, and shoreline migration. Major unconformities separate the clastic rocks into sequences that can be documented over wide areas and may be linked to eustatic lowstands as identified in the Exxon global cycle chart (Haq and others, 1987; Cant and Stockmal, 1989; Van Wagoner and others, 1990).

North America occupied middle to high paleolatitudes, from 30° to 85° N., in the Late Cretaceous (fig. 1) (Irving, 1979), and the vegetation ranged from tropical in Mexico and the southeastern United States to temperate in northern Canada and Alaska (Saward, 1992). Based on analyses of physiognomy of leaf assemblages, most Late Cretaceous plants evolved in a climate characterized by the absence of freezing temperatures and low to moderate amounts of precipitation (Wolfe and Upchurch, 1987). Evidence of polar glaciation is lacking (Kauffman, 1984).

METHODS

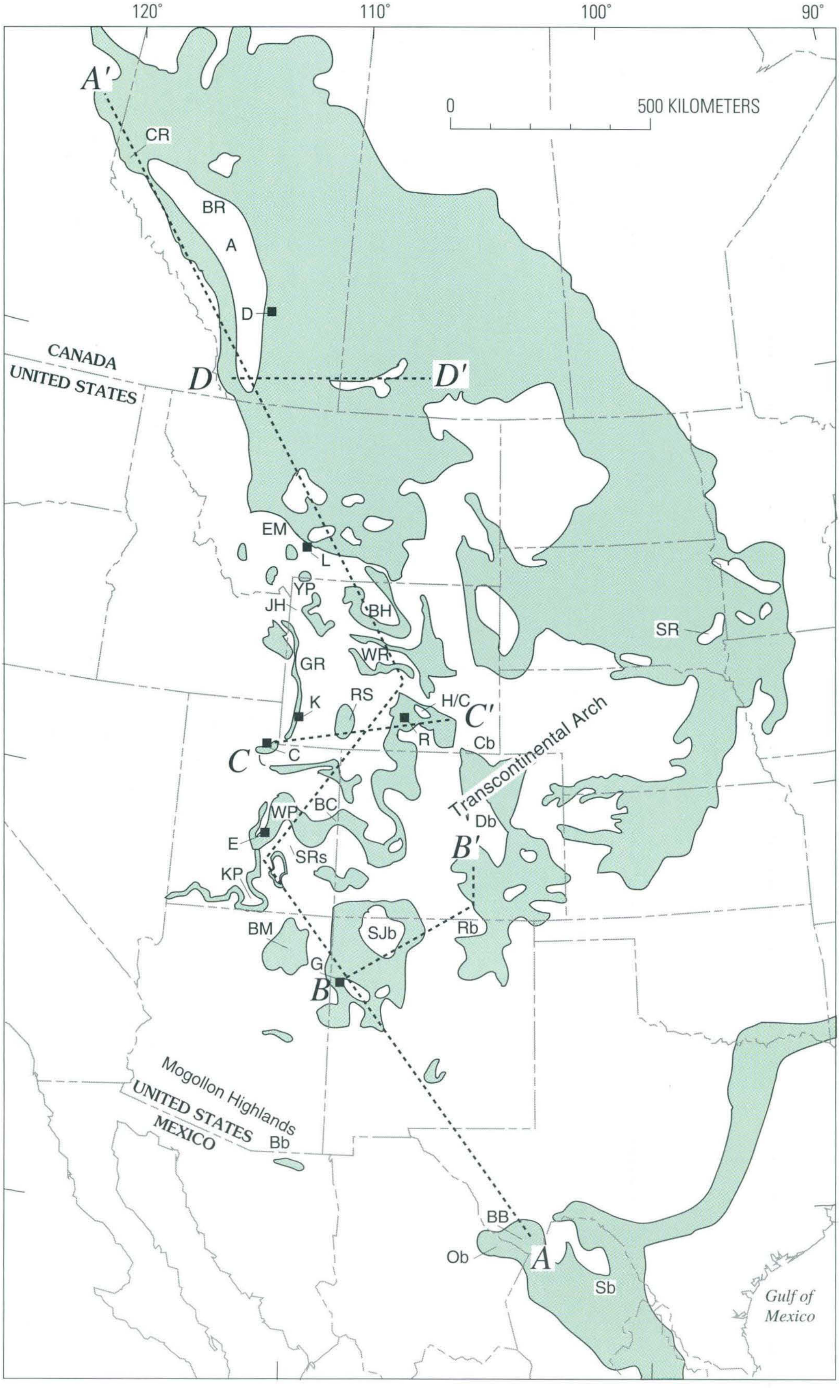
Several workers (Beeson, 1984; Fielding, 1987; McCabe, 1991) have observed that tectonic subsidence exerts a dominant control on peat accumulation, and we wanted to understand this control more comprehensively as it pertains to the Upper Cretaceous coals in North America. To this end, we constructed paleogeographic maps for biostratigraphically constrained intervals spanning the Cenomanian through Maastrichtian ages emphasizing the areal distribution of peat-forming environments. We also constructed isopach maps showing the thickness of sedimentary rocks of each interval represented by the paleogeographic maps. The change in location of major depocenters through time (as shown on the isopach maps) and the distribution of key lithofacies, such as conglomerates (as shown on the paleogeographic maps), will be useful to those workers interested in tectonic subsidence and how it relates to the evolution of the Late Cretaceous foreland basin.

Many paleogeographic reconstructions exist for parts or all of the Late Cretaceous, most of which emphasize the marine and nearshore marine realms (Williams and Stelck, 1975; Kauffman, 1984; Reeside, 1944, 1957; Gill and Cobban, 1973; Stott, 1984; Jeletzky, 1971). Paleogeographic maps that show the distribution of peat-forming environments are typically only at the local scale of investigation (for example, Jerzykiewicz, 1992; Lawrence, 1992; Flores and others, 1991; Ryer, 1981a). McGookey and others (1972) showed generalized areas of peat-forming environments on their maps, but did not include the Canadian or Mexican part of the Western Interior seaway. Our paleogeographic maps depict the evolution of the Late Cretaceous peat-forming and coeval environments of the study area during six time intervals, which are based on well-established faunal zones. Figure 2 shows the distribution of Upper Cretaceous outcrops in the study area, and figures 3 and 4 are chronostratigraphic cross sections oriented along general depositional strike and depositional dip, respectively. The cross sections show the regional relations of many of the units mentioned in the text. Table 1 gives short versions of references indicated by numbers in figures 3, 4, and others, and on plate 1.

BIOSTRATIGRAPHY

A key factor in producing the best representative paleogeographic and isopach maps is assigning the most accurate age possible to the study interval. For the Cretaceous Western Interior seaway, ammonite zonations are well established (Cobban, 1994; Kauffman, 1977; Obradovich and Cobban, 1975; Jeletzky, 1968, 1971) and allow a comparison of strata at different localities, especially in the geographic center of the seaway where marine conditions prevailed for much of the Late Cretaceous. In the marine sections, inoceramids and foraminifers are also useful in supplementing the biostratigraphic record. Problems in age control arise for two main reasons. First, precise correlation of terrestrial and marine successions is difficult; units deposited in terrestrial environments cannot be traced into marine environments because of facies changes and lack of common fauna. Terrestrial units may contain abundant remains of leaves, palynomorphs, bivalves, and vertebrates, but these flora and fauna tend to have longer biostratigraphic ranges than their marine counterparts. Second, most of the ammonite zone fossils are restricted to the geographic center of the seaway (covering the Rocky Mountain and plains region of the United States) because of the ecotone that existed due to mixing of cool boreal faunas of Canada with warm temperate faunas of the Gulf (Obradovich and Cobban, 1975; Kauffman, 1984). For this study, it was necessary therefore to understand the relationships of the different biostratigraphic zonations for various geographic regions.

Plate 1 represents a compilation and partly our interpretation of the zonations of many different paleontologists. A complete ammonite zonation is provided, and for details adjacent to the interval boundaries, supplementary fossil zonations or, in the case of the bivalves, taxon ranges are given. We stress that this chart is only intended to document our understanding of the biostratigraphy and to provide a framework for us to collect the data we used to construct the maps. We divided the Late Cretaceous into six intervals of time with similar lengths (rounded off to the nearest 0.5 m.y. based on the geochronology of Obradovich (1993)). For the most part, the interval boundaries are placed at Upper Cretaceous stage boundaries mainly because of the extensive research conducted on these


120°
110°
100°
90°
50°
40°
30°
0
500 KILOMETERS
A′
CR
BR
A
D
CANADA
UNITED STATES
D
D′
EM
L
YP
JH
BH
WR
GR
K
RS
H/C
C′
R
Cb
C
C
Transcontinental Arch
WP
BC
Db
E
SRs
B′
KP
BM
SJb
Rb
G
B
SR
Mogollon Highlands
UNITED STATES
MEXICO
Bb
BB
Ob
A
Sb
Gulf of Mexico

boundaries worldwide (Hancock, 1991; Kennedy, 1989; Caldwell and North, 1984; Cobban, 1984, among others). Many of the stage boundaries also are near highstands of sea level in the Western Interior. The marine shale tongues deposited during these highstands usually have good ammonite control and wide geographic distribution, and tend to bracket packages of poorly dated terrestrial strata. The plethora of research on the Cretaceous-Tertiary boundary has aided identification of the top of the Cretaceous (Pillmore and Flores, 1987; Newman, 1987; Jerzykiewicz and Sweet, 1988; Lerbekmo and Coulter, 1985).

The six Late Cretaceous time intervals are each defined at the base by the base of a faunal zone and at the top by the top of a faunal zone. The oldest study interval encompasses the entire Cenomanian Stage (98.5–93.5 Ma), which in the Western Interior is defined at the base by the ammonite zone *Neogastroplites cornutus* and at the top by *Neocardioceras juddii.* Foraminifers are particularly useful in many of the Canadian and Gulf Coast sections (pl. 1). The next youngest interval, which corresponds to the Turonian Stage (93.5–88.5 Ma), is bracketed by *Pseudaspicoceras flexuosum* at the base and by *Prionocyclus quadratus* at the top. Inoceramids also proved very useful in determining boundaries in this interval. The next interval is picked to include both the Coniacian and Santonian Stages (88.5–83.5 Ma) and is delineated by the ammonite zones *Forresteria peruana* at the base and *Desmoscaphites bassleri* at the top. The Campanian Stage is divided and placed into three different intervals. The oldest interval, designated Campanian I, extends from the zone of *Scaphites leei* III through *Baculites asperiformis* (83.5–79 Ma); the Campanian II spans the ammonite zones *Baculites* sp. (late smooth form) to *B. cuneatus* (79–72 Ma); and the remainder of the Campanian (Campanian III), which includes only two ammonite zones, is included with the Maastrichtian Stage to form the uppermost study interval. This study interval, referred to for the remainder of the report as the Maastrichtian (72–65.5 Ma), is defined at the base by the ammonite zone *B. reesidei* and at the top by the last appearance of the dinosaur *Triceratops*.

Figure 2 (facing page). Index map of study area showing distribution of Upper Cretaceous outcrops (shaded green) and lines of section shown in figures 3 and 4. Basinal areas contain Upper Cretaceous rocks at depth. Compare with the paleogeographic maps to identify areas where reconstructions have been made by interpolating between outcrops. Generalized from the Stratigraphic Atlas of North and Central America (Shell Oil Company Exploration Department, 1975).

Letters refer to basins, uplifts, or locations mentioned in text.

Uplifts: RS, Rock Springs uplift; SR, Sioux ridge; SRs, San Rafael Swell.

Basins: A, Alberta basin; BH, Big Horn basin; WR, Wind River basin; JH, Jackson Hole; GR, Green River basin; H/C, Hanna and Carbon basins; Cb, Cheyenne basin; Db, Denver basin; SJb, San Juan Basin; Rb, Raton Basin; Bb, Bisbee basin; Ob, Ojinaga basin; Sb, Sabinas basin.

Locations: CR, Cutbank River; BR, Blackstone River; EM, Elkhorn Mountains; YP, Yellowstone Park; WP, Wasatch Plateau; KP, Kaiparowits Plateau; BC, Book Cliffs; BM, Black Mesa; BB, Big Bend; D, Drumheller; L, Livingston; K, Kemmerer; R, Rawlins; C, Coalville; E, Emery; G, Gallup.

BASIN SUMMARIES

In order to unravel the relative importance of tectonics, climate, and eustasy to the accumulation of coal, we have compiled a total of 123 basin summaries (table 2), whose locations are shown in figure 5, and the data for which are included in the appendix. The basin summaries are the building blocks of this study; they provide ground truth for the construction of the isopach and paleogeographic maps.

Each basin summary shows the thickness of the study interval at a particular locality. Difficulty in determining the interval thickness varies greatly, and consequently so does the reliability of thickness information. Ideally, we used stratigraphic sections with the best biostratigraphic control, that is, those that contain index fossils (for example, see L16ma in appendix). Less reliable thickness data were obtained when age control is extrapolated to other areas based on physical stratigraphy (for example, L6ce in appendix). The least reliable thickness data were obtained by projecting index fossil horizons into areas where few or no age-diagnostic fossils exist in the section. In this latter case, we used stratigraphic and geologic information to estimate how many Western Interior ammonite zones the undated interval most likely represents. We then assumed a constant sedimentation rate and did the necessary calculations to arrive at an estimated thickness (for example, L7ca in appendix). The majority of the thickness values recorded in the basin summaries were obtained through a combination of the three methods, and relatively few values were obtained using only the third method.

Coal information shown in each basin summary includes (1) cumulative thickness of coal in beds at least 1 m thick, (2) average thickness of coal beds at least 1 m thick, (3) maximum thickness of coal beds at least 1 m thick, (4) number of coal beds at least 1 m thick, (5) percent thickness of the interval that is coal, and (6) cumulative thickness and number of coal beds that are less than 1 m thick. Values recorded in this last category are considered minimum values because very thin coal beds (less than a few centimeters)

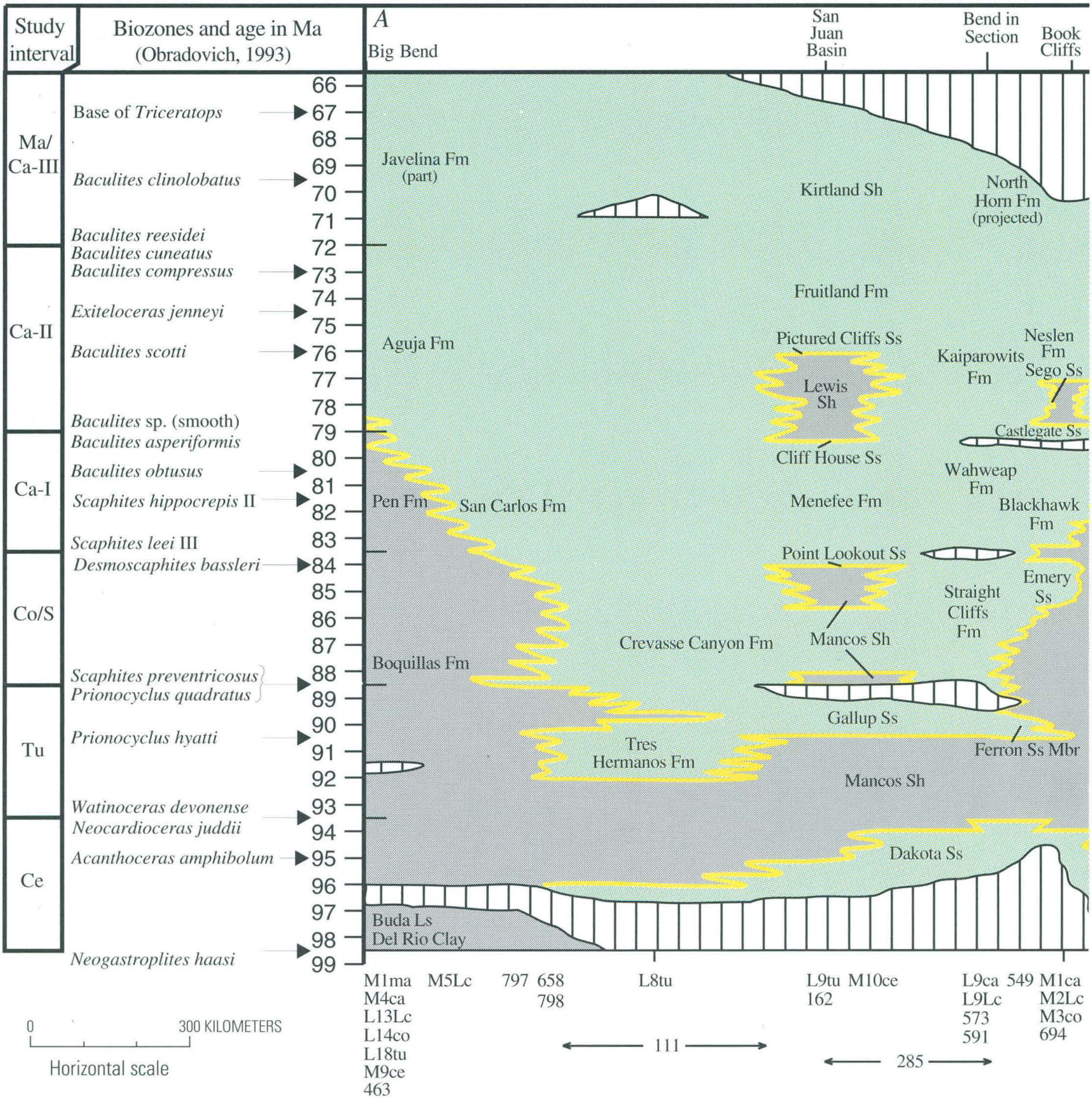
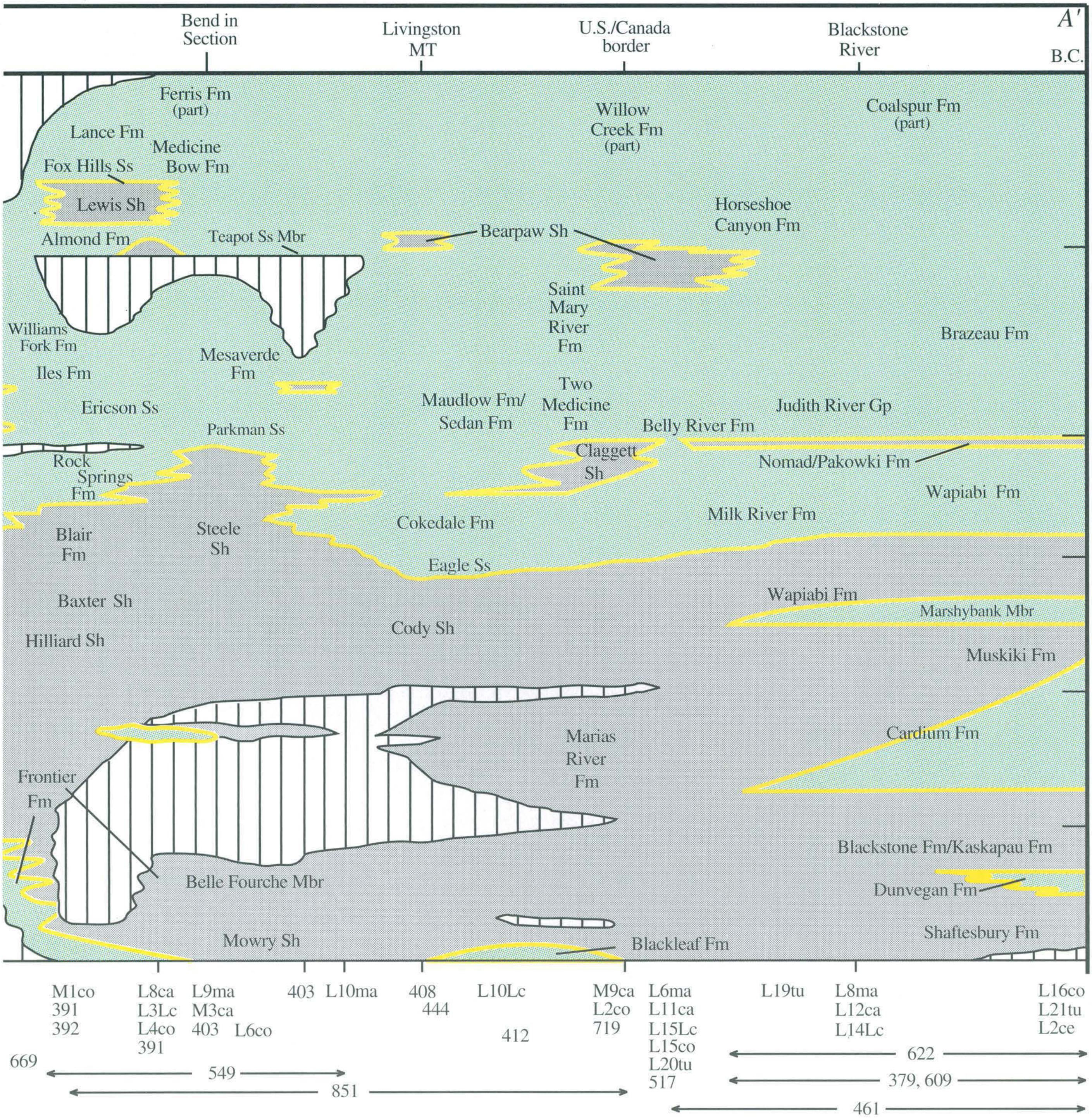
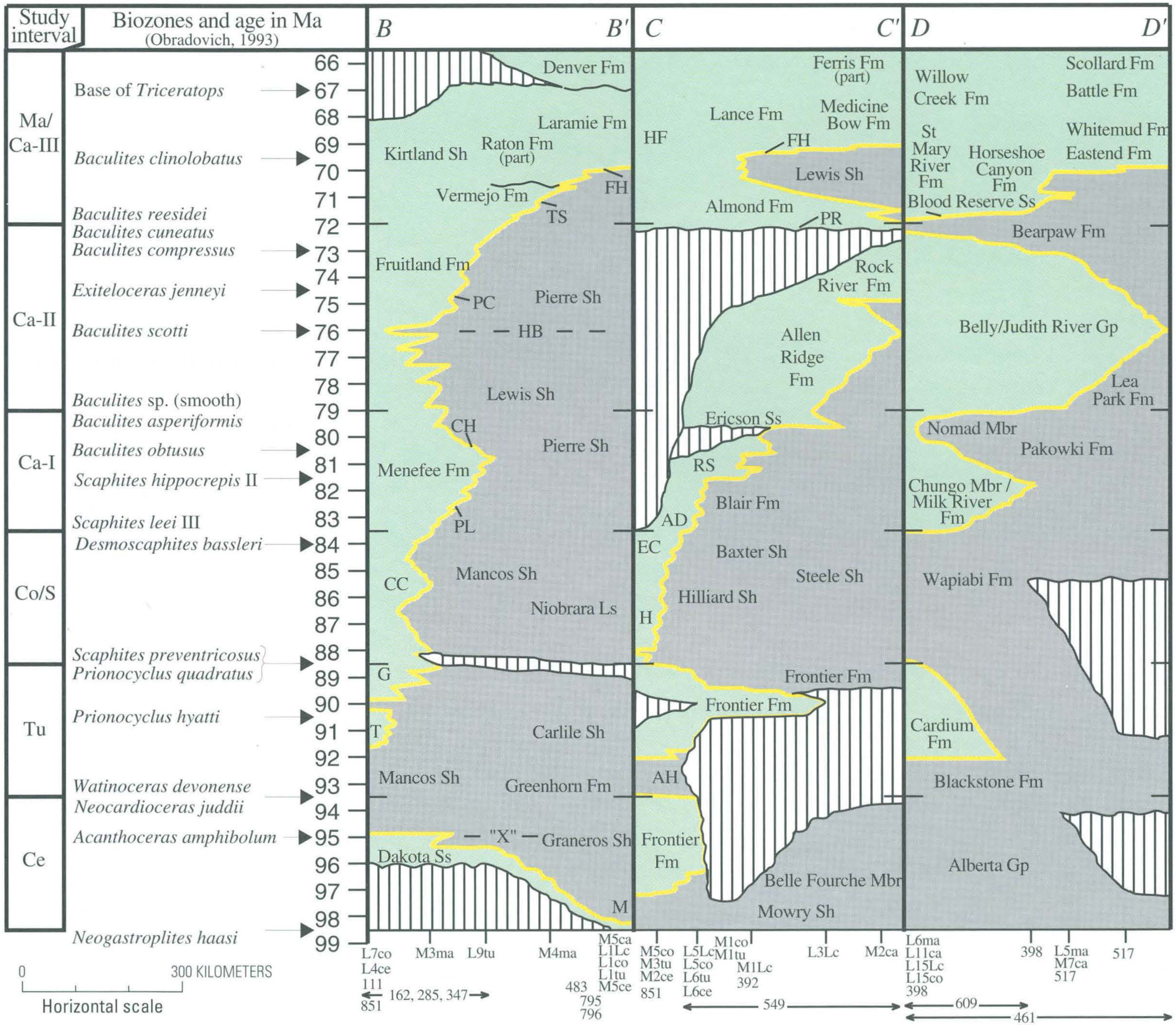


Figure 3. Generalized chronostratigraphic cross section *A–A'*, restored. Generalized depositional environments are also shown: green, nonmarine; figure 2 and is oriented approximately parallel to depositional strike. Arrows in the biozones column indicate sequential location of radiometrically not necessarily shown. Numbers at the base of the figure represent references listed in table 1; combined letter/number designations refer to basin



yellow, shoreface; gray, marine; and white with vertical ruled lines, significant time breaks (erosion or nondeposition). Line of section is shown in dated rocks (Obradovich, 1993). Vertical scale is age in millions of years. Section shows only selected stratigraphic names; formation contacts are summaries in the appendix.



Study interval
Biozones and age in Ma
(Obradovich, 1993)
B
B′
C
C′
D
D′
Ma/ Ca-III
Ca-II
Ca-I
Co/S
Tu
Ce
Base of Triceratops
Baculites clinolobatus
Baculites reesidei
Baculites cuneatus
Baculites compressus
Exiteloceras jenneyi
Baculites scotti
Baculites sp. (smooth)
Baculites asperiformis
Baculites obtusus
Scaphites hippocrepis II
Scaphites leei III
Desmoscaphites bassleri
Scaphites preventricosus
Prionocyclus quadratus
Prionocyclus hyatti
Watinoceras devonense
Neocardioceras juddii
Acanthoceras amphibolum
Neogastroplites haasi
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92
93
94
95
96
97
98
99
Denver Fm
Laramie Fm
Kirtland Sh
Raton Fm (part)
Vermejo Fm
FH
TS
Fruitland Fm
PC
Pierre Sh
HB
Lewis Sh
CH
Pierre Sh
Menefee Fm
PL
CC
Mancos Sh
Niobrara Ls
G
T
Carlile Sh
Mancos Sh
Greenhorn Fm
"X"
Graneros Sh
Dakota Ss
M
Ferris Fm (part)
Lance Fm
Medicine Bow Fm
HF
FH
Lewis Sh
Almond Fm
PR
Rock River Fm
Allen Ridge Fm
Ericson Ss
RS
Blair Fm
AD
EC
Baxter Sh
Steele Sh
Hilliard Sh
H
Frontier Fm
Frontier Fm
AH
Frontier Fm
Belle Fourche Mbr
Mowry Sh
Willow Creek Fm
Scollard Fm
Battle Fm
Whitemud Fm
St Mary River Fm
Horseshoe Canyon Fm
Eastend Fm
Blood Reserve Ss
Bearpaw Fm
Belly/Judith River Gp
Lea Park Fm
Nomad Mbr
Pakowki Fm
Chungo Mbr / Milk River Fm
Wapiabi Fm
Cardium Fm
Blackstone Fm
Alberta Gp
L7co
L4ce
111
851
M3ma
L9tu
162, 285, 347
M4ma
483
795
796
M5ca
L1Lc
L1co
L1tu
M5ce
M5co
M3tu
M2ce
851
L5Lc
L5co
L6tu
L6ce
M1co
M1tu
M1Lc
392
L3Lc
M2ca
549
L6ma
L11ca
L15Lc
L15co
398
398
L5ma
M7ca
517
517
609
461
0
300 KILOMETERS
Horizontal scale

are sometimes not recorded by geologists. For example, on the outcrop, some thin coal beds may be covered by colluvium and are therefore not recorded. Similarly, on well logs, coals less than a meter thick are difficult to distinguish and may not be recorded. The arbitrary thickness categories were chosen mainly to show those areas where mire conditions persisted long enough (or not long enough) for the accumulation of thick peats. Coal information from the basin summaries was used to construct the paleogeographic maps in the form of areas outlined in dark green (representing areas that have at least one thick coal bed) or in light green (representing areas that have only thin coal beds).

The section titled "Age" on a basin summary is a brief explanation of how the base and top of the interval were picked at that particular locality (thereby resulting in a thickness of the interval). This section includes information on fossil occurrences in the interval and local and regional correlations of units. When reading this section of a basin summary, the reader is referred to the biostratigraphic chart (pl. 1) that shows the ammonite zonation for the Western Interior.

The section on "Stratigraphy" contains information about formations represented in the interval, from oldest at the bottom of the list to youngest at the top. References from which the information on thicknesses and coals were obtained are listed here. The general environments in which the sediments were deposited, usually broken out by formation, are reported in the section, "Depositional environments." This information was then incorporated onto the paleogeographic maps.

Figure 4 (facing page). Generalized chronostratigraphic cross sections *B–B'*, *C–C'*, and *D–D'*. Generalized depositional environments are also shown: green, nonmarine; yellow, shoreface; gray, marine; and white with vertical ruled lines, significant time breaks (erosion or nondeposition). Lines of sections are shown in figure 2 and are oriented approximately parallel to depositional dip. Arrows in the biozones column indicate sequential location of radiometrically dated rocks (Obradovich, 1993). Vertical scale is age in millions of years. Sections show only selected stratigraphic names; formation contacts may not be shown. Letters are abbreviations for the following stratigraphic units: FH, Fox Hills Sandstone; TS, Trinidad Sandstone; HF, Hams Fork Conglomerate Member of the Evanston Formation; PR, Pine Ridge Sandstone; PC, Pictured Cliffs Sandstone; HB, Huerfanito Bentonite Bed; CH, Cliff House Sandstone; PL, Point Lookout Sandstone; RS, Rock Springs Formation; AD, Adaville Formation; CC, Crevasse Canyon Formation; EC, Echo Canyon Conglomerate; H, Henefer Formation; AH, Allen Hollow Shale Member of the Frontier Formation; G, Gallup Sandstone; T, Tres Hermanos Formation; M, Mowry Shale; "X," "X" bentonite. Numbers at the base of the figure represent references listed in table 1; the combined letter/number designations refer to basin summaries in the appendix. *B–B'*, across the San Juan Basin, N. Mex., represents a restored cross section.

Table 1. References used in figures 3, 4, 8, 11, 14, 17, 20, 23, and on plate 1 listed in numerical order.

[This table represents selected references from a larger data base; therefore, there are gaps in the number order. Full reference can be found in "References Cited," beginning p. 50]

39	Beeson, 1984
111	Hook and others, 1983
116	Jeletzky, 1971
121	Kauffman, 1977
123	Kauffman, 1984
139	Lee, 1917
148	McGookey and others, 1972
162	Molenaar, 1983a
168	Obradovich and Cobban, 1975
175	Peterson, 1969b
191	Ryer, 1976
233	Williams and Stelck, 1975
242	Ryer and McPhillips, 1983
285	Peterson and Kirk, 1977
347	Sears, 1925
378	Cobban and Kennedy, 1989b
379	Stott, 1982
388	Irish, 1970
391	Gill and others, 1970
392	Roehler, 1983
395	Furnival, 1950
396	Douglas, 1950
397	Jerzykiewicz and Sweet, 1988
398	Wall and Rosene, 1977
400	Dorf, 1942
402	Keefer, 1965
403	Gill and Cobban, 1973
406	Barclay, 1980a
407	Dobbin and others, 1929
408	Roberts, 1972
412	Gill and others, 1972
413	Jensen and Varnes, 1964
418	Stephenson and others, 1942
419	Pessagno, 1969
421	Gude and McKeown, 1952
426	Baltz and others, 1966
431	Robeck and others, 1956
436	Kennedy, 1989
437	Nichols and others, 1982
438	Lillegraven and Ostresh, 1990
444	Skipp and McGrew, 1977
447	Stott, 1967
449	Caldwell and North, 1984
450	Kennedy and Cobban, 1990
451	Averitt, 1962
452	Cashion, 1961
455	Wegemann, 1915
459	Young, 1986a
460	Kauffman and others, 1976
461	Caldwell and others, 1978
463	Young and Powell, 1978
466	Merewether, 1973
467	McNeil and Caldwell, 1981
471	Huffman and others, 1978

Table 1. (Continued)

472	Kennedy, 1988
473	Mancini, 1979
477	Schoewe, 1952
478	Keefer, 1972
483	Kauffman and Pratt, 1985
494	Sliter, 1989
497	Maxwell and others, 1967
512	Lehman, 1985a
517	Forester and others, 1977
519	Russell and Landes, 1940
520	Lorenz and Gavin, 1984
524	Enos, 1983
528	Stott, 1984
531	Lehman, 1987
538	Cobban, 1964
539	Cobban, 1969
543	Eicher, 1962
546	Kirschbaum, 1985
547	Hansen, 1965
549	Merewether and Cobban, 1986
553	Lupton, 1916
554	Clark, 1928
556	M'Gonigle, 1992
558	M'Gonigle, 1980
560	Weaver and M'Gonigle, 1987
561	Barnes and others, 1954
562	Fisher and others, 1960
565	Tysdal and others, 1990
566	Franzcyk, 1988
567	Carr, 1987
570	Rice, 1976
571	Peterson, 1969a
573	Eaton, 1991
574	Elder, 1989
578	Young, 1963
579	Lorenz, 1981
591	Kirschbaum and McCabe, 1992
598	Robaszynski and others, 1984
600	Cobban and Kennedy, 1989a
601	Scott, 1970
602	Kennedy and Cobban, 1991a
603	Kennedy and Cobban, 1991b
604	Cobban, 1994
605	Cobban and Kennedy, 1992
606	Leckie, 1985
607	Kauffman and others, 1993
609	Stott, 1963
610	Plint and others, 1990
611	Love, 1973
622	Plint and Norris, 1991
623	Pierce and Andrews, 1941
625	Roberts, 1966
630	Hewett, 1926
634	Fassett and Hinds, 1971
635	Erdmann, 1934
636	Johnson and Brownfield, 1988
637	Johnson, 1989
638	Lee, 1912
639	Hanks, 1962
640	Collins, 1976
641	Glass and others, 1975
642	Wegemann, 1918
643	Rich, 1962
645	Barclay, 1980b
647	Thom and others, 1935
648	Woolsey, 1909
649	Stone, 1909
650	Pepperberg, 1910
651	Stanton and Hatcher, 1905
656	Cobban and Hook, 1984
657	Elder and Kirkland, 1993
658	Arkell, 1986
659	Gregory, 1950
661	Hunt and others, 1953
662	Kinney, 1955
663	Doelling and Graham, 1972
664	Peirce and others, 1970
666	Stebinger, 1916
667	Viele and Harris, 1965
669	Molenaar and Wilson, 1990
677	Vaughn, 1900
680	Roberts and McCabe, 1992
681	Franczyk and others, 1992
682	Ball and Stebinger, 1910
684	Goldman, 1910
685	Murray, 1980
686	Kirkham and Ladwig, 1979
688	Lloyd, 1914
689	Bauer, 1914
690	Bowen, 1912
691	Crowder, 1983
692	Fisher, 1936
694	Gill and Hail, 1975
696	Osgood, 1931
697	Bass and others, 1955
699	Berryhill and others, 1950
700	McCabe and others, 1986
701	Macdonald and others, 1986
707	Keefer and Troyer, 1964
708	Thompson and White, 1952
712	Del Arenal, 1964
713	Wilson and Livingston, 1980
714	Owen, 1973
715	Ruby, 1973
716	Cobban and Merewether, 1983
717	Entzminger, 1979
719	Rice and Shurr, 1983
721	Whitley and Brenner, 1981
722	Curtis, 1960
724	Fraser and others, 1969
725	Campbell and Gregory, 1911
727	Love and others, 1948
728	Shomaker and others, 1971
730	Balsley, 1980
731	Lawrence, 1992
732	Tabet and Frost, 1979
736	Bhattacharya and Walker, 1991
741	Kennedy and others, 1992

Table 1. (Continued)

742	McArthur and others, 1992
743	Hancock, 1991
744	Cobban, 1984
745	Trexler, 1966
746	Weidie and others, 1972
747	Hettinger, 1993
750	Hunt, 1936
753	Jones, 1982
754	Pierce, 1961
755	Sloan, 1964
759	Oliver, 1971
772	Spieker, 1931
773	Eaton, 1990
780	Weise, 1980
795	Kluth and Nelson, 1988
796	Nichols, 1985
797	Hook and Cobban, 1983
798	Cobban, 1986
801	Hares, 1928
802	Winchester and others, 1916
805	Snedden, 1991
817	Spieker and Baker, 1928
824	Molenaar and Cobban, 1991
846	Landman and Waage, 1993
847	Obradovich and others, 1990
851	Dyman and others, 1994
852	Cobban and others, 1994
855	Hancock and others, 1993
858	Ryer, 1993
860	Siemers, 1975
861	Merewether and others, 1975
864	Stewart, 1919

Table 2. General location and identification number for basin summaries listed in the appendix.

[Gaps exist in the numbering of the basin summaries because the list is part of a larger data base. All locations are plotted in figure 5]

Cenomanian (locations also plotted in fig. 8):		
L2ce	Pine River	British Columbia
L3ce	Carthage	New Mexico
L4ce	San Juan Basin	New Mexico
L5ce	Sun River Canyon	Montana
L6ce	Kemmerer	Wyoming
L7ce	Southeast	Saskatchewan
L10ce	Wind River basin	Wyoming
L11ce	Pioneer Mountains	Montana
L13ce	Black Hills uplift	Wyoming
L14ce	Yellowstone Park	Wyoming
M1ce	Kanarra Mountain	Utah
M2ce	Coalville	Utah
M3ce	Bryan County	Oklahoma
M4ce	Russell County	Kansas
M5ce	Rock Canyon anticline	Colorado
M9ce	Big Bend	Texas
M10ce	Black Mesa	Arizona

Table 2. (Continued)

Turonian (locations also plotted in fig. 11):		
L1tu	Canon City	Colorado
L2tu	Sweetgrass Arch	Montana
L3tu	Black Hills	Wyoming
L4tu	Rawlins	Wyoming
L5tu	Emery	Utah
L6tu	Kemmerer	Wyoming
L7tu	Wind River basin	Wyoming
L8tu	Puertecito	New Mexico
L9tu	San Juan Basin	New Mexico
L10tu	Yellowstone Park	Wyoming
L11tu	Ruby River	Montana
L12tu	Black Mesa	Arizona
L13tu	Mosby	Montana
L14tu	Kaiparowits Plateau	Utah
L15tu	Central	Kansas
L16tu	Dallas	Texas
L17tu	Austin	Texas
L18tu	Big Bend	Texas
L19tu	Central foothills	Alberta
L20tu	Crowsnest-Waterton	Alberta
L21tu	East-central	British Columbia
M1tu	Dutch John	Utah
M2tu	Riding Mountain	Manitoba
M3tu	Coalville	Utah
Coniacian-Santonian (locations also plotted in fig. 14):		
L1co	Pueblo	Colorado
L2co	Sweetgrass Arch	Montana
L3co	Black Hills	Wyoming
L4co	Rawlins	Wyoming
L5co	Kemmerer	Wyoming
L6co	Wind River basin	Wyoming
L7co	Gallup	New Mexico
L8co	Green River	Utah
L9co	Black Mesa	Arizona
L10co	Mosby	Montana
L11co	Kaiparowits Plateau	Utah
L12co	Austin	Texas
L14co	Big Bend	Texas
L15co	Crowsnest-Waterton	Alberta
L16co	East-central	British Columbia
M1co	Antelope Flat	Utah
M2co	Riding Mountain	Manitoba
M3co	Joes Valley	Utah
M4co	Livingston	Montana
M5co	Coalville	Utah
Campanian I (locations also plotted in fig. 17):		
L1Lc	Pueblo	Colorado
L2Lc	Porcupine dome	Montana
L3Lc	Rawlins	Wyoming
L4Lc	Black Hills	Wyoming
L5Lc	Kemmerer	Wyoming
L6Lc	Wind River basin	Wyoming
L7Lc	Barker Dome	Colorado
L8Lc	Grand Junction	Colorado
L9Lc	Kaiparowits Plateau	Utah
L10Lc	Judith River	Montana

Table 2. (Continued)

L11Lc	Austin	Texas
L13Lc	Big Bend	Texas
L14Lc	Blackstone River	Alberta
L15Lc	Crowsnest	Alberta
M1Lc	Rock Springs uplift	Wyoming
M2Lc	Kenilworth	Utah
M3Lc	Riding Mountain	Manitoba
M4Lc	Livingston	Montana
M5Lc	San Carlos	Texas
Campanian II (locations also plotted in fig. 20):		
L1ca	Red Bird	Wyoming
L2ca	Kremmling	Colorado
L3ca	Boulder	Colorado
L4ca	Hardin	Montana
L5ca	Sand Wash basin	Colorado
L6ca	Porcupine dome	Montana
L7ca	Dearborn River	Montana
L8ca	Rawlins	Wyoming
L9ca	Kaiparowits Plateau	Utah
L11ca	Crowsnest	Alberta
L12ca	Blackstone River	Alberta
M1ca	Sego Canyon	Utah
M2ca	Rock River	Wyoming
M3ca	Wind River basin	Wyoming
M4ca	Big Bend	Texas
M5ca	Barker dome	New Mexico
M6ca	Florence	Colorado
M7ca	Cypress Hills	Saskatchewan
M8ca	Turtle Mountain	Manitoba
M9ca	Two Medicine River	Montana
M10ca	Livingston	Montana
Maastrichtian (locations also plotted in fig. 23):		
L2ma	Red Deer Valley	Alberta
L3ma	Rock Springs uplift	Wyoming
L4ma	Black Hills uplift	Wyoming
L5ma	Cypress Hills	Saskatchewan
L6ma	Crowsnest	Alberta
L7ma	Red Bird	Wyoming
L8ma	Blackstone River	Alberta
L9ma	Wind River basin	Wyoming
L10ma	Cody	Wyoming
L11ma	Baggs	Wyoming
L12ma	Livingston	Montana
L13ma	Porcupine dome	Montana
L14ma	Fort Peck	Montana
L16ma	Golden	Colorado
L19ma	Yellowstone Park	Wyoming
M1ma	Big Bend	Texas
M2ma	North Horn Mountain	Utah
M3ma	San Juan Basin	New Mexico
M4ma	Raton Basin	New Mexico
M5ma	Hanna basin	Wyoming
M6ma	Sabinas basin	Mexico
M8ma	Sand Wash basin	Colorado

ISOPACH MAPS

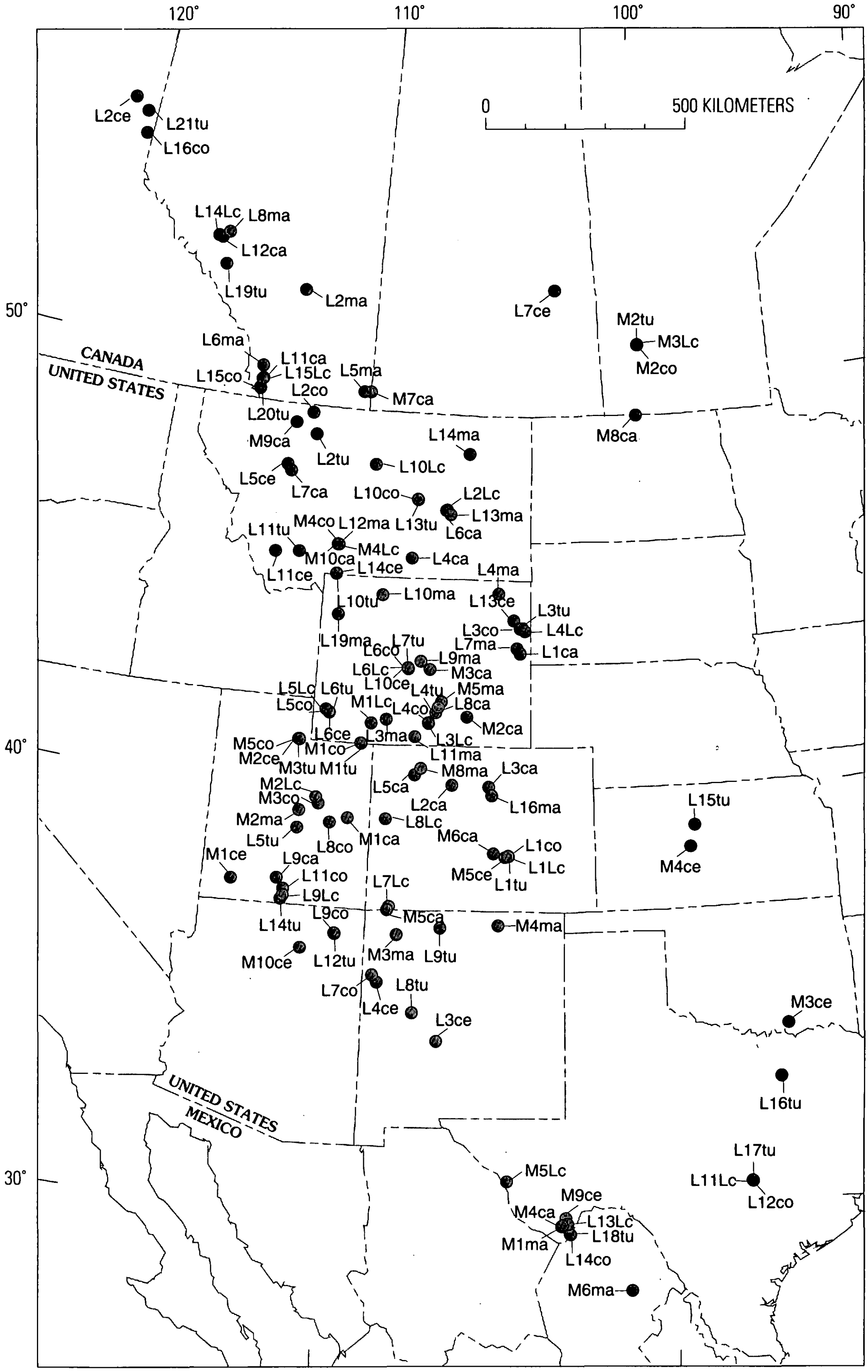
To help test the significance of tectonic subsidence in determining the location and size of coal deposits, we constructed isopach maps of each of the six biostratigraphically constrained intervals. The isopach maps were constructed from the thickness data in the basin summaries, from interpretations of existing isopach maps of similar time intervals, and from the authors' knowledge of stratigraphic interval thicknesses determined from field studies. We assumed a zero line, which approximates the western edge of Upper Cretaceous outcrops of McGookey and others (1972, their fig. 22), to more realistically portray the original sedimentary basin configurations. As a continuous series from Cenomanian through Maastrichtian time, the maps show a generalized evolution of the foreland basin for the Western Interior.

PALEOGEOGRAPHIC MAPS

The base map upon which the isopachs, paleogeography, and references are plotted (figs. 2, 5, 6–23) is a Transverse Mercator projection, with a scaling factor of 0.926 and a central meridian of 104°. The paleogeographic maps were made by combining coal occurrence data with what is known about the geology of the area. Figure 2 shows the distribution of Upper Cretaceous outcrops in the area covered by the paleogeographic maps and shows, at a glance, where extrapolation was required (in areas between exposures of Upper Cretaceous rocks).

The physical features represented on the maps include the epicontinental seaway; two shorelines separated by an area considered to be coastal plain for some time during the interval; upland areas; position of the orogenic front; active volcanic centers with associated volcaniclastic deposits; alluvial fans, represented by conglomerates; alluvial plains, rivers, and lakes; paleosols; and mire areas, represented by existing coal deposits. The quality of the maps is obviously dependent on the nature of the published works used in their creation (typically 50 references were used for each map) and on the validity of the extrapolation required to supplement the paleogeographic data.

Figure 5 (facing page). Index map showing location of all basin summaries in the appendix. Suffixes ce, Cenomanian (also plotted in fig. 8); tu, Turonian (also plotted in fig. 11); co, Coniacian/Santonian (see also fig. 14); Lc, Campanian I (see also fig. 17); ca, Campanian II (see also fig. 20); ma, Maastrichtian (see also fig. 23). General locations and basin summary identifiers are listed by age in table 2.



120°
110°
100°
90°
50°
40°
30°
0
500 KILOMETERS
CANADA
UNITED STATES
UNITED STATES
MEXICO
L2ce
L21tu
L16co
L14Lc
L8ma
L12ca
L19tu
L2ma
L7ce
M2tu
M3Lc
M2co
L6ma
L11ca
L15Lc
L15co
L5ma
M7ca
L2co
L20tu
M8ca
M9ca
L14ma
L2tu
L10Lc
L5ce
L7ca
L10co
L2Lc
L13ma
L13tu
L6ca
L11tu
M4co
L12ma
M4Lc
M10ca
L4ca
L11ce
L14ce
L4ma
L10tu
L10ma
L13ce
L3tu
L3co
L4Lc
L19ma
L6co
L7tu
L7ma
L1ca
L9ma
L6Lc
M3ca
L5Lc
L6tu
L10ce
L4tu
M5ma
L5co
M1Lc
L4co
L8ca
M2ca
L6ce
L3ma
L3Lc
M5co
M1co
L11ma
M2ce
M3tu
M1tu
M8ma
L3ca
M2Lc
L5ca
M3co
L2ca
L16ma
M2ma
L8Lc
L5tu
L8co
M1ca
M6ca
L1co
L9ca
L1Lc
M1ce
L11co
M5ce
L1tu
L9Lc
L7Lc
L14tu
L9co
M5ca
M4ma
M10ce
L12tu
M3ma
L9tu
L7co
L8tu
L4ce
L3ce
L15tu
M4ce
M3ce
L16tu
L17tu
M5Lc
L11Lc
L12co
M9ce
M4ca
L13Lc
L18tu
M1ma
L14co
M6ma

Each paleogeographic map covers a time interval that spans from a minimum of 4.5 m.y. (Campanian I) to a maximum of 7 m.y. (Maastrichtian). Problems arise in the depiction of environments and paleogeographic features, such as shoreline positions, that varied greatly over the time span. Lillegraven and Ostresh (1990) plotted the position of the paleoshoreline along the western edge of the seaway for each standard Western Interior ammonite zone for the time period from earliest Campanian through the Maastrichtian. Each ammonite zone represents about 600,000 years. Variations in the shoreline position are evident at different places along the seaway when examined at this relatively fine resolution of time. Because the maps in our report span as much as 7 m.y., shoreline positions for each map varied even more dramatically. The changing position of the shorelines is important in this study because most of the peat that formed thick coal accumulated in coastal plain environments (a coastal plain is defined by the American Geological Institute (Bates and Jackson, 1984) as "a low, broad plain that has its margin on an oceanic shore and its strata either horizontal or very gently sloping toward the water, and that generally represents a strip of recently prograded or emerged seafloor").

We chose to address the problem of showing non-static features on the maps in the following manner. The paleogeographic maps show the extent of maximum transgression and regression as lines that delimit the yellow area on the maps, and the yellow area consequently represents the area covered by coastal plain deposits at any one time during the map interval. The exception to this method of depicting coastal plain settings is the map of the Maastrichtian (fig. 21). The sea retreated rapidly northward and southeastward from the Western Interior during this time, and the position of the southern shoreline in latest Maastrichtian time is in the extreme southeastern corner of the map area in southern Texas (Lillegraven and Ostresh, 1990; Lehman, 1987). We chose to show a shoreline position at about early late Maastrichtian time (between Lillegraven and Ostresh's *Sphenodiscus* and *Discoscaphites roanensis* zones) to give a sense of the direction and magnitude of the retreat of the seaway. In addition, if the published reconstructions showed that the seaway was present in an area where there are known coastal plain or coal deposits of that age, then we modified the shoreline position only far enough basinward to accommodate these terrestrial deposits.

The Cordilleran fold and thrust belt is another major feature that changes position throughout the series of paleogeographic maps. The position of the thrust belt plotted on the Cenomanian map (fig. 7) represents, in a general way, the western edge of present-day Upper Cretaceous outcrops in the Western Interior (McGookey and others, 1972) and approximates the position of the leading edge of the deformation front during Cenomanian time. The paleogeographic maps that follow the Cenomanian map show a gradual eastward migration of the deformation front, which has been plotted assuming a distance of about 2.5 km/m.y. (a rate consistent with that estimated in Jordan, 1981, her fig. 5), to a position west of the present-day leading edge of the thrust belt. Although numerous interpretations appear in the literature of the timing and magnitude of thrusting of individual plates along the deformation front, determining the exact position of the deformation front for each map interval is not within the scope of this study.

The distribution of conglomerates and volcaniclastics on the maps gives a general idea of the energy level of the fluvial systems and of possible tectonic and volcanic activity in the adjacent mountain front. Coal beds are thin or absent where these lithofacies predominate, presumably because environments were not conducive to thick peat accumulation. In order to consider the effects of climate on peat accumulation, the distribution of climatically sensitive facies is plotted on each paleogeographic map. Coal beds, red-mottled and variegated beds, and the presence of carbonate nodules in fluvial rocks have been interpreted as paleosols by several workers (Jerzykiewicz and Sweet, 1988; Joeckel, 1987; Lehman, 1987, 1989; Retallack and Dilcher, 1981) and are thought to be indicative of certain paleoclimatic conditions (Ziegler and others, 1985). Coal, for example, generally indicates extended periods of time when precipitation was greater than evaporation. Caliches, on the other hand, are interpreted to have formed in semiarid or arid climates, which may be the result of regional climatic factors such as orographic effects (Jerzykiewicz and Sweet, 1988).

The most important aspect of the maps from our perspective, and perhaps the most challenging to research, is the distribution of coals. Reports specifically on coal fields in the western United States have been produced since the beginning of the 20th century, when the stratigraphy in this area was only beginning to be unraveled. It was necessary to reinterpret these early studies and place the coal data in the context of modern stratigraphy. Rather than just outline the presence of coal on the maps, we collected data on the thickness of the coal beds in each area to better understand what conditions favor thick and extensive peat accumulation.

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DISCUSSION OF MAPS

We begin here with the Cenomanian interval and proceed to intervals of younger age. For each interval, the isopach map is discussed first and then the paleogeographic map. Locations mentioned in the text are shown in figure 2. Basin summary locations (L5ce, M4ma, and so on) are shown in figure 5 and refer to data presented in the appendix. Following each paleogeographic map is a "reference map" that shows the basin summary locations for that time interval. The reference maps also have plotted number locations that correspond to published references used to create the maximum transgressive and regressive shoreline position and to delineate areas of thick or thin coals.

CENOMANIAN

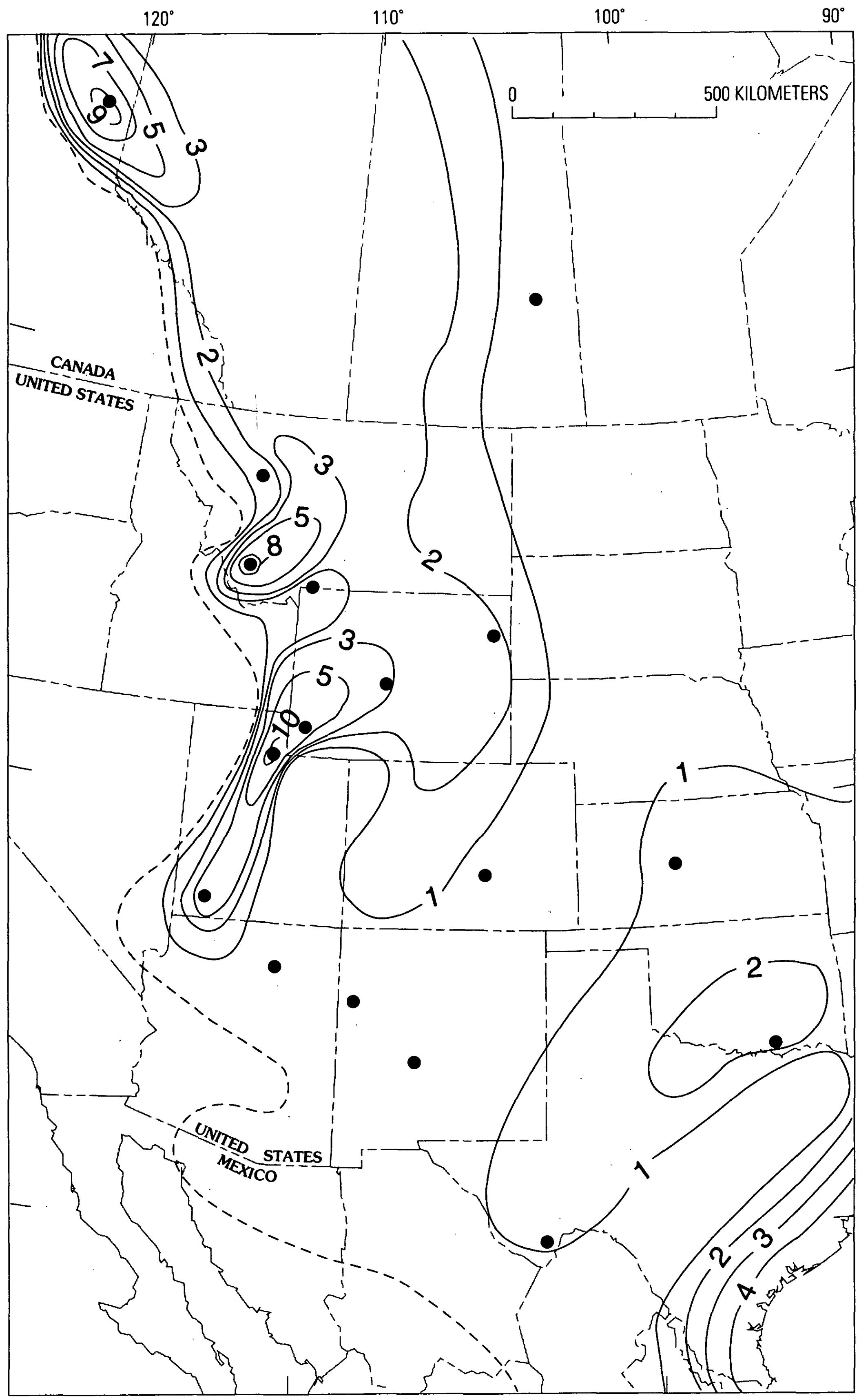
ISOPACH MAP

Isopachs of sediment thickness for the Cenomanian interval (fig. 6) reveal three areas that experienced relatively high rates of sediment accumulation. In a north-northeast-trending basin from southwestern Utah to central Wyoming, sediment thickness reaches a maximum at Coalville, Utah (fig. 2), of 1,070 m (Ryer, 1976; M2ce). The thickness values in this area are consistent with those shown in Reeside (1944). This basin apparently expanded southward from early to late Cenomanian time, because Cenomanian strata present in southern Utah represent only the last 2 m.y. of the interval (Kirschbaum and McCabe, 1992), whereas a more complete section is represented at Coalville. To the east of this depocenter, in northeastern Utah, northwestern Colorado and adjacent areas in Wyoming, less than 100 m of only the earliest Cenomanian rocks are preserved either due to nondeposition or erosion of older Cenomanian and early Turonian rocks (Molenaar and Wilson, 1990). A smaller depocenter existed in southwestern Montana where sediment thickness is about 900 m (Dyman and Tysdal, 1990; L11ce). Only a few hundred kilometers to the east, on the Wyoming-Montana border, in northern Yellowstone Park (L14ce) the thickness is less than 200 m. Biostratigraphic studies in this area show that there was a significant hiatus during deposition of the Frontier Formation, from early middle Cenomanian to mid-Turonian (Tysdal and others, 1990) (figs. 3, 4). The third area of thick Cenomanian strata is in a southeast-northwest-trending basin in east-central British Columbia, with a maximum thickness of almost 1,000 m. This basin may extend to the south along the orogenic front into southwestern Alberta, but the age of the rocks in this area could not be adequately constrained. An area where Cenomanian sediments are thin coincides with the location of the Transcontinental Arch, from western Colorado to southern South Dakota (Weimer, 1983). Other areas where Cenomanian sediments are thin, possibly due to local upwarping, are in southeast Utah in the area of the San Rafael Swell (fig. 2), where sediments thin to zero, and in eastern Texas, where Cenomanian strata thin toward the paleo-Sabine uplift (Oliver, 1971).

PALEOGEOGRAPHY

The paleogeographic reconstruction of the Cenomanian interval (fig. 7) represents about 5 m.y. and spans the ammonite zones from *Neogastroplites cornutus* through *Neocardioceras juddii* (pl. 1). At the beginning of the Cenomanian, the seaway was rising from a lowstand position that is represented by the late Albian valley-fill deposits of the Muddy Sandstone (Weimer, 1983). The sea transgressed from the north and the south, finally joining in southern Colorado and northern New Mexico near the time of the *Neogastroplites cornutus* zone (figs. 7, 8) as inferred from the work of Cobban and Kennedy (1989b). The Cenomanian is a time of overall eustatic rise (Haq and others, 1987) that caused the transgressive episode of the Greenhorn cyclothem (Kauffman, 1977). The central part of the seaway was the site of continuous deposition of marine shales, as represented by pelagic detrital muds of the Mowry Shale at the base, passing upward through the Belle Fourche Shale, and ending with the lower part of the Greenhorn Formation (figs. 3, 4). Marine deposits in Manitoba during the Cenomanian are the Ashville Formation and the lower part of the Keld Member of the Favel Formation. Early in the Cenomanian, extensive platform and basin carbonates were deposited in southern Texas and northern Mexico (Enos, 1983) and comprise the Buda Limestone and Cuesta del Cura Formation, respectively (Sohl and others, 1991). A regressive phase within the overall transgression is represented by the deltaic to piedmont alluvial deposits of the Dunvegan Formation in eastern British Columbia and western Alberta, which accounts for the bulge in the maximum regressive shoreline in this area (figs. 7, 8). Similarly, though on the opposite side of the seaway in Oklahoma and eastern Texas, this regressive phase is represented by the lower three members of the Woodbine Formation, which are fluvial to nearshore marine units. Sand units within the Belle Fourche Member of the Frontier Formation in the

Figure 6 (overleaf). Isopach map of Cenomanian rocks spanning about 5 m.y. during the biochrons of *Neogastroplites cornutus* through *Neocardioceras juddii*. Thickness in hundreds of meters. Contour interval varies, therefore all isopachous lines are labeled. Dashed line, inferred "zero isopach line," which approximates western edge of Upper Cretaceous outcrops (modified from McGookey and others (1972, their fig. 22)). Shaded circle, basin summary location plotted with "ce" identifier in figures 5 and 8. The 300-m contour line in western Alberta approximates the pinch-out of the Dunvegan Formation sandstones (Bhattacharya and Walker, 1991).


120°
110°
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500 KILOMETERS
50°
40°
30°
CANADA
UNITED STATES
UNITED STATES
MEXICO
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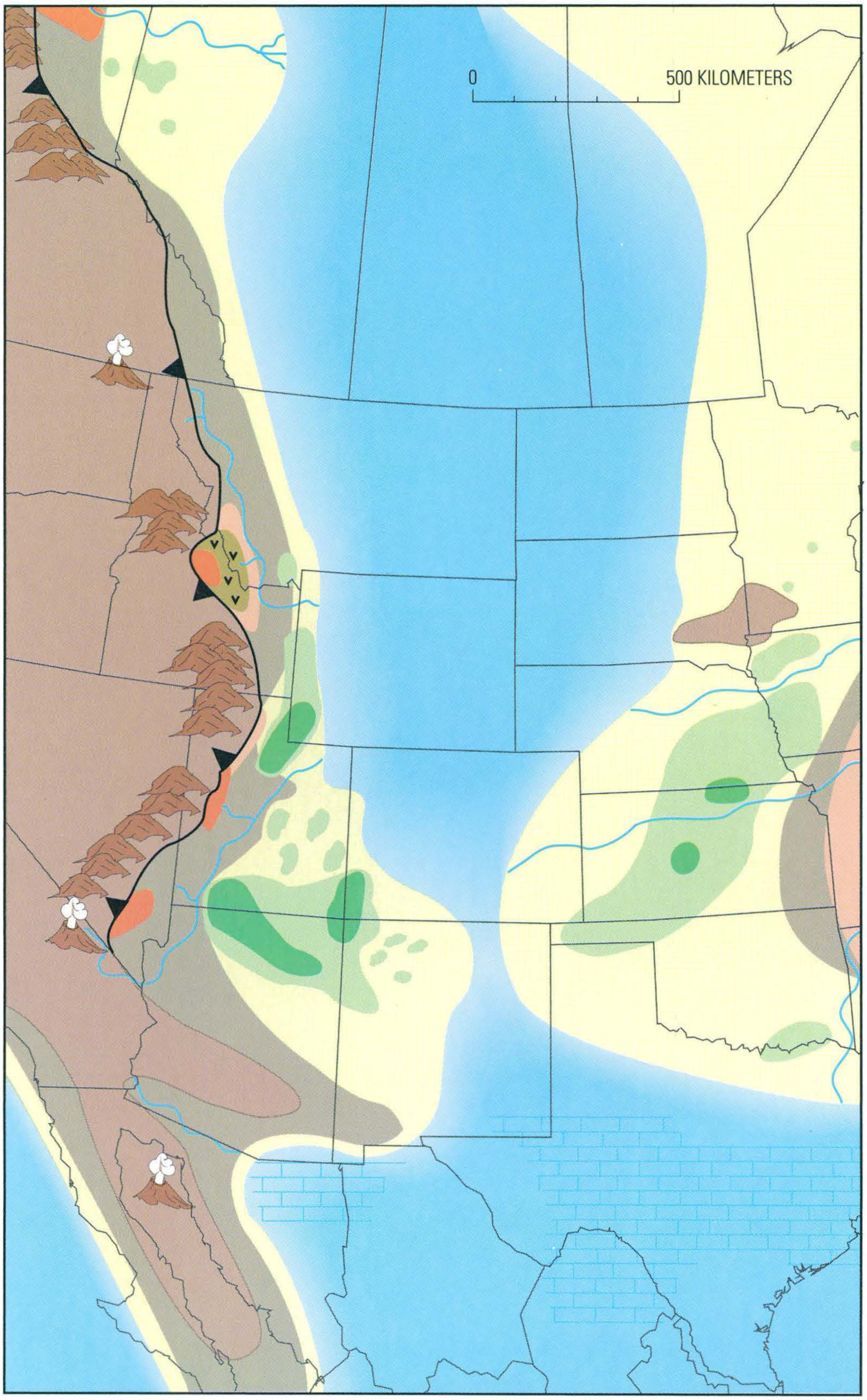


Figure 7 (above and overleaf). Paleogeographic reconstruction during Cenomanian. See next page for complete caption, and explanation.

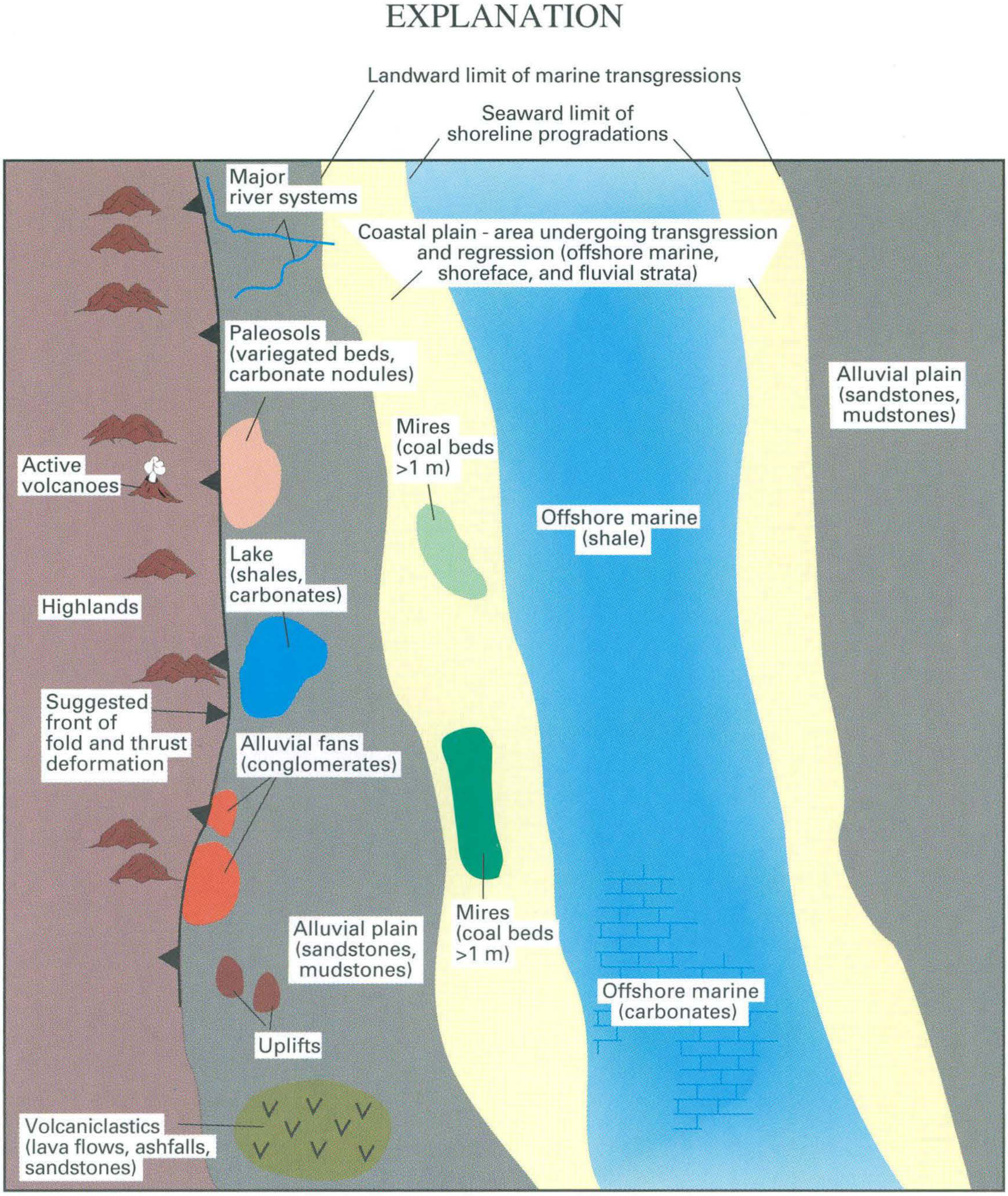


Figure 7—Continued. Paleogeographic reconstruction spanning about 5 m.y. during the Cenomanian biochrons of *Neogastroplites cornutus* through *Neocardioceras juddii* from about 98.5 to 93.5 Ma. Explanation of features shown on paleogeographic maps (figs. 10, 13, 16, 19, and 22) is also shown. Sawteeth on upper plate of deformation front. Details and references used to determine shoreline positions and extent of coal deposits are shown in figure 8.

Wyoming area are marine or nearshore marine deposits (fig. 9 of Merewether and Cobban, 1986) the latter of which could possibly represent a paleoshoreline. However, no documentation exists of the presence of Cenomanian coastal plain deposits associated with these units. Therefore, a shoreline position for the Belle Fourche Member is not shown on the paleogeographic map (fig. 7) but an interpretation for a possible shoreline is presented in figure 8.

Based on the number and thickness of volcanic ash layers in the sediments, the early Cenomanian was a time of intense volcanism. Later in the stage, volcanism continued at moderately intense levels (Kauffman, 1984). Isopachs of bentonite marker beds in Cenomanian marine shales of the Western Interior United States indicate that the source areas for the volcanic ash were near or west of the juncture of Nevada, California, and Arizona and possibly in northern Idaho (Elder, 1988). The Mowry Shale contains abundant bentonites, and the Graneros Shale contains one of the most extensive ashfall deposits for the Upper Cretaceous (the "X" bentonite, fig. 4, *B–B'*). This ashfall is used as a regional marker, as it is recognized in the subsurface from Alberta to as far south as northern Texas (Kauffman, 1977). The Vaughn Member of the Blackleaf Formation (fig. 3) in western Montana is characterized by numerous porcellanites, volcaniclastics, tuffaceous debris, and bentonitic shales (Mudge, 1972; Dyman and Nichols, 1988; Dyman and Tysdal, 1990; and Rice and Cobban, 1977). Evidence from isotopically dated basaltic rocks in the southern Cordillera suggests volcanic activity during the Cenomanian (Damon and others, 1981).

EASTERN SIDE OF THE SEAWAY

The Cenomanian is unique in the Upper Cretaceous in that terrestrial strata are preserved on both sides of the seaway. The eastern side of the seaway is part of the stable craton (fig. 1). Consequently, processes such as sediment accumulation, subsidence, uplift, and erosion are much less dramatic than those of the foreland basin setting on the western side. Because the effects of local tectonism are negligible as compared to the other side of the seaway, and because of a low gradient, the migration rate of the eastern shoreline during the overall Cenomanian transgression was relatively rapid, estimated at a maximum of 140 km/m.y. from the time of the *Neogastroplites cornutus* zone through *Neocardioceras juddii*.

Mires developed on the eastern side of the seaway between about 35° and 45° paleolatitude (figs. 1, 7). They were associated with backstepping, tide-dominated deltas (Retallack and Dilcher, 1981), and the peat accumulated marginal to interdistributary or lagoonal settings (Retallack and Dilcher, 1981; Daniel, 1990). Coals from these peats are generally thin lignites that do not warrant commercial development (Abernathy and others, 1947; Burchett, 1977). The Janssen Clay Member of the Dakota Formation in Kansas contains thin coal that formed in both coastal plain environments, with some marine influence, and in entirely freshwater environments (Retallack and Dilcher, 1981). The Woodbury Member of the Dakota Formation in eastern Nebraska and western Iowa also contains thin lignitic coals as does the Red Branch Member of the Woodbine Formation in southern Oklahoma (fig. 8).

On the eastern side of the seaway, paleocurrent indicators in Cenomanian rocks show that rivers flowed generally westward (Dakota Formation) in Iowa and Kansas (Witzke and others, 1983; Karl, 1976; Franks and others, 1959; Siemers, 1976). Studies of the Woodbine Formation in northeast Texas, including sandstone isopach maps, suggest that a distributary channel complex existed, with flow directions across deltas to the south-southwest (Oliver, 1971).

An extensive paleosol occurs at the base of the Cenomanian in the Gulf Coast region and northward to southern Illinois (Sigleo and Reinhardt, 1988). Austin (1970) also documented a basal Cenomanian kaolinitic regolith in Minnesota. Both studies interpret this horizon to represent a soil that formed in a humid subtropical or tropical climate. Sigleo and Reinhardt (1988) interpreted the paleosol as a laterite that formed in a strongly seasonal climate. This soil horizon may be replaced to the west by braided streams deposits of the Nishnabotna Member and Rocktown Channel Sandstone Member of the Dakota Formation in Kansas (Witzke and others, 1983; Siemers, 1976). The middle part of Cenomanian strata in Kansas and Nebraska is dominated by red-mottled mudstones of the Terra Cotta Clay Member of the Dakota and equivalents (Franks, 1975). These mudstones are interpreted as well-differentiated paleosols (Joeckel, 1987). In contrast, the upper parts of the Dakota (Janssen Clay Member and equivalents) are dominated by gray mudstones, with lesser amounts of red mottling, interpreted as weakly differentiated to well-differentiated paleosols, and minor amounts of coal. The transition from red-tinged, well-differentiated paleosols stratigraphically upward to coal-bearing paleosols reflects the shifting of environments from an inland alluvial plain to a coastal plain as the seaway expanded during the Cenomanian.

The Sioux ridge, in southeastern South Dakota (fig. 2), is composed of Precambrian quartzite overlain directly by onlapping units of Cenomanian to Campanian age (Reeside, 1957; Rice and Shurr, 1983). It is inferred that the area was a rocky peninsula and island that were never entirely submerged from the Cenomanian probably all the way into the Campanian (Rice and Shurr, 1983) and is so indicated on the Cenomanian through Coniacian-Santonian paleogeographic maps (figs. 7, 10, 13).

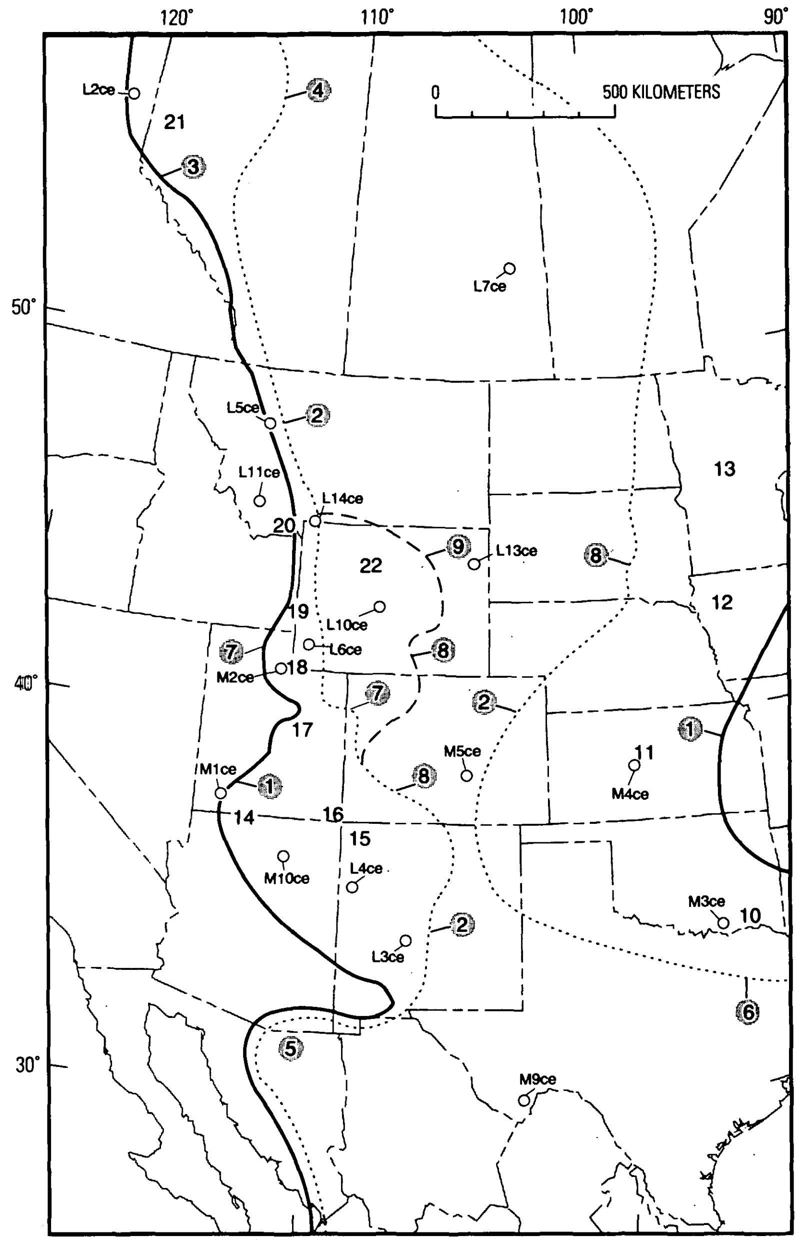


Table A

Map ref.	Faunal zones representing shorelines	Comments	References (table 1)
1	*Neocardioceras juddii*	Dakota Fm and Frontier Fm shorelines	162, A
2	*Neogastroplites cornutus*	Dakota Fm shorelines	233, A
3	*N. juddii*, and *Neogastroplites maclearni*	marine transgressions of the Shaftesbury Fm and equivalents, and the Kaskapau Fm	528
4	*Verneuilnoides perplexus*	Dunvegan Fm deltas	116, 736
5	*N. cornutus* to *N. juddii*	embayment into remnant of Bisbee trough	524
6	mid-Cenomanian	Woodbine Fm deltas	759
7	*Neogastroplites americanus*	Dakota shoreline	681
8	*Conlinoceras tarantense*	Belle Fourche shoreline (not shown on fig. 7)	852
9	*Acanthoceras amphibolum*	Belle Fourche shoreline (not shown on fig. 7)	549, 858

A = Kauffman, written commun., 1990

Table B

Map ref.	Formation	Member	Coal (basin summary in appendix)	References (table 1)
10	Woodbine	Red Branch	thin (M3ce)	471, 722
11	Dakota	Janssen Clay	thin/thick (M4ce)	477
12	Dakota	Woodbury	thin	721
13	Windrow and Coleraine		none/thin	716, 754, 755
14	Dakota		thick/thin (M1ce, M10ce)	175, 451, 452, 664, 725
15	Dakota Sandstone		thin/none (L4ce)	714, 728
16	Dakota Sandstone		thick	713, this study
17	Dakota Sandstone		thin/none	661, this study
18	Frontier	Spring Canyon Tongue and Chalk Creek	thick (M2ce, L6ce)	191, 455, 556, 560
19	Blind Bull		thin	715
20	Frontier		thin	T.S. Dyman, oral commun.
21	Dunvegan		thin/none (L2ce)	379, 447, 736
22	Frontier		thin/thick-age uncertain, not shown on figure 7 (L10ce)	478, 860, 861

WESTERN SIDE OF THE SEAWAY

In general, the western side of the seaway is a foreland basin setting with rising highlands to the west due to periodic eastward movement of thrust plates, accompanied by local subsidence, erosion, and highly variable rates of sediment accumulation along the orogenic belt. Differences between the two sides of the seaway during the Cenomanian are evident from the paleogeographic map (fig. 7). For example, the shoreline configuration is more variable on the western side, ranging from an expanse of coastal plain environment 400 km wide in the Four Corners area to a narrow belt of coastal plain, less than 100 km wide, from northwest Wyoming to southern Alberta. The southern part of the map, in southernmost Arizona and northern Mexico, shows an embayment, which is the final stages of filling of the Bisbee basin, an Early Cretaceous backarc rift (Bilodeau and Lindberg, 1983).

Unlike the eastern side of the seaway, the western side has thick coal deposits that are the result of significant peat accumulation in mires that extended in irregular patches from northwestern New Mexico to southwestern Montana. Most Upper Cretaceous coals formed in mires in coastal plain environments; however, the thick extensive coals up to 5.5 m thick in the Dakota Formation in southwestern Utah and northern Arizona are an anomaly: these coals formed on a low-gradient alluvial plain (Kirschbaum and McCabe, 1992) at a time when the shoreline was probably at least 200 km to the northeast. In southwestern Colorado, the Dakota Sandstone contains coals with average thickness of about 1 m, but some coals reach a thickness of 4 m (Shomaker and others, 1971). Examples of coal deposits associated with coastal plain environments include those of the Spring Canyon Member of the Frontier Formation in northern Utah and those of the Chalk Creek Member of the Frontier Formation in southwestern Wyoming, which are up to 4.8 m thick (L6ce, M'Gonigle, 1991). Coastal and delta-plain environments in western Alberta apparently were only favorable for the accumulation of minor peat deposits, which resulted in thin, widely scattered deposits of coal in the Dunvegan Formation (Stott, 1967, 1968, 1982). Figure 8 shows additional details of coal data represented in figure 7.

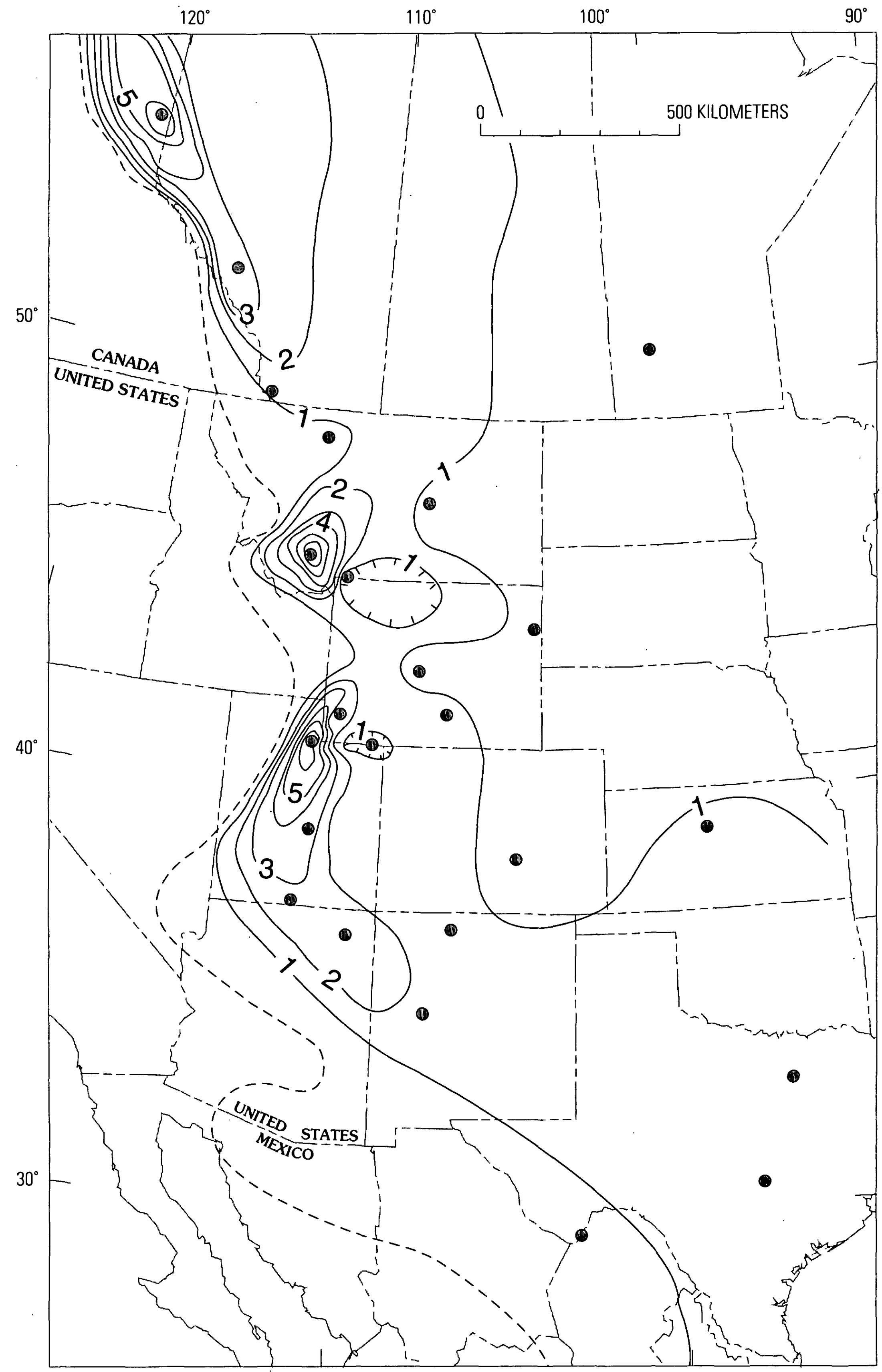
Consistent with the more varied paleogeography on the western side of the seaway, the interpreted paleocurrent directions are more complex. A trunk stream flowed northeast along the orogenic front, based on paleocurrent directions in southwestern Utah in the Iron Spring Formation and in central Utah in the Dakota Sandstone (Fillmore, 1991; Kirschbaum and McCabe, 1992). Similarly, we interpret that a trunk stream flowed southeast in western Montana, subparallel to the mountain front (with a northeast component in southwestern Montana), based on paleocurrent data in the Frontier Formation (Dyman and others, 1989). Inman (1987) noted south to southeasterly paleocurrents in the lower transitional unit of the Bisbee Group in northern Mexico. In the subsurface in west-central Alberta, trends in sandstone isopachs of the Dunvegan Formation indicate that paleoflow was to the southeast (Bhattacharya and Walker, 1991).

Paleosol horizons on the western side of the seaway have not been documented as they have on the eastern side; however, very thick fluvial units of the Chalk Creek Member of the Frontier Formation in northern Utah (Ryer, 1976) and the Vaughn Member of the Blackleaf Formation in southwestern Montana (Dyman and Nichols, 1988) contain variegated beds, some with carbonate nodules and calcareous cements that are interpreted as paleosols (Porter and others, 1993).

The Baseline Sandstone and Iron Springs Formation in southwestern Utah and southeastern Nevada (Bohannon, 1983; Fillmore, 1991) and the Sanpete Formation in central Utah (Lawton, 1985) all contain conglomerates and pebbly sandstones, interpreted as synorogenic deposits. In southwestern Montana, conglomerates and pebbly sandstones dominate the lower clastic lithofacies of the Frontier Formation (Dyman and others, 1989). In British Columbia, the Dunvegan Formation consists of numerous conglomeratic units, some reaching a thickness of 75 m (Stott, 1982, 1984).

◄ **Figure 8 (facing page).** Reference map of Cenomanian paleogeography. Bold line, maximum landward extent of seaway; dotted line, maximum seaward extent of shoreline progradation during the time interval; dashed line, suggested maximum seaward extent of shoreline progradation of other workers (composite of Belle Fourche clastic wedge (Ryer, 1993; Merewether and Cobban, 1986) and *Conlinoceras tarrantense* zone (Cobban and others, 1994)). Number in shaded circle, item in accompanying Table A. Faunal zones that represent all or part of a shoreline position and references used to determine the shoreline position are listed in Table A. Open circle, basin summary location (M5ce, L3ce), data for which are in the appendix. Other numbers, locations with data on coal deposits, corresponding to items listed in Table B. The coal-bearing formations and references used to compile the coal data are listed in Table B.

Figure 9 (overleaf). Isopach map of Turonian rocks spanning about 5 m.y. during the biochrons of *Pseudaspidoceras flexuosum* through *Prionocyclus quadratus.* Thickness in hundreds of meters. Contour interval, 100 m. Hachures, area of local thinning. Dashed line, inferred "zero isopach line," which approximates western edge of Upper Cretaceous outcrops (modified from McGookey and others (1972, their fig. 22)). Shaded circle, basin summary location plotted with "tu" identifier in figures 5 and 11. ►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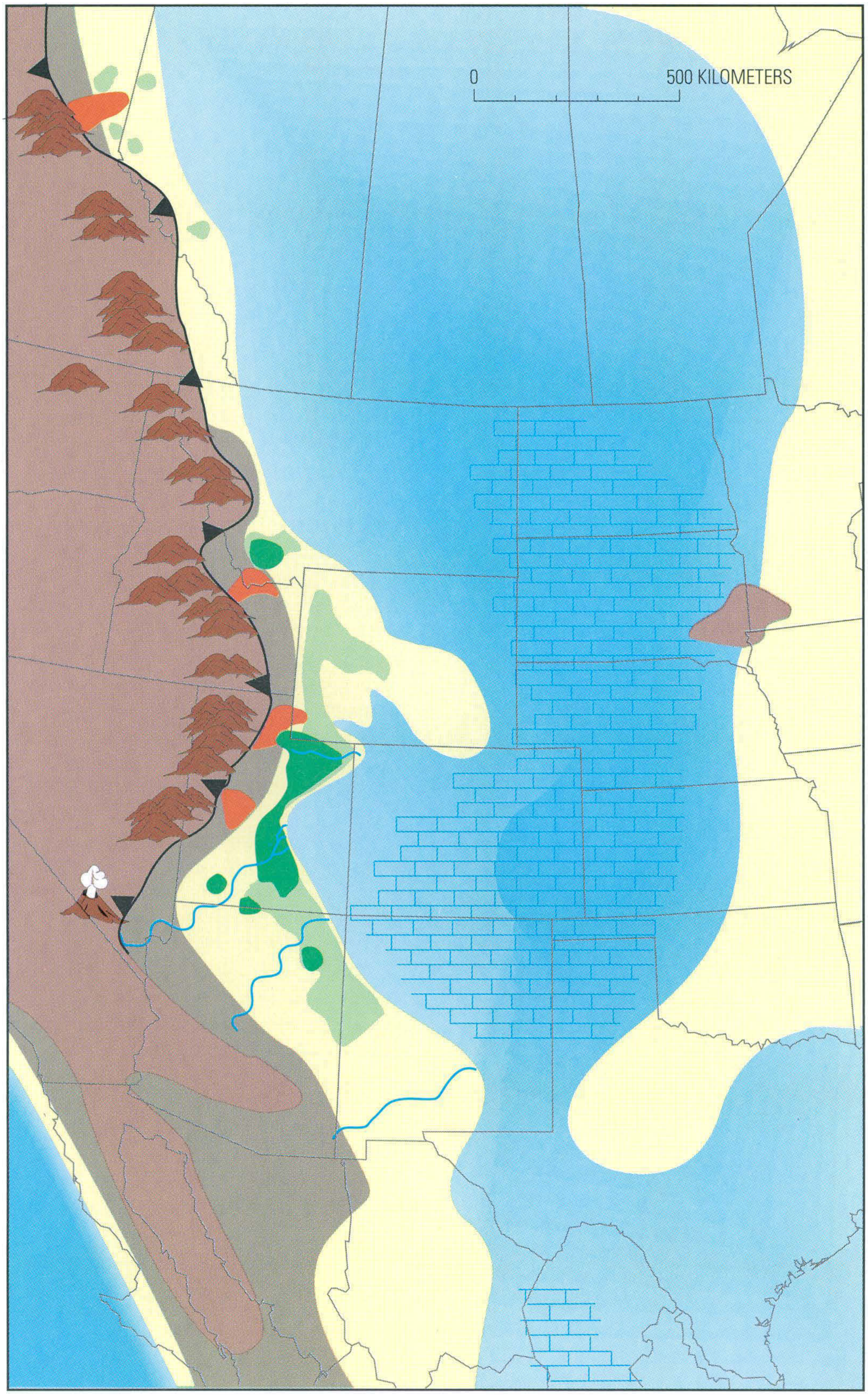


Figure 10 (above and overleaf). Paleogeographic reconstruction during Turonian. See next page for complete caption, and explanation.

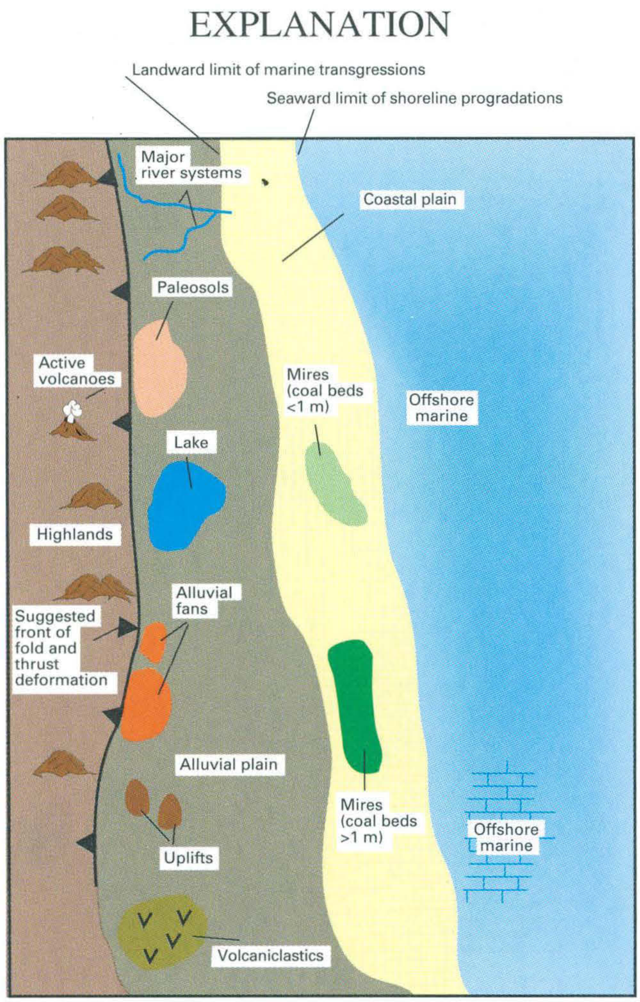


Figure 10—Continued. Paleogeographic reconstruction spanning about 5 m.y. during the Turonian biochrons of *Pseudaspidoceras flexuosum* through *Prionocyclus quadratus* (93.5–88.5 Ma). Sawteeth on upper plate of deformation front. Figure 11 gives details and references used to determine shoreline positions and extent of coal deposits. Figure 7 gives more detailed explanation of map features.

TURONIAN

ISOPACH MAP

The isopach map of Turonian rocks (fig. 9) shows a foreland basin configuration very similar to that of the Cenomanian: three separate basinal areas adjacent to the orogenic front. Depocenters were in the Coalville area of Utah (Ryer and Lovekin, 1986), in southwestern Montana, and in eastern British Columbia. In all three areas, Turonian strata reach a maximum thickness of almost 700 m. In general, the thickness of the Turonian is everywhere less than that of the Cenomanian except in the vicinity of northern Arizona and northwestern New Mexico, where the Turonian is more than twice as thick as the Cenomanian. Merewether and Cobban (1986) have considered vast areas in Wyoming and Colorado to represent a lacuna during much of the Turonian—that is, an area of erosion or nondeposition (figs. 3, 4). Their maps indicate an area along the Wyoming-Montana border where little or no Turonian sediment was deposited. This area is shown on our isopach map as an area of locally thin strata (less than 100 m thick). Gaps in the rock record (hiatuses) are documented in Turonian rocks in the central Rocky Mountain region, suggesting that structural upwarping and subsequent erosion occurred in this area as a result of thrust movement in the Sevier orogenic belt (Merewether and Cobban, 1986). Thickness data in Canada show that the depocenter in eastern British Columbia during the Cenomanian extended southeastward along the orogenic belt (Stott, 1963).

PALEOGEOGRAPHY

The Turonian interval lasted about 5 m.y. and spans the ammonite zones from the base of *Pseudaspidoceras flexuosum* through *Prionocyclus quadratus* (pl. 1). The paleogeography for this time interval is shown in figure 10. In early Turonian time, the Western Interior seaway had reached its maximum transgressive phase. The Turonian was the first stage of the Cretaceous during which deposits of highly calcareous muds were produced over a vast area of the eastern part of the seaway (upper part of the Greenhorn Limestone) (Reeside, 1957; Kauffman, 1977), indicating reduced influx of terrigenous clastics and probably very warm climatic conditions (Reeside, 1957). Westward, calcareous muds grade into gray muds and sandy muds (Frontier Formation); northward they grade into impure calcareous muds (the Favel Formation of Manitoba).

A rapid regressive phase (R6 of Kauffman, 1984) followed the highstand of the early Turonian and culminated in the widespread distribution of sandy deposits of the Codell Sandstone and Turner Sandy Members of the Carlile Shale in the central part of the seaway (McGookey and others, 1972). The shoreline promontory in eastern Wyoming, which is represented by the Wall Creek Sandstone Member of the Carlile Shale, was deposited during the zone of *Scaphites whitfieldi* (Merewether and Cobban, 1986) and represents the easternmost lowstand position of the shoreline (fig. 10). According to the generalized time scale of Kauffman (1977) for ammonite zones in the central Western Interior, the migration rate of the shoreline eastward across Wyoming from the time of *Collignoceras woollgari* zone (middle Turonian) to *Scaphites whitfieldi* zone (late Turonian) can be estimated at about 300 km/m.y., whereas in Arizona to Colorado, during the time of *Watinoceras coloradoense* (early Turonian) to *S. whitfieldi,* shoreline migration rate is only about 80 km/m.y. (fig. 10). In the terrestrial deposits in the southwestern part of the region, this dramatic drop in relative sea level is represented as a major sequence boundary, which records a significant basinward shift in facies at the base of the Calico bed in the Smoky Hollow Member of the Straight Cliffs Formation in the Kaiparowits Plateau, southern Utah, and at the base of the upper sandstone member of the Toreva Formation at Black Mesa (fig. 2), northern Arizona (Shanley, 1991). The shoreline in central Utah and western Montana remained at a relative highstand position and was less affected by changes in relative sea level, perhaps because subsidence was able to keep pace with sediment accumulation. In Canada, the Cardium Formation (fig. 4) was deposited during an overall regressive phase, though interrupted by several pauses and minor transgressive pulses (Stott, 1984). Toward the end of the Turonian, sea level began to rise, representing the beginning of the Niobrara marine cyclothem (Kauffman, 1977; T7 of Kauffman, 1984).

The paleogeographic map (fig. 10) shows that mires were present mainly in coastal plain environments on the western side of the seaway. A narrow belt of mires about 100 km wide extended for 1,200 km north from west-central New Mexico to southwestern Montana, although at any one time during the Turonian, the extent of the mires was considerably less. The area most favorable for thick peat accumulation was in central Utah in a relatively narrow stretch of north-south-trending coastal plain, confined on the west by the thrust belt and on the east by what may have been an embayment for most of Turonian time. Important coals that formed from these peats are in the Ferron Sandstone Member of the Mancos Shale in the Emery coal field of central Utah (fig. 2); they reach a maximum thickness of 7.6 m (Ryer, 1981b), although most beds are considerably thinner. Demonstrated coal reserves in the Emery coal field total about 760 million tons (Doelling, 1972). The Frontier Formation (figs. 3, 4), which is recognized from central Utah to southwestern Montana, contains thick mineable coals in the Coalville Member in northern Utah, and Tysdal and others (1990) reported locally thick coal in southwestern Montana. In Wyoming, however, the Frontier Formation and equivalents in the Blind Bull Formation contain only thin coal (Ruby, 1973). In the southeastern part of Black Mesa, Ariz., the thickest, most extensive coals are in the Toreva Formation; coal was mined at three locations in this area (Peirce and others, 1970). Less significant coal beds are found at the base of the Straight Cliffs Formation in southern Utah. In Canada, only localized areas of minor peat development are evident, and thin coal occurs mostly in the subsurface in the Cardium Formation. On the eastern side of the seaway, evidence for any peat accumulation is no longer preserved as erosion has removed terrestrial rocks of Turonian age and younger. Figure 11 shows localities where coal data are available.

Paleocurrent indicators in Turonian rocks in southern Utah (Peterson, 1969b) show flow of major rivers to the northeast, parallel to the regional tectonic strike of the Sevier orogenic belt. At Black Mesa, Ariz., Franczyk (1988) also showed flow to the northeast, probably from the source area provided by the remnants of the Mogollon highlands (fig. 2), which from Turonian through Coniacian-Santonian time (Hayes, 1970) provided the slope or gradient for northeasterly drainages.

Conglomerates of the Indianola Group were deposited in alluvial fans and on braid plains along the mountain front in central Utah (Lawton, 1985; Lawton and others, 1994). At the base of the Dry Hollow Member of the Frontier Formation in north-central Utah and southwestern Wyoming, conglomeratic units of Turonian age are as much as 20 m thick (Ryer, 1976; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). Conglomerates of the upper unit of the Frontier Formation in southwestern Montana (Dyman and others, 1991), and the Cardium Formation in eastern British Columbia (Stott, 1984) occur as isolated deposits. These coarse clastics were derived from areas of active thrusting and subsequent erosion in the adjacent mountains to the west. Based on the number and magnitude of volcanic ash events, the early to middle part of the Turonian was an episode of intense to moderately intense volcanism (Kauffman, 1984) with probable source areas west of southern Utah or northern Arizona (Elder, 1988).

CONIACIAN-SANTONIAN

ISOPACH MAP

The striking feature on the isopach map of Coniacian-Santonian strata (fig. 12) is the single major depocenter of northeastern Utah and southwestern Wyoming. The Coalville, Utah area (fig. 2) continued to be the site of thickest sediment accumulation, with a maximum of 2,037 m (M5co) for Coniacian-Santonian strata. This accumulation is three times as thick as that of the Turonian and twice as thick as that of the Cenomanian, both of which also have time span intervals of about 5 m.y. The northwesterly trend of thickening strata across east-central Utah is consistent with isopachs of strata that include Coniacian-Santonian rocks shown by Johnson and Finn (1986). Slightly northeast in the Kemmerer, Wyo. area (fig. 2), sediments reach a thickness of 2,008 m (L5co), which is three times and nine times thicker than those of the Cenomanian and Turonian, respectively. Adequate age data for rocks of this age in western Montana are lacking, but it is likely that this part of the foreland basin accumulated more sediment than is represented on the map, in which case, a fairly continuous basin extended along the orogenic front for about 1,200 km. Thickness data in Canada show that the major site of sediment accumulation in eastern British Columbia in the Cenomanian and Turonian shifted to southwestern Alberta during the Coniacian-Santonian (Stott, 1963). Also, although definitive age data are sparse in Texas and northern Mexico, apparently the rate of sediment accumulation was increasing in this area.

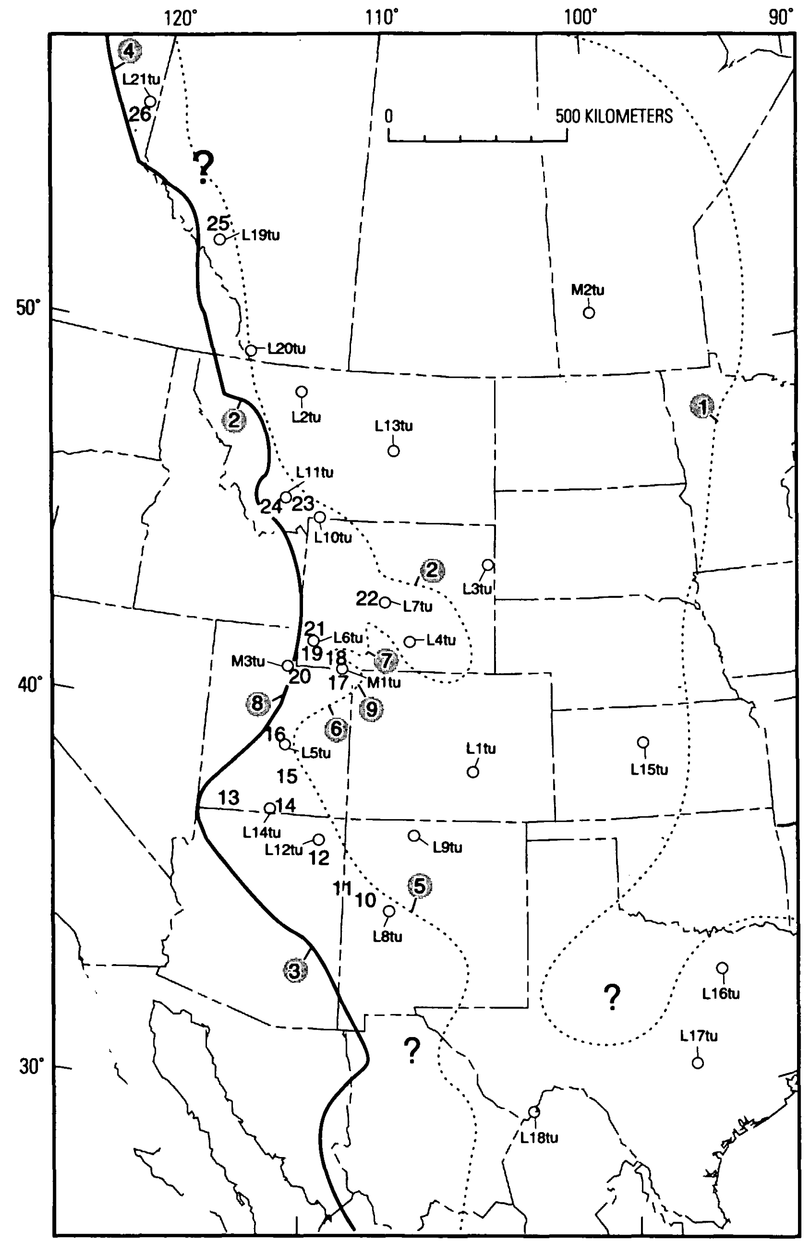


Table A

Map ref.	Faunal zones representing shorelines	References (table 1)
1	*Scaphites whitfieldi*	39
2	*S. whitfieldi*	148
3	*Watinoceras coloradoense*	657
4	*Inoceramus labiatus*	116
5	*S. whitfieldi*	656
6	*Prionocyclus hyatti*	657
7	*P. hyatti*	549
8	*Collignoniceras woollgari*	657
9	*Prionocyclus macombi*	824

Table B

Map ref.	Formation	Member	Coal (basin summary in appendix)	References (table 1)
10	Tres Hermanos Moreno Hill	Carthage	thin (L8tu) thin	111
11	Mesaverde		thin	664
12	Toreva		thick and thin (L12tu)	566
13	Straight Cliffs		thin, pinches out to south	451, 659
14	Straight Cliffs	Smoky Hollow (lower part)	thick to thin	175
15	Mancos Shale	Ferron Sandstone	thick	661, 663
16	Mancos Shale	Ferron Sandstone	thick (L5tu)	553, 242
17	Frontier		thick to thin eastward	662
18	Frontier (lower part)		thin (M1tu)	547
19	Frontier (lower part)		thin	663, 669
20	Frontier	Dry Hollow Coalville	thick (M3tu)	455
21	Frontier	Dry Hollow	thin (L6tu)	556, 558
22	Frontier (upper part)		thin, pinches out at L7tu	478
23	Frontier		thin	408
24	Frontier (upper part)		thick (L11tu)	565
25	Cardium	Moosehound	thin	609
26	Cardium		thin	447, 609

PALEOGEOGRAPHY

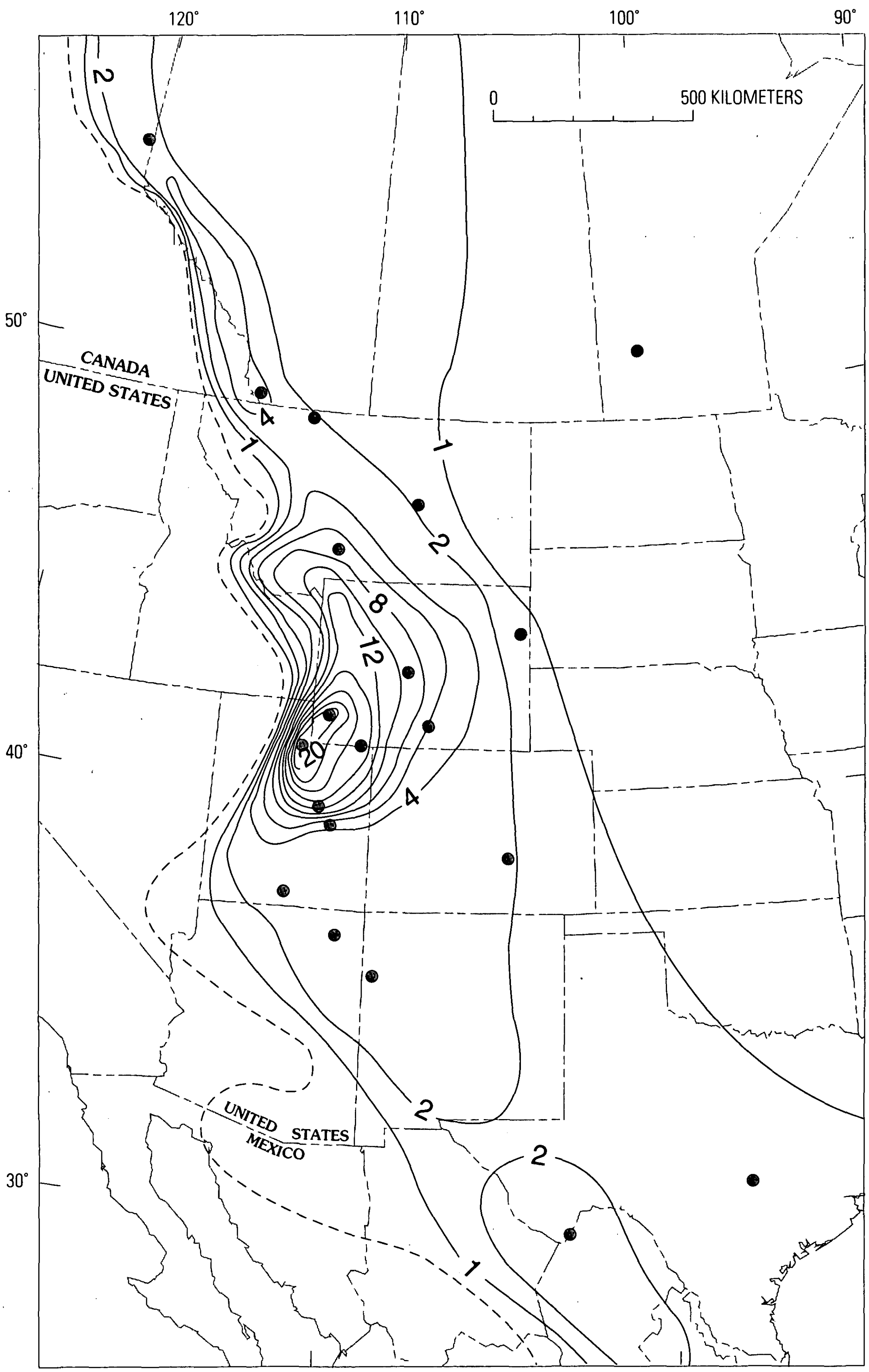
Figure 13 is the paleogeographic reconstruction for the Coniacian-Santonian, which spans about 5 m.y. from the zone of *Forresteria peruana* through *Desmoscaphites bassleri* (pl. 1). A major transgressive phase (Niobrara cyclothem) was underway at the beginning of the Coniacian, and relative highstand conditions persisted for the remainder of the Coniacian-Santonian, although this was interrupted by three relatively minor regressive phases (cycle T7a–d of Kauffman, 1977). Initial deposits in the eastern part of the interior region and in the Big Bend area of Texas (fig. 2), were fairly pure calcareous muds (Fort Hays Limestone Member of the Niobrara Formation and the San Vincente Member of the Boquillas Formation, respectively) (figs. 3, 4). In central Texas, similar deposits prevailed for the entire time interval (Austin Group). Coeval with lime mud deposition and eventually replacing it to the west, detrital muds accumulated over an extensive area in the southwestern part of the region (upper shale member of the Mancos Shale), in Wyoming (lower parts of the Hilliard Shale and the Cody Shale), in Montana (Kevin Member of the Marias River Shale), and in southern Alberta (Wapiabi Formation) (figs. 3, 4).

Along the western paleoshoreline, fluctuations in relative sea level resulted in intertonguing of nonmarine and marine rocks. Because sea level remained fairly high for the duration of the Coniacian-Santonian, coastline positions remained fairly static. Consequently, the width of the belt of coastal plain deposits in New Mexico, Arizona, and southern Utah during the Coniacian-Santonian is about half as wide as during the Turonian. In central and northern Utah, shoreline positions remained confined to a narrow belt along the orogenic front, as in the Turonian; however, the embayment, previously located in central Utah, had migrated to southern Utah. The shoreline bulge in central Wyoming, represented by the youngest sandstone units of the Frontier Formation, is a remnant of the lowstand position in the late Turonian. The rate of shoreline migration westward in central Wyoming during the early Coniacian, which is a maximum for the entire time interval, can be estimated at about 170 km/m.y. In Montana, Alberta, and British Columbia, shoreline positions were very stable, hugging the eastern edge of the mountain front and never advancing or retreating more than 100 km.

The distribution of mires during Coniacian-Santonian was similar to that in the Turonian, except that mires extended farther south to south-central New Mexico and farther north to the United States–Canadian border. In northwestern New Mexico, in the southwestern part of the San Juan Basin (fig. 2) and in small coal fields to the southeast, commercial coal deposits are present in the Dilco and Gibson Members of the Crevasse Canyon Formation (figs. 3, 4), where individual beds are 1–2 m thick (Shomaker and others, 1971; Tabet and Frost, 1978). The thickest bed in this area measures 3.7 m. At Black Mesa, Ariz., the carbonaceous members of the Wepo Formation (fig. 4) together contain at least 10 coal beds thicker than 1 m along the northwest rim (Peirce and others, 1970). Thick coals of Coniacian-Santonian age in the Kaiparowits Plateau, Utah, occur in coastal plain deposits of the John Henry Member of the Straight Cliffs Formation (fig. 4) where bed thicknesses reach 12 m (R.D. Hettinger, oral commun., 1993). In central Utah, thick coals in the Emery Sandstone Member of the Mancos Shale are only found in the subsurface as distinguished on geophysical logs (M3co). Coal beds of the Dry Hollow Member of the uppermost Frontier Formation in southwestern Wyoming indicate that a favorable environment for peat formation continued to exist through the end of the Turonian into the Coniacian. The Kemmerer coal zone of the Dry Hollow Member, which spans the stage boundary (based on palynology, D.J. Nichols, written commun., 1981; L5co and L5tu), contains coal beds that are extensively mined in the Kemmerer area. The upper coals in the Kemmerer zone are probably Coniacian in age. In the Jackson Hole coal field of northwestern Wyoming (fig. 2), the most important coal-bearing formation is the Bacon Ridge Sandstone (Jones, 1982), which contains coal beds up to 2 m thick in the lower part, and several beds in the overlying "coaly sequence" that are 1.5–3 m thick (Berryhill and others, 1950). To the north in the Livingston coal field (fig. 2), southern Montana, coal beds averaging a little more than 1 m in thickness occur in two well-defined zones, one near the middle and one near the top of the Eagle Sandstone

◄ **Figure 11 (facing page).** Reference map of Turonian paleogeography. Bold line, maximum landward extent of seaway; dotted line, maximum seaward extent of shoreline progradation during the time interval, queried where unknown. Number in shaded circle, item in accompanying Table A. Faunal zones that represent all or part of a shoreline position and references used to determine the shoreline position are listed in Table A. Open circle, basin summary location (M1tu, L5tu), data for which are in the appendix. Other numbers, locations with data on coal deposits, corresponding to items listed in Table B. The coal-bearing formations and references used to compile the coal data are listed in Table B.

Figure 12 (overleaf). Isopach map of Coniacian-Santonian rocks spanning about 5 m.y. during the biochrons of *Forresteria peruana* through *Desmoscaphites bassleri*. Thickness in hundreds of meters. Contour interval, 200 m, with 100 m contour also shown. Dashed line, inferred "zero isopach line," which approximates western edge of Upper Cretaceous outcrops (modified from McGookey and others (1972, their fig. 22)). Shaded circle, basin summary location plotted with "co" identifier in figures 5 and 14. ►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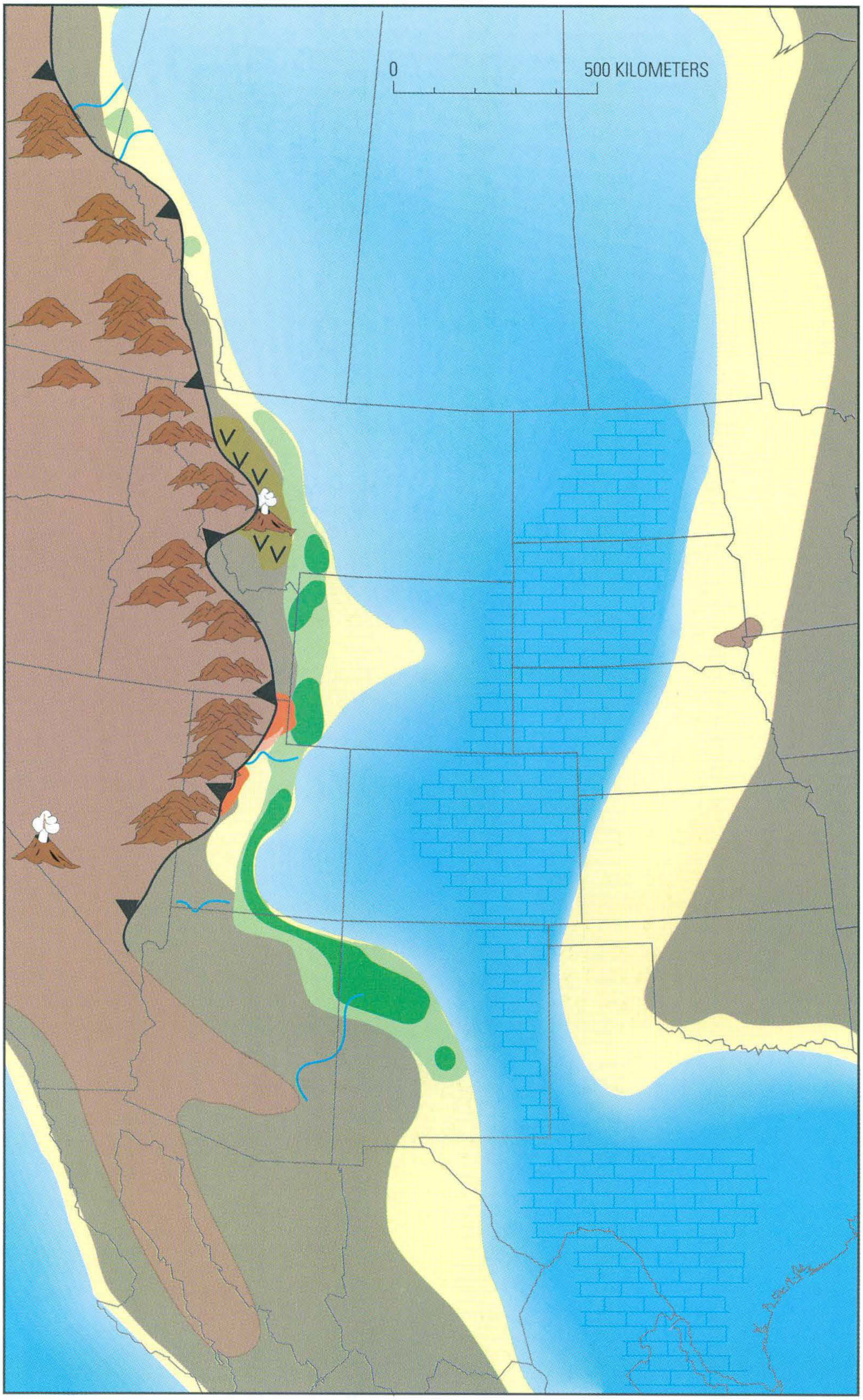


Figure 13 (above and overleaf). Paleogeographic reconstruction during Coniacian-Santonian. See next page for complete caption, and explanation.

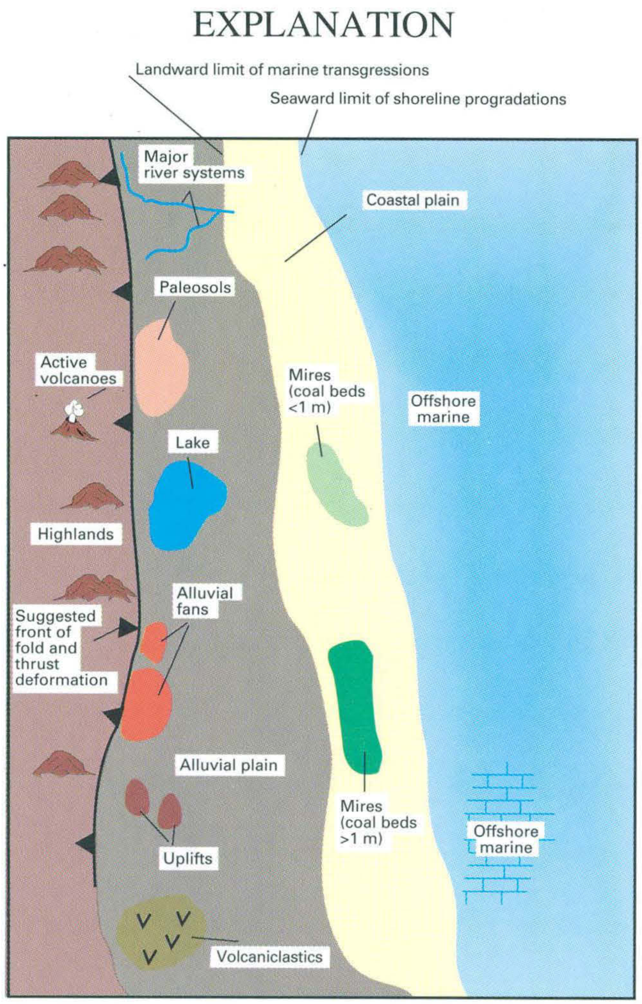


Figure 13—Continued. Paleogeographic reconstruction spanning about 5 m.y. during the Coniacian-Santonian biochrons of *Forresteria peruana* through *Desmoscaphites bassleri* (88.5–83.5 Ma). Sawteeth on upper plate of deformation front. Figure 14 gives details and references used to determine shoreline positions and extent of coal deposits. Figure 7 gives more detailed explanation of map features.

(Roberts, 1966). These coal zones become thinner and have more partings to the north and east of this area. In Canada, the Coniacian-Santonian distribution of mires was similar to that in the Turonian. Only thin coal occurs in isolated deposits in the Cardium Formation (figs. 3, 4) of southwestern Alberta (Stott, 1963) and in the Marshybank/Bad Heart Formation of eastern British Columbia (Stott, 1967). Additional data on coal deposits are shown in figure 14 and listed on the accompanying table.

Most of the information on paleodrainage during the Coniacian-Santonian comes from studies of fluvial strata in Utah. DeCelles (1988) reported eastward paleocurrent indicators in the Echo Canyon Formation (fig. 4) in northeastern Utah, and Peterson (1969b) and Shanley (1991) reported eastward directions in the Straight Cliffs Formation (fig. 3) in southern Utah. In the Gallup area of New Mexico, Flores and others (1991) interpreted paleoflow direction to the northeast during deposition of the Coniacian-Santonian part of the Gallup Sandstone (figs. 3, 4). Northeast-flowing rivers provided sediment for the prograding shoreline represented by the Marshybank Formation in eastern British Columbia (Plint and Norris, 1991).

Conglomerates of the Indianola Group continued (since the Turonian) to be deposited in alluvial fans, and in pebbly and sandy braided rivers along the mountain front in central Utah (Lawton, 1985). In northern Utah, the 700+ m-thick Echo Canyon Conglomerate (fig. 4) represents a coarse-grained alluvial fan derived from several nearby sources to the west (DeCelles, 1988). Synorogenic conglomerates of Coniacian-Santonian age (Jacobson and Nichols, 1982) were also deposited in southwesternmost Wyoming in the Little Muddy Creek area as a result of minor movement along the Absaroka thrust (Wiltschko and Dorr, 1983).

Volcanism resumed at a moderately intense level at the beginning of the Coniacian (Kauffman and others, 1976) and intensified in the Santonian, evidenced by the predominantly volcaniclastic units in the lower part of the Cokedale Formation (Roberts, 1972; Tysdal and Nichols, 1991; McGookey and others, 1972) (fig. 3) and in the basal parts of the Sedan and Maudlow Formations (Skipp and McGrew, 1977) in southwestern Montana.

CAMPANIAN I

ISOPACH MAP

The overall configuration of the foreland basin takes on a different appearance by the end of the 4.5-m.y.-interval of the Campanian I (fig. 15). An east-west component is added to the generally north-south asymmetrical basin, in the central Rocky Mountain region. The thickest rocks of this age are in south-central Wyoming, near Rawlins (fig. 2) (1,087 m; L3Lc), and the thickness is maintained westward all the

Figure 14 (facing page). Reference map of Coniacian-Santonian paleogeography. Bold line, maximum landward extent of seaway; dotted line, maximum seaward extent of shoreline progradation during the time interval. Shoreline positions on the eastern side of the seaway are queried because of lack of data. Number in shaded circle, item in accompanying Table A. Faunal zones that represent all or part of a shoreline position and references used to determine the shoreline position are listed in Table A. Open circle, basin summary location (M4co, L3co), data for which are in the appendix. Other numbers, locations with data on coal deposits, corresponding to items listed in Table B. The coal-bearing formations and references used to compile the coal data are listed in Table B.

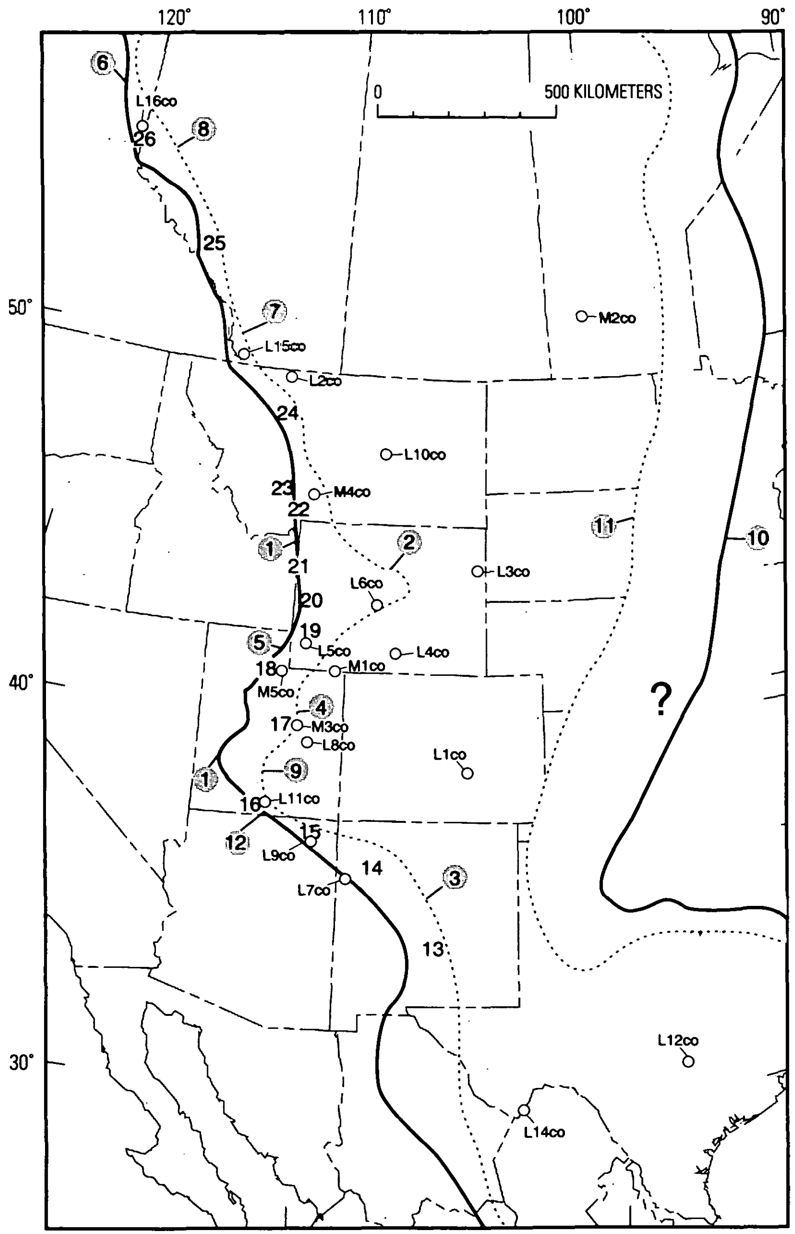


Table A

Map ref.	Faunal zones representing shorelines	Comments	References (table 1)
1	*Scaphites depressus*		148
2	*Inoceramus erectus*		148, 549
3		maximum early Santonian regression	657
4	*Desmoscaphites bassleri*		681
5	*I. deformis*		681
6	*S. ventricosus*	inferred	116
7	*Desmoscaphites* spp.	inferred	116
8		maximum progradation of Marshybank Fm.	622
9	*S. ventricosus*		657
10	*I. deformis* to *Clioscaphites choteauensis*	maximum highstand	Kauffman, written commun., 1990
11	*D. bassleri*	extrapolated from position of *S. hippocrepis* of Williams and Stelck (1975)	233
12		stacked shorelines of John Henry Member of the Straight Cliffs Formation	571

Table B

Map ref.	Formation	Member	Coal (basin summary in appendix)	References (table 1)
13	Crevasse Canyon		thick	658
14	Crevasse Canyon	Dilco and Gibson	thick (L7co)	347, 750
	Gallup Sandstone		thin (L7co)	111
15	Wepo	upper and lower carbonaceous	thick (L9co)	566, 567
16	Straight Cliffs	John Henry	thick (L11co)	175, 747
17	Mancos Shale	Emery Sandstone	thick (M3co)	this study
18	Frontier/Henefer	Dry Hollow (upper part)/	thin (M5co)	191, 745
19	Frontier	Dry Hollow (upper part)		558
20	Blind Bull		thin	715
21	Bacon Ridge Sandstone (including coaly sequence)		thin, coals probably extend into lower Campanian	717, 727
22	Cokedale (lower part)		thin (M4co)	625, 408
	Eagle Sandstone		thick (M4co)	
23	Sedan		thin	444
24	Two Medicine		thin	520, 667, 666
25	Cardium	Sturrock	one thin coal bed	609 (sec. 5-37)
26	Marshybank		thin (L16co)	610, 447

way to southwesternmost Wyoming. The Campanian I is the first of the study intervals to have sediment accumulations greater than 1,000 m as far as 300 km east of the orogenic front. Southwestern Montana continued to be a significant locus of thick sediment accumulation since the beginning of the Late Cretaceous. It is difficult to constrain the age of rocks in this area with precision, but we applied a minimum thickness based on the thickness of the Lima Conglomerate of the Beaverhead Group, which is 610 m thick (Ryder and Scholten, 1973). Nichols and others (1985) determined the age of the Lima Conglomerate to be middle Campanian (Campanian I), based on palynomorphs. However, some of the underlying units may also be of this age, thereby indicating an even greater thickness. The contour orientation and trend of thickening of Campanian I strata along the western edge of the Dakotas are consistent with isopachs of Shurr and Reiskind (1984) for rocks of about the same age. In Alberta and eastern British Columbia, Campanian I strata are thinner than those of all the other time intervals. This period of relative quiescence of sediment accumulation coincides with a gap in the accretion of Cordilleran terranes (Cant and Stockmal, 1989).

To the south, in a minor basin (Ojinaga basin) in the area west of Big Bend, Texas (fig. 2), sediment continued to accumulate. Farther still to the south, a rapid influx of black calcareous muds (Parras Shale) and clastics (lower part of the Difunta Group) occurred in the developing Parras basin of northern Mexico (McBride and others, 1974; Peterson, 1983) during the Campanian (Tardy, 1972). A conservative estimate for the thickness of the entire Campanian interval is about 1,650 m (Tardy, 1972; McBride and others, 1974). We arbitrarily divided the thickness of these strata and placed half in the Campanian I (fig. 15) and half in the Campanian II (fig. 18).

PALEOGEOGRAPHY

The paleogeographic reconstruction of the Campanian I study interval (fig. 16) spans the ammonite zones *Scaphites leei* III through *Baculites asperiformis*. The Campanian I interval is characterized by an overall regression of the shorelines along the Western Interior seaway, interrupted by asynchronous transgressions (end of Niobrara and beginning of Claggett cyclothems of Kauffman, 1977). At the beginning of the Campanian, the central part of the seaway in Texas and eastern Colorado was an area of platform carbonates (upper part of the Austin Group and uppermost unit of the Niobrara Formation, respectively) reflecting the highstand at the close of the Santonian. In other parts of the seaway, pelagic muds accumulated, represented by all or parts of the Pierre, Gammon, Claggett, Cody, Steele, Mancos, and Lewis Shales in the United States, and the Pakowki and Lea Park Formations in Canada (figs. 3, 4).

As during the Coniacian-Santonian, fluctuations in relative sea level resulted in intertonguing of marine and nonmarine rocks along the western shoreline. Active thrusting and erosion in the orogenic belt resulted in the deposition of clastic wedges adjacent to the highlands. Examples of such clastic wedges include the Star Point Sandstone/Blackhawk Formation of central Utah; the Adaville and Rock Springs Formations of southwestern Wyoming; and the Milk River Formation and Chungo Member of the Wapiabi Formation of southern Alberta (figs. 3, 4). The overall paleogeographic position of the western shoreline (figs. 16, 17) at the lowstand (maximum regression) is farther to the east than in previous intervals. This eastward migration of the paleoshoreline is the dominant trend for the remainder of the Cretaceous. An embayment was still evident in Utah; however, it had migrated to the eastern part of the State. For the first time in the Late Cretaceous, the western shoreline along the Canadian part of the foreland basin moved back and forth for great distances—at least 250 km, and perhaps as much as 600 km in central Alberta.

During the Campanian I, mires extended for a distance of about 2,400 km from south to north, with a maximum width in southwestern Wyoming of 300 km, although at any one time the extent of the mires was probably less. As in the two previous time intervals, thick accumulations of peat surrounded the embayment that extended from northwestern New Mexico through Utah to northwestern Wyoming. Coal beds as thick as 3.5 m are present in outcrops of the Menefee Formation (figs. 3, 4) in the northwestern part of the San Juan Basin (Hayes and Zapp, 1955), and beds as thick as 6.7 m occur in the subsurface in the southwestern part of the basin (Shomaker and others, 1971). In the active mines of the Wasatch Plateau and Book Cliffs of central Utah (fig. 2), coal beds up to 4.3 m thick are mined from the Blackhawk Formation (Keystone Coal Industry Manual, 1993) of Campanian I age (fig. 3). In southwestern Wyoming, the thickest known coal bed (35 m) of the Upper Cretaceous is currently mined from the Adaville Formation (Weaver and M'Gonigle, 1987; L5Lc). To the east in the Rock Springs uplift (fig. 2), Wyoming, approximately 15 major coal zones with individual beds as thick as 6.7 m occur in the Rock Springs Formation (figs. 3, 4) (Levey, 1985). The Eagle Sandstone and its equivalents in Montana, and the Milk River Formation/lower part of the Belly River of southern Alberta, contain minor coal deposits. The area in eastern British Columbia and western Alberta that showed minor coal deposits in the two previous stages shows no coal mainly due to the marine conditions that prevailed in this area during most of Campanian I time. Data and references on other minor coal-bearing units are given in figure 17.

Based on paleocurrent information for the Campanian I interval, southeasterly flowing rivers are interpreted from paleocurrent measurements in fluvial units in the Green River basin (fig. 2) of Wyoming (Shuster, 1986). We project this trend southeastward to the area of delta deposition represented by the Rock Springs Formation (Kirschbaum, 1986). In the southwestern part of the map area, the general paleodrainage direction apparently was to the north-northeast, seaward from the ancestral Mogollon highland, based on measurements taken from the Menefee Formation in New Mexico (Cavaroc and Flores, 1984; Tabet and Frost, 1979). Balsley (1980) reported paleocurrent directions from the Blackhawk Formation also to the northeast in Utah, which agrees with Peterson's (1969b) measurements from the Drip Tank Member of the Straight Cliffs Formation and from the Wahweap Formation of the Kaiparowits Plateau. During Campanian I time, intermontane basins began to form as the result of early phases of the Laramide deformation in southern Arizona and northern Mexico (Dickinson and others, 1989). Infill of the basins includes the lower part of the Fort Crittenden Formation and its equivalents, which are conglomerates composed of clasts of volcanic rocks deposited in alluvial fans and braided streams. Interbedded shales, red shales with carbonate nodules, and black shales of this formation were deposited in lakes and lake margins (Inman, 1987; Hayes, 1970). To the southeast, in northern Mexico and eastern Texas, Lehman (1985a) reported paleocurrent data in the Aguja Formation (fig. 3) indicating east-northeastward sediment transport, perhaps with a source area in the intermontane basins.

Few sedimentary units of this age in the study area have been interpreted as paleosols. However, in northwestern Montana, Lorenz (1981) described minor amounts of carbonate nodules in the lower part of the Two Medicine Formation (fig. 4), some of which he interpreted to have formed during deposition, rather than diagenetically. We indicate paleosols for this area in Montana for the Campanian I, but the evidence for paleosols in this area is much stronger in the Campanian II.

The very coarse clastics that were deposited along the front of the orogenic belt in southwest Wyoming and Utah during the previous intervals are not evident during the Campanian I. However, in southwestern Montana, the Lima Conglomerate probably accumulated in coalescing alluvial fans, which derived their deposits from nearby exposed uplifts along the Montana-Idaho border and from the Blacktail-Snowcrest arch (Ryder and Scholten, 1973). Farther north in Montana, along the orogenic belt, members B, C, and D of the Maudlow Formation of the Livingston Group contain alluvial conglomerates and breccias composed of volcanic clasts derived from the Elkhorn Mountain Volcanics to the west (Skipp and McGrew, 1977).

A notable event for this time is intense volcanism in western Montana, which resulted in extensive deposition of volcanic material, represented not only by the Maudlow Formation (Skipp and McGrew, 1977) (fig. 2), but also by the Landslide Creek Formation in the northwest corner of Wyoming (age determined in Tysdal and Nichols, 1991) and farther north in Montana, the correlative part of the Cokedale Formation. Persistent bentonite beds in the transgressive part of the Claggett Shale of Montana and equivalent rocks elsewhere also represent periods of explosive volcanism (Gill and Cobban, 1973). The Ardmore Bentonite Bed, deposited at about the time of *Baculites obtusus* (Gill and Cobban, 1966a), is used as a regional marker bed from west-central Montana to south-central Wyoming and at least as far east as southwesternmost South Dakota (Gill and Cobban, 1973). Volcanic activity is also evident during this time in the open seaway in central and southwestern Texas (Garner and Young, 1976; Rodgers, 1989).

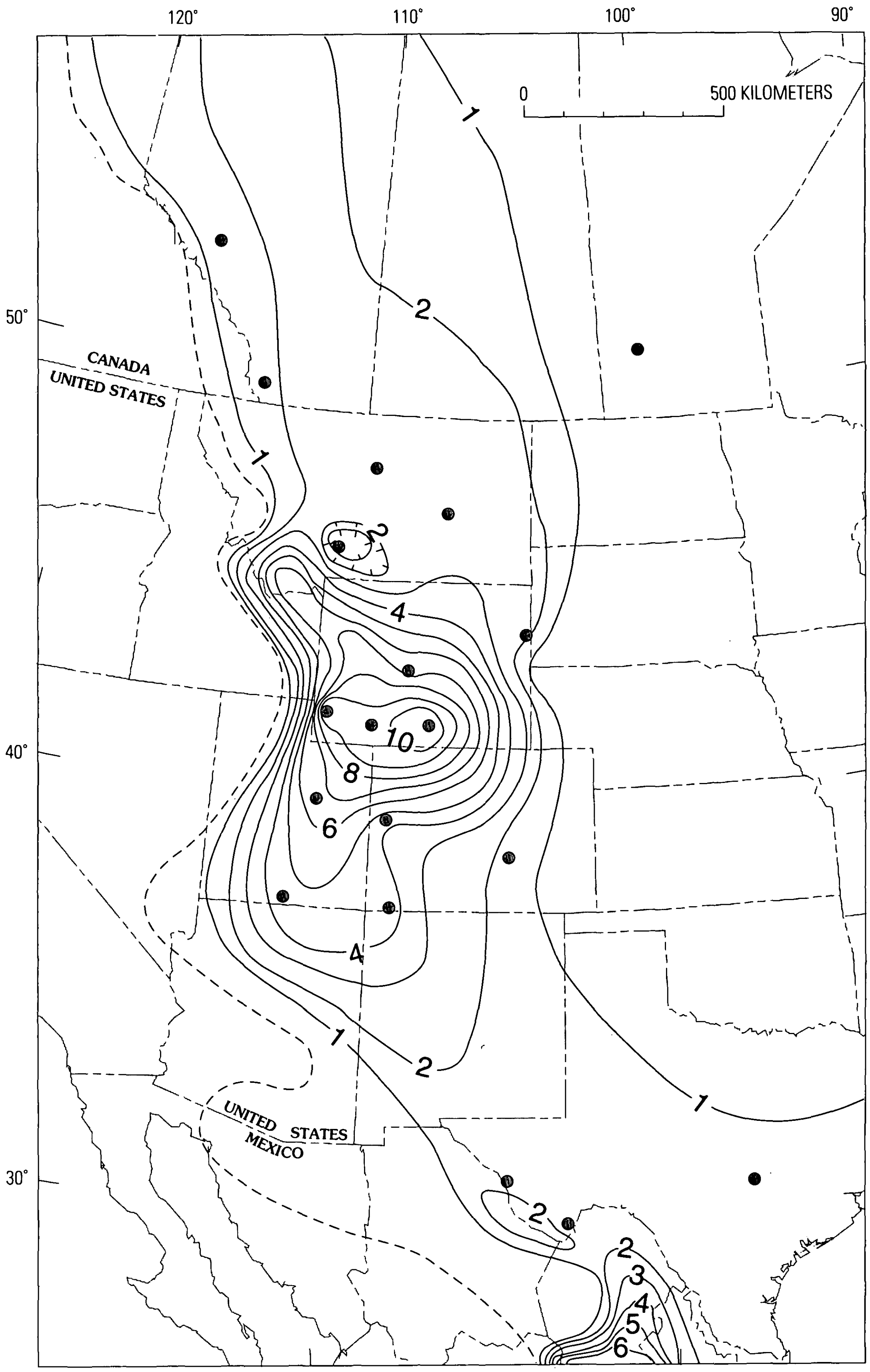
CAMPANIAN II

ISOPACH MAP

A major difference in the isopach map of the Campanian II (fig. 18) as compared to that of the Campanian I (fig. 15), is the elongate foreland basin that developed from northwestern Montana through southern Alberta after a period of relative quiescence since the Santonian. The thickness of sediment that accumulated in southern Alberta (778 m; L11ca) was more than three times that deposited in the same area during the Campanian I. In the central Rocky Mountain region, the thickness of the Campanian II interval is the greatest in a southwest-northeast-trending basin extending from southern Utah to eastern Wyoming with a maximum thickness of about 920 m in the Kaiparowits Plateau of southern Utah (L9ca). The overall sediment thickness in this area is similar to that of the Campanian I interval, but the depocenter that was previously in southwestern Wyoming has migrated to the south and east. Although adequate age control is lacking for rocks of this age in southwestern Montana, the area continued to be the site for the accumulation of thick volumes of sediment.

In western Wyoming, the Campanian II incorporates the major unconformity at the base of the Teapot Sandstone Member of the Mesaverde Formation, and its correlatives, the Pine Ridge Sandstone and the upper part of the Ericson Sandstone (figs. 3, 4). The Teapot Sandstone Member has been interpreted as a valley-fill, and the unconformity represents a major drop in base level (Van Wagoner and others, 1990). An unknown amount of sediment was removed during this event, or may not have been deposited due to low

Figure 15 (overleaf). Isopach map of Campanian I rocks spanning about 4.5 m.y. during the biochrons of *Scaphites leei* III through *Baculites asperiformis*. Thickness in hundreds of meters. Contour interval, 100 m. Hachures, area of local thinning. Dashed line, inferred "zero isopach line," which approximates western edge of Upper Cretaceous outcrops (modified from McGookey and others (1972, their fig. 22)). Shaded circle, basin summary location plotted with "Lc" identifier in figures 5 and 17.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500 KILOMETERS
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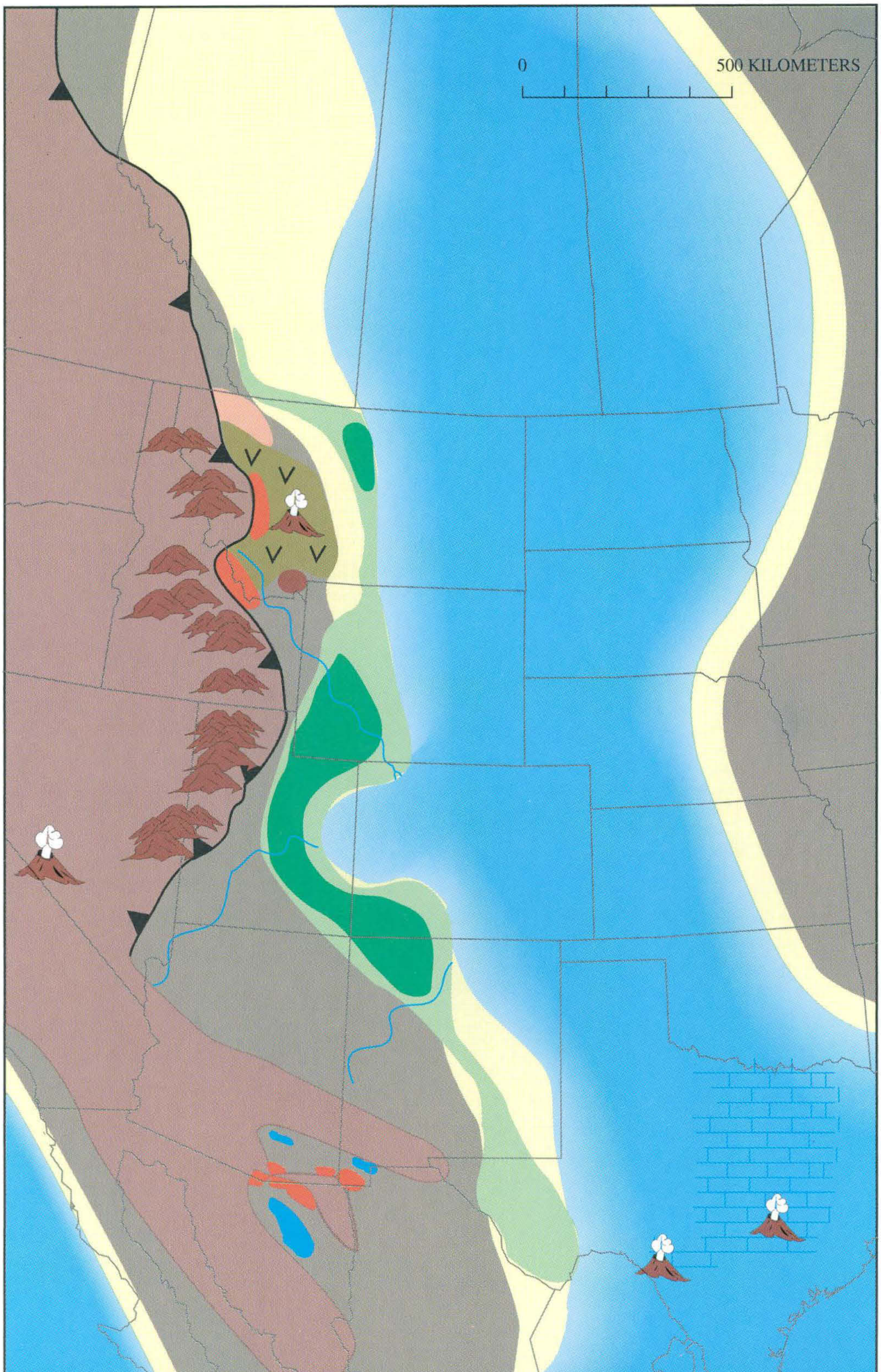


Figure 16 (above and overleaf). Paleogeographic reconstruction during Campanian I. See next page for complete caption, and explanation.

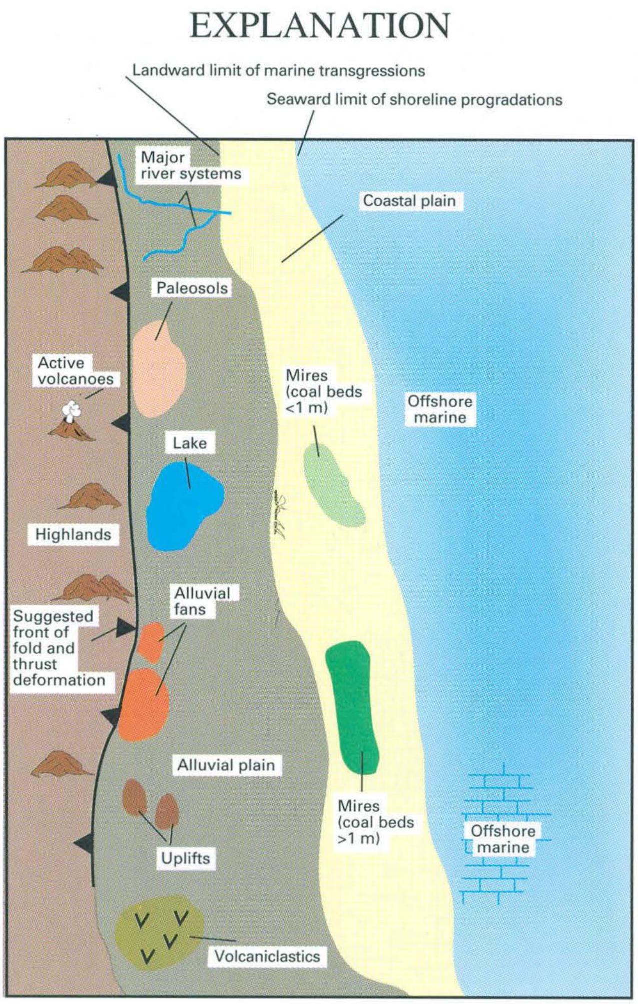


Figure 16—Continued. Paleogeographic reconstruction spanning about 4.5 m.y. during the Campanian I biochrons of *Scaphites leei* III through *Baculites asperiformis* (83.5–79 Ma). Sawteeth on upper plate of deformation front. Figure 17 gives details and references used to determine shoreline positions and extent of coal deposits. Figure 7 gives more detailed explanation of map features.

subsidence rate or local uplift in the area of western Wyoming. However, unless a notable angular relationship exists between the Teapot Member and older strata, a significant thickness of strata need not have been removed from that area, as suggested by Gill and Cobban (1973). Whatever the case, the result is a large area in western Wyoming and northern Utah that has only a thin interval of Campanian II rocks.

PALEOGEOGRAPHY

The Campanian II interval spans about 7 m.y. from the faunal zone of *Baculites* sp. (smooth) through that of *B. cuneatus*. During the Campanian II, the Western Interior seaway continued from the previous time interval to become restricted as the shorelines at their lowstand position were farther to the east than they were previously (figs. 19, 20). Minor amounts of carbonates accumulated in northeastern Texas at the beginning and at the end of the Campanian II, as represented by the Pecan Gap Chalk and the Saratoga Chalk, respectively (Hancock, 1993). Deposition of the Saratoga Chalk continued into the early Maastrichtian. Continuous deposition of marine sediments in the central part of the seaway is represented by the middle part of the Pierre Shale, which was deposited as pelagic muds. Sandy members of the Pierre Shale in Colorado, such as the Kremmling, Muddy Buttes, Hygiene, and Carter Sandstone Members, represent fluctuations in sediment supply from the west, but they portend the eastward-advancing shoreline. Areas that had been entirely marine mud up to this time began to experience sandier deposition, and in some places, terrestrial deposits predominated for the first time (in southwestern Texas, western Colorado, and eastern Alberta).

The Campanian II began with the waning of the Claggett sea (R8 of Kauffman (1984)), represented by the deposition of continental strata of the Judith River Formation of Montana and Alberta, and closed with the last major sea level rise in the history of the Western Interior seaway (first phase of the Bearpaw cyclothem of Kauffman (1977); T9 of Kauffman (1984)). This transgression is reflected in the sedimentary record more clearly in Montana and Canada than in areas to the south. In fact, the opposite scenario is seen in the San Juan Basin, N. Mex., in that the sea was in a transgressive phase at the beginning of the Campanian II, reached its maximum at about the time of *Baculites scotti*, and then began a final retreat from this region. Shoreface deposits of the Pictured Cliffs Sandstone and the terrestrial deposits of the overlying Fruitland Formation and lower part of the Kirtland Shale (figs. 3, 4) reflect the progradation. Along the western margin of the seaway between New Mexico and Montana, the shoreline advanced, paused, and retreated asynchronously resulting in complex packages of intertonguing marine and nonmarine sediments.

Figure 17 (facing page). Reference map of Campanian I paleogeography. Bold line, maximum landward extent of seaway; dotted line, maximum seaward extent of shoreline progradation during the time interval, queried where uncertain. Shoreline positions on the eastern side of the seaway are queried because of lack of data. Number in shaded circle, item in accompanying Table A. Faunal zones that represent all or part of a shoreline position and references used to determine the shoreline position are listed in Table A. Open circle, basin summary location (M5Lc, L3Lc), data for which are in the appendix. Other numbers, locations with data on coal deposits, corresponding to items listed in Table B. The coal-bearing formations and references used to compile the coal data are listed in Table B.

Figure 18 (see page 38). Isopach map of Campanian II rocks spanning about 7 m.y. during the biochrons of *Baculites* sp. (smooth) through *B. cuneatus*. Thickness in hundreds of meters. Contour interval, 100 m. Dashed line, inferred "zero isopach line," which approximates western edge of Upper Cretaceous outcrops (modified from McGookey and others (1972, their fig. 22)). Shaded circle, basin summary location plotted with "ca" identifier in figures 5 and 20.

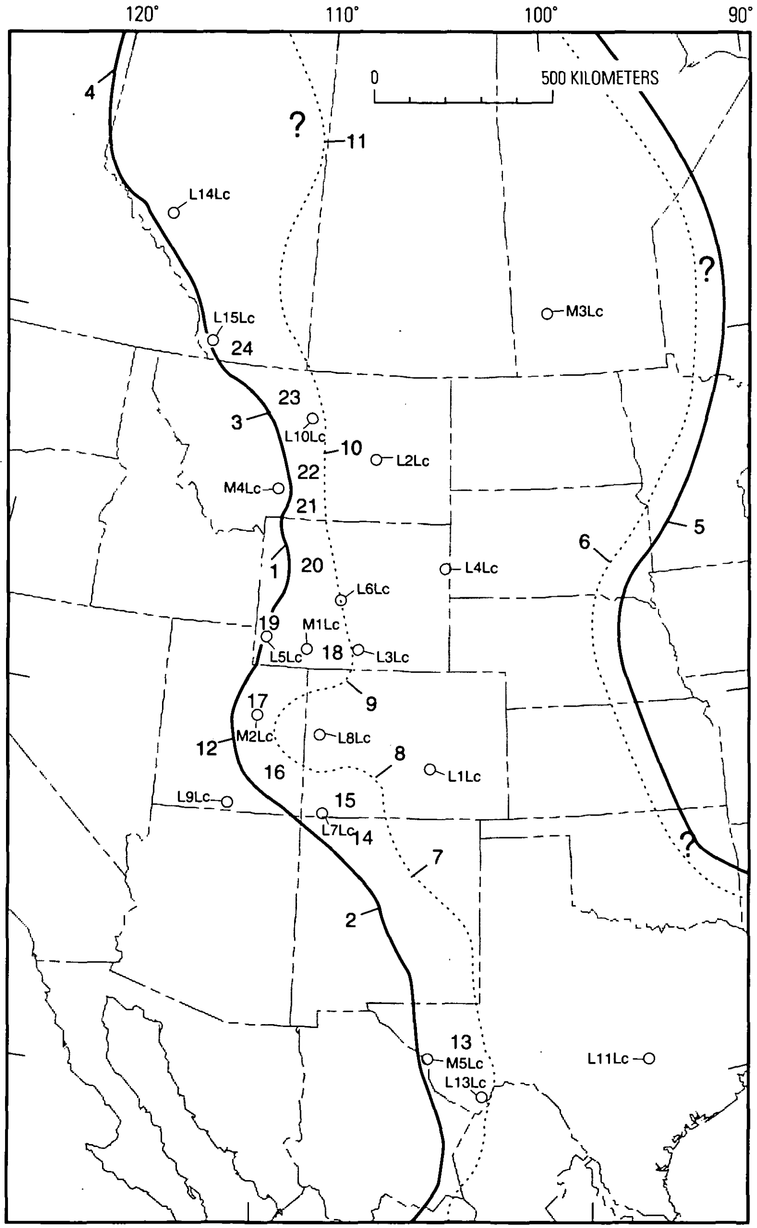
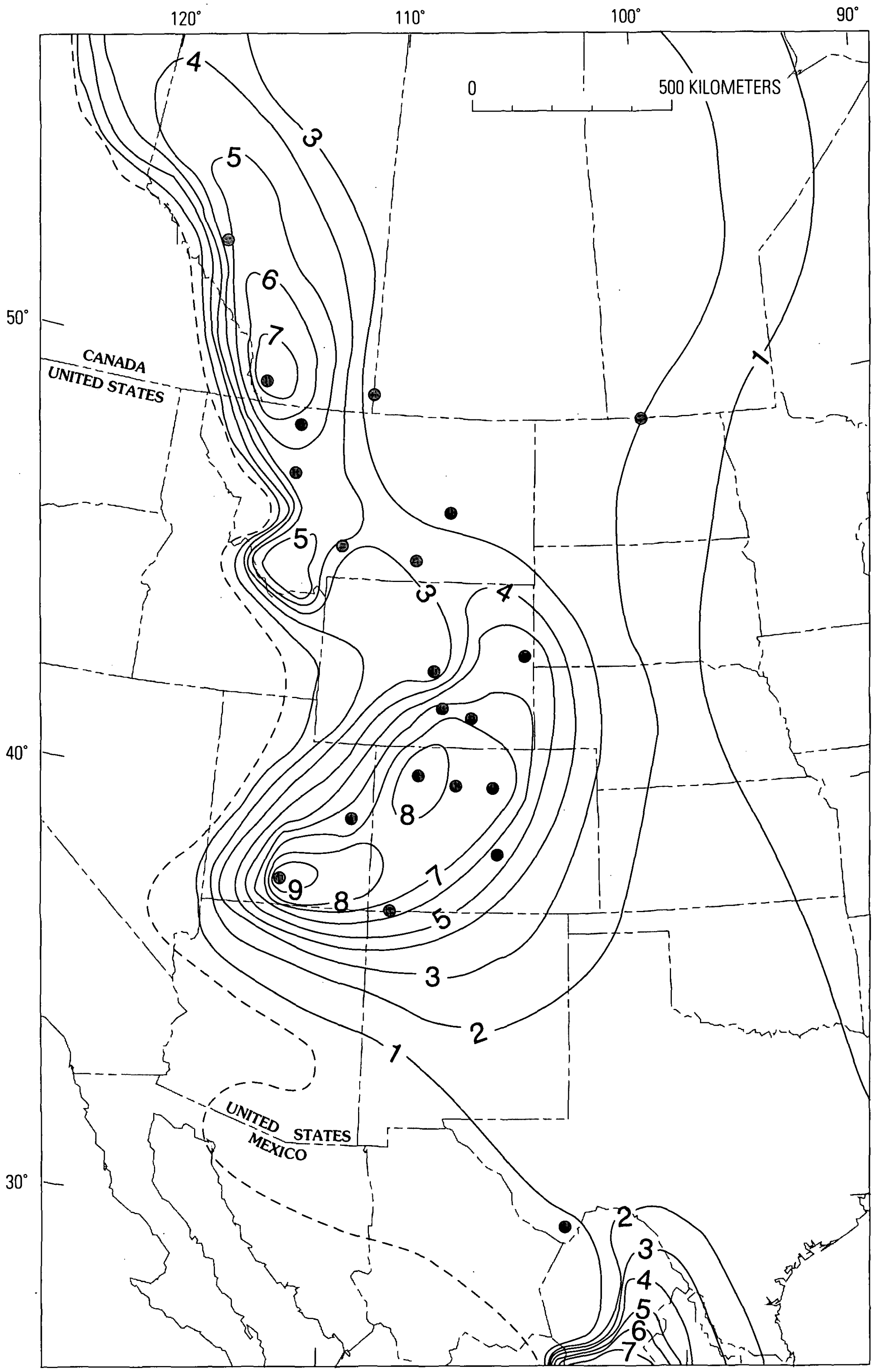


Table A

Map ref.	Faunal zones representing shorelines	Comments	References (table 1)
1	*Scaphites hippocrepis* I		438
2	*Baculites asperiformis*		512, 657
3	*B. maclearni*		438
4		maximum transgression, Pakowki sea	116, 233, 528
5		western limit of area designated as terrestrial	39
6	*B. asperiformis*	hypothetical, assuming overall regression	
7	*B.* sp. (weak-flank ribs)		162, 512, 657
8	*B.* sp. (weak-flank ribs)		438
9	*B. asperiformis*		438
10	*B.* sp. (smooth: early form)		438
11		hypothetical, between max. transgression of Pakowki sea and max. regression of Belly River Fm	116, 233, 528
12		shoreline modified from previous workers based on basin summaries M3co, M2Lc, & L9Lc	this report

Table B

Map ref.	Formation	Member	Coal (basin summary in appendix)	References (table 1)
13	San Carlos		thin M5Lc	677
	Aguja		thin L13Lc	497, 512
14	Menefee		thick/thin	661, 732
15	Menefee		thick/thin L7Lc	561
16	Masuk (Mancos Shale)	(Emery Ss)	thick/thin	661, 773
17	Blackhawk		thick/thin M2Lc	554, 730, 772, 817
18	Rock Springs		thick/thin M1Lc	392, 546
19	Adaville		thick/thin L5Lc (up to 35 m)	560, 731
20	Mesaverde		thin L6Lc	478, 623
	Sohare		thin/none	727, 753
21	Eagle Sandstone		thin/thick L10Lc	724
22	Maudlow		none/thin	444
23	Eagle Sandstone		thin/thick L10Lc	570
	Two Medicine		thin/none	579
24	Milk River/lower Belly River		thin/none L15Lc	397, 519, 609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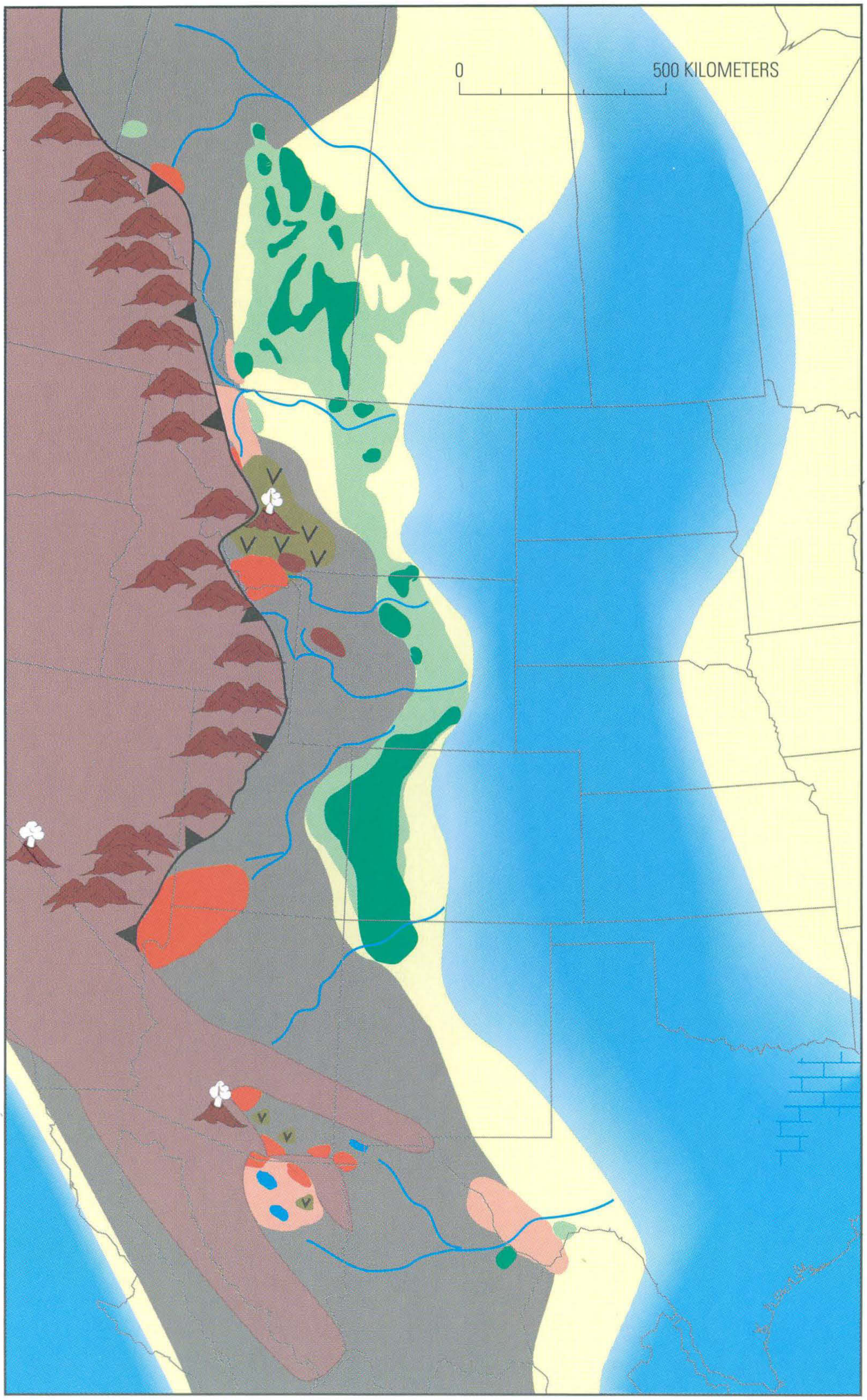

Figure 19 (above and overleaf). Paleogeographic reconstruction during Campanian II. See next page for complete caption, and explanation.

EXPLANATION

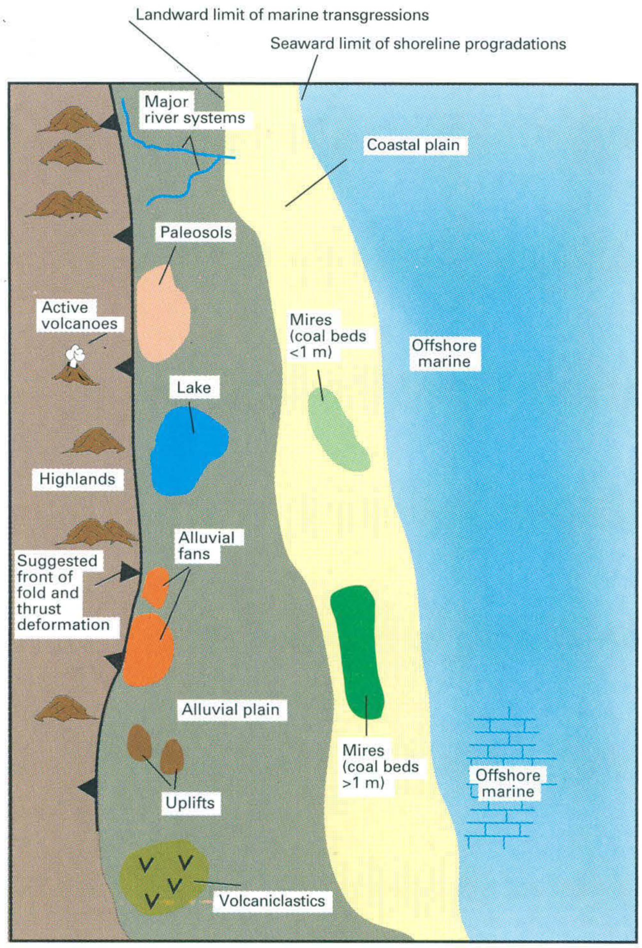

Figure 19—Continued. Paleogeographic reconstruction spanning about 7 m.y. during the Campanian II biochrons of *Baculites* sp. (smooth) through *B. cuneatus* (79–72 Ma). Sawteeth on upper plate of deformation front. Figure 20 gives details and references used to determine shoreline positions and extent of coal deposits. Figure 7 gives more detailed explanation of map features.

Coastal plain environments continued to be the major sites for peat accumulation during the Campanian II. A continuous belt of mires extended from northwestern New Mexico to central Alberta and Saskatchewan. In the San Juan Basin, thick, extensive coal of the Fruitland Formation formed from these peat deposits. In New Mexico, Fruitland coals are currently mined; Biewick and others (1991) have estimated coal resources in the Fruitland Formation to be about 168 billion short tons. Fruitland Formation coals are also an important source of methane gas: cumulative production in the entire basin surpassed 1.6 TCFG (trillion cubic feet of gas) at the end of 1993 (Carol Tremain, oral commun., 1994). In eastern Utah, four named coal zones, all with beds locally more than 1.2 m thick, occur in the Neslen Formation (fig. 4) (Doelling and Graham, 1972). The "Palisade seam" at the base of the correlative Mount Garfield Formation in Colorado is as thick as 2.8 m (Hornbaker and Holt, 1973). The Iles Formation and lower part of the Williams Fork Formation of the Mesaverde Group in northwestern Colorado are of Campanian II age and contain coals of major importance that are currently exploited at several mines in the area (Keystone Coal Industry Manual, 1993). As a continuation of this coal-bearing interval to the north in Wyoming, extensive coals are found in the Allen Ridge Formation and locally in the Pine Ridge Sandstone (fig. 3) (Merewether, 1973; Barclay, 1980a, 1980b). A notable difference in the paleogeography at this time as compared to the previous study intervals is the vast expanse of coal deposits in the Alberta plains region. These coals occur in the Belly River Formation. Subsurface data from Macdonald and others (1986, their maps 5, 11, and 16) were compiled to arrive at the distribution and thickness of coal deposits. Figure 20 shows locations, and lists coal-bearing formations and references for other coal deposits of Campanian II age.

Paleocurrent data from the Aguja Formation in western Texas (Lehman, 1985a) indicate a continued east-northeasterly direction of sediment transport. Evidence for a general east-northeastward paleoflow direction for streams in the northwestern San Juan Basin is based on paleocurrent measurements in sandstone units of the Fruitland Formation (Erpenbeck, 1979; Roberts and Uptegrove, 1991); the same paleoflow direction is indicated in east-central Utah, based on paleocurrent indicators in the upper part of the Castlegate Sandstone and the Farrer Formation (Lawton, 1986; Franczyk and others, 1990). Paleodispersal paths, based on petrofacies analysis of the Kaiparowits Formation, show flow directions from the thrust belt in southern Nevada northeastward into southern Utah (Goldstrand, 1990). In western Wyoming and southwestern Montana, the drainage pattern for the Campanian II shifted to the southeast (Shuster, 1986) and turned eastward in east-central Wyoming, based on paleocurrent data in the Parkman Sandstone (Hubert and others, 1972). Sandstones in the upper part of the Two Medicine Formation in northwestern Montana exhibit a general northeastward paleoflow direction (Lorenz, 1981), which we extend to the north to intersect a predominantly eastward

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Figure 20 (facing page). Reference map of Campanian II paleogeography. Bold line, maximum landward extent of seaway; dotted line, maximum seaward extent of shoreline progradation during the time interval. Shoreline position on the eastern side of the seaway is queried because of lack of data. Number in shaded circle, item in accompanying Table A. Faunal zones that represent all or part of a shoreline position and references used to determine the shoreline position are listed in Table A. Open circle, basin summary location (M5ca, L3ca), data for which are in the appendix. Other numbers, locations with data on coal deposits, corresponding to items listed in Table B. The coal-bearing formations and references used to compile the coal data are listed in Table B.

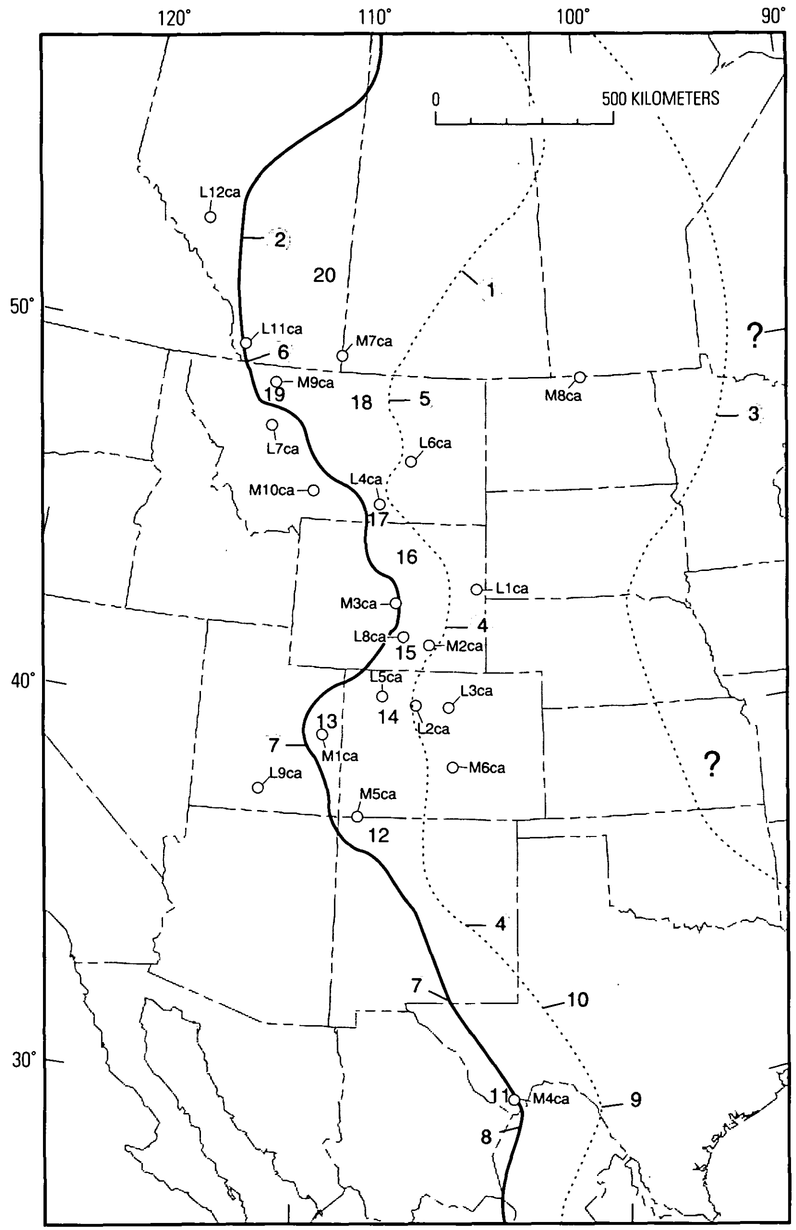


Table A

Map ref.	Faunal zones representing shorelines	Comments	References (table 1)
1	~*Baculites nebrascense*	maximum regression of Belly River	233
2	~*B. compressus*	maximum transgression of Bearpaw sea	528
3	*B.* sp (smooth)-*B. cuneatus*	hypothetical composite shoreline	39, 123
4	*B. cuneatus*		403, 438
5	*B. gregoryensis*		403, 438
6	*B. compressus*		438
7	*B.* sp (smooth)		438
8	*B.* sp (smooth)	extrapolated from *B. asperiformis* & M4ca	512, 746
9	~*B. compressus*	San Miguel Fm shorelines	512, 746, 780
10	~*B. compressus*	hypothetical shoreline connecting 4 & 9	

Table B

Map ref.	Formation	Coal (basin summary in appendix)	References (table 1)
11	Aguja	thin/thick M4ca	512, 712
12	Fruitland	thick M5ca	634, 680, 728
13	Neslen	thick/thin M1ca	692
14	Mount Garfield/Mesaverde	thick	635
	Williams Fork/Iles	thick L5ca	636-640, 697
15	Allen Ridge/Pine Ridge Ss	thick/thin M2ca, L8ca	466, 645, 696
16	Mesaverde	thin	623, 641-643
17	Parkman Sandstone/ Mesaverde	thick/none L4ca	641, 647
18	Judith River	thin	648-651
19	Two Medicine	thin/none	520
20	Belly River	thick/thin M7ca, L12ca, L11ca	395, 701, 864

flowing river based on data in the Belly River Formation in southern Alberta (Jerzykiewicz and Labonté, 1991). Other sources of information used to depict paleodrainage directions in Alberta include Koster (1983) and Dodson (1971).

In the Trans-Pecos region of western Texas, Lehman (1989) reported purple and gray banded paleosols, with numerous petrocalcic horizons, in the upper shale member of the Aguja Formation. Lehman's study of these deposits suggests that the climatic regime in this region may have fluctuated between humid and semiarid in the late Campanian and Maastrichtian. Paleosols are also reported in the upper part of the Two Medicine Formation of northwestern Montana (Lorenz and Gavin, 1984) and correlative strata in the Belly River Formation in southwestern Alberta (Jerzykiewicz and Sweet, 1988). Facies analysis and correlation of Upper Cretaceous rocks along the central and southern foothills of Alberta led to the conclusion that the Belly River semiarid facies coincides with the lowstand in Campanian II time and that the regressions of the sea resulted in a trend of increasing aridity (Jerzykiewicz and Sweet, 1988).

In the intermontane basin of southeastern Arizona and northern Mexico, sediments were deposited on extensive alluvial fans (conglomerates) and in lakes (shales) represented by the upper part of the Fort Crittenden Formation and equivalents (Dickinson and others, 1989; Inman, 1987; Hayes, 1970). Pebble to cobble conglomerates of the Canaan Peak Formation in southwestern Utah represent deposition in a perennial braided fluvial system that drained northeastward from the mountainous terrain that resulted from thrust faulting in southwestern Utah (Bowers, 1972; Goldstrand, 1990; Schmitt and others, 1991). In southwestern and west-central Montana, conglomerates and sandstones occur in the upper part of the Beaverhead Group (stratigraphically above the Lima Conglomerate) (Viele and Harris, 1965; Nichols and others, 1985), and minor conglomeratic deposits are present in the lower part of the Brazeau Formation (fig. 3) of western Alberta (Jerzykiewicz and Labonté, 1991).

Southwestern Montana was the site of deposition of volcaniclastic sediments as indicated by strata composed predominantly of detritus eroded from largely volcanic terranes. These strata include the upper part of the Cokedale Formation and overlying Miner Creek Formation, the Big Skunk and upper parts of the Two Medicine, Maudlow, and Sedan Formations (Roberts, 1972; Viele and Harris, 1965; Lorenz, 1981; and Skipp and McGrew, 1977). Explosive volcanic activity is evident in the highly bentonitic shale and numerous bentonite beds in the lower part of the Bearpaw Shale (figs. 3, 4) in southeastern Montana (Gill and others, 1972). Volcanic activity commenced in southwestern Arizona during this time, producing volcanic-rich sediments in the upper part of the Fort Crittenden Formation in southeastern Arizona. Volumes of ash were expelled northeastward and fell in the Lewis sea as evidenced by the extensive Huerfanito Bentonite Bed (fig. 4) of the San Juan Basin (Fassett and Hinds, 1971) and the numerous kaolinitic partings in Fruitland Formation coals (Roberts and McCabe, 1992).

MAASTRICHTIAN

ISOPACH MAP

The isopach map of Maastrichtian rocks (fig. 21) shows a continuous asymmetric foreland basin extending for at least 1,300 km from northwestern Wyoming to west-central Alberta, with sediment thickness considerably greater than in any of the previous time intervals. At the southern end of this linear basin, in the Yellowstone Park area of northwestern Wyoming (fig. 2), Maastrichtian rocks are 2,750 m thick (L19ma). South and east of Yellowstone Park, the isopachs show an area of abrupt thinning, which reflects uplift of the Wind River Mountains (Shuster, 1986). Farther southeast the stratal thickness increases dramatically to almost 3,000 m (M5ma) in the Hanna basin of southeastern Wyoming (fig. 2). The isopachs suggest a single rounded basin; however, it is actually a large basin complex that developed during the Laramide orogeny, with several minor uplifts and associated intermontane basins. The Four Corners area during the Maastrichtian was generally an area of low subsidence, especially as compared to the Campanian II, when this area accumulated large volumes of sediment (fig. 18). The presence of uplifts of the ancestral Sangre de Cristo Mountains and of interpreted uplifts around the southern and western margin of the present-day San Juan Basin (Lehman, 1987) may explain the low sediment accumulation rates of this area. In northern Mexico, sediments continued to accumulate as during the Campanian, but at a much higher rate. In the Sabinas basin (fig. 2), more than 1,000 m of Maastrichtian rocks are present (M6ma). Late Campanian uplift of the Sierra Madre Oriental to the south and west of the Parras basin (just off the map to the south) provided a new source of coarse clastics and resulted in more than 2,600 m of Maastrichtian rocks (middle formations of the Difunta Group) in the Parras basin (Weidie and others, 1972; McBride and others, 1974).

PALEOGEOGRAPHY

The duration of the Maastrichtian interval was about 6.5 m.y. and spans from the zone of *Baculites reesidei* to the end of the Cretaceous Period (pl. 1). This time interval is unique among those considered here in that the tectonic style of deformation changed from the folding and thrusting style of the Sevier orogeny to localized uplifts and partitioning of basins of the Laramide orogeny. In general, the Maastrichtian marks the major retreat of the epicontinental sea from the Western Interior (Bearpaw regression, R9 of Kauffman (1984)). Marine sediments of this time interval in Alberta, Saskatchewan, and the Western Interior United States include the upper part of the Riding Mountain Formation, the upper part of the Bearpaw Shale, upper part of the Pierre Shale, and Lewis Shale (of Wyoming and northwestern Colorado), and in northeastern Mexico, the Escondido

Formation and Mendez Shale. From the beginning of the Maastrichtian to about *B. baculus* time, the shorelines remained relatively stable, at least north of Wyoming. South of Wyoming, the shoreline advanced eastward gradually and fairly uniformly. Wyoming, as such, was an area of rapidly fluctuating shorelines, resulting in embayments and delta-like promontories until the end of the *Sphenodiscus* (*Coahuilites*) biochron, when the seaway had entirely retreated from the area of the State (Lillegraven and Ostresh, 1990). By the end of the Maastrichtian, the seaway had retreated from the Western Interior, leaving the "*Triceratops*" biochron shoreline (Lillegraven and Ostresh, 1990) near that of the present-day Gulf Coast in southernmost Texas (fig. 23). On the paleogeographic map (fig. 22) we show a shoreline position intermediate between the maximum transgression and maximum regression, in order to give a sense of the direction and extent of the progradation. Littoral sands deposited during this progradation include the Fox Hills Sandstone over much of the area (figs. 3, 4), the Horsethief Sandstone in northern Montana, the Blood Reserve Sandstone in southern Alberta (Rice and Cobban, 1977), and the Trinidad Sandstone in New Mexico and Colorado (Lee, 1917).

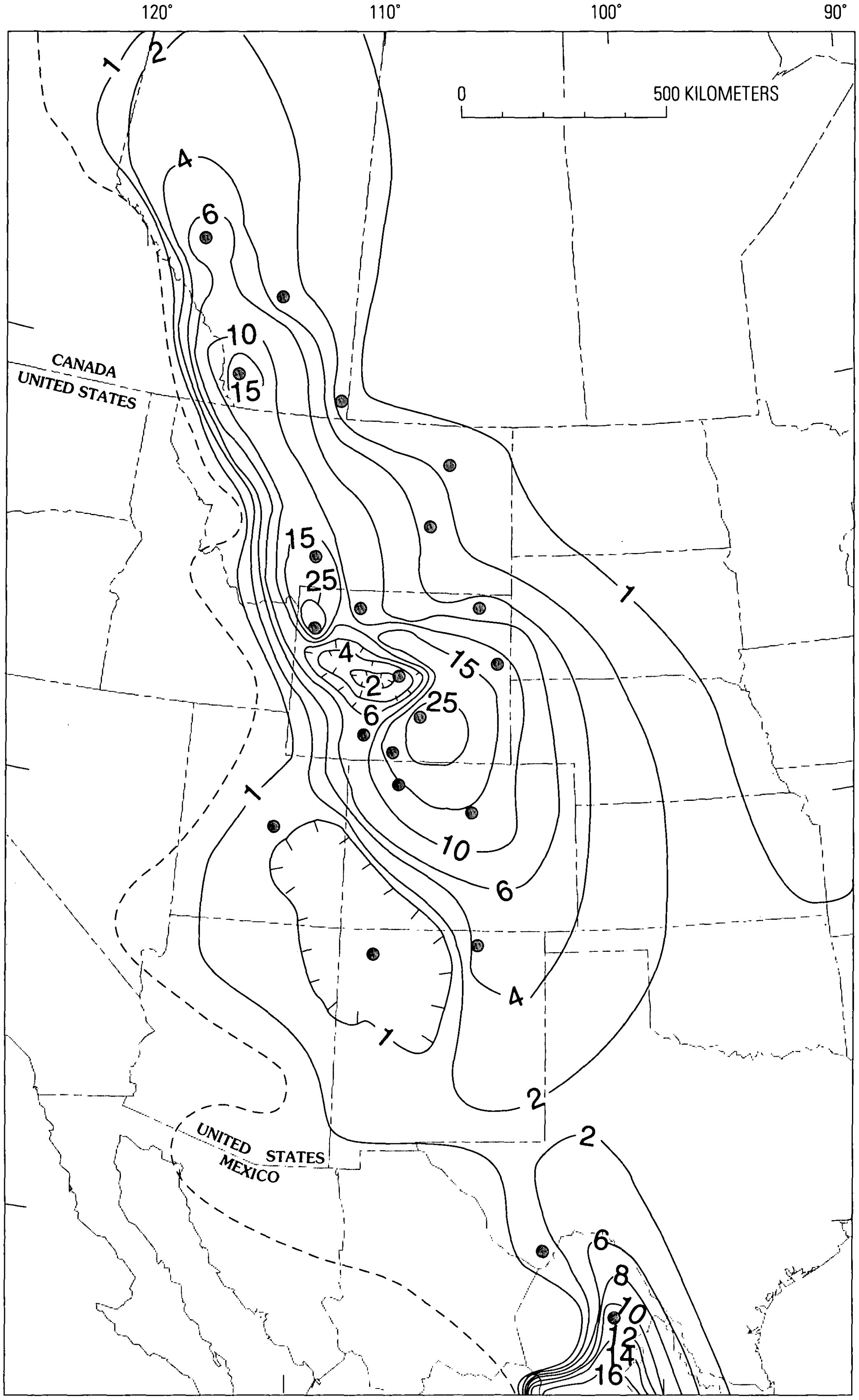
The distribution of Maastrichtian mires follows a general southeast to northwest trend, roughly parallel to the shoreline during the highstand, from northeastern Mexico to western Alberta. Compared to the intervals since the Turonian, two obvious differences are apparent—the discontinuous distribution of mires and evidence of their existence as far east as the Dakotas.

Vaughn (1900) and Robeck and others (1956) reported thick coal in the Olmos Formation in Texas and northern Mexico (M6ma, appendix). High-quality coal beds as much as 4.5 m thick occur at the base and top of the Vermejo Formation in the Raton Basin, northeastern New Mexico (Pillmore, 1991), and coals as thick as 2.2 m lie in the lower part of the Vermejo Formation 170 km north near Canon City, Colo. (Speltz, 1976). In the Denver Basin (fig. 2), the Laramie Formation (fig. 4) contains thick coal (L16ma) (Goldman, 1910). Kirkham and Ladwig (1979) presented a map showing where coal beds of the Laramie Formation are known to be greater than 1.5 m thick in the subsurface. Coal in the Laramie Formation in the Cheyenne basin (fig. 2) in Wyoming is not as thick or as extensive. Favorable conditions for peat accumulation continued from the Campanian II in northwestern Colorado as evidenced by the thick (as much as 3 m) economic coals of the upper part of the Williams Fork Formation (Bass and others, 1955). Stratigraphically higher, in the basal units of the Lance Formation in this area, a coal bed as thick as 3 m was worked in small wagon mines in the early 1920's (Bass and others, 1955). There is thick coal in the Medicine Bow and Almond Formations (figs. 3, 4) in the Hanna and Carbon basins (fig. 2), and in the Rock Creek coal field of south-central Wyoming (Dobbin and others, 1929; Blackstone, 1975). In the Rock Springs uplift of Wyoming, Roehler (1977) estimated nearly 6 billion short tons of coal in the Almond Formation in beds greater than 0.8 m thick under less than 915 m of overburden. A few thick coal beds, between 1.5 and 3.0 m thick, also occur in the Lance Formation in this area (Glass, 1981). In central and northern Wyoming, in the Wind River (L9ma) and Bighorn basins (L10ma) (fig. 2), thick coals of Maastrichtian age are present in the Meeteetse Formation and thin coal beds occur in the Lance Formation (Hewett, 1926; Keefer and Troyer, 1964; Glass, 1981).

The majority of the coal in east-central Alberta is in the Horseshoe Canyon Formation. Two open pit mines were operational in the region (as of 1989), producing in excess of 1.5 million t (metric tons) annually from the Horseshoe Canyon coals for electric power generation (Dawson and others, 1989). The distribution and thickness of coal in this area were taken from maps in McCabe and others (1986). In southwesternmost Alberta and a little to the north, the thick coal is in the St. Mary River Formation (Jerzykiewicz and Sweet, 1988; Douglas, 1950; Stewart, 1919), which is the western equivalent of the Horseshoe Canyon (fig. 3). In the central foothills of Alberta (L8ma) there is thin coal in the upper part of the fluvial Brazeau Formation, and in the Cutbank River area (fig. 2) there is thick and thin coal of probable Maastrichtian age in the middle part of the Wapiti Formation (Dawson and Kalkreuth, 1989). The entire Wapiti Formation is a very thick sequence of coal-bearing fluvial strata that ranges in age from middle Campanian to Paleocene. Both the precise stratigraphic position of the coals and their age are admittedly speculative, but for the purposes of this report we have assigned the coals in the middle part of the Wapiti to the Maastrichtian and those in the lower part to the Campanian II.

Presentation of paleodrainages on the paleogeographic map of the Maastrichtian (fig. 23) is not practical in parts of the area that were greatly affected by Laramide deformation because of the multiple drainage directions away from local uplifts into intermontane basins. Also, in this area, most of the paleocurrent data are from the Lance Formation. These data, therefore, only represent the latter part of the time interval—a time when the shoreline was at extremely variable

Figure 21 (overleaf). Isopach map of Maastrichtian rocks spanning about 6.5 m.y. during the biochrons of *Baculites reesidei* through *Triceratops*. Thickness in hundreds of meters. Contour interval varies, therefore all isopachous lines are labeled. Hachures, area of local thinning. Dashed line, inferred "zero isopach line," which approximates western edge of Upper Cretaceous outcrops (modified from McGookey and others (1972, their fig. 22)). Shaded circle, basin summary location plotted with "ma" identifier in figures 5 and 23.


120°
110°
100°
90°
0
500 KILOMETERS
50°
40°
30°
CANADA
UNITED STATES
UNITED STATES
MEXICO
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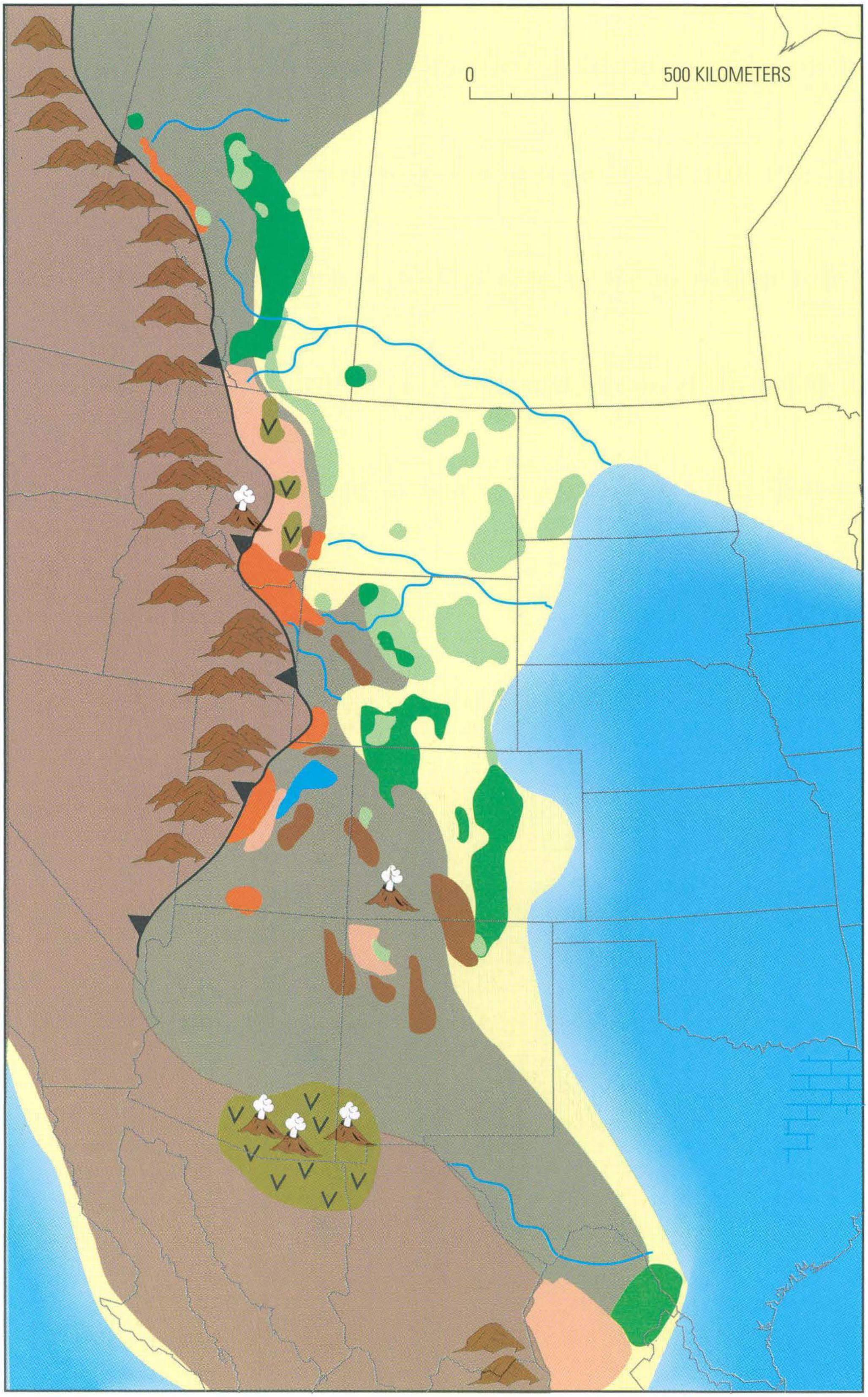

Figure 22 (above and overleaf). Paleogeographic reconstruction during Maastrichtian. See next page for complete caption, and explanation.

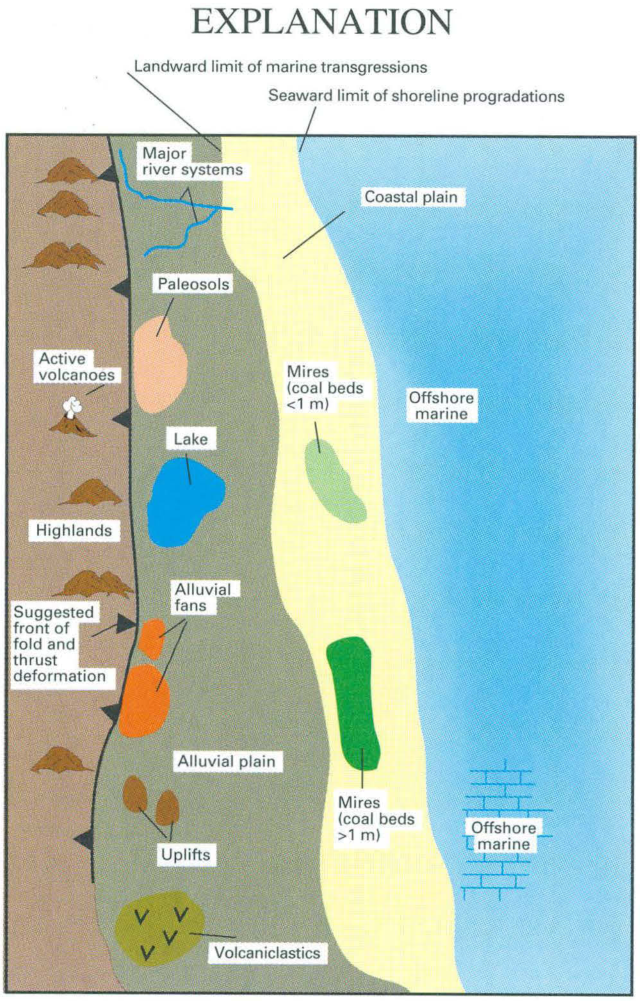

Figure 22—Continued. Paleogeographic reconstruction spanning about 6.5 m.y. during the Maastrichtian biochrons of *Baculites reesidei* through *Triceratops* (72–65.5 Ma). Sawteeth on upper plate of deformation front. Figure 23 gives details and references used to determine shoreline positions and extent of coal deposits. Figure 7 gives more detailed explanation of map features.

distances and orientations from the source areas. Sparse paleocurrent data in the Rock Springs uplift area from the Lance Formation suggest a flow direction to the south (Shuster, 1986). On the northeastern side of the Wind River Range, data indicate that rivers initially flowed east toward the Lewis sea but were later diverted northward in the subsiding basin axis (Gillespie and Fox, 1991). Crossbedding orientations in the Lance on the western flank of the Bighorn basin indicate northeasterly flow (Lindsey, 1972). Farther to the east, Lance rivers flowed easterly to southeasterly (Connor, 1992; Dodge and Powell, 1975). In the Trans-Pecos area of Texas, paleocurrent data from the Javelina and correlative El Picacho Formation show a predominant southeastward sediment transport direction (Lehman, 1986). A northeast to southeast orientation of directional sedimentary structures was recorded in fluvial channels of the St. Mary River, upper Brazeau, and lower Willow Creek Formations in west-central Alberta (Jerzykiewicz and Labonté, 1991). Our interpretation of the paleodrainage in this area is taken from Jerzykiewicz (1992).

The Maastrichtian has more extensive redbeds than do the previous stages. Redbeds in the Difunta Group in northern Mexico (Imlay, 1944; McBride and others, 1974) and in the Kirtland Shale in northwestern New Mexico (Lehman, 1985b) are interpreted as paleosols. Jerzykiewicz and Sweet (1988) described the lower part of the Willow Creek Formation in southwestern Alberta as a caliche-bearing interval (semiarid fluvial facies) that correlates with an interval (semiarid to humid facies) in the lower part of the Coalspur Formation in west-central Alberta. The different type of paleoclimatic indicators in the two areas may serve as an example of the climatic diversity south to north along the basin (Jerzykiewicz and Sweet, 1988). Other units that are possible paleosol deposits include (1) the Billman Creek Formation of Montana, consisting of grayish-green and grayish-red calcareous mudstone (Roberts, 1972; Skipp and McGrew, 1972); (2) the St. Mary River Formation and Willow Creek Formation, undifferentiated, of Montana (Viele and Harris, 1965) containing sequences of shaly redbeds, some of which reach a thickness of 60 m; and (3) the North Horn Formation of central Utah, which contains pedogenic limestone nodules and redbeds (Fouch and others, 1983; T.D. Fouch, oral commun., 1992). Fresh-water limestones also occur in the North Horn Formation, indicating the presence of lakes (Franczyk and Pitman, 1991; Fouch and others, 1983).

Deposition of conglomerates of the Canaan Peak Formation probably continued from the late Campanian into the Maastrichtian in southern Utah (Schmitt and others, 1991), along with those of the upper part of the Beaverhead

Figure 23 (facing page). Reference map of Maastrichtian paleogeography. Bold line, maximum landward extent of seaway; dotted line, maximum seaward extent of shoreline progradation during the time interval. Dashed line, intermediate shoreline position (shown in fig. 22) at about early late Maastrichtian (see item 4, Table A). Number in shaded circle, item in accompanying Table A. Faunal zones that represent all or part of a shoreline position and references used to determine the shoreline position are listed in Table A. Open circle, basin summary location (M5ma, L3ma), data for which are in the appendix. Other numbers, locations with data on coal deposits, corresponding to items listed in Table B. The coal-bearing formations and references used to compile the coal data are listed in Table B.

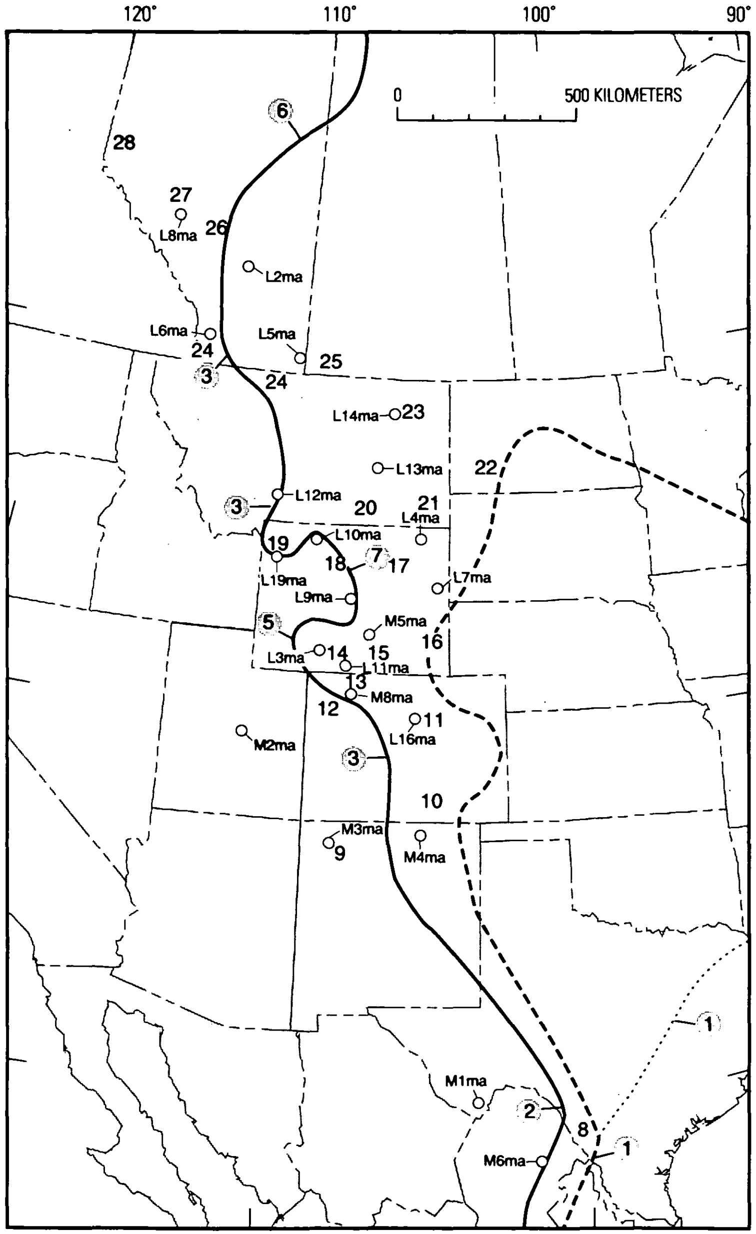

Table A

Map ref.	Faunal zones representing shorelines	Comments	References (table 1)
1	~*Triceratops*	maximum regressive Escondido Fm shoreline	531, 746, 805
2	~*Baculites reesidei*	Olmos Fm shorelines	512, 746, 780
3	*B. reesidei*		438
4	*Sphenodiscus/ Discoscaphites roanensis*	extrapolated between two zones	438
5	*B. grandis*	Lewis Shale embayment	392, 438
6	~*B. reesidei*	extrapolated from maximum Bearpaw transgression and basin summaries L2ma and L6ma	528
7	*B. eliasi/jenseni*	maximum Lewis/Bearpaw transgression	402, 403, 438

Table B

Map ref.	Formation	Member	Coal (basin summary in appendix)	References (table 1)
8	Olmos		thick M6ma	431, 677
9	Kirtland	upper shale	none/thin M3ma	426
10	Vermejo		thick M4ma	139
11	Laramie		thick L16ma	421, 684, 686
12	Hunter Canyon/ Williams Fork	/Paonia Shale	none/thick L16ma	562, 640
13	Williams Fork	upper part	thick	685, 697
14	Almond/Lance		thick L3ma, L11ma	392, 406, 682
15	Medicine Bow/Almond		thick M5ma	407
16	Lance		thin	685, 699
17	Lance		thin L4ma, L7ma	400, 642
18	Meeteetse/Lance		thick/none L10ma	402, 630, 707, 708
19	Harebell		thin L19ma	611
20	Lance		thin	648
21	Lance		thin L13ma	690, 691, 802
22	Lance/Hell Creek		thin/none	688, 801
23	Lance/Hell Creek		thin/none L14ma	413, 689, 691
24	St. Mary River		thin/thick	396, 397, 666, 864
25	Bearpaw Shale		thick L5ma	395
26	Horseshoe Canyon		thick L2ma	388, 700
27	Brazeau		thin L8ma	397
28	Wapiti		thick	397

Group in southwestern Montana (Nichols and others, 1985). The Sevier orogenic belt in central and north-central Utah was a major sediment source for conglomeratic deposits of the lower part of the North Horn Formation during the Maastrichtian (Fouch and others, 1983; Lawton and Trexler, 1991). Coarse clastics of the Hams Fork Conglomerate Member of the Evanston Formation (age determined in Jacobson and Nichols, 1982) were deposited in proximal braided streams and distal gravelly rivers in northeastern Utah and southwestern Wyoming (Salat and Steidtmann, 1991). In the Jackson Hole area (fig. 2), the Bobcat Member of the Harebell Formation consists of more than 900 m of quartz roundstone conglomerate and becomes less conglomeratic southward (Lindsey, 1972). The lower member of the Fort Union Formation in the Livingston area, southwestern Montana, contains conglomerate composed of clasts suggesting a source area from an incipient Bridger Range to the northwest (Roberts, 1972). Numerous conglomeratic units ("piedmont lithosome" of Lehman (1987)) occur adjacent to local uplifts in the central Rocky Mountain area east of the thrust belt. The Entrance Conglomerate Member of the Coalspur Formation in western Alberta is interpreted as the distal facies of an alluvial fan system (McLean and Jerzykiewicz, 1978).

Volcanic activity diminished in southwestern Montana; however, minor sporadic explosive volcanism is recorded in the vitric tuffs and bentonites in the Billman Creek and Hoppers Formations of west-central Montana (Skipp and McGrew, 1972). Toward the end of Maastrichtian time, volcanic eruptive centers emerged in southwestern Colorado, as evidenced by volcanic flows, breccias, tuffs and associated conglomerates of the Cimarron Ridge Formation (Keith, 1978; Lehman, 1987). Also in the late Maastrichtian, extensive plutonism and associated volcanic eruptions took place along a belt extending from southern Arizona to New Mexico. This volcanic center was the source area for thick volumes of andesitic volcanics, rhyodacite welded tuffs, and clastics of the Salero Formation and its numerous equivalents in southeastern Arizona and southwestern New Mexico (Hayes, 1970; Drewes, 1981). A summary of late Maastrichtian volcanic units in this area is presented in Lehman (1987).

SUMMARY

The accumulation and preservation of Upper Cretaceous peats and associated sediments were affected by the complex interaction of foreland basin tectonics, eustatic changes in sea level, and climate. The majority of peat accumulated north of paleolatitude 35° N. in areas considered to have had a temperate to subtropical climate. Although the climate was suitable for peat accumulation throughout the Late Cretaceous, the resulting coals are not equally distributed over the study area. The style of peat accumulation evolved during the Late Cretaceous.

The Western Interior seaway was rising during Cenomanian to middle Turonian time (Haq and others, 1987; Kauffman, 1984). The Sevier-style deformation along the orogenic front provided moderately thick accumulation of sediments (a maximum of 1,070 m in 5 m.y.) in small isolated basins located adjacent to the mountains in northern Utah, southwestern Montana, and east-central British Columbia. Peat accumulated during the early Cenomanian in fluvial settings far inland from the encroaching shoreline; then the accumulation shifted to coastal plain settings during the latter part of the Cenomanian and early Turonian, as the sea advanced into the subsiding foreland basin. Shoreface and associated coastal plain deposits were more readily preserved in the active foreland than on the eastern side of the seaway where accommodation space was minimal.

From late Turonian until well into the Maastrichtian, shoreline positions fluctuated asynchronously, but ultimately migrated eastward as the Western Interior sea slowly retreated. Sevier-style deformation prevailed, contributing sediment from the west to the evolving foreland basin. In the central part of the region, the small, isolated basins of Cenomanian and Turonian time coalesced into a broad, asymmetric basin that gradually expanded and migrated to the east and southeast away from the orogenic front by the end of the Campanian. From Coniacian through to late Maastrichtian time, peat formed predominantly in coastal plain environments. Favorable environments for peat accumulation expanded southward to Texas during the early part of the Campanian, although not so favorable as to form thick coals. In the later part of the Campanian, peat-forming environments expanded northward to central Alberta and Saskatchewan. Coincident with the initiation of peat development in southwestern Canada in the late Campanian was an increase in rates of sediment accumulation in the Canadian portion of the foreland basin.

During the late Maastrichtian, the change from Sevier-style deformation to Laramide-style deformation in the United States and the relatively rapid waning of the epeiric sea caused dramatic changes to the overall paleogeography and basin configuration. Uplifts and intermontane basins formed in the central part of the region, creating internal drainage patterns. The peat-forming environments that previously had been relatively continuous along the margin of the seaway became isolated. Areas of very rapid subsidence were centralized in northwestern and southeastern Wyoming (2,948 m in 6.5 m.y.), southwestern Alberta, and northern Mexico.

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APPENDIX

The Appendix contains 123 basin summaries. The map locations where information was obtained for the summaries are shown in figure 5 and general locations with basin summary identifier are listed by age in table 2. The summaries provide the "ground truth" for the isopach maps and for compiling the paleogeographic maps. A sample basin summary that describes information given in each category is provided on the following page. Where a reference is cited and figure, table, or page numbers are given in parentheses, the numbers refer to those of the cited reference. A few gaps exist in the numbering of the basin summaries because the summaries presented here are part of a larger data base.

SAMPLE BASIN SUMMARY

Point Id: **L1ce** - Basin summary identifier. The suffix ce = Cenomanian; tu = Turonian; co = Coniacian-Santonian; Lc = Campanian I; ca = Campanian II; ma = Maastrichtian

Study interval: One of the six study intervals of the Late Cretaceous:

Maastrichtian	72 - 65.5 m.y.
Campanian II	79 - 72 m.y.
Campanian I	83.5 - 79 m.y.
Coniacian-Santonian	88.5 - 83.5 m.y.
Turonian	93.5 - 88.5 m.y.
Cenomanian	98.5 - 93.5 m.y.

Location: Brief description of location of basin summary. Includes nearby geographic location and approximate latitude (N) and longitude (W).

Type of data: Data in basin summaries were taken from measured sections or well logs or a composite of both.

Data:

Thickness of study interval	**= 929 m**	- Thickness of strata in study interval at this location
Cumulative thickness of coal beds	**= 5.4 m**	- Includes only coal beds at least 1 m thick
Average coal bed thickness	**= 1.3 m**	- Average thickness of coal beds at least 1 m thick
Maximum coal bed thickness	**= 1.4 m**	- Maximum only if coal bed is at least 1 m thick
Number of coal beds	**= 4**	- Number of coal beds that are at least 1 m thick
Percent of interval that is coal	**= 0.6**	- Cumulative thickness of coal beds divided by thickness of study interval, × 100
Coal beds < 1 m thick	**7.2 m in 27 beds**	- Cumulative thickness and number of coal beds less than 1 m thick; "Yes"= thin coal beds exist, but exact thicknesses are not known

Comments: Information such as facies changes or lateral thickness variation or supplemental coal data.

Age: Brief explanation of how the base and top of the interval were picked (resulting in a thickness of the interval). Information on fossil occurrences in the interval and local and regional correlations of units. When reading this section, the reader is also referred to the biostratigraphic chart (pl. 1).

Stratigraphy: Information on thickness of formations represented in the interval, in ascending order from oldest to youngest. References are listed for the information on thicknesses and coals.

Depositional environments: This note describes the general environments in which the sediments were deposited.

Cenomanian basin summaries

Point Id: L2ce
Study interval: Cenomanian
Location: Pine River area, east-central British Columbia; lat 55°27', long 121°
Type of data: well log
Data:

Thickness of study interval	=	991 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		Yes

Comments: Exact thickness of coal in the Dunvegan Formation at this locality could not be determined from well cuttings, but in general, only thin coal occurs in the Dunvegan Formation.

Age: We arbitrarily pick the base of the Cenomanian 465 m below the top of the Shaftesbury Formation, because: Stott (1982, fig. 5) showed the upper 80 percent of the 581-m-thick Shaftesbury Formation to be above the base of the *Neogastroplites cornutus* zone; the Shaftesbury contains *N. cornutus* at several localities along the outcrop about 90 km to the north; and the lower beds of the Shaftesbury contain the Albian foraminifer *Haplophragmoides gigas* (Stott, 1982, p. 21, 22). The top of the interval is picked at the top of the Sunkay Member of Kaskapau Formation because it contains *Dunveganoceras* and the overlying Vimy Member contains Turonian index fossils *Watinoceras coloradoense* and *Inoceramus labiatus* (Stott, 1967, p. 21, 24).

Stratigraphy: Thickness data are from Phillips Puggins No. 1 well (Stott, 1967, p. 112, and Stott, 1968, p. 254–255).

Smoky Group (part):		
Kaskapau Formation (part):		
Sunkay Member	=	241 m
Dunvegan Formation	=	285 m
Fort St. John Group (part):		
Shaftesbury Formation (part)	=	465 m

Depositional environments: The Shaftesbury is marine with an unconformity at the base. The Dunvegan Formation is alluvial and deltaic to piedmont alluvial (Stott, 1982, p. 72). The Sunkay Member was deposited in a nearshore marine environment (Stott, 1967, p. 21).

Point Id: L3ce
Study interval: Cenomanian
Location: Carthage, central New Mexico; T. 55 S., R. 2 E.; lat 33°53', long 106°45'
Type of data: outcrop
Data:

Thickness of study interval	=	97 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the Cenomanian interval is picked at the base of the Dakota Sandstone (it unconformably overlies Jurassic rocks). The Cenomanian-Turonian boundary is picked in the middle of the 12-m-thick Bridge Creek Limestone Beds that yield *Mytiloides mytiloides* and *Mammites nodosoides* (Turonian) at the top and *Sciponoceras gracile* (Cenomanian) at the base.

Stratigraphy: Thicknesses were measured from Hook and others (1983, sec. 59, sheet 1, part B).

Bridge Creek Limestone Beds (lower half)	=	6 m
Mancos Shale (lower part)	=	66 m
Dakota Sandstone	=	25 m

Depositional environments: From Hook and others (1983, sheet 1). The Mancos Shale and Bridge Creek Limestone Beds are marine. The lower 20 m of the Dakota Sandstone is nonmarine and the upper 5 m is nearshore marine.

Point Id: L4ce
Study interval: Cenomanian
Location: Upper Nutria area, west-central New Mexico; T. 12 N., R. 16 W.; lat 35°15', long 108°33'
Type of data: outcrop
Data:

Thickness of study interval	=	73 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the Cenomanian is picked at the base of the Dakota Sandstone (it unconformably overlies Jurassic rocks). The Cenomanian-Turonian boundary is picked halfway between the 12-m-thick interval of the Bridge Creek Limestone Beds that yielded *Mytiloides mytiloides* and *Mammites nodosoides* (Turonian) at the top and *Sciponoceras gracile* (Cenomanian) at the base.

Stratigraphy: Thicknesses were measured from Hook and others (1983, sec. 32B sheet 1, part A).

Bridge Creek Limestone Beds (lower half)	=	6 m
Mancos Shale (lower part)	=	7 m
Twowells Tongue of Dakota Sandstone	=	2 m
Whitewater Arroyo Tongue of Mancos Shale	=	35 m
Dakota Sandstone	=	23 m

Depositional environments: Taken from sheet 1 (Hook and others, 1983). The Dakota Sandstone is nonmarine; the Twowells Tongue of the Dakota is nearshore marine; and the Mancos Shale (including the Whitewater Arroyo Tongue) and Bridge Creek Limestone Beds are marine.

Point Id: L5ce
Study interval: Cenomanian
Location: Sun River Canyon, northwestern Montana; T. 22 N., Rs. 8, 9 W.; lat 47°37'30", long 112°40'
Type of data: outcrop (composite)
Data:

Thickness of study interval	=	161 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked at the base of the Vaughn Member of the Blackleaf Formation because the underlying Taft Hill Member contains the Albian *Inoceramus comancheanus* at its top (Mudge, 1972, p. 59). The top of the interval is picked, for convenience, at the top of the Floweree Member of the Marias River Shale because the Turonian ammonite *Watinoceras reesidei* was collected only 0.6 m above the base of the overlying Cone Member (Mudge, 1972, p. 68, 124).

Stratigraphy: The thickness values are from Mudge (1972). There is an unconformity at the top of the Vaughn Member. The thickness of the Vaughn is from a location 15 km west-northwest of where the thickness of the Marias River Shale was measured.

Marias River Shale:		
Cone Member		
Floweree Member	=	9 m
Blackleaf Formation:		
Vaughn Member	≈	152 m

Depositional environments: The Vaughn Member of the Blackleaf Formation is nonmarine and contains volcanic ash beds (porcellanite) and tuffaceous debris in the upper part; the Marias River Shale is marine.

Point Id: L6ce
Study interval: Cenomanian
Location: Southwestern Wyoming, near Kemmerer; T. 20 N., R. 116 W.; lat 41°42', long 110°32'
Type of data: outcrop
Data:

Thickness of study interval	=	635 m
Cumulative thickness of coal beds	=	2.6 m
Average coal bed thickness	=	1.3 m
Maximum coal bed thickness	=	1.4 m
Number of coal beds	=	2
Percent of interval that is coal	=	2
Coal beds < 1 m thick		5.6 m in 14 beds

Comments: There is a coal bed 4.8 m thick, 26 km north of this data point location (M'Gonigle, 1992).

Age: The Albian-Cenomanian boundary is picked at the base of the Aspen Shale, which contains numerous Cenomanian index fossils of *Neogastroplites cornutus* and *N. americanus* in southwestern Wyoming (Reeside and Cobban, 1960). The underlying Bear River Formation was correlated with the Shell Creek Shale from the type area in the Big Horn basin (Ryer and others, 1987, p. 180), which has Albian *Neogastroplites haasi* near its top (Eicher, 1962, p. 83). The Cenomanian-Turonian boundary is picked at the base of the Coalville Member of the Frontier Formation. The Coalville Member is correlated southwestward to Coalville, Utah, where it contains the Turonian inoceramid *Mytiloides opalensis*.

Stratigraphy: Thickness and coal data are from M'Gonigle (1992).

Frontier Formation:		
Chalk Creek Member	=	417 m
Aspen Shale	=	218 m

Depositional environments: The lower part interfingers with the marine Aspen Shale several kilometers to the south. The Chalk Creek Member is mostly nonmarine and contains the coal.

Point Id: L7ce
Study interval: Cenomanian
Location: Southeastern Saskatchewan; 1-5-35-8W2; lat 52°, long 103°06'
Type of data: outcrop and well log
Data:

Thickness of study interval	=	68 m
Cumulative thickness of coal beds	=	0

Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The Albian-Cenomanian boundary is picked at the base of the Westgate Member of the Ashville Formation (top of Newcastle Sandstone Member). The Westgate is the "homotaxial equivalent" of the Mowry Shale of the Western Interior United States and it corresponds to foraminifer zone of *Milliamina manitobensis*. The underlying Newcastle Sandstone Member correlates with the Muddy Sandstone and corresponds with the Albian foraminifer zone *Haplophragmoides gigas* (McNeil and Caldwell, 1981, p. 88). The Cenomanian-Turonian boundary is picked 6 m above the base of the Keld Member of the Favel Formation. The Cenomanian bivalve *Inoceramus pictus,* which is suggestive of the *Sciponoceras gracile* zone, was found in the lower 6 m; and the Turonian bivalve *Mytiloides labiatus* was found above that horizon (McNeil and Caldwell, 1981, p. 53). The underlying Belle Fourche Member of the Ashville Formation is in the zone of the Cenomanian foraminifer *Verneuilinoides perplexus.*

Stratigraphy: The thicknesses were measured from a well log (McNeil and Caldwell, 1981, text fig. 22).

Favel Formation (part):		
Keld Member (part)	=	6 m
Ashville Formation (part):		
Belle Fourche Member	=	26 m
Westgate Member	=	36 m

Depositional environments: All the units are marine.

Point Id: L10ce
Study interval: Cenomanian
Location: Conant Creek, southern Wind River basin, Wyoming; T. 33 N., R. 94 W.; lat 42°51', long 108°
Type of data: outcrop
Data:

Thickness of study interval	=	333 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: A coal bed 1.3 m thick occurs in the upper part of the Frontier Formation about 65 km to the west, but it is uncertain whether this part of the Frontier is Cenomanian or Turonian.

Age: The base of the Cenomanian is picked at the base of the Mowry Shale, because *Neogastroplites cornutus* was collected 69 m above the base of the Mowry (Reeside and Cobban, 1960, p. 22, 49) 48 km due east of Conant Creek. The top of the Cenomanian is picked at the top of beds that contain the mid-Cenomanian ammonite *Plesiacanthoceras wyomingense,* which occur 170 m above the base of the Frontier Formation. The mid-Turonian ammonite *Prionocyclus hyatti* occurs 22 m above *P. wyomingense.* No fossils were found in the interval between the two ammonites, so at least eight ammonite zones are represented in this 22-m interval. Cobban and Reeside (1952, p. 1952) suggested that the interval above the bed containing *P. wyomingense* is most likely Turonian age.

Stratigraphy: Thickness data are from Love and others (1947, p. 45–47). The Mowry overlies 3 m of the Muddy Sandstone Member of the Thermopolis Shale.

Frontier Formation (part)	=	170 m
Mowry Shale	=	163 m

Depositional environments: From Keefer (1972, p. 21). The Mowry Shale is marine. The Frontier Formation is marine and nearshore marine.

Point Id: L11ce
Study interval: Cenomanian
Location: Eastern Pioneer Mountains, southwestern Montana; T. 5 S., R. 8 W.; lat 45°24', long 112°47'
Type of data: outcrop
Data:

Thickness of study interval	=	884 m (minimum)
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked at the base of the Vaughn Member of the Blackleaf Formation, which correlates with the base of the Mowry Shale to the east (Dyman and others, 1989, p. 105). The base of the Mowry contains *Neogastroplites cornutus* at many localities (Reeside and Cobban, 1960, p. 11). Geochronometric dates reported for the top of the Vaughn Member of the Blackleaf Formation in southwestern Montana are 95 Ma (Zartman and others, 1990), which is about the age for the middle of the Cenomanian. D.J. Nichols (oral commun. via T.S. Dyman, 1990) has said that at least the lower 300 m of the overlying 2,900-m-thick Frontier

Formation in the Snowcrest Range (80 km southeast of this data point) is definitely Cenomanian, based on pollen. Also, based on pollen, the top of the Frontier in the Snowcrest Range could be Cenomanian or Turonian in age, so the Cenomanian part of the Frontier could be considerably thicker than 300 m and our thickness is a minimum value.

Stratigraphy: The thickness of the Vaughn Member is from Dyman and Tysdal (1990, pamphlet, p. 6).

Frontier Formation (part)	=	300 m
Blackleaf Formation (part):		
Vaughn Member	=	584 m

Depositional environments: Dyman and Nichols (1988, p. 25). The upper part of the Vaughn Member is composed of maroon siltstone and mudstone beds with small calcareous nodules; porcellanites and volcaniclastics were deposited on floodplains and in lakes and lagoons. The Frontier Formation is nonmarine to shallow marine.

Subsidiary data point: Ruby River, Mont.; lat 45°03', long 112° (same location as L11tu). Thickness of interval is ≈ 431 m. There is thin coal in the Frontier Formation.

Point Id: L13ce
Study interval: Cenomanian
Location: Western Black Hills uplift, Wyoming; Tps. 45, 46, 48 N., Rs. 63, 65 W.; lat 44°, long 104° 35'
Type of data: outcrop (composite)
Data:

Thickness of study interval	=	257 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: This data point is continued as L3tu.

Age: The base of the interval is picked at the base of the Mowry Shale because *Neogastroplites cornutus* is found in the lower part of the Mowry Shale on the east side of the Black Hills uplift (about 80 km east of where the section for this data point was measured). Also, the underlying Newcastle Sandstone is thought to be a facies equivalent of the Shell Creek Shale, which contains *N. haasi* in the upper part in the Big Horn basin (Eicher, 1962, p. 83). The top of the interval is picked at the base of the uppermost unit of the Greenhorn Formation ("fourth unit," terminology of Cobban, 1951), which contains abundant *Inoceramus labiatus*. The underlying "second unit" contains *Sciponoceras gracile*.

Stratigraphy: The thicknesses of the Belle Fourche and Mowry are from Robinson and others (1964); thicknesses of units in the Greenhorn Formation are averages from Cobban (1951).

Greenhorn Formation (part):		
third unit	=	5 m
second unit	=	17 m
first unit	=	57 m
Belle Fourche Shale	=	113 m
Mowry Shale	=	65 m

Depositional environments: All formations are marine; the Mowry contains bentonites throughout.

Point Id: L14ce
Study interval: Cenomanian
Location: Yellowstone Park, Wyo.; lat 44°57', long 110°39'
Type of data: outcrop
Data:

Thickness of study interval	=	183 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: This data point is continued as L10tu.

Age: The base of the study interval is picked at the base of the Mowry Shale, because *Neogastroplites haasi* was found just below the Mowry Shale about 70 km to the north (Reeside and Cobban, 1960). The top of the interval is picked 37 m above the base of the overlying Frontier Formation; the Frontier at this location is about 55 m thick. Fauna of the mid-Turonian *Collignoniceras woollgari* zone were found in the uppermost beds of the Frontier and lower to middle Cenomanian marine palynomorphs were found 19 m above the base of the Frontier—"A significant time break must therefore lie within the sequence between the *** two fossil horizons" (Tysdal and others, 1990). The undated 36-m interval is arbitrarily split in half between the Cenomanian and Turonian (18 m for each), therefore, the Cenomanian part of the Frontier is about 37 m thick (18+19=37).

Stratigraphy: Thicknesses are from Tysdal and others (1990).

Frontier Formation (part)	=	37 m
Mowry Shale	=	146 m

Depositional environments: The Mowry Shale is marine and the Frontier Formation is shoreface.

Point Id: M1ce
Study interval: Cenomanian
Location: Kanarra Mountain, Utah; Tps. 37–38 S., Rs. 11–12 W.; lat 37°32', long 113°07'
Type of data: outcrop
Data:

Thickness of study interval	=	355 m
Cumulative thickness of coal beds	=	3.1 m
Average coal bed thickness	=	3.1 m
Maximum coal bed thickness	=	3.1 m
Number of coal beds	=	1
Percent of interval that is coal	=	1
Coal beds < 1 m thick		2.3 m in 9 beds

Comments: none

Age: The base of the interval is placed at the base of the Dakota Formation. About 100 km to the east of Kanarra Mountain, the palynomorph *Nyssapollenites albertensis* of Cenomanian age is found 1 m above the base of the middle member of the Dakota (am Ende, 1991). Physical correlation of the middle member by Kauffman and others (1987) and Gustason (1989) also suggests a Cenomanian age for this member at Kanarra Mountain. The age of the lower member (15 m thick at Kanarra Mountain) is in question and could be Albian (am Ende, 1991). The top of the interval is placed at the top of the upper member (Tropic Formation of Averitt, 1962) where fossils characteristic of the *Neocardioceras juddii* zone are found in associated shoreface deposits (Kauffman and others, 1987; Gustason, 1989).

Stratigraphy: Thicknesses are from Gustason (1989) for the lower member; Kauffman and others (1987, p. 133, section 1) for the middle member; and Averitt (1962, p. 48, section 34) for the upper member. Note that Averitt (1962) referred to the Dakota as the lower part of the Tropic Formation. The coal information is from Averitt (1962, sections 29 and 34).

Dakota Formation:		
upper member	=	45 m
middle member	=	310 m
lower member	=	15 m

Depositional environments: The lower and middle members are alluvial and the upper member is nearshore marine and coastal plain (Gustason, 1989). At this locality, most of the coal is in a marginal marine setting. However, 20–50 km to the east, coal as much as 5.5 m thick occurs in the base of the nonmarine section (Cashion, 1961).

Point Id: M2ce
Study interval: Cenomanian
Location: Coalville, Utah; lat 40°58', long 111°23'
Type of data: outcrop
Data:

Thickness of study interval	=	1,070 m (minimum)
Cumulative thickness of coal beds	=	2.2 m
Average coal bed thickness	=	1.1 m
Maximum coal bed thickness	=	1.2 m
Number of coal beds	=	2
Percent of interval that is coal	=	0.2
Coal beds < 1 m thick		thin stringers

Comments: none

Age: The base of the interval is picked, for convenience, at the base of the Longwall Sandstone Member of the Frontier Formation because the Longwall Member is equivalent to the Aspen Shale at Rockport, Utah, which contains *Neogastroplites cornutus* (Ryer, 1976). Some unknown thickness of the underlying Kelvin Formation is Cenomanian in age as it contains *Inoceramus dunveganensis* in the uppermost beds (Ryer, 1976). The top of the study interval is picked arbitrarily at the base of the Coalville, because it contains *Mytiloides opalensis,* a lower Turonian guide fossil (Ryer, 1976).

Stratigraphy: Thickness data are from Ryer (1976, text fig. 5). Coal data are from Wegemann (1915) locality G.

Frontier Formation:		
Coalville Member (Turonian)		
Chalk Creek Member	=	960 m
Spring Canyon Member	=	90 m
Longwall Sandstone Member	=	20 m
Kelvin Formation (Albian-Cenomanian)		

Depositional environments: From Ryer (1976). The Longwall Sandstone Member is nearshore marine (it marks a locality of the pinchout of the Aspen Shale); the Spring Canyon is marginal marine with coal; and the Chalk Creek is nonmarine with variegated beds and calcareous cements (possibly caliches).

Point Id: M3ce
Study interval: Cenomanian
Location: Bryan County, Okla.; lat 34°, long 96°22'
Type of data: well log/outcrop
Data:

Thickness of study interval	=	218 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		0.8 m in 3 beds

Comments: none

Age: The Albian/Cenomanian boundary is in the basal 1.5 m of the Grayson Formation near Waco, Tex., 270 km to the south based on the presence of *Rotalipora evoluta* (Pessagno, 1969). The basal part of the Grayson Formation also contains *Mariella brazoensis* indicating an Albian age (Mancini, 1979). In Oklahoma *M. brazoensis* is found in the lowest 2 m of the Grayson (Huffman and others, 1978) and this is included in the Albian. The Cenomanian-Turonian boundary is located within the Eagle Ford Group, specifically within the Britton Formation. Pessagno (1969) noted that all but the upper 1 to 4 m of the Britton Formation contains foraminifers assignable to the *R. cushmani-greenhornensis* subzone indicating a Cenomanian age. The upper part of the Britton contains foraminifers assignable to *Praeglobotruncana (Marginotruncana) helvetica,* which indicates a missing foraminifer subzone and an unconformity in the upper Britton. This boundary is confirmed by Kennedy (1988), who found an assemblage including *Sciponoceras gracile* in the upper Britton in Dallas County, Tex., and a missing ammonite zone above. The upper boundary is projected into drill hole 5 of Surles (1987), for convenience, to the top of the Britton.

Stratigraphy: Thickness data for Grayson and Woodbine Formations are from Huffman and others (1978); for Eagle Ford from Surles (1987) drill hole 5 located about 20 km south of Bryan County, Okla.

Eagle Ford Group:		
Britton Formation	=	70 m
Tarrant Formation	=	15 m
Woodbine Formation:		
Templeton Member	=	21 m
Lewisville Member	=	35 m
Red Branch Member	=	21 m
Dexter Member	=	51 m
Grayson Formation (part)	=	5 m

Depositional environments: The Grayson Formation is marine. The Dexter, the Red Branch, and the Lewisville Members (except for the lowest 10 m), are fluvial sandstone units; there are varicolored shales in the upper part of the Dexter Member. Coal occurs in the Red Branch Member, which is alluvial plain. The Tarrant Formation and the Templeton Member of the Woodbine are marine. The Britton Formation is marine and contains thin limestones and a large number of bentonites, one of which is probably the "X" bentonite (Kennedy and Cobban, 1990, p. 80).

Point Id: M4ce
Study interval: Cenomanian
Location: Ellsworth and Russell Counties, Kans.; lat 38°30', long 99°
Type of data: outcrop
Data:

Thickness of study interval	=	101 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		1.1 m in 5 beds

Comments: none

Age: The Albian-Cenomanian boundary is probably at the base of or within the Terra Cotta Clay Member of the Dakota Formation. The *Inoceramus comancheanus* and *I. bellvuensis* zones are present in the underlying Kiowa Shale (Scott, 1970). We place the boundary at the basal Terra Cotta unconformity but the boundary may be within the member. The top of the study interval is picked 4 m above the base of the Hartland Shale Member of the Greenhorn Limestone at the top of the LS7 marker bed of Elder (1989) based on his regional study of the Cenomanian-Turonian boundary, which is at the top of the *Neocardioceras juddii* zone.

Stratigraphy: Thickness of the Dakota is from Schoewe (1952); the Graneros is from Hattin (1965, locality 8); and the Hartland is from Hattin (1975b, locality 3 in Russell County) and Elder (1989).

Greenhorn Limestone (part):		
Hartland Shale Member (part)	=	4 m
Lincoln Limestone Member	=	6 m
Graneros Shale	=	10 m
Dakota Formation:		
Janssen Clay Member	=	23 m
Terra Cotta Clay Member	=	58 m

Depositional environments: The Dakota Formation is nonmarine. Red-mottled mudstones occur in the Terra Cotta Clay Member; coals occur in the Janssen Member. The "X" bentonite is identified in the upper part of the marine Graneros Shale. Members of the Greenhorn Limestone are marine.

Point Id: M5ce
Study interval: Cenomanian
Location: Rock Canyon anticline, Colorado; lat 38°20', long 104°45'
Type of data: outcrop
Data:

Thickness of study interval	=	71 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the Cenomanian is picked 3 m below the top of the Muddy Sandstone transition beds, which contain fauna normally associated with the *I. bellvuensis* zone (Gustason and Kauffman, 1985, p. 82; Kauffman and Pratt, 1985). The top of the Cenomanian is picked at the top of bed 79 of Cobban and Scott's (1972) measured section of the Bridge Creek Limestone. The underlying bed 73 contains *Sciponoceras gracile*. Bed 79 contains *Inoceramus pictus*, which ranges into the Turonian but is usually indicative of the *S. gracile* and *Neocardioceras juddii* zones of latest Cenomanian age. Bed 86, 1.5 m above bed 79, contains the Turonian bivalve *I. labiatus*.

Stratigraphy: Thicknesses from Kauffman and Pratt (1985), and Cobban and Scott (1972).

Greenhorn Limestone:		
Bridge Creek Limestone Member	=	3 m
Hartland Shale Member	=	17 m
Lincoln Limestone Member	=	12 m
Graneros Shale:		
upper shale member	=	15 m
Thatcher Limestone Member	=	1 m
lower shale member	=	23 m
Mowry Shale: Cretaceous erosion	=	0 m
Muddy Sandstone: transition beds	=	3 m

Depositional environments: The transition beds of the Muddy are offshore to lagoonal and represent the upper part of a valley fill sequence. The Mowry Shale, Graneros Shale, and Greenhorn Limestone are entirely marine.

Point Id: M9ce
Study interval: Cenomanian
Location: Big Bend, Tex.; lat 29°35', long 103°
Type of data: outcrop
Data:

Thickness of study interval	=	103 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The Albian-Cenomanian boundary is placed at the base of the Del Rio Clay based on its stratigraphic equivalence to the Grayson Formation of central Texas (see Pessagno, 1969). The Grayson contains the *Graysonites* fauna, which defines the Albian-Cenomanian boundary in the Gulf Coast (see Mancini, 1979, p. 1016), and the foraminifer *Rotalipora evoluta*, whose first occurrence is in the lowest part of the Cenomanian (Pessagno, 1969). The Cenomanian-Turonian boundary is thought to be within the Ernst Member of the Boquillas Formation (Maxwell and others, 1967). The presence of *Kanabiceras (=Euomphaloceras* Kennedy, 1988) is indicative of the *Sciponoceras gracile* zone. *Kanabiceras* generally occurs at a level about 3/5 above the base of the unit in several sections in the area. Therefore at this locality the lower 3/5 of the 52-m-thick Ernst section (3/5×52=31) is included in the Cenomanian. An unconformity is interpreted at the top of the Buda Limestone by Maxwell and others (1967).

Stratigraphy: Thickness data are from Maxwell and others (1967, Dog Canyon section #7).

Boquillas Formation (part):		
Ernst Member (part)	=	31 m
Buda Limestone	=	35 m
Del Rio Clay	=	37 m

Depositional environments: All units are fully marine.

Point Id: M10ce
Study interval: Cenomanian
Location: Coal Canyon, Black Mesa, Ariz.; lat 35°58', long 110°54'
Type of data: outcrop
Data:

Thickness of study interval	=	33 m
Cumulative thickness of coal beds	=	1.3 m
Average coal bed thickness	=	1.3 m
Maximum coal bed thickness	=	1.3 m
Number of coal beds	=	1
Percent of interval that is coal	=	4
Coal beds < 1 m thick		1.7 m in 5 beds

Comments: none

Age: The base of the interval is placed at the base of the Dakota Sandstone because Agasie (1969) found *Artiopollis indivisus* throughout the Dakota section and this palynomorph is restricted to the Cenomanian part of the *Nyssapollenites* zone (Nichols and others, 1982). About 30 km south of Coal Canyon at Blue Point, the Cenomanian-Turonian boundary is located 6 m above the base of the Mancos Shale where the boundary between the *Neocardioceras juddii* and *Pseudaspidoceras flexuosum* zones was identified (see Elder, 1991b, p. 121).

Stratigraphy: Thickness of the Dakota is from Peirce and others (1970, section 2); thickness of the Mancos is from Elder (1991b, p. 121). Coal data are from Peirce and others (1970, p. 30).

Mancos Shale (part)	=	6 m
Dakota Sandstone	=	27 m

Depositional environments: The Dakota Sandstone is alluvial in the lower part and nearshore marine and coastal plain in the upper part. The Mancos Shale is marine.

Turonian basin summaries

Point Id: L1tu
Study interval: Turonian
Location: Canon City, Colo.; lat 38°20', long 104°45'
Type of data: outcrop
Data:

Thickness of study interval	=	68 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The base of the interval is picked at the base of the *Watinoceras* Spp. biozone of Kauffman and Pratt (1985), which is 5 m below the top of the Greenhorn Formation in the Bridge Creek Limestone Member. A regional unconformity occurs at the top of the Codell Sandstone Member. A regional disconformity is found above and below the Juana Lopez Member and a few centimeters above the base of the Niobrara Formation. The top of the interval is picked at the top of the *Mytiloides fiegei* biozone of Kauffman and Pratt (1985), about 1 m above the base of the Niobrara Formation.

Stratigraphy:

Niobrara Formation (part):		
Fort Hays Limestone Member (part)	=	1 m
Carlile Shale (includes the following members):	=	62 m
Sage Breaks equivalent		
Juana Lopez		
upper member		
Codell Sandstone		
Blue Hill Shale		
Fairport Chalky Shale		
Greenhorn Formation (part):		
Bridge Creek Limestone Member (part)	=	5 m

Depositional environments: All units are marine. The Codell is a shoreface sand.

Point Id: L2tu
Study interval: Turonian
Location: Sweetgrass arch, northwestern Montana; T. 35 N., R. 1 W.; lat 48°15', long 111°45' (Cone Member measured about 100 km south, same thickness, but better exposure)
Type of data: outcrop (composite)
Data:

Thickness of study interval	=	72 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The base of the interval is picked 11 m below the top of the Cone Member of the Marias River Shale where *Mytiloides mytiloides* was found (Cobban and others, 1976, p. 44). *Sciponoceras gracile* was found 1 m below this horizon (Cobban and others, 1976, p. 44). The top is picked where *Scaphites corvensus* and *Prionocyclus* sp. were found, 61 m above the base of the Ferdig Member of the Marias River Shale.

Stratigraphy: Thicknesses are from Cobban and others (1976).

Marias River Shale (part):		
Ferdig Member (part)	=	61 m
Cone Member (part)	=	11 m

Depositional environments: Both units are marine. A disconformity lies at the base of the Ferdig Member (Cobban and others, 1976, p. 43). At the top of the interval (61 m above the base of the Ferdig Member), a 5-cm-thick conglomeratic sandstone contains polished chert and quartz pebbles. It is possibly equivalent to the conglomerate unit in the Cardium ("Bighorn") Formation of southwestern Alberta (Cobban and others, 1976, p. 45, 46).

Point Id: L3tu
Study interval: Turonian
Location: Western Black Hills uplift, Wyoming; Tps. 45, 46 N., Rs. 61, 63 W.; lat 43°53', long 104°15'
Type of data: outcrop
Data:

Thickness of study interval	=	95 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: This data point is continued from L13ce and is continued as L3co.

Age: The base of the interval is picked at the base of the uppermost unit ("fourth unit," terminology of Cobban, 1951, p. 2185) of the Greenhorn Formation, which contains abundant *Inoceramus labiatus* (see L13ce). The top is picked 6 m above the base of the Sage Breaks Member of the Carlile Shale.

Turonian-age *I. perplexus* was found 14 m below the top of the underlying Turner Sandy Member (Robinson and others, 1964, p. 72), and Coniacian-age *I. deformis* was found 24 m above the base of the Sage Breaks Member (Robinson and others, 1964, p. 73). We divide the undated interval (38 m) in half, which makes the lower 6 m of the Sage Breaks Turonian in age, and the remaining 32 m Coniacian (see L3co). This is not unreasonable, because about 130 km north of this area, the Turonian-age ammonite *Scaphites corvensis* is found 6 m above the base of the Sage Breaks Member (Robinson and others, 1964, p. 69).

Stratigraphy: Thickness of Turonian part of Greenhorn Formation is from Cobban (1951); thicknesses of members of the Carlile Shale are from Robinson and others (1964, p. 72, 73).

Carlile Shale (part):		
Sage Breaks Member (part)	=	6 m
Turner Sandy Member	=	46 m
unnamed lower member	=	27 m
Greenhorn Formation (part)		
upper part	=	16 m

Depositional environments: The Greenhorn Formation and the Carlile Shale are marine.

Point Id: L4tu
Study interval: Turonian
Location: Near Rawlins, Wyo.; T. 21 N., R. 86 W.; lat 41°48', long 107°06'
Type of data: outcrop
Data:

Thickness of study interval	=	108 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked at the base of the unnamed member of the Frontier Formation (terminology of Merewether and Cobban, 1972) because *Prionocyclus hyatti* is found in this unit and *Dunveganoceras pondi*, a middle-upper Cenomanian ammonite, was found 15 m below the base of the unnamed member (Merewether and Cobban, 1972, p. D60). There is a major unconformity at the base of the unnamed member (Merewether and Cobban, 1986, p. 447). The top of the interval is picked at the top of the Wall Creek Sandstone Member of the Frontier Formation because the Coniacian-age *Inoceramus erectus* was found 20 m above the base of the overlying Cody Shale (Cobban and Reeside, 1952, p. 1943; Merewether and Cobban, 1986, p. 447), and *Scaphites corvensis* and other uppermost Turonian fossils were found at the top of the Wall Creek Sandstone Member (Merewether and Cobban, 1972, p. D59, D60). There is an unconformity within and another at the base of the Wall Creek Member.

Stratigraphy: The thicknesses were taken from the description of the Sinclair section (Cobban and Reeside, 1952, p. 1942–1943, units 46–28). A graphic representation of the section appears in Merewether and Cobban (1972) as measured section 6, fig. 2, p. D60.

Frontier Formation:		
Wall Creek Sandstone Member	=	100 m
unnamed member	=	8 m

Depositional environments: The Frontier Formation is marine shale and shoreface sandstone.

Point Id: L5tu
Study interval: Turonian
Location: Emery, Utah; T. 23 S., R. 6 E.; lat 38°52', long 111°15'
Type of data: outcrop
Data:

Thickness of study interval	=	343 m
Cumulative thickness of coal beds	=	6.7 m
Average coal bed thickness	=	1.7 m
Maximum coal bed thickness	=	2.5 m
Number of coal beds	=	4
Percent of interval that is coal	=	2
Coal beds < 1 m thick		2.3 m in 6 beds

Comments: A maximum coal bed thickness nearby is 7.6 m (Ryer, 1981b, p. 4).

Age: The base of the interval is picked at the base of the Mancos Shale (Tununk Shale Member), because *Mytiloides mytiloides* was found 4 m above the base of the Tununk and the upper part of the underlying Dakota Formation contains a diverse fauna assigned to the uppermost Cenomanian *Neocardioceras juddii* zone (Eaton and others, 1990, p. 42). The top of the interval is picked at the top of the Ferron Sandstone Member because an inoceramid sp. "possibly****Inoceramus waltersdorfensis*" was found at the base of the overlying Blue Gate Shale Member of the Mancos Shale (Ryer, 1981b, p. 32) and *Scaphites preventricosus* was found 30 m above the top of the Ferron Member, 15 km southwest of this data point (Cobban, 1976, p. 124).

Stratigraphy: Thickness of the Tununk Member is from Ryer and McPhillips (1983, p. 259, drill hole in T. 22 S., R. 6 E.); coal and thickness data from the Ferron Member are from Lupton (1916, p. 32–33).

Mancos Shale (lower part):

Ferron Sandstone Member	=	145 m
Tununk Shale Member	=	198 m

Depositional environments: The Tununk Shale Member is marine; the Ferron Sandstone Member consists of deltaic, shoreface and coastal plain deposits and contains coal.

Point Id: L6tu
Study interval: Turonian
Location: Kemmerer, Wyo.; Tps. 17, 19, 20 N., R. 116 W.; lat 41°40', long 110°30'
Type of data: outcrop
Data:

Thickness of study interval	≈	241 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	0.9 m in 1 bed	

Comments: none
Age: The base of the interval is picked at the base of the Coalville Member of the Frontier Formation, because the Coalville Member can be correlated southwestward to Coalville, Utah, where it contains *Mytiloides opalensis* (Ryer, 1976, see M2ce). The top of the interval is picked near the top of the Dry Hollow Member of the Frontier Formation at the top of the lowest coal bed, which yielded three guide species of Turonian age including a fern spore *Appendicisporites auritus* (Nichols and Jacobson, 1982a, p. 76). The coal bed 4 m higher contains the Coniacian palynomorph *Chatangiella* sp. cf. *C. victoriensis* (D.J. Nichols, written commun., 1981).
Stratigraphy: Average thickness of members from M'Gonigle (1992); coal thickness data from M'Gonigle (1980).

Frontier Formation (upper part):

Dry Hollow Member of Hale (1960) (part)	≈	96 m
Oyster Ridge Sandstone Member	≈	30 m
Allen Hollow Member of Hale (1960)	≈	85 m
Coalville Member of Hale (1960)	≈	30 m

Depositional environments: The Coalville Member is brackish to marine; the Allen Hollow is marine shale, but sandy toward the top; the Oyster Ridge Sandstone Member is nearshore marine; and the Dry Hollow Member is marine to coastal plain and contains coal.

Point Id: L7tu
Study interval: Turonian
Location: Conant Creek, southern Wind River basin, Wyoming; T. 33 N., R. 94 W.; lat 42°51', long 108°
Type of data: outcrop
Data:

Thickness of study interval	=	92 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: This point is a continuation of L10ce.
Age: The base of the interval is picked 107 m below the top of the Frontier Formation at the top of beds that contain mid-Cenomanian fossils indicative of the *Plesiacanthoceras wyomingense* zone. Fossils indicative of the mid-Turonian *Prionocyclus hyatti* zone were found 22 m above the *P. wyomingense* zone. The undated strata between these two fossil horizons are most likely Turonian (Cobban and Reeside, 1952, p. 1952). The top of the interval is picked 15 m below the top of the Frontier Formation at the horizon where faunas associated with the zone of *Scaphites preventricosus* were found (Keefer, 1972, pl. 2 and table 2).
Stratigraphy: Thickness between fossil-bearing horizons in the Frontier Formation is from Keefer (1972, measured from pl. 2, Conant Creek section).

Frontier Formation (part)	=	92 m

Depositional environments: The Frontier Formation is composed of marine shale and shoreface sandstone.

Point Id: L8tu
Study interval: Turonian
Location: Puertecito, central-west New Mexico; Tps. 2, 3 N., Rs. 5, 6 W.; lat 34°30', long 107°30'
Type of data: outcrop
Data:

Thickness of study interval	=	193 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: Coal is found in the Carthage Member of Tres Hermanos Formation, 65 km to the northwest.

Age: The base of the interval is picked 55 m below the top of the Rio Salado Tongue of the Mancos Shale. Cenomanian *Sciponoceras gracile* was found 62 m below the top and Turonian *Mytiloides mytiloides* was found 48 m below the top. We arbitrarily assign half of the undated strata (14 m) to the Turonian and half to the Cenomanian. The top of the interval is picked at the top of the E sandstone of the Gallup Sandstone. Beds at the top of the E sandstone yield the Coniacian bivalve *Inoceramus erectus* and beds only 2 m below yield the Turonian ammonite *Prionocyclus novimexicanus* (Hook and others, 1983).

Stratigraphy: Thickness data and position of fossil horizons are from Hook and others (1983, measured section 58A, Sheet 1).

Gallup Sandstone (part):		
E sandstone	=	18 m
Mancos Shale (part):		
D-Cross Tongue	=	45 m
Tres Hermanos Formation:		
Fite Ranch Sandstone Member	=	15 m
Carthage Member	=	40 m
Atarque Sandstone Member	=	20 m
Mancos Shale (part):		
Rio Salado Tongue (part)	=	55 m

Depositional environments: The Rio Salado Tongue is marine; the Atarque is nearshore marine; the Carthage is nonmarine coastal- or delta-plain; the Fite Ranch is nearshore marine; the D-Cross Tongue is marine; and the Gallup Sandstone is nearshore marine.

Point Id: L9tu
Study interval: Turonian
Location: Northern San Juan Basin, N. Mex.; T. 27 N., R. 2 E.; lat 36°35', long 106°45'
Type of data: outcrop
Data:

Thickness of study interval	=	134 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The base of the study interval is picked at the base of the Greenhorn Limestone Member (terminology of Landis and Dane, 1967) of the Mancos Shale, which contains *Inoceramus labiatus* (Landis and Dane, 1967, pamphlet, p. 5). The underlying Graneros Shale Member (terminology of Landis and Dane, 1967) contains the Cenomanian ammonite *Sciponoceras gracile* (Landis and Dane, 1967, pamphlet, p. 5). The top of the study interval is picked at the top of the unnamed shale member of the Mancos Shale (terminology of King, 1974), 8 m below which, *Scaphites* aff. *S. ferronensis* was found. Although the species is unidentified, W.A. Cobban (written commun. in King, 1974, p. 261) stated that it is late Carlile (late Turonian) in age. *Volviceramus involutus,* which is associated with the Coniacian zones of *Scaphites preventricosus* and *S. ventricosus* (Kauffman and others, 1976), was found 24 m above the base of the overlying Cooper Arroyo Sandstone Member (King, 1974, fig. 2). An unconformity may exist at the base of the Cooper Arroyo Sandstone Member.

Stratigraphy: Thicknesses of Mancos Shale units are averages from Landis and Dane (1967).

Mancos Shale (lower part):		
Cooper Arroyo Sandstone Member (Coniacian)		
unnamed shale member	=	27 m
Juana Lopez Member	=	33 m
lower shale unit	=	58 m
Greenhorn (Bridge Creek) Limestone Member	=	16 m
Graneros Shale Member (Cenomanian)		

Depositional environments: The Mancos Shale is entirely marine.

Point Id: L10tu
Study interval: Turonian
Location: Yellowstone Park, Wyo.; lat 44°57', long 110°39'
Type of data: outcrop
Data:

Thickness of study interval	=	18 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The Turonian interval is entirely within the Frontier Formation and is estimated to be about 18 m thick. The Frontier Formation yielded fauna of the mid-Turonian *Collignoniceras woollgari* zone in the uppermost bed and 36 m lower there are lower to middle Cenomanian marine palynomorphs (Tysdal and others, 1990, pamphlet, p. 3–4). A significant hiatus must exist between the two fossil horizons. We arbitrarily split the undated strata in half, placing 18 m in the Turonian interval and 18 m in the Cenomanian (see subsidiary data point on L11ce). Overlying the Frontier Formation is the Cody Shale, which contains middle Coniacian *Inoceramus deformis* at the base (Merewether and Cobban, 1986, p. 449), so there is an unconformity at the top of the interval as well.

Stratigraphy: The thickness of the Frontier Formation between fossil horizons is from Tysdal and others (1990, Mount Everts section).

Frontier Formation (upper part) = 18 m

Depositional environments: The Frontier Formation consists of shoreface and offshore (prodelta) deposits (Tysdal and others, 1990, pamphlet, p. 2).

Point Id: L11tu
Study interval: Turonian
Location: Ruby River, southwest Montana; lat 45°03', long 112°
Type of data: outcrop
Data:

Thickness of study interval	=	668 m
Cumulative thickness of coal beds	=	2.9 m
Average coal bed thickness	=	1.4 m
Maximum coal bed thickness	=	1.7 m
Number of coal beds	=	2
Percent of interval that is coal	=	0.4
Coal beds < 1 m thick	6.1 m in 7 beds	

Comments: none

Age: The base of the study interval is picked arbitrarily 216 m above the base of the 668-m-thick Frontier Formation. The top of the underlying Mowry Shale correlates with the top of the Vaughn Member of Blackleaf Formation in southwest Montana. Geochronologic dates reported for the top of the Vaughn in southwest Montana are 95 Ma (Zartman and others, 1990), about middle Cenomanian. So, the 216-m-thick Mowry (Tysdal and others, 1990, pamphlet, p. 6; Hadley, 1980, p. 77) was deposited during the early half of the Cenomanian; to account for deposition during the late half, we arbitrarily assigned an equal thickness of the overlying Frontier to the Cenomanian. This is not unreasonable, considering that D.J. Nichols (Tysdal and others, 1990) stated that at least the lower 300 m of the Frontier Formation, 40 km to the southwest of Ruby River, is definitely Cenomanian based on palynology. The top of the study interval is picked at the top of the Frontier Formation based loosely on a correlation of the top of the Frontier 110 km to the southeast in Yellowstone Park, Wyo., where the overlying Cody Shale yielded Coniacian fossils indicative of the *Inoceramus deformis* zone (Merewether and Cobban, 1986). No Cody Shale is present at Ruby River due to truncation by a thrust fault. Twenty-five kilometers southwest of Ruby River, the Frontier is overlain unconformably by the Upper Cretaceous and lower Tertiary(?) Beaverhead Group (Tysdal and others, 1990, pamphlet, p. 6). At Ruby River, 668 m of the Frontier Formation is Turonian in age (884–216=668).

Stratigraphy:

Frontier Formation (upper part) = 668 m

Depositional environments: The lower units of the Turonian part of the Frontier Formation consist of estuarine and backswamp deposits of a delta plain and contain coals; the upper part is nonmarine to brackish; and the uppermost beds are coastal plain (Tysdal and others, 1990).

Point Id: L12tu
Study interval: Turonian
Location: Northeastern Black Mesa, Ariz.; lat 36°23', long 109°54'
Type of data: outcrop
Data:

Thickness of study interval	=	214 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	0.9 m in 2 beds	

Comments: A maximum thickness of coal in the middle carbonaceous member, in the vicinity, is 3.4 m (Franczyk, 1988).

Age: The base of the study interval is picked 14 m above the base of the Mancos Shale (at the base of bed BM 13, Lohali Point section, of Kirkland, 1991) at the first occurrence of a new species of *Mytiloides* and other fossils that are characteristic of the *Pseudaspidoceras flexuosum* zone (Kirkland, 1991, p. 92). The top of the study interval is picked at the top of the middle carbonaceous member of the Toreva Formation. Overlying this unit is an unconformity that is interpreted to be late Turonian in age, based on regional sequence stratigraphic correlations (Shanley, 1991, fig. 18, p. 108).

Stratigraphy: Data on the Mancos Shale are from Kirkland (1991, section measured at Lohali Point); data on the Toreva Formation and coal data are from Franczyk (1988, section measured at Needle, pl. 1).

Toreva Formation:		
middle carbonaceous member	=	27 m
lower sandstone member	=	1 m
Mancos Shale:		
upper shale	=	84 m
Hopi Sandy Member	=	21 m
middle shale	=	43 m
lower shale	=	38 m

Depositional environments: The Mancos Shale is marine; the lower sandstone member is nearshore marine, deltaic, and contains thin coal; the middle carbonaceous member of the Toreva Formation is coastal plain and contains thin to thick coal.

Point Id: L13tu
Study interval: Turonian
Location: Mosby, central Montana; T. 14 N., R. 31 E.; lat 46°55', long 107°55'
Type of data: outcrop
Data:

Thickness of study interval	=	94 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This section is continued as L10co.

Age: The base of the interval is picked at the base of the Carlile Shale because a bed 2 m above the base yields *Collignoniceras woollgari* and *Inoceramus labiatus* (Cobban, 1953b, p. 46). The underlying Mosby Sandstone Member of the Greenhorn Formation contains Cenomanian age *Dunveganoceras albertense* (Cobban, 1953b, p. 46). We pick the top of the study interval at the top of the Carlile Shale, because the basal beds of the overlying Niobrara Formation contain the Coniacian index fossils *Scaphites preventricosus* and *Inoceramus deformis* (Cobban, 1953a, p. 99–100).

Stratigraphy: The thicknesses and stratigraphic position of the fossils are from Johnson and Smith (1964). A graphic representation of this same section is shown as data location 34 in Rice (1976, pl. 3).

Carlile Shale	=	94 m

Depositional environments: The Carlile Shale is marine.

Point Id: L14tu
Study interval: Turonian
Location: Kaiparowits Plateau, southern Utah; Tps. 42, 43 S., Rs. 3, 4 E.; lat 37°06', long 111°35'
Type of data: outcrop
Data:

Thickness of study interval	=	248 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		0.5 m in 1 bed

Comments: This section is continued as L11co.

Age: We pick the base of the study interval 12 m above the base of the Tropic Shale (Elder, 1991b, p. 127) based on the appearance of *Mytiloides* n. sp. (*M. hattini* of Elder, 1991a). The top of the interval is picked at the top of the barren zone in the Smoky Hollow Member of the Straight Cliffs Formation (terminology of Peterson, 1969a). Overlying this unit is an unconformity that is interpreted to be late Turonian in age, based on regional sequence stratigraphic correlations (Shanley, 1991, fig. 19, p. 108).

Stratigraphy: The thickness and stratigraphic position of fossils of the Tropic Shale are from Peterson (1969b, p. 40); data on the Tibbet Canyon and the Smoky Hollow Members of the Straight Cliffs Formation are from Peterson (1969a, p. J25–J26).

Straight Cliffs Formation (part):		
Smoky Hollow Member:		
Calico bed (unconformity at base)		
barren zone	=	26 m
coal zone	=	4 m
Tibbet Canyon Member	=	32 m
Tropic Shale (all but lower 12 m)	=	186 m

Depositional environments: The Tropic Shale is marine and lower shoreface; the Tibbet Canyon Member is shoreface and shallow water marine; the Smoky Hollow Member is coastal plain.

Point Id: L15tu
Study interval: Turonian
Location: Central Kansas; T. 11 S., R. 16 W. (upper part) and T. 13 S., R. 12 W. (lower part); lat 39°, long 98°50'
Type of data: outcrop, composite section
Data:

Thickness of study interval	=	107 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the study interval is picked 3 m below the top of the Hartland Shale Member of the Greenhorn Limestone where *Mytiloides* n. sp. A (*M. hattini* of Elder, 1991a) first appears above the disappearance of *Sciponoceras gracile* (Elder, 1989, fig. 10, p. 308). Marker beds, identified by both Hattin and Elder, were used to determine the thickness of the interval below the top of the Hartland Member (thus HL-4 of Hattin equals bentonite bed C of Elder, see Elder, 1989, fig. 4, p. 302). The top of the interval is picked at the top of the Codell Sandstone Member of the Carlile Shale because *Prionocyclus wyomingensis* was found at the top of the Carlile Shale (Juana Lopez Member), 200 km to the west (Hattin, 1975a, p. 208, fig. 5). Hattin (1975a) showed an unconformity at the Carlile/Niobrara contact that expands progressively from westernmost Kansas to northeastern Nebraska. At the data point location the overlying Fort Hays Limestone Member of the Niobrara Chalk contains *Inoceramus deformis* and lies unconformably on the Codell Sandstone Member.

Stratigraphy: Greenhorn Limestone data from Hattin (1975b, measured section 3, Bunker Hill); Carlile Shale data from Hattin (1962, measured sections, 25 and 26).

Carlile Shale:		
Juana Lopez Member (missing)		
Codell Sandstone Member (unconformity at top)	=	9 m
Blue Hill Shale Member	=	56 m
Fairport Member	=	27 m
Greenhorn Limestone:		
Pfeifer Shale Member	=	6 m
Jetmore Chalk Member	=	6 m
Hartland Shale Member (part)	=	3 m

Depositional environments: The Greenhorn Limestone and Carlile Shale are marine.

Point Id: L16tu
Study interval: Turonian
Location: Dallas, Tex.; lat 32°45', long 96°45'
Type of data: outcrop
Data:

Thickness of study interval	=	43 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the Kamp Ranch Limestone Member defines the base of the Arcadia Park Formation and the top of the underlying Britton Formation. The base of the study interval is picked 3 m below the Kamp Ranch Limestone Member at an unconformity in the upper Britton Formation; Cenomanian *Sciponoceras gracile* zone faunal elements were found 0.3 m below the unconformity, and Turonian *Pseudaspidoceras flexuosum* zone faunal elements were found immediately above it (Kennedy, 1988, p. 12). The top of the interval is picked at the top of the Arcadia Park Formation, where *Prionocyclus* cf. *macombi* Meek was found, suggesting that the top of the formation just extends into the base of the *P. macombi* zone (Kennedy, 1988, p. 13). An unconformity lies at the base of the overlying Atco Member of the Austin Chalk, which contains "*Inoceramus* of Coniacian aspect" (Kennedy, 1988, p. 14). All or the greater part of *P. macombi, P. wyomingense, Scaphites whitfieldi,* and *P. quadratus* zones are missing.

Stratigraphy: Thickness data are from Kennedy (1988, p. 11, fig. 4).

Eagle Ford Group:		
Arcadia Park Formation	=	40 m
Britton Formation (uppermost part)	=	3 m

Depositional environments: Both formations are marine.

Point Id: L17tu
Study interval: Turonian
Location: Austin, Tex.; lat 30°20', long 97°45'
Type of data: outcrop
Data:

Thickness of study interval	=	7 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This data point is continued as L12co.

Age: The base of the interval is picked at the base of the South Bosque Formation, which unconformably overlies the upper Cenomanian Lake Waco Formation. The Lake Waco Formation was assigned by Pessagno (1969, p. 63–64) to the *Rotalipora cushmani - greenhornensis* subzone (equivalent to *R. cushmani* on Cenomanian part of biostratigraphic chart). The top of the interval is picked at the top of the Eagle Ford Group; at the top of the Eagle Ford condensed zone, where present, which contains reworked fauna of the *Prionocyclus hyatti* zone; or the top of the South Bosque Formation, which contains *Mytiloides submytiloides* in the top 5 m (Kennedy, 1988, p. 17). The overlying Austin Chalk (base of Atco Member) contains "fragmentary *Inoceramus* of Coniacian aspect" (Kennedy, 1988, p. 17).

Stratigraphy: Thickness of the South Bosque Formation is from Pessagno (1969, pl. 8, section measured at Bouldin Creek).

Eagle Ford Group (part):		
South Bosque Formation	=	7 m

Depositional environments: The South Bosque Formation is marine chalk and marl.

Point Id: L18tu
Study interval: Turonian
Location: Big Bend, Tex.; lat 29°11', long 103°
Type of data: outcrop
Data:

Thickness of study interval	=	57 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0

Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This data point is continued from M9ce.

Age: The Cenomanian-Turonian boundary is thought to be within the Ernst Member of the Boquillas Formation (Maxwell and others, 1967). The presence of *Kanabiceras* (=*Euomphaloceras* Kennedy, 1988) is indicative of the *Sciponoceras gracile* zone. The presence of *Inoceramus* (=*Mytiloides*) *labiatus* indicates a Turonian age for some of the Ernst Member; unfortunately, Maxwell reported this fossil throughout the unit but did not show the positions stratigraphically. *Kanabiceras* generally occurs at a level about 3/5 above the base of the unit in several sections in the area. Therefore, the upper 2/5 of the 143-m-thick Ernst at this locality is here considered Turonian in age (2/5×143=57 m). Also specimens of the Turonian ammonite *Coilopoceras* occur at the top of the Ernst Member. An unconformity lies at the base of the overlying San Vincente Member. The San Vincente is thought to be Coniacian in age (Maxwell and others, 1967, p. 65, 70).

Stratigraphy: Thickness data are from Maxwell and others (1967, section measured at Hot Springs 2, no. 21, pl. VII).

Boquillas Formation (part):		
Ernst Member (part)	=	57 m

Depositional environments: The Ernst Member is marine limestone, siltstone, and calcareous clay.

Point Id: L19tu
Study interval: Turonian
Location: Central foothills, Alberta; lat 52°, long 116°
Type of data: outcrop
Data:

Thickness of study interval	=	313 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked for convenience at the base of the Vimy Member of the Blackstone Formation because *Watinoceras reesidei* and *Inoceramus labiatus* were found just 8 m above the base (Stott, 1963, p. 44, 253). The underlying Sunkay Member contains Cenomanian *Dunveganoceras* fauna throughout the Alberta foothills. The top of the interval is placed at the top of the Cardinal Member of the Cardium Formation, because the overlying Sturrock Member is "known to be within the *Scaphites preventricosus* zone" in the area 190 km to the south (Stott, 1963, p. 62).

Stratigraphy: Thickness data are from Stott's (1963) section 5-45.

Cardium Formation (part):		
Cardinal Member	=	7 m
Kiska Member	=	11 m
Ram Member	=	31 m
Blackstone Formation (part):		
Opabin Member	=	51 m
Haven Member	=	76 m
Vimy Member	=	137 m

Depositional environments: All units are marine; sandy units of the Ram Member are nearshore marine (Stott, 1963, p. 147–153).

Point Id: L20tu
Study interval: Turonian
Location: Crowsnest Pass–Waterton area, southern Alberta; lat 49°15', long 114°
Type of data: outcrop
Data:

Thickness of study interval	=	133 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This point is continued as L15co.

Age: The base of the interval is picked at the base of the Vimy Member of the Blackstone Formation, which contains *Watinoceras coloradoense* and *Inoceramus labiatus*. Also, the underlying Sunkay Member, 30 km to the northwest, has yielded the upper Cenomanian index fossil *Dunveganoceras*. The top of the interval is picked 31 m above the base of the 47-m-thick Cardium Formation, below where *Scaphites preventricosus* was found (Stott, 1963, p. 76, 290).

Stratigraphy: Thickness data are from Wall and Rosene (1977, p. 852).

Cardium Formation (part)	=	31 m
Blackstone Formation (part):		
Opabin Member	=	31 m
Haven Member	=	10 m
Vimy Member	=	61 m

Depositional environments: The Blackstone Formation is marine. The Cardium Formation is marine sandstone and intercalated shale.

Point Id: L21tu
Study interval: Turonian
Location: East-central British Columbia; lat 55°08', long 120°20'
Type of data: well log
Data:

Thickness of study interval	=	627 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: This interval thins to 193 m, 125 km due east of this location.

Age: The base of the interval is picked at the base of the Vimy Member of the Blackstone Formation. The Vimy Member contains *Watinoceras coloradoense* and *Inoceramus labiatus* (Stott, 1967, fig. 5 and p. 25). The top of the interval is placed at the top of the Moosehound Member of the Cardium Formation, because the overlying basal beds of the Muskiki Formation contain the lower Coniacian ammonite *Scaphites preventricosus* (Stott, 1967, p. 37, 41).

Stratigraphy: Thickness data from Can. Southern Kelly Lake No.1 well (Stott, 1967, fig. 8).

Cardium Formation:		
Moosehound Member	=	14 m
Ram Member	=	24 m
Blackstone Formation (part):		
Opabin Member	=	110 m
Haven Member	=	167 m
Vimy Member	=	312 m

Depositional environments: The Blackstone Formation is marine. The Ram Member of the Cardium Formation is nearshore marine. The Moosehound Member is coastal plain (lagoonal and marsh). There are thin coals in the Moosehound Member, 150 km to the southeast in Alberta.

Point Id: M1tu
Study interval: Turonian
Location: Dutch John, Utah; T. 3 N., R. 22 E.; lat 40°58', long 109°25'
Type of data: outcrop and well data
Data:

Thickness of study interval	=	76 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	0.6 m in 1 bed	

Comments: This data point is continued as M1co.

Age: The base of the interval is picked at the unconformity between the Frontier Formation and the underlying Mowry Shale. The lower shale of the Frontier contains *Prionocyclus hyatti* 55 km to east. The top of the interval is picked 24 m above the base of the Hilliard Shale. The Turonian-age *Prionocyclus novimexicanus* was found 4 m above the base of the Hilliard Shale near Dutch John (Merewether and others, 1984). About 130 km north in bore hole 2 of Merewether and others (1984, their fig. 1), the early Coniacian-age *Scaphites uintensis,* indicative of the *Inoceramus deformis* zone (Kennedy and Cobban, 1991a), was found about 10 m above the base of the Hilliard Shale. This fossil horizon is about the same distance above the base of the Hilliard Shale as the datum shown in the nearby bore hole 3 (Merewether and others, 1984, their fig. 5). The same datum is also present about 44 m above the base of the Hilliard in bore hole 23, near Dutch John (Merewether and others, 1984, their fig. 3). Therefore, the top of the Turonian interval is picked arbitrarily halfway between this datum and the horizon yielding *Prionocyclus novimexicanus*, thus 24 m above the base of the Hilliard Shale.

Stratigraphy: The thickness of the Frontier Formation is from Hansen (1965, p. 94). The stratigraphic nomenclature of the Frontier is that of Merewether and others (1984).

Hilliard (Baxter) Shale (part)	=	24 m
Frontier Formation:		
2nd sandstone	=	34 m
lower shale (unconformity at the base)	=	18 m
Mowry Shale		

Depositional environments: The lower shale is marine to nearshore marine and contains thin discontinuous coal and the 2nd Frontier sandstone is nearshore marine; the Hilliard (Baxter) Shale is marine.

Point Id: M2tu
Study interval: Turonian
Location: Riding Mountain, Manitoba; lat 50°40', long 99°59'
Type of data: well log
Data:

Thickness of study interval	=	44 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: The interval is 86 m thick in hole 80 at Turtle Mountain 175 km to the south. This point is continued as M2co.

Age: The lower boundary is picked within the Favel Formation. All but the lower 6 m of the Keld Member at the holostratotype (Vermillion River, 45 km to the north) contains *Mytiloides labiatus*, which is indicative of the lower to middle Turonian, and the lowest beds in the Keld contain *Inoceramus pictus*, which is suggestive of the Cenomanian *Sciponoceras gracile* zone. The upper boundary is picked at the contact between the Morden Shale and the overlying Niobrara Formation. Possible remains of the upper Turonian and lower Coniacian index fossil *Scaphites corvensis* were found in the lower part of the Niobrara Formation (McNeil and Caldwell, 1981, p. 100–101).

Stratigraphy: Thickness data are from well log 7 (McNeil and Caldwell, 1981, fig. 21).

Niobrara Formation		
Morden Shale	=	20 m
Favel Formation:		
Assiniboine Member	=	11 m
Keld Member (part)	=	13 m

Depositional environments: All units are marine.

Point Id: M3tu
Study interval: Turonian
Location: Coalville, Utah; lat 40°58', long 111°23'
Type of data: composite outcrop
Data:

Thickness of study interval	=	660 m
Cumulative thickness of coal beds	=	3.7 m
Average coal bed thickness	=	3.7 m
Maximum coal bed thickness	=	3.7 m
Number of coal beds	=	1
Percent of interval that is coal	=	0.6
Coal beds < 1 m thick	3 m in 3 beds	

Comments: This point is continued as M5co.

Age: The base of the Turonian is arbitrarily picked at the base of the Coalville Member of the Frontier Formation, because the Coalville contains *Mytiloides opalensis*, a lower Turonian guide fossil (Ryer, 1976). The top of the interval is placed 60 m below the top of the Dry Hollow Member of the Frontier Formation at the base of marine sandstones that contain *Inoceramus deformis* of early middle Coniacian age (Ryer, 1976, p. 79).

Stratigraphy: Thickness data are from Ryer (1976). Coal data are from Wegemann (1915), localities C and D.

Frontier Formation (part):		
Dry Hollow Member (part)	=	325 m
Oyster Ridge Sandstone Member	=	25 m
Allen Hollow Shale Member	=	240 m
Coalville Member	=	70 m

Depositional environments: From Ryer (1976). The Coalville is nearshore marine to coastal plain and contains coals as thick as 3.7 m. The Allen Hollow Shale Member is marine. The Oyster Ridge Sandstone Member is nearshore marine. The Dry Hollow Member has an unconformity at its base and has a basal conglomerate unit; the member is mainly nonmarine and contains the Dry Hollow coal, which is as much as 2.6 m thick near the top.

Coniacian-Santonian basin summaries

Point Id: L1co
Study interval: Coniacian-Santonian
Location: Pueblo, Colo.; lat 38°20', long 104°40'
Type of data: outcrop
Data:

Thickness of study interval	=	206 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The base of the interval is picked at the base of *Inoceramus erectus*, n. subsp. biozone of Kauffman and Pratt (1985), which is 11 m below the top of the Fort Hays Limestone Member of the Niobrara Formation. The top is picked at the top of *Desmoscaphites bassleri* biozone of Kauffman and Pratt (1985), which is 195 m above the base of the Smoky Hill Shale Member of the Niobrara Formation.

Stratigraphy: Thickness data are from Scott (1969). The entire interval is within the Niobrara Formation.

Smoky Hill Shale Member (part):		
upper chalky shale unit	=	65 m
middle chalk unit	=	9 m
middle shale unit	=	86 m
lower limestone unit	=	12 m
lower shale unit	=	17 m
shale and limestone unit	=	6 m
Fort Hays Limestone Member (part)	=	11 m

Depositional environments: All units are marine.

Point Id: L2co
Study interval: Coniacian-Santonian
Location: Sweetgrass arch, northwestern Montana; Tps. 35, 32 N., R. 3 W.; lat 48°45', long 112°
Type of data: outcrop

Data:

Thickness of study interval	=	244 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The base of the interval is picked where *Scaphites corvensis* and *Prionocyclus* were found, 11 m below the top of the Ferdig Member (Cobban and others, 1976, p. 47). The top of the interval is picked 45 m above the base of the Telegraph Creek Formation where *Desmoscaphites bassleri* was found (locality 2, Cobban, 1964, p. I3, I5).

Stratigraphy: Thickness of Ferdig and Kevin Members is from Cobban and others (1976). Thickness of Telegraph Creek Formation is from Cobban (1964).

Telegraph Creek Formation (part)	=	45 m
Marias River Shale (part):		
Kevin Member	=	188 m
Ferdig Member (part)	=	11 m

Depositional environments: All units are marine. The upper part of the Ferdig Member consists mostly of concretionary limestone beds.

Point Id: L3co
Study interval: Coniacian-Santonian
Location: Western Black Hills uplift, Wyoming; T. 45 N., Rs. 62, 63 W.; lat 43°53', long 104°20'
Type of data: outcrop
Data:

Thickness of study interval	=	119 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: This data point is continued from L3tu and continued as L4Lc.

Age: The base of the interval is picked 6 m above the base of the 78-m-thick Sage Breaks Member of the Carlile Shale, because Coniacian-age *Inoceramus deformis* is present 24 m above the base of the Sage Breaks Member (Robinson and others, 1964, p. 73), and Turonian-age *I. perplexus* and *Prionocyclus wyomingensis* are found 14 m below the top of the underlying Turner Sandy Member (Robinson and others, 1964, p. 72). By splitting the undated interval (38 m) in half, 6 m of Sage Breaks is Turonian in age (see L3tu); the remaining is of Coniacian age. The top of the interval is picked at the contact of the Niobrara Formation with the overlying Pierre Shale because *Scaphites hippocrepis* var. *tenuis* Reeside (Reeside, 1927), which was later identified as *S. hippocrepis* II (Cobban, 1969, p. 18), was found about 40 m above the base of the Pierre Shale, 130 km northwest of this data point (see L4Lc). Some portion of the uppermost Niobrara Formation may be Campanian I in age (Gill and Cobban, 1966a, pl. 4).

Stratigraphy: Thickness data are from Robinson and others (1964, p. 61).

Niobrara Formation	=	47 m
Carlile Shale (part):		
Sage Breaks Member (part)	=	72 m

Depositional environments: Both formations are marine. The Sage Breaks Member is predominantly septarian limestone concretions. The Niobrara is mostly chalk with abundant bentonite layers. Phosphate nodules are present at the base of Niobrara in many places.

Point Id: L4co
Study interval: Coniacian-Santonian
Location: Near Rawlins, Wyo.; Tps. 19, 22 N., Rs. 87, 88 W.; lat 41°35', long 107°18'
Type of data: outcrop
Data:

Thickness of study interval	=	581 m (max 705 m)
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The base is of the interval is picked at the base of the Niobrara Formation, because the top of the underlying Wall Creek Sandstone Member of the Frontier Formation, 25 km to the north, contains Turonian age *S. corvensis* (Merewether and Cobban, 1972, p. D58–D60). The top is picked 197 m above the base of the Steele Shale. *Desmoscaphites bassleri* was found 73 m above the base of the Steele Shale and *Scaphites hippocrepis* I was found 321 m above the base (Smith, 1965, pl. 3). We place half of the 248 m (124 m) of the undated interval in the Santonian (73+124=197).

Stratigraphy: The thickness of the Niobrara is from Merewether (1972); the thickness of the Steele Shale is from Smith (1965, pl. 3).

Steele Shale (part)	=	197 m
Niobrara Formation	=	384 m

Depositional environments: All units are marine.

Point Id: L5co
Study interval: Coniacian-Santonian
Location: Kemmerer, Wyo.; Tps. 17, 19 N., R. 117 W.; lat 41°40', long 110°30'
Type of data: outcrop
Data:

Thickness of study interval	=	2,008 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		0.9 m in 2 beds

Comments: This data point is a continuation of L6tu.

Age: The base of interval is picked near the top of the Dry Hollow Member of the Frontier Formation at the base of the second lowest coal bed, which yielded Coniacian palynomorph *Chatangiella* sp. cf. *C. victoriensis* (D.J. Nichols, written commun., 1981). A coal bed 4 m lower contains Turonian-age palynomorph *Appendicisporites auritus* (Nichols and Jacobson, 1982a, p. 76). The top of the interval is picked at the top of the Hilliard Shale. The Hilliard Shale ranges in age from Coniacian at the base to late Santonian near the top, based on the occurrence of ammonites (W.A. Cobban, oral commun. in Nichols and Jacobson, 1982b, p. 122). The ammonites referred to here include *Baculites thomi*, which was found 336 m below the top of the Hilliard Shale about 30 km to the south (locality 33, Cobban and Kennedy, 1991, p. C4). *B. thomi* ranges from *Desmoscaphites erdmanni* to *Scaphites hippocrepis* (III), but its peak development was in the Santonian (Cobban and Kennedy, 1991, p. C5).

Stratigraphy: The thickness of the Coniacian part of the Frontier Formation and the coal data are from M'Gonigle (1980); the thickness of the Hilliard Shale is from M'Gonigle (1992).

Hilliard Shale:		
Hinshaw Member	=	180 m
main body (minimum estimate)	=	1,800 m
Frontier Formation (uppermost part):		
Dry Hollow Member (part)	=	28 m

Depositional environments: The Dry Hollow Member is marine to coastal plain and contains coal; the main body of the Hilliard Shale is marine; and the Hinshaw Member is lower shoreface.

Point Id: L6co
Study interval: Coniacian-Santonian
Location: Conant Creek, southern Wind River basin, Wyoming; T. 33 N., R. 94 W.; lat 42°51', long 108°
Type of data: outcrop
Data:

Thickness of study interval	=	915 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This point is a continuation of L7tu.

Age: The base of the interval is picked 15 m below the top of the Frontier Formation at the horizon where fauna associated with the zone of *Scaphites preventricosus* were found (Keefer, 1972, pl. 2 and table 2). The top of the interval is picked 900 m above the base of the Cody Shale at the base of a calcareous unit that contains *Scaphites hippocrepis* I (Keefer, 1972, pl. 2 and table 2).

Stratigraphy: The thicknesses for the parts of the Frontier Formation and the Cody Shale are from pl. 2, the Conant Creek section (Keefer, 1972).

Cody Shale (part)	=	900 m
Frontier Formation (uppermost part)	=	15 m

Depositional environments: The uppermost Frontier Formation is nearshore marine and the Cody Shale is marine.

Point Id: L7co
Study interval: Coniacian-Santonian
Location: Gallup, N. Mex.; T. 15 N., R. 18 W.; lat 35°30', long 108°45'
Type of data: outcrop
Data:

Thickness of study interval	=	237 m
Cumulative thickness of coal beds	=	2.1 m
Average coal bed thickness	=	1.0 m
Maximum coal bed thickness	=	1.1 m
Number of coal beds	=	2
Percent of interval that is coal	=	0.7
Coal beds < 1 m thick		5.4 m in 20 beds

Comments: Thickest coal bed reported in the vicinity is 3.3 m (Sears, 1925).

Age: The base of the interval is picked at the base of the Torrivio Member of the Gallup Sandstone. A tongue of the Crevasse Canyon Formation underlies the Torrivio and is the landward facies equivalent of the C sandstone tongue of the Gallup Sandstone (Molenaar, 1983b, fig. 14, p. 36). Latest Turonian fossils including *Prionocyclus quadratus* were found in the marine shale below the C sandstone (C.M. Molenaar, oral commun., 1993). According to C.M. Molenaar, "the Turonian-Coniacian boundary is near or at the top of the C sandstone tongue." The top of the study interval is picked arbitrarily in the middle of the "Gibson coal member of the Mesaverde formation" (terminology of Sears, 1925), which correlates northeastward to where the Point Lookout Sandstone and Hosta Tongue of the Point Lookout merge and the Satan Tongue of the Mancos pinches out (Peterson and Kirk, 1977, fig. 2). Where the Point Lookout and Hosta Tongue are separated by the Satan Tongue, the Point Lookout contains *Scaphites hippocrepis* and the Hosta Tongue contains *Texanites texanus* (Peterson and Kirk, 1977, biostratigraphic notes 16 and 17, p. 176). In the absence of the Hosta Tongue, the "Gibson coal member" of Sears (1925) is equivalent to the Gibson Coal Member of the Crevasse Canyon Formation and the Cleary Coal Member of the overlying Menefee Formation (Beaumont and others, 1956, p. 2153), undivided.

Stratigraphy: The thickness of the Torrivio Member of the Gallup Formation is from Molenaar (1983b, section 29A, Puerco Gap, table 8, p. 33). Coal data and other thicknesses are averages from Sears (1925).

Crevasse Canyon and Menefee Formations, undivided:		
Gibson and Cleary Coal Members, undivided (part)	=	27 m
Crevasse Canyon Formation:		
Bartlett Barren Member	=	111 m
Dilco Coal Member	=	82 m
Gallup Sandstone:		
Torrivio Member	=	17 m

Depositional environments: The Torrivio Member is braid-plain deposits. The Crevasse Canyon Formation is nonmarine, coastal plain, and contains thick coal.

Point Id: L8co
Study interval: Coniacian-Santonian
Location: Green River, Utah; T. 20 S., R. 14 E.; lat 39°06', long 110°20'
Type of data: outcrop
Data:

Thickness of study interval	=	440 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked 145 m above the base of the Mancos Shale, because late Turonian age fossils, including *Scaphites whitfieldi* and *S. ferronensis*, were found 145 m above the base of the Mancos (Fisher and others, 1960, table 5), and the late Coniacian age *Scaphites depressus* was found 150–180 m above the base (Molenaar and Cobban, 1991, p. 21). The top of the interval is picked 585 m above the base of the Mancos Shale, which is the highest level where *Desmoscaphites bassleri* was found.

Stratigraphy: The thickness of the Mancos Shale between fossil-bearing horizons is taken from measured section 8, pl. 10, Fisher and others (1960), and from Molenaar and Cobban (1991, p. 21).

Mancos Shale (lower part)	=	440 m

Depositional environments: The Mancos Shale is entirely marine.

Point Id: L9co
Study interval: Coniacian-Santonian
Location: Northeastern Black Mesa, Ariz.; lat 36°23', long 109°54'
Type of data: outcrop
Data:

Thickness of study interval	=	253 m
Cumulative thickness of coal beds	=	1.2 m
Average coal bed thickness	=	1.2 m
Maximum coal bed thickness	=	1.2 m
Number of coal beds	=	1
Percent of interval that is coal	=	0.5
Coal beds < 1 m thick		8.5 m in 18 beds

Comments: The maximum coal bed thickness is 2.7 m (Carr, 1987) nearby in the upper carbonaceous member of the Wepo Formation.

Age: The base of the study interval is picked at the base of the Upper Sandstone Member of the Toreva Formation. Underlying this unit is an unconformity that is interpreted to be late Turonian in age, based on regional sequence stratigraphic correlations (Shanley, 1991, fig. 18, p. 108). The top of the study interval is picked at the top of the Yale Point Sandstone, which is considered Santonian in age by recent workers based on lithostratigraphic correlations (Peterson and Kirk, 1977; Eaton and others, 1987). The top is eroded.

Stratigraphy: Thickness data on the units below the upper carbonaceous member of the Wepo Formation and associated coal data are from Franczyk (1988, measured section at Needle). Thickness data on the upper carbonaceous member of the Wepo and associated coal data (measured section 41), and data on the Yale Point Sandstone are from Carr (1987).

Yale Point Sandstone	=	91 m
Wepo Formation:		
upper carbonaceous member	=	84 m
Rough Rock Sandstone	=	26 m

Mancos Shale:		
Wind Rock Tongue	=	20 m
Wepo Formation:		
lower carbonaceous member	=	16 m
Toreva Formation:		
upper sandstone member	=	16 m

Depositional environments: The upper sandstone member of the Toreva Formation is braided-fluvial and contains thin coal; the carbonaceous members of the Wepo Formation are deltaic/alluvial plain and contain thin to thick coals; the Wind Rock Tongue of the Mancos Shale is marine; the Rough Rock Sandstone is nearshore marine; and the Yale Point Sandstone is nearshore marine.

Point Id: L10co
Study interval: Coniacian-Santonian
Location: Mosby, central Montana; T. 14 N., R. 31 E.; lat 46°55', long 107°55'
Type of data: outcrop
Data:

Thickness of study interval	=	115 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This section is continued from L13tu.

Age: We pick the base of the study interval at the base of the Niobrara Formation, because the Coniacian index fossils *Scaphites preventricosus* and *Inoceramus deformis* were found 2 m above the base (Cobban, 1953a, p. 99–100). Immediately above the Niobrara Formation, at the base of the Telegraph Creek Formation, the early Campanian age *Scaphites hippocrepis* was found. This species is assumed to be *S. hippocrepis* I, because in an exposure 35 km to the west, Cobban (1969) reported *Scaphites hippocrepis* I in the lowest sandstone unit of the Eagle Sandstone, at a stratigraphic horizon above the base of the Telegraph Creek. Therefore, we are including all the Niobrara Formation in the Coniacian-Santonian interval.

Stratigraphy: The thickness of the Niobrara is from Johnson and Smith (1964, p. 36). A graphic representation of this same section is shown as data location 34 in Rice (1976, pl. 3).

Niobrara Formation	=	115 m

Depositional environments: The Niobrara Formation is marine. Phosphatic pebbles, which mark a minor hiatus (Johnson and Smith, 1964), were found 17 m above the base of the Niobrara.

Point Id: L11co
Study interval: Coniacian-Santonian
Location: Kaiparowits Plateau, southern Utah; T. 40 S., R. 4 E.; lat 37°22', long 111°31'
Type of data: outcrop
Data:

Thickness of study interval	=	244 m
Cumulative thickness of coal beds	=	19.6 m
Average coal bed thickness	=	2.2 m
Maximum coal bed thickness	=	4.2 m
Number of coal beds	=	9
Percent of interval that is coal	=	8
Coal beds < 1 m thick		7.3 m in 18 beds

Comments: This section is continued as L9Lc.

Age: We pick the base of the study interval at the base of the Calico bed in the upper part of the Smoky Hollow Member of the Straight Cliffs Formation. Underlying the Calico is an unconformity that is interpreted to be late Turonian in age, based on regional sequence stratigraphic correlations (Shanley, 1991, fig. 18, p. 108). The top of the interval is picked at the top of the John Henry Member of the Straight Cliffs Formation. *Desmoscaphites* sp. was found in the upper mudstone tongue, a genus not reported from the Campanian, suggesting that this member is no younger than Santonian (Eaton, 1991, p. 52). Also, palynomorph data suggest that the Straight Cliffs Formation is within the *Proteacidites retusus* zone, which is Coniacian-Santonian in age (Nichols and others, 1982).

Stratigraphy: Data for this point are from Hettinger (1993); description of core from drill hole SMP-1-91.

Straight Cliffs Formation (part):		
John Henry Member	=	233 m
Smoky Hollow Member (upper part):		
Calico bed (unconformity at base)	=	11 m

Depositional environments: The Calico bed consists of braided fluvial, valley-fill deposits; the John Henry Member is mostly coastal plain and contains thick coal. To the northeast, this member is predominantly nearshore marine, and to the southwest, it is mostly fluvial and contains thin coal beds.

Point Id: L12co
Study interval: Coniacian-Santonian
Location: Austin, Tex.; lat 30°20', long 97°45'
Type of data: outcrop
Data:

Thickness of study interval	=	76 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0

Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This data point is continued from L17tu.

Age: The base of the interval is picked at the base of the Austin Group (base of formation "A," terminology of Young (1963), which is equivalent to the "Atco Member," terminology of Kennedy (1988)), which contains "fragmentary *Inoceramus* of Coniacian aspect" (Kennedy, 1988, p. 17). A condensed zone in the underlying Eagle Ford Group contains reworked fauna of the *Prionocyclus hyatti* zone. There is a questionable unconformity at the base of the Austin. The top of the interval is picked 4 m above the base of the Dessau Formation of the Austin Group at the horizon where the presence of the upper Santonian *Texanites shiloensis* overlaps with the lower Campanian *Submortoniceras tequesquitense* (Young, 1963, p. 98). Pessagno (1969) placed the Santonian/Campanian boundary higher in the section, based on planktonic foraminifers. Lillegraven (1991) reviewed the discrepancy at this boundary, and ultimately agreed with Young.

Stratigraphy: Nomenclature and thickness data are from Young (1963, p. 23).

Austin Group (part):		
Dessau Formation (lower part)	=	4 m
formation "C"	=	10 m
formation "B"	=	29 m
formation "A"	=	33 m

Depositional environments: The Austin Group is entirely marine chalk and limestone.

Point Id: L14co
Study interval: Coniacian-Santonian
Location: Big Bend, Tex.; lat 29°11', long 103°
Type of data: outcrop
Data:

Thickness of study interval	=	304 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This data point is continued from L18tu.

Age: The base of the interval is picked at the base of the San Vincente Member of the Boquillas Formation of the Terlingua Group, because Maxwell and others (1967) reported the Turonian ammonite *Coilopoceras* at the top of the underlying Ernst Member. The lower Santonian *Inoceramus (Cladoceramus) undulatoplicatus,* which is found in association with *Clioscaphites saxitonianus* (Kennedy and Cobban, 1991b), occurs at the top of the San Vincente Member. The top of the study interval is picked 91 m above the base of the overlying Pen Formation at the midpoint between the occurrence of the lower Campanian *Delawarella delawarensis* and the top of the San Vincente Member. Also, in the Dawson Creek section 50 km to the west, Maxwell and others (1967) collected fossils 91 m above the base of the Pen Formation. These fossils are part of the *Boehmoceras* fauna, which are indicative of the *Texanites shiloensis* zone (Kennedy and Cobban, 1991b). At the base of the San Vincente Member is an unconformity.

Stratigraphy: Thickness data are from the section measured at Hot Springs 2, no. 21 (Maxwell and others, 1967, pl. VII).

Terlingua Group (part):		
Pen Formation (part)	=	91 m
Boquillas Formation:		
San Vincente Member	=	213 m

Depositional environments: The San Vincente Member and the Pen Formation are entirely marine limestone and marl.

Point Id: L15co
Study interval: Coniacian-Santonian
Location: Crowsnest Pass–Waterton, southern Alberta; lat 49°15', long 114°
Type of data: outcrop
Data:

Thickness of study interval	=	545 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This point is a continuation of L20tu and continued as L15Lc.

Age: The base of the interval is picked 16 m below the top of the Cardium Formation, where *Scaphites preventricosus* was found (Stott, 1963, p. 76, 290). The top of the interval is picked at the top "transition member" of the Wapiabi Formation of Wall and Rosene (1977), which is probably equivalent to the Hanson Member of Stott (1963), which in turn lies within the *Desmoscaphites bassleri* zone (Stott, 1963; Jeletzky, 1971).

Stratigraphy: Terminology and thickness data for the Wapiabi Formation are from Wall and Rosene (1977, p. 852). Thickness for the Cardium Formation is from Stott (1963, section 6-49).

Wapiabi Formation:

transition member	=	47 m
"Hanson Member" (upper Thistle?)	=	133 m
Thistle Member	=	154 m
Dowling Member	=	90 m
Marshybank Member	=	49 m
Muskiki Member	=	56 m
Cardium Formation (part)	=	16 m

Depositional environments: The Cardium Formation and the Muskiki Member of the Wapiabi Formation are nearshore marine; all other units are marine. The transition member is considered deltaic (Wall and Rosene, 1977, p. 845).

Point Id: L16co
Study interval: Coniacian-Santonian
Location: Mistanusk Creek, east-central British Columbia; lat 54°40', long 120°10'
Type of data: outcrop
Data:

Thickness of study interval	=	326 m (minimum)
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		0.8 m in 3 beds

Comments: The interval thins to 134 m, 135 km to northeast (Stott, 1967, fig. 8) and thickens to greater than 500 m, 300 km to the southeast (Stott, 1963, fig. 17 and p. 103).

Age: Base of study interval is picked at the base of the Muskiki Formation based on the presence of *Scaphites preventricosus* and *Inoceramus deformis* in the lower 23 m (Stott, 1967, p. 40). The underlying Cardium Formation is undated in this area; however, Stott (1963, p. 62–63) suggested that the top of the Cardium is time-transgressive and is probably entirely Turonian in age at this location. The top of the interval is picked at the top of the Hanson Member of the Puskwaskau Formation, because it correlates with the Telegraph Creek Formation, which contains fauna of the upper Santonian *Desmoscaphites bassleri* zone (Stott, 1967, p. 56).

Stratigraphy: The thickness of Puskwaskau Formation and the coal data are from measured section 8–12 of Stott (1967, fig. 8). Terminology and thickness data of the Muskiki and Marshybank Formations are from Plint and others (1990, p. 82, fig. 4). A hiatus is possible between the Muskiki Formation and underlying Cardium Formation.

Puskwaskau Formation:

Hanson Member	=	35 m
Thistle Member	=	160 m
Dowling Member	=	43 m
Marshybank Formation	=	49 m
Muskiki Formation	=	39 m
Cardium Formation (Turonian)		

Depositional environments: All units are marine except the Marshybank Formation, which comprises nearshore marine and coastal plain deposits and contains thin coal.

Point Id: M1co
Study interval: Coniacian-Santonian
Location: Dutch John, Utah, T. 3 N., R. 21 E.; lat 40°59', long 109°32'
Type of data: outcrop
Data:

Thickness of study interval	=	1,512 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This data point is continued from M1tu.

Age: The base of the interval is picked 24 m above the base of the Hilliard Shale. The Turonian-age *Prionocyclus novimexicanus* was found 4 m above the base of the Hilliard Shale near Dutch John (Merewether and others, 1984). About 130 km north in a bore hole (hole 2 of Merewether and others, 1984, fig. 1), the early Coniacian-age *Scaphites uintensis,* indicative of the *Inoceramus deformis* zone (Kennedy and Cobban, 1991a), was found about 10 m above the base of the Hilliard Shale. This fossil horizon is about the same distance above the base of the Hilliard Shale as the datum shown in the nearby bore hole 3 (Merewether and others, 1984, fig. 5). The same datum is also present about 44 m above the base of the Hilliard in bore hole 23, near Dutch John (Merewether and others, 1984, fig. 3). Therefore, the top of the Turonian interval is picked arbitrarily halfway between this datum and the horizon yielding *Prionocyclus novimexicanus*, thus 24 m above the base of the Hilliard Shale. The top of the interval is placed 384 m below the top (1,536 m above the base) of the Hilliard Shale just below a bed containing *S. hippocrepis* I (Hansen, 1965; Cobban, 1969). This same interval boundary is 152 m below the top of the Baxter Shale (Hilliard equivalent, in part) on the Rock Springs uplift 50 km to the north (see data point M1Lc).

Stratigraphy: Thickness of this part of the Hilliard Shale is from Hansen (1965).

Hilliard Shale (middle part) = 1,512 m

Depositional environments: The Hilliard Shale is entirely marine.

Point Id: M2co
Study interval: Coniacian-Santonian
Location: Riding Mountain, Manitoba; lat 50°40', long 99°59'
Type of data: well log
Data:

Thickness of study interval	=	13 m (maximum)
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: The study interval is 47 m thick in hole 80 at Turtle Mountain 175 km to the south and 68 m thick in hole 14, 150 km to the southeast (McNeil and Caldwell, 1981, fig. 21). This data point is continued as M3Lc.

Age: The entire Niobrara Formation (informally divided into a lower calcareous shale member and an upper chalky member) is within the *Globigerinelloides* sp. foraminifer zone, which is as old as late Turonian and as young as early Campanian (McNeil and Caldwell, 1981). In the Vermilion River Valley on the north side of Riding Mountain, the lowest part of the Niobrara contains fossils that resemble *Scaphites corvensis* of late Turonian age, and another *Scaphites* indicative of the *S. preventricosus* zone of early Coniacian age (McNeil and Caldwell, 1981, p. 100–101). In the Pembina River Valley, about 200 km southeast of this data point, the upper part of the calcareous shale member contains probable *Baculites thomi*, which ranges from *Desmoscaphites erdmanni* zone to the *S. hippocrepis* III zone, but is most abundant in the upper Santonian (Cobban and Kennedy, 1991). We interpret the thickness of the Coniacian-Santonian interval at drill hole 7 to be no greater than the thickness of the Niobrara, which is only 13 m thick.

Stratigraphy: Thickness of the Niobrara is taken from drill hole 7, McNeil and Caldwell (1981, fig. 21).

Niobrara Formation = 13 m

Depositional environments: The Niobrara Formation is entirely marine.

Point Id: M3co
Study interval: Coniacian-Santonian
Location: Joes Valley, Utah; T. 15 N., R. 6 E.; lat 39°30', long 110°39'
Type of data: well log
Data:

Thickness of study interval	=	1,257 m
Cumulative thickness of coal beds	=	10.4 m
Average coal bed thickness	=	1.7 m
Maximum coal bed thickness	=	3.3 m
Number of coal beds	=	6
Percent of interval that is coal	=	0.8
Coal beds < 1 m thick		Probably, but they are not distinguishable on the logs.

Comments: none

Age: The base of the interval is picked at the base of the Blue Gate Member of the Mancos Shale because the inoceramid *Mytiloides dresdensis* was found at the top of the underlying Ferron Sandstone Member of the Mancos, 65 km to the south of the study area (Ryer and McPhillips, 1983) and *Scaphites preventricosus* was found 31 m above the base of the Blue Gate Member 65 km south-southwest of the area (Cobban, 1976). The top of the interval is arbitrarily picked in the middle of the 484-m-thick Masuk Member (uppermost member of the Mancos Shale), because *Baculites aquilaensis*, which has affinities with *S. hippocrepis*, is found 91 m below the top (Cobban, 1976), and *Desmoscaphites bassleri*? and *Inoceramus patootensiformis* are found in the underlying Emery Sandstone Member about 45 km to the northeast of the study area (Cobban, 1976). These correlations match those of Fouch and others (1983).

Stratigraphy: Thickness data are picked from Three States National Gas Company, Joes Valley No. 3 well.

Mancos Shale (part):

Masuk Member (part)	=	242 m
Emery Sandstone Member	=	357 m
Blue Gate Member	=	658 m

Depositional environments: The Blue Gate and Masuk Members are marine. The Emery Sandstone Member consists of nearshore marine and coal-bearing coastal plain deposits.

Point Id: M4co
Study interval: Coniacian-Santonian
Location: Livingston, Mont.; T. 2 S., Rs. 8, 9 E.; lat 45°42', long 110°42'
Type of data: outcrop

Data:

Thickness of study interval	=	622 m
Cumulative thickness of coal beds	=	1.2 m
Average coal bed thickness	=	1.2 m
Maximum coal bed thickness	=	1.2 m
Number of coal beds	=	1
Percent of interval that is coal	=	0.2
Coal beds < 1 m thick		1.9 m in 13 beds

Comments: This point is continued as M4Lc.

Age: The Cody Shale is Cenomanian to Santonian in age in this area and no diagnostic fossils of early Coniacian age are present. The base of the interval is arbitrarily placed at the base of the Eldridge Creek Member of the Cody Shale, which contains the upper Coniacian *Inoceramus involutus* and *Scaphites depressus*. Therefore, the thickness of Cody Shale included in this interval is a minimum value. The top of the interval is placed 129 m above the base of the Cokedale Formation at the top of unit 84 (Roberts, 1972, p. 81), which contains palynomorphs indicative of the *Proteacidites retusus* interval zone (paleobotany locality D1611—see Tysdal and Nichols, 1991).

Stratigraphy: Thickness data are from Roberts (1972), sections 11, 12, 14, and 16.

Cokedale Formation (part)	=	129 m
Eagle Sandstone	=	197 m
Telegraph Creek Formation	=	84 m
Cody Shale (part):		
upper shale member	=	175 m
Eldridge Creek Member	=	37 m

Depositional environments: The Cody Shale is marine; the Telegraph Creek Formation is nearshore marine; the Eagle Sandstone is nearshore marine and coastal plain; and the Cokedale contains continental volcaniclastics. Thick coal is present in the Eagle Sandstone and thin coals occur in the lower part of the Cokedale Formation.

Point Id: M5co
Study interval: Coniacian-Santonian
Location: Coalville, Utah; lat 40°58', long 111°23'
Type of data: composite outcrop
Data:

Thickness of study interval	=	2,037 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		0.7 m in 2 beds

Comments: This point is a continuation of M3tu.

Age: The base of the interval is arbitrarily placed at the base of 60 m of marine sandstones that are present at the top of the Dry Hollow Member of the Frontier Formation, because the sandstones contain *Inoceramus deformis* of early middle Coniacian age (Ryer, 1976, p. 79). The top is picked at the top of the Echo Canyon Conglomerate, which is thought to be Coniacian-Santonian in age, because it contains palynomorphs indicative of the *Proteacidites retusus* interval zone (Jacobson and Nichols, 1982).

Stratigraphy: Thickness data for Frontier and Henefer Formations are compiled from Ryer (1976). Thickness data for the Echo Canyon Conglomerate and coal thickness data are from Trexler (1966).

Echo Canyon Conglomerate	=	762 m
Henefer Formation	=	760 m
Frontier Formation (part):		
Upton Sandstone Member	=	75 m
Judd Shale Member	=	90 m
Grass Creek Member	=	290 m
Dry Hollow Member (part)	=	60 m

Depositional environments: From Ryer (1976). The Dry Hollow Member is nearshore marine to coastal plain and contains thin coal. The Grass Creek Member is nonmarine with a nearshore marine sandstone at the top. The Judd Shale Member is marine. The Upton Member is nearshore marine. The Henefer Formation is nonmarine and contains a thin coal near the base. The Echo Canyon Conglomerate is an alluvial fan deposit.

Campanian I basin summaries

Point Id: L1Lc
Study interval: Campanian I
Location: Pueblo, Colo.; lat 38°20', long 104°40'
Type of data: outcrop
Data:

Thickness of study interval	=	163 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked 12 m below the top of the upper chalky shale unit of the Smoky Hill Shale Member of the Niobrara Formation where *Scaphites hippocrepis* was found in association with *Baculites haresi* and *Haresiceras placentiforme* (Scott, 1969). This assemblage occurs in the *Scaphites hippocrepis* I and II zones (Cobban, 1964, 1969).

The top of the interval is picked 17 m above the base of the Sharon Springs Member of the Pierre Shale, where *B.* aff. *B. asperiformis* Meek was found. The upper beds of the Sharon Springs Member contain the Campanian II ammonite *B.* aff. *B. perplexus* (Cobban) (Scott, 1969).

Stratigraphy: Thickness data are from Scott (1969).

Pierre Shale (part):		
Sharon Springs Member (part)	=	17 m
Apache Creek Sandstone Member	=	61 m
transition member	=	70 m
Niobrara Formation (part):		
Smoky Hill Shale Member (part):		
upper chalk unit	=	3 m
upper chalky shale unit (part)	=	12 m

Depositional environments: All units are marine.

Point Id: L2Lc
Study interval: Campanian I
Location: Porcupine dome, east-central Montana; lat 46°38', long 106°53'
Type of data: outcrop
Data:

Thickness of study interval	=	232 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The base of the interval is picked 38 m above the base of the Gammon Shale where *Scaphites leei* III was found (Cobban, 1964, p. I3, I6, and Cobban, 1969, p. 3, 17). The Gammon Shale is about 244 m thick, based on electric logs of nearby oil and gas test wells (Gill and others, 1972, p. 97). The top of the interval is picked at the base of a unit, 26 m above the base of the Claggett Shale, that yielded *Baculites* sp. (smooth) and *B. perplexus* (early form) (Gill and others, 1972, p. 97).

Stratigraphy: Thickness data are from Gill and others (1972).

Claggett Shale (part)	=	26 m
Gammon Shale (part)	=	206 m

Depositional environments: Both units are entirely marine. The upper 20 m of the Gammon Shale contains two thin layers of chert granules and pebbles and a layer of phosphate pebbles. The Ardmore Bentonite Bed (3 m thick) is at the base of Claggett Shale.

Point Id: L3Lc
Study interval: Campanian I
Location: Rawlins, Wyo.; T. 19 N., R. 88 W.; lat 41°35', long 107°18'
Type of data: outcrop
Data:

Thickness of study interval	=	1,087 m
Total coal bed thickness	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: All information for this data point is from Gill and others (1970). This interval thickens to 1,280 m, 30 km to the northeast.

Age: The base of the interval is picked 961 m below the top of the Steele Shale. *Scaphites hippocrepis* I was found 837 m below the top of the Steele Shale, and *Desmoscaphites bassleri* was found 1,087 m below the top. We place half of the 249 m of undated section in the Campanian I (837+124=961). The top of the interval is picked in the middle of the Hatfield Sandstone Member of the Haystack Mountains Formation. *Baculites asperiformis* was found within the Hatfield Member at other nearby localities and *B. perplexus* was found above it.

Stratigraphy: Thickness data are from Gill and others (1970; Haystack Mountains Formation, p. 19–20, and Steele Shale, p. 10–11).

Haystack Mountains Formation (part):		
Hatfield Sandstone Member (part)	=	25 m
Espy Tongue of Hale (1961)	=	89 m
Deep Creek Sandstone of Hale (1961)	=	12 m
Steele Shale (part)	=	961 m

Depositional environments: Units are marine shale and shoreface sandstone.

Point Id: L4Lc
Study interval: Campanian I
Location: Western Black Hills uplift, Wyoming; lat 43°45', long 104°10'
Type of data: outcrop
Data:

Thickness of study interval	=	235 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: At Redbird, Wyo., 55 km to the south, the Campanian I interval is 97 m thick (Gill and Cobban, 1966a, pl. 2). This data point is continued from L3co.

Age: The base of the interval is picked at the contact between the Niobrara Formation and the overlying Mitten Black Shale Member of the Pierre Shale. At a location 130 km northwest, the Mitten Black Shale Member is underlain by the Gammon Ferruginous Member, which contains *Scaphites hippocrepis* var. *tenuis* Reeside and *S. aquilaensis* var. *nanus* (Reeside, 1927) (later identified as *S. hippocrepis* II and I, respectively, Cobban, 1969). However, the Gammon is missing at this data point. Some minor portion of the Niobrara Formation may be in the zone of *Scaphites hippocrepis* (Gill and Cobban, 1966a, pl. 4). The top of the interval is picked 99 m above the base of the upper part of the Mitten Black Shale Member where *Baculites* sp. (smooth) was found (Robinson and others, 1964, p. 85).

Stratigraphy: Thickness data are from Robinson and others (1964, p. 85 and 86).

Pierre Shale (part):		
Mitten Black Shale Member (part):		
upper part (part)	=	99 m
lower part	=	136 m

Depositional environments: For correlation with other data points, the Ardmore Bentonite bed is 14 m above the base of the Pierre Shale. There may be an unconformity above the Ardmore Bentonite bed (Robinson and others, 1964, p. 82). Pierre Shale is marine.

Point Id: L5Lc
Study interval: Campanian I
Location: Kemmerer, Wyo.; T. 21 N., R. 116 W.; lat 41°48', long 110°37'
Type of data: outcrop
Data:

Thickness of study interval	≈	976 m
Cumulative thickness of coal beds	=	90.2 m
Average coal bed thickness	=	9.0 m
Maximum coal bed thickness	=	35.0 m
Number of coal beds	=	10
Percent of interval that is coal	=	9
Coal beds < 1 m thick		3.4 m in 5 beds

Comments: This data point is a continuation of L5co.

Age: The base of the interval is picked at the contact between the Hilliard Shale and the overlying Lazeart Sandstone Member of the Adaville Formation. The top of the Hilliard is probably late Santonian in age based on ammonites (W.A. Cobban, oral commun., in Nichols and Jacobson, 1982b, p. 122). Also, *Baculites thomi* was found 336 m below the top of the Hilliard Shale about 30 km to the south (locality 33, Cobban and Kennedy, 1991, p. C4) and it ranges from *Desmoscaphites erdmanni* to *Scaphites hippocrepis* III, but its peak development was in the Santonian (Cobban and Kennedy, 1991, p. C5). According to Nichols and Jacobson (1982, p. 123), the age of the top of the Adaville is uncertain, but it is unlikely to be younger than early Campanian based on the absence of the upper Campanian palynomorph *Aquilapollenites* from the Adaville. Therefore, we include all of the Adaville Formation in the Campanian I interval. The Adaville is unconformably overlain by the Evanston Formation, which is Maastrichtian and Paleocene in age, based on the presence of *Triceratops* and palynomorphs respectively.

Stratigraphy: Coal data and thickness of the Adaville Formation are from Weaver and M'Gonigle (1987).

Adaville Formation:		
main body	=	884 m
Lazeart Sandstone Member	=	92 m

Depositional environments: The Adaville Formation is marginal marine to brackish.

Point Id: L6Lc
Study interval: Campanian I
Location: Conant Creek, southern Wind River basin, Wyoming; lat 42°51', long 108°
Type of data: outcrop
Data:

Thickness of study interval	=	681 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		2 beds < 1 m

Comments: This point is a continuation of L6co.

Age: The positions of fossil horizons are from Keefer (1972). The base of the interval is picked 681 m below the top of the Cody Shale at the horizon where *Scaphites hippocrepis* I was found. The top of the interval is picked at the base of the overlying Fales Sandstone Member of the Mesaverde Formation because an upper Campanian ammonite *Baculites perplexus* was found 15 m above the top of the Fales Member (in the Wallace Creek Tongue of the Cody Shale) and a Campanian I ammonite *B.* sp. (weak flank ribs) was found 30 m below the Fales Member (see documentation for M3ca).

Stratigraphy: Thickness measured from plate 2, Keefer (1972).

Fales Sandstone Member of Mesaverde Formation (Campanian II)

Cody Shale	=	323 m
Mesaverde Formation (a lower tongue)	=	35 m
Cody Shale (part)	=	323 m

Depositional environments: The Cody is marine shale; the Mesaverde Formation is shoreface sandstone and coastal plain deposits and contains thin coal.

Subsidiary data point: At Zimmerman Butte, southern Big Horn basin, lat 43°46', long 108°, the minimum thickness of the Campanian I interval is 560 m, which is the thickness of the interval between the horizon containing *S. hippocrepis* and that containing *B. maclearni* in the Cody Shale. Also, the thickness can be no greater than 720 m, which is the thickness from the horizon containing *S. hippocrepis* to the top of the Teapot Sandstone Member of the Mesaverde Formation.

Point Id: L7Lc

Study interval: Campanian I

Location: Mesa Verde, Barker dome, Colorado; lat 37°07', long 108°20'

Type of data: outcrop

Data:

Thickness of study interval	=	432 m
Cumulative thickness of coal beds	=	2.4 m
Average coal bed thickness	=	1.2 m
Maximum coal bed thickness	=	1.2 m
Number of coal beds	=	2
Percent of interval that is coal	=	0.4
Coal beds < 1 m thick		2.3 m in 4 beds

Comments: This point is a continuation of M5ca.

Age: The base is picked in the uppermost part of the Mancos Shale, 5 m below the transition beds of the overlying Point Lookout Sandstone (lower unit of Barnes and others, 1954), where *S. hippocrepis* I was found. The top of the interval is picked 104 m above the base of the Lewis Shale, midway between the occurrence of *Baculites asperiformis,* 44 m above the base, and *B. perplexus*, 165 m above the base (Cobban, 1973).

Stratigraphy: Thicknesses are from Barnes and others (1954).

Lewis Shale (lower part)	=	104 m
Mesaverde Group:		
Cliffhouse Sandstone	=	105 m
Menefee Formation	=	116 m
Point Lookout Sandstone	=	102 m
Mancos Shale (uppermost part)	=	5 m

Depositional environments: The Mancos Shale is marine; the Point Lookout Sandstone is nearshore marine; the Menefee Formation is nonmarine, coastal plain, and contains coal; the Cliffhouse Sandstone is shoreface sandstone; and the Lewis Shale is marine.

Point Id: L8Lc

Study interval: Campanian I

Location: Grand Junction, Colo.; T. 8 S., R. 100 W.; lat 39°12', long 108°30'

Type of data: outcrop

Data:

Thickness of study interval	=	427 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked 640 m below the top of the Mancos Shale at the horizon where *Scaphites hippocrepis* (DeKay) var. *tenuis* Reeside was found (Fisher and others, 1960). This species has subsequently been identified as *S. hippocrepis* II or III in other parts of the Western Interior (Cobban, 1969, p. 19, 21). Therefore, some portion of the Mancos below this fossil horizon may be Campanian I. The top is picked 213 m below the top of the Mancos Shale at the highest horizon of *B. asperiformis* (Cobban, 1973, p. 152).

Stratigraphy: The thickness of the Mancos Shale between fossil-bearing horizons is taken from measured section 21, pl. 10, Fisher and others (1960).

Mancos Shale (middle part)	=	427 m

Depositional environments: The Mancos Shale is entirely marine.

Point Id: L9Lc

Study interval: Campanian I

Location: Kaiparowits Plateau, southern Utah; T. 40 S., R. 3 E.; lat 37°12', long 111°35'

Type of data: outcrop

Data:

Thickness of study interval	=	458 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This section is continued as L9ca.

Age: The base of the study interval is picked at the base of the Drip Tank Member of the Straight Cliffs Formation. The age of the Drip Tank Member is constrained by a late Santonian age for the underlying uppermost John Henry Member (see L11co) and by the early Campanian age of the overlying Wahweap Formation. The age of the Wahweap is based on its mammalian fauna, which suggests a biostratigraphic correlation with the Milk River fauna of Canada (Eaton, 1991, p. 55). The Milk River Formation spans the *Scaphites hippocrepis* II through *Baculites* sp. (smooth) ammonite zones (Eaton, 1991, p. 55). Also, Peterson (1969a) suggested a lithostratigraphic correlation of the capping sandstone member (at the top of the Wahweap Formation) with the Castlegate Sandstone of the Book Cliffs, which in turn has been correlated to the middle Campanian *Baculites asperiformis* zone.

Stratigraphy: Data on Drip Tank Member are from Peterson (1969a); data on Wahweap Formation are from Eaton (1991).

Wahweap Formation:		
capping sandstone member	=	100 m
upper member	=	138 m
middle member	=	112 m
lower member	=	65 m
Straight Cliffs Formation (part):		
Drip Tank Member	=	43 m (unconformity at base)

Depositional environments: Both formations are fluvial.

Point Id: L10Lc
Study interval: Campanian I
Location: Judith River, Mont.; Tps. 22, 23 N., Rs. 16, 17 E.; lat 47°40', long 109°35'
Type of data: outcrop
Data:

Thickness of study interval	=	288 m
Cumulative thickness of coal beds	=	2.1 m
Average coal bed thickness	=	2.1 m
Maximum coal bed thickness	=	2.1 m
Number of coal beds	=	1
Percent of interval that is coal	=	0.7
Coal beds < 1 m thick		0.5 m in 2 beds

Comments: The 2.1-m-thick coal bed in this section is described as containing thin carbonaceous shale partings.

Age: The base of the interval is picked 34 m below the top of the Virgelle Sandstone Member of the Eagle Sandstone, where *Scaphites* cf. *S. hippocrepis* (coarse early form) was found (Gill and Schultz, unpublished notes). It is probably *S. hippocrepis* I, because *S. hippocrepis* I is reported in the lower sandstone member of the Eagle Sandstone at Mosby, Mont., 160 km to the southeast (Cobban, 1969; see L10co). The top of the interval is picked 11 m above the base of the Parkman Sandstone Member of the Judith River Formation, where *Baculites asperiformis* was found (Gill and Schultz, unpublished notes).

Stratigraphy: The stratigraphic positions of fossils, and the thicknesses of the Eagle Sandstone (including coal data) and the Parkman Sandstone were taken from an unpublished section measured in sec. 31, T. 23 N., R. 17 E. by J.R. Gill and L.G. Schultz. Thickness of the Claggett Shale was determined by Gill in secs. 36 and 37, T. 23 N., R. 16 E. Section 30 of Rice (1976, pl. 3), is a generalized graphic representation of Gill and Schultz's section.

Judith River Formation (part):		
Parkman Sandstone Member (part)	=	11 m
Claggett Shale	=	180 m
Eagle Sandstone:		
upper part	=	54 m
Virgelle Sandstone Member	=	43 m

Depositional environments: The Eagle Sandstone is nearshore marine and coastal plain, and contains coal; the Claggett Shale is marine; the Parkman Sandstone Member is nearshore marine.

Point Id: L11Lc
Study interval: Campanian I
Location: Austin, Tex.; lat 30°20', long 97°45'
Type of data: outcrop
Data:

Thickness of study interval	=	72 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This data point is continued from L12co.

Age: The base of the interval is picked 19 m below the top of the Dessau Formation of the Austin Group at the horizon where the presence of the upper Santonian *Texanites shiloensis* overlaps with that of the lower Campanian *Submortoniceras tequesquitense* (Young, 1963, p. 98). The top of the interval is picked at the top of the Pecan Gap Chalk, because it contains fossils indicative of the lower Campanian *Baculites maclearni* and *B. asperiformis* zones (Cobban and Scott, 1964, p. E4 and E5; Cobban and Kennedy, 1992, p. 66).

Stratigraphy: Nomenclature and thickness data are from Young (1963, p. 23) except for the Pecan Gap Chalk thickness, which is from Garner and Young (1976, p. 20).

Pecan Gap Chalk	=	24 m
"lower Taylor clay"	=	15 m
Austin Group:		
formation "D"	=	6 m
Burditt Marl	=	8 m
Dessau Formation (upper part)	=	19 m

Depositional environments: All units are entirely marine chalks and marls. A volcano (Pilot Knob) was active in the Austin area during the early part of this time interval.

Point Id: L13Lc
Study interval: Campanian I
Location: Big Bend, Tex.; lat 29°25', long 103°07'
Type of data: outcrop
Data:

Thickness of study interval	=	103 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		one thin coal bed

Comments: This data point is continued as M4ca.

Age: The base of the interval is picked arbitrarily in the middle of the 46-m-thick Pen Formation. The age of the Pen Formation is constrained at the base by the occurrence of *Inoceramus undulatoplicatus* (upper Santonian) in the top of the underlying San Vincente Member of the Boquillas Formation (Maxwell and others, 1967, no. 19 and 21, pl. VII) and near the top by the occurrence of *Delawarella delawarensis* (early Campanian) in a measured section 24 km to the southeast (Maxwell and others, 1967, no. 21, pl. VII). The top of the interval is picked at the base of the Terlingua Creek Sandstone Member of the Aguja Formation (terminology of Lehman, 1985b), because *Baculites asperiformis* is present in the underlying McKinney Springs Tongue of the Pen Formation (Lehman, oral commun., 1991).

Stratigraphy: Thickness data are from the section measured at McKinney Hills 2 (Maxwell and others, 1967, no. 19, pl. VII). Stratigraphic terminology is from Lehman (1985a).

Pen Formation:		
McKinney Springs Tongue	=	73 m
Aguja Formation:		
basal sandstone member	=	7 m
Pen Formation (part)	=	23 m

Depositional environments: The Pen Formation is marine; the basal sandstone member is nearshore marine with thin coal at the base; and the McKinney Springs Tongue is marine.

Note: Fifty km to the west at Tule Mountain (Lehman, 1985b, see pl. I and II), the Campanian I interval grades into intertonguing nonmarine and shoreface deposits of the lower shale member of the Aguja Formation, which is 200 m thick and contains 10 m of coal in six beds (Maxwell and others, 1967).

Point Id: L14Lc
Study interval: Campanian I
Location: Blackstone River area, west-central Alberta; lat 52°38', long 116°30'
Type of data: outcrop
Data:

Thickness of study interval	=	126 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This point is continued as L12ca.

Age: The base of the interval is picked at the base of the Chungo Member of the Wapiabi Formation, because the underlying Hanson Member correlates with the Telegraph Creek Formation (Stott, 1963) that contains fauna of the *Desmoscaphites bassleri* zone (Cobban, 1964, p. I5). The top of the interval is picked at the base of the Brazeau Formation. The underlying Nomad Member of the Wapiabi Formation correlates with the marine shale of the Pakowki Formation, which contains *Baculites maclearni* (Jerzykiewicz, 1992, p. 140).

Stratigraphy: Thicknesses are from measured section 5-28 of Stott (1963, fig. 12).

Brazeau Formation (lower part, Campanian II)		
Wapiabi Formation:		
Nomad Member	=	39 m
Chungo Member	=	87 m
Hanson Member (Santonian)		

Depositional environments: The Chungo Member is nearshore marine and transitional between marine and nonmarine; the Nomad Member is marine.

Point Id: L15Lc
Study interval: Campanian I
Location: Crowsnest area, southwestern Alberta; lat 49°30', long 114°
Type of data: outcrop

Data:

Thickness of study interval	=	168 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		1 bed

Comments: This point is continued from L15co and continued as L11ca.

Age: The base of the interval is picked at the base of the "thick bedded sandstone" unit of the Belly River Formation of Wall and Rosene (1977). The "thick bedded sandstone" unit is correlative to the lower Campanian Chungo Member of the Wapiabi Formation (Stott, 1963; Wall and Rosene, 1977). The underlying "transition member" of the Wapiabi Formation (Wall and Rosene, 1977) is probably equivalent to the Hanson Member, which is within the *Desmoscaphites bassleri* zone (Stott, 1963; Jeletzky, 1971). The top of the interval is placed at the top of the "thick bedded sandstone" unit although some part of the overlying "lower sandstone and shale" unit may be equivalent to the Nomad Member of the Wapiabi (Wall and Rosene, 1977, p. 850) and the Pakowki Formation, which contains lower Campanian *Baculites maclearni* and *B. asperiformis.* The 168 m section at this locality is a reasonable thickness for the Campanian I because the combined Chungo and Nomad interval is between 90 and 110 m thick 95 km to the north (see Stott, 1963, fig. 10, sections 6-45 and 6-25).

Stratigraphy: Terminology and thickness data are from Wall and Rosene (1977, p. 852); unit numbers in parentheses are terminology of Jerzykiewicz and Sweet (1988). Coal data are from Jerzykiewicz and Sweet (1988).

Belly River Formation (part):		
"thick bedded sandstone" (unit 1)	=	168 m

Depositional environments: The "thick bedded sandstone" member of the Belly River Formation is nearshore marine with a thin coal at the top (Jerzykiewicz and Sweet, 1988, fig. 2, p. 32).

Point Id: M1Lc
Study interval: Campanian I
Location: Rock Springs uplift, Wyoming; Tps. 17–19 N., Rs. 103–105 W.; lat 41°30', long 109°11'
Type of data: outcrop
Data:

Thickness of study interval	=	929 m
Cumulative thickness of coal beds	=	5.4 m
Average coal bed thickness	=	1.3 m
Maximum coal bed thickness	=	1.4 m
Number of coal beds	=	4
Percent of interval that is coal	=	0.6
Coal beds < 1 m thick		7.2 m in 27 beds

Comments: none

Age: The Santonian-Campanian boundary is picked at the top of the Airport Sandstone Member (of Smith, 1961) of the Baxter Shale, which contains *Desmoscaphites bassleri* (Smith, 1965, p. 13). This boundary is no higher than the top of the Baxter Shale because *Scaphites hippocrepis* I is found in its upper part about 50 km to the south (Cobban, 1969). The top of the interval is probably within the Ericson Sandstone, because *Baculites* sp. (weak flank ribs) is present 60 m below the Ericson in the Rock Springs Formation (Kirschbaum, 1986). Gill and others (1970) also believed the lower/upper Campanian boundary to be within the Ericson. We arbitrarily pick the boundary at the contact between the Trail zone and the Rusty zone within the Ericson Sandstone.

Stratigraphy: Thickness data for the Rock Springs Formation, Ericson Sandstone, and the coal are from Kirschbaum (1985, sections 144, 147, 158, and 161), and thickness data of the Baxter and Blair Formations are from Smith (1965).

Ericson Sandstone (part):		
Trail zone	=	21 m
Rock Springs Formation	=	381 m
Blair Formation	=	375 m
Baxter Shale (part)	=	152 m

Depositional environments: The Baxter Shale and Blair Formation are fully marine; the Rock Springs Formation is coastal plain to nearshore marine and contains all the coal; the Trail zone of the Ericson Sandstone is alluvial.

Point Id: M2Lc
Study interval: Campanian I
Location: Kenilworth, Utah; Tps. 12, 13 N., R. 10 E.; lat 39°40', long 110°47'
Type of data: outcrop
Data:

Thickness of study interval	=	681 m
Cumulative thickness of coal beds	=	6 m
Average coal bed thickness	=	1.5 m
Maximum coal bed thickness	=	1.8 m
Number of coal beds	=	4
Percent of interval that is coal	=	0.9
Coal beds < 1 m thick		4.8 m in 20 beds

Comments: Coal beds as thick as 4.8 m are found a few kilometers to the west.

Age: The base of the interval is picked within the 400-m-thick upper shale tongue of the Mancos Shale, because *Baculites aquilaensis*, which has affinities with *Scaphites hippocrepis*, is found 91 m below the top of the Mancos (Cobban, 1976); and *Desmoscaphites bassleri*? and *Inoceramus patootensiformis* are found in the underlying Emery Sandstone Member of the Mancos (Cobban, 1976). We arbitrarily pick the boundary in the middle of the upper tongue of the Mancos. These correlations are consistent with those of Fouch and others (1983). The top of the interval is picked at the contact between the Blackhawk Formation below and the Castlegate Sandstone above; the base of the Castlegate Sandstone can be no older than *Baculites asperiformis* (see data point M1ca where the base of the Castlegate was arbitrarily picked as the base of the Campanian II).

Stratigraphy: Thickness data are from a composite section by Russon (1987), which matches other sections in the area. Coal data are from Clark (1928), sections 472–651.

Blackhawk Formation (unconformity at the top)	=	338 m
Star Point Sandstone	=	143 m
Mancos Shale (part)	=	200 m

Depositional environments: The Mancos Shale is marine; the Star Point Sandstone is nearshore marine to marine; and the Blackhawk Formation is nonmarine to nearshore marine and contains the coal.

Point Id: M3Lc
Study interval: Campanian I
Location: Riding Mountain, Manitoba; lat 50°40', long 99°59'
Type of data: well log
Data:

Thickness of study interval	=	22 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This data point is continued from M2co.

Age: The lower boundary is arbitrarily placed at the contact between the Niobrara Formation and the Pierre Shale, at the base of the Gammon Member of the Pierre Shale (see discussion in M2co). The overlying Pembina Member contains foraminifers of the *Trochammina ribstonensis* zone (McNeil and Caldwell, 1981), which is thought to span from *Baculites obtusus* to *B. perplexus* based on correlations to the Pembina Member in North Dakota (Gill and Cobban, 1965, p. 5). Therefore, the 16-m-thick Pembina represents five ammonite zones, the lower three of which are Campanian I in age (3/5×16=10 m).

Stratigraphy: Thickness data are from drill hole 7 (McNeil and Caldwell, 1981, fig. 21).

Pierre Shale:		
Pembina Member (part)	=	10 m
Gammon Member	=	12 m

Depositional environments: All units are marine.

Point Id: M4Lc
Study interval: Campanian I
Location: Livingston, Mont.; T. 2 S., Rs. 8, 9 E.; lat 45°42', long 110°42'
Type of data: outcrop
Data:

Thickness of study interval	=	69 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This point is a continuation of M4co and is continued as M10ca.

Age: The base of the interval is placed 129 m above the base of the Cokedale Formation at the top of unit 84 (Roberts, 1972, p. 81), which contains palynomorphs indicative of the *Proteacidites retusus* interval zone (paleobotany locality D1611; Tysdal and Nichols, 1991). The top of the interval is placed 198 m above the base of the Cokedale Formation at the base of unit 101, section 16 (Roberts, 1972—paleobotany locality 1815-1) that contains palynomorphs indicative of the *Aquilapollenites quadrilobus* interval zone (Tysdal and Nichols, 1991).

Stratigraphy: Thickness is from Roberts (1972), section 16.

Cokedale Formation (part)	=	69 m

Depositional environments: This part of the Cokedale consists of volcaniclastic sediments that were deposited primarily in coastal plain environments and secondarily in nearshore marine environments.

Point Id: M5Lc
Study interval: Campanian I
Location: San Carlos, Tex.; lat 30°27', long 104°45'
Type of data: outcrop
Data:

Thickness of study interval	=	164 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		0.9 in 2 beds

Comments: none

Age: The base of the interval is placed at the base of the San Carlos Formation, whose lower part contains the index fossils *Submortoniceras tequesquitense* and *Exogyra ponderosa* (Wolleben, 1967). The top of the interval is placed at the base of the upper shale member of the San Carlos Formation, which contains *Kritosaurus*, a Judithian (Campanian II) age dinosaur (Lehman, 1985a).

Stratigraphy: Thickness from Lehman (1985a, pl. IV, section 4).

San Carlos Formation (part):

upper shale member (Campanian II)		
upper sandstone member	=	25 m
middle shale member	=	16 m
lower sandstone member	=	123 m

Depositional environments: The San Carlos Formation consists of nearshore marine to coastal plain deposits (Lehman, 1985a). Coal is found in the middle shale member and laterally in the lower sandstone member (Vaughn, 1900).

Campanian II basin summaries

Point Id: L1ca

Study interval: Campanian II

Location: Red Bird, Wyo.; reference surface section; sections 13, 14, and 24, T. 38 N., R. 62 W.; lat 43°15', long 104°16'

Type of data: outcrop

Data:

Thickness of study interval	=	533 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the Campanian II interval is placed within unit 20 in the Mitten Black Shale Member of the Pierre Shale where the base of the *Baculites* sp. smooth zone was estimated (Gill and Cobban, 1966a, pl. 2). The top of the interval is placed at the top of unit 68 (Gill and Cobban, 1966a, p. 54) above which are abundant remains of *B. reesidei.*

Stratigraphy: Thickness measured from Gill and Cobban (1966a, p. 54–61).

Pierre Shale (part):

lower unnamed shale member (part)	=	113 m
Red Bird Silty Member	=	185 m
Mitten Black Shale Member (part)	=	235 m

Depositional environments: Pierre Shale is all marine.

Subsidiary data points used for control on isopach map only: No coal data for these points. Locations are not plotted on any of the maps.

Name	Lat	Long	Thickness
Parkman, Wyo.	44°55'	107°30'	335 m
Salt Creek, Wyo.	43°21'	106°20'	490 m
Judith River, Mont.	47°50'	110°	409 m
Wheeler Ridge, S. Dak.	43°10'	98°35'	42 m

Thicknesses were measured from plate 3 of Gill and Cobban (1966a). Positions of base of *B. reesidei* and *B.* sp. smooth were estimated from positions of baculite zones shown on correlation diagram.

Point Id: L2ca

Study interval: Campanian II

Location: Kremmling, Colo.; Tps. 1–3 N., Rs. 80, 81 W.; lat 40°08', long 106°22'

Type of data: outcrop

Data:

Thickness of study interval	=	718 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The Campanian II interval includes members of the Pierre Shale between the base of the *Baculites perplexus* zone (early form) (the *B.* sp. smooth zone is shown to have zero thickness), and the top of the *B. cuneatus* zone (Izett and others, 1971, table 1, p. A5).

Stratigraphy: Within the study interval, the Pierre contains a series of sandstones including (from the base up) Kremmling Sandstone Member, Muddy Buttes Sandstone Member, Hygiene Sandstone Member, and Carter Sandstone Member.

Pierre Shale (part)	=	718 m

Depositional environments: Pierre Shale is marine.

Point Id: L3ca

Study interval: Campanian II

Location: Boulder, Colo.; Tps. 1, 2 N., Rs. 70, 71 W.; lat 40°05', long 105°15'

Type of data: outcrop

Data:

Thickness of study interval	=	756 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the Campanian II interval is placed within the Pierre Shale at the base of *Baculites perplexus* zone (early form) (the *B.* sp. smooth zone is shown to have zero thickness). The top of the interval is placed between the highest occurrence of *B. cuneatus* and the lowest occurrence of *B. reesidei* (Scott and Cobban, 1965).

Stratigraphy: Thickness taken from stratigraphic section shown in Scott and Cobban (1965).

Pierre Shale (part)	=	756 m

Depositional environments: Pierre Shale is marine including (from the base up) Hygiene Sandstone Member and Terry Sandstone Member.

Point Id: L4ca
Study interval: Campanian II
Location: Hardin, Mont.; Tps. 1, 2 S., Rs. 33–35 E.; lat 45°30', long 108°
Type of data: outcrop
Data:

Thickness of study interval	=	335 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The base of the *Baculites* sp. smooth zone was estimated from other ammonite zones; the top of the interval (top of *B. cuneatus*) was estimated from the positions of other ammonite zones (Gill and Cobban, 1966, pl. 3).

Stratigraphy: Thickness was measured from plate 3 of Gill and Cobban (1966a), but was originally published in Richards (1955). The section and baculite names were updated by Gill and Cobban (1966a) (W.A. Cobban, oral commun., 1991).

Bearpaw Shale (part)	=	189 m
Parkman Sandstone	=	76 m
Claggett Shale (part)	=	70 m

Depositional environments: Claggett and Bearpaw Shales are marine; Parkman Sandstone is nearshore marine.

Point Id: L5ca
Study interval: Campanian II
Location: Southeastern Sand Wash basin, Colorado; T. 5 N., Rs. 90, 91 W.; lat 40°21', long 107°34'
Type of data: well log and outcrop, composite
Data:

Thickness of study interval	=	872 m
Cumulative thickness of coal beds	=	13.5 m
Average coal bed thickness	=	2.2 m
Maximum coal bed thickness	=	3.5 m
Number of coal beds	=	6
Percent of interval that is coal	=	1.5
Coal beds < 1 m thick	8.6 m in 21 beds	

Comments: A coal bed 5.6 m thick was reported in the Williams Fork Formation in T. 6 N., R. 87 W. (Bass and others, 1955).

Age: Base of the Campanian II is picked midway between the occurrence of *B. perplexus* and *B. asperiformis* in the upper part of the Mancos Shale. The presence of these baculites in the sections measured by Konishi (1959) and Bass and others (1955) is reported by Izett and others (1971, p. A18). The top of the Campanian II is picked in the Williams Fork Formation at the base of the shale tongue below the Twentymile Sandstone Member. This shale tongue contains *Baculites reesidei* 42 km to the east at Fish Creek (Izett and others, 1971, fig. 2, see M8ma).

Stratigraphy: Thickness data for the Mancos Shale and Iles Formation are from Konishi (1959, meas. sec. 3, pl. 1). Thickness of the Williams Fork Formation from the top of Trout Creek Sandstone Member of the Iles Formation to the base of the shale tongue below the Twentymile Sandstone Member is from Bass and others (1955, meas. sec. 1, pl. 20). Coal data in both the Iles and Williams Fork Formations are from Bass and others (1955, Jeffway Gulch section, pl. 21).

Mesaverde Group (part):		
Williams Fork Formation (part)	=	250 m
Iles Formation	=	440 m
Mancos Shale (part)	=	182 m

Depositional environments: From Konishi (1959). The Mancos Shale is marine with nearshore marine sandstone. The Iles Formation is a nearshore marine sandstone at the base and top and coastal plain deposits in the middle with thin coals; thick coals in this interval are found to the east. The lower 2/3 of the Williams Fork Formation is coastal plain with thick coals; the upper 1/3 is a marine shale tongue capped by a nearshore marine sandstone.

Point Id: L6ca
Study interval: Campanian II
Location: Porcupine dome area, east-central Montana; Tps. 7, 8 N., Rs. 38, 40 E. and T. 12 N., R. 37 E.; lat 46°33', long 106°53'
Type of data: outcrop, composite section

Data:

Thickness of study interval	=	299 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This data point is continued as the Maastrichtian point L13ma.

Age: The base of Campanian II is picked 8 m below the top of the Claggett Shale beneath the occurrences of *Baculites* sp. (smooth) and *B. perplexus* (early form) (Gill and others, 1972, p. 97, unit 37). The top of the interval is picked at the base of the unit in the Bearpaw Shale that contains *B. reesidei* (Gill and others, 1972, p. 94, unit 65).

Stratigraphy: Thickness data are from the reference section for rocks of the Montana Group on Porcupine dome (Gill and others, 1972).

Bearpaw Shale (part)	=	176 m
Parkman Sandstone	=	115 m
Claggett Shale (part)	=	8 m

Depositional environments: All units are marine.

Point Id: L7ca
Study interval: Campanian II
Location: Dearborn River, Mont.; T. 17 N., R. 5 W.; lat 47°25', long 112°30'
Type of data: outcrop
Data:

Thickness of study interval	=	479 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: The Campanian II interval is as much as 1,400 m thick just 30 km to the south (Schmidt, 1978).

Age: The base of the Campanian II interval (base of the *Baculites* sp. smooth zone) was estimated to be about 430 m below the top of the volcanic member of the Two Medicine Formation (Gill and Cobban, 1966a, pl. 3). This horizon was obtained by projecting the base of the *B. perplexus* zone (385 m below the top of the volcanic member) and the base of the *B. obtusus* zone (565 m below the top) from the Judith River section (Gill and Cobban, 1966a, pl. 3, section 2) to the Dearborn River section (Gill and Cobban, 1966a, pl. 3, section 1). The 180 m of strata between the two projected bases represent four ammonite zones. The projected base of *B.* sp. smooth therefore is 45 m (180 divided by 4) below the projected base of *B. perplexus*. The Campanian II interval of the volcanic member is 430 m thick (385+45=430). The Campanian/Maastrichtian boundary is picked arbitrarily at the top of an oyster bed 49 m above the base of the St. Mary River Formation based on correlations to the *B. cuneatus* zone (Schmidt, 1978, p. 46 and pl. 2).

Stratigraphy: Thickness data for the Two Medicine Formation are from Gill and Cobban (1966a, pl. 3) and data for the St. Mary River Formation are from Schmidt (1978, p. 42).

St. Mary River Formation (part)	≈	49 m
Two Medicine Formation (part):		
volcanic member (part)	≈	430 m

Depositional environments: The volcanic member of Two Medicine Formation consists of tuffs, clastic volcanic rocks, and latite flows; the St. Mary River Formation is fluvial.

Point Id: L8ca
Study interval: Campanian II
Location: Rawlins area, Wyoming; Tps. 22, 23 N., Rs. 85, 86 W.; lat 41°54', long 107°05'
Type of data: outcrop and well log (composite)
Data:

Thickness of study interval	=	664 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		Yes (see comment)

Comments: Nearby, Merewether (1973) showed a coal bed as much as 1 m thick near the top of the Allen Ridge Formation. All other coal beds along the outcrop are < 1 m thick.

Age: The base of the study interval is picked in the middle of the Hatfield Sandstone Member of the Haystack Mountains Formation. *Baculites asperiformis* was found within the Hatfield at other nearby localities and *B. perplexus* was found above it. Gill and others (1970, p. 15) reported that the "Hatfield apparently was deposited during the time of *B. asperiformis* or early during the time of *B. perplexus*." The top of the Campanian II is picked at the top of the Pine Ridge Sandstone, because the overlying Almond Formation has *B. reesidei* at the base (Gill and others, 1970, p. 8, Sinclair section). There is a major unconformity at the base of the Pine Ridge.

Stratigraphy: Thickness of the Pine Ridge is from Merewether (1973). Other formation thickness data are from Gill and others (1970, p. 15, 16).

Pine Ridge Sandstone	=	46 m
Allen Ridge Formation	=	465 m
Haystack Mountains Formation (part):		
upper unnamed marine member	=	130 m
Hatfield Sandstone Member (upper half)	=	23 m

Depositional environments: The Campanian II part of the Haystack Mountains Formation is marine shale and shoreface sandstone; the Allen Ridge Formation is marine at the base and top, but mainly fluvial, with thin coal; and the Pine Ridge Sandstone is a fluvial deposit, possibly a valley fill.

Point Id: L9ca
Study interval: Campanian II
Location: Kaiparowits Plateau, southern Utah; T. 36 S., R. 1 W.; lat 37°40', long 111°42'
Type of data: outcrop
Data:

Thickness of study interval	=	920 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: This section is continued from L9Lc.

Age: The base of the study interval is tentatively placed at the base of the Kaiparowits Formation. This formation is middle to late Campanian in age, based on mammalian faunal elements that compare favorably with Judithian faunas (Eaton, 1991, p. 57–60). The top of the Campanian II is arbitrarily placed 65 m above the base of the Canaan Peak Formation. Two palynomorphs (*Araucariacites* and *Rugubivesiculites*) found 65 m above the base indicate an age older than Maastrichtian (Bowers, 1972). The uppermost part of the Canaan Peak Formation could be Maastrichtian or as young as Paleocene in age (Bowers, 1972).

Stratigraphy: Thickness of Kaiparowits Formation is from Eaton (1991, p. 56, 57); thickness of Canaan Peak Formation is from Bowers (1972, p. B32, B33).

Canaan Peak Formation (part)	=	65 m
Kaiparowits Formation	=	855 m

Depositional environments: Both formations are fluvial; the Canaan Peak contains conglomerate.

Point Id: L11ca
Study interval: Campanian II
Location: Crowsnest area, southwestern Alberta; lat 49°30', long 114°
Type of data: outcrop
Data:

Thickness of study interval	=	778 m
Cumulative thickness of coal beds	=	1.2 m
Average coal bed thickness	=	1.2 m
Maximum coal bed thickness	=	1.2 m
Number of coal beds	=	1
Percent of interval that is coal	<	0.1
Coal beds < 1 m thick	0.6 m in 2 beds	

Comments: This point is continued from L15Lc and continued as L6ma.

Age: The base of the interval is picked in the lower part of the Belly River Formation at the base of the "lower sandstone-shale" unit of Wall and Rosene (1977). The underlying marginal marine deposits ("thick-bedded sandstone" unit of Wall and Rosene, 1977) are correlative to the marine Pakowki Shale that contains *Baculites maclearni* (Jerzykiewicz, 1992, p. 140) and to the lower Campanian Chungo Member of the Wapiabi Formation (Stott, 1963; see L15Lc). The top of the interval is picked at the top of the Bearpaw Formation, because *B. cuneatus* is found in the middle of the formation and faunal elements indicative of the *Haplophragmoides fraseri* zone are present throughout the formation (Wall and Rosene, 1977, p. 852, 863).

Stratigraphy: The thickness of the Belly River Formation is from Wall and Rosene (1977, p. 852), and the thickness of the Bearpaw Formation is from Jerzykiewicz and Sweet (1988, fig. 2); unit numbers in parentheses are from Jerzykiewicz and Sweet (1988). Coal data are estimated from Jerzykiewicz and Sweet (1988, fig. 13).

Bearpaw Formation	=	200 m
Belly River Formation:		
"upper sandstone-shale" (unit 4)	=	152 m
"concretionary" (unit 3)	=	91 m
"lower sandstone-shale" (unit 2)	=	335 m
"thick-bedded sandstone" (unit 1)	Campanian I	

Depositional environments: Upper three units of Belly River Formation are nonmarine; upper two units are interpreted as paleosols (Jerzykiewicz and Sweet, 1988). Coal is found in the uppermost Belly River Formation (Jerzykiewicz and Sweet, 1988). Bearpaw Formation is marine.

Point Id: L12ca
Study interval: Campanian II
Location: Blackstone River area, west-central Alberta; lat 52°43', long 116°17'
Type of data: outcrop
Data:

Thickness of study interval	=	500 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0

Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This point is continued from L14Lc and continued as L8ma.

Age: The base of the interval is picked at the base of the Brazeau Formation. The underlying marine Wapiabi Formation correlates with the marine shale of the Pakowki Formation, which contains *Baculites maclearni* (Jerzykiewicz, 1992, p. 140). The top of the interval is picked 500 m above the base of the Brazeau Formation, where uppermost Campanian palynomorphs were found (Jerzykiewicz and Sweet, 1988, p. 46, 54) that are indicative of the lower part of the *Aquilapollenites quadrilobus* zone of Nichols and others (1982, pl. 1). The Maastrichtian palynomorph *Wodehouseia* occurs above this horizon (Jerzykiewicz and Sweet, 1988, p. 32, 56).

Stratigraphy: The thickness of the Campanian part of the Brazeau Formation is from Jerzykiewicz and Sweet (1988, fig. 2, p. 32). Because *Wodehouseia* appears around the time of *B. baculus* zone, the thickness is a maximum.

Brazeau Formation (lower part)	=	500 m

Depositional environments: Lower part of Brazeau Formation is fluvial and lacustrine (Jerzykiewicz and Sweet, 1988, fig. 15, p. 60).

Point Id: M1ca
Study interval: Campanian II
Location: Sego Canyon, Utah, T. 20 S., R. 20 E.; lat 39°10', long 109°40'
Type of data: outcrop
Data:

Thickness of study interval	=	638 m
Cumulative thickness of coal beds	=	4.5 m
Average coal bed thickness	=	1.5 m
Maximum coal bed thickness	=	1.9 m
Number of coal beds	=	3
Percent of interval that is coal	=	0.3
Coal beds < 1 m thick		0.4 m in 1 bed

Comments: none

Age: The base of the study interval is placed at the base of channelized deposits of the Castlegate Sandstone. Seventy kilometers to the east, Gill and Hail (1975) reported *Baculites asperiformis* below the marine part of the Castlegate Sandstone; the closest is 20 m below the unit. They also reported *B. perplexus* 15 m above the Castlegate. The Castlegate consists of a nearshore marine facies and a valley-fill facies (Van Wagoner and others, 1990). Since the valley fill is younger than the nearshore marine, which could be as old as *B. asperiformis*, we arbitrarily pick the base of the valley-fill facies to correspond with the base of the *B.* sp. (smooth) zone. The top of the Campanian II is placed at the top of the Tuscher Formation. Palynomorphs in the Tuscher are from the *Aquilapollenites quadrilobus* zone, which extends from the Campanian into the Maastrichtian (Franczyk and others, 1990). The presence of *Kuylisporites scutatus*, found 10 m below the top of the Tuscher, indicates that most of the Tuscher is in the lower part of the *A. quadrilobus* zone and is Campanian II in age (Franczyk and others, 1990).

Stratigraphy: Thicknesses from Franczyk and others (1990) except the Castlegate from Van Wagoner and others (1990). Unconformity at base of Castlegate and at top of Tuscher. Coal thicknesses from Fisher (1936, section 177).

Tuscher Formation	=	83 m
Farrer Formation	=	316 m
Neslen Formation	=	96 m
Sego Sandstone	=	57 m
Buck Tongue of Mancos Shale	=	69 m
Castlegate Sandstone (part)	=	17 m

Depositional environments: The Castlegate is a valley fill; the Buck Tongue is marine; the Sego is nearshore marine to offshore marine; the Neslen is coastal plain and contains coal throughout; and the Farrer and Tuscher are fluvial.

Point Id: M2ca
Study interval: Campanian II
Location: Rock River, Wyo.; T. 20 N., R. 76 W.; lat 41°43', long 105°57'
Type of data: outcrop
Data:

Thickness of study interval	=	624 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		1.3 m in 2 beds

Comments: Coals as thick as 3 m in Pine Ridge Sandstone in the same township and range (Osgood, 1931, p. 78).

Age: The base of the Campanian II is placed 122 m below the top of the Steele Shale. This is a minimum thickness value for the Campanian I part of the Steele Shale because at Rock River only the upper 140 m of the Steele Shale was measured, and *Baculites perplexus* was found in the upper 122 m (Gill and others, 1970, p. 24). The upper boundary of the study interval is arbitrarily placed at the top of the Pine Ridge Sandstone. *B. reesidei* was found in the marine shales above the Pine Ridge at Rock River and at other localities in south-central Wyoming (Gill and others, 1970).

Stratigraphy: The Rock River thickness is from the type section (Gill and others, 1970, p. 21–24), and the Pine Ridge Sandstone thickness is from the principal reference section (Gill and others, 1970, p. 31).

Pine Ridge Sandstone	=	25 m
Rock River Formation	=	477 m
Steele Shale (part)	=	122 m

Depositional environments: The Steele is marine. The Rock River is nearshore to offshore marine; laterally equivalent beds of the Allen Ridge Formation, 45 km to the west, contain coals more than 1 m thick. The Pine Ridge is fluvial, possibly a valley fill, and contains coal.

Point Id: M3ca
Study interval: Campanian II
Location: Southeastern Wind River basin, Wyoming; lat 42°52', long 107°15'
Type of data: well log and outcrop, composite
Data:

Thickness of study interval	=	286 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: We pick the base of the Campanian II at the base of the Fales Sandstone Member of the Mesaverde Formation, because *Baculites perplexus* was found 15 m above base of the overlying Wallace Creek Tongue of the Cody Shale (Keefer, 1972; measured sec. 30, pl. 2) and *B.* sp. (weak flank ribs) was found below strata equivalent to the Fales Sandstone at Conant Creek (Keefer, 1972, measured sec. 20; 70 km west of this data point). The upper boundary of the study interval is placed at the top of the Teapot Sandstone Member based on regional correlations by Gill and Cobban (1973), who showed the Teapot being equivalent to the Pine Ridge Sandstone (see M2ca).

Stratigraphy: Thickness data from Keefer (1972, measured section 30 and drill hole 31, pl. 2).

Mesaverde Formation:		
Teapot Sandstone Member	=	15 m
unnamed middle member	=	132 m
Parkman Sandstone Member	=	16 m
Cody Shale:		
Wallace Creek Tongue	=	44 m
Mesaverde Formation:		
Fales Sandstone Member	=	79 m

Depositional environments: The Cody Shale is marine. The Fales Sandstone Member is nearshore marine. The unnamed middle member is nonmarine; the Parkman Sandstone Member is nearshore marine and nonmarine; and the Teapot Sandstone Member is fluvial.

Subsidiary data point used for control on isopach map only: *B. maclearni* was found in the lower part of the Mesaverde Formation 150 m below the top of the Teapot Sandstone Member (Keefer, 1972, measured section 46, pl. 3). No coal occurs in this interval. Location is not plotted on any of the maps.

Name	Lat	Long	Thickness
Big Horn basin, Wyoming	43°45'	108°	150 m (maximum)

Point Id: M4ca
Study interval: Campanian II
Location: Big Bend, Tex.; lat 29°20', long 103°08'
Type of data: outcrop
Data:

Thickness of study interval	=	96 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		Yes

Comments: One coal bed of unknown thickness was reported by Lehman (1989). Maxwell and others (1967) reported one bed 0.6 m thick at section 13 of Lehman (1989).

Age: The lower boundary of the study interval is arbitrarily placed at the base of the Terlingua Creek Sandstone Member of the Aguja Formation because of the presence of *Baculites asperiformis* in the underlying McKinney Springs Tongue of the Pen Formation (Lehman, 1985a; Lehman, oral commun., 1991). The upper boundary in the Big Bend area can be approximately placed at the contact between the Aguja Formation and the overlying Javelina Formation (Lehman, oral commun., 1991). The upper shale member of the Aguja contains the dinosaur *Kritosaurus*, which is Judithian in age (upper Campanian), and the Javelina Formation contains *Alamosaurus*, a Lancian (Maastrichtian) dinosaur. The Campanian/Maastrichtian boundary may be midway in the upper shale member of the Aguja, but no definitive fossils have been found at this time (Lehman, oral commun., 1991).

Stratigraphy: Thickness data are from the McKinney Springs section of Maxwell and others (1967), modified by Lehman (1985a, 1989).

Aguja Formation:		
upper shale member	=	94 m
Terlingua Creek Sandstone Member	=	2 m
McKinney Springs Tongue of Pen Formation (Campanian I)		

Depositional environments: The Terlingua Creek Sandstone Member of the Aguja Formation is a nearshore marine sandstone. Thin lignites were deposited on coastal plains in the lower part of the upper shale member (Lehman, 1989). Variegated beds and caliche nodules (paleosols) were deposited in alluvial settings in the upper part of the upper shale member of the Aguja Formation (Lehman, 1989).

Point Id: M5ca
Study interval: Campanian II
Location: Barker dome, New Mexico-Colorado; Tps. 31, 32 N., Rs. 12, 13 W.; lat 36°59', long 108°13'
Type of data: well log and outcrop
Data:

Thickness of study interval	=	634 m
Cumulative thickness of coal beds	=	14.6 m
Average coal bed thickness	=	3.7 m
Maximum coal bed thickness	=	8.2 m
Number of coal beds	=	4
Percent of interval that is coal	=	2.3
Coal beds < 1 m thick		2.4 m in 4 beds

Comments: none
Age: The lower boundary of the study interval is placed 332 m below the top of the Lewis Shale midway between the occurrence of *Baculites asperiformis,* 44 m above the base, and *B. perplexus,* 165 m above the base (Cobban, 1973). The upper boundary of the study interval is placed arbitrarily at the top of the lower shale member of the Kirtland Shale. The overlying Farmington Sandstone Member contains the guide fossil *Gunnera microreticulata* (Newman, 1987), which is indicative of the Maastrichtian *Wodehouseia spinata* zone of Nichols and others (1982). Some portion of the lower shale member of the Kirtland is possibly Maastrichtian in age, but no diagnostic fossils have been identified.
Stratigraphy: Thicknesses from section H of Hayes and Zapp (1955). Coal data from Roberts (1989).

Kirtland Shale, lower member	=	129 m
Fruitland Formation	=	85 m
Pictured Cliffs Sandstone	=	88 m
Lewis Shale (part)	=	332 m

Depositional environments: The Lewis Shale is marine and the Pictured Cliffs Sandstone is nearshore marine. The Fruitland is dominantly coastal plain (Roberts and McCabe, 1992) and contains all the coal. The lower member of the Kirtland is nonmarine.

Point Id: M6ca
Study interval: Campanian II
Location: Florence, Colo.; T. 18 S., R. 69 W.; lat 38°27', long 105°07'
Type of data: outcrop
Data:

Thickness of study interval	=	585 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none
Age: The base of the study interval is at the base of the Rusty zone of the Pierre Shale, which contains *Baculites perplexus* (Scott and Cobban, 1975). The underlying Sharon Springs Member of the Pierre Shale contains baculites including *B. asperiformis*. The top of the study interval is within the basal 27 m of the Cone-in-cone zone of the Pierre Shale based on interpretation of the position of the base of the *B. reesidei* zone by Scott and Cobban (1975).
Stratigraphy: Thickness data are from Scott and Cobban (1975).

Pierre Shale:		
Cone-in-cone zone (part)	=	27 m
Tepee zone	=	236 m
Rusty zone	=	322 m

Depositional environments: The Pierre Shale is marine.

Point Id: M7ca
Study interval: Campanian II
Location: Cypress Hills, Saskatchewan (T. 1, R. 27, W3) and Alberta; lat 49°30', long 110°
Type of data: outcrop
Data:

Thickness of study interval	=	279 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		0.9 m in 3 beds

Comments: none
Age: We pick the lower boundary of the study interval arbitrarily at the Pakowki Formation/Judith River Group contact. In the Cypress Hills region, *Baculites maclearni* is found 10 m below the top of the Pakowki, and *B. maclearni* and *B. asperiformis* are found in the Bear Gulch sandstone about 60–75 m below the top of the Pakowki Formation (Russell and Landes, 1940, p. 34–45, 166, 169). The top of

the interval is picked 102 m above the base of the Bearpaw Formation midway in the Manyberries Member of the Bearpaw Formation (Lines, 1963, fig. 1) because, in nearby sections (at Box Elder Creek), about 15 km north, the zonal boundary between *Baculites reesidei* and *B. cuneatus* is approximately in the middle of the Manyberries Member (North and Caldwell, 1970, p. 72).

Stratigraphy: The Judith River Group thickness (measured in Alberta) is from Furnival (1950; his Foremost and Oldman Formations, p. 31–33), and the Bearpaw Formation thickness (measured in Saskatchewan) is from Lines (1963, fig. 1). Coal thickness data in the Judith River are from Furnival (1950, p. 31–33).

Bearpaw Formation (part):		
Manyberries Member (part)	=	102 m
Judith River Group	=	177 m

Depositional environments: The Judith River has nearshore marine sands at the base and top, and is coastal plain to nonmarine in between. In the Milk River region, Ogunyomi and Hills (1977) found coals and associated brackish-water deposits in the Foremost Formation, which indicates deposition in coastal plain environments. The Bearpaw is marine.

Point Id: M8ca
Study interval: Campanian II
Location: Turtle Mountain, Manitoba; lat 49°, long 100°05'
Type of data: well log
Data:

Thickness of study interval	=	204 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: We pick the lower boundary 6 m above the base of the Pembina Member of the Pierre Shale. The Pembina Member contains foraminifers of the *Trochammina ribstonensis* zone (McNeil and Caldwell, 1981), which is thought to span from *Baculites obtusus* to *B. perplexus*, based on correlations to the Pembina in North Dakota (Gill and Cobban, 1965, p. 5). The 15-m-thick Pembina therefore represents five ammonite zones, the upper two of which are Campanian II in age (2/5×15=6 m). The overlying Millwood Member contains foraminifers of the *Eoeponidella linki* and *Glomospira corona* zones. The *E. linki* zone spans from *B. gregoryensis* to *B. stevensoni*. Approximately 10 m of the basal Millwood falls within the *Glomospira* zone, which in Manitoba spans from *B. perplexus* to *B. scotti* (McNeil and Caldwell, 1981). We arbitrarily pick the top of the interval at the top of Odanah Member of the Pierre Shale. The Odanah Member contains foraminifers of the *Haplophragmoides fraseri* zone, whose uppermost subzone, *Praebulimina kickapooensis*, probably spans from *B. compressus* to *B. cuneatus* (Caldwell and others, 1978).

Stratigraphy: Thickness data are from hole 80 (McNeil and Caldwell, 1981, fig. 30).

Pierre Shale (part):		
Odanah Member	=	156 m
Millwood Member	=	42 m
Pembina Member (part)	=	6 m

Depositional environments: All members are marine.

Point Id: M9ca
Study interval: Campanian II
Location: Two Medicine River, Mont.; lat 48°30', long 112°30'
Type of data: outcrop
Data:

Thickness of study interval	=	554 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	see depositional environments	

Comments: none

Age: The lower boundary of the Campanian II is placed 455 m below the top of the Two Medicine Formation at the top of the lower lithofacies of Lorenz and Gavin (1984). They identified a unit at the top of their lower lithofacies that they correlated with the Claggett Shale, which contains *Baculites maclearni* 300 km southeast of Two Medicine River (Gill and Cobban, 1973). We place the top of the study interval 99 m above the base of Bearpaw Shale. On the Blackfoot Indian Reservation, 10–40 km to the north, the Bearpaw contains *B. compressus*, *B. cuneatus*, and *B. reesidei* (Gill and Cobban, 1966a). We split these ammonite zones into three equal thicknesses following Gill and Cobban (1966a) and include the two-thirds of the Bearpaw thickness in the Campanian II.

Stratigraphy: Two Medicine thickness from Lorenz and Gavin (1984) and Bearpaw thickness from Stebinger (1916).

Bearpaw Shale (part)	=	99 m
Two Medicine Formation (part)	=	455 m

Depositional environments: The Two Medicine Formation is mostly nonmarine with thin nearshore marine and coal deposits at the base and top. The nonmarine part contains carbonaceous shales, carbonate nodules, variegated beds, and lacustrine limestones (Lorenz and Gavin, 1984). The Horsethief Sandstone overlies the Two Medicine Formation 45 km north of this data location, and contains coal up to 2 m thick (Stebinger, 1916). The Bearpaw Shale is marine.

Point Id: M10ca
Study interval: Campanian II
Location: Livingston, Mont.; T. 2 S., Rs. 8, 9 E.; lat 45°42', long 110°42'
Type of data: outcrop
Data:

Thickness of study interval	=	396 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This point is a continuation of M4Lc.

Age: The base of the interval is placed 274 m below the top of the Cokedale Formation at the base of unit 101, section 17 (Roberts, 1972—paleobotany locality D1815-1), which contains palynomorphs indicative of the *Aquilapollenites quadrilobus* interval zone (Tysdal and Nichols, 1991). The top of the interval is picked 122 m above the base of the Miner Creek Formation at the base of unit 77, section 17 (Roberts, 1972—paleobotany locality D1612), which contains palynomorphs indicative of the upper part of the *A. quadrilobus* interval zone and thought to have an early Maastrichtian age (Tysdal and Nichols, 1991, p. 17). This age designation is consistent with Roberts (1972, p. 39) based on his lithostratigraphic correlations to sections dated with ammonites.

Stratigraphy: Thicknesses are from Roberts (1972, sections 16 and 17).

Miner Creek Formation (part)	=	122 m
Cokedale Formation (part)	=	274 m

Depositional environments: The Cokedale and Miner Creek Formations consist of alluvial volcaniclastic sediments.

Maastrichtian basin summaries

Point Id: L2ma
Study interval: Maastrichtian
Location: Red Deer River Valley, south-central Alberta; lat 51°40', long 112°55'
Type of data: outcrop, composite section
Data:

Thickness of study interval	=	307 m
Cumulative thickness of coal beds	=	2.4 m
Average coal bed thickness	=	1.2 m
Maximum coal bed thickness	=	1.2 m
Number of coal beds	=	2
Percent of interval that is coal	=	0.8
Coal beds < 1 m thick		9.2 m in 15 beds

Comments: Maximum coal thickness reported in the basin is 8 m.

Age: The base of the interval is picked 25 m below the top of the Bearpaw Formation because this uppermost shale unit of the Bearpaw correlates with the *Baculites reesidei* zone in the South Saskatchewan Valley (Lerbekmo and Coulter, 1985, p. 577). The Cretaceous-Tertiary boundary is picked at the base of the Nevis coal, 42 m above the base of the Scollard Formation, where the "terminal Cretaceous Ir anomaly" was located (Lerbekmo and Coulter, 1985, p. 581).

Stratigraphy: Terminology is from Irish (1970). The thickness data of the Maastrichtian part of the Bearpaw Formation are from Lerbekmo and Coulter (1985). The Bearpaw Formation intertongues with the Horseshoe Canyon Formation. Thickness and coal data are from Irish (1970, type section for Horseshoe Canyon and Scollard Formations along the Red Deer River). Position of Cretaceous-Tertiary boundary in the Scollard Formation.

Scollard Formation (part)	=	42 m
Battle Formation	=	8 m
Whitemud Formation	=	4 m
Horseshoe Canyon Formation	=	228 m
Bearpaw Formation (part)	=	25 m

Depositional environments: The Bearpaw Formation is upper and lower shoreface sands and muds. The Horseshoe Canyon Formation is coastal plain or deltaic and contains the coal. The Whitemud, Battle, and Scollard Formations are nonmarine.

Point Id: L3ma
Study interval: Maastrichtian
Location: Rock Springs uplift, Wyoming; Tps. 18, 19, 20 N., R. 100 W.; lat 41°36', long 108°42'
Type of data: outcrop, composite section
Data:

Thickness of study interval	=	750 m
Cumulative thickness of coal beds	=	11.2 m
Average coal bed thickness	=	1.6 m
Maximum coal bed thickness	=	2.3 m
Number of coal beds	=	7
Percent of interval that is coal	=	1.5
Coal beds < 1 m thick		7.4 m in 23 beds

Comments: Coal as thick as 3.5 m is reported in the vicinity. This is the thickest Maastrichtian section; in other parts of the uplift, the Fort Union Formation (Paleocene) cuts into underlying rocks.

Age: The base of the interval is arbitrarily picked at the base of the Almond Formation because Gill and others (1970 , table 1, p. 6) showed the base of the *Baculites reesidei* zone to be in the upper part of the underlying Ericson Sandstone, not far below the base of the Almond. The Cretaceous-Tertiary boundary is picked at the unconformity between the Lance and the overlying Paleocene Fort Union Formation.

Stratigraphy: Thickness and coal data are from Roehler (1983, measured sections 3276, 3476, 3576 (Almond); 3077 (Lewis); and 5481(Fox Hills and Lance)).

Lance Formation	=	305 m
Fox Hills Sandstone	=	52 m
Lewis Shale	=	213 m
Almond Formation	=	180 m

Depositional environments: From Roehler (1983). The Almond Formation is coastal plain and contains coal, and the Lewis Shale is marine. The Fox Hills Sandstone is nearshore marine; the Lance Formation is coastal plain and contains coal.

Point Id: L4ma
Study interval: Maastrichtian
Location: Northwest Black Hills uplift, Wyoming; Tps. 54, 56.5 N., Rs. 68, 69 W.; lat 44°40', long 105°06'
Type of data: outcrop (composite)
Data:

Thickness of study interval	=	597 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked 61 m below top of Pierre Shale where *Baculites reesidei* was found (Robinson and others, 1964). The top of the interval is picked at the contact between the Lance Formation and the overlying Paleocene Tullock Member of the Fort Union Formation.

Stratigraphy: The thickness of the Maastrichtian part of the Pierre Shale is from Robinson and others (1964, pl. 5, measured section at Rocky Point anticline), and the thickness of the Fox Hills Sandstone is calculated at Rocky Point anticline from their geologic map. The thickness of the Lance is from the measured section of Dodge and Powell (1975, pl. 1).

Lance Formation	=	500 m
Fox Hills Sandstone	=	36 m
Pierre Shale (part)	=	61 m

Note: The Maastrichtian part of the Pierre Shale thickens to 323 m at the Red Bird section 160 km to the southeast.

Depositional environments: The Pierre Shale is marine; the Fox Hills Sandstone is nearshore marine; the Lance Formation is coastal plain and fluvio-deltaic (Dodge and Powell, 1975); paleocurrent directions are to the south and southeast.

Point Id: L5ma
Study interval: Maastrichtian
Location: Western Cypress Hills, southeastern Alberta; lat 49°30', long 110°15'
Type of data: outcrop (composite section)
Data:

Thickness of study interval	=	156 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		3.9 m in 7 beds

Age: The base of the interval is picked 102 m below the top of the Bearpaw Formation midway in the Manyberries Member of the Bearpaw Formation (Lines, 1963, fig. 1) because, in nearby sections (at Box Elder Creek), about 15 km north, the zonal boundary between *Baculites reesidei* and *B. cuneatus* is approximately in the middle of the Manyberries Member (North and Caldwell, 1970, p. 72). The Cretaceous-Tertiary boundary is picked at the top of the Frenchman Formation, which contains *Triceratops* (Furnival, 1950, p. 94). The Frenchman Formation is overlain by the Paleocene Ravenscrag Formation.

Stratigraphy: Thickness of the Bearpaw Formation is from Lines (1963, fig. 1). All other thickness and coal data (including coal in the Bearpaw) are from Furnival (1950, p. 71–72).

Frenchman Formation	=	1 m
Battle Formation	=	2 m
Whitemud Formation	=	14 m
Eastend Formation	=	37 m
Bearpaw Formation (part):		
Manyberries Member (part)	=	102 m

Depositional environments: The Bearpaw Formation is marine and nearshore marine (thin coal in the Oxarart Member). The Eastend Formation is marginal marine to nonmarine and contains thin coal. The Whitemud Formation is nonmarine. The Battle Formation is of volcanic origin containing bentonite and bentonitic shale; it correlates with the Kneehills Tuff. The Frenchman Formation is nonmarine; there is an unconformity at the base with as much as 60 m of relief in places.

Point Id: L6ma
Study interval: Maastrichtian
Location: Crownest area, southern Alberta; general lat 49°45', long 114°08'
Type of data: outcrop (composite section)
Data:

Thickness of study interval	=	1,650 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		0.8 m in 1 bed

Comments: This point is contined from L11ca.
Age: The base of the Maastrichtian interval is arbitrarily picked at the base of the St. Mary River Formation, because the underlying Bearpaw Formation contain *Baculites cuneatus* and *Haplophragmoides fraseri* (Wall and Rosene, 1977, fig. 9, p. 863). The Cretaceous-Tertiary boundary (based on palynomorphs) is from Jerzykiewicz and Sweet (1988, p. 32).
Stratigraphy: Thicknesses and coal data are estimated from Jerzykiewicz and Sweet (1988, fig. 2, p. 32 and fig. 13, p. 52).

Willow Creek Formation (part)	=	880 m
St. Mary River Formation	=	770 m

Depositional environments: The St. Mary River Formation is nonmarine, with numerous nodular limestone concretions, to littoral and coastal plain with thin coals near the base. The Willow Creek Formation is nonmarine, floodplain, caliches, and redbeds (interpreted as paleosols (Jerzykiewicz and Sweet, 1988)).

Point Id: L7ma
Study interval: Maastrichtian
Location: Red Bird, Wyo.; T. 38 N., R. 67 W. and T. 39 N., R. 62 W.; general lat 43°22', long 104°30'
Type of data: outcrop
Data:

Thickness of study interval	=	1,187 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		(Dorf, 1942, p. 91)

Comments: One coal bed 1.5 m thick was reported in the Lance Formation, 32 km southwest of Red Bird (Hancock, 1921).
Age: The base of the interval is picked 329 m below the top of the Pierre Shale where the lowest *Baculites reesidei* was found (Gill and Cobban, 1966a, unit 69). The Cretaceous-Tertiary boundary (top of Lance Formation) is picked above the unit containing *Triceratops* and below the first coal of the Paleocene Fort Union Formation (Dorf, 1942).
Stratigraphy: The thickness of the Lance Formation is from Dorf (1942). Thicknesses of the Fox Hills Sandstone and the Maastrichtian part of the Pierre Shale are measured from Gill and Cobban (1966a, pl. 2).

Lance Formation	=	774 m
Fox Hills Sandstone	=	84 m
Pierre Shale (part)	=	329 m

Depositional environments: The Pierre Shale is marine; the Fox Hills Sandstone is nearshore marine; and the Lance Formation is nonmarine.

Point Id: L8ma
Study interval: Maastrichtian
Location: Blackstone River, Alberta; T. 43, R.16 W5; general lat 52°45', long 116°15'
Type of data: outcrop
Data:

Thickness of study interval	=	625 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		≈ 3.5 m in 7 beds

Comments: This data point is continued from L12ca.
Age: The base of the interval is picked 450 m below the top of the Brazeau Formation above which the Maastrichtian palynomorph *Wodehouseia* was found (Jerzykiewicz and Sweet, 1988, p. 32, 56). Below this horizon, Campanian palynomorphs were found (Jerzykiewicz and Sweet, 1988, p. 46, 54) that are indicative of the lower part of the *Aquilapollenites quadrilobus* zone of Nichols and others (1982, pl. 1). The Cretaceous-Tertiary boundary (also based on palynology) occurs at the base of the first coal bed above the "Entrance Conglomerate," 175 m above the base of the Coalspur Formation.
Stratigraphy: Both formations are part of the Saunders Group. The thickness data are from Jerzykiewicz and Sweet (1988, fig. 2). The coal data are from Jerzykiewicz and Sweet (1988, fig. 19).

Coalspur Formation (part):		
"Entrance Conglomerate"	=	175 m
Brazeau Formation (part)	=	450 m

Depositional environments: The Maastrichtian parts of both formations are of fluvial origin. The Brazeau Formation contains the thin coal.

Point Id: L9ma
Study interval: Maastrichtian
Location: Castle Gardens, Wind River basin, Wyoming; T. 34 N., R. 90 W.; general lat 43°, long 107°40'
Type of data: outcrop
Data:

Thickness of study interval	=	262 m
Cumulative thickness of coal beds	=	2.7 m
Average coal bed thickness	=	1.4 m
Maximum coal bed thickness	=	1.5 m
Number of coal beds	=	2
Percent of interval that is coal	=	1
Coal beds < 1 m thick	2.7 m in 9 beds	

Comments: The maximum recorded coal thickness in the basin is 5 m (Keefer, 1965, p. A62).

Age: The base of the interval is picked at the base of the Meeteetse Formation because the top of the underlying Teapot Sandstone Member of the Mesaverde Formation corresponds with the zone of *Baculites reesidei* (Gill and Cobban, 1973, p. 25). Also *B. eliasi* was found in the lower part of the lower tongue of the Lewis Shale (Keefer, 1965, p. A10), which intertongues with the Meeteetse Formation. The Cretaceous-Tertiary boundary is picked at the base of the Castle Gardens sandstone of the Lance Formation (Keefer, 1965, p. 63, 64, units 44–53). The Castle Gardens sandstone is included at the base of a 67 m section dated as earliest Paleocene (P1 zone of Nichols and others, 1982) in Flores and others (1992, fig. 9). Cretaceous palynomorphs found in the Castle Gardens sandstone (Keefer, 1965, p. 64) have been determined to be reworked (R.M. Flores, oral commun., 1993).

Stratigraphy: Coal and formation thickness data are from Keefer (1965, p. A63–64). The Lance thickens to 1,563 m, 40 km to the north. There is an unconformity at the top of the Meeteetse Formation.

Lance Formation	=	0 m
Meeteetse Formation	=	262 m

Depositional environments: The Meeteetse Formation is fluvial, nearshore marine, and coastal plain, and contains coal. The Meeteetse intertongues with the marine Lewis Shale in other parts of the basin.

Point Id: L10ma
Study interval: Maastrichtian
Location: Shoshone River at Cody, Wyo.; western Big Horn basin; general lat 44°32', long 109°03'
Type of data: outcrop
Data:

Thickness of study interval	=	884 m
Cumulative thickness of coal beds	=	1.4 m
Average coal bed thickness	=	1.4 m
Maximum coal bed thickness	=	1.4 m
Number of coal beds	=	1
Percent of interval that is coal	=	< 0.5
Coal beds < 1 m thick	nearby, as many as 5 beds <0.03 m	

Comments: none

Age: The base of the interval is picked at the base of the Meeteetse Formation. The top of the underlying Mesaverde Formation is considered equivalent to the top of the Teapot Sandstone Member. The Teapot Sandstone Member is recognized in the southern Bighorn basin (Gill and Cobban, 1966b, p. B25) and corresponds with the zone of *Baculites reesidei* (Gill and Cobban, 1973, p. 25). The Cretaceous-Tertiary boundary is at the unconformable contact between the top of the Lance and the overlying Paleocene Fort Union Formation.

Stratigraphy: Thickness and coal data are for the "Ilo Formation" (abandoned) from Hewett (1914). A change in the nomenclature for this area was documented in Hewett (1926).

Lance Formation ("Ilo Formation")	=	546 m
Meeteetse Formation	=	338 m

Depositional environments: Both formations are nonmarine. Thin, lenticular coals occur in the upper part of the Meeteetse; no coal is found in the Lance Formation at this locality.

Point Id: L11ma
Study interval: Maastrichtian
Location: Southern Washakie basin; Baggs, Wyo.; T. 15 N., R. 91 W.; lat 41°15', long 107°38'
Type of data: well log and outcrop, composite
Data:

Thickness of study interval	=	1,580 m
Cumulative thickness of coal beds	=	8.8 m
Average coal bed thickness	=	1.5 m
Maximum coal bed thickness	=	1.7 m
Number of coal beds	=	6
Percent of interval that is coal	=	0.6
Coal beds < 1 m thick	0.6 m in 1 bed (Lance) and 6.9 m in 12 beds (Almond)	

Comments: The maximum coal thickness in the area is 4.3 m.

Age: The base of the interval is picked at the base of Almond Formation, which contains *Baculites reesidei* in the Rawlins uplift, 100 km to the northeast (Gill and others, 1970). The Cretaceous-Tertiary boundary is picked based on palynology within the unnamed K/T sandstone unit (Hettinger and others, 1991).

Stratigraphy: Data on the Lewis Shale and Almond Formation are from Barclay (1980a). The coal data are from drill hole DM-D56 in Barclay (1980a). Thickness data on the Lance, Fox Hills, and unnamed K/T unit are from Honey and Roberts (1989).

unnamed K/T Sandstone (part)	=	104 m
Lance Formation	=	512 m
Fox Hills Sandstone (average thickness in the area)	=	53 m
Lewis Shale	=	762 m
Almond Formation	=	149 m

Depositional environments: The Almond Formation is nonmarine, coastal plain, marginal marine, and marine, and contains coal throughout; the Lewis Shale is marine; the Fox Hills Sandstone is nearshore marine; the Lance Formation is nonmarine and coastal plain and contains coal in the lower part; and the unnamed K/T unit is fluvial with an unconformity at the top of the Cretaceous part.

Point Id: L12ma
Study interval: Maastrichtian
Location: Livingston, Mont.; SW Crazy Mountain basin; T. 2 N., Rs. 8, 9 E.; lat 45°39', long 110°42'
Type of data: outcrop
Data:

Thickness of study interval	=	1,663 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: This is a continuation of M10ca.

Age: The base of the interval is picked 283 m below the top of the Miner Creek Formation at the base of unit 77, section 17 (Roberts, 1972— paleobotany locality D1612), which contains palynomorphs indicative of the upper part of the *A. quadrilobus* interval zone and thought to have an early Maastrichtian age (Tysdal and Nichols, 1991, p. 17). The Cretaceous-Tertiary boundary is picked at the base of the middle member of the Fort Union Formation, based on palynomorphs (Roberts, 1972, p. 54).

Stratigraphy: Thicknesses are from sections 17, 18, 19, and 20 (Roberts, 1972).

Fort Union Formation (Cretaceous part)	=	297 m
Hoppers Formation	=	294 m
Billman Creek Formation	=	789 m
Miner Creek Formation (part)	=	283 m

Depositional environments: Entire section is nonmarine. The Miner Creek Formation consists of volcaniclastics, the Billman Creek Formation is grayish red as result of weathering of volcanic deposits, and the Hoppers Formation consists mostly of volcanic lithic sandstone (Roberts, 1972).

Point Id: L13ma
Study interval: Maastrichtian
Location: Porcupine dome area, east-central Montana; T. 5 N., R. 38 E. and Tps. 6, 7 N., Rs. 39, 40 E.; lat 46°33', long 106°53'
Type of data: outcrop, composite section
Data:

Thickness of study interval	=	366 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked 116 m below the top of the Bearpaw Shale at the level of the *Baculites reesidei* zone (base of unit 65, Gill and others, 1972, p. 94). The Cretaceous-Tertiary boundary is the contact of the Hell Creek Formation and the overlying Tullock Member of the Paleocene Fort Union Formation. The base of the lowest lignite bed is the base of the Tullock Member. *Triceratops* bones were found 15 m below top of Hell Creek Formation (Rogers and Lee, 1923, p. 28).

Stratigraphy: Thickness data for the Bearpaw Shale and Fox Hills are from Gill and others (1972); thickness of the Hell Creek Formation ("lower Lance") is from Rogers and Lee (1923).

Hell Creek Formation	=	247 m
Fox Hills Sandstone	=	3 m
Bearpaw Shale (part)	=	116 m

Depositional environments: The Bearpaw Shale is marine; the Fox Hills Sandstone is nearshore marine; and Hell Creek Formation is nonmarine floodplain deposits with a possible unconformity at the base.

Point Id: L14ma
Study interval: Maastrichtian
Location: Fort Peck area, Montana; T. 26 N., Rs. 42, 43 E.; lat 48°03', long 106°19'
Type of data: outcrop, composite section
Data:

Thickness of study interval	=	166 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	None	

Comments: none

Age: The base of the interval is approximately 38 m below the top of the Bearpaw Shale where *Acanthoscaphites brevis* and *A. quadrangularis* occur (middle part of unit 6, Jensen and Varnes, 1964). These fossils possibly occur within the *Baculites reesidei* zone (Jeletzky, 1968). Also, the upper Campanian index fossil *B. compressus* is found in the underlying unit 5 (Jeletzky, 1968). The Cretaceous-Tertiary boundary is the top of the Hell Creek Formation (which contains dinosaur remains) and the base of the lowest lignite of the overlying Paleocene Fort Union Formation.

Stratigraphy: Bearpaw Shale thickness is from Jensen and Varnes (1964). Thickness data for the Fox Hills and Hell Creek (estimated thickness) are from Jensen (1951).

Hell Creek Formation	=	91 m
Fox Hills Sandstone	=	37 m
Bearpaw Shale (part)	≈	38 m

Depositional environments: The Bearpaw Shale is marine; the Fox Hills Sandstone is nearshore marine; and the Hell Creek Formation is nonmarine floodplain deposits with a possible unconformity at the base. Fastovsky and McSweeney (1987) reported paleosols in the uppermost Hell Creek Formation.

Point Id: L16ma
Study interval: Maastrichtian
Location: Golden, Colo.; Tps. 2, 3 S., R. 70 W.; lat 39°50', long 105°14'
Type of data: outcrop and core hole, composite
Data:

Thickness of study interval	=	1,421 m
Cumulative thickness of coal beds	=	4.9 m
Average coal bed thickness	=	2.5 m
Maximum coal bed thickness	=	3.4 m
Number of coal beds	=	2
Percent of interval that is coal		<0.5
Coal beds < 1 m thick	6.5 m in 17 beds	

Comments: Maximum thickness of coal reported in the field is 4.3 m.

Age: The base of the interval is picked at the base of the *B. reesidei* zone in the middle of the Pierre Shale (Van Horn, 1976, p. 21). The Cretaceous-Tertiary boundary is in the lower part of the Denver Formation—above remains of *Triceratops* and below Puercan mammals (Newman, 1987, p. 153).

Stratigraphy: All formation thicknesses are from Van Horn (1976, p. 31, 34, 35, 37). Coal data are from hole LE-2 at the Leyden mine (Gude and McKeown, 1952, thicknesses adjusted according to angle of drill hole and dip of strata).

Denver Formation (part)	=	78 m
Arapahoe Formation	=	26 m
Laramie Formation	=	223 m
Fox Hills Sandstone	=	21 m
Pierre Shale (part)	=	1,073 m

Depositional environments: The Pierre Shale is marine; the Fox Hills Sandstone is nearshore marine; the Laramie (coal in the lower 60 m) and Arapahoe Formations (conglomeratic) are nonmarine; and the Denver Formation is nonmarine (volcaniclastics).

Point Id: L19ma
Study interval: Maastrichtian
Location: South Yellowstone Park, Wyo.; lat 44°, long 110°30'
Type of data: outcrop, composite
Data:

Thickness of study interval	=	2,750 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick	1.7 m in at least 5 beds	

Comments: none

Age: The Harebell Formation is considered Maastrichtian in age based on a collection of pollen and spores that are equivalent to those found in the Lance Formation and (or) the Lewis Shale, the Kirtland Shale, and the Hell Creek Formation (Guennel and others, 1973). J.D. Love measured only partial sections of the Harebell Formation; however, the most complete section is about 2,750 m (Love, 1973, p. A7, A10, section 2). The Harebell is unconformably overlain by the Paleocene Pinyon Conglomerate and unconformably overlies the Bacon Ridge Sandstone (Love, 1973).

Stratigraphy: Coal data are from the type section of the Harebell Formation (Love, 1973).

Harebell Formation	≈	2,750 m

Note: The Harebell Formation ranges in thickness from 15 to 245 m to the south along the Gros Ventre drainage (Lindsey, 1972).

Depositional environments: The Harebell Formation consists primarily of continental alluvial deposits; however, fossil evidence suggests proximity to marine environments. Thin coals exist in the lower part of the Harebell Formation.

Point Id: M1ma
Study interval: Maastrichtian
Location: Big Bend, Tex.; lat 29°20', long 103°08'
Type of data: outcrop
Data:

Thickness of study interval	=	190 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: The Campanian-Maastrichtian boundary is in question; the Maastrichtian may be thicker by a maximum of 50 m.

Age: The age of the Javelina Formation is based on the presence of dinosaurian *Alamosaurus* fauna, which is considered to be middle to late Maastrichtian (Lancian after Russell, 1975). The highest occurrence of *Alamosaurus* approximates the Cretaceous-Tertiary boundary (Lehman, 1989). The lowest occurrence of *Alamosaurus* is about at the base of the Javelina Formation. The underlying Aguja Formation contains the genus *Kritosaurus*, which has Judithian affinities and is therefore late Campanian in age (see Lillegraven and Ostresh, 1990).

Stratigraphy: Thickness based on Lehman (1989, fig. 1b, section 12).

Javelina Formation (part) = 190 m
Aguja Formation (Campanian II)

Depositional environments: The Javelina Formation is a fluvial section with numerous paleosols. Paleosols are pale gray, purple, or red and contain calcite nodules and coalesced masses of nodules.

Point Id: M2ma
Study interval: Maastrichtian
Location: North Horn Mountain, Utah; T. 18 N., R. 6 W.; lat 39°15', long 111°15'
Type of data: outcrop
Data:

Thickness of study interval	=	150 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None

Comments: none

Age: The base of the interval is picked at the base of the North Horn Formation according to Fouch and others (1983, fig. 8). The underlying Price River Formation contains palynomorphs of late Campanian age (Fouch and others, 1983). The Cretaceous-Tertiary boundary is probably about 150 m above the base of the formation. The lower 150 m of the North Horn Formation contains dinosaur remains that were identified as the Maastrichtian genus *Alamosaurus* (Spieker, 1946, p. 134–135; Gilmore, 1946).

Stratigraphy: The North Horn Formation has an unconformity at the base. Thickness data from (Spieker, 1946).

North Horn Formation (part) = 150 m

Depositional environments: The unit is fluvial to lacustrine and contains pedogenic limestone nodules and variegated beds (Fouch and others, 1983).

Point Id: M3ma
Study interval: Maastrichtian
Location: Southwest San Juan Basin, N. Mex.; T. 24 N., R. 11 W.; lat 36°20', long 108°
Type of data: outcrop
Data:

Thickness of study interval	=	41 m
Cumulative thickness of coal beds	=	0
Average coal bed thickness	=	0
Maximum coal bed thickness	=	0
Number of coal beds	=	0
Percent of interval that is coal	=	0
Coal beds < 1 m thick		None (see comment)

Comments: Thin lignites are present laterally in the upper shale member of the Kirtland Shale.

Age: The base of the interval is placed at the base of the Farmington Sandstone Member of the Kirtland Shale. Maastrichtian palynomorphs are found in the Farmington Sandstone Member (Newman, 1987; locality 8); Newman (1987) included the upper shale member and part of the Farmington Sandstone Member in the Maastrichtian (maximum thickness 380 m). Lehman (1985b) cited *Torosaurus* and *Alamosaurus* specimens from the Naashoibito Member, which are indicative of a Maastrichtian age (he also included the upper shale member and part of the Farmington Sandstone Member in the Maastrichtian). The top of the interval is arbitrarily placed at the top of the Naashoibito Member. Cretaceous dinosaur remains and Paleocene mammal fossils have been found in the overlying Ojo Alamo Sandstone; however, there is disagreement on an age assignment because some workers think the dinosaur remains may be reworked while others do not (Lehman, 1985b; Lucas and others, 1987).

Stratigraphy: Thicknesses are from Baltz and others (1966, pl. 1, section 9). Other thicknesses around the San Juan Basin range from 0 to 380 m (Newman, 1987).

Kirtland Shale (part):

Naashoibito Member	=	17 m
upper shale member	=	18 m
Farmington Sandstone Member	=	6 m

Depositional environments: All units are terrestrial. Thin lignites are present in the upper shale member. The Naashoibito Member is fluvial with purple mudstones interpreted as soils by Lehman (1985b).

Point Id: M4ma
Study interval: Maastrichtian
Location: Raton Basin, Colorado and New Mexico; T. 31 N., R. 18 E., Vermejo Park, N. Mex.; lat 36°54', long 105°
Type of data: outcrop section
Data:

Thickness of study interval	=	407 m
Cumulative thickness of coal beds	=	4.8 m
Average coal bed thickness	=	1.2 m
Maximum coal bed thickness	=	2.0 m
Number of coal beds	=	4
Percent of interval that is coal	=	1.2
Coal beds < 1 m thick		2.0 m in 5 beds

Comments: There are coals as much as 4 m thick in the basin.

Age: The base of the interval is picked 134 m below the top of the Pierre Shale. In the Raton Basin, Cobban (1962, p. 131) reported *Baculites jenseni* in the Pierre Shale 43 m below the base of the overlying Trinidad Sandstone; some undetermined thickness of the Pierre belongs in the *B. reesidei* zone. In Canon City, 145 km to the north, the underlying *B. reesidei* zone is as much as 91 m thick (Scott and Cobban, 1975). Therefore, we arbitrarily include 91 m of Pierre in the *B. reesidei* zone (total Maastrichtian Pierre: 43+91=134). The Cretaceous-Tertiary boundary in the Raton Basin is located at an iridium-bearing altered volcanic ash 127 m above the base of the Raton Formation (Pillmore and Flores, 1987). A major unconformity is present at the base of the Raton Formation.

Stratigraphy: Thickness of the Trinidad and Vermejo Formations and coal thickness data in the Vermejo Formation are from Lee (1917, section 123, pl. 17) and thickness data for the Raton Formation are from Pillmore and Flores (1987, section at Vermejo Park, fig. 3).

Raton Formation (part)	=	127 m
Vermejo Formation	=	113 m
Trinidad Sandstone	=	33 m
Pierre Shale (part)	=	134 m

Depositional environments: The Pierre Shale is marine and the Trinidad Sandstone is nearshore marine. The Vermejo and Raton Formations are fluvial. Coals are present in the Vermejo.

Point Id: M5ma
Study interval: Maastrichtian
Location: Hanna basin, Wyoming; Tps. 23, 24 N., Rs. 83–85 W.; lat 42°03', long 106°54'
Type of data: composite outcrop section
Data:

Thickness of study interval	=	2,812 m
Cumulative thickness of coal beds	=	2.4 m
Average coal bed thickness	=	2.4 m
Maximum coal bed thickness	=	2.4 m
Number of coal beds	=	1
Percent of interval that is coal	=	0.1
Coal beds < 1 m thick		10.5 m in 16 beds

Comments: none

Age: The base of the interval is picked at the base of the Almond Formation because several specimens of *Baculites reesidei* were found in the lower Almond in southern Wyoming (Gill and others, 1970, fig. 2); the *B. reesidei* zone could range into underlying Pine Ridge Sandstone, but we arbitrarily pick the base of the Maastrichtian interval at the base of the Almond Formation. The top of the interval is picked 335 m above the base of the Ferris Formation based on a collection of palynomorphs from this interval, including the genera *Proteacidites* and *Aquilapollenites* (Gill and others, 1970, p. 46). The upper part of the Ferris contains palynomorphs that suggest a Paleocene age.

Stratigraphy: Thickness data are from Merewether (1972) except for the Ferris Formation, which is from Gill and others (1970, p. 46). Coal data are from Dobbin and others (1929, pl. 8, 11).

Ferris Formation	=	335 m
Medicine Bow Formation	=	1,480 m
Fox Hills Sandstone	=	142 m
Lewis Shale	=	700 m
Almond Formation	=	155 m

Depositional environments: There is a marine shale tongue at the base of the Almond Formation, above which occur some thick and some minor discontinuous coal beds, in coastal plain deposits. The Fox Hills Sandstone is nearshore marine and the Lewis Shale is shoreface and marine. The Medicine Bow is nonmarine and contains the bulk of the coal, albeit thin. The Ferris Formation is nonmarine.

Point Id: M6ma
Study interval: Maastrichtian
Location: Sabinas Basin, Coahuila, Mexico; lat 27°45', long 101°15'
Type of data: outcrop
Data:

Thickness of study interval	=	1,019 m
Cumulative thickness of coal beds	=	1 m
Average coal bed thickness	=	1 m
Maximum coal bed thickness	=	1 m
Number of coal beds	=	1
Percent of interval that is coal	=	0.6
Coal beds < 1 m thick		0.5 m in 1 bed

Comments: none

Age: The base of the study interval is arbitrarily picked as the base of the Olmos Formation. The underlying San Miguel Formation contains *Exogyra ponderosa* (Robeck and others, 1956, p. 86), which indicates an age older than the Maastrichtian. The Olmos Formation has no diagnostic fossils. The top of the interval is placed at the top of the Múzquiz Formation. In Coahuila, the Múzquiz Formation intertongues with the Escondido Formation (McBride and Caffey, 1979), which contains *Coahuilites sheltoni* in the lower part of the unit and *Sphenodiscus pleurisepta* in the upper part (Bose, 1912). Young (1986b) showed these ammonites to be indicative of the Maastrichtian. The Múzquiz also contains *Coahuilites sheltoni* (Robeck and others, 1956, p. 39). The Múzquiz is overlain by Tertiary conglomerates (Robeck and others, 1956).

Stratigraphy: Thickness data from Robeck and others (1956, El Cedral no. 1).

Múzquiz Formation	=	430 m
Escondido Formation	=	208 m
Olmos Formation	=	381 m
San Miguel Formation (Campanian)		

Depositional environments: McBride and Caffey (1979). The Olmos Formation is coastal plain to fluvial with coal at the base. The Escondido is mostly marine with some nearshore marine. The Múzquiz Formation is terrestrial with red and purple mudstones and is conglomeratic in part (Robeck and others, 1956).

Point Id: M8ma
Study interval: Maastrichtian
Location: Sand Wash basin, Colorado; Tps. 5–9 N., Rs. 90, 91 W.; lat 40°30', long 107°15'
Type of data: composite from well logs and outcrop
Data:

Thickness of study interval	=	1,372 m
Cumulative thickness of coal beds	=	18.9 m
Average coal bed thickness	=	2.1 m
Maximum coal bed thickness	=	4.2 m
Number of coal beds	=	9
Percent of interval that is coal	=	1.4
Coal beds < 1 m thick		4.3 m in 8 beds

Comments: none

Age: The base of the Maastrichtian is picked in the Williams Fork Formation at the base of the shale tongue below the Twentymile Sandstone Member. This shale tongue contains *Baculites reesidei* 42 km to the east at Fish Creek (Izett and others, 1971, fig. 2, see M8ma). The top of the Maastrichtian is based on correlations by Honey and Hettinger (1989), who collected palynomorphs from their K/T sandstone unit. They found *Aquilapollenites* in the lower part of the sandstone unit and *Momipites* in the upper part (Honey and Hettinger, 1989).

Stratigraphy: Coal data for the Williams Fork Formation are from Hancock (1925, pl. 18, Yampa River section) and coal data for the Lance are from Bass and others (1955, pl. 24, section 423). Thickness of the Williams Fork Formation is from Bass and others (1955, pl. 20, section 1). Thickness of the Lewis is measured from the base of the "datum" in the Carter Oil drill hole in T. 8 N., R. 90 W. (Irwin, 1986, fig. 3) to the base of the Fox Hills Sandstone. This datum correlates to the top of the Williams Fork in sections up depositional dip where the coal data for this data point were collected. Thickness of the Fox Hills Sandstone was estimated from the Cities Service drill hole in T. 9 N., R. 90 W. (Honey and Hettinger, 1989; Irwin, 1986, fig. 4). Thicknesses of the Lance Formation and the Cretaceous part of the K/T sandstone unit come from the Cities Service drill hole (Honey and Hettinger, 1989).

Cretaceous-Tertiary sandstone unit (part)	=	82 m
Lance Formation	=	280 m
Fox Hills Sandstone	=	61 m
Lewis Shale	=	602 m
Williams Fork Formation (part)	=	347 m

Depositional environments: The Williams Fork Formation is nearshore marine to coastal plain and contains the majority of the coal. The Lewis Shale is offshore marine, and the Fox Hills Sandstone is nearshore marine with minor thin coals. The Lance Formation is coastal plain to alluvial plain with minor thin coals and one thick coal (4.2 m) in the lower one-third of the unit.

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