5-16-1947

Upper Cretaceous Sediment in Montana

Frank J. Frankovich

UPPER CRETACEOUS SEDIMENTATION IN MONTANA

A Thesis
Presented to
The Department of Geology
Montana School of Mines

In partial Fulfillment
of the Requirements for the Degree
of Bachelor of science in Geological Engineering

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LIST OF PLATES

LIST OF TABLES

TABLE OF CONTENTS

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INTRODUCTION

Cretaceous sediments in Montana record events during a period of unusual geologic interest. After a long period of extensive submergence of the area during Jurassic time, came a period of varying continental and marine deposition with consequent variations in the types of sediments laid down. A study of these variations, their extent, and their cause has been the primary object of this thesis. Usually detailed descriptions of Cretaceous sediments are limited to very small areas, the overall picture being neglected. The writer has attempted to fill this gapby trying to give a description of the overall sedimentary record of this period.

During Montana time geographic conditions differed considerably with the fluctuating shorelines. So far as the writer is aware these geographic conditions during the various stages of Montana time (Upper Cretaceous) have been described only in a very general way. Usually paleogeography is described only incidental to some other geologic consideration. The writer has therefore attempted to draw a more complete paleogeographic picture of this period. The detailed picture, that is, the rivers, deltas, and climates existing at this time, has not been attempted since that would require a lengthy field study of the actual sediments in place. Rather, the main effort was devoted to determining the areas of marine and continental deposition, the areas of coastal marshes, and the general location of the sources of sediments.

The source of information for this study was the geologic literature on the sediments of Montana. It is the writer's opinion that enough sufficiently descriptive material has been written on the Upper Cretaceous of Montana to provide adequate data for this problem.

Collecting and recording in a useful way the scattered information contained in the abundant literature on this subject at first posed quite a problem. Several methods of procedure were tried, and the one finally adopted proved to be the simplest and most useful. It is as follows. A series of eight prints of the State of Montana were made and each labeled with the name of an individual formation in the Upper Cretaceous. These were assembled into a workbook with blank pages between to provide space for notes. Whenever a pertinent fact (such as lithology, thickness, etc.) was encountered in the literature, it was entered in the right locality on the map of the formation concerned. After sufficient information had been recorded, the overall picture became apparent--that is, direction of thinning, direction of probable sources of sediments, and areal distribution. The text of this thesis is then a summary of this information.

The author wishes to express the deepest thanks and appreciation for the direction and advice received from Dr. E. S. Perry. His suggestions concerning the general plan of the thesis and the use of diagrams were invaluable. His permission to use the mimeographed geological correlation table is also much appreciated.

GENERAL NORTH AMERICAN UPPER CRETACEOUS PALEOGEOGRAPHY

Upper Cretaceous time saw extensive submergence of land areas in the United States with considerable transgression of the seas over the continent. From Cape Cod to Texas, the Atlantic and Gulf shorelines of the preceding period had retreated. From the Gulf to the Arctic marine waters then spread over what is now the Great Plains and the eastern Rocky Mountains. The Pacific transgressed the shores of California and Oregon. Farther north, however, from British Columbia to Alaska the land emerged somewhat.

In the central west, from New Mexico to Alberta, the invasion of the sea was followed by progressive emergence of the area (see Plate I) and became the site of alternately marine and continental deposition. The surface of the area was built up by sediments which were derived from uplands to the west, and the sediments accumulated about as fast as the sea bottom sank. The area thus formed a broad coastal plain between the western uplands and the eastern sea. Extensive marshes prevailed on this plain and locally coal swamps developed. Seas, marshes, and river flood plains alternated in sequence until almost the close of the period; then in the western Montana region certain areas became mountains.

PLATE I

General Distribution of Upper Cretaceous
Lands and Seas of North America.
(After Willis & Sallisbury)

East of the ancient Rocky Mountain coastal plain the inland sea prevailed until the end of the period. It divided the continent, reduced the northern land area, and admitted warm waters to the Arctic. These conditions favored the mild climate which the northern regions then enjoyed.

The close of the Cretaceous was marked by a general retreat of the seas that had prevailed over the continents, possibly because the ocean basins were deepened. In central western North America the land was rising also. The combined effect was to withdraw the waters of the sea to the Gulf on the south and to the Arctic to the north.

Table 2. Correlation chart of formations in Wyoming, Montana, and Alberta (Modified after U.S.G.S.)

AGE		Central Wyoming	Black Hills area Wyoming	North-central Wyoming	South-central Montana	Central Montana	North-central Montana	Alberta Canada
Quaternary		Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary	Quaternary
Tertiary	Miocene				Pliocene ?			
	Oligocene	White River						Oligocene
	Eocene	Wind River		Wind River	Wasatch			?
		Fort Union	Fort Union	Fort Union	Fort Union	Fort Union		Paskapoo
Cretaceous	Upper Cretaceous	Lance	Lance	Lance	Lance	Lance	Willow River St.Mary River	Edmonton and St. Mary River
		Lewis	Fox Hills		Lennep		Horsethief	
				Bearpaw	Montana: Bearpaw	Bearpaw	Bearpaw	Bearpaw
		Mesaverde: Teapot	Pierre	Judith River	Montana: Judith River	Judith River	Two Medicine	Belly River
		Mesaverde: Parkman		Claggett	Montana: Claggett / Parkman	Claggett		
		Steele / Shannon		Eagle	Montana: Eagle	Eagle		
					Montana: Telegraph Creek		Virgelle	
		Niobrara	Niobrara	Niobrara	Colorado: Niobrara	Colorado	Colorado	Colorado
		Carlile	Carlile	Carlile	Colorado: Carlile			
		Frontier: Wall Creek	Greenhorn	Frontier	Colorado: Frontier: Torchlight			
		Frontier: Peay	Graneros		Colorado: Frontier: Peay			
		Mowry	Graneros: Mowry	Mowry	Colorado: Mowry			
		Thermopolis		Thermopolis			Blackleaf	
		Dakota	Dakota	Cloverly: Greybull	Greybull	Kootenai	Kooteani	Kootenai
	Lower Cretaceous	Lower Cretaceous	Fuson	Cloverly	Cloverly			
			Lakota	Cloverly: Lakota				
Jurassic		Morrison	Morrison	Morrison	Morrison	Morrison ?	Morrison ?	?
		Sundance	Sundance	Sundance	Sundance	Ellis	Ellis	Fernie
Triassic		Chugwater	Spearfish Minnekahta	Chugwater	Chugwater	Absent	Absent	?
Carboniferous	Permian	Embar	Opeche	Embar	Embar ?			Upper Banff Shale
	Pennsylvanian	Tensleep	Minnelusa	Tensleep	Tensleep	Absent	Absent	Upper Banff Limestone
		Amsden	?	Amsden	Amsden	Amsden ?		
	Mississippian					Big Snowy		
		Madison	Pahasapa	Madison	Madison	Madison	Madison	Lower Banff Shale Lower Banff Ls.
Devonian		Absent	Absent	Absent	Absent ?	Jefferson ?	(Anhydrite) ?	Devonian
Silurian		Absent	Absent	Absent	Absent	Absent ?	Absent	Silurian
Ordovician		Big Horn	Absent	Big Horn	Big Horn	Absent ?	?	Ordovician
Cambrian		Deadwood	Deadwood	Deadwood	Cambrian	Cambrian	Cambrian	Cambrian

TABLE I (Taken from Mont. Bur. of Mines and Geol. Miscellaneous Contributions No. 8)

-x-

DESCRIPTION OF FORMATIONS

Colorado Group

Lowermost of the Upper Cretaceous sediments are those of the Colorado Group. The name comes from exposures along the east base of the Colorado or Front Range in Colorado. These strata are present throughout most of Montana, and range in thickness from 1800 to 2500 feet. They are essentially dark fissile marine shales with a few scattered sandstones. This is a remarkably uniform and persistent group, and is recognized from southern Alberta to northeastern New Mexico, and eastward to Nebraska and Iowa. It is conformable with the underlying Dakota sandstone and the Kootenai, and likewise with the overlying Eagle sandstone and the Telegraph Creek formation.

In south central Montana and Wyoming the Colorado can, on a lithologic basis, be differentiated from top to bottom into the following formations: Niobrara and Carlile shales, the Frontier shale and sandstone, and the Mowry and Thermopolis shales. The sandstones thin markedly to the east and north. In northern Montana the Colorado cannot readily be differentiated on a lithologic basis, but perhaps it can be done if based on sufficient paleontologic evidence. For practical purposes geologists and drillers find that in northern Montana it is convenient to group the Colorado as one unit with the lower 400 or 500 feet designated as the Black Leaf sandy member.

Thermopolis Shale. The Thermopolis shale is a mass of dark argillaceous rocks making up the basal formation of the Colorado group. It was named for exposures near the town of Thermopolis, Wyoming by D. F. Hewett and C. F. Lupton (7, page 19). It is limited below by the upper sandstone of the Cloverly formation, and above by the base of the Mowry shale, with both of which formations it is conformable.

The formation is mainly dark shale, but is sandy near its base and top, and contains a persistent sandstone (Muddy sand of drillers) near its middle. The sandy shale of the base passes upward into a uniform body of regular thin-bedded fissile carbonaceous shale, which is identical in appearance and character with the upper shaly portion.

Above the lower shale member in southern Montana occurs a thin fluvial sandstone which ranges from a few inches to 30 feet in thickness. The sandstone is normally coarse grained to pebbly in channels cut in the underlying shale. It contains much organic debris in the form of plant fragments, fish teeth, and bits of bone and turtle shell. The uniform occurrence of the coarse grained sandstone as a thin sheet between channels suggests that it was deposited on a slightly submerged mud flat over which streams of considerable size meandered. (8, page 28).

The upper shale member is very similar to the lower, and becomes more sandy upward where it grades into the Mowry shale. It contains several persistent beds of greenish-yellow bentonite and in the middle portion numerous beds of gray alkaline clay.

As the Thermopolis shale is traced north and eastward, the middle sandstone member is replaced by a dark unit of ferruginous clay and bentonite. Throughout all of northern and eastern Montana the Thermopolis can not be distinguished from the other shales in the Colorado except by paleontological evidence.

In northcentral Montana, north and west of Great Falls, several sandstone members appear in strata equivalent to the Thermopolis; and this portion of the Colorado, together with the lower portion of the Mowry are grouped together and designated the Black Leaf member. A zone of bentonite occurs about 500 to 600 feet above the base, and at the Mowry horizon, is persistent for many miles east and west of Great Falls.

Mowry Shale. The Mowry beds are a mass of siliceous shales and thin bedded sandstones that are recognized over a broad area--from the west side of Big Horn Basin to the Black Hills and from northern Montana to the Uinta Basin, utah. Over northern and eastern Montana it shows an unusual uniformity in thickness of between 100 and 150 feet, but in southwestern Montana it may be 300 feet. Unfailingly large numbers of fish scales are found in the Mowry, and no less remarkable is the almost complete absence of identifiable fish bones and vertebrae.

This formation was named for Mowry Creek, northwest of Buffalo, Wyoming by N. H. Darton (3, page 400) in 1904. In south central Montana, according to Knappen (8, page 30) the Mowry "consists of interbedded black shale and gray sandstone and sandy shale." On a freshly broken surface it is brown or black in color, but on weathering it becomes light-colored, and breaks into porcelain-like debris. A. J. Collier writes that "thin sections under the microscope show that this shale consists of small, angular grains of quartz interbedded with a dark amorphous substance, probably carbon." Some writers attribute the siliceous character of the Mowry to the deposition of silica which was dissolved out of volcanic ash dropped into the overlying seas.

The equivalent of the Mowry in Montana northwest of Great Falls is the upper portion of the Blackleaf sandy member; in eastern Wyoming and the Black Hills region it is known also as the Aspen. The Mowry shale is one of the best known and most reliable horizon markers within the Colorado in the northern Great Plains.

Frontier Formation. The type locality of the Frontier formation, named by W. E. Knight (8, page 32), is near a town of the same name in southwestern Wyoming. Here the formation is a sandy shale, and is coal bearing. It is a very fine-grained marine formation which is about 2000 feet thick.

The Frontier is known as such in Montana, Wyoming, and northwest Colorado. The limestone equivalent to the east, however, is known as the Greenhorn limestone in North and South Dakotas, Nebraska, and southwest Colorado. The Frontier also contains a thin, commonly fine-grained sandstone which extends over wide areas. It is given the name Ferron in eastern Utah, Codell in Kansas, and Wall Creek in Wyoming.

In the type area the Frontier contains a thin sandstone member near the base called the Peay, and a heavy yellow-brown sandstone member at the top named the Torchlight sandstone. Between the two are black and brown sandy shales. The top and bottom sandstone members thin considerably to the north and east and in the area east and north of Billings they cannot be distinguished with certainty. There the Frontier is 400 feet thick. A line showing the eastern limit of the thick Frontier sands would be drawn from northeast Wyoming across the Montana border at Powder River, through Billings, and northwest to Harlowton. The Frontier sandstone is not definitely identified in southwestern Montana and western Wyoming.

In north central Montana and southern Alberta the

Frontier cannot at present be distinguished from the remainder of the Colorado, although the gas-producing sands of the Bowdoin-Saco gas field are about at this horizon.

Carlile and Niobrara Shales. These two formations are here considered together since over most of Montana they can not be readily distinguished , one from the other. In northern Montana these marine formations are not ordinarily recognized as separate parts of the Colorado group. These units differ generally from the preceding unit in that they are less sandy in the western margins and less calcareous in the eastern areas.

W. T. Thom, Jr. (16, page 38) describes the Carlile in the Crow Indian reservation area in southern Montana as having a thickness of 425 feet, and consisting mainly of dark marine shales, and having several distinctive zones. At the top, marking the Carlile-Niobrara contact, is a zone of yellow concretions, beneath which is 60 feet of black shale containing many whitish concretions, and below is another zone of yellow concretions. Thirty-five feet lower in the column is a zone of easily recognized thin, hard, rust-red concretions. About 250 feet above the base of the Carlile is a zone containing two streaks of bluish limy shale which at many places weathers into whitish streaks.

The Niobrara shale in the Crow Indian Reservation is about 400 feet thick. The top is composed of blue limy shale, which weathers yellowish, giving the formation its generally characteristic yellowish color. The lower part of the formation also consists of blue shale, and at the base is a zone of large yellow concretions.

In northeast Wyoming the Carlile consists of black fissile shale containing biscuit-shaped concretions and a thin sandstone member at the bottom. The Niobrara in this area consists of 200 feet of chalk and soft limy shales.

The Carlile and Niobrara southwest of Fort Benton consist of dark-gray or black shales in zones 50 to 200 feet thick, alternating with yellowish, rather massively bedded sandstones (8, page 4). Northeast of Fort Benton, however, the rocks are more uniform in composition and color, forming a homogeneous series of leaden-gray clay shales alternating with arenaceous shales. Farther north the Niobrara loses its distinctive and characteristic light-yellow color.

Montana Group

The Montana Group consists of continental and marine sediments which interfinger in an east-west direction, showing a former oscillation of shorelines in the same directions. The group has four formational subdivisions which are in ascending order, the Telegraph Creek, Eagle sandstone, Claggett formation, Judith River formation, and Bearpaw shale. The group is characterized by a general nonpersistence of lithologic units from east to west where continental and littoral sediments wedge out into the group's marine equivalent, the Pierre shale of the Dakotas. The group was named for extensive exposures in Montana, especially along Missouri River.

Telegraph Creek Formation. This is a transitional formation between the marine Colorado and the terrestial Eagle sediments. It is present in south central Montana, and thins rapidly to the north and east, and it thickens considerably to the south in Wyoming. The formation was named by W. T. Thom, Jr. (18, page 38, 1922) in a description of a typically developed section at the head of Telegraph Creek ten miles southeast of Billings. According to Thom it consists of"320 feet of yellow sandy shale parted in the middle by a thin bed of concretionary sandstone which caps an escarpment." Less prominent layers of concretionary sandstone occur in the upper half of the formation. Thom separated the Telegraph Creek formation from the adjacent formations above and below because it contains a fauna comprising both the Montana and Colorado elements. The formation was placed in the Montana group because of its close lithologic affiliations with the overlying Eagle sandstone.

Eagle Sandstone. The Eagle sandstone, named by Weed (18, page 4) from exposures on Eagle Creek, 60 miles northeast of Great Falls, is one of the most conspicuous formations of central Montana. In the type locality the formation as defined by Weed consists of three more or less distinct units--an upper member of thin-bedded sandstone, a middle member of shale, and a lower member of massive ledge-making sandstone. This lower member is so persistent and characteristic over a large area, even where other divisions of the formation are not recognizable, that it seemed desirable to give it a name. Weed named it the Virgelle sandstone member and defined it as "the lower massive ledge-making sandstone of the Eagle sandstone." It is well exposed along the Missouri River eastward from the town of Virgelle, a few miles from Fort Benton. The massive characteristics of the Eagle disappear eastward, and a line tracing the approximate eastward limits of the sandstone would run northward from Sheridan, Wyoming, through Hardin, Montana, Malta, and northeastward to central Saskatchewan where the formation thins out and disappears. Over most of central Montana the Eagle is about 225 feet thick and generally uniform in lithologic character.

The formation thins eastward, and east of the line just mentioned it grades through thin sandstones with shale partings into the massive Pierre shale. The pinching out is not due to unconformity but to seaward thinning of shoal deposits. Northwestward it merges with the Two Medicine formation and cannot be readily differentiated.

C. F. Bowen (2, page 95) describes the Eagle formation in central Montana as consisting of "the dull-gray to brownish massive, ledge-making Virgelle sandstone about 100 feet thick; the middle division of the Eagle is a thin-bedded shaly sandstone; and the upper division is a thick-bedded, resistant sandstone in which large rusty-brown concretions are locally very numerous." The Virgelle in the southern part of the state is gray or buff and massive, but in the north it is grayish white to white and strongly cross-bedded. The formation is a medium-grained sandstone consisting of quartz, feldspar, and black chert with a small amount of mica enclosed in a calcareous matrix.

The middle shale member locally contains coal throughout most of central Montana. The coal ranges from good quality workable seams to very thin shaly seams and lignite. Commonly the coal has coking qualities.

Claggett Formation. The name Claggett was given by Stanton and Hatcher (7, page 13) to the formation overlying the Eagle sandstone because the formation is well exposed in the neighborhood of Judith (Old Fort Claggett) on Missouri River, which therefore becomes the type locality. As originally defined the Claggett is separable into two divisions--a lower one of shale and an upper one consisting predominantly of sandstone and having a thickness of about 500 feet. Stanton and Hatcher included this upper division with the Claggett because it contains a marine fauna, but some geologists do not approve of this. C. F. Bowen(8, page 100) states that there is no sharp line of demarcation between the Claggett and the overlying Judith River beds either in lithology or paleotology, but there is a marked lithologic change between the upper and lower Claggett. It may be concluded therefore that the upper Claggett should have been included in the Judith River.

As the Claggett is traced westward continental or littoral sediments replace the marine, the unit becomes part of the Two Medicine formation. In southwestern Montana the typical Claggett and Bearpaw shales wedge out westward and merge into the tuffaceous Livingston formation which replaces the entire Montana group. In the east, near the Montana border, the Claggett becomes part of the massive Pierre shale.

In south central Montana R. S. Knappen (2, page39) says that the argillaceous material of the Claggett in that area "is a very soft shale and commonly a clay, of light to medium-gray color." There light-gray or white sandstone compose 20 to 40 per cent of the formation in different exposures. At one place the sandstones thicken until they comprise over 40 per cent of the formation, and then thin again further south. In addition to the massive soft sandstone at the base, the upper part of the formation is very sandy. Shale predominates in the central part of the formation.

In central Montana the Claggett consists of 600 to 700 feet of dark-gray shale containing numerous calcareous concretions in which invertebrate fossils occur. The shale is but slightly consolidated and becomes very plastic when wet, and therefore soils resulting from weathering of Claggett shale are referred to as "gumbo." Crystals of selenite occur characteristically in varying quantities in the shale and locally accumulate in considerable quantities on weathered slopes.

Noteworthy are statements concerning the Claggett made by C. F. Bowen, (9, page 125) that "at the top of the formation there is a zone that is especially prolific in large calcareous concretions, many of which show a well-developed cone-in-cone structure. This feature, so far as the writer is aware, is peculiar to the Claggett throughout a large part of Montana and does not occur in either the Colorado or the Bearpaw. It therefore constitutes one criterion for the recognition of the Claggett in central Montana."

Dr. E. S. Perry (10, page 32) says that the "concretions in the upper part of the Claggett shale may be persistent beds 1 to 2 feet thick at intervals of about 50 feet--whereas the concretions in the Bearpaw are not so much confined to definite beds. In general these two formations much resemble one another."

The twofold division of the Claggett persists wherever the formation is known except in northeastern Montana where the upper sandstone becomes irregular and difficult to trace. The Claggett extends northward into Canada where it is known as the Pakowki formation and has the same general lithologic character. The Pakowki in Alberta as M. Y. Williams (19, page 996) describes it, is generally sandy and in the west contains brackish-water fossils. Elsewhere the fauna is sparse but marine. A peculiar feature of the western occurrences of the formation is the presence, at or near the upper and lower contacts, of 2 or 3 inches of fine conglomerate composed of shining polished black argillite pebbles about one-half inch in diameter. The Pakowki (Claggett) shale is from 215 to 330 feet in thickness in southwestern

Alberta and 700 feet thick in the vicinity of Medicine Hat (Eastern Alberta). In the foothills it is replaced by the sandstone of the middle Belly River formation.

Judith River Formation. The Judith River formation is chiefly of fresh or brackish water origin. It was named by Hayden (12, page 97) in 1871 for exposures along Missouri River between the mouths of Judith and Musselshell Rivers, but at that time its stratigraphic position was not understood. In 1903 Stanton and Hatcher determined that the formation is a member of the Montana group. The name Judith River is applied only in east and central Montana. In Canada its equivalents are the Pale and Foremost beds, in the Glacier Park region it is part of the Two Medicine, in southwest Montana it is part of the Livingston, and in Wyoming its equivalent is the upper Mesa Verde formation.

In south central Montana the formation consists of alternating beds of sandstone, sandy clay, and some shale--about 500 feet thick. The formation has an exceedingly variable character. Stanton and Hatcher say: "A detailed section taken at any point is of little value since a similar section made at a distance of only a mile or two would give quite a different sequence of the alternating strata of sandstones and shales."

In spite of this variable character, as the formation is traced northward a threefold division becomes apparent; upper and lower members of essentially sandstone and a middle member of sandstones, sandy clays, and carbonaceous shales. This threefold division is recognizable in southern Alberta and even eastward into the marine equivalent of the Judith River (9, page 15).

In central Montana the lower sandstone is massive, brownish, and poorly cemented, the middle division is ash-gray shale, and the upper division is grayish-white to brown massive and heavy-bedded sandstone. A few miles east of the Musselshell River the continental sediments grade into a marine facies which is in every way similar to the fresh water divisions except that the middle shale member is darker.

The mineralogical composition of the Judith River sandstones is very similar to that of the Eagle sandstone. C. F. Bowen, who has made a thin-section study of these sandstones, concludes that the marine and fresh water facies are as similar in microscopic appearance as they are in outward physical appearance. He finds that they are composed of angular to subangular grains of feldspar, quartz, and black chert, with small amounts of muscovite and biotite enclosed in a matrix or cement of calcite. Most of the feldspar shows very little alteration; many of the grains are perfectly clear and fresh showing no signs of kaolinization. The unusual condition of highly assorted yet angular grains is attributed by Bowen to the cleavage of the feldspar and to their small size (0.075 to 0.2 mm. in diameter).

At many places, particularly in northern Montana, there is near the top of the formation a bed ranging from less than one foot to several feet in thickness that is made up almost wholly of shells of "Ostrea subtrigonalis", and is therefore called the Ostrea marl or breccia. The formation also contains bones of vertebrates, much silicified wood, and stems and fragments of plants. Well preserved leaves are exceedingly rare. R. S. Knappen mentions an interesting occurrence in south central Montana of lenses of coal 8 to 24 inches in extent and one-fourth to three-fourths inches thick. They occur in a layer of fresh unweathered volcanic ash 4 to 8 inches thick. These coal lenses appear to be greatly compressed tree trunks and show a compression ratio of about 30 or 50 to one.

In Canada conditions during deposition of the Judith River formation were much the same as in Montana. The beds there have the same olive-drab color, same lithology, and has coal at similar horizons.

<u>Bearpaw Shale</u>. The Bearpaw shale was named and described by Stanton and Hatcher (13, page 13) from exposures

in north-central Montana, and has its typical development on the south side of the Bearpaw Mountains. This soft gray plastic marine clay-shale extends southwestward into northern Wyoming, northward into southern Alberta, and occurs everywhere in Montana east of the front of the present Rocky Mountains. It is conformably underlain by the Judith River, and overlain by the Lennep sandstone in south-central Montana, the Horsethief sandstone in northwest Montana, and the Fox Hills sandstone in eastern Montana.

This formation is remarkably uniform in thickness and lithology, except that near the mountains many sandstone beds appear. It ranges from 500 feet thick near Glacier Park to 1000 feet or more in eastern Montana. From north to south there is very little change in thickness.

The Bearpaw is similar to the Claggett in lithology and contained fauna. Though the shales of the two formations are similar, the sandstone beds are different. The Claggett sandstones are soft , and composed of gray quartz, whereas those of the Bearpaw are hard, well-cemented, brown-weathering andesitic tuffs. C. F. Bowen (2, page 102) notes the following differences between the Claggett and the Bearpaw: (1) The Bearpaw is much thicker. (2) The Bearpaw is more fossiliferous and contains a more diversified fauna. (3) In many places, a bed consisting almost wholly of brackish-water shells, largely "Ostrea subtrigonalis," lies immediately beneath the Bearpaw (this is not true of the Claggett). (4) The Claggett does not have concretions showing cone-in-cone structure as does the Bearpaw. Calcite is present in many of these Bearpaw concretions and smaller masses of barite have been noted in several localities. The formation contains much gypsum, which at some places is transparent, and at other places occurs in uncrystallized forms replacing oyster shells.

The Bearpaw is known as such in southern Alberta, and is essentially the same as in Montana. It extends to the foothills of the Rocky Mountains on the west, and to the North Saskatchewan River on the north. M. Y. Williams (19, page 997) reports that the Bearpaw shale of the Cypress Hills region contains numerous sandstone dikes which cut it from bottom to top. These dikes were eroded at the top before the overlying Fox Hills sandstone was deposited, and are believed to have been intruded during the initial movements accompanying the building of the Rocky Mountains.

Fox Hills Sandstone. The Fox Hills sandstone marks the final retreat of the Montana sea over the immense area included in southern Alberta, the Dakotas, Wyoming, Colorado, and probably, New Mexico. The remarkable extent of this comparatively thin, generally marine unit, together with its uniform lithologic character and fossil content, makes it one of the best horizon markers in the Cretaceous system. It is the youngest formation of undoubted Upper Cretaceous age. The name Fox Hills is in general use throughout the area of its occurrence, both in Canada and the United States. Two other local names are in use however; Horsethief sandstone in northwest Montana, and Lennep sandstone in central and southern Montana.

The Lennep is composed of dark greenish brown beds of lenticular sandstone and clay. It is essentially a shallow-water or fluviatile sandstone. In some areas it contains thin coal beds in its upper part and grades eastward into marine sandstones which intertongue with the uppermost part of the Bearpaw shale. The Lennep contains much volcanic material and is an eastward extension of a part of the tuffaceous Livingston formation. The thickness of the Lennep varies inversely with that of the Bearpaw, and probably one formation replaces the other, the Lennep becoming thicker as it is traced southwestward. Reported thicknesses of the Lennep ranges from 100 to about 200 feet.

The Fox Hills was named for exposures at Fox Ridge in northwest South Dakota. It overlies the Bearpaw shale conformably, and commonly consists of a brown sandstone or sandy shale overlain by a white sandstone, both of which are of marine origin, at least in eastern Montana. Erosion channels filled by brown sandstone or carbonaceous shale are quite common at the top of the Fox Hills. This has been regarded by many investigators as evidence of a considerable hiatus between the Fox Hills and Lance. This opinion is no longer held, however, since similar channels and cross-bedding are equally abundant, both within the Fox Hills, and in the overlying strata to the top of the geologic column. Generally, the Fox Hills throughout eastern Montana maintains all the essential characteristics of the type area.

The "Colgate sandstone member" is the term applied to the conspicuous white upper sandstone member of the Fox Hills. It is typically developed between Colgate station and Glendive, Montana, and is extensively exposed along the Cedar Creek (Baker-Glendive) anticline and elsewhere in eastern Montana. The Colgate also is strikingly developed along Missouri River between Hell Creek and Musselshell River, consisting there of 15 to 20 feet of white sandstone probably of fresh-water origin (17, page 490).

In contrast with the impure brown or tan sandstone of the lower part of the Fox Hills, and some impure brown sandstones of the Judith River formation, which are largely composed of material derived from weathered granitic rocks, and stained by ferruginous alteration products, the typical

Colgate sandstone consists of clean angular quartz and feldspar grains mixed with a small amount of clay-like interstitial material. Many investigators have referred to this interstitial material as being bentonitic derivations of volcanic tuffs. C. E. Dobbin (4, page 24) finds, however, that the interstitial material is largely clay minerals derived from the alteration in place of detrital grains from metamorphosed or igneous rocks.

In the Glacier Park region the Fox Hills equivalent is named the Horsethief sandstone for exposures on Horsethief Ridge, in the Blackfoot quadrangle. There it is composed of about 360 feet of massive gray to buff sandstone, very similar to the Eagle. In the northern part of the Blackfeet Indian Reservation the Horsethief contains a magnetite-bearing zone in its upper 25 feet. The zone contains several beds of magnetite which range in thickness from a few inches to 6 feet. Eugene Stebinger (14, page 334) says these beds consist of "a fine grained aggregate composed mainly of magnetite." He believes these beds originated in a manner similar to "accumulations of black sands which are found in many places along present-day beaches of the Oregon and California coasts."

Lance Formation. The name Lance formation is an abbreviated form of "Lance Creek beds," a term used by J. B. Hatcher in 1903 to apply to the "Ceratops beds." The name was taken from the principal stream in the region where the beds are best represented, in Niobrara County, Wyoming.

Whether the Lance is of Cretaceous or Tertiary Age has long been a debated problem, because deposition was continuous from Cretaceous into Tertiary time, and there is no sharp lithologic or paleontologic division. The problem is further complicated by the fact that the Lance fauna is closely related to that of the Upper Cretaceous, whereas the Lance flora is closely related to that of the overlying Fort Union formation. However, the Lance is here considered as Upper Cretaceous because it seems to be genetically related to the Upper Cretaceous sediments. The continental sediments of the Lance complete the last of three cycles of marine to continental deposition which took place during Upper Cretaceous time.

The Lance formation comprises all the continental deposits between the marine or brackish-water Fox Hills sandstone below, and the fresh-water Fort Union formation above. It is known as the St. Mary River formation in northwestern Montana and in southwestern Alberta, and as the Edmonton formation in southern Alberta. Farther south in Wyoming and Colorado the essentially equivalent rocks are known as the Laramie formation or by various local names.

In central Montana the Lance consists of about 700 feet of yellowish-gray sandstones, clay of various colors, and grayish sandy shale. In south central Montana the Lance, according to R. S. Knappen (8, page 50) consists in general of "repeatedly alternating andesitic and yellow sandstones separated by beds of yellow, buff, and dark-green clay, all containing much volcanic matter."

As the lower part of the Lance is traced into eastern Montana, the fluviatile sandstones are replaced by somber "badland clays" to which the name Hell Creek member is applied. It is typically exposed on Hell Creek, Garfield County.

The Tullock member of the Fort Union formation, overlying the Hell Creek, has often been described in the older literature as Upper Cretaceous in age. Recently, however, oil geologists familiar with the area have placed the Tullock in the Tertiary Fort Union formation. (12, page 1414).

GEOLOGIC HISTORY

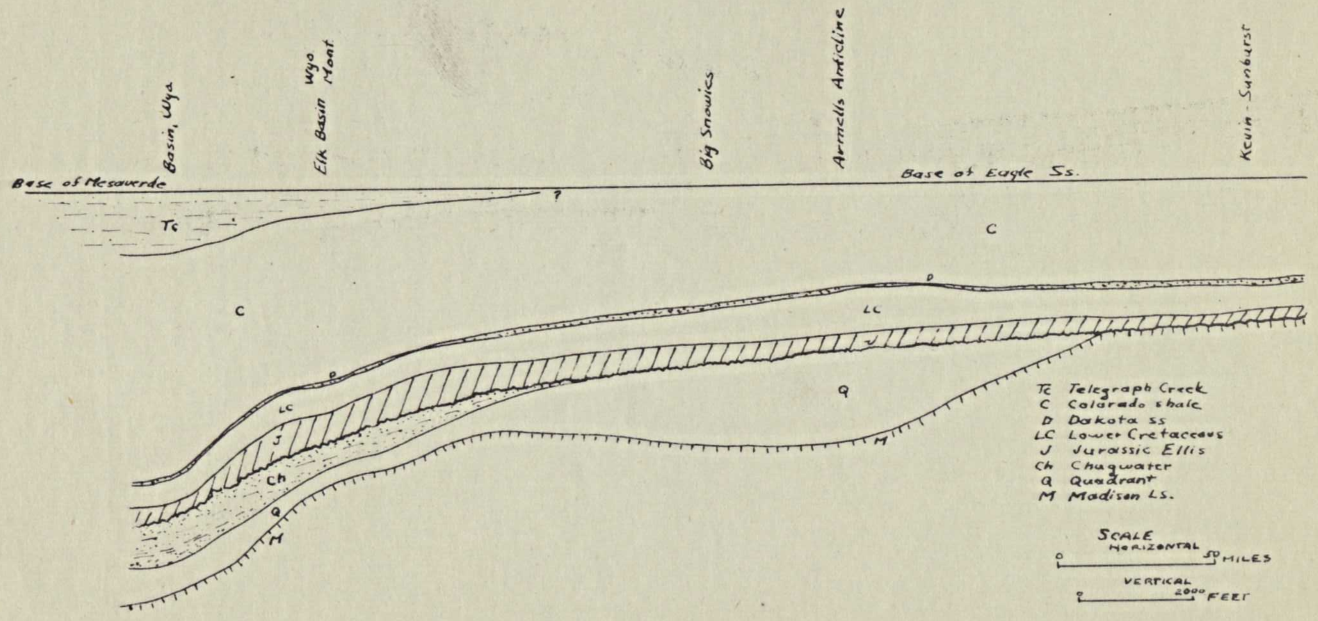
Diastrophism

During Upper Cretaceous time two types of diastrophism took place: (1) vertical crustal movements, resulting in a subsidence, and in a thickening of sediments to the south in Colorado time, and an intertonguing of marine and continental sediments in Montana time; and (2) volcanism which was active throughout most of the period, being minor in Colorado time and extensive in Montana time, particularly in western Montana.

Subsidence. Upper Cretaceous sediments were deposited in the Great Plains region and westward into the Rocky Mountains and there were several areas of greater subsidence resulting in local thickening of the sediments. Several areas of notable thickness are: the Denver Basin in Colorado, the Hanna Basin in southern Wyoming, an area in western Wyoming, another area in central Utah, and one in Alberta.

Plate II shows how Colorado sediments thicken from north to south, suggesting that a basin of greater subsidence or of more rapid deposition existed in northern Wyoming and southern Montana. That subsidence of the basin did not occur prior to Colorado time is shown by the uniform

PLATE II



Cross-section from Big Horn Basin, Wyo to Sweetgrass Arch, Mont.

Showing variation in thickness of sediments.

(After A. A. Hammer, 13 Fig. I)

thickness of Jurassic and Lower Cretaceous sediments. The deposition of these sediments had leveled the irregular surface that existed at the beginning of late Jurassic time, so that at the close of Lower Cretaceous time the surface was a broad monotonous plain, much of which, particularly to the southeast, was covered by brackish and fresh waters. It was upon this plain that the Colorado seas advanced and deposited its sandstones and shales without any apparent unconformity (11, page 555).

A. A. Hammer (5, page 895) states, "That subsidence began just at or near the beginning of Upper Cretaceous time, and was continuous throughout Colorado time and later, is shown by the similarity in the changes in thickness of the various subdivisions of the Colorado Group over the entire area." In other words, each member thins to the north in proportion to the thinning of the entire group. This could only result from continued and uniform subsidence.

The Telegraph Creek formation was deposited over this basin of subsidence as a deltaic deposit at about the same rate as it subsided, so that at the beginning of Eagle time the entire area was at or near sea level.

Fluctuating Shorelines. The most striking characteristics of the Montana Group of sediments of Montana are the alternations of fresh-water sandstone and marine shale which accumulated to thicknesses of thousands of feet.

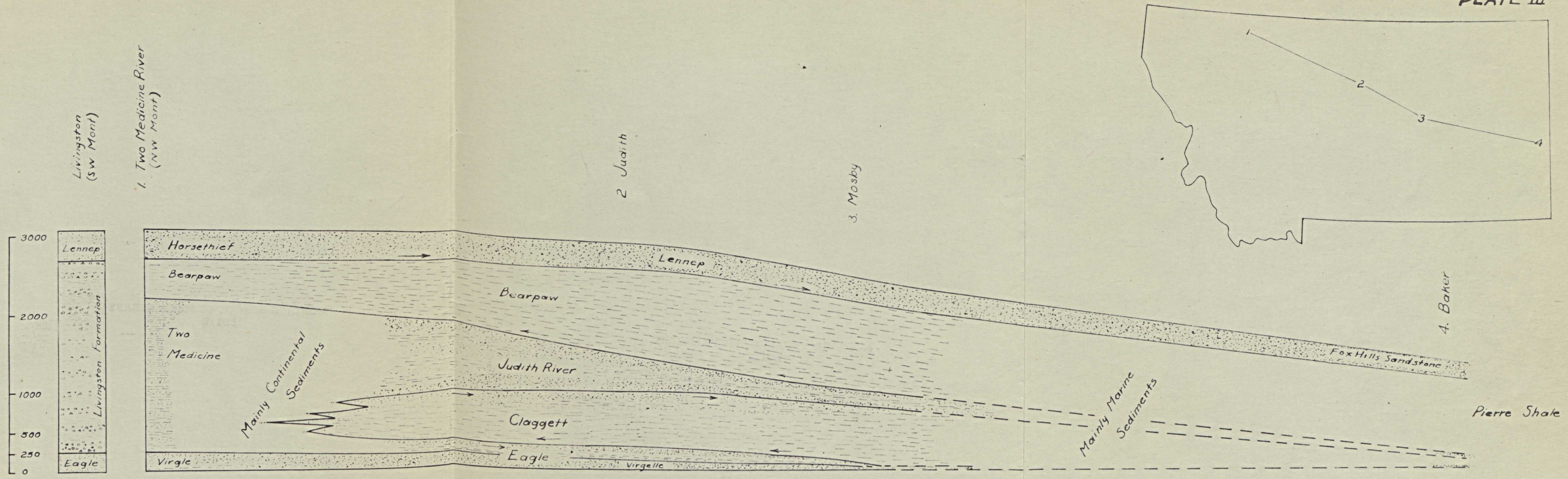
In the west, near the front of the Rocky Mountains, sandstones predominate, and in the mountain area the series is mapped as "Cretaceous undifferentiated." Further east well defined units, essentially marine shale, or essentially terrestial sandstone, constitute the series. Brackish-water Mollusca identify transition beds from fine to coarse clastics, and mark temporary near-shore conditions. True limestones are lacking, and current action of rivers and shallow seas is indicated in the sediments by cross-bedding and by lenticular deposits.

Plate III is a diagram showing the gradations from continental to marine sediments, and changes in thicknesses, from west to east across Montana. It shows how the series is limited by the persistent Eagle sandstone below and the extensive Fox Hills sandstone above. Though the Eagle sands thin to a slight thickness of marine sediments east of the Musselshell River and become shaly, sands from this horizon have been identified much farther to the east in gas wells on the Baker-Glendive Anticline.

The arrows in the center section of the diagram show the movement of shorelines during the deposition of Montana sediments.

The variation in thickness of the Claggett and Bearpaw shales from west to east poses an interesting question.

PLATE III



Diagrammatic Cross-Section Showing Relation of Marine and Continental Sediments of the Montana Group in Montana

Why is it that the Claggett shales thin so much to the east, while the Bearpaw does not; and its source of sediments was much farther west than that of the Claggett? The Claggett shows the normal condition, wherein the rate of sedimentation decreases away from the source. The uniform thickness of the Bearpaw in central and eastern Montana then calls for another explanation. One possible explanation is that ocean currents in the Bearpaw sea were much stronger than in the Claggett, and carried the sediments farther into the interior sea. The Bearpaw thins noticeably in the Glacier Park area beneath Horsethief sandstone, and it is possible that an erosional unconformity exists between the Bearpaw and Horsethief in northwestern Montana. This would account also for the lack of sandy transition beds in the upper Bearpaw such as are present in the upper Claggett.

Generally fluctuations of a shoreline, such as occurred in Montana time, are explained as being caused by deepening of the sea floor or uplifts of the adjacent land mass. Since all the Montana sediments were deposited near sea level (in shallow water or on low flood plains), and no important unconformities exist within the group, it appears that subsidence of the ocean bottom, and uplift of the land mass must have been nearly constant. It is difficult to imagine, however, that the rate of the two movements were always equal. Hence, when the rate of sedimentation was greater than that of subsidence, floodplain deposits pushed the shoreline eastward. This would cause an overloading of the basin, eventually inducing an increased rate of subsidence, which in turn would result in an eastward advance of the sea. It may be concluded then, that fluctuation of the shorelines in Montana time were due to a lack of balance between the rates of sedimentation and subsidence

Volcanism--Livingston Formation. Volcanism is an important feature in Upper Cretaceous geologic history in Montana. It was active throughout most of the period, being minor in Colorado time, but of major importance in Montana time, when the extensive Livingston volcanics were deposited.

Zones of bentonite at various horizons in the Colorado shale provide evidence of the volcanic activity which occurred in Colorado time. The bentonite was derived from volcanic ash deposited over great expanses of the shallow Colorado sea. The ash came from volcanoes in the western land mass (probably in eastern Washington and Idaho) which exploded from time to time with great violence. The first such explosion occurred in Mowry time when a blanket of ash was deposited in the western margins of the sea from Wyoming to Alberta. This ash may have killed fish in the sea, which would account for the incredible abundance of fish scales in the Mowry formation. Silica derived from the ash is responsible for the siliceous character of the shale. After Mowry time only minor volcanic outbursts occurred, as recorded in the thin bentonitic zones above the Mowry shale.

A prolonged period of intense volcanic activity occurred in southwestern Montana after deposition of the Eagle beach sands at the beginning of Montana time. This activity resulted in the deposition of the Livingston formation, and continued until the Lennep sandstone was deposited at the close of Montana time.

The name Livingston was first applied by Weed (1893) to about 7000 feet of tuffaceous sandstones, shales, and agglomerates north, east, and west of Livinston, Montana (9, page 1177). Later studies have shown that the Livingston formation grades laterally eastward into the Claggett, Judith River, and Bearpaw formations in much the same fashion that its equivalent, the Two Medicine formation of northern Montana grades into these formations. (Plate III).

R. W. Stone and W. R. Calvert (15, page 764), after extensive study of the formation, made the following significant statement: "It is concluded that the lithologic unit of tuffaceous deposits originally described as the Livingston formation has no definite age, and no formational value except in the immediate vicinity of the type locality."

Paleogeography

Upper Cretaceous time seems to have been ushered in by a widespread transgression of the sea, extending westward beyond the eastern front of the present Rocky Mountains. Deposition of dark marine shales in quiet waters persisted throughout most of Colorado time. In Frontier time a slight uplift of the western land mass, or increased erosion, resulted in the deposition of a great sandy delta-like deposit in northern Wyoming whose fringes extended into southern Montana. Slightly earlier in Colorado time another similar environment of deposition in northwestern Montana had extended its fringes eastward to the Glacier Park region resulting in the deposition of the Blackleaf formation. At one time this deltaic deposition was the scene of rank vegetational growth as is attested by the presence of a coal in this formation (personal communication with Dr. E. S. Perry).

The long period of quiet deposition in the Colorado sea was brought to a close by uplift of the western land mass. The Telegraph Creek formation marks the arrival in the flood of the sands from this uplift, which was later to come in much greater quantity as the Eagle sands were deposited.

The sands brought down from the uplift by accelerated streams were reworked by the retreating sea to be deposited as the Virgelle beach sands. As the sea retreated vegetation flourished on the plains, and lagoons formed along a sinuous coastline which have resulted in carbonaceous shales and coals in the middle Eagle. More sand covered these deposits and eventually pushed the sea far to the east as shown in figure 1, Plate IV.

In Claggett time the sea repidly advanced over the land to the line shown in figure 2, Plate IV. The lack of sandy transition beds in the lower Claggett indicates a rapid advance of the sea. It is believed that the Claggett shoreline oscillated as is shown in Plate III. The retreat of the Claggett sea was a slow and oscillatory process resulting in an intertonguing of sands and shales.

It seems probable that Judith River time was not inaugurated by tectonic uplift, but that the Claggett sea was driven eastward by an advancing fringe of coalescing deltas (Fig. 2, Plate V). Regional subsidence kept approximate pace with deposition, thus maintaining a broad coastal plain approximately at sea level. In middle Judith River time the terrain must have been almost flat, very

PLATE IV

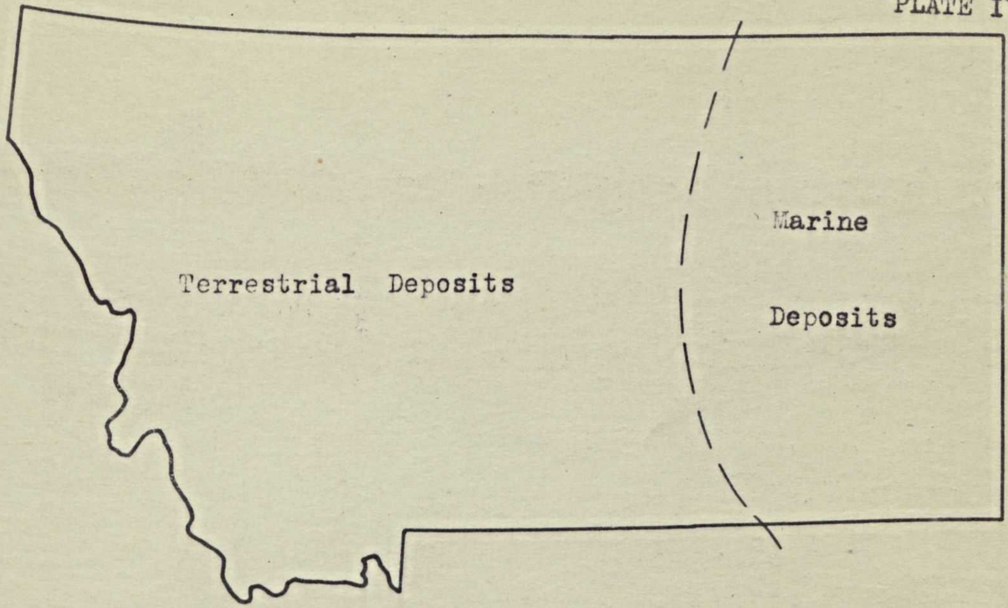


Fig. 1 Maximum Emergence in Eagle Time

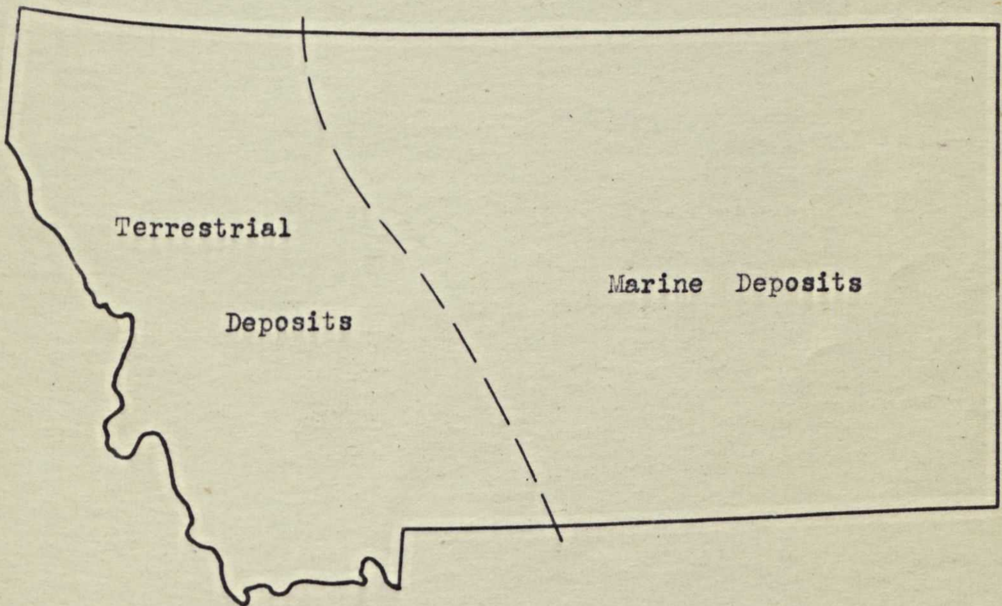


Fig. 2 Maximum Submergence in Claggett Time

PLATE V

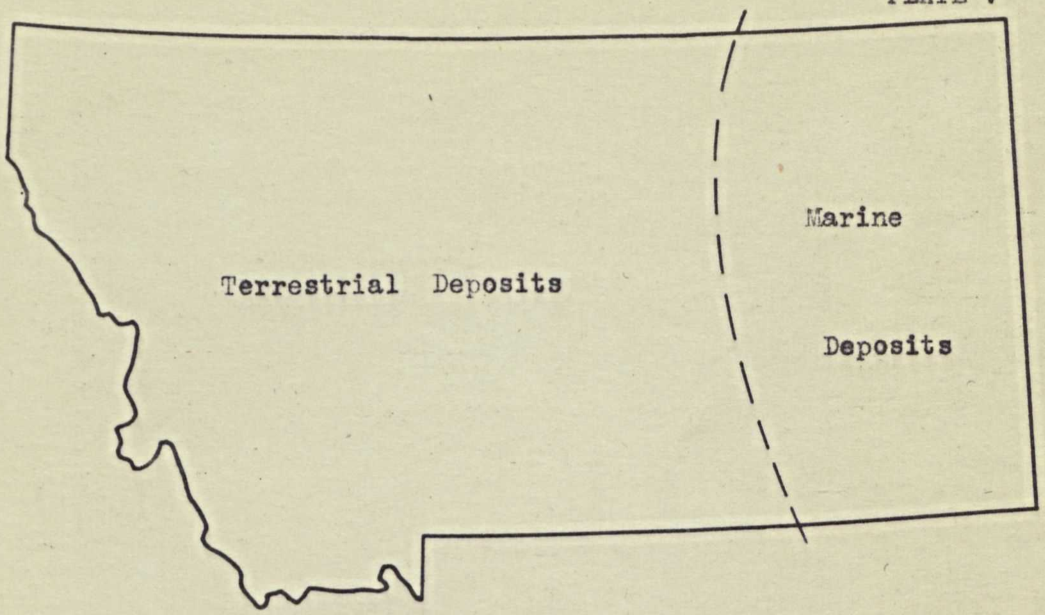


Fig. 1 Maximum Emergence in Judith River Time

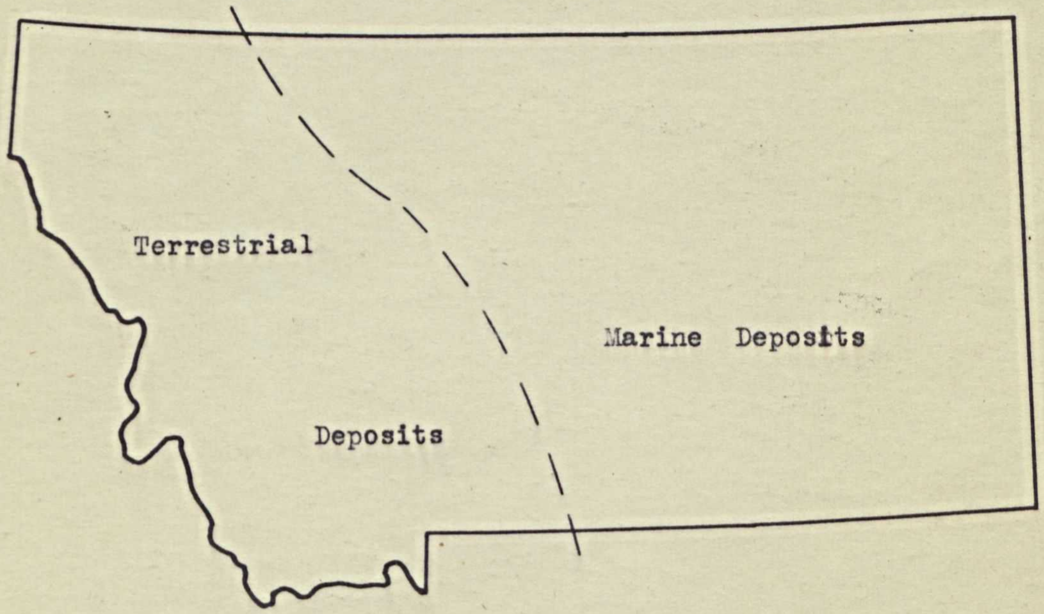


Fig. 2 Maximum Submergence in Bearpaw Time

poorly drained, and nearly covered by rank vegetation. Later the land must have been well drained, because the lack of coal indicates that organic material was oxidized rather than carbonized. Widespread recurrence of swamp conditions just prior to the invasion of the Bearpaw sea suggests that the plains were tilted to the west, thereby destroying effective drainage.

The advance of the Bearpaw sea is recorded only by a thin and insignificant beach sand. This absence of important littoral deposits at the base of the Bearpaw shows that the region was suddenly inundated by marine waters, probably as a result of subsidence. Figure 2, plate V shows the western limits of reported Bearpaw shale; however, the sea probably advanced somewhat west of that line. The Bearpaw shale is a record of remarkably uniform marine conditions during a considerable time, which ended with the retreat of the Bearpaw sea and deposition of the beach sand of the Fox Hills formation.

The final emergence of the land during Fox Hills time was probably the result of regional uplift. The rejuvenated streams brought much sand and mud down onto the lowlands where extensive vegetable growths were accumulating. The Upper Cretaceous period was brought to a close after Lance time by a widespread orogenic disturbance to the west, accompanied by folding and thrusting which produced the principal features of the Rocky Mountain System. The great marine invasion of the Great Plains of the United States and Canada came to an end, and marine waters retreated to the Gulf of Mexico.

SUMMARY

By way of summary it should be pointed out that Upper Cretaceous time began with widespread regional subsidence, which continued throughout all of Upper Cretaceous time. A lack of balance between subsidence and sedimentation produced oscillations of the shoreline in Montana time. Finally the period was closed by a widespread regional uplift, tectonic disturbances, and withdrawal of seas. The Upper Cretaceous sedimentary record is remarkable for the absence of any appreciable unconformities; emergence was accompanied by increased deposition rather than by erosion.

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