



The transition from the Judith River Formation to the Bearpaw Shale (Campanian), north-central Montana

by Roger Elmer Braun

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences

Montana State University

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Abstract:

The upper 15 m of the Judith River Formation on and adjacent to the Fort Belknap Indian Reservation, north-central Montana is composed mostly of overbank mudrock, siltstone, fine-grained sandstone, and coal, with some cross-stratified channel sandstone in the lower part. The lower 15 m of the overlying Bearpaw Shale is a transgressive deposit composed primarily of concretionary silty shale with some clayey, silty sandstone zones and one bentonite bed. The source area for both formations was primarily in western Montana and Idaho, with the Elkhorn Mountains volcanics a major source of debris.

The contact between the Judith River and Bearpaw formations is abrupt and lacks a transgressive sandstone facies. The transgression of the Bearpaw sea across the study area is considered to have been a nearly isochronous event because of the nature of the transition, small east-west differences in thickness between marker horizons, and similar elevations of the contact from east to west across undeformed parts of the study area.

The Bearpaw transgression was caused mainly by tectonic thickening in the western Cordillera, which created subsidence primarily in the western and central portions of the Western Interior basin. The transgression was a nearly isochronous event that took place approximately 72 m.y. ago according to radiometric age dates on bentonite beds. Discrepancies between these radiometric dates and faunal zonation that implies a diachronous transgression can be explained by paleogeography and salinity stratification of the Bearpaw sea before and at the beginning of the transgression. The marine nektonic organisms used in the faunal zonation studies are thought to have been excluded from the initial transgressive pulse because of low salinity water in the surface layer of the sea. The sea probably invaded subsided areas through inlets that formed around topographic highs, which are major Judith River Formation deltaic complexes in central Montana and southern Alberta and Saskatchewan. Nektonic fauna probably did not occupy the newly subsided basin until well after the entire region was inundated, thus giving the impression of a diachronous transgression throughout the region.

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Bozeman, Montana

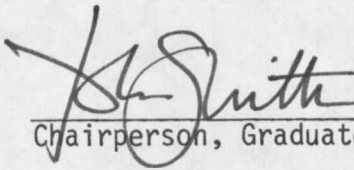
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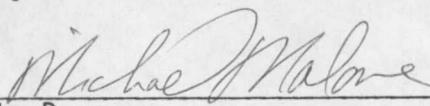
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ABSTRACT

The upper 15 m of the Judith River Formation on and adjacent to the Fort Belknap Indian Reservation, north-central Montana is composed mostly of overbank mudrock, siltstone, fine-grained sandstone, and coal, with some cross-stratified channel sandstone in the lower part. The lower 15 m of the overlying Bearpaw Shale is a transgressive deposit composed primarily of concretionary silty shale with some clayey, silty sandstone zones and one bentonite bed. The source area for both formations was primarily in western Montana and Idaho, with the Elkhorn Mountains volcanics a major source of debris.

The contact between the Judith River and Bearpaw formations is abrupt and lacks a transgressive sandstone facies. The transgression of the Bearpaw sea across the study area is considered to have been a nearly isochronous event because of the nature of the transition, small east-west differences in thickness between marker horizons, and similar elevations of the contact from east to west across undeformed parts of the study area.

The Bearpaw transgression was caused mainly by tectonic thickening in the western Cordillera, which created subsidence primarily in the western and central portions of the Western Interior basin. The transgression was a nearly isochronous event that took place approximately 72 m.y. ago according to radiometric age dates on bentonite beds. Discrepancies between these radiometric dates and faunal zonation that implies a diachronous transgression can be explained by paleogeography and salinity stratification of the Bearpaw sea before and at the beginning of the transgression. The marine nektonic organisms used in the faunal zonation studies are thought to have been excluded from the initial transgressive pulse because of low salinity water in the surface layer of the sea. The sea probably invaded subsided areas through inlets that formed around topographic highs, which are major Judith River Formation deltaic complexes in central Montana and southern Alberta and Saskatchewan. Nektonic fauna probably did not occupy the newly subsided basin until well after the entire region was inundated, thus giving the impression of a diachronous transgression throughout the region.

INTRODUCTION

Location

The study area is in north-central Montana and includes all of the Fort Belknap Indian Reservation as well as an adjacent area to the west. It is bounded on the north by the Milk River, on the east and south by the reservation boundary, and on the west by 109° west longitude. The area lies just north of the Little Rocky Mountains and approximately 30 km east of the Bearpaw Mountains in Blaine and Phillips counties.

Purpose

This study focuses on the stratigraphy of the upper 15 m of the Judith River Formation and the lower 15 m of the Bearpaw Shale and, specifically, on the rate of transgression of the Bearpaw sea. Toward this end, an understanding of regional stratigraphic relationships, depositional environments, provenience, and direction of sediment transport is necessary.

Procedure

A field study was conducted on and adjacent to the Fort Belknap Indian Reservation during the summer of 1981. Field work was initiated by first finding exposures through the use of aerial photographs and 7½ minute topographic maps. Because of the flat-lying attitude of the

strata and the propensity of the Judith River and Bearpaw formations to erode and slump, most exposures were found only near active, modern drainage systems.

Field work consisted of measuring stratigraphic sections at a total of 64 localities with steel tape and Jacob's staff. Specific information recorded at each locality includes: (1) thickness and geometry of beds; (2) azimuth, dip, and thickness of cross-stratified sets; (3) description of cross-stratification; (4) notation of other primary sedimentary features such as graded bedding, fossils, and ichnofossils; (5) diagenetic features such as concretions and degree of induration; (6) description of lithology; and (7) vertical and horizontal variation of lithologies. Samples were collected at every change of sedimentary structure or lithology.

Laboratory analyses included thin section and binocular microscope examination of selected samples from various localities. Standard thin sections and ring-mount thin sections of poorly consolidated sediments were examined under the petrographic microscope. Precise determination of mineralogy was not an objective of this study. However, analyses confirmed more detailed petrographic studies of Rubey (1930), McLean (1971), and Schultz and others (1980).

General Geology

Bedrock in the study area is predominantly of Cretaceous age, except for several Tertiary intrusions in the southern and western portions (Fig. 1). The larger intrusions have tilted Paleozoic and Precambrian rocks around their perimeters.

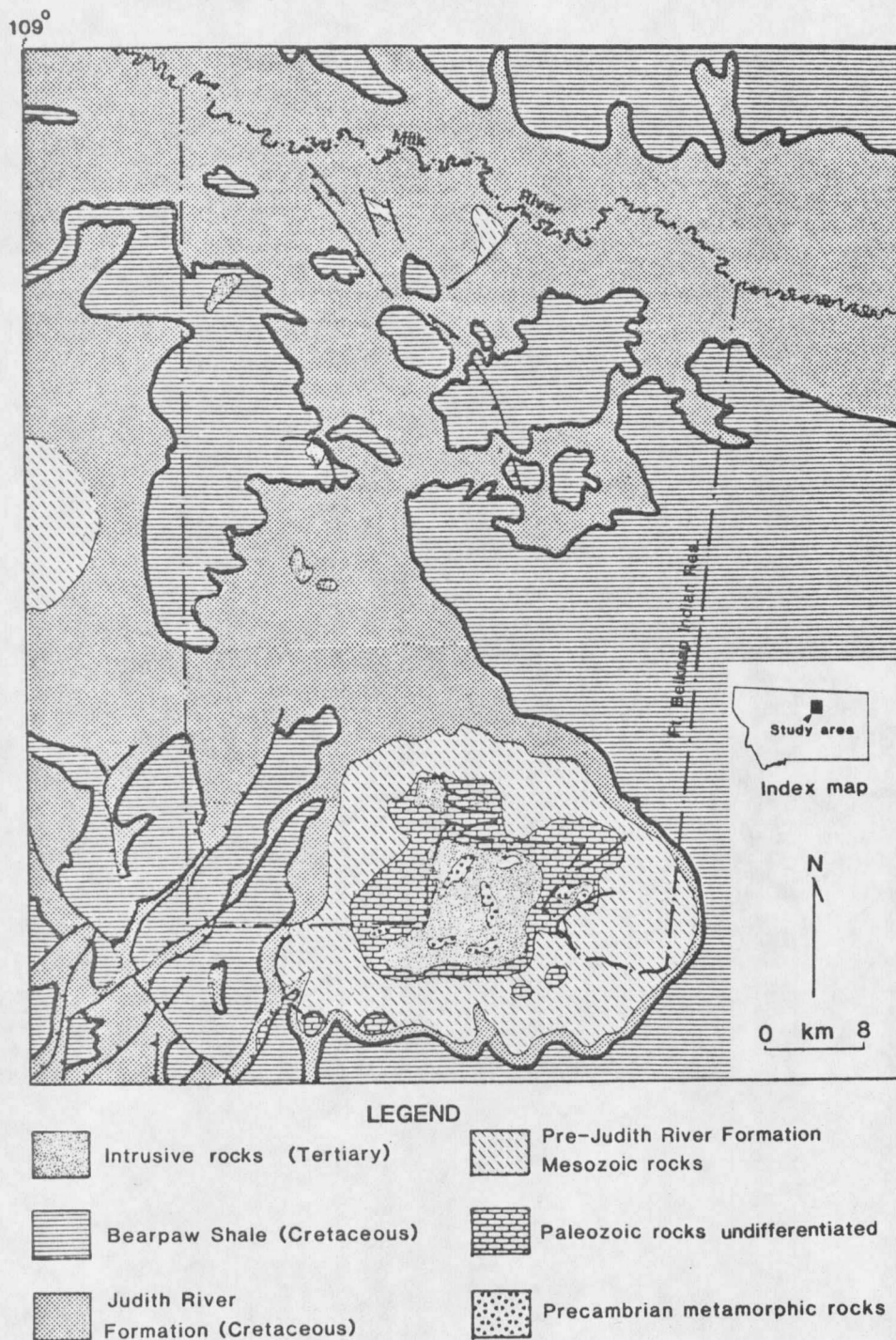


Figure 1. Generalized geologic map of the study area (modified from Alverson, 1965; other data from Ross and others, 1958).

Upper Cretaceous sedimentary rocks of the region are part of the Montana Group (Fig. 2). Two units near the top of this group are the focus of this study: the Judith River Formation and the overlying Bearpaw Shale. The Judith River Formation is primarily a freshwater, regressive deposit of sandstone, siltstone, and mudrock¹. The Bearpaw is a transgressive marine deposit composed primarily of dark-colored shale.

Much of the study area is covered by a veneer of alluvium or glaciofluvial material up to 30 m thick (Hauptmann and Todd, 1953). Glaciofluvial deposits are usually associated with uplands and alluvium with modern stream drainages as well with the preglacial Missouri River.

The dominant structural features in the area were formed in response to stresses that formed the Little Rocky and Bearpaw mountains. Strata dip steeply off the Little Rocky Mountains as well as off associated outlying intrusive bodies (Knechtel, 1959). In the north and northwest parts of the study area, however, sedimentary strata are nearly flat-lying, usually dipping less than one degree (Alverson, 1965).

Two low-angle thrust-fault systems, the trends of which are mutually perpendicular, are depicted on maps by Erdmann and Koskinen (1953) and Alverson (1965). The thrust fault system in the northwest part of the study area has a N40°W trend; the system in the southwestern corner trends N30°E. These are believed to be gravity slide faults

¹The term mudrock, as used here, refers to a nonfissile mixture of clay, silt, and sand particles of indefinite proportions.

		STAGE	NW MONTANA	SE ALBERTA	N-C MONTANA	CRAZY MTS BASIN	SE MONTANA	BIGHORN BASIN		
UPPER CRETACEOUS	Camp- anian		St Mary River	Battle Fm	Fox Hills Ss	Lenne- p Ss	Fox Hills Ss	Lenne- p Ss		
		Horsethief Ss	White Mud Fm	Bear- paw Sh					Judith River Fm	Meeteetse Sh
			Eastend Fm							
		Bearpaw Sh	Bearpaw Sh	Bearpaw Sh	Judith River Fm	Mesa Verde Fm				
		Two Medicine Fm	Belly R Foremost	Claggett	Eagle		Pierre Sh			
								Pakowki	Claggett Sh	Eagle
		Virgelle Ss	Milk River Fm	Eagle	Virgelle	Cody Sh				
		Telegraph Creek		Telegraph Creek	Telegraph Creek					
		San- tonian								

Figure 2. Stratigraphic correlation chart of Upper Cretaceous rocks in Montana and adjacent areas (from Balster, 1980). Shaded area is interval studied.

associated with the Bearpaw Mountains (Reeves, 1946). Numerous normal faults are associated with domal features near the Little Rocky Mountains (Alverson, 1965).

Previous Investigations

Stratigraphy of Upper Cretaceous rocks has been the subject of numerous detailed studies throughout the Western Interior. The studies mentioned here are those considered most pertinent to this study and are only a fraction of the total published material.

Early descriptions and mapping of the Judith River and Bearpaw formations were done by Meek and Hayden (1856), Hatcher and Stanton (1903), Pepperberg (1908, 1910), and Bowen (1912, 1915). The stratigraphy and biostratigraphy of Upper Cretaceous rocks in Montana and adjacent areas were studied by Cobban (1955), Reeside (1957), Gill and Cobban (1966, 1973), and Tschudy (1973). Geologic maps were produced on and adjacent the study area by Knechtel (1959), Hearn and others (1964), Schmidt and others (1964), and Alverson (1965). Studies that focused on the transgression of the Bearpaw sea are those of McLean (1971), Gill and Cobban (1973), and Lorenz (1981).

Rocks of this area deposited during the Campanian Stage of the Upper Cretaceous have been studied from many vantage points and at numerous scales. It is generally agreed that the Judith River Formation was deposited in nonmarine environments by streams that flowed from the Cordilleran highland eastward toward the Cretaceous epeiric sea. The Bearpaw Shale is considered to be of marine origin, but the rate of

transgression of the Bearpaw sea is variously interpreted by several authors within the region.

PALEOGEOGRAPHY AND TECTONIC SETTING

The Cretaceous Western Interior basin was an asymmetrical, elongate structural trough lying east of the Cordilleran geanticline (Kauffman, 1977). The epeiric sea that occupied this basin was up to 1,600 km wide, more than 5,000 km long, and connected the present-day Gulf of Mexico with the proto-Arctic Ocean (Fig. 3).

The development of the Western Interior basin began in the Late Jurassic as a result of the accretion of exotic terrain onto the North American craton during subduction of the Pacific plate (Price, 1973). With the development of the resulting orogen and subsequent crustal shortening, the mass of the eastward-displaced supracrustal rocks initiated subsidence along the western margin of the basin (Price, 1973). This tectonic thickening on top of "an old, cool, thick, lithospheric plate" (Caldwell, 1982, p. 296) and resultant subsidence probably affected a large part of the eventual basin area.

Isostatic adjustment of the lithosphere due to tectonic thickening was supplemented by that from sediment loading east of the fold and thrust belt. These thick, eastward-building prisms of sediment gave rise to the "migrating foredeep" concept of Bally and others (1966) (Fig. 4).

Orogenic pulses in the Cordilleran highland to the west provided source areas for most of the sediment supplied to the basin, with very little detritus derived from the North American craton to the east (Gill

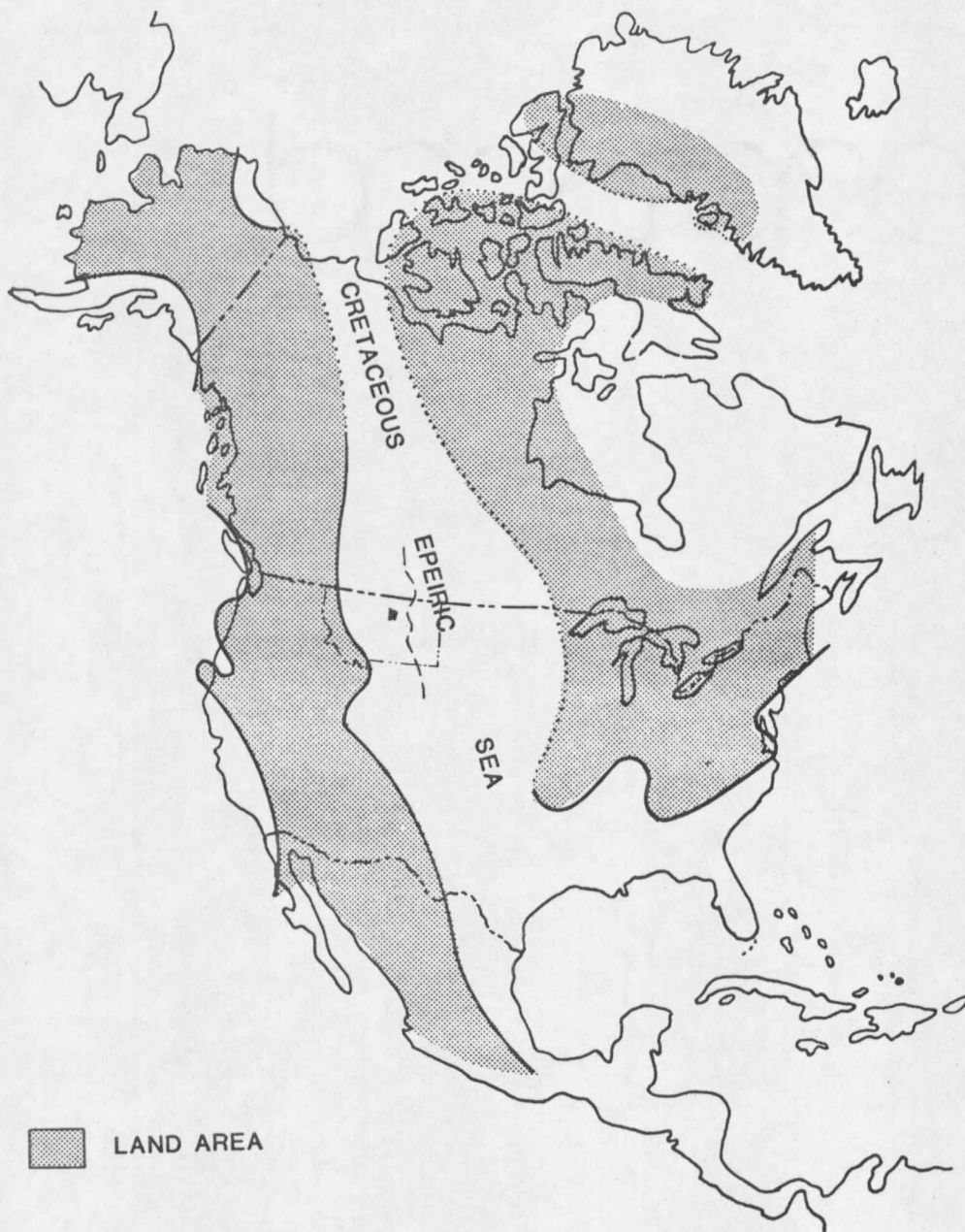


Figure 3. North American paleogeographic map showing general maximum distribution of Cretaceous epeiric sea. State of Montana is outlined, study area shown in black. Dashed line indicates approximate position of shoreline just prior to Bearpaw transgression (modified from Gill and Cobban, 1973).

Figure 4. Schematic reconstruction showing eastward migration of the Rocky Mountain foredeep from the Jurassic to the Tertiary. Note tectonic thickening by successive thrust faulting and isostatic adjustment of Precambrian basement rocks (from Bally and others, 1966, p. 366).

and Cobban, 1973). The geometry of the basin evolved into an asymmetric profile, with much thicker, coarser deposits along the more rapidly subsiding western margin (Fig. 5).

Most of the sediment from the Cordilleran highland was delivered to the basin by streams that formed at least five major deltaic complexes in the northern part of the basin during the Campanian Stage (Fig. 6). Weimer (1970) showed deltaic complexes located in northern Colorado, central Wyoming, and central Montana, and Williams and Stelk (1975) found evidence for two others, one in northern Alberta and a second in southern Alberta and Saskatchewan. Numerous minor deltaic systems fed by smaller streams probably existed between the major complexes (McLean, 1971).

Provenance of the Judith River Formation and partial time-stratigraphic equivalents in western Montana was studied by McLean (1971), McMannis (1965), Roberts (1963), Viele and Harris (1965), and Mudge and Sheppard (1968). These authors agree that the majority of clasts in these formations were derived from volcanic sources. The primary volcanic source was the Elkhorn Mountains, although the Deer Creek volcanic centers probably supplied some volcanic detritus in southwest Montana (Parsons, 1942). Viele and Harris (1965) studied volcanoclastic-rich Upper Cretaceous rocks in northwest Montana and speculated that the source of the large volcanic fragments there was a northern extension of the Elkhorn Mountains. They postulated that the Elkhorn Mountains volcanics extended north of their present distribution and have since been covered by thrust sheets emplaced during the Paleocene. Other important source rocks for the Judith River Formation

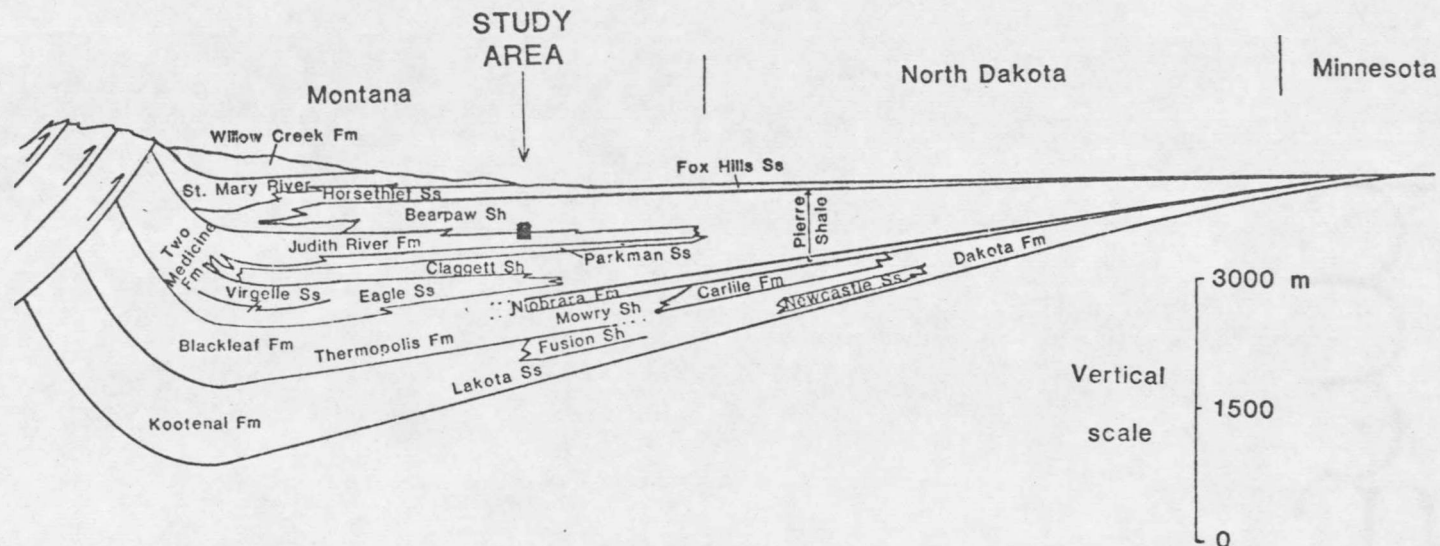


Figure 5. Schematic east-west cross section from northwest Montana to northwest Minnesota showing the geometry of the Western Interior basin and general stratigraphic relationships (data from Schultz and others, 1980; Gill and Cobban, 1965; Hansen, 1958; and McGooky and others, 1972).

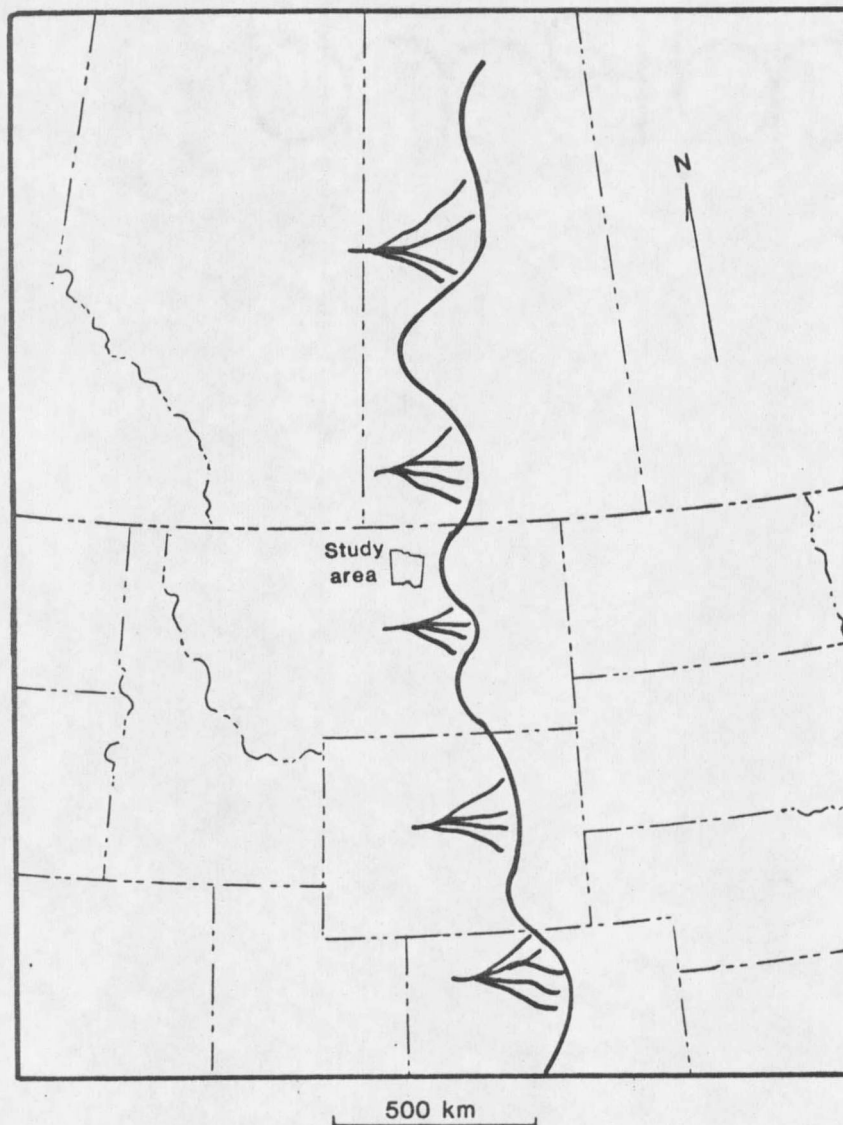


Figure 6. Paleogeographic map showing shoreline and positions of five deltaic complexes just prior to the Bearpaw transgression. Northern two from data of Williams and Stelk (1975), southern three from data of Weimer (1970).

are the Belt Supergroup, Archean metamorphic rocks, and Paleozoic and Mesozoic sedimentary rocks, all of which were uplifted during the Sevier and early part of the Laramide orogeny (McLean, 1971).

STRATIGRAPHY

Regional Stratigraphy

The Montana Group was named by Eldridge (1889) for Upper Cretaceous sedimentary rocks which are best exposed in the state of Montana. With more recent revisions by Cobban and Reeside (1952), the formations of this group are, in ascending order: Eagle, Claggett, Judith River, Bearpaw, and Fox Hills (Fig. 2). Equivalent rock-stratigraphic units also included in the Montana Group are the Pierre Shale, Telegraph Creek Formation, Virgelle Sandstone, Parkman Sandstone, Two Medicine Formation, Lennep Sandstone, and Horsethief Sandstone (Fig. 2). These units generally consist of eastward-thinning wedges of regressive, nonmarine and marginal marine deposits that enclose westward-thinning wedges of transgressive, marine strata. Figure 7 is a diagrammatic east-west cross section showing the general relationships of the Montana Group.

The stratigraphic units of interest in this study are the Judith River Formation and the overlying Bearpaw Shale. The Judith River Formation is an eastward-thinning, primarily freshwater deposit that accumulated during the middle Campanian. The Bearpaw Shale is a complimentary westward thinning formation deposited in marine environments during the later Campanian and the earliest part of the Maestrichtian (Figs. 2 and 7).

In western Montana, the time-stratigraphic equivalent of the Judith River Formation is the upper part of the Two Medicine Formation.

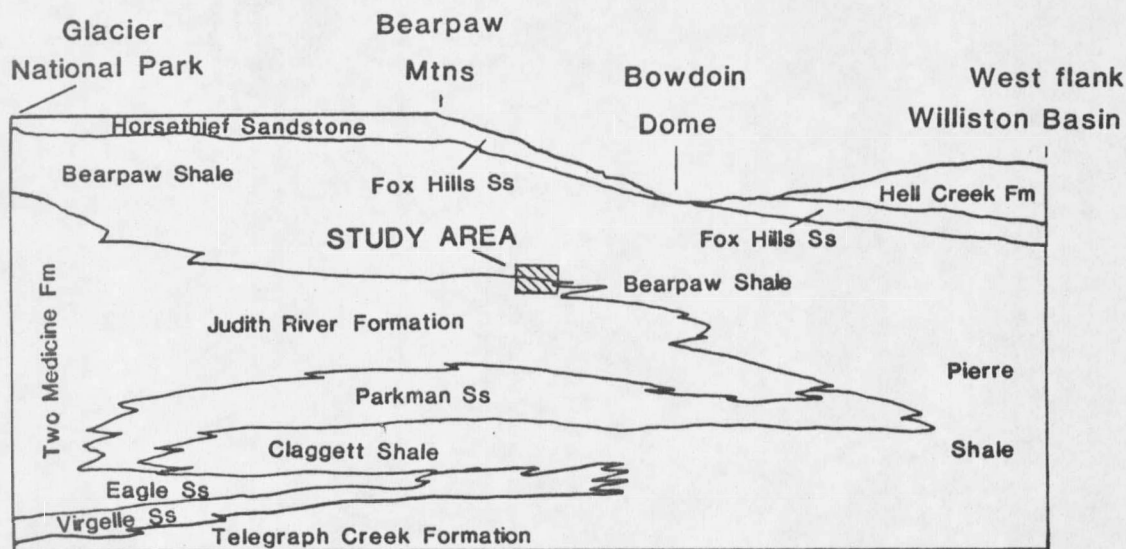


Figure 7. Diagrammatic east-west cross section through northern Montana showing the general relationships of the Montana Group (modified from Rice and Shurr, 1980).

On the west side of the Sweetgrass Arch, approximately 250 km west of the study area, the Two Medicine Formation is greater than 600 m thick and is almost entirely nonmarine sandstone, siltstone, and shale (Cobban, 1955). The lithologically similar time-stratigraphic equivalent of the Judith River Formation in southern Alberta and Saskatchewan is called the Belly River Group that is divided into the Oldman and Foremost formations (McLean, 1971). In Wyoming, the Judith River equivalent is the Mesa Verde Formation which has been reported as being unconformably overlain by the Meeteetse Shale, the Bearpaw Shale equivalent (Gill and Cobban, 1966).

Stratigraphy of the Judith River/Bearpaw Transition

This study focuses on the stratigraphy of the upper 15 m of the Judith River Formation and the transition into the lower part of the Bearpaw Shale. A composite lithologic sequence for this interval is shown in Figure 8. This diagram illustrates the relative positions of all significant horizons and lithologies in the upper part of the Judith River and lower part of the Bearpaw within the study area. No single outcrop studied included all horizons or lithologies shown in the figure. The upper part of the Judith River is a light-colored, heterogenous mixture of sandstone, siltstone, and mudrock with a few thin coal beds near the top. Although the lithology of a certain bed may remain constant for several hundred meters, lateral and vertical variation effectively eliminates use of most beds as regional marker horizons.

The geometry of individual beds within the upper part of the Judith River Formation in the study area is generally lenticular, although some coal and mudrock beds appear tabular across short exposures of isolated outcrops. Mudrock and sandstone lithosomes are commonly intertongued at both large scale (beds up to 3 m thick) and small scale (beds less than 5 cm thick). Contacts between fine and overlying coarse lithosomes are usually sharp, and a gradational transition usually occurs between coarse and overlying mudrock facies.

The transition from the Judith River into the Bearpaw is distinct in all exposures but is most abrupt in the eastern portion of the study area. The contact is characterized by an upward decrease in grain size, an increase in fissility, and darker color. Because the Bearpaw Shale is a relatively nonresistant unit containing a significant amount of

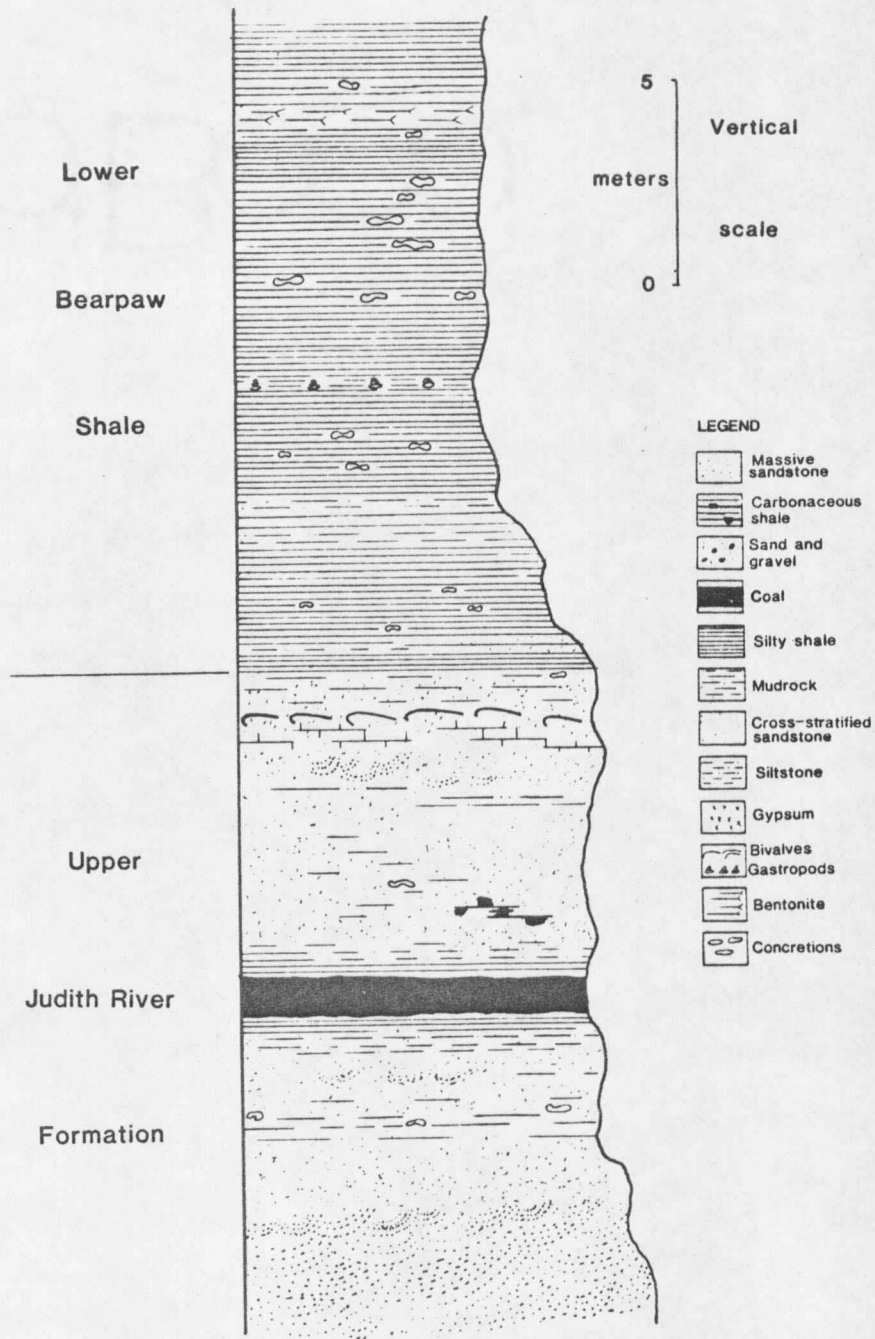


Figure 8. Composite stratigraphic section of the upper 15 m of the Judith River Formation and the lower 15 m of the Bearpaw Shale in the study area.

expandable clay, it forms a subdued topography that supports little vegetation, which further delineates the contact.

The lower part of the Bearpaw is composed of dark-colored silty shale that weathers light gray and contains at least one yellow-white to white bentonite bed. Sanidine and biotite from bentonite beds in the Bearpaw Shale have been dated by potassium-argon techniques (Folinsbee and others, 1961, 1965) and these ages have been applied to ammonite and foraminiferan zonation for greater resolution of time relationships in the Western Interior (Gill and Cobban, 1973; North and Caldwell, 1975). However, the lower part of the Bearpaw Shale lacks the biostratigraphic control used throughout the rest of the formation (Hearn and others, 1965; Caldwell, 1968). This lack of fossils may have been caused by unfavorable conditions for faunal occupation and will be addressed in a later section. In the study area, the lower part of the Bearpaw Shale contains numerous concretions but none were found that contained ammonites as described from higher parts of the formation elsewhere (Gill and Cobban, 1973; Schultz and others, 1980).

Exposures of the Bearpaw Shale exhibit a popcorn-weathered surface that compacts easily under weight and, when wetted, produces a very sticky or gumbo surface. This type of weathering is due to expansion and contraction by smectite clays that locally comprise a large proportion of the shale (Schultz and others, 1980).

Although the Bearpaw Shale was reported to contain numerous bentonite beds (Knechtel, 1959; Gill and Cobban, 1973; Caldwell, 1968; Schultz and others, 1980), the lower 15 m in the study area contains only one discrete, relatively continuous bed. This bentonite bed occurs

approximately 13 to 15 m above the Judith River/Bearpaw contact in the northern part of the study area and has a maximum thickness of 0.65 m. Apparently this bentonite bed was deposited in locally agitated water, since the thickness varies considerably within in few meters laterally and the upper surface is irregular and appears scoured. Currents may have shifted the volcanic ash from one area to another where tranquil conditions allowed abnormally thick accumulations.

Other bentonite beds occur in the study area at a level approximately 30 to 35 m above the Judith River/Bearpaw contact. These beds appear less disrupted than the lower bentonite bed and may not have been subjected to currents during or shortly after deposition.

Sandstone tongues were reported within the Bearpaw Shale by Knechtel (1959) and Caldwell (1968). Caldwell described these sandstone tongues as well-sorted, fine-grained, and locally cross-stratified. No comparable sandstone lithologies occur in the lower part of the Bearpaw in the study area, although zones of clayey and silty sandstone do occur at various horizons (Fig. 8). The maximum thickness of these zones in the study area is 0.5 m and they usually pinch out within 50 m laterally. Mineralogy of grains within the sandstone zones suggests they are related to the Judith River Formation. These may be offshore or delta front bars that accumulated in response to increased sediment input from the alluvial system.

LITHOLOGY OF THE JUDITH RIVER/BEARPAW TRANSITION

Introduction

The upper 15 m of the Judith River Formation is an heterogenous mixture of light-colored mudrock and sandstone with some thin lignite beds in the upper part. Judith River sandstone is texturally and mineralogically immature and is classified as feldspathic litharenite (Folk, 1974 classification triangle). Mudrock constitutes a major part of the Judith River Formation and is generally poorly sorted and highly bentonitic. Mineralogy of the silt-size grains in the mudrock is similar to the mineralogy of Judith River sandstone.

The lower 15 m of the Bearpaw Shale is composed primarily of dark-colored silty shale that contains numerous siderite concretions. Bentonite and gypsum beds and several light-colored clayey and silty sandstone zones also occur in the lower part of the formation.

Judith River Mudrock

In the upper 15 m of the Judith River Formation in the study area, mudrock is the predominant rock type with some interfingered sandstone and thin coal beds. The mudrock is usually light brown to gray, massive, poorly sorted, and concretionary. McLean (1971) determined that the mudrock was composed of montmorillonite, illite, kaolinite, and chlorite, and silt-sized grains of quartz, feldspar, clinoptilolite, dolomite, calcite, biotite, and pyrite. Both septarian and nonseptarian

concretions occur within the mudrock. Most concretions are composed of siderite although some contain abundant clasts similar to those in the host rock. The cementing agent in clastic-rich concretions is usually siderite, calcite, or sometimes a well-indurated siliceous, clay matrix. No fossils were found in any concretions in the mudrock. The mudrock is generally poorly indurated and on weathered exposures often contains gypsum and jarosite.

Judith River Sandstone Beds

Sandstone beds within the upper 15 m of the Judith River Formation are of two types: those that are greater than 3 m thick, that are moderately sorted, and display large-scale cross-stratification, and those that are less than 3 m thick, are well-sorted, and display small-scale cross-stratification or ripple-drift laminae. The thick, large-scale cross-stratified sandstone beds generally occur lower in the sequence and the thin, small-scale cross-stratified units usually occur higher in the Judith River Formation near the contact, although they sometimes are found just above the thicker sandstone beds (Fig. 8). Both types of sandstones are composed mainly of plagioclase, rock fragments, quartz, and potassium feldspar, with calcite and glauconite as minor constituents.

The thick-bedded sandstone facies is generally poorly to moderately sorted and up to 6 m thick. Sedimentary structures within the thicker, lower sandstone beds are large-scale omikron cross-stratification (Fig. 9). Most cross-stratified sets are characterized by tangential bases and erosional upper surfaces. The thickness of individual

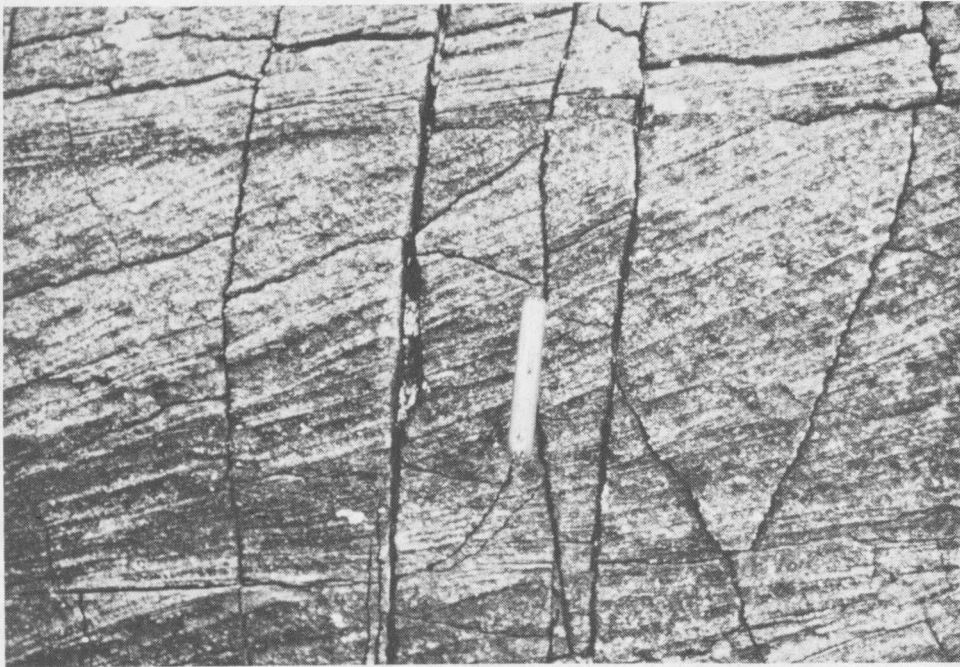


Figure 9. Photograph of large-scale omikron cross-stratification that occurs in the thicker, lower sandstone beds in the upper 15 m of the Judith River Formation in the study area.

cross-stratified sets ranges up to 40 cm. Seventy-four azimuths of cross-stratified sandstone beds in the upper 15 m of the Judith River Formation were measured throughout the study area and are plotted on a rose diagram shown in Figure 10.

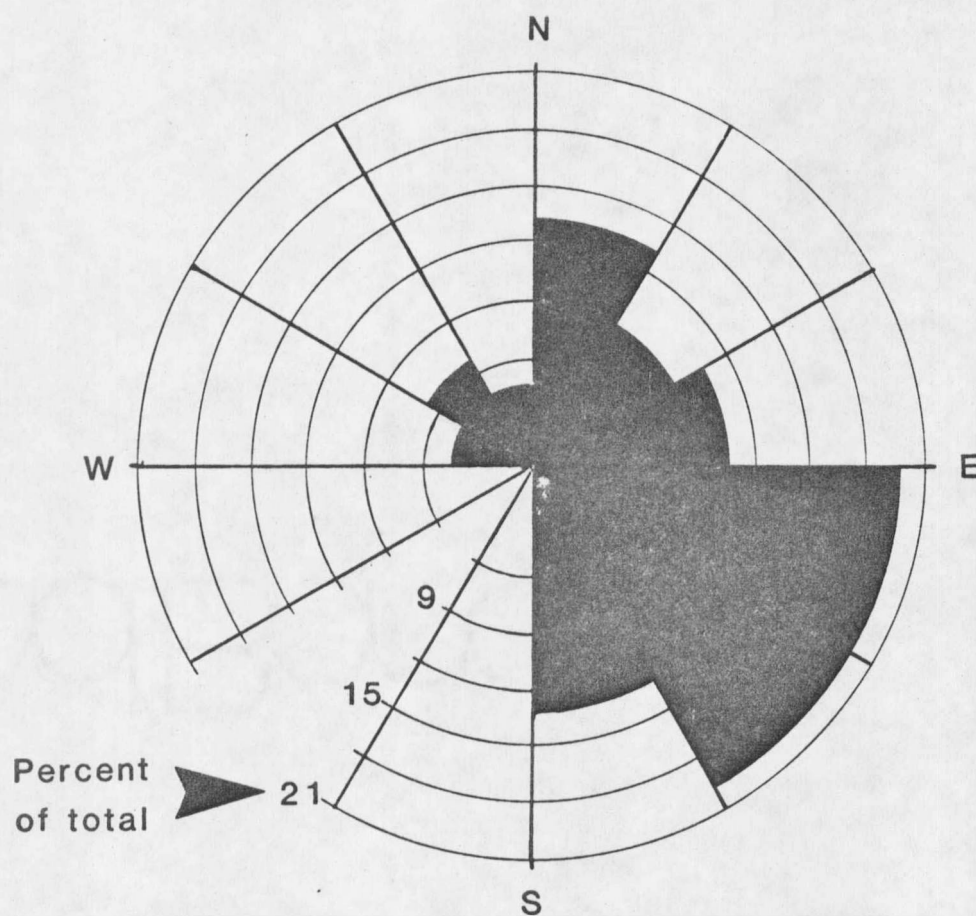


Figure 10. Current rose diagram showing azimuths of foresets of 74 cross-stratified sandstone beds in the upper part of the Judith River Formation in the study area. Compass headings were taken in the direction toward which foreset beds dipped.

Cosets of the lower, thick sandstone beds display a fining-upward grain size sequence and upward decreased thickness of cross-stratified sets. At locality "A" (Fig. 11) the fluvial system produced cyclic deposits as follows.

- TOP D 0 - 2 m Mudrock with thin lenses of very fine-grained sandstone containing climbing ripples: interpreted as levee or overbank deposits.
- C 0 - 1 m Coal and coal fragment mudstone: interpreted as floodplain and swamp deposits.
- B 1 - 3 m Clayey sandstone and mudrock: interpreted as levee, crevasse splay, and chute deposits.
- BOTTOM A 3 - 6 m Omikron cross-stratified sandstone with upward decrease in grain size, sometimes capped with ripple drift cross-lamination: interpreted as migrating fluvial point bar deposits.

The cycles are often multistoried with a "stacked" sequence that follows a (n)A - B - (n)A - B - C - D pattern where (n) could be a number from 1 to 3, giving several repetitions of omikron cross-stratified sandstones, each with an erosional upper surface. This pattern is similar to that described by Allen (1965b) for fining-upward cycles of meandering streams.

Thin, well sorted sandstone beds that contain small-scale cross-stratification often occur with a thicker sequence of mudrock, 9 to 10 m below the Judith River/Bearpaw contact (Fig. 8). These thin sandstone beds accumulated to a maximum thickness of 1 m and often display climbing ripples or ripple-drift cross-laminae (Fig. 12). At some exposures the thin sandstone beds contain burrows and small coal fragments. Small-scale cross-stratification also occurs as a

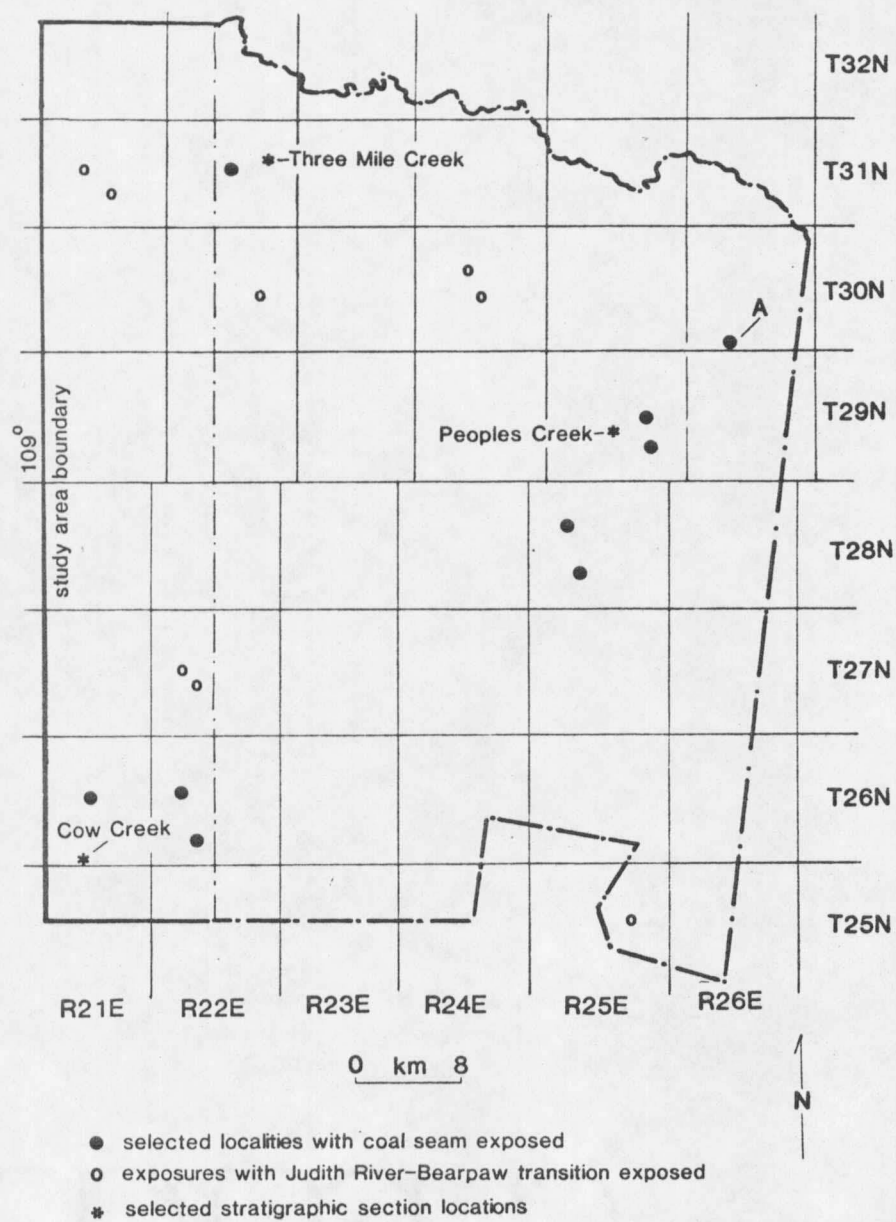


Figure 11. Map of study area showing locations of various outcrops referred to in the text.

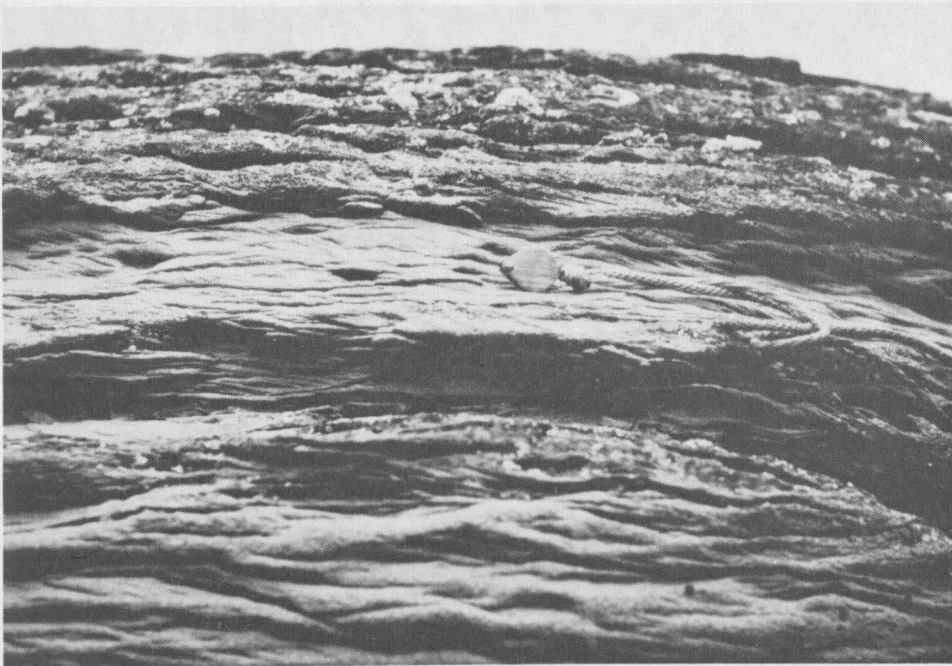


Figure 12. Photograph of climbing ripples or ripple-drift cross-lamination from near the top of the Judith River Formation in the study area.

"cap" on top of thick, large-scale cross-stratified sandstone beds, usually 12 to 13 m below the Judith River/Bearpaw contact (Fig. 8). Climbing ripples or ripple drift cross-lamination is indicative of rapid sedimentation and is produced by migrating small-scale current ripples with both the stoss and lee side of the ripple preserved (Allen, 1965b).

Other isolated beds of cross-stratified, moderately well-sorted sandstone have foresets that dip as much as 32° . These sandstone beds pinch out laterally and grade into laminated mudrock and light-colored siltstone. In the study area, these beds occur just below the contact with the overlying Bearpaw Shale and usually above the coal seam (Fig. 8). No recurring sequences occur in these steeply dipping beds.

Judith River Coal and Lignite

Near the top of the Judith River Formation, thin seams of lignite and subbituminous coal occur within mudrock beds (Fig. 8). The maximum lignite or coal thickness in the study area is 1.06 m, but a seam 2.5 m thick was described by Pepperberg (1910) within the upper part of the Judith River Formation about 25 km west of the study area. In those localities where coal could be studied in outcrop (Fig. 11), the deposits were generally lenticular, invariably pinching out within a few hundred meters. Weathered exposures of coal often contain the mineral jarosite identified by J. P. Wehrenberg using X-ray diffraction techniques at the University of Montana (personal communication, 10/16/81). Jarosite ($\text{KFe}_3(\text{OH})_6(\text{SO}_4)_2$) apparently forms as a weathering product of pyrite and probably would not occur in unweathered coal

(Warshaw, 1956). The coal contains abundant fragments of silicified and/or carbonized wood. At the Peoples Creek exposure (Fig. 11) an in situ stump of silicified wood with roots intact appears to have grown at an angle oblique to the coal seam (Fig. 13).

Bearpaw Silty Shale

The lower 15 m of the Bearpaw Shale in the study area is composed primarily of dark-colored, popcorn- or frothy-weathering silty shale. Most definitions of shale emphasize the fissile character of the fine-grained detrital rock and this is true of all rocks referred to here as silty shale. The percentage of silt-size grains in this unit varies from place to place but averages 15 to 20 percent as estimated from binocular microscope analyses.

Schultz and others (1980) analyzed the lower Bearpaw Shale at a location approximately 55 km south of the study area and found that the silt-size particles were composed of mostly quartz, plagioclase, biotite, potassium feldspar, calcite, dolomite, and cristobalite. Clay minerals comprise 75 to 80 percent of the frothy- or popcorn-weathered Bearpaw Shale. Minerals include mixed-layer clays, illite, chlorite, and kaolinite (Schultz and others, 1980). Mixed-layer clay in frothy- or popcorn-weathered shale is composed of a high proportion of montmorillonite and illite with subordinate beidellite (Schultz and others, 1980). The popcorn- or frothy-weathering is usually explained as the result of swelling and shrinking of clays rich in the exchangeable cations Na^+ and Ca^+ .

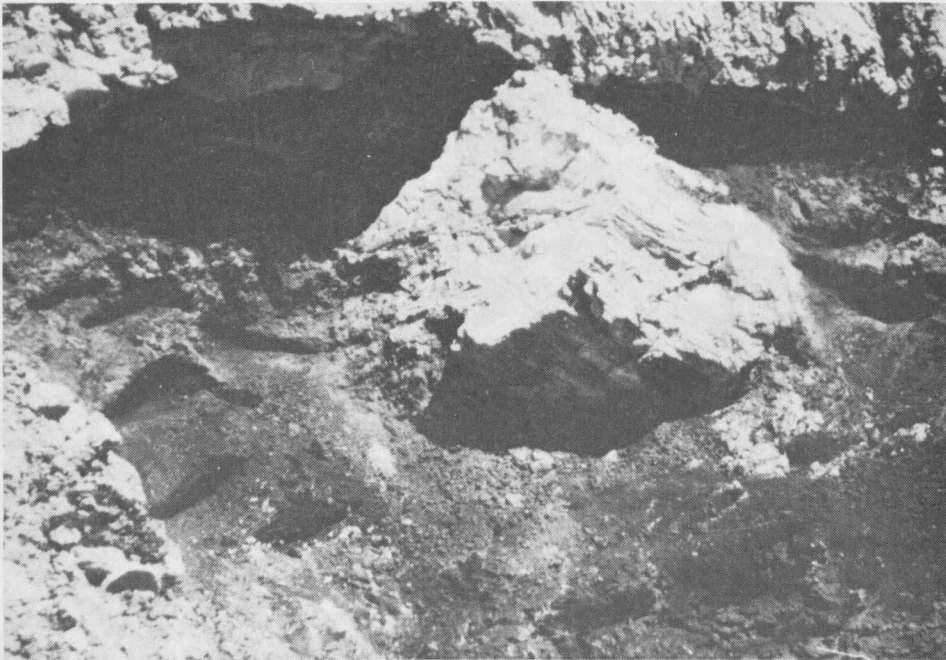


Figure 13. Photograph of in situ silicified tree stump in lignite at locality "A" (Fig. 11) in the upper part of the Judith River Formation in the study area. Diameter of stump is approximately 20 cm.

Bearpaw Clayey, Silty Sandstone

Several thin, poorly sorted and poorly indurated zones of sandstone occur in the lower part of the Bearpaw Shale in the study area. Mineralogy of the silt and sand fraction of these nonresistant beds is similar to that of the upper part of the Judith River Formation except that quartz is the major constituent followed in abundance by feldspar and rock fragments. Clay mineralogy within the sandy tongues was not determined.

Bearpaw Bentonite

The single discrete bentonite bed in the lower 15 m of the Bearpaw Shale in the study area is white to yellowish-white and has a maximum thickness of 0.65 m. Compositional analyses were not performed on this bentonite. However, Schultz and others (1980) used X-ray diffraction analyses and determined that a typical Bearpaw bentonite is composed of 80 to 100 percent clay minerals of which 100 percent is beidellite-montmorillonite mixed-layer. They found quartz, plagioclase, and biotite to comprise up to 20 percent of the typical bentonite.

DESCRIPTIONS AND INTERPRETATION OF SPECIFIC OUTCROPS

Three widely separated locations (Fig. 11) were selected for detailed lithologic study and interpretive discussion. All three include good exposures of the Judith River Formation, transitional beds, and the overlying Bearpaw Shale. Included with the discussion of each locality is a figure showing the stratigraphic section and a lithologic description of the Judith River/Bearpaw transition at that location.

Three Mile Creek Exposure

This outcrop is located in the northwest part of the study area near the center of Sec. 11, T31N, R22E along the interflueves of Three Mile Creek and the Milk River. A stratigraphic section and description of this locality is given in Figure 14.

The basal unit of this exposure is a light-colored, small-scale cross-stratified sandstone that may represent the upper part of a point bar deposit or an accumulation within a crevasse splay or levee. The overlying fine-grained sandstone, siltstone, mudrock and coal beds are interpreted as overbank deposits that resulted from lateral stream migration, which brought the floodplain environment over the former channel. Above the coal seam are light-colored siltstone, mudrock, and carbonaceous shale beds with a total thickness of 2.5 m. These beds may be a continuation of overbank deposits or, alternatively, the result of

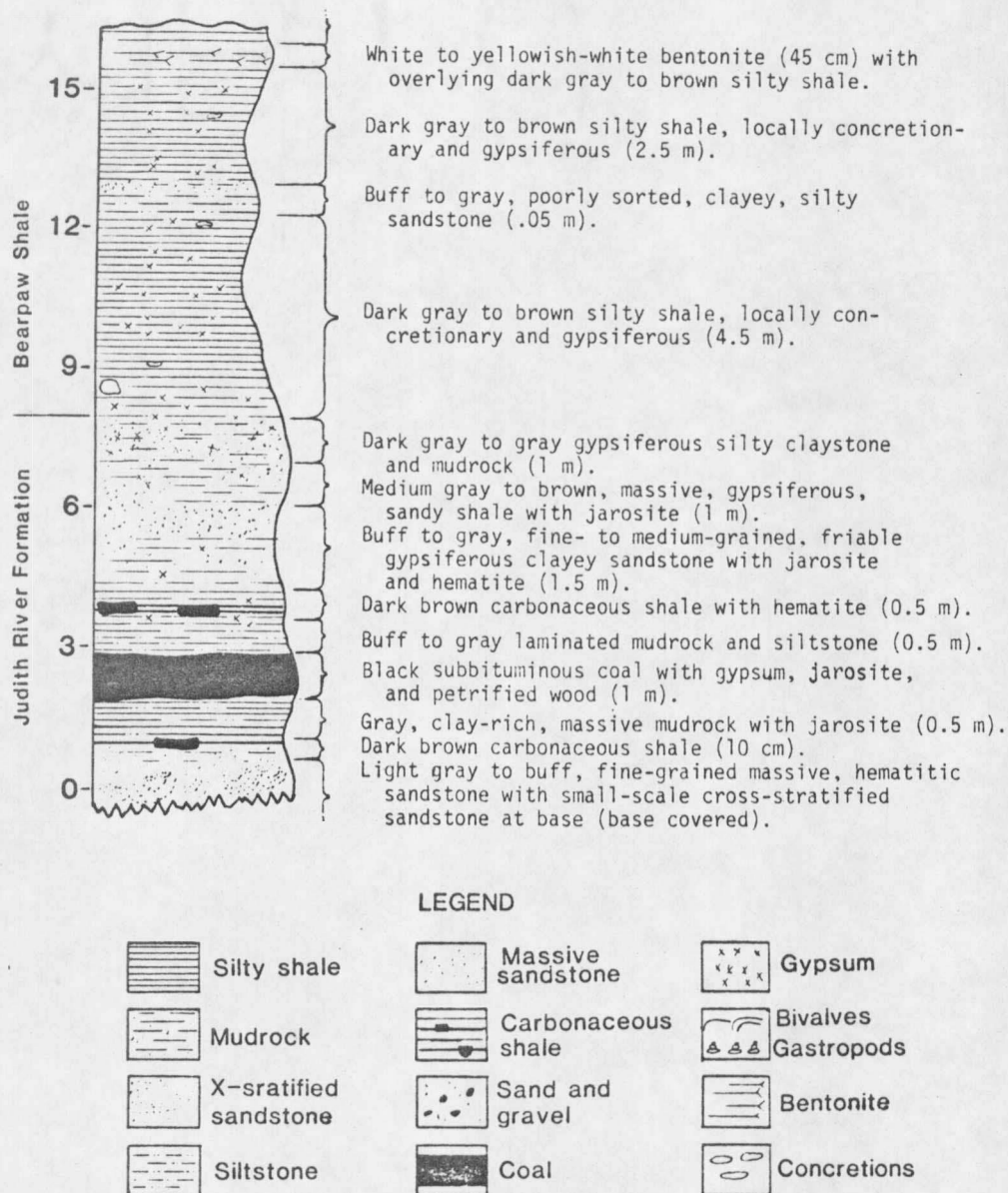


Figure 14. Lithologic log and description of the Three Mile Creek exposure. Vertical scale in meters.

brackish-water estuary, lagoonal, or delta plain sedimentation. Lack of brackish-water fossils favors the former explanation but is not conclusive. Overlying the floodplain deposits is a 4 m thick, generally darker colored sequence of clayey sandstone, sandy shale, and mudrock beds. These are interpreted as crevasse splay, levee, and delta plain deposits that accumulated in fresh or brackish-water environments. Similar deposits were described by Coleman and Prior (1982) from the Mississippi delta. No fossils were found at this stratigraphic horizon at the Three Mile Creek outcrop that might confirm this environment of deposition.

Sharply overlying the last mudrock bed is dark grayish-brown shale that is interpreted as the initial deposit of the Bearpaw transgression. Approximately 3 m above the first appearance of dark-colored shale, is a thin zone of poorly sorted, massive, clayey sandstone that may be the result of storm activity or increased sediment input from the fluvial system. Currents were apparently strong enough to bring in sand grains, but of insufficient duration or magnitude to produce a well-sorted deposit. The thickness and lateral extent of this coarse-grained facies varies significantly within 50 m.

Approximately 8 m above the lowest marine deposit, a 30 to 45 cm thick bentonite bed occurs. This ashfall deposit has variable thickness and an irregular, apparently scoured upper surface that suggests some erosion occurred before burial and, therefore, deposition within wave base.

Peoples Creek Exposure

This outcrop is located in the east-central part of the study area in the NE $\frac{1}{4}$ of Sec. 21, T29N, R25E. A stratigraphic section and description of this locality is given in Figure 15.

The sequence of lithologies at this outcrop is similar to that at Three Mile Creek with a basal fine-grained, small-scale and ripple-drift cross-laminated sandstone bed. This type of cross-stratification can occur in two environments of a fluvial system (Allen, 1965a): as the final deposit in point bar sequences, or on levees and crevasse splays.

Above the basal sandstone, a gradual upward decrease in grain size occurs. Moderately sorted, fine-grained sandstone is interbedded with mudrock that grades upward into a thick bed of sandy mudrock containing lenses of carbonaceous shale and a 1 m thick coal seam. A thin bed consisting of light-colored, fine-grained, massive silty sandstone containing abundant coal fragments overlies the coal-mudrock sequence. The entire lower 7 m of the exposure is interpreted as an accumulation that occurred in overbank environments, beginning with levee deposits that were succeeded by fine-grained floodplain and swamp deposits. The vertical juxtaposition of lithologies may be explained by shifting environments as a stream channel migrated, as postulated by Allen (1965b) from similar recent deposits.

Overlying these overbank lithologies is a bioturbated, dark gray shale that contains numerous "floating" fine-grained sand particles near the base of the unit. This bed is probably of marine origin and may have been deposited on a flooded delta plain or in a lagoon created

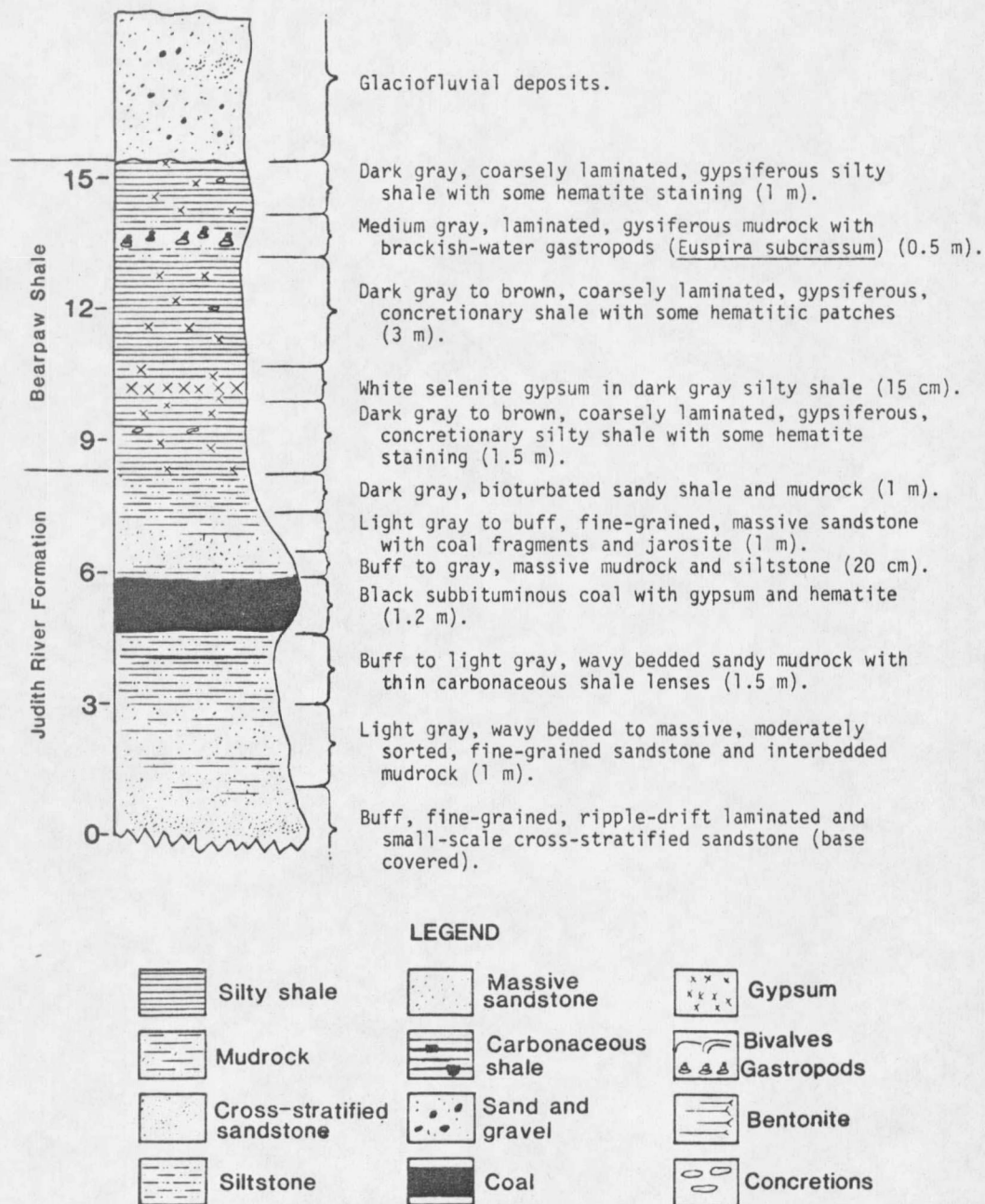


Figure 15. Lithologic log and description of the Peoples Creek exposure. Vertical scale in meters.

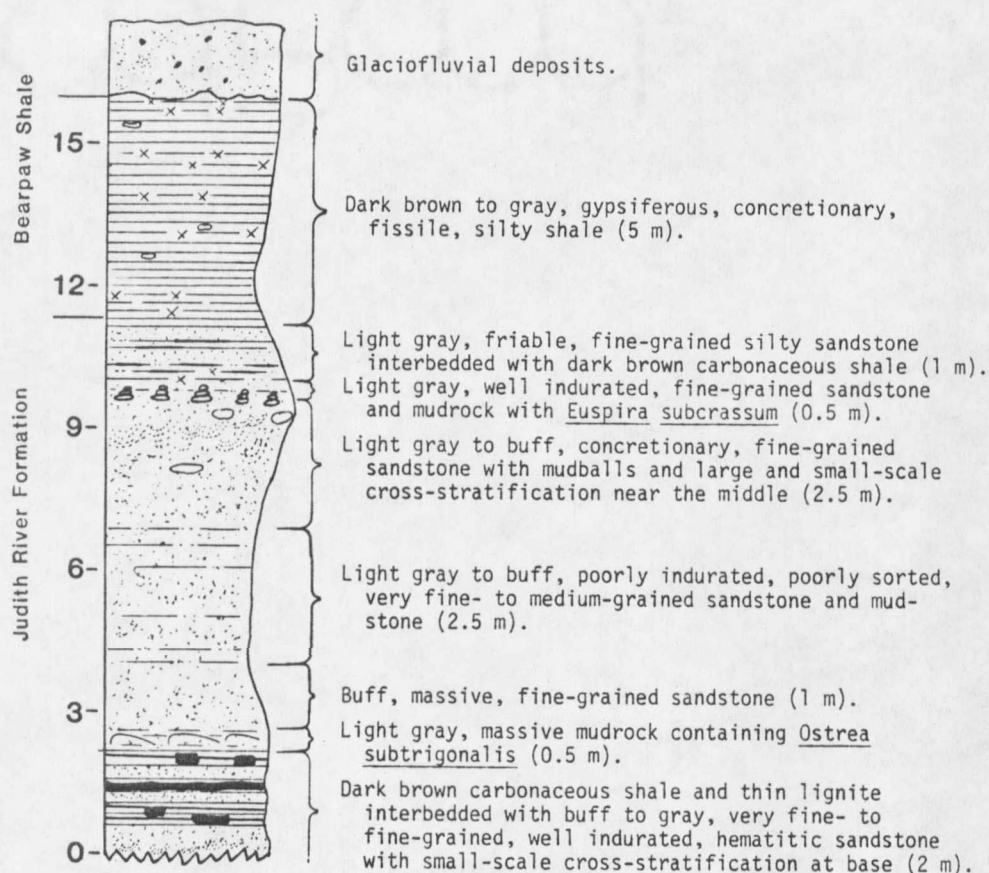
during a transgressive pulse of the Bearpaw sea. The bioturbated sandy shale grades upward into a dark gray, coarsely laminated, gypsiferous shale interpreted as the initial deposit of the advancing Bearpaw sea.

The juxtaposition of strata at this horizon suggests that some fluctuation of the depositional environment occurred at this location. A 0.5 m thick mudrock containing Euspira subcrassum, a brackish-water gastropod (W. A. Cobban, personal communication, 2/3/82), occurs approximately 5 m above the Judith River/Bearpaw contact within the Bearpaw Shale. Fluctuation of marine and brackish-water environments may have been caused by slight regressions of the sea or locally decreased tidal range. Overlying this brackish-water deposit is dark grayish-brown, concretionary, gypsiferous, silty shale typical of the Bearpaw Formation.

Cow Creek Exposure

This outcrop is located in the southwest part of the study area in Sec. 33, T26N, R21E, approximately 0.5 km east of Cow Creek (Figs. 11 and 16).

The lowest strata exposed are an alternating sequence of carbonaceous shale and buff to light gray, very fine-grained, hematite-stained sandstone, which has small-scale cross-stratification at the base. The inferred depositional environment is a levee followed by overbank swamps that were occasionally covered by crevasse splay sedimentation similar to recent deposits described by Collinson (1978).



LEGEND

	Silty shale		Massive sandstone		Gypsum
	Mudrock		Carbonaceous shale		Bivalves
	Cross-stratified sandstone		Sand and gravel		Gastropods
	Siltstone		Coal		Bentonite
					Concretions

Figure 16. Lithologic log and description of the Cow Creek exposure. Vertical scale in meters.

The next lithology in the sequence is a light gray, massive mudrock containing numerous brackish-water oysters, including Ostrea sub-trigonalis. This 0.5 m thick brackish-water facies occurs between thicker sequences of freshwater alluvial deposits. The environment that produced the brackish-water deposit may have formed by local subsidence and tidal flooding or in an estuary by a brief advance of the Bearpaw sea.

The oyster-bearing horizon is overlain by a massive, nonresistant fine-grained sandstone, which grades into a poorly sorted, massive to poorly bedded, fine-grained sandstone and mudrock. Overlying the sandstone and mudrock sequence is a well indurated, fine- to medium-grained, cross-stratified sandstone bed up to 3 m thick. Cross-strata dip as much as 22° and contain calcareous concretions and mudballs. Cross-strata are in sets up to 60 cm thick with erosional upper surfaces and tangential bases and are classified as omikron cross-strata (Allen, 1963). Grain size decreases upward in cosets, with some climbing ripples in the upper part of the facies.

From the top of the brackish-water oyster horizon upward, the environments of deposition appear to have been dominated by alluvial processes as indicated by primary sedimentary structures and facies relationships. The thin, massive sandstone and overlying mudrock is similar to those described by Collinson (1978) as crevasse splay and floodplain deposits. The cross-stratified sandstone is interpreted as a point bar deposit that accumulated on top of the floodplain facies as a channel migrated laterally.

Overlying the cross-stratified sandstone is a thin, light gray, gypsiferous, concretionary, gastropod-bearing, fine-grained sandstone with interbedded mudstone. The gastropods were identified by W. A. Cobban (personal communication, 2/3/82) as Euspira subcrassum (Meek and Hayden) that he presumed to be shallow water forms from their association with other proven marine fauna. This facies probably was deposited in an environment that resulted from another brief advance of the sea or by lateral shift of facies.

Overlying this gastropod bed is a succession of alternating silty sandstone and dark brown carbonaceous shale beds, the latter predominating in the upper part. These are interpreted as coastal or delta plain swamp deposits that formed as the Bearpaw sea advanced, creating a higher ground-water table. The carbonaceous shale grades upward into dark gray, gypsiferous, silty shale, the first Bearpaw lithology.

DEPOSITIONAL MODELS

Development of a Model

Sedimentary rocks at the Judith River Formation/Bearpaw Shale transition are so varied that no single environmental model satisfactorily explains them. The technique used here has been to describe the characteristics of the deposits and then apply different models as they fit, resulting in a composite model.

A model can be devised using modern analogues by exercising some restraint. Several authors have observed that modern fluvial systems do not parallel conditions that affected most ancient fluvial environments. Differences between modern and ancient conditions pointed out by Friend (1978) include different climates, vegetation, and orogenic conditions. Leeder (1978), Friend (1978), and McLean and Jerzykiewicz (1978) all agreed that the thickness and lateral extent of floodplain deposits of ancient river systems is far greater than those of modern analogues. This is especially true when subsidence allows frequent flood events that provide the accumulation and burial of floodplain sediments, which may have been the case during Judith River time.

A number of factors suggest that streams which deposited the Judith River Formation were relatively stable and not prone to lateral migration. Grain size, composition, and sedimentary packaging indicates that the upper 15 m of the Judith River Formation in the study area is composed of 50 to 60 percent overbank deposits. Gant (1982) pointed

out that when stream banks are composed of fine-grained, cohesive sediments with thick vegetative growth, there is a high resistance to erosion and channel migration. Overbank accumulation of peat, a fibrous, cohesive material also resists erosion and the development of a new channel across it by river avulsion (Ryer, 1981). Channel migration would also be inhibited by clay plugs formed in abandoned meanders. Another factor to be considered is that Judith River streams may have been confined to broad, incised valleys produced initially by lowering of base level during regression of the Claggett sea and possibly sustained by sporadic uplifts in the west. All of these factors probably contributed to laterally stable streams that confined deltaic complexes to areally limited centers of deposition for relatively long periods of time.

Determination of alluvial environments is often facilitated by recognition of point bar deposits that display characteristic sequential properties (Allen, 1965a; Reineck and Singh, 1973; and Leeder, 1978). This ideal point bar model is distinguished by a distinct vertical pattern that displays an upward decrease in grain size and an upward decrease in thickness of sedimentary units, which allows the deposit to be divided into upper and lower parts.

Figure 17 is a diagram showing a complete sequence in a point bar deposit as described by Reineck and Singh (1973). The base of an ideal sequence is characterized by a scoured surface followed by channel lag deposits and large-scale, relatively coarse-grained, cross-stratified sandstone. Transition to the upper point bar is often marked by a zone of horizontal lamination. The upper portion of an

ideal point bar displays small-scale cross-stratification and ripple drift cross-lamination, which are sometimes capped by a mud layer.

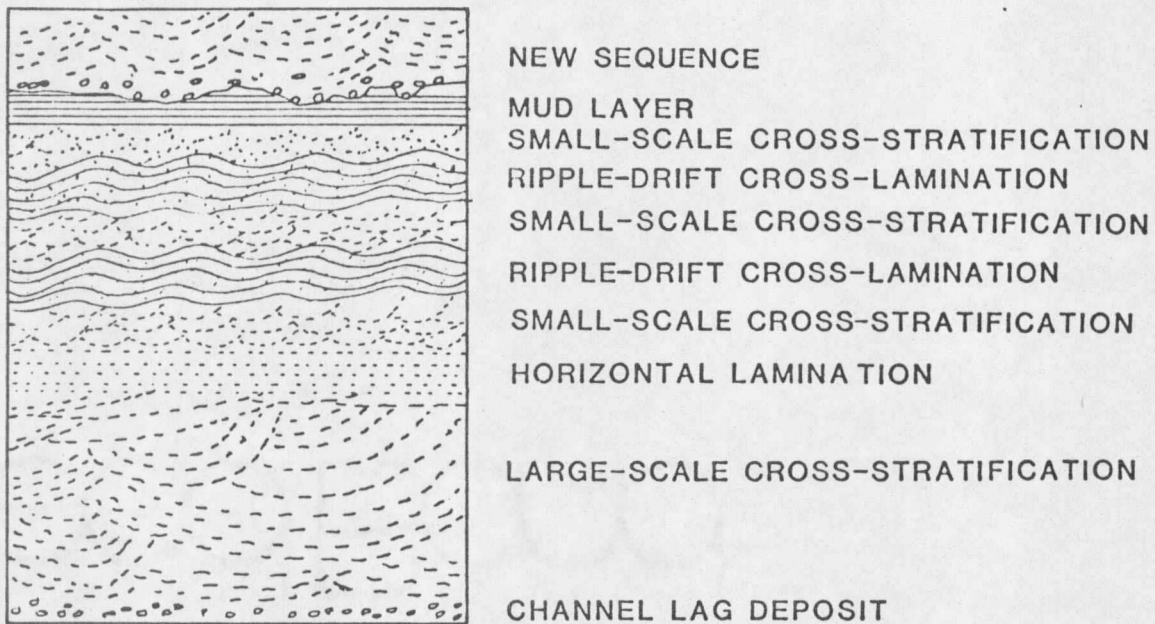


Figure 17. Idealized fining upward sequence of a point bar deposit. Grain size and sedimentary unit thickness decrease upward (from Reineck and Singh, 1973, p. 240).

Entire ideal point bar sequences seldom occur. The upper or fine-grained deposits are often missing due to either erosion during reoccupation of an old channel by a stream or by simple nondeposition. However, most point bar sequences display sufficient diagnostic features for confident interpretation of the deposit.

In the study area, the thickness of point bar sequences in the upper 15 m of the Judith River Formation indicates deposition by

relatively small, well organized fluvial systems on alluvial and deltaic plains. Much larger alluvial and deltaic systems existed 100 to 200 km to the north and the south (Weimer, 1960; Williams and Stelk, 1975).

The marine depositional environment of the Bearpaw Shale has been established through paleontologic evidence. However, oceanographic conditions in this marine environment are not as easily documented. Ryer and Kauffman (1980) suggested mesotidal ranges existed in the Cretaceous epeiric sea of the Western Interior. As evidence they cited linear sand bars and thick foreshore sequences. Ryer and Kauffman also proposed the existence of tidal inlets, tidally influenced reaches of river systems, and tidal flats. However, linear sand bars and thick foreshore sequences do not occur in the study area, which may reflect a smaller tidal range before the Bearpaw transgression or simply a lack of detritus for such accumulations. The possibility of daily wave activity was suggested by Caldwell (1968) from evidence he found in the lower Bearpaw Shale in southern Saskatchewan. This evidence includes thanatocoenosis, primary sedimentary structures within sandstone tongues, and scoured bentonite beds, all suggesting deposition within wave base. However, no shoreface sequences or laterally continuous delta front sandstones, which Ryer (1981) considered as evidence of significant wave activity, occur in the study area.

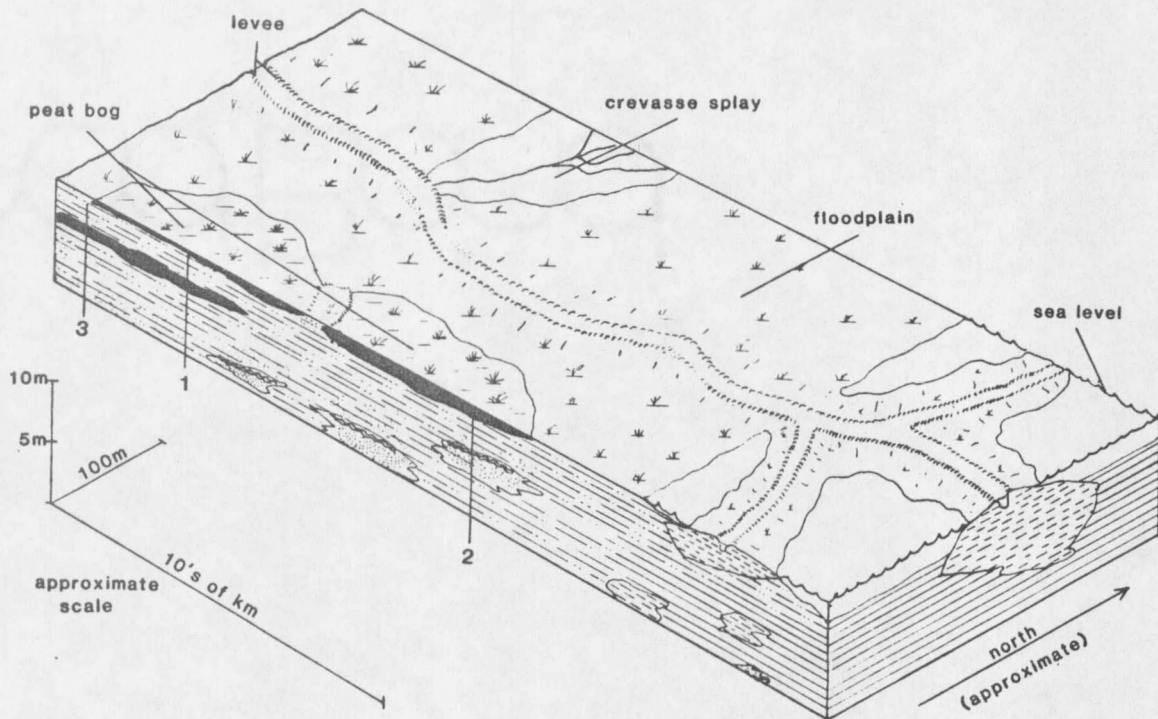
Lacking detailed lithologic or paleontologic evidence, it is difficult to precisely characterize the depositional environment of the lower Bearpaw Shale in the study area. However, the presence of brackish-water fauna and a scoured bentonite bed at some locations in the study

area, and stratigraphic relationships that indicate a rapid transgression, all suggest shallow marine and brackish-water environments existed during deposition of the lower Bearpaw Shale.

Environments of Deposition During the Transgression

As subsidence occurred in the western part of the basin, sedimentation of the Judith River Formation in the study area probably decreased and sea level rose, shifting depositional environments to the west. Figures 18 through 21 are a series of block diagrams showing the alluvial, deltaic, and marine systems believed responsible for deposition of the upper Judith River Formation and the lower Bearpaw Shale. The diagrams show a time-transgressive sequence with the encroachment of the Bearpaw sea over the top of the Judith River Formation and the inferred environments produced during the transgression. The locations of the stratigraphic sections shown in Figures 14, 15, and 16 are indicated in Figures 18 through 21.

Figure 18 shows the environments at approximately 72.5 m.y. B.P., before the major transgressive pulse of the Bearpaw sea. At this time, development of Judith River alluvial and deltaic facies was probably approaching the final stage. With the initiation of increased subsidence in the western part of the Western Interior basin due to tectonic thickening, peat bogs were probably common in overbank and deltaic swamps. The lack of well developed point bar deposits at this stage suggests decreased stream load and therefore decreased stream gradients.



LEGEND

Judith River Formation

Mudrock with some siltstone, shale, and coal; overbank and delta plain deposits

Sand-rich mudrock; over bank deposits

Large-scale cross-stratified sandstone; point bar and channel deposits

Ripple-drift and small-scale cross-stratified sandstone; crevasse splay and upper point bar deposits

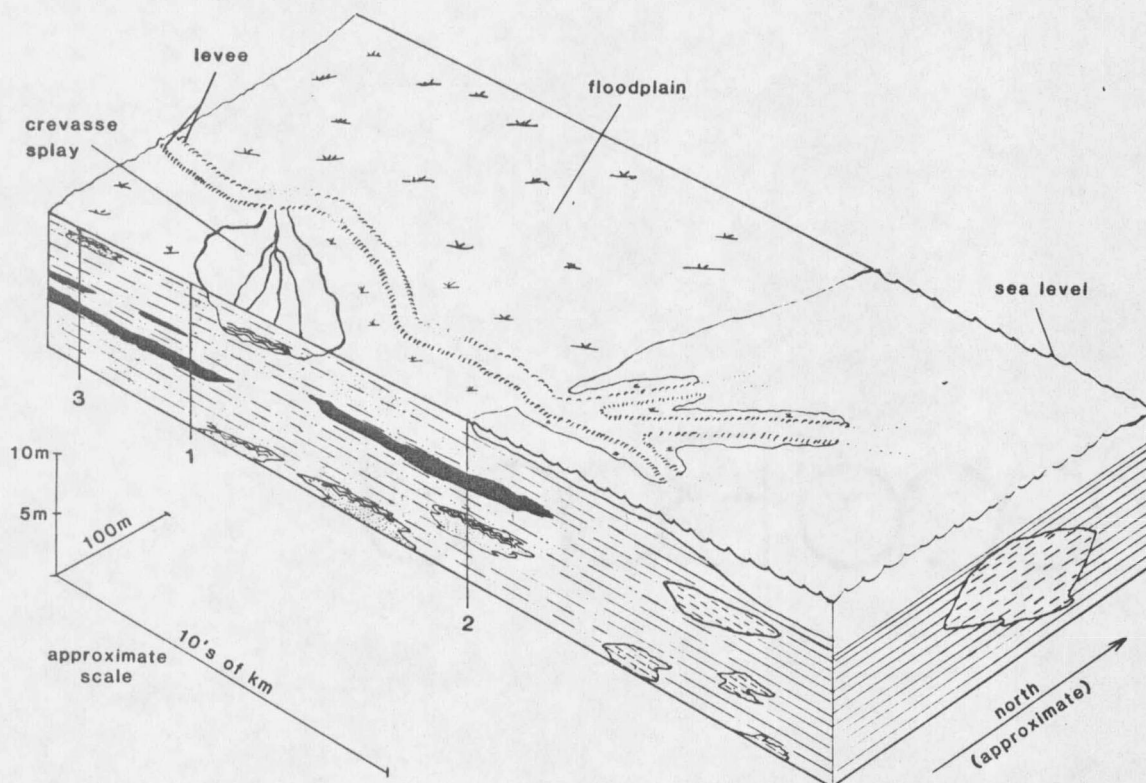
Coal and lignite; overbank deposits

Bar finger sandstone and siltstone; delta front and delta margin deposits

Bearpaw Shale

Silty shale with minor bentonite; Marine deposits

Figure 18. Diagrammatic oblique view showing alluvial, deltaic, and marine environments approximately 72.5 m.y. B.P. Numbers indicate locations of stratigraphic sections shown in Figures 14, 15, and 16. Number 1 refers to Three Mile Creek section; 2 refers to Peoples Creek section; and 3 refers to Cow Creek section.



LEGEND

Judith River Formation

Mudrock with some siltstone, shale, and coal; overbank and delta plain deposits

Sand-rich mudrock; over bank deposits

Large-scale cross-stratified sandstone; point bar and channel deposits

Ripple-drift and small-scale cross-stratified sandstone; crevasse splay and upper point bar deposits

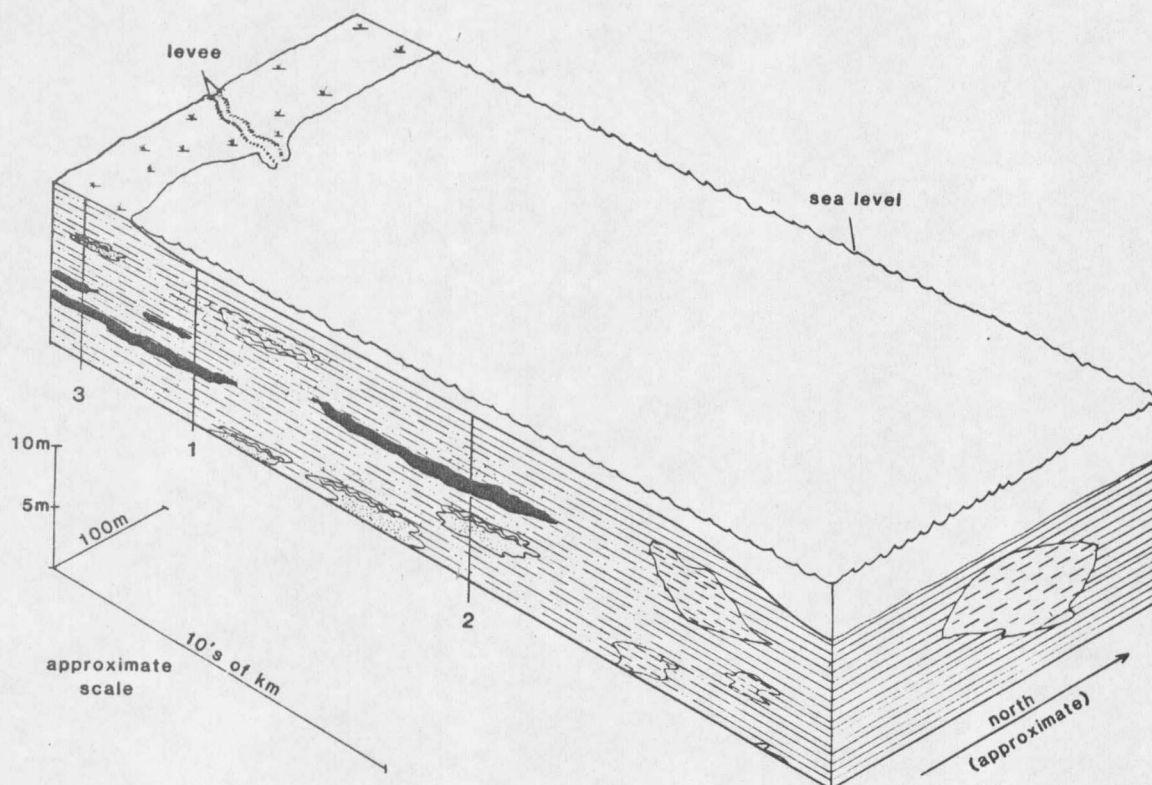
Coal and lignite; overbank deposits

Bar finger sandstone and siltstone; delta front and delta margin deposits

Bearpaw Shale

Silty shale with minor bentonite; Marine deposits

Figure 19. Diagrammatic oblique view showing alluvial, deltaic, and marine environments approximately 72 m.y. B.P. Numbers indicate locations of stratigraphic sections shown in Figures 14, 15, and 16. Number 1 refers to Three Mile Creek section; 2 refers to Peoples Creek section; and 3 refers to Cow Creek section.



LEGEND

Judith River Formation



Mudrock with some siltstone, shale, and coal; overbank and delta plain deposits



Sand-rich mudrock; over bank deposits



Large-scale cross-stratified sandstone; point bar and channel deposits



Ripple-drift and small-scale cross-stratified sandstone; crevasse splay and upper point bar deposits



Coal and lignite; overbank deposits



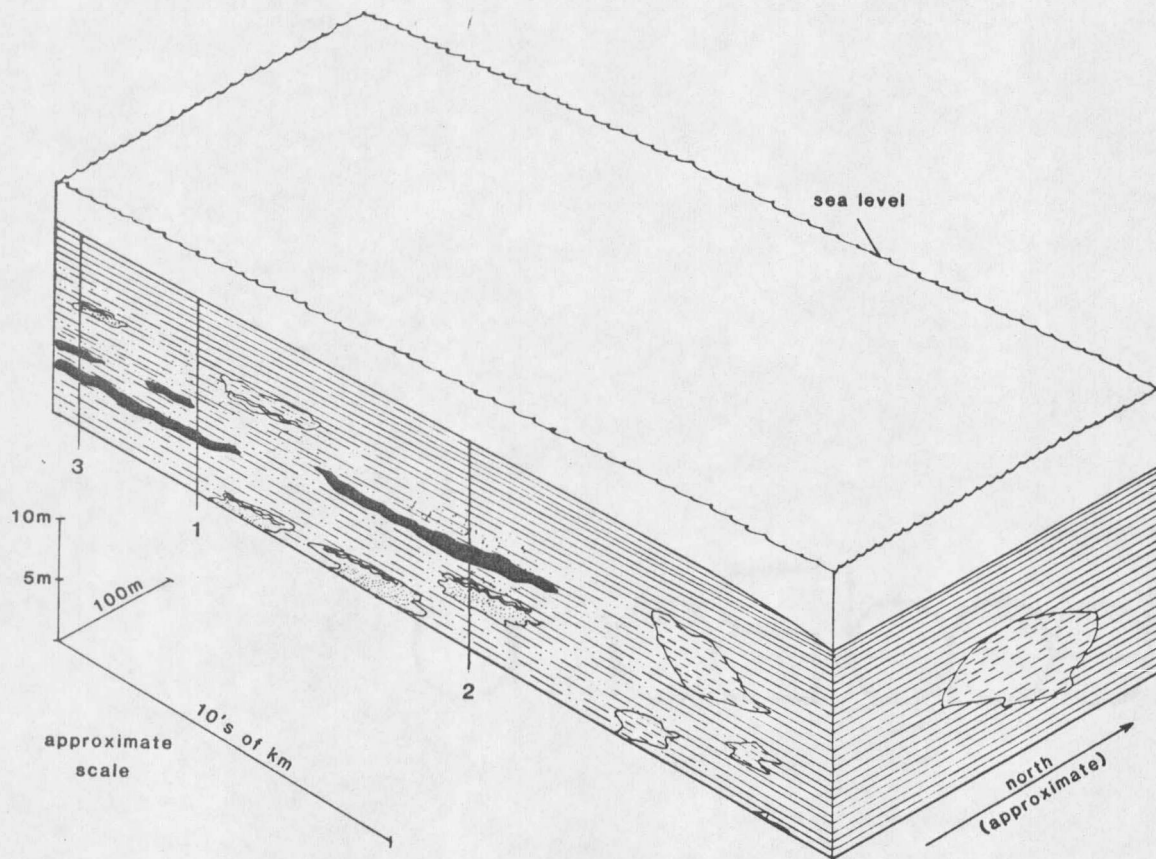
Bar finger sandstone and siltstone; delta front and delta margin deposits

Bearpaw Shale



Silty shale with minor bentonite; Marine deposits

Figure 20. Diagrammatic oblique view showing alluvial, deltaic, and marine environments approximately 71.5 m.y. B.P. Numbers indicate locations of stratigraphic sections shown in Figures 14, 15, and 16. Number 1 refers to Three Mile Creek section; 2 refers to Peoples Creek section; and 3 refers to Cow Creek section.



LEGEND

Judith River Formation

 Mudrock with some siltstone, shale, and coal; overbank and delta plain deposits

 Sand-rich mudrock; over bank deposits

 Large-scale cross-stratified sandstone; point bar and channel deposits

 Ripple-drift and small-scale cross-stratified sandstone; crevasse splay and upper point bar deposits

 Coal and lignite; overbank deposits

 Bar finger sandstone and siltstone; delta front and delta margin deposits

Bearpaw Shale

 Silty shale with minor bentonite; Marine deposits

Figure 21. Diagrammatic oblique view showing alluvial, deltaic, and marine environments approximately 71 m.y. B.P. Numbers indicate locations of stratigraphic sections shown in Figures 14, 15, and 16. Number 1 refers to Three Mile Creek section; 2 refers to Peoples Creek section; and 3 refers to Cow Creek section.

In Figure 19 the initial transgressive pulse of the Bearpaw sea is shown with attendant westward migration of alluvial and deltaic systems. A further decrease in Judith River sedimentation is implied, probably caused reduced sediment supply due to reduced stream gradients. Deltaic accumulations were probably negligible, lacking sufficient time and detritus for development.

Continuation of the transgression of the Bearpaw sea is shown in Figure 20 with the alluvial environment shifted farther west. In the study area at this stage, stream discharge and gradient were probably reduced to the point where sediment accumulation was insignificant. Marine and brackish-water conditions dominated at this time except for proximal continental environments in western Montana.

Figure 21 shows probable environments at approximately 71 m.y. ago with inundation by the Bearpaw sea across the entire study area. The resulting marine silty shale and occasional clayey sandstone and bentonite beds accumulated on top of the fresh and brackish-water Judith River Formation.

BEARPAW TRANSGRESSION

Interpretations in the Literature

Rate of Transgression

The rate of transgression of the Bearpaw sea in the northern United States and southern Canada has long been debated with several authors supporting a rapid transgression using stratigraphic and radiometric evidence, while others found faunal evidence that suggested a diachronous event.

Russell (1939) first suggested that the Bearpaw transgression was a nearly isochronous event from stratigraphic work in southern Alberta. McLean (1971) also considered the transgression to have been rapid over much of Alberta and western Montana because he found no transgressive sandstones at the Judith River/Bearpaw contact. In northern Montana, Lorenz (1981) showed the transgressive Bearpaw shoreline migrated rapidly, at a rate of approximately 450 km/m.y. Folinsbee and others (1961, 1965) radiometrically dated bentonite beds at the base of the Bearpaw Shale from locations in south-central Alberta in the Cypress Hills, in southern Saskatchewan along the Saskatchewan River, and along the Missouri River in north-central Montana. These potassium-argon dates were obtained from sanidine and biotite and indicated a rapid transgression of the Bearpaw sea. Folinsbee and others (1965) dated this isochronous transgression at 72 - 73 m.y. ago with a maximum deviation of ± 5 percent.

Conversely, Caldwell (1968, 1978, 1982) used ammonite zonation to show that the transgression in southern Alberta and Saskatchewan was markedly diachronous. Gill and Cobban (1973) provided similar evidence in central and southern Montana and adjacent areas where they used ammonite zonation to calculate that the transgressive shoreline had migrated about 110 km/m.y. Both studies found considerable age differences indicated by faunal change in the lowest fossils found in the Bearpaw Shale from east to west.

In some areas of the Western Interior basin, transgressive movement of the Bearpaw shoreline has been reported as minimal to nonexistent. Gill and Cobban (1966) reported a major unconformity at the base of the Teapot Sandstone Member of the Mesa Verde Formation in several basins of Wyoming. Gill and Cobban placed a date of 72 m.y. B.P. on the unconformity and suggested it resulted from erosion following a broad regional uplift. This occurred at about the same time as the relatively rapid transgression of the Bearpaw sea in northern Montana, which was radiometrically dated at about 72 m.y. (Folinsbee and others, 1965).

Causes of the Bearpaw Transgression

Interpretations of the cause of the Bearpaw transgression are divided between tectonoeustasis and local tectonic control. Hancock and Kauffman (1979) proposed a eustatic control on sea level fluctuation in the Western Interior as well as in northwest Europe, Nigeria, and India. Conversely, Gill and Cobban (1966, 1973) and Jeletzky (1971, 1977) considered tectonic mechanisms largely responsible for shifts of the strand line. Bally and others (1966), McLean and Jerzykiewicz (1978), and Lorenz (1981) related tectonic thickening along the western

Cordillera to basin subsidence, which they postulated initiated the Bearpaw transgression. Considering the various interpretations regarding the transgression of the Bearpaw sea and mechanisms that caused it, no single explanation is likely to be correct for the entire Western Interior basin.

Tectonoeustasis was probably a major cause for the initial formation of the Cretaceous epeiric sea because similar seas existed at the same time on other continents (Hancock and Kauffman, 1979). However, transgressions and regressions apparently occurred too rapidly to have been caused by changes in mid-ocean ridge spreading rates. Pitman (1978) considered the maximum rate of sea level rise due to changes in mid-ocean ridge spreading would be about 10 m/m.y. Other causes of eustasy suggested by Donovan and Jones (1979) such as glaciation or desiccated basins are not known to have occurred during the Cretaceous.

Figure 22 is a paleogeographic map of Montana and adjacent areas during deposition of upper Judith River rocks (approximately 72 m.y. ago) showing the inferred shoreline and major deltaic centers. Lorenz (1981) suggested a mechanism of strandline movement that invokes regional thrust events that modified the large reentrant deltas, which appears to account for widely different rates of transgression reported for the Bearpaw sea in different regions (Fig. 22). The rate of transgression created would have varied from place to place depending on the relative position with respect to the thrust sheets (and therefore subsidence) and deltaic centers. According to this model, the transgression was nearly isochronous in rapidly subsiding areas and slower over large, recently abandoned deltas. Lorenz (1981) postulated that the Bearpaw

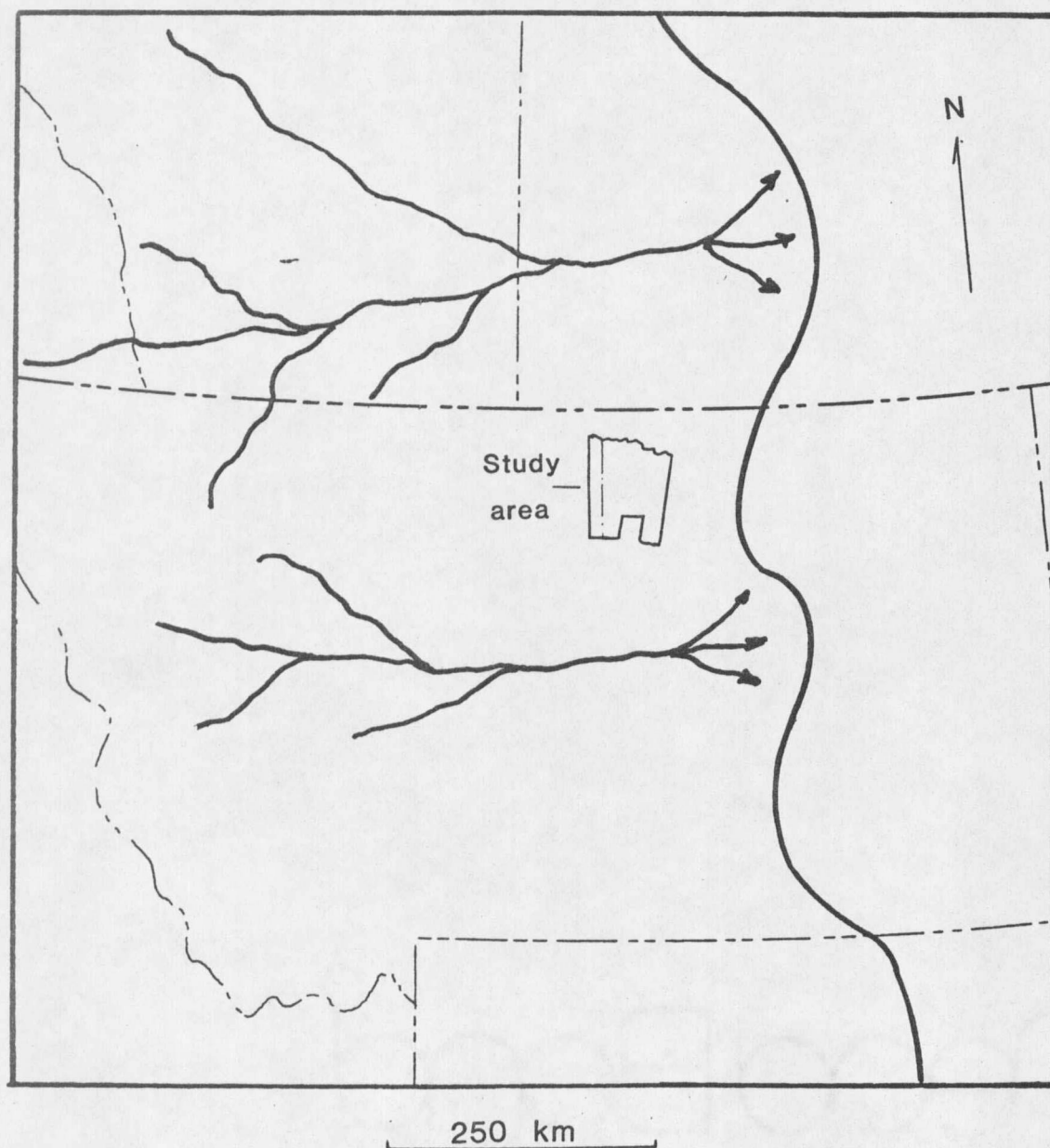


Figure 22. Paleogeographic map of Montana and adjacent area showing inferred position of shoreline, major deltaic complexes, and direction of sediment transport (data from Weimer, 1970; Williams and Stelk, 1975; Williams and Burke, 1964; Wilson, 1970).

transgression was slowest in that area occupied by the major Judith River Formation deltaic complexes in central Montana and southern Alberta and Saskatchewan. In addition, the radiometric age date of 72 m.y. B.P. obtained by Hoffman and others (1976) for the beginning of the last episode of thrusting in northwestern Montana correlates very well with the 72-73 m.y. B.P. date given by Folinsbee and others (1965) for the isochronous advance of the Bearpaw sea.

Lorenz' mechanism has several positive points. However, his transgressive rates contradict those implied by faunal zonation reported by Caldwell (1969, 1978) and Gill and Cobban (1973). This incongruity may be explained by examining possible differences in paleotopography. The rapid transgression occurred over the low-relief, near-sea level coastal plain deposits of the Judith River Formation and not as rapidly over the major deltaic complexes to the north and south. Small, shallow inlets between the major deltaic centers may have allowed brackish-water to invade the subsiding western part of the basin around and adjacent to the topographically high deltaic complexes (Fig. 23). Kauffman (1977, Fig. 11, p. 15) postulated there was a salinity stratification in the Cretaceous sea with a slightly brackish, low-density surface layer produced by freshwater inflow of river systems draining adjacent land areas. Beneath the brackish-water surface layer, Kauffman suggested the existence of a warm, normal-salinity marine bottom layer. Because nektonic ammonites apparently preferred normal marine surface water they may not have inhabited the surface brackish-water layer. Thus, the brackish-water of newly subsided areas would have lacked the

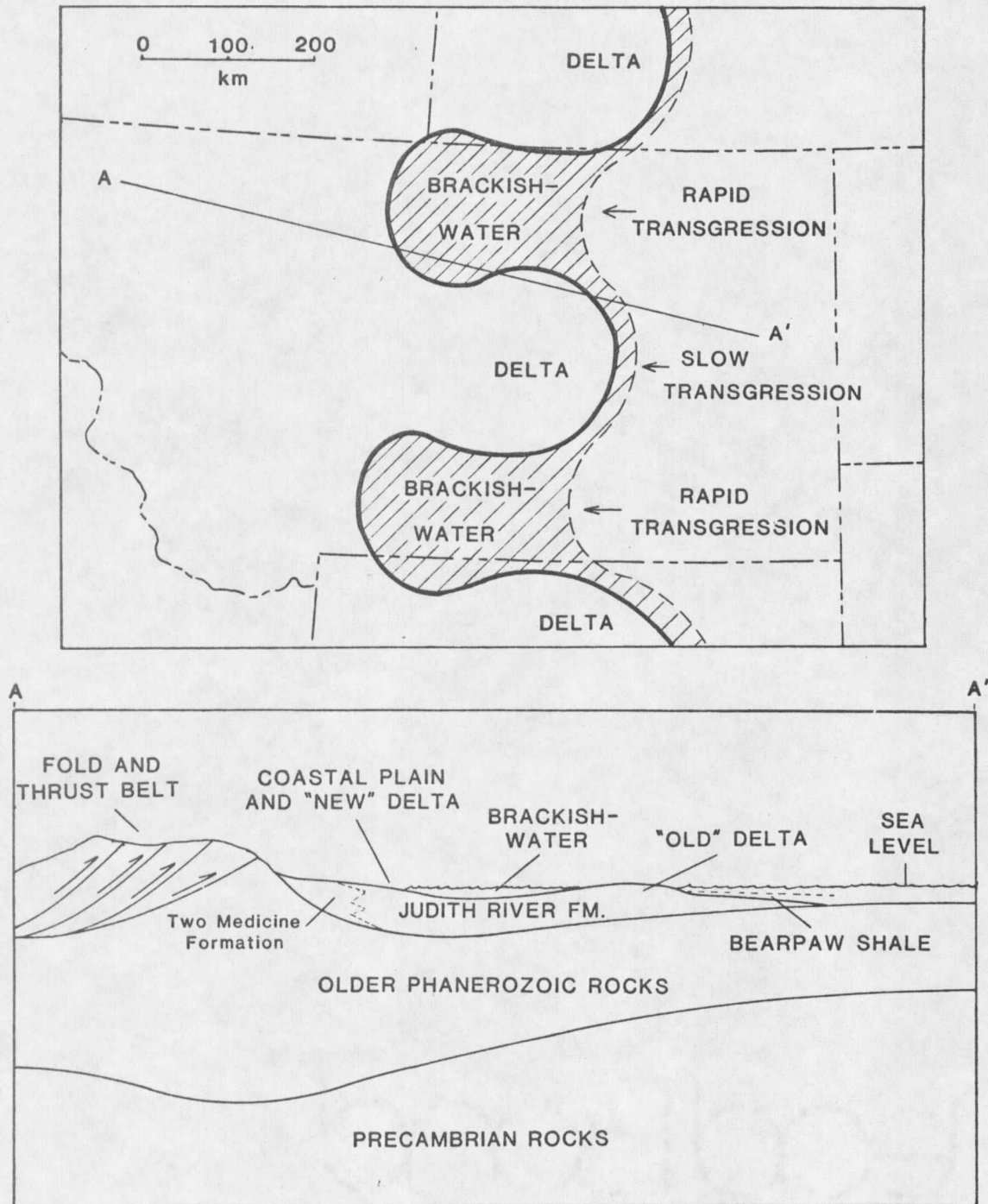


Figure 23. Map and cross section showing major Judith River deltaic complexes that probably prevented full circulation of normal marine salinity water but allowed surface brackish-water to enter subsiding basin to west. Hachure area in map view is brackish-water, dark black line is shoreline.

rich fauna of the rest of the basin, accounting for the east-west age differences of ammonites and the attendant diachronous interpretations.

Evidence for a Rapid Transgression in the Study Area

In the study area, several lines of evidence suggest a nearly isochronous transgression of the Bearpaw sea. This evidence includes a lack of sandy transgressive deposits at the contact, small east-west differences in thickness between marker horizons, and apparently similar elevations of the contact from east to west in undeformed areas. Although none of these considerations is, by itself, conclusive, when considered together with other studies in the region, the implications are convincing.

The most striking lithologic feature suggesting a nearly isochronous transgression is the lack of a sandy transgressive shoreline facies at the contact. Russell (1939), McLean (1971) and Lorenz (1981), among others, inferred that the absence of nearshore, sand-rich deposits is evidence that the Bearpaw transgression was so rapid that such deposits never developed.

Swift (1968) and Ryer (1977) studied more diachronous transgressive sequences that lacked nearshore sand facies. They explained this absence as resulting from shoreface erosion and sediment dispersal during the transgression. The resulting disconformity between nonmarine and marine deposits is termed a ravinement.

Swift (1968) listed five criteria for recognizing a ravinement: 1) a sharp contact, 2) no nearshore sandstones, 3) a slight angular unconformity, 4) few interfingering lithosomes of marine and nonmarine

sediments, and 5) the presence of a basal lag gravel in the overlying marine unit. Only the first and fourth of the five features Swift described were found at the contact between the Judith River and Bearpaw formations. Moreover, no evidence for an unconformity at this horizon in this part of the Western Interior basin has been reported in the literature.

Another possible explanation for a lack of nearshore sands at the contact may be that insufficient detritus was delivered to the marine environment. If tectonic thickening to the west produced contemporaneous subsidence, stream gradients in the distal part of the basin may have decreased so that they were no longer able to carry sand-size grains, with most coarse detritus deposited adjacent to the mountain front.

The second line of evidence suggesting a rapid transgression in the study area is the small difference in thickness between certain horizons from east to west. Bentonite beds within the Bearpaw Shale can serve as isochronic horizons. Unfortunately, subsurface control is insufficient and those bentonite beds found in isolated outcrops could not be correlated with a high degree of confidence. However, coal beds can be used as marker horizons under some circumstances. Although coal seams near the top of the Judith River are not laterally continuous as discrete beds, they do serve as evidence that similar environments existed at about the same time across the study area. From the earlier discussion on specific stratigraphic sections, it can be noted that coal seams of the widely separated sections all occur within 6 to 9 m below the first occurrence of Bearpaw Shale (Figs. 14-16).

The elevation of the contact between the Judith River and Bearpaw formations is similar in several locations within the study area. Because a large part of the study area appears to have escaped tectonic disturbance with the beds still flat-lying, comparison of contact elevations in both the east and west may give a very gross first approximation of transgressive synchrony. In the case of stratigraphic sections from Three Mile Creek (Fig. 14) and Peoples Creek (Fig. 15), the Judith River/Bearpaw contact occurs at an elevation of approximately 780 m at both locations, which are separated by about 34 km (Fig. 11). If contact elevations are valid indicators of the rate of transgression in the study area, it would appear that the transgression of the Bearpaw sea occurred at about the same time at both locations.

In summary, the rate of the Bearpaw transgression apparently varied geographically in response to paleotopography. Those areas that were the site of major deltas were topographically high and not inundated as rapidly as adjacent coastal plains. The study area was occupied by a coastal plain and relatively small fluvial systems during Judith River deposition and was the site of rapid transgression by the Bearpaw sea.

CONCLUSIONS

(1) In the study area, the upper 15 m of the Judith River Formation was deposited primarily by small, meandering streams that produced a low-relief fluvial and deltaic plain. The lower 15 m of the Bearpaw Shale was deposited in a shallow, marine and brackish-water environment.

(2) The transgression of the Bearpaw sea was probably rapid in the study area because the area was relatively topographically low. Areas to the north and south were sites of major deltaic complexes during Judith River deposition, were topographically high, and were inundated by the Bearpaw sea more slowly.

(3) Faunal zonation that suggests a diachronous transgression of the Bearpaw sea is probably misleading. The nektonic fauna used in this zonation probably did not inhabit the surface brackish-water layer that was the first water to flood the subsiding basin. This fauna may not have occupied the western part of the basin until well after the initial transgression.

(4) The Bearpaw transgression was probably caused by subsidence in response to tectonic thickening during the Sevier and Laramide orogenies. The basin subsided most in the west with added subsidence due to sediment loading.

(5) Additional detailed study of the regional stratigraphy is required before any firm conclusions can be made concerning the rate of the Bearpaw transgression. A careful study of the biostratigraphy of

the lower Bearpaw Shale should be made, precisely documenting horizons where fossils are found. Local stratigraphic studies of the Judith River/Bearpaw transition should be done on and adjacent to the major deltaic complexes to determine the impact these features had on the transgression.

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