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

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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APPROVAL

of a thesis submitted by

Roger Elmer Braun

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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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.

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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, provenence, 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 mircoscope. 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 instrusions in the southern and western portions (Fig. 1). The larger intrusions have tilted Paleozoic and Precambrian rocks around their perimeters.

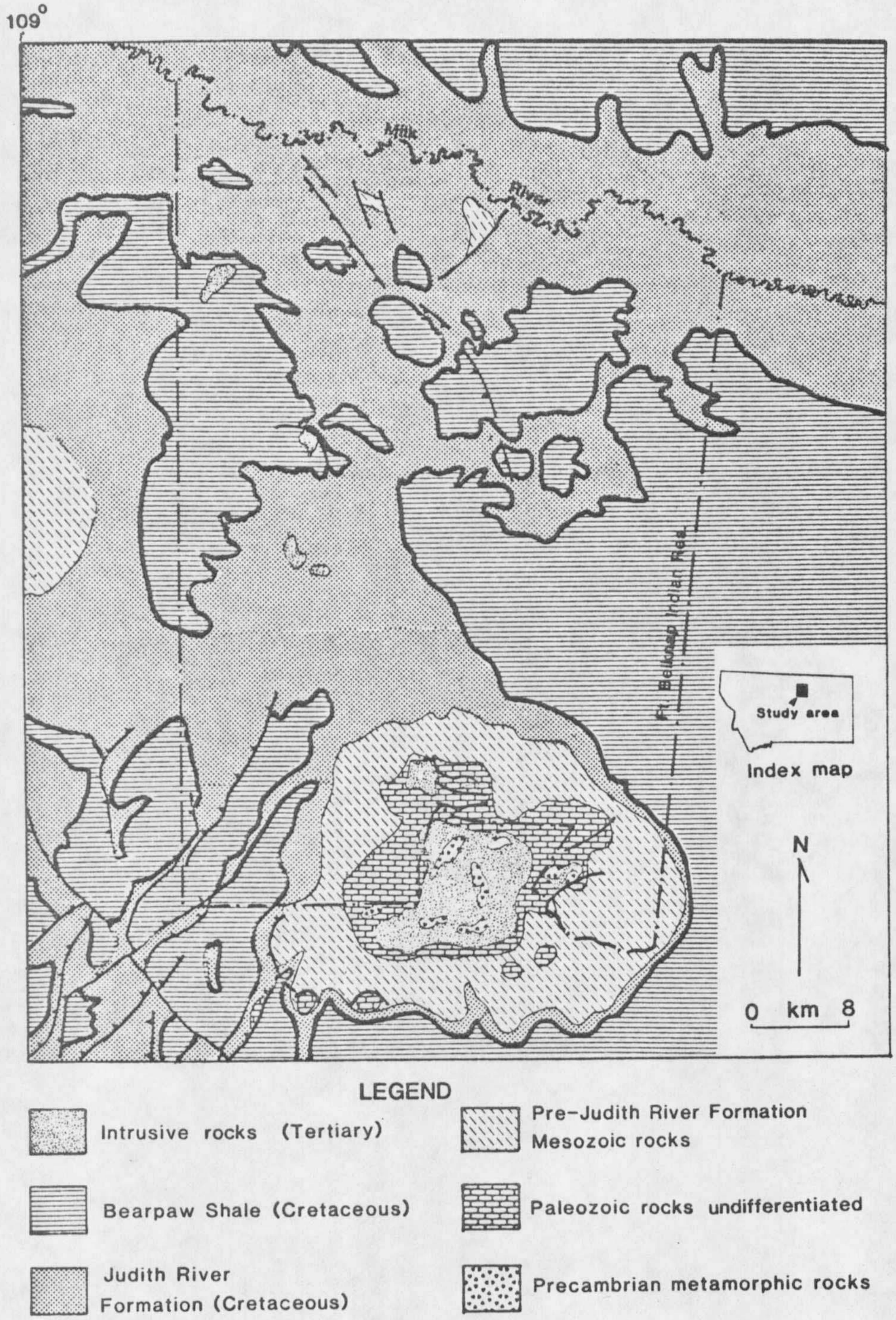

Figure 1. Generalized geologic map of the study area (modified from Alverson, 1965; other data from Ross and others, 1958).

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 mudrock[1]. 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

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

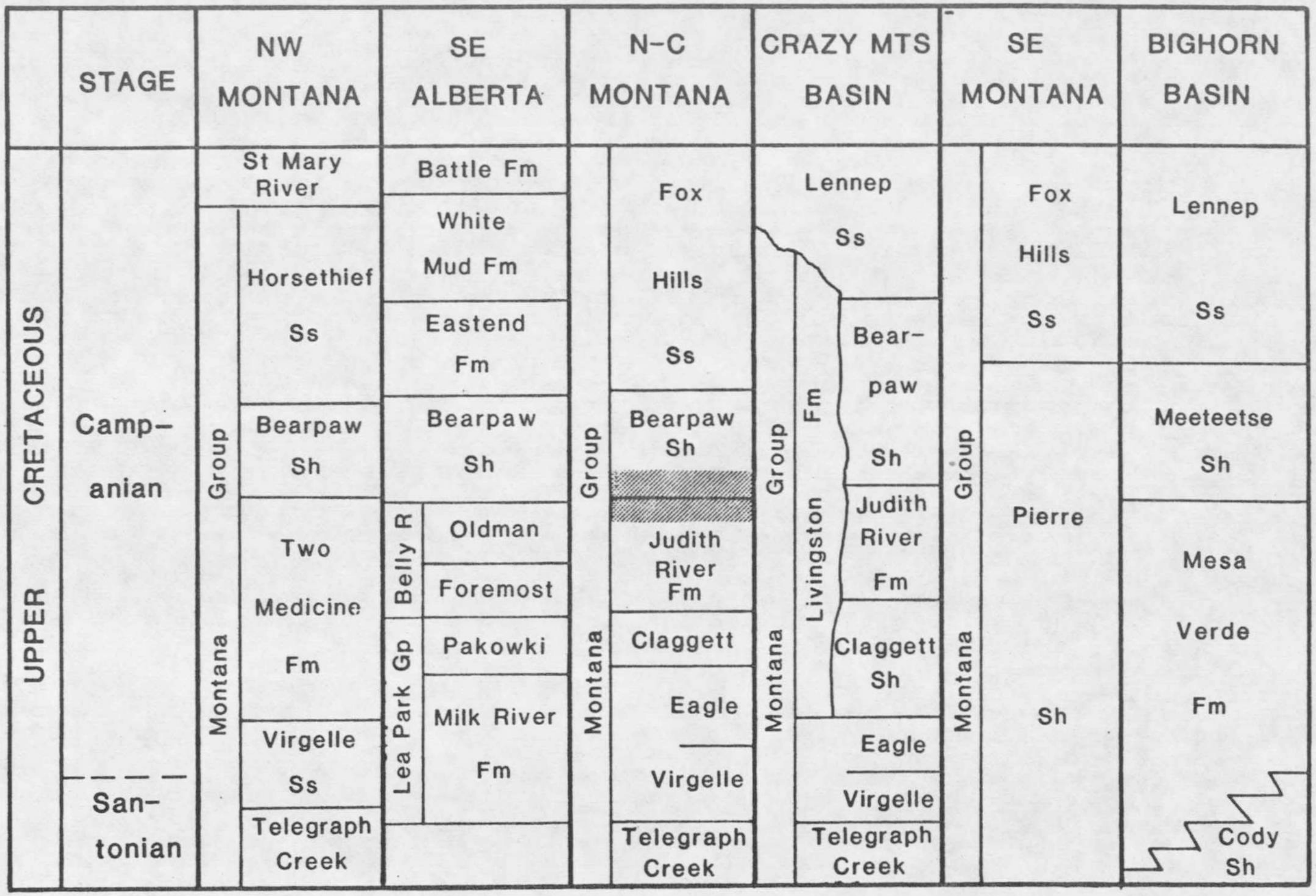

Figure 2. Stratigraphic correlation chart of Upper Cretaceous rocks in Montana and adjacent areas (from Balster, 1980). Shaded area is interval studied.

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

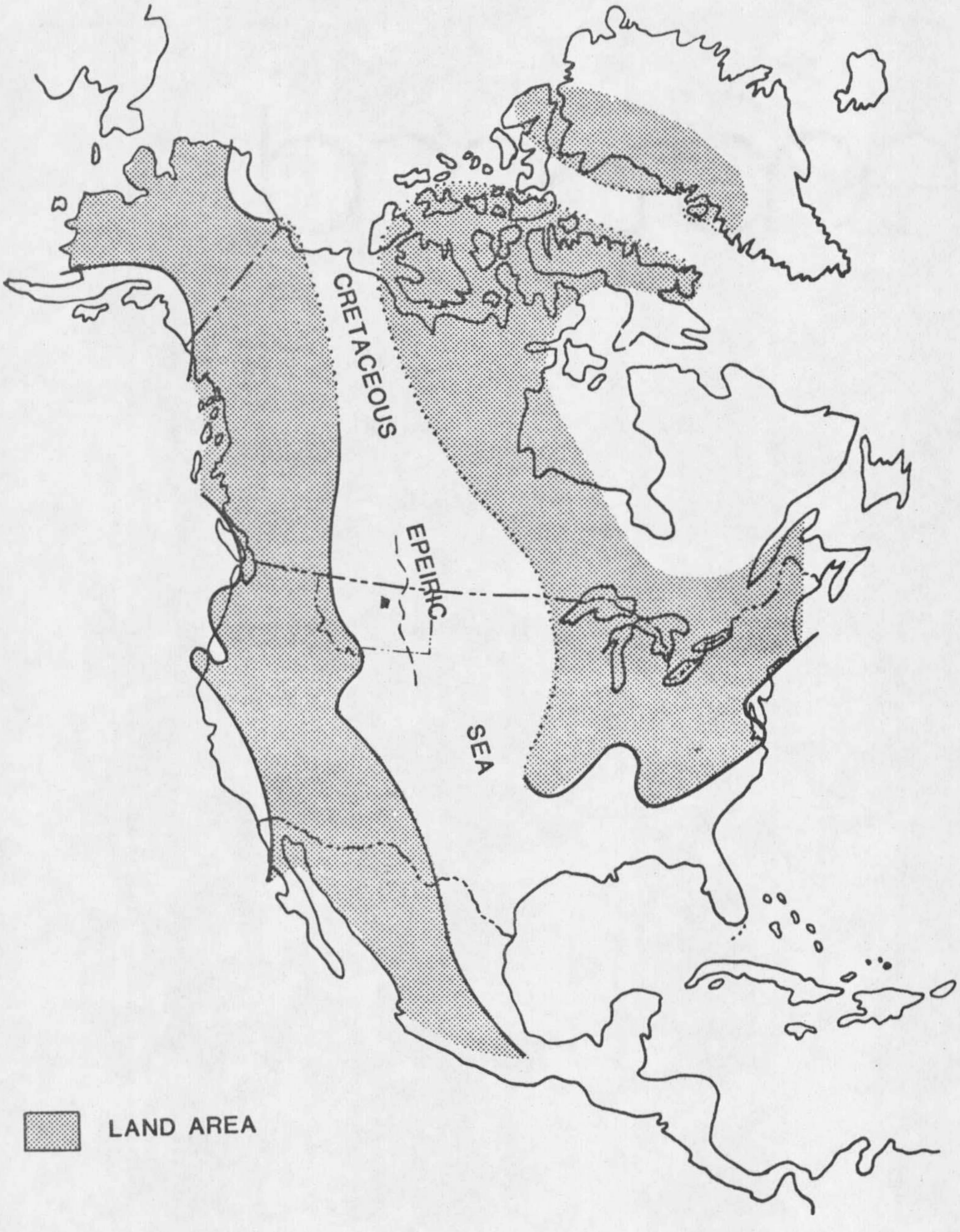

Figure 3. North American paleogeographic map showing general maximum distribution of Cretaceous epeiric sea. State of Montana is outlined, study area shown in black. Dashed line indicates approximate position of shoreline just prior to Bearpaw transgression (modified from Gill and Cobban, 1973).

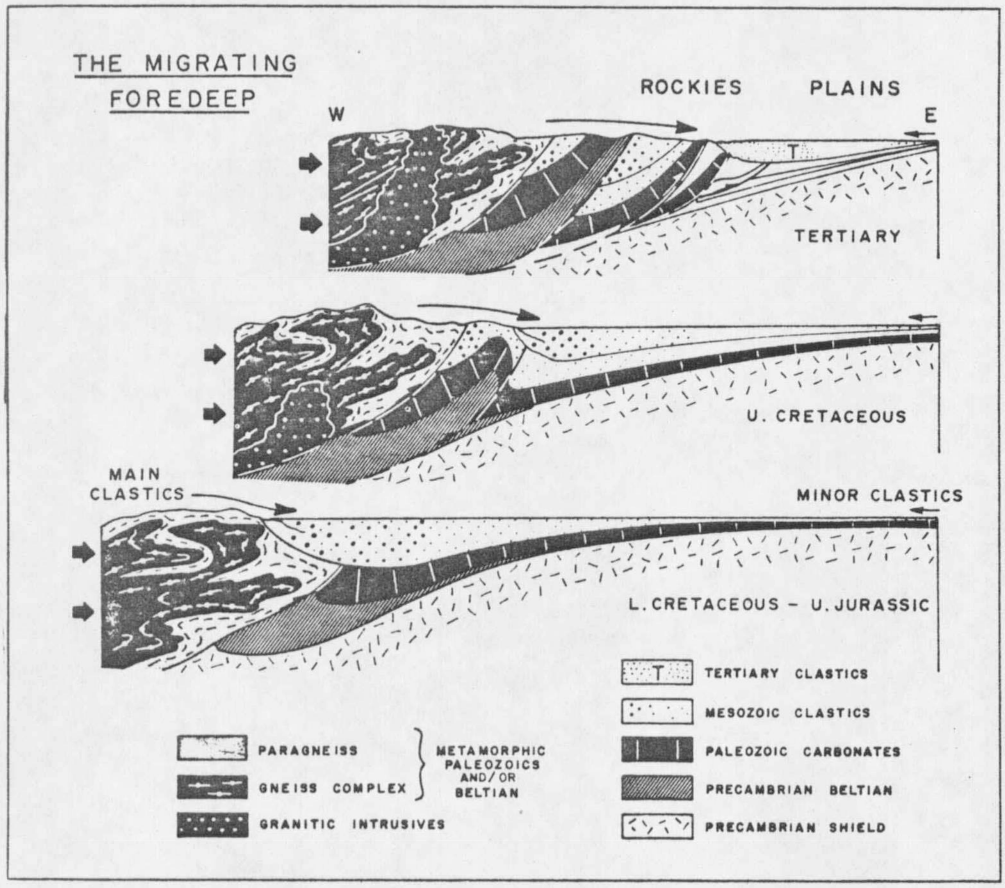

Figure 4. Schematic reconstruction showing eastward migration of the Rocky Mountain foredeep from the Jurassic to the Tertiary. Note tectonic thickening by successive thrust faulting and isostatic adjustment of Precambrian basement rocks (from Bally and others, 1966, p. 366).

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).

Provenence 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 volcaniclastic-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

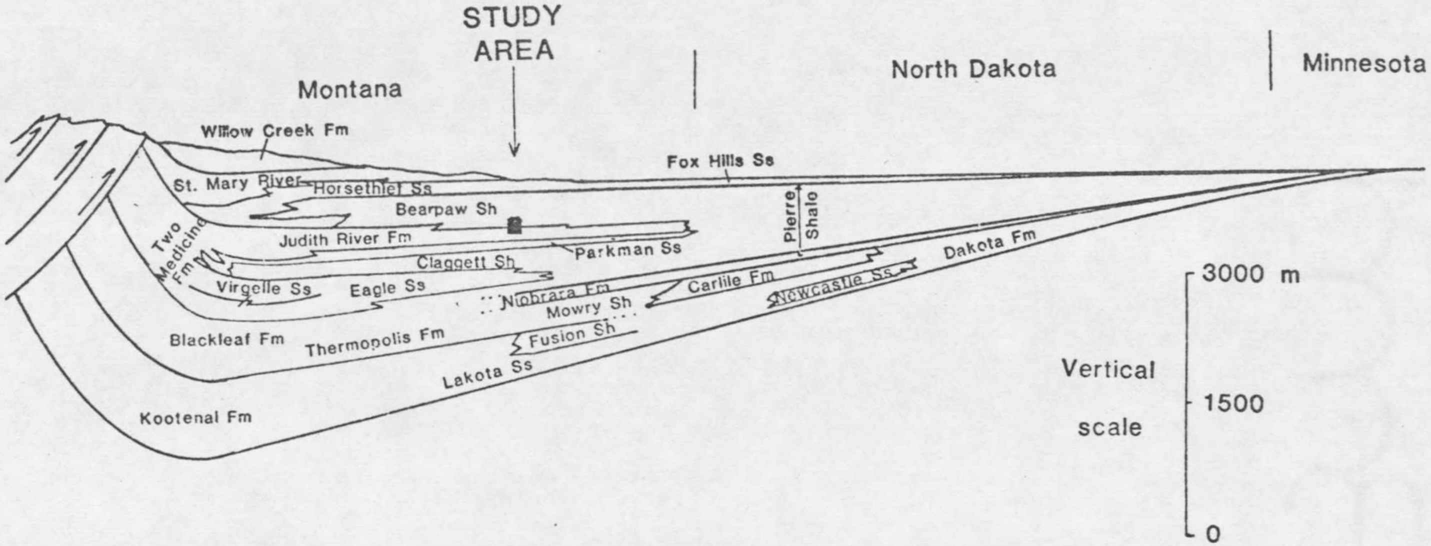

Figure 5. Schematic east-west cross section from northwest Montana to northwest Minnesota showing the geometry of the Western Interior basin and general stratigraphic relationships (data from Schultz and others, 1980; Gill and Cobban, 1965; Hansen, 1958; and McGooky and others, 1972).

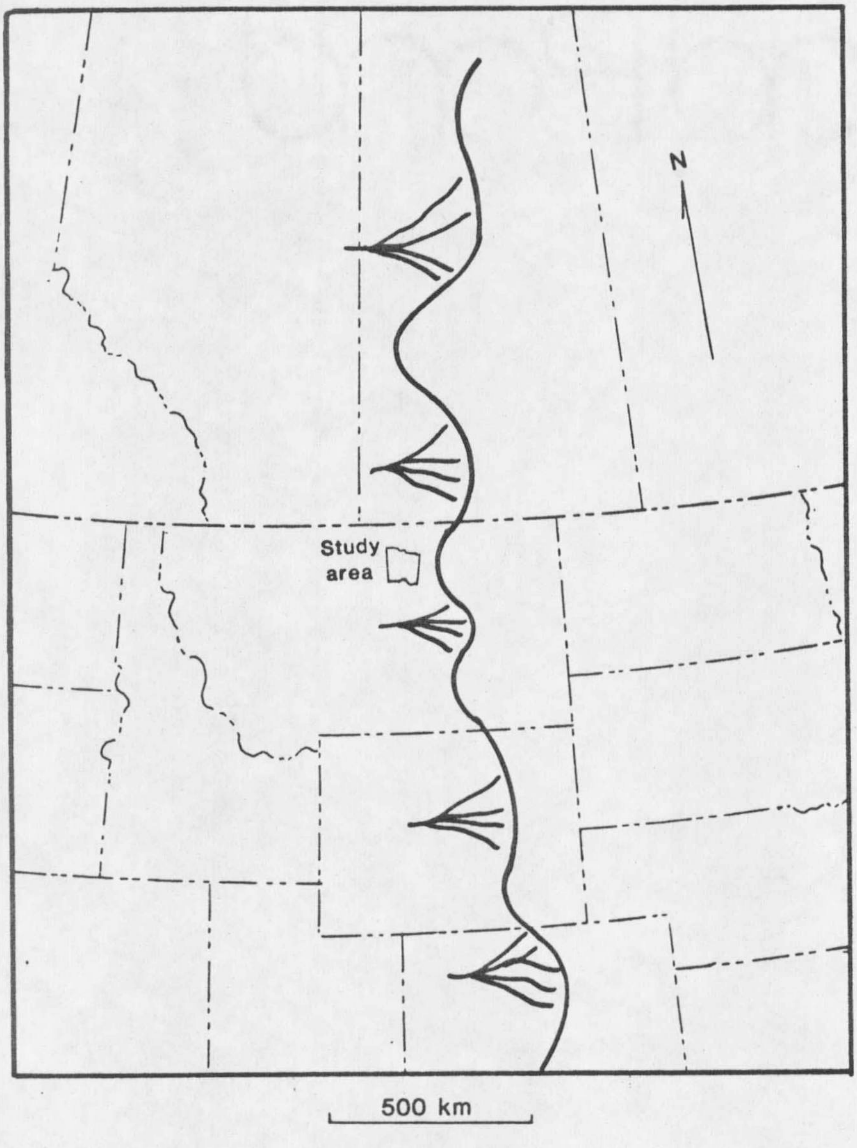

Figure 6. Paleogeographic map showing shoreline and positions of five deltaic complexes just prior to the Bearpaw transgression. Northern two from data of Williams and Stelk (1975), southern three from data of Weimer (1970).

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.

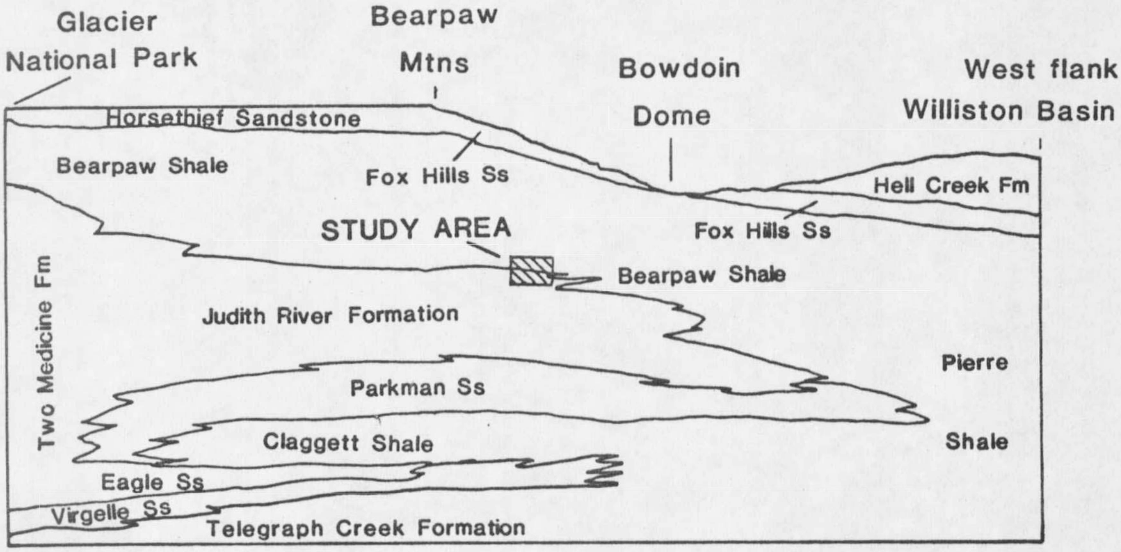

Figure 7. Diagrammatic east-west cross section through northern Montana showing the general relationships of the Montana Group (modified from Rice and Shurr, 1980).

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

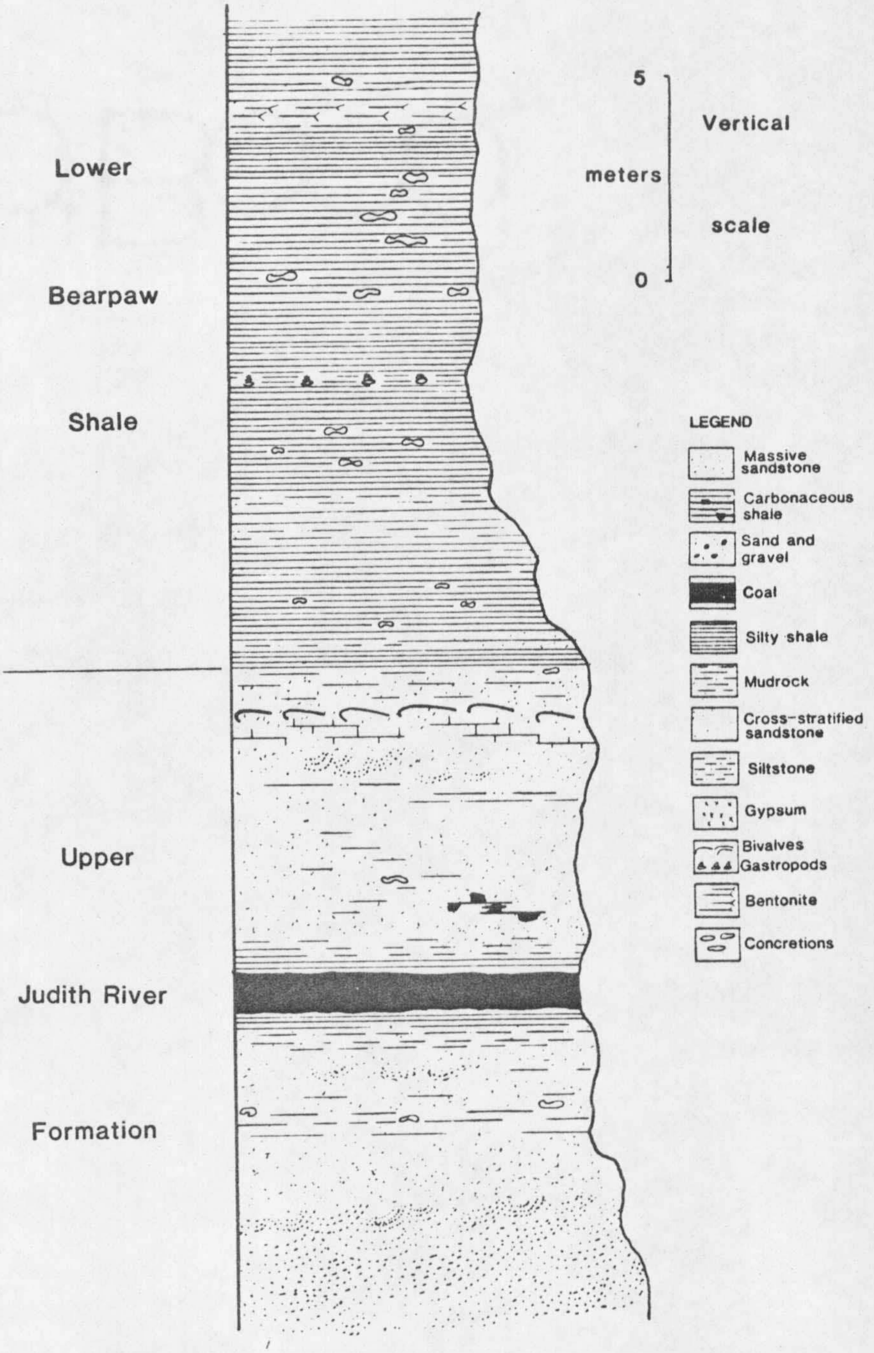

Figure 8. Composite stratigraphic section of the upper 15 m of the Judith River Formation and the lower 15 m of the Bearpaw Shale in the study area.

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

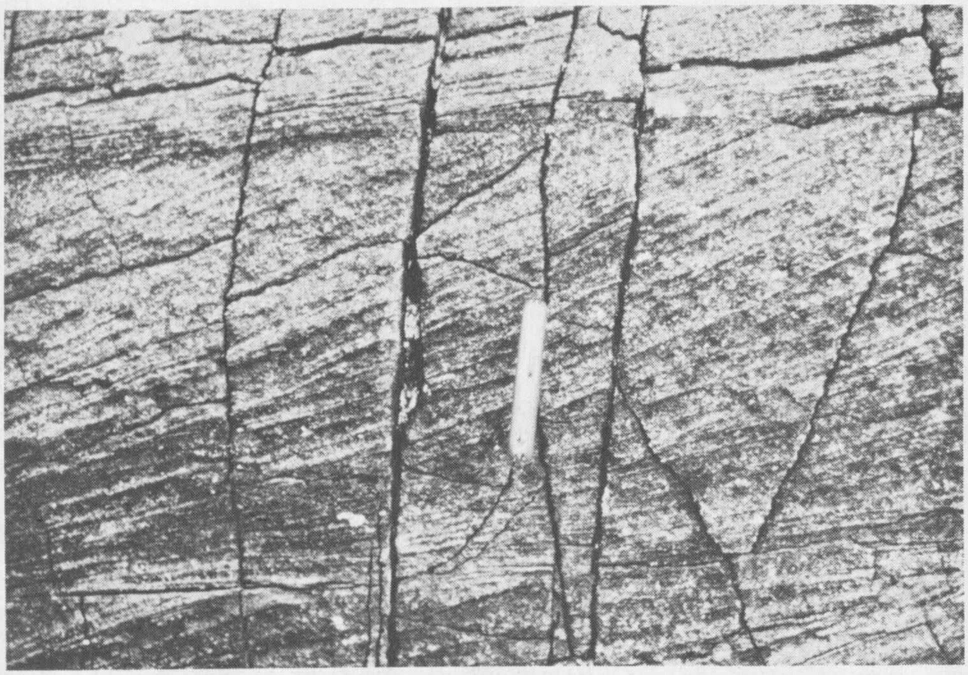

Figure 9. Photograph of large-scale omikron cross-stratification that occurs in the thicker, lower sandstone beds in the upper 15 m of the Judith River Formation in the study area.