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Basin-Margin Depositional Environments of the Fort Union and Wasatch Formations in the Buffalo-Lake De Smet area, Johnson County, Wyoming

By Stanley L. Obernyer

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Contents

ILLUSTRATIONS

Plates

FIGURES

Page

Page

TABLES

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ABSTRACT

The Paleocene Fort Union and Eocene Wasatch Formations along the east flank of the Bighorn Mountains in the Buffalo-Lake De Smet area, Wyoming, consist of continental alluvial fan, braided stream, and poorly drained alluvial plain deposits. The Fort Union conformably overlies the Cretaceous Lance Formation, which is marine in its lower units and nonmarine in its upper part.

The formations dip steeply along the western margin of the study area and are nearly horizontal in the central and eastern portions. This structural configuration permits the reconstruction of depositional environments as an aid to understanding: (1) the evolution of the Bighorn uplift and its effects on the depositional patterns marginal to the uplift during Paleocene and Eocene time and (2) the changing depositional environments basinward from the margin of the uplift during a relatively small period of time in the Eocene.

The upper half of the Lance Formation is characterized by light-yellowish-gray sandstones, dark-gray shales, and minor carbonaceous shales. The lower member of the Fort Union Formation differs from the Lance in that its sandstones are brown, ferruginous, and resistive in character. The upper half of the Fort Union is characterized by locally thick boulder conglomerates. The fine-grained, coal-bearing facies of the Wasatch consist of interbedded yellowish-orange sandstones, siltstones, mudstones, carbonaceous shales, and coals. To the west, near the Bighorn Mountains, the sandstones become conglomeratic and the coals rapidly thin and disappear. The Kingsbury Conglomerate and the Moncrief Members are conglomerate facies which front the Bighorn Mountains and are correlative to parts of the Wasatch coal-bearing strata.

Along the western margin of the study area, a composite vertical section displays a general upward increase in grain size with at least three major angular unconformities: these mark the basal contacts of the conglomerate member of the Fort Union and of the Kingsbury and Moncrief Members of the Wasatch Formation. Reddish-colored strata cap most of the process-controlled genetic units[1] within the conglomerate member of the Fort Union. Such reddish strata are less conspicuous in the Kingsbury Conglomerate Member, occurring sporadically in sandy lenses within the conglomerates, and are absent in the Moncrief Member of the Wasatch Formation. The conglomerates vary considerably in size of boulders, thickness and lateral extent of massive conglomerate beds, and amounts of sandstone and siltstone. All these factors help to identify the major drainages emanating from the Bighorn uplift to the west. Hence, the growth of the uplift is reflected in the stratigraphy. Uplift of the region resulted in the retreat of the Late Cretaceous sea. Then, in turn, alluvial plain sandstones, siltstones, and mudstones of the upper Lance and lower Fort Union Formations gave way to the alluvial fan and braided stream deposits of the conglomerate member of the Fort Union Formation and of the Kingsbury Conglomerate and Moncrief Members of the Wasatch Formation.

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[1]A process-controlled genetic unit is defined as a deposit resulting primarily from the physical, chemical, and biological processes operating within the environment at the time of deposition (Weimer, 1975).

The Wasatch Formation in the central and eastern portions of the study area displays a rapid and relatively sharp change from alluvial fan and braided stream deposits to a poorly drained alluvial plain sequence represented by meander channel, levee, crevasse splay, paludal, and lacustrine deposits. The change from one depositional environment to the other is marked by a very thick, linear, carbonaceous shale and coal sequence, the Lake De Smet coal bed, which ranges from approximately 20-75 m thick. From an area north of Lake De Smet, the bed extends at least 24 km southward. Its extent south of Buffalo is undetermined. The Lake De Smet coal bed is quite narrow compared to its length--in most places it is no more than 1-3 km wide. Its western boundary is quite sharp; the coal fingers out into thin carbonaceous shale and coal stringers which pinch out abruptly westward. Braided stream deposits characterize the strata west of the coal seam. On the east, the coal splits into five major mappable coal beds, each of which possesses significant coal reserves. The coal beds which are correlative with the Lake De Smet coal bed include the Ucross, Murray, Cameron, Healy, and Walters. Intervening deposits between these coals consist of related alluvial plain deposits. The sandstones in this interval are very fine to medium grained and well sorted; they persist as thick, regionally extensive sheets.

The unusual thickness of the Lake De Smet coal bed reflects a delicate balance between tectonics and sedimentation. The coal bed's great length, narrow width, and orientation (with its long dimension roughly parallel to the uplift) suggest that a basement fault may be a controlling factor in the coal's location and formation. Relatively greater uplift on the west prevented coal formation there, while relatively greater subsidence on the east resulted in a splitting of the coal bed with substantial clastic intervals separating the coals.

INTRODUCTION

The purpose of this study was to recreate the depositional environments and to propose a depositional model for the area which might explain the anomalously thick Lake De Smet coal bed and the wide range of high-energy to low-energy continental deposits which flank this coal bed. "Lake De Smet" is used throughout this study to identify the thick coal bed described by Mapel, Schopf, and Gill (1953) in the Lake De Smet area, which extends southward for an unknown distance south of Buffalo. To accomplish this objective, stratigraphic studies of the lower Tertiary deposits related to the coal beds were done to provide a better understanding of the tectonic controls governing the location, thickness, and geometry of coal beds adjacent to an area undergoing active uplift.

Location

The study area is along the east flank of the Bighorn Mountains in northern Johnson County, Wyoming (fig. 1). Lake De Smet is along the northern boundary of the study area. Buffalo is in the southern portion of the study area at the intersection of Interstates I-90 and I-25 and U.S. Highway 16. Most outcrops are within walking distance of county roads. Topographic relief is as great as 450 m where the conglomerates crop out along the western margin of the area, while elevation differences in the clinker-capped butte topography in the eastern portion seldom exceed 120 m.

The study area encompasses approximately 517.8 km^2.

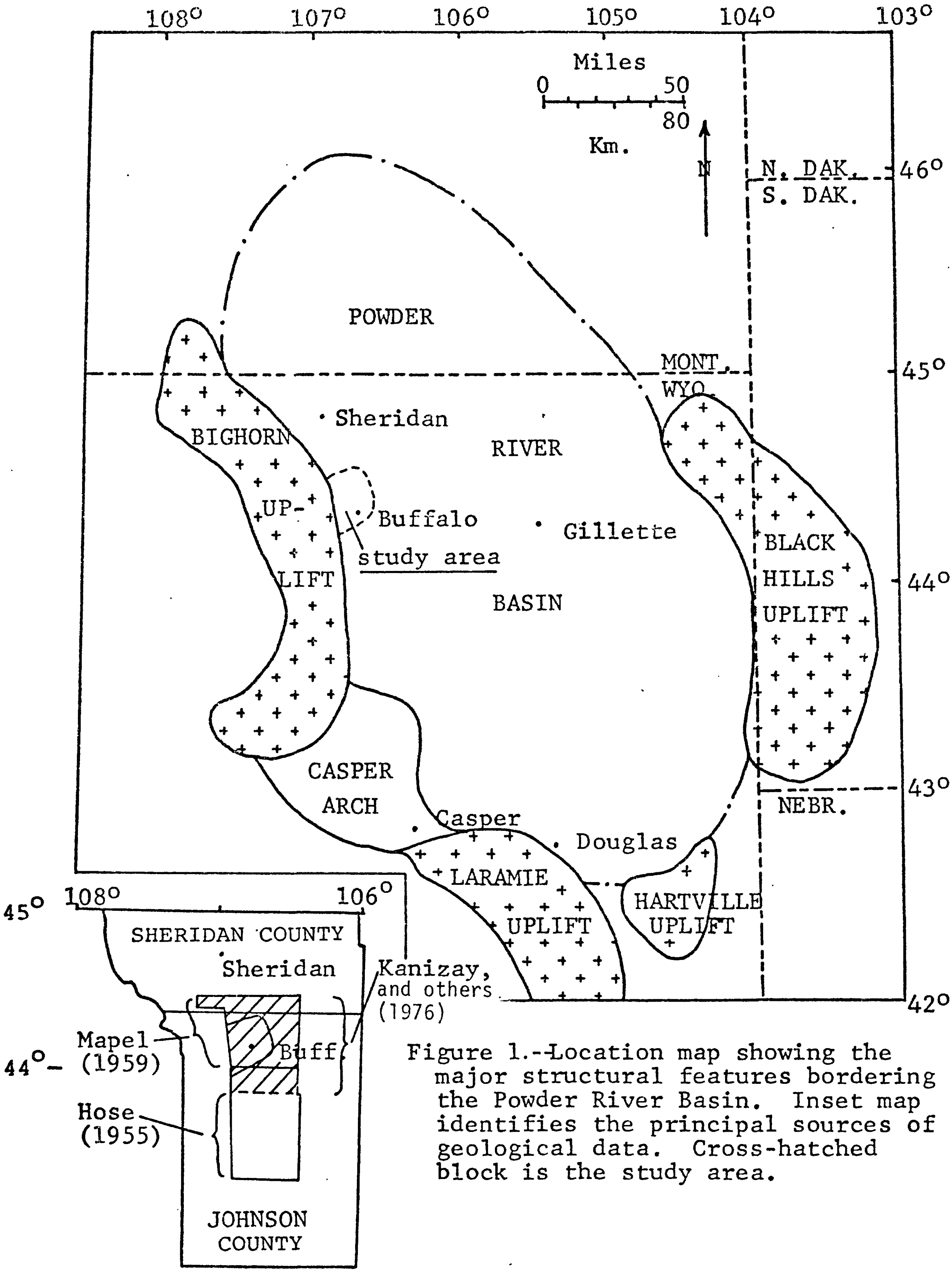


Figure 1.--Location map showing the major structural features bordering the Powder River Basin. Inset map identifies the principal sources of geological data. Cross-hatched block is the study area.

Methods of investigation

Fieldwork was done during the summers of 1975 and 1976. Mapping and stratigraphic studies were restricted to bedrock geology; that is, to pre-Quaternary deposits. Mapping was limited to those localities where there was disagreement with existing maps or there was a need to map to understand the stratigraphy. In addition to displaying the outcrop pattern and structure of the older rocks flanking the Bighorn Mountains along the study area's western margin, plate 1 (in pocket) shows primarily only that geology which was mapped during the course of the fieldwork. Portions of the conglomerate contacts were extended from the field observations on the basis of aerial photograph interpretations. U.S. Geological Survey topographic maps (scale of 1:24,000) were used for field mapping. Outcrops were described in detail for lithologic types, sedimentary structures, and fossil content, and fossils and lithologic samples were collected for additional study. Twenty-seven thin sections, some of which had to be precemented, were made of sandstones and limestones of the Fort Union and Wasatch Formations. However, most of the lithologic samples, because of their poor consolidation, were studied under a binocular microscope. Four pollen samples were analyzed for age dating purposes. Logs of 55 drill holes, ranging from 6 to 212 m in depth, were obtained from the USGS and from various industry sources for subsurface studies of the Lake De Smet coal bed and adjacent strata. Drill hole data obtained from the USGS included those previously reported by Mapel, Schopf, and Gill (1953) and Mapel (1959) and those for drill hole B-1, located within the city limits of Buffalo (Farrow, 1976). The data existing for most of these holes are in the form of brief lithologic descriptions. Mechanical logs were run for only a few holes.

Previous work

Darton (1906) mapped the Bighorn Mountains and the flanking sedimentary deposits at the beginning of this century. Only within the last 25 years has subsequent mapping begun to replace portions of his original work. Geologic maps by Mapel (1959) and Hose (1955) were the principal sources of data used during this study.

Darton (1906) gave the name "Piney formation" to strata in the study area that are now divided into Lance and Fort Union Formations, and "De Smet formation" to the fine-grained, coal-bearing sequences near Buffalo-Lake De Smet and eastward. He also gave the name "Kingsbury conglomerate" to the conglomerate forming Kingsbury Ridge southwest of Buffalo but did not recognize the conglomerate as a lateral equivalent of his De Smet Formation. On the basis of fossil evidence, Wegemann (1917) split the Piney Formation into the Cretaceous Lance Formation and the Paleocene Fort Union Formation and assigned the name Wasatch Formation to Darton's De Smet Formation. He noted that the Kingsbury Conglomerate was Eocene and interfingered with the Wasatch. In 1924 (Geol. Map of Wyoming) the Kingsbury was made a member of the Wasatch. Sharp (1948) described and named the "Moncrief gravel." Love and Weitz (1951) were the first to consider the Moncrief as a member of the Wasatch Formation. Studies relating to stratigraphy and depositional environments for the Tertiary deposits will be cited in the text in appropriate places.

General geology

The outcrop pattern and structural asymmetry of the Powder River Basin resemble the shape of a pelecypod shell, with the umbo region in the Buffalo-Lake De Smet area. The Paleozoic and Mesozoic deposits show relatively broad outcrop patterns and shallow dips along the eastern side of the basin near the Black Hills uplift, whereas narrow outcrop bands and steep dips prevail along the central portion of the east flank of the Bighorn Mountains. The dips become less steep to the north and south along the east flank of the Bighorns (fig. 3).

The same generalizations can be made for the lower Tertiary Fort Union and Wasatch Formations. Dips, in general, are steeper west of Buffalo and Lake De Smet than anywhere else in the basin. However, dips of Wasatch strata within the study area abruptly flatten to nearly horizontal within 6-8 km of their westernmost outcrops.

System	Series	Group, formation, and member	Thickness (feet)	Character
QUARTERNARY			0-50	Unconsolidated silt, sand, and gravel comprising deposits of alluvium, and terrace and pediment gravels
TERTIARY	Oligocene	White River formation(?)	0-150	Conglomerate, coarse-grained arkosic sandstone, and brown sandy clay
		Unconformity		
	Eocene	Wasatch formation: Moncrief member	0-1400 ± (Wasatch formation 1000-2000 ±)	Light-gray and light yellowish-gray sandstone, gray shale, gray and brown carbonaceous shale, and coal, grading and interfingering westward into conglomerate. Moncrief member contains cobbles and boulders of Precambrian igneous and metamorphic rocks. Kingsbury conglomerate member contains pebbles and cobbles of Paleozoic limestone and dolomite
		Unconformity		
		Wasatch formation: Kingsbury conglomerate member	200-800 ±	
		Unconformity		
	Paleocene	Fort Union formation: Upper conglomeratic member	1200 ±-3900	Light-colored sandstone and drab-colored shale. Upper conglomeratic member contains beds composed of pebbles and cobbles of Paleozoic limestone and dolomite and overlies a local unconformity
		Unconformity		
CRETACEOUS	Upper Cretaceous	Lance formation	1960	Massive light-gray channel sandstone and dark-gray shale
		Montana Group: Bearpaw shale	200	Dark greenish-gray marine shale, in part sandy
		Montana Group: Parkman sandstone	720	Lower half is massive light yellowish-gray sandstone, upper half is light-gray sandstone and gray shale
		Cody shale: Upper shale member	930 (Cody shale 3570)	Dark-gray noncalcareous shale with a few partings of fine-grained light-gray sandstone
		Cody shale: Shannon sandstone member	215	Light gray fine-grained sandstone and sandy shale, locally glauconitic. Contains an Eagle sandstone fauna
		Cody shale: Sandstone and shale member	1070	Interbedded and interlaminated dark-gray shale and light-gray sandstone. Several thin beds of bentonite. Upper and middle parts contain an Eagle sandstone fauna
		Cody shale: Niobrara shale member	985	Grayish-black shale, variably calcareous. A few thin beds of bentonite. Lower part contains a fauna common to the lower Niobrara shale of the Black Hills
		Cody shale: Carlile shale member	155	Dark-gray to grayish-black shale, noncalcareous ; sandy in the lower part. Fauna is common to the upper part of the Turner sandy member and the Sage Breaks member of the Carlile shale of the Black Hills
		Cody shale: Greenhorn calcareous member	140	Upper part is light-gray fine-grained sandstone: lower part is grayish-black calcareous shale. Fauna is common to the upper part of the Greenhorn formation of the Black Hills
		Cody shale: Lower shale member	65-80	Dark-gray to grayish-black noncalcareous shale. Upper part contains a fauna common to the middle part of the Greenhorn formation of the Black Hills
		Colorado group: Frontier formation	495-515	Dark-gray shale and light-gray sandstone, interbedded and interlaminated. Conglomeratic chert-pebble sandstone as much as 40 feet thick at top
	Lower Cretaceous	Colorado group: Mowry shale: Light gray siliceous shale member	325 (Mowry shale 525)	Siliceous shale and siltstone weathering light silvery-gray; numerous thin beds of bentonite
		Colorado group: Mowry shale: Black shale member	200	Soft grayish-black shale weathering black; numerous thin beds of bentonite
		Colorado group: Newcastle sandstone	40	Light-gray fine-grained sandstone
		Colorado group: Skull Creek shale	175	Grayish-black shale with some thin beds of brown siltstone in the lower part
		Cloverly formation	155	Interbedded grayish-black shale and brown siltstone. A bed of light-gray medium- to coarse-grained crossbedded sandstone 30 feet thick at base. Numerous globular dahllite concretions near top
		Unconformity(?)		
JURASSIC	Upper Jurassic	Morrison formation	185	Variegated shale and claystone, and light-gray fine-grained sandstone
		Sundance formation	280	Green calcareous shale and light-gray calcareous glauconitic sandstone
		Unconformity		
	Middle Jurassic	Gypsum Spring formation	145-185	Upper part is interbedded light-gray limestone and red shale; lower part is red shale
		Unconformity(?)		
TRIASSIC		Chugwater formation	790	Red sandstone, siltstone, and shale. Prominent ledge-forming bed of light-gray limestone 6-13 feet thick about 70 feet below top
PERMIAN		Gypsum and red shale sequence	180	Red shale and siltstone with thick beds of gypsum in the upper part
		Unconformity(?)		
CARBONIFEROUS: PENNSYLVANIAN		Tensleep sandstone	275	Massive light-gray crossbedded sandstone
		Amsden formation	250	Red and purple shale, and light-gray cherty dolomite
		Unconformity		
CARBONIFEROUS: MISSISSIPPIAN		Madison limestone	665	Light-gray limestone, dolomitic limestone, and dolomite, sandy at base
		Unconformity(?)		
ORDOVICIAN		Bighorn dolomite	310-340 (370-395)	Massive cliff-forming yellowish-gray dolomite becoming thin-bedded in upper part
		Bighorn dolomite: Sandstone member	57-65	White fine-grained sandstone
		Unconformity(?)		
CAMBRIAN	Upper Cambrian and Middle Cambrian, undifferentiated	Gros Ventre and Gallatin formations, undifferentiated	645	Upper part is thin-bedded light-gray limestone and glauconitic flat-pebble limestone conglomerate; middle part is green micaceous shale with some interbedded light gray limestone, flat-pebble limestone conglomerate, and brown glauconitic sandstone; lower part is brown glauconitic sandstone with some interbedded green shale
	Middle Cambrian	Flathead sandstone	345	Light yellowish-gray sandstone with some interbedded green shale and siltstone. Bottom few feet are red and conglomeratic
		Unconformity		
PRECAMBRIAN			(?)	Mostly red and gray granite

From Mapel, 1959

Figure 2.--Composite geologic section of the rocks exposed in the Buffalo-Lake De Smet area.

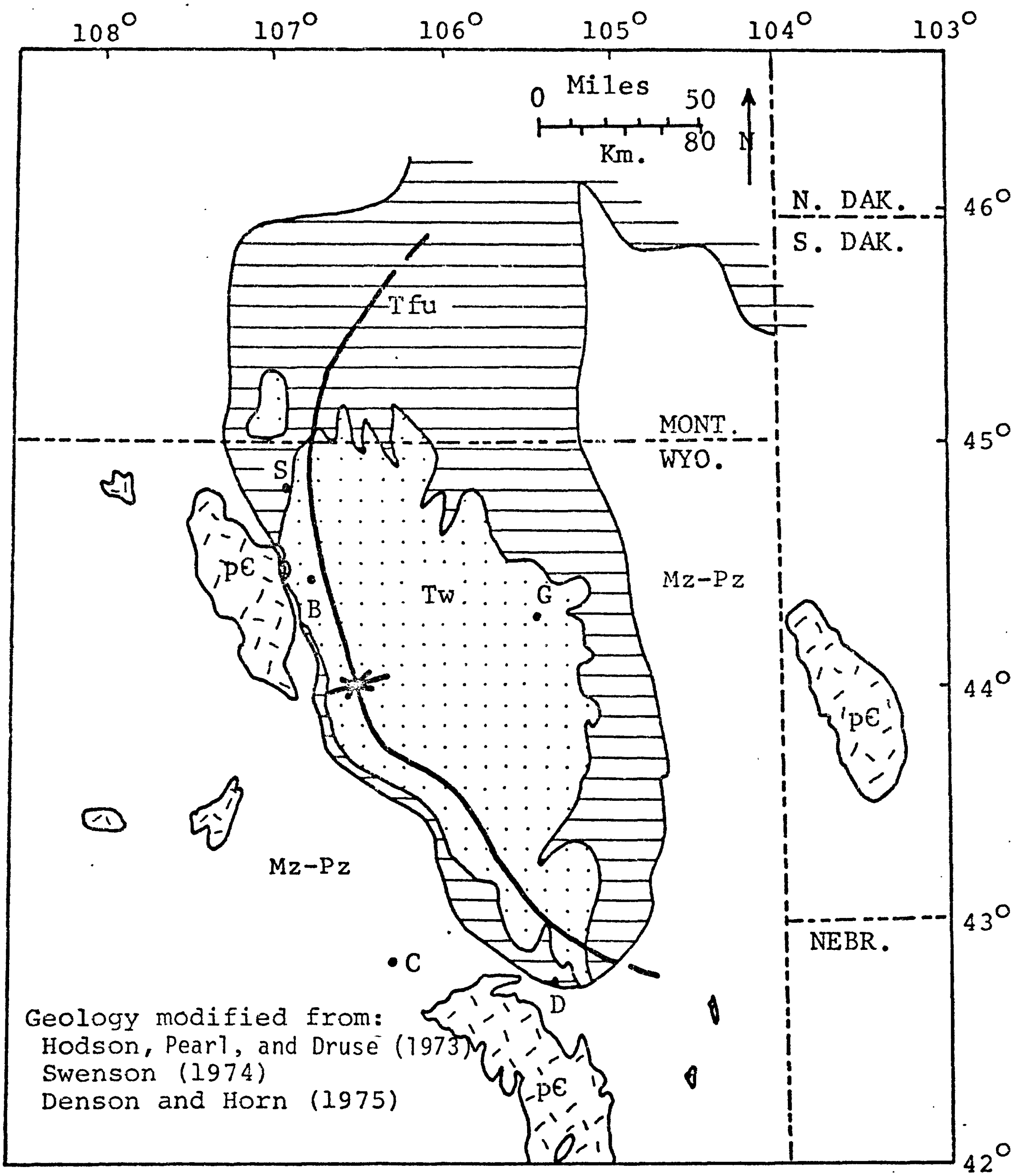


Figure 3.--General geology of the Powder River Basin with the structural axis based on the top of the Madison Limestone. Tw = Wasatch Formation; Tfu = Fort Union Formation; Mz-Pz = Paleozoic and Mesozoic; pЄ = Precambrian. B = Buffalo; C = Casper; D = Douglas; G = Gillette; S= Sheridan.

The asymmetrical basin and the fault block uplift of the core of the Bighorns, with the blanketing sediments draping over the uplift in anticlinal fashion, are typical of Rocky Mountain tectonics. The doubly plunging synclinal axis of the Powder River Basin, as shown on the Madison Limestone by Swenson (1974, pl. 1) (fig. 3), is a few kilometers east of Buffalo and Lake De Smet. The deepest portion of the basin is near Kaycee, Wyo., approximately 65 km south of Buffalo. Structural relief exceeds 9150 m from the lowest point in the basin to the top of the Bighorn uplift. Utilizing electric logs, Curry (1971, p. 56) demonstrated that the depositional axis of the lower Tertiary deposits coincides with the structural axis of the basin. Along this axis, the thickest deposits, and the inferred region of greatest subsidence in the Powder River Basin during the early Tertiary, are near Lake De Smet and Buffalo (fig. 4). Hence, the region of greatest subsidence in the early Tertiary does not correspond to the area of greatest subsidence during pre-Tertiary depositional episodes.

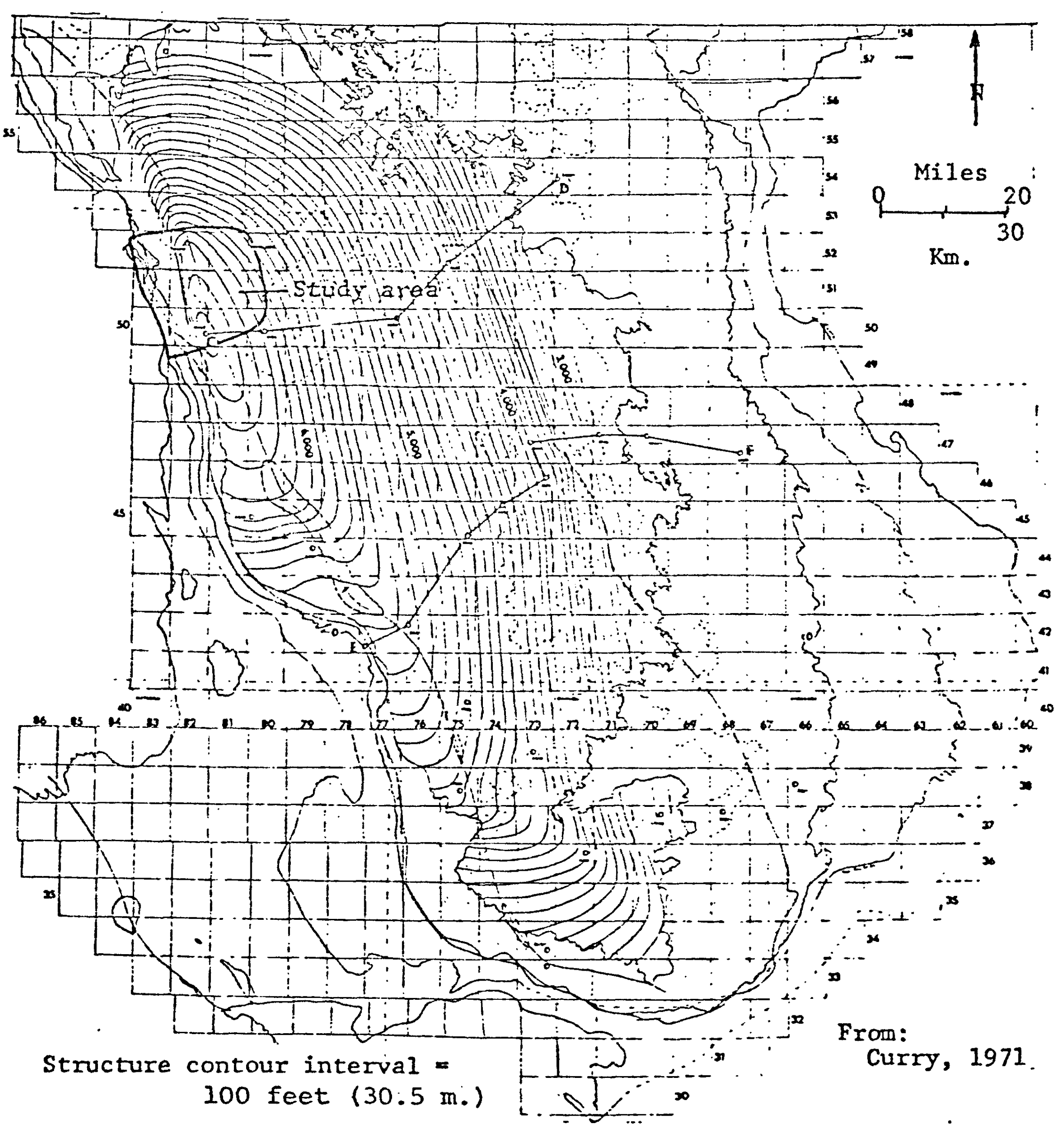


Figure 4: Isopach map of the Fort Union and Wasatch Formations. Datum for the synclinal axis is not identified by the author. The depositional axis of the lower Tertiary units skirts the Powder River Basin's western margin with the thickest deposits occurring in the Buffalo area.

Major structural features within and adjacent to the study area are intimately tied to the tectonic interplay between the uplift and basin crustal blocks. Steeply dipping, north-south faults cut Mesozoic and lower Fort Union strata in Mowry Basin. Local thrust faults extend from the North Fork of Crazy Woman Creek 24 km southwest of Buffalo to the Piney Creek Fault system north of Story on the north.

In the Tertiary strata to the northeast, a northwest-trending graben at the north end of Lake De Smet was drilled by oil companies. A few northeast, east, and northwest faults are mapped in the coal-bearing strata (pl. 1). Strong parallel drainage patterns within the study area follow these same structural trends.

Moderately plunging, eastward-trending anticlinal structures encompassing Kingsbury Conglomerate Member and older strata occur at Mowry Basin and the southern end of Kingsbury Ridge. A synclinal structure of similar attitude occurs west of and includes Kingsbury Ridge (pl. 1). Numerous anticlinal and synclinal structures with less than 60 m of closure were mapped by Mapel (1959) in the coal-bearing strata east of Lake De Smet and Buffalo. These structures are probably the result of differential compaction between coal and clastic sequences.

Numerous Quaternary pediment deposits cap many of the ridges west of Buffalo and Lake De Smet. Some pediment deposits emanate directly outward from the mountain front or from lower Tertiary conglomerate ridges, while others exist as erosion-remnant buttes away from the mountains. Clinker-capped buttes blanket much of the study area east of Lake De Smet and Buffalo. Colluvium and alluvium dominate much of the remaining landscape.

Acknowledgments

To Professors Robert Weimer, Karl Newman, and John Haun, I offer grateful acknowledgment for their assistance, suggestions, and thought-provoking discussions. The U.S. Geological Survey provided generous support for the study in the form of part-time employment, field expenses, maps, air photos, and a stimulating environment where geologic thought was shared and discussed. Among the many people of the USGS who contributed to the study in some manner, F. W. Osterwald, J. M. Cattermole, Ernest Dobrovolny, and S. P. Kanizay deserve special thanks for their continuing interest and support. The writer particularly appreciates the cooperation and hospitality extended by the many local landowners and by Texaco, Inc., who provided access to their properties for field studies. Thanks are extended to Michael Hendricks, who assisted in preparing the palynology samples. Finally, the support and encouragement of my present employer, Martin-Trost Associates, and my family are immeasurably appreciated.

"It is too easy to go into a field situation expecting or hoping to find this or that, for invariably you come out having found what you wanted. Selectivity can do great things in blinding one to a wider reality."

Colin M. Turnbull

The Mountain People

DESCRIPTIVE STRATIGRAPHY OF THE FORT UNION AND WASATCH FORMATIONS

Fort Union Formation

The Fort Union Formation is mapped as a narrow band of poor outcrops approximately 8 km long in secs. 18, 19, 20, 28, 29, and 33, T. 52 N., R. 83 W., and secs. 4, 8, and 9, T. 51 N., R. 83 W. Outcrops recur west and south of Kingsbury Ridge. Strong structural deformation and its effect on depositional patterns during the Eocene is primarily responsible for the intermittent, limited exposure of the Fort Union Formation in the study area. This limited exposure of Fort Union strata is in sharp contrast to the broad expanse of Fort Union outcrops observed elsewhere around the periphery of the Powder River Basin.

The lithology of the Fort Union is characterized by a lower sequence of sandstones, siltstones, and mudstones and occasional thin carbonaceous shales and an upper sequence dominated by conglomerate beds. The upper conglomerate member overlies older deposits with an erosional angular unconformity. Contact relations between the lower Fort Union and the underlying Lance Formation in Mowry Basin are unknown due to cover. Hose (1955, p. 67) reported no unconformity between these two formations south of Kingsbury Ridge. He also reported two laterally discontinuous conglomerate sequences in the upper 275 m of the Fort Union: one east of the Billy Creek anticline and the other 20 km south of this study area. However, at neither locality has he reported an angular unconformity.

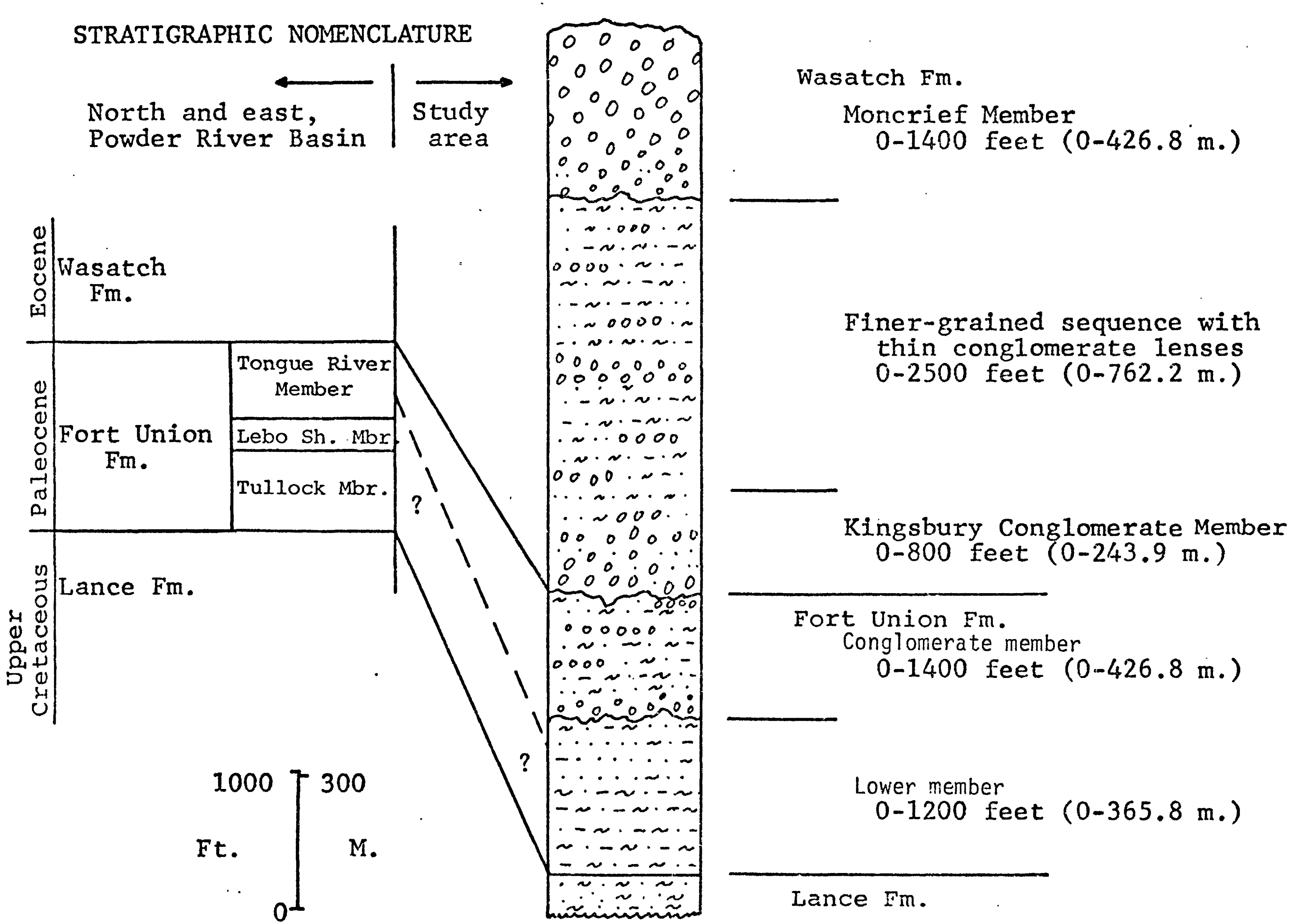


Figure 5: Generalized stratigraphic column for the conglomerate sequences of the Fort Union and Wasatch Formations west of Buffalo and Lake De Smet.

Lower member

The lower member of the Fort Union is composed of sandstones, silty sandstones, siltstones, and mudstones. Aside from a few brown thin, lenticular, resistive, ferruginous sandstones, these rocks are weakly resistant to weathering. Colluvium, alluvium, and pediment gravels of Quaternary age cover the member except where resistive sandstones form low-lying ridges. The most prominent outcrops occur in the S 1/2 sec. 29, T. 52 N., R. 83 W. (fig. 9). A few resistive ferruginous sandstones, but virtually no other lithologies, crop out in sec. 19, T. 52 N., R. 83 W.

Dips within the lower member vary greatly, ranging from 22° to nearly vertical in sec. 19, T. 52 N., R. 83 W. Abrupt changes in dip appear to result from faults which considerably displace lower Fort Union strata. The most consistent dips are in sec. 29, T. 52 N., R. 83 W., thus permitting about 365 m of strata in the lower member of the Fort Union Formation to be measured at this locality. The base of the Fort Union was arbitrarily placed below the lowermost outcrop of resistive ferruginous sandstone.

Abrupt lateral and vertical lithologic changes characterize the lower member. The lenticular, ferruginous sandstones display decreasing grain size, bed form, and cementation upward. Both laterally and vertically, these ferruginous sandstones grade into interbedded, poorly consolidated, gray, poorly sorted, sandy siltstones, siltstones, and mudstones and yellowish-orange, very fine-grained sandstones and silty sandstones. Locally, ripple stratification can be discerned in the unconsolidated sandstones and siltstones. These poorly consolidated deposits compose most of the lower member.

The ferruginous sandstones are 0.3-4.5 m thick and extend laterally from a few meters to a few tens of meters. Where these sandstones crop out, one can observe that they stack one atop another. The sandstones commonly are separated by interbedded sandy siltstones, siltstones, and mudstones.

A typical outcrop of ferruginous sandstone is brown, very fine to coarse grained, subangular to rounded, poorly sorted, trough cross-stratified and limonite cemented. Chert and quartz are the dominant minerals composing the sandstones. The sandstones exhibit scour bases and become finer grained upward. Basal, 1- to 2-grain-thick, coarse-grained sandstone gives way to medium- to fine-grained sandstone. Angular to subangular clay clasts, commonly weathered out, cluster immediately above the scour and at the base of individual crossbedded troughs near the base of the sandstone. Wood fragments and logs as much as 13 cm in diameter are common. Individual sets of trough cross-stratification seldom exceed 0.6 m in thickness and generally decrease in size upward. Direction of sediment transport is consistently toward the northeast.

Conglomerate member

Prominent beds of pebble to boulder conglomerate characterize the upper member of the Fort Union. The ridges that enclose Mowry Basin on the northeast, east, and southeast are predominantly conglomerate member deposits capped by beds of the Kingsbury Conglomerate Member of the Wasatch Formation. Strata of the conglomerate member also crop out at the base of Kingsbury Ridge at its northern end.

The conglomerate member overlies older beds with erosional unconformity. The greatest angularity, approximately 40°, is along the boundary of secs. 18 and 19, T. 52 N., R. 83 W. The dip discordance is approximately 20° in the SE 1/4 sec. 29, T. 52 N., R. 83 W. In the NW 1/4 sec. 4, T. 51 N., R. 83 W., where the conglomerate is directly on the Lance Formation, the dip discordance is too small to detect. At the north end of Kingsbury Ridge, there is little change in dip but the contact is oblique to the strike of the underlying lower member of the Fort Union Formation. The conglomerate deposits show the greatest degree of unconformity where they are most massive and extensive, as for example, at the northern and southern ends of Mowry Basin. The least degree of unconformity occurs where the lower member of the Fort Union is absent.

Because of truncation and onlap by the overlying Kingsbury Conglomerate Member, the conglomerate member varies greatly in thickness. Thicknesses range from zero meters where it pinches out against the mountain front or is truncated by the Kingsbury at the northern and southern ends of Mowry Basin, to approximately 430 m in the SE 1/4 sec. 29 and SW 1/4 sec. 28, T. 52 N., R. 83 W.

The conglomerate member consists of subangular to rounded, granule- to boulder-size material composed dominantly of carbonate, chert, and sandstone derived primarily from the Paleozoic formations that crop out to the west. Sorting is very poor in the massive conglomerates. Very poor to fair sorting is the rule where lenses of conglomerate represent a minor (less than 25 percent) portion of the total outcrop. In most localities, the boulders are in grain contact while the matrix material apparently filled the voids during and subsequent to the boulder deposition. Poorly sorted, subangular to well-rounded, silt to pebble-size quartz, chert, and carbonate grains compose the matrix material. Very little clay is present.

A massive, tan to light-yellowish-orange boulder conglomerate more than 30 m thick forms a prominent cliff face, referred to locally as Castle Rock, in N 1/2 sec. 19, T. 52 N., R. 83 W. The conglomerate is very poorly sorted, with stratification often impossible to discern; it contains boulders as great as 1.5 m in the long dimension (fig. 6). Reddish, poorly sorted sandstone lenses appear toward the top and lateral to the massive boulder conglomerate cliff face. Scour and fill structures can be observed where these lenses occur (fig. 34). Along the southern edge of Mowry Basin in the NW 1/4 sec. 9, T. 51 N., R. 83 W., a similar massive boulder conglomerate crops out, but is less extensive.

Directions of sediment transport were obtained by measuring cross-strata, scour and fill structures, and the somewhat crude imbrication of flat pebbles in the conglomerates. Paleocurrent directions around Mowry Basin display a fanning of the paleodrainages from dominantly east-northeast on the north to east-southeast on the south.

Previous investigators have not identified Fort Union strata underlying the Kingsbury Conglomerate Member at the north end of Kingsbury Ridge. The conglomerate member of the Fort Union west of Kingsbury Ridge (pl. 1) displays stratigraphic and structural features which closely resemble those along the eastern ridge flanking Mowry Basin. Sequences possessing basal conglomerates which grade upward into increasingly finer grained strata and which frequently show reddish coloration in the uppermost strata predominate. However, unlike the Mowry Basin section where virtually all the detritus is derived from Paleozoic and Mesozoic rocks, the Kingsbury Ridge section displays detritus which came from sources in the Precambrian, Paleozoic, and Mesozoic rocks. The angular unconformity between the conglomerate member of the Fort Union Formation and the overlying Kingsbury Conglomerate Member, identified primarily by strike and dip changes and by vegetative patterns, is strikingly similar to that at Mowry Basin (figs. 8 and 9).

Figure 7.--Conglomerate grading upward to finer grained gray and reddish beds in the conglomerate member in SE 1/4 sec. 29, T. 52 N., R. 83 W.

Typical of the conglomerates of the Fort Union are those along the base and slope of the ridge on the eastern edge of Mowry Basin. These strata consist of successive sequences, each becoming finer grained upward and ranging in thickness from less than 0.6 m to greater than 27 m. Each sequence contains a basal pebble to boulder conglomerate, seldom greater than 1.5 m thick, that grades upward into interbedded sandstones, siltstones, mudstones, and occasional thin carbonaceous shales and coals.

Colors of the strata above the conglomerates reflect progressions from reducing to oxidizing conditions. Immediately above the conglomerate beds, the sandstones, siltstones, and mudstones exhibit greenish-gray, light gray, and olive-brown colors which give way upward to yellowish-orange to red coloration in progressively finer grained rock near the top of each sequence (fig. 7). More than one repetition of this color zonation may occur within a single sequence. The thin coals and carbonaceous shales always occur within the drab-colored units.

The sandstones are very fine to very coarse grained, subangular to rounded, and poorly sorted. Dark-colored chert, angular to subrounded clay and siltstone clasts as great as 2 cm in size, and carbonaceous and organic material are abundant constituents. Stratification ranges from small (less than 15 cm) trough cross-strata at the base, to ripple cross-strata and parallel laminations upward. Carbonaceous material and organic matter are also abundant in the siltstones and mudstones. Locally, ripple and parallel lamination stratification are observed in the siltstones, but the mudstones are not internally stratified.

Figure 6.--Massive pebble to boulder conglomerate in the conglomerate member of the Fort Union Formation at Castle Rock. The boulder in the center of the photograph is approximately 1.2 m in diameter.

Figure 8.--Angular unconformity between the conglomerate member (Tfuc?) of the Fort Union Formation and the Kingsbury Conglomerate Member (Twk) of the Wasatch Formation at the north edge of Kingsbury Ridge. The sage grows preferentially on the conglomerate horizons. View is to the south.

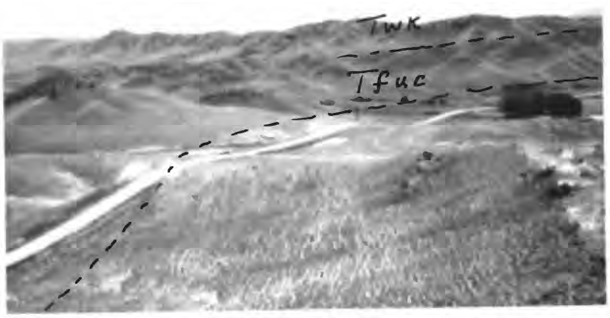


Figure 9.--Angular unconformity between the conglomerate member (Tfuc) of the Fort Union Formation and the Kingsbury Conglomerate Member (Twk) of the Wasatch Formation along the eastern boundary of Mowry Basin. Lower member of Fort Union (Tfu) resistive, ferruginous sandstones crop out in the lower right corner of the photograph. View is to the south.

Palynomorph specimens from the Fort Union identified by K. R. Newman were recovered in sec. 30, T. 50 N., R. 82 W from a carbonaceous shale bed approximately 9 m below the base of the conglomerate(?) member. A late Paleocene age for the sampled strata is indicated by the palynomorphs, which include Caryapollenites sp., Alnus sp., Momipites coryloides, Ulmoidepites trizostatus, and cf. Tiliaepollenites. Additional palynomorph studies and stratigraphic work will be necessary to identify the Cretaceous-Paleocene boundary.

Wasatch Formation

The contact between the Fort Union and Wasatch Formations in the Powder River Basin has been and remains the source of considerable controversy. The formations are not uniquely distinctive from each other. Hence, several criteria have been proposed to delineate the boundaries, most of which direct a benevolent eye toward placing the formation contact at the Paleocene-Eocene boundary. The various proposals for placing the formation contact, as summarized by Tschudy (1976, p. 73), include:

1. The top of the Smith coal bed.
2. The top of the Roland coal bed of Taff (1909, p. 129-130).
3. The top of the Roland coal bed of Baker (1929, p. 25-28).
4. The use of pollen studies to determine the Paleocene-Eocene boundary.
5. The use of heavy minerals which principally reflect the source rocks; that is, the evolution of erosion of the uplifts.
6. The identification of an unconformity.

Serious objections to all these proposals can be made, which is the probable reason why no one proposal is preferred over another. The use of coal beds over regional distances for correlation purposes, without close subsurface control, is highly suspect. Pollen studies would appear to be the most useful in establishing the time boundary but are not helpful to the field geologist who requires physical, observable data for field mapping of formations. Based on observations made in the course of this study, which will be discussed below, heavy mineral studies are probably invalid for delineating the time boundary. R. H. Tschudy (U.S. Geological Survey, 1974, p. 155) demonstrated with palynology studies that the lithologic and heavy mineral changes distinguishing the Fort Union and Wasatch Formations, as described by Denson and Pipiringos (1969), do not coincide with the Paleocene-Eocene boundary. In all but a few localities, no unconformity can be observed at the outcrops. Connor, Denson, and Hamilton (1976, p. 291) maintain that a basin-wide unconformity between the Fort Union-Wasatch exists. An unconformity exists between the Fort Union and Wasatch in the western portion of the study area. This unconformity does not coincide with the Paleocene-Eocene time boundary. The proposed unconformity is not verifiable in the eastern portion of the study area due to deep burial.

In the study area, the formation contact is placed at the base of the Kingsbury Conglomerate Member. However, this boundary, represented by an unconformity, is not without controversy. Mapel (1959) (pl 1) included all conglomerate beds comprising Kingsbury Ridge within the Kingsbury. Stratigraphic and structural data support the author's contention that the conglomerate beds at Kingsbury Ridge can be separated into conglomerate member (of Fort Union) and Kingsbury Conglomerate Member (of Wasatch). Unfortunately, no datable fossils or detritus have been unearthed to confirm this definition of strata.

Kingsbury Conglomerate Member

The Kingsbury Conglomerate Member forms an almost continuous outcrop along the mountain front except where it is unconformably overlain by the Moncrief Member. The most prominent exposure is at Kingsbury Ridge. Angular unconformity with the conglomerate member at the top of the Fort Union ranges from a maximum of 25° along the east flank of Mowry Basin to a virtually nondiscernible unconformity north of Rock Creek along the northern and northeastern margins of Mowry Basin. To the east and south, the conglomerate beds thin and merge with the coal-bearing strata and the unconformity disappears into a conformable sequence (Mapel, 1959, p. 63; Hose, 1955, p. 67).

The Kingsbury is restricted to the strata which also contain other conglomerates. Thicknesses for the Kingsbury range from less than 30 m where the unit crosses Rock Creek in secs. 33 and 34, T. 52 N., R. 83 W., to a maximum of 245 m at Kingsbury Ridge and above Castle Rock on the northern edge of Mowry Basin (Mapel, 1959, p. 64).

Allowing for minor differences, the lithologies and the vertical and lateral relationships between lithologic types are virtually identical to those described for the conglomerate member of the Fort Union. Massive conglomerate beds occur at the base of the Kingsbury. Stratigraphically upward and laterally to the east, the Kingsbury grades into a drab sequence of tan sandstones, greenish-gray siltstones and mudstones, and occasional brown, thin, carbonaceous shales. Thin lenses of conglomerate and conglomeratic sandstone are intercalated throughout. Structural evidence east of Mowry Basin suggests that this sequence of dominantly nonconglomerate deposition above the Kingsbury Conglomerate Member produced 600-765 m of strata. Hence, in gross lithology, the Kingsbury appears to represent a coarse basal unit of a sequence that becomes finer grained upward (fig. 5).

As the proportion of detritus derived from Precambrian rocks becomes greater in the Kingsbury (compositionally, the conglomerates and the sandstones contain 0-40 percent detritus derived from Precambrian rocks), the angularity of matrix material within the conglomerates and the sandstones increases. In general, the fine-grained fraction of a sandstone contains a greater percentage of angular material than the coarse-grained fraction. Depending on the amount of Precambrian detritus, the sandstones range from lithic quartz arenites, to lithic arkosic arenites, to arkosic arenites.

Sandstones containing detritus derived from Paleozoic and Mesozoic rocks have as much as 60 percent rounded and subrounded carbonate and lithic grains. Rounded quartz grains are the dominant remaining constituent. Sandstones possessing detritus derived from Precambrian rocks are composed of feldspars and quartz with minor biotite, magnetite, and hornblende. The angularity of the grains in these sandstones is striking. Between these end-member sandstone lithologies, the compositions and physical properties of the sandstones reflect detritus from Precambrian, Paleozoic, and Mesozoic source rocks in varying amounts (fig. 10).

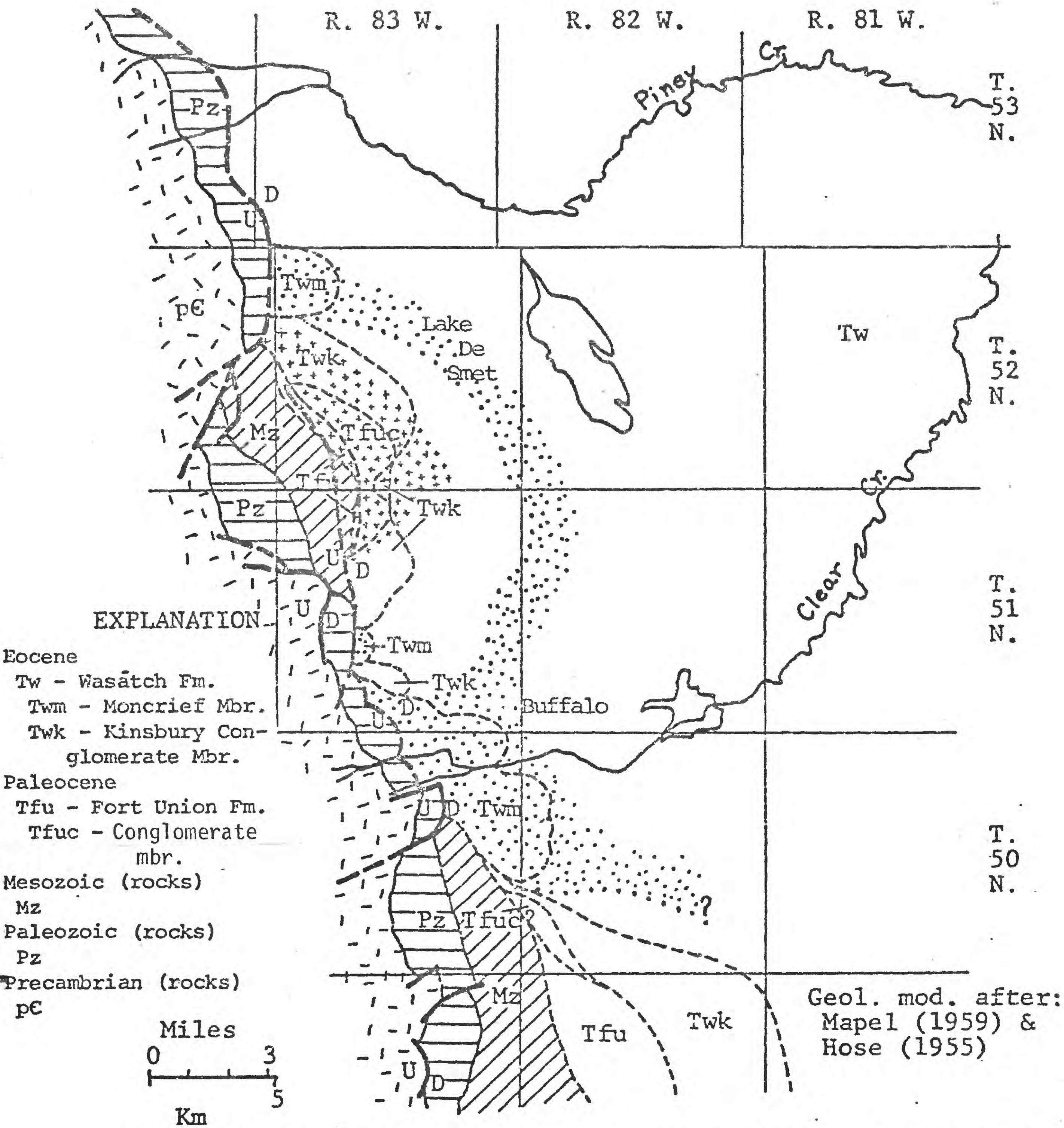


Figure 10: Map reflects the source rocks of detrital grains in the Tertiary sediments. Older Tertiary sediments, Fort Union (Tfu and Tfuc) and lower Wasatch (Twk and Tw), marked with +, consist of detritus derived from Paleozoic and Mesozoic rocks. Younger Tertiary sediments, upper Wasatch (Twm and Tw), east of the dotted area, are comprised of detritus derived from Precambrian rocks (greater than 99%). Compositions of sediments between these end-member lithologies show increasing volumes of detritus derived from Precambrian rocks as one proceeds upward through the section stratigraphically.

The lowest megascopically visible evidence of Precambrian material, when mapped as a boundary, forms an interesting relationship with respect to formation boundaries (fig. 10). Such compositional boundaries cross formation and member contacts and, hence, are not good criteria for establishing formation or member boundaries. From north to south in the study area, the boundary marking the first megascopic appearance of Precambrian material trends downward across the stratigraphic section from approximately 245 m above the contact between the conglomerate member of the Fort Union and the Kingsbury Conglomerate Member of the Wasatch along the northern edge of Mowry Basin to the base of the conglomerate member at Kingsbury Ridge. This suggests several possible conclusions: (1) differential uplift of the mountains or differential erosion of the uplift and deposition within the basin, (2) major drainage systems originated on Precambrian outcrops and carried primarily Precambrian detritus to the basin, and (3) lesser drainage systems originated in the flanking sedimentary units, thus supplying Paleozoic and Mesozoic detritus only. The conglomerate member of the Fort Union and the Kingsbury Conglomerate Member contain interbedded sandstone deposits that are alternately rich in and devoid of Precambrian detritus. Hence, drainage systems may play a significant role in determining the composition of these units at any one locality. The regional trend of such compositional boundaries has broader implications for the tectonic and erosional history of the Bighorn Mountains and for the use of heavy-mineral compositions in sandstones for mapping purposes in this area and, perhaps, elsewhere.

Denson and Pipiringos (1969, p. 9) found that tourmaline and zircon constitute the majority of nonopaque heavy minerals in Fort Union strata and that these concentrations are largely the result of erosion of Paleozoic and Mesozoic strata. Hornblende, epidote, and garnet derived from Precambrian rocks are the predominant nonopaque heavy minerals in Eocene rocks. Observations made of the strata, however, render highly questionable the use of heavy-mineral studies as a means for delineating the contact between the Fort Union and Wasatch in the study area, particularly in areas close to the uplift where nearby Precambrian outcrops would alter the expected heavy mineral compositions.

Reddish strata are much less abundant in the Kingsbury than in the conglomerate member of the Fort Union. They are most closely associated with the massive and pervasive conglomerates in the lower part of the section. Laterally and vertically, coinciding with decreasing amounts of conglomerate, the reddish beds give way to gray and greenish-gray siltstones and mudstones which are characteristic of the fine-grained facies of the Wasatch.

Directions of sediment transport, obtained from cross-strata and pebble imbrication, display a northeast-southeast pattern. No single outcrop displays a pattern that is uniquely distinctive.

A few thin coal stringers, with woody texture strongly apparent, occur locally within the conglomerate sequences. All indications point to a transported origin for these coals. Poorly preserved, broken gastropod and pelecypod shells are clustered at the base of many conglomeratic sandstones. Evidence presented by Brown (1948) and specimens collected by R. K. Hose in 1951 and identified by T. C. Yen confirm the age of the Kingsbury as Eocene (Mapel, 1959, p. 64).

Moncrief Member

Massive boulder conglomerates, comprising as much as 427 m of strata, crop out within the study area at the mouth of Clear Creek west of Buffalo and north of the study area at Moncreiffe Ridge. They form ridges which stand several hundred meters higher than the topography to the east. Along the western margin of the study area, thrust faulting has thrown Paleozoic strata up and over the Moncrief.

Dips within the Moncrief range from 0°-5° to the east. No angular unconformity can be observed at the base of the Moncrief along Clear Creek. However, along the flanks of the deposit north and south of Clear Creek, Mapel (1959, p. 66) reported an abrupt dip change where the Moncrief overlaps older deposits. Noting that the base of the Moncrief along Clear Creek is approximately 305 m lower at Clear Creek than it is 2.5 km to the southwest, Sharp concluded that there was considerable local topographic relief at the time of Moncrief deposition (Mapel, 1959, p. 66; Sharp, 1948, p. 6).

The Moncrief Member becomes increasingly coarser grained upward. Basal units of the Wasatch at Clear Creek are lensing and interbedded, gray to tan sandstones and dark-gray to greenish-gray to brown siltstones, shales, and mudstones which closely resemble those in the Wasatch west of the Lake De Smet coal bed.

These basal units gradually give way upward to the conglomerate beds composing the Moncrief. From bottom to top stratigraphically within the Moncrief Member, conglomerate lenses occur with increasing frequency and with greater thicknesses. Pebbles and cobbles give way to boulders commonly 1.5-3.0 m in the maximum dimension. Below the crest of Bald Ridge (pl. 1) boulders larger than 6 m in the largest dimension can be found. The best outcrops of the Moncrief are along U.S. Highway 16 west of Buffalo and along the north flank of Moncreiffe Ridge (fig. 11).

Stratification is virtually impossible to discern in the conglomerates; occasionally, however, a horizon of abnormally large boulders will crop out identifying a single depositional event. Poorly sorted boulder deposits greater than 30 m thick crop out on Moncreiffe Ridge. The boulder compositions are dominantly granite, gneisses, amphibolites, schists, pegmatites, hornfels, and diabase, all of which are common rocks in the Precambrian terrane to the west. Many of the cobbles and boulders are so extremely weathered that picking at them with a rock hammer will reduce them to sand and gravel (fig. 12).

Figure 11.--Moncrief Member along U.S. Highway 16, 8 km west of Buffalo. The largest boulders in the photograph are approximately 1 m in the largest dimension.

Figure 12.--Weathered cobbles and boulders of the Moncrief Member at Moncreiffe Ridge. N 1/2 sec. 2, T. 53 N., R. 84 W.

Occasional thin lenses, usually less than 1 m thick, of gray and greenish-gray sandstones and silty sandstones comprise less than 1 percent of the total deposit within the massive conglomerates. The sandstones and the matrix within the conglomerates are angular to subangular, poorly sorted, micaceous, and arkosic.

Conflicting opinions still exist as to the age of the Moncrief Member. Previous workers have variously described the Moncrief as glacial outwash debris (Salisbury and Blackwelder, 1903, p. 221-223; Alden, 1932, p. 41-44) or as upper Tertiary or lower Quaternary bench gravels (Darton, 1906, p. 67-70). Taff (1909, p. 131) and Demorest (1941, p. 168) suggested that the deposit was a lateral facies of lower Tertiary coal-bearing strata. Sharp (1948, p. 1) argued that one could follow this lateral facies change outward from Moncreiffe Ridge into the coal-bearing strata of the Wasatch. Recently, Keefer (1974, pl. A-3) equated the Moncrief with the younger Oligocene White River and Miocene Arikaree Formations. Unfortunately, no means were found within the study area to accurately date the Moncrief, and tracing of the Moncrief laterally into the Wasatch coal-bearing strata is not sufficiently conclusive (due to extensive cover and erosion) to end the controversy.

For several reasons, the Moncrief is here considered to be an upper conglomerate member of the Wasatch Formation. These reasons, considered individually, are far from conclusive but, considered together, they provide substantial support for concluding that the Moncrief is Eocene and that it is a member of the Wasatch Formation. These reasons include:

1. Sharp's (1948) work led to the conclusion that the Moncrief is a lateral equivalent to the coal-bearing strata of the Wasatch is accurate.

2. The deposits at the base of the Moncrief at Clear Creek are strikingly similar to Wasatch strata immediately to the east.

3. Figure 9 and plate 1 suggest considerable Eocene topography after Kingsbury deposition. A paleo-valley along the present Clear Creek drainage was filled with conglomerate deposits which in turn graded eastward into finer grained sediments. The conglomerates indicate drainage from a highland where Precambrian rocks were exposed to erosion.

4. Keefer (1974, pl. A-3) equated Moncrief deposits with the Oligocene White River and Miocene Arikaree Formations. White River deposits exist west of the Moncrief deposits west of Buffalo on the Bighorn Mountain subsummit surface. Hence, one may argue there is correlation between the White River and Moncrief deposits even though a thrust fault separates the two. However, nowhere else along the east flank of the Bighorn Mountains does this relationship between Moncrief and White River deposits exist. Wherever one of these two deposits is present, the other is conspicuously absent. If, in fact, there is a genetic connection between the two units, Moncrief-type deposits should be preserved east of the White River deposits located on the subsummit surface.

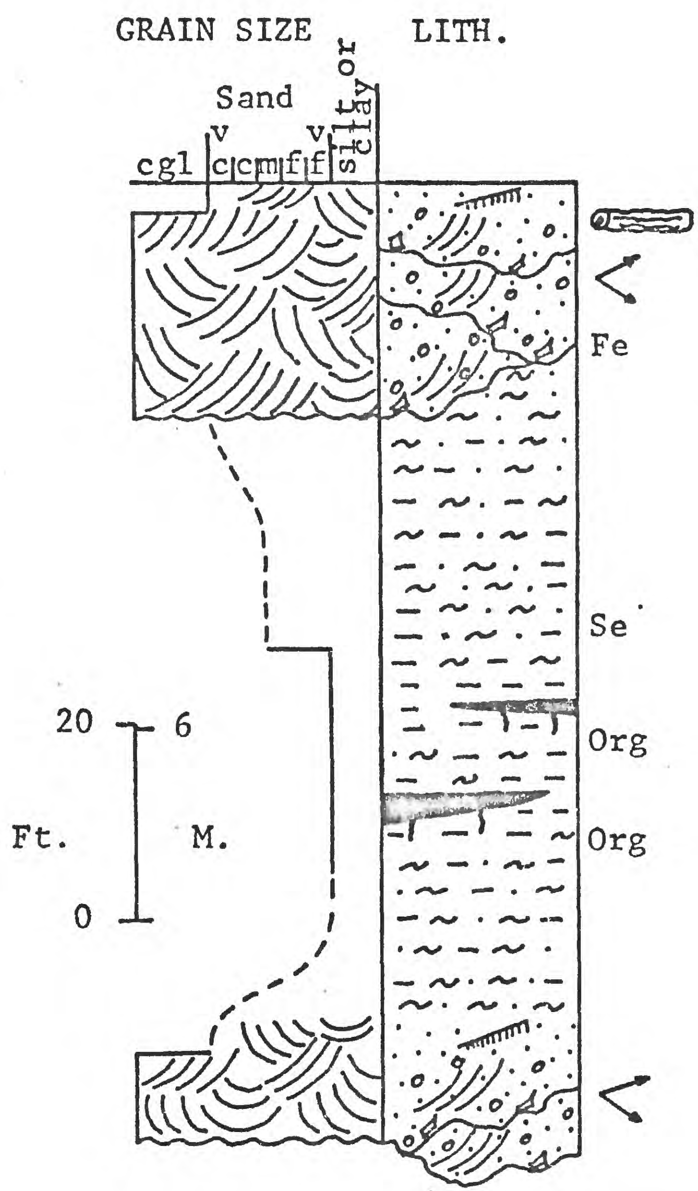
5. Similar thick conglomerates bounded on the side of an uplift by thrust faults and grading basinward into fine-grained coal-bearing sequences of Eocene age were reported by Knight (1951, p. 48-53) in the Hanna Basin and by Blackstone (1975, p. 258-262) in the Laramie Basin. As in the study area, all conglomerates, except the youngest one, of Paleocene and Eocene age in these basins are strongly folded and faulted. The youngest conglomerate has been subjected only to minimum horizontally oriented tectonic stresses.

Coal-bearing strata--Wasatch Formation

The massive conglomerates of the Moncrief grade eastward into succeedingly finer grained sedimentary beds. The dips to the east remain relatively flat, although local steepening associated with either post-depositional faulting, differential compaction structures, or slumping and collapse adjacent to burned-out coals, is observed in the coal-bearing strata. The flat dips enable lateral lithologic changes to be studied over a wide area, but permit only limited views of vertical changes. The knoll-and-butte topography in the plains east of the Bighorn Mountains reflects the more resistive lithologies of the pediment gravels, clinker deposits (baked sediments overlying burned-out coal beds), and coarse-grained and/or locally cemented sandstones.

The lithologies of the Wasatch coal-bearing beds in the study area are characterized by two types of sandstones. They are lithologically and geometrically different, laterally correlative, and separated by the thick Lake De Smet coal bed (fig. 16 shows the approximate position of the Lake De Smet coal bed). Sandstones west of the Lake De Smet coal bed are thin, lenticular, and conglomeratic. Thick, broad sheets of well sorted, very fine- to medium-grained sandstones dominate the stratigraphy east of the coal bed. Thick, areally extensive coals are present east of the Lake De Smet coal bed, but only thin carbonaceous shales and coals exist to the west.

Conglomeratic sandstone sequence.--Lenticular and interbedded, poorly consolidated, conglomeratic sandstones, sandstones, siltstones, mudstones, and thin organic and carbonaceous shales and coal stringers dominate the equivalent strata west of the Lake De Smet coal bed. These lithologies interfinger to the west with the conglomerate facies and, to the east, with the Lake De Smet coal bed. Figure 13 is a composite section of a sequence representative of the strata west of the Lake De Smet coal bed. It is based on limited outcrop exposures and one drill hole in sec. 28, T. 51 N., R. 82 W. Sequences which become finer grained upward are characteristic of these strata. This pattern is repeated many times, and the grain size may or may not coarsen again toward the top of each unit. Coal and shales rich in organic material locally are present. Field observations suggest that lateral continuity of any single lithologic unit is very limited.



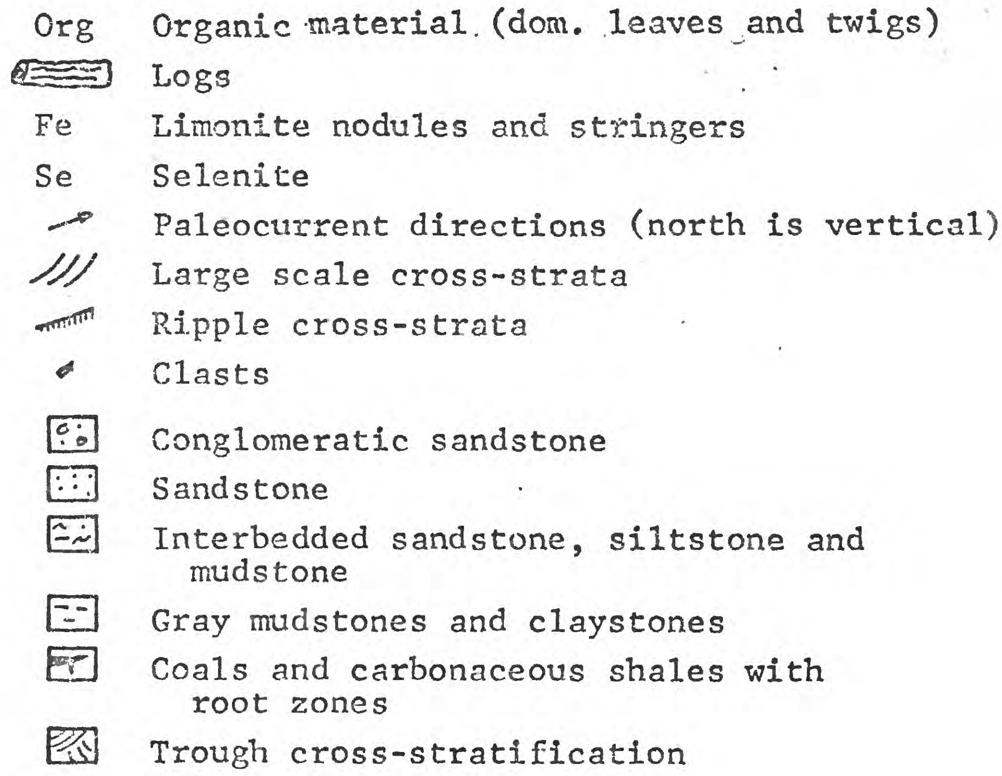


Figure 13: A composite vertical section showing a representative sequence within the coal-bearing strata west of the Lake De Smet coal bed.

Figure 14.--Outcrop west of the Lake De Smet coal bed, which illustrates many of the features described in figure 13. SE 1/4 sec. 21, T. 51 N., R. 82 W.

Figure 15.--Trough cross-strata within a channel deposit west of the Lake De Smet coal bed. Extremely poor sorting and conglomeratic detritus are characteristic of these deposits. Camera lens cap provides scale. N 1/4 sec. 22, T. 51 N., R. 82 W.

The conglomeratic sandstones and sandstones are tan to pale-yellowish-orange. They contain angular to subangular, silt- to pebble-sized, micaceous, arkosic detritus derived primarily from Precambrian rocks. Virtually all the sandstones contain abundant carbonaceous material. Sorting varies from fair to poor, with fine-grained sandstones being better sorted than coarse-grained sandstones. Wood fragments, in situ roots, and logs serve as loci for numerous brown, calcareously cemented concretions. Many limonite nodules less than 1 cm in size are sprinkled thoughout the sandstones.

The conglomeratic sandstones and sandstones occur as lenses up to 12 m thick and greater than 6 m wide. Scour surfaces occur at the base and within the sandstone lenses.

Most of the conglomeratic sandstone lenses become finer grained upward. They also display sets of cross-strata which decrease in thickness upward. A few of these lenses become coarser grained upward. Irregular water energies during deposition are reflected in the grain size distributions, as individual cross-stratified beds contain much coarser material than adjacent layers (fig. 35). Trough cross-strata up to 1 m thick near the base of the lenses are replaced vertically by smaller trough sets, parallel laminations, and ripple cross-stratification. Angular siltstone and mudstone clasts cluster near the base of many trough sets as well as above the scour surfaces of the sandstone lenses.

Laterally and vertically, these thick conglomeratic sandstone lenses grade into interbedded, poorly sorted, thin- to thick-bedded, pale-yellowish-orange conglomeratic sandstones and sandstones, and greenish-gray siltstones and mudstones. These interbedded units have a much greater lateral extent than the conglomeratic lenses described above. Sandstones in the interbedded sequences display few scour surfaces. Their contacts are frequently limonite cemented. Stratification is often either disrupted or impossible to discern, although large-scale and ripple cross-strata are occasionally observed. The thick sandstone beds locally contain clasts. A proportionate decrease in sandstone volume occurs both laterally and vertically with increasing distance from the conglomeratic sandstone lenses.

The siltstones and mudstones are very carbonaceous and contain numerous imprints of twigs and leaves. At two localities (N 1/2 sec. 35 and NW 1/4 sec. 15, T. 51 N., R. 82 W.) tree trunks 0.3-0.6 m in diameter are buried upright, normal to the bedding, in a sequence of interbedded sandstones, siltstones, and mudstones. Some siltstones contain ripple stratification, but the mudstones are not stratified.

Occasional thin lenses of brown shale contain abundant plant debris, carbonaceous shale, and woody coals up to 1.5 m thick. Root zones penetrate underlying clays, silts, and sands. Abundant yellow resins and occasional pyrite crystals can be found within these units. Both laterally and vertically adjacent to these units, yellowish-orange sandstones are generally absent or are present in minor quantities.

The Lake De Smet coal bed.--Reputed to be the thickest coal bed in the United States and second thickest in the world (Texaco press release, 1975), the Lake De Smet coal bed extends north-south through the study area for more than 24 km with a thickness ranging from 20 m to more than 75 m and a width of approximately 1-3 km. This thick coal was first reported by Mapel, Schopf, and Gill (1953), after the U.S. Geological Survey and the U.S. Bureau of Reclamation drilled several holes at the northern and southern ends of Lake De Smet. Subsequent drilling by several industrial concerns has vastly extended the known length and breadth of the coals initially discovered.

Although hundreds of holes were drilled in the Buffalo-Lake De Smet area, logs of only a few holes, aside from those drilled by the Government agencies, are publically available. However, the 55 available logs give general coverage for the area and, thus, provide an expanded view of the extensive lateral and vertical continuity of the coals.

The drill hole data are of highly variable quality. Some describe only the presence or absence of coal. Others, such as the log of a hole drilled in Buffalo by the U.S. Geological Survey in 1975 (Farrow, 1976, p. 29-77), provide very detailed lithologic breakdowns. Few lithologic logs have accompanying geophysical logs. Some of the holes may not have penetrated the total thickness of the Lake De Smet coal bed, as they may have bottomed either in coal or within a few meters below a coal layer. A basal fossiliferous mudstone, which might serve as a marker bed (figs. 17, 18, 20), has been reported to underlie the Lake De Smet coal bed at Buffalo (Farrow, 1976, p. 8) and along the northern and western margins of Lake De Smet; however, its existence has not been verified elsewhere. With these limitations, logs of selected drill holes were assembled to construct north-south and east-west cross sections (figs. 16, 17, 18, 19) to delineate the extent and thickness of the coal. The thickest coals are north of Lake De Smet and near Buffalo. One drill hole, in sec. 10, T. 51 N., R. 82 W., penetrated no coal.

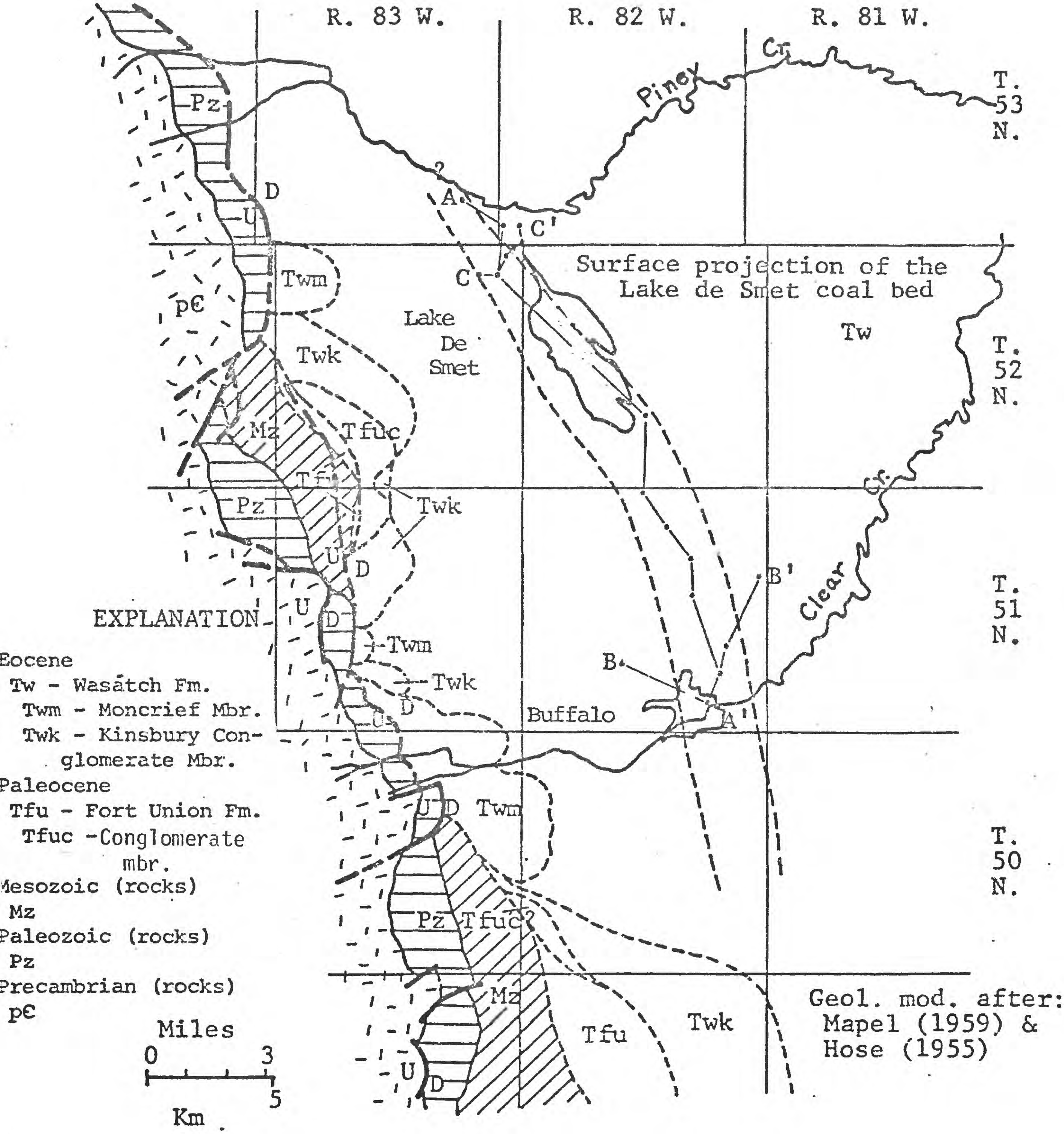


Figure 16: Surface projection of the Lake De Smet coal bed. Cross-sections A-A', B-B', and C-C' appear in figures 17, 18 and 19 respectively.

Table 1.--Drill hole locations.

Drill hole no.	Location	Drilled by	Cored hole
Cross section A-A' (north to south):			
Hepp well	SE 1/4 sec. 26, T. 53 N., R. 83 W.	Unknown	
A-8	SW 1/4 sec. 31, T. 53 N., R. 82 W.	USBR	Yes
C	SE 1/4 sec. 1, T. 52 N., R. 83 W.	J. E. Rice	
305	SW 1/4 sec. 15, T. 52 N., R. 82 W.	USBR	
H-4	NW 1/4 sec. 3, T. 51 N., R. 82 W.	Unknown	
H-3	NW 1/4 sec. 10, T. 51 N., R. 82 W.	Unknown	
H-2	SE 1/4 sec 10, T. 51 N., R. 82 W.	Unknown	
---	SW 1/4 sec. 14, T. 51 N., R. 82 W.	Anonymous	
---	NE 1/4 sec. 26, T. 51 N., R. 82 W.	Anonymous	
B-1	NW 1/4 sec. 35, T. 51 N., R. 82 W.	USGS	Yes
Cross section B-B' (west to east):			
---	NW 1/4 sec. 28, T. 51 N., R. 82 W.	Anonymous	
B-1	NW 1/4 sec. 35, T. 51 N., R. 82 W.		
---	NE 1/4 sec. 26, T. 51 N., R. 82 W.	Anonymous	
---	SE 1/4 sec. 23, T. 51 N., R. 82 W.	Anonymous	
---	NE 1/4 sec. 13, T. 51 N., R. 82 W.	Anonymous	
Cross section C-C' (west to east):			
F	SW 1/4 sec. 1, T. 52 N., R. 83 W.	J. E. Rice	
C	SE 1/4 sec. 1, T. 52 N., R. 83 W.		
7	NE 1/4 sec. 1, T. 52 N., R. 83 W.	USBR	Yes
5	NE 1/4 sec 1, T. 52 N., R. 83 W.	USBR	Yes
6	NW 1/4 sec 6, T. 52 N., R. 82 W.	USBR	Yes
A-5	SE 1/4 sec. 31, T. 53 N., R. 82 W.	USBR	Yes

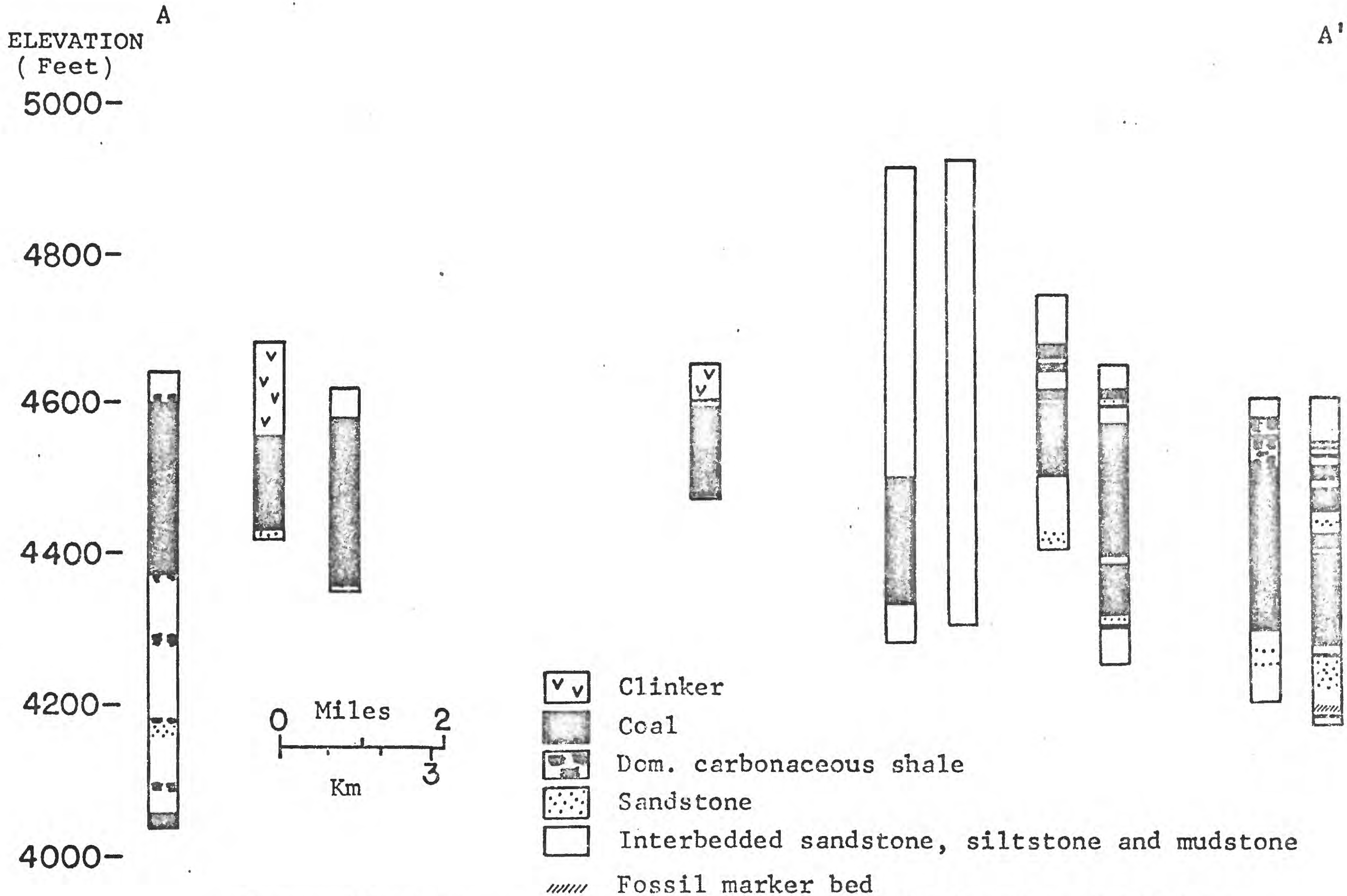


Figure 17: Cross section A-A' (from fig. 16), based on drill hole lithologic logs.

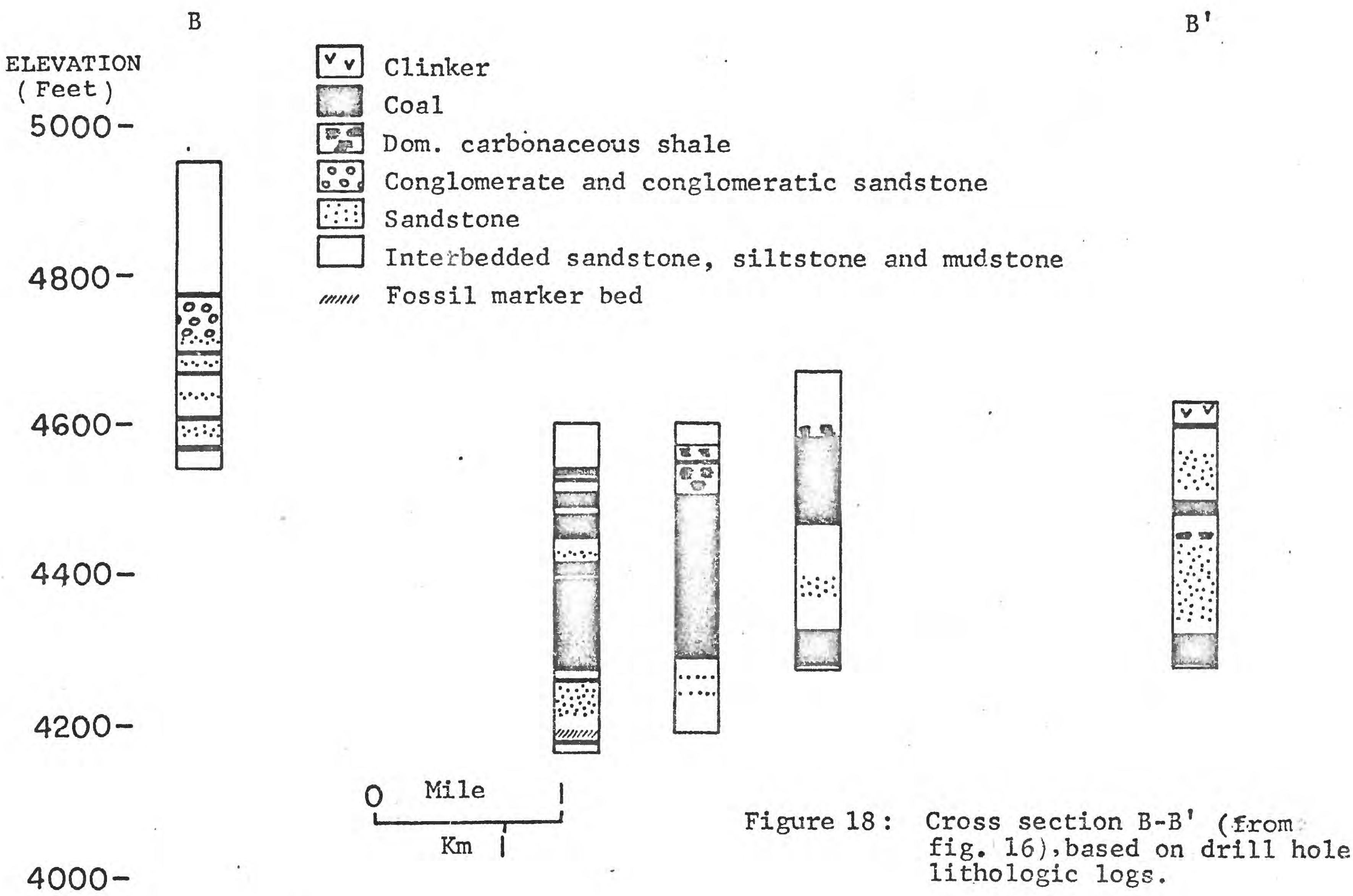


Figure 18: Cross section B-B' (from fig. 16), based on drill hole lithologic logs.

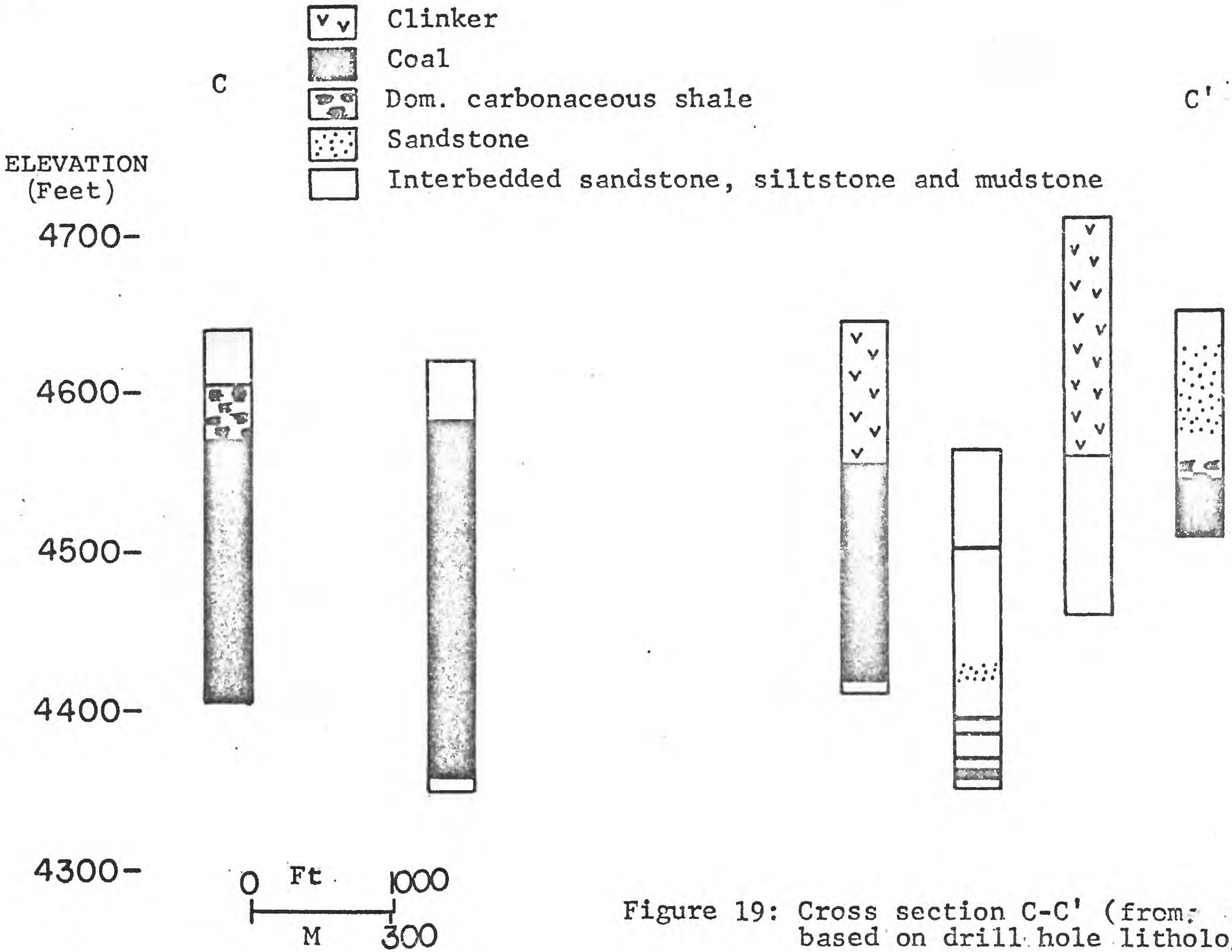


Figure 19: Cross section C-C' (from: fig. 16), based on drill hole lithologic logs.

Figure 21.--Carbonized root zone in a conglomeratic sandstone beneath a coal bed in NE 1/4 sec. 29, T. 52 N., R. 82 W. (Photo taken by Robert Weimer.)

Many lenticular thin partings of very fine- to medium-grained sandstone, siltstone, mudstone, claystone, and shale rich in organic material occur throughout the coal. Sandstone and siltstone partings are more abundant to the west than to the east. The western boundary of the coal is relatively abrupt, with coal rapidly tonguing out westward into thin brown shale rich in organic material, carbonaceous shale, and coal stringers. At outcrops, these stringers are directly underlain by pale-yellowish-orange conglomeratic sandstones displaying root zones (figs. 20, 21).

To the east of the Lake De Smet coal bed, coal beds in the Wasatch Formation are generally underlain by dark gray clays which are commonly conchoidally fractured and possess grooves resembling slickensides. "Clay skins" is the term often applied to such structures. They may result from roots penetrating and expanding in the clay zones (Weimer, 1977, p. 18). These features may also be the result of differential compaction.

Figure 20.--Carbonaceous shale and coal interbedded with conglomeratic sandstones along the west side and near the top of the Lake De Smet bed in sec. 2, T. 51 N., R. 82 W. The middle coal unit is approximately 1 m thick.

Five major coal beds, which merge westward to form the Lake De Smet coal bed, can be traced over a large area both in outcrops and in the subsurface (fig. 22). The five coal beds include the Ucross, Murray, Cameron, Healy, and Walters. Mapel, Schopf, and Gill (1953, p. 3) and Mapel (1959, p. 84-85) tentatively identified a portion of the Lake De Smet coal to be the equivalent to the Healy bed. Subsequent work by oil companies has resulted in correlating the lowermost coal fingering eastward from the Lake De Smet coal bed with the Ucross coal bed. The Walters coal bed is interpreted by this author to be the uppermost coal that can be indentified as part of the Lake De Smet coal bed. Two pieces of field evidence support this conclusion. The lowest conglomeratic sandstone east of the Lake De Smet coal bed is above the Walters coal bed. A coquina mudstone of wide areal extent also overlies the Walters coal bed but underlies the conglomeratic sandstone east and south of Lake De Smet. This fossil bed exists above a thick coal sequence, interpreted to be a portion of the Lake De Smet coal bed that was unearthed by construction crews at the southeast corner of Lake De Smet (fig. 23). Small channel deposits trending east and northeast also were exposed by construction crews in the NE 1/4 sec. 28, T. 52 N., R. 82 W., and in the W 1/2 sec. 1, T. 51 N., R. 82 W. (fig. 24).

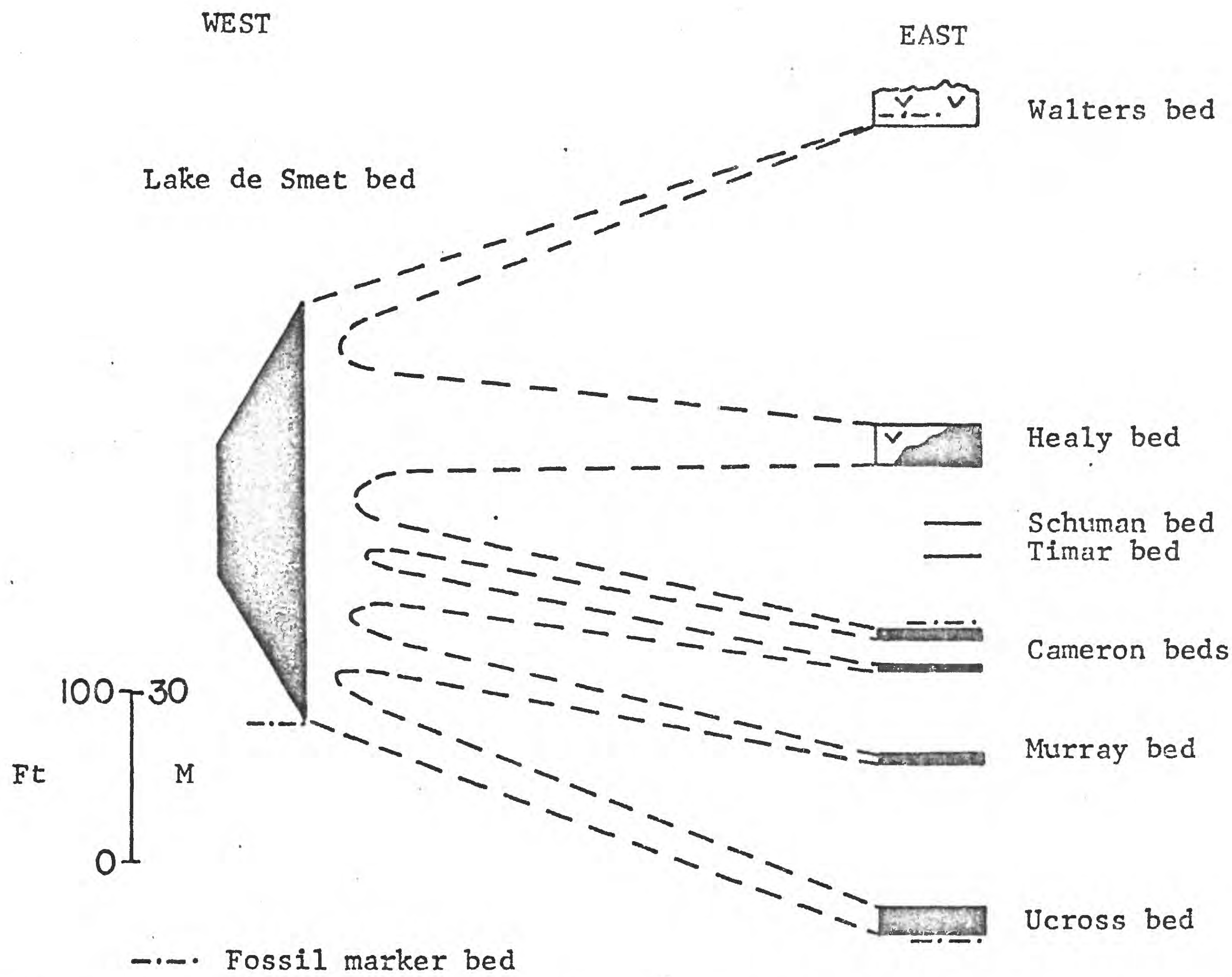


Figure 22: Schematic diagram showing the relationship of the Lake De Smet coal bed with the major coal beds to the east using Mapel's (1959) coal bed designations. This diagram is not drawn to scale horizontally.

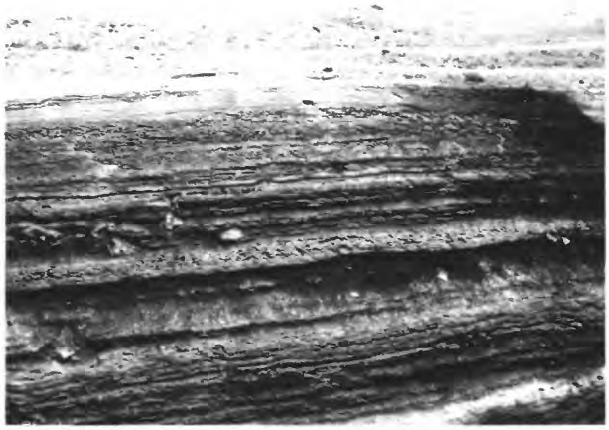


Figure 23.--Thick coal with mudstone and siltstone partings, southeast corner of Lake De Smet. Stumps are at the bases of coals. Zone near the top is the fossiliferous mudstone marker bed whose stratigraphic position is above the Walters bed. Vertical outcrop exposure is about 30 m high. SE 1/4 sec. 21, T. 52 N., R. 82 W.

Figure 24.--Conglomeratic sandstone channel preserved in a clinker outcrop in the W 1/2 sec. 1, T. 51 N., R. 82 W.

Mapel, Schopf, and Gill (1953, p. 1) reported the coal's rank is borderline between subbituminous C and lignite (ASTM classification). The coal is a dull black when wet, brown when dry, and has a strong tendency to slake when exposed to the air. Metamorphism of the coal has not progressed sufficiently to produce vitrain. Fusain probably represents less than 1 percent of the deposit. Core analyses reveal that woody material makes up 34-39 percent of the coal. Numerous partially coalified tree trunks litter the outcrops of the thin coaly splits along the western margin of the coal bed. Tree stumps greater than 1 m in diameter are common at or near the base of coal layers. Analyses of coal samples from drill holes near Lake De Smet, as reported by Mapel (1959, p. 91), appear in table 2.

Karl Newman identified several early Eocene palynomorph specimens separated from core samples obtained from the U.S. Geological Survey drill hole within the city limits of Buffalo in the N 1/4 sec. 25, T. 51 N., R. 82 W. The sample was taken from near the base of the Lake De Smet coal bed. Palynomorph identification included *Platycarya* sp., *Pistillipollenites* sp., and *Alnus* sp.

Table 2.--Analyses of coal from the Lake De Smet area.

Weighted analyses of coal found in drill holes

near Lake De Smet, Johnson County, Wyoming (from Mapel (1959).

[Form of analysis: A, as received; B, mineral-matter free;

C, mineral and moisture free; D, moist mineral-matter free]

Core-hole designation (pl. 12)	Total coal thickness (inches)	Present									Btu		
		Mineral (1.08 ash plus	Ash A	Sulfur A	Moisture B	Moisture A	Volatile matter C	Volatile matter A	Fixed carbon C	Fixed carbon A	C	D	A
GS-1	545.7	7.0	5.1	0.6	31.3	29.1	45.8	29.0	54.2	434.5	12,440	8,550	7,950
GS-2A	489.8	6.9	6.1	.5	32.8	30.5	47.4	30.3	52.6	33.0	12,540	8,410	7,845
GS-3	446.7	8.6	7.7	.6	27.9	28.3	45.3	29.4	54.7	34.6	12,470	8,690	7,800
GS-6	817.5	10.3	9.2	.6	32.7	29.3	45.8	28.6	54.2	32.8	12,470	8,380	7,515
7	1,219.0	11.0	9.7	1.0	26.1	23.6	45.0	31.9	53.0	34.8	12,570	9,240	8,270
Total or average values	3,418.7	9.3	8.1	.7	29.6	27.0	46.4	30.1	53.6	34.0	12,510	8,750	7,940

Very fine to medium-grained sandstone sequence.--The clastic intervals separating the coal beds east of the Lake De Smet coal bed consist of very fine to medium-grained sandstones, siltstones, mudstones, claystones, and occasional thin, lenticular coals and shales rich in plant material. The intervening clastic intervals range from a few meters thick between the Lower and Upper Cameron beds to greater than 61 m between the Healy and Walters coal beds. These clastic intervals are absent in the Lake De Smet coal bed but increase to the reported thicknesses in horizontal distances of 60-150 m to the east of that bed (fig. 22). Figure 25 is a schematic section of the intervening clastic interval between the Healy and Walters coal beds. Fieldwork and drill core data suggest that this stratigraphic section represents the other clastic intervals as well.

The sandstones are gray tan to pale yellowish orange, very fine to medium grained, poorly consolidated, micaceous, and arkosic, with both grain size and bed thickness decreasing upward. The sand grains are angular to subangular and well sorted. Abundant fine- to coarse-grained carbonaceous detritus commonly outlines bedding plane surfaces. Some coarse portions of the sandstones display calcareous cementation; however, the resulting concretionary aspect of the sandstone displays no continuity with the stratification. Commonly, logs, tree trunks, and tree roots are associated with the sandstones where cemented with calcite.

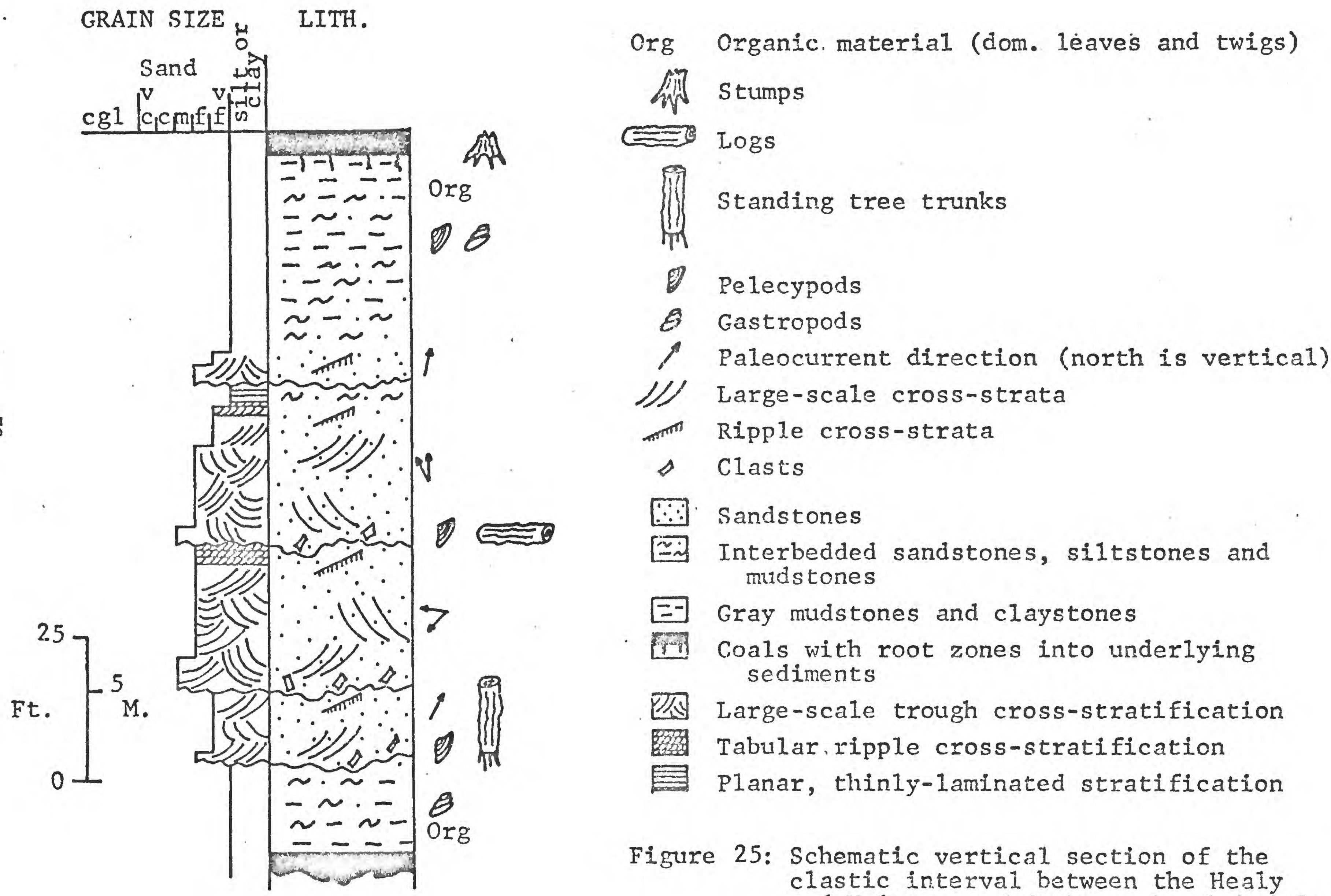


Figure 25: Schematic vertical section of the clastic interval between the Healy and Walters coal beds, as developed from studies of outcrops along Boxelder Creek east of Lake De Smet.

Bed thicknesses within the sandstones range from approximately 1.5 m at the base to less than 2.2 cm at the top. Trough cross-stratification gives way upward to tabular ripple cross-stratification and parallel lamination (figs. 28, 29). Asymmetrical, symmetrical, and climbing ripple forms are variously present. Thus, the stratification reveals an upward decrease in the inferred water energies during deposition.

These sandstones are composed of one to four genetic units which become finer grained upward (fig. 26). Each genetic unit has a scour base which is most easily distinguished by the sudden change in stratification and in the thickness of sets of cross strata. Angular to subrounded claystone, siltstone, and sandstone clasts, as well as lag deposits of pelecypod and gastropod shell fragments, often occur near the bases of the sandstone units.

Paleocurrent directions vary widely throughout from southward to nearly eastward, although a regional flow direction to the north is indicated. However, within each genetic unit, the paleocurrent direction is constant in one direction (figs. 25, 36, 38).

Figure 26.--A typical sandstone outcrop between the Healy and Walters coal beds. Base of the clinker capping the buttes marks the Walters coal bed. View is to the east along Boxelder Creek, sec. 12, T. 52 N., R. 82 W.

Figure 27.--Tree trunk that is nearly normal to interbedded sandstones, siltstones, and shales, NW 1/4 sec. 31, T. 51 N., R. 80 W. Nearby, a tree trunk of roughly the same diameter has approximately 500 growth rings.

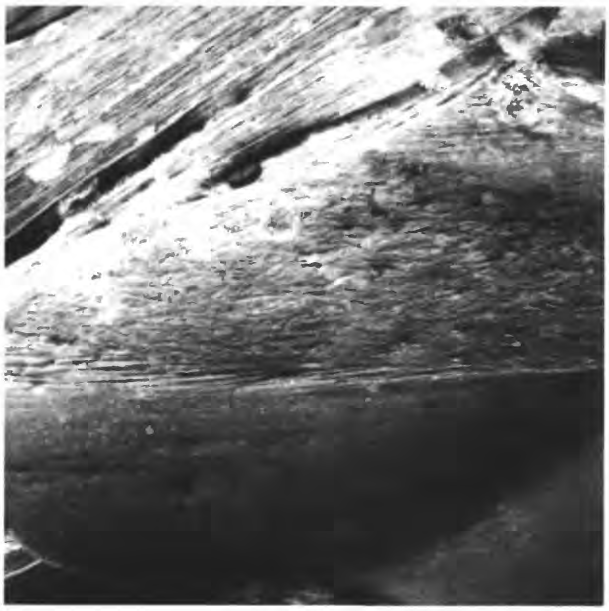


Figure 28.--Large-scale and ripple trough cross-strata near the base of a sandstone unit between the Healy and Walters coal beds suggest variable fluvial energies. Lens cap provides the scale. NE 1/4 sec. 14, T. 52 N., R. 82 W.

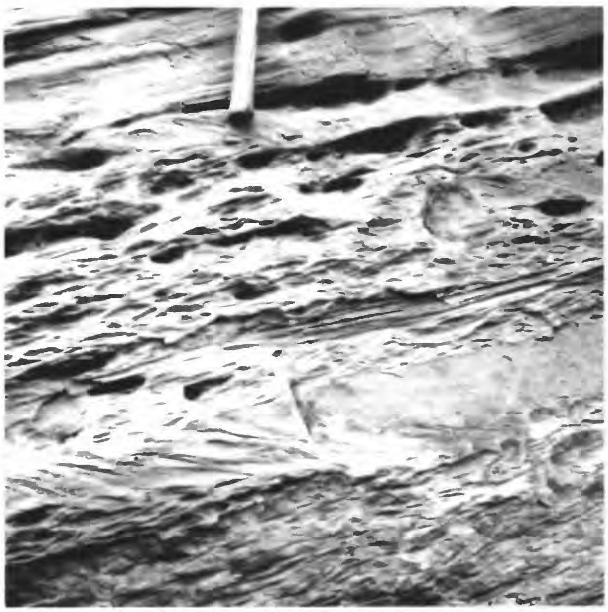


Figure 29.--Ripple cross-strata and parallel laminations near the top of a sandstone unit between the Healy and Walters coal beds. Sec. 14, T. 52 N., R. 82 W.

Petrified logs (replaced largely by silica and calcite), both parallel and normal or nearly normal to the strata (fig. 27), and imprints of large tree roots are common. Generally, transported logs are near the base of channel sandstone units and are parallel to the strata. Logs normal to the strata, actually in situ buried tree trunks, crop out in clusters (the best locations for observing such occurrences are in sec. 2, T. 51 N., R. 82 W.; SE 1/4 sec. 32, T. 53 N., R. 81 W.; and NW 1/4 sec. 31, T. 51 N., R. 80 W.). Some of these tree trunks occur in sandstone while others are present in interbedded yellowish-orange sandstones and gray siltstones and mudstones (fig. 27).

In a broad sense, these sandstones appear to be broad, regionally extensive sandstone sheets. Thicknesses range from a few meters to almost 30 m. The sandstone between the Healy and Walters coal beds is continuous and extends beyond the boundaries of the study area eastward from the Lake De Smet coal bed.

Interbedded yellowish-orange sandstones and gray siltstones, mudstones, and claystones are above and below the sandstones. The thick sandstones are in sharp contact with the rocks below but are gradational with the overlying rocks. Above and below the coal, in a typical section, the yellowish-orange cast to the sandstones disappears, and the ratio of sandstone to siltstone, mudstone, and claystone decreases.

Limestone lenses, less than 1.2 m thick and a few tens of meters across, are scattered throughout these interbedded sequences. They generally fill shallow depressions atop sandstone or siltstone beds. The limestones are silty, very fine grained, and crystalline and contain small, thin-shelled gastropods. Jacob (1973, p. 1043), who observed similar limestones in the Paleocene Tongue River Formation[2] of North Dakota, suggests that these lenses formed in small isolated pools occupying depressions where evaporation and photosynthetic activity contributed to the crystallization of calcite.

Twig and leaf imprints and carbonaceous material are common in the mudstones and claystones, while carbonaceous detritus is abundant in the sandstones and siltstones. Thin, brown shale lenses containing organic material frequently supplant mudstone beds. Occasional mudstone lenses contain abundant pelecypod and gastropod shells. Some fossiliferous beds are coquinas.

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[2]Jacob (1973, p. 1038) notes that the North Dakota Geological Survey considers the Tongue River a formation within the Fort Union Group while the U.S. Geological Survey assigns member status to the Tongue River and formation status to the Fort Union.

The coals are physically and chemically similar to those of the Lake De Smet coal bed. Laterally, they display great variations in thickness, physical character, and quality. Root zones extending downward into the underlying claystones attest to the in situ origins of the coals. Many of the coals were burned as a result of spontaneous combustion after the coal was exposed to the atmosphere by erosion (Rogers, 1917, p. 1-4). This burning resulted in baking of the strata overlying the coal beds. The clinker, as the baked strata are called, forms the characteristic resistive reddish-colored butte topography.

Fossil marker beds.--Three fossiliferous beds are regional in extent and, hence, are excellent marker beds within a formation that is characterized by rapid lateral and vertical lithologic changes (fig. 30). One of the fossiliferous beds underlies the Lake De Smet coal bed (p. 42). In addition to a gastropod and pelecypod assemblage, pyritized gar scales and vertebrae have been recovered from this bed (Waynard Olsen, oral commun., 1976).

The second marker bed is a fossiliferous limestone above the Upper Cameron coal bed. Mapel (1959, p. 72) reports its areal extent to be greater than 320 km . Much of this limestone is northeast of the study area. Within the study area, the limestone is a few centimeters to approximately 0.6 m thick and lies less than 1.5 m above the coal bed.

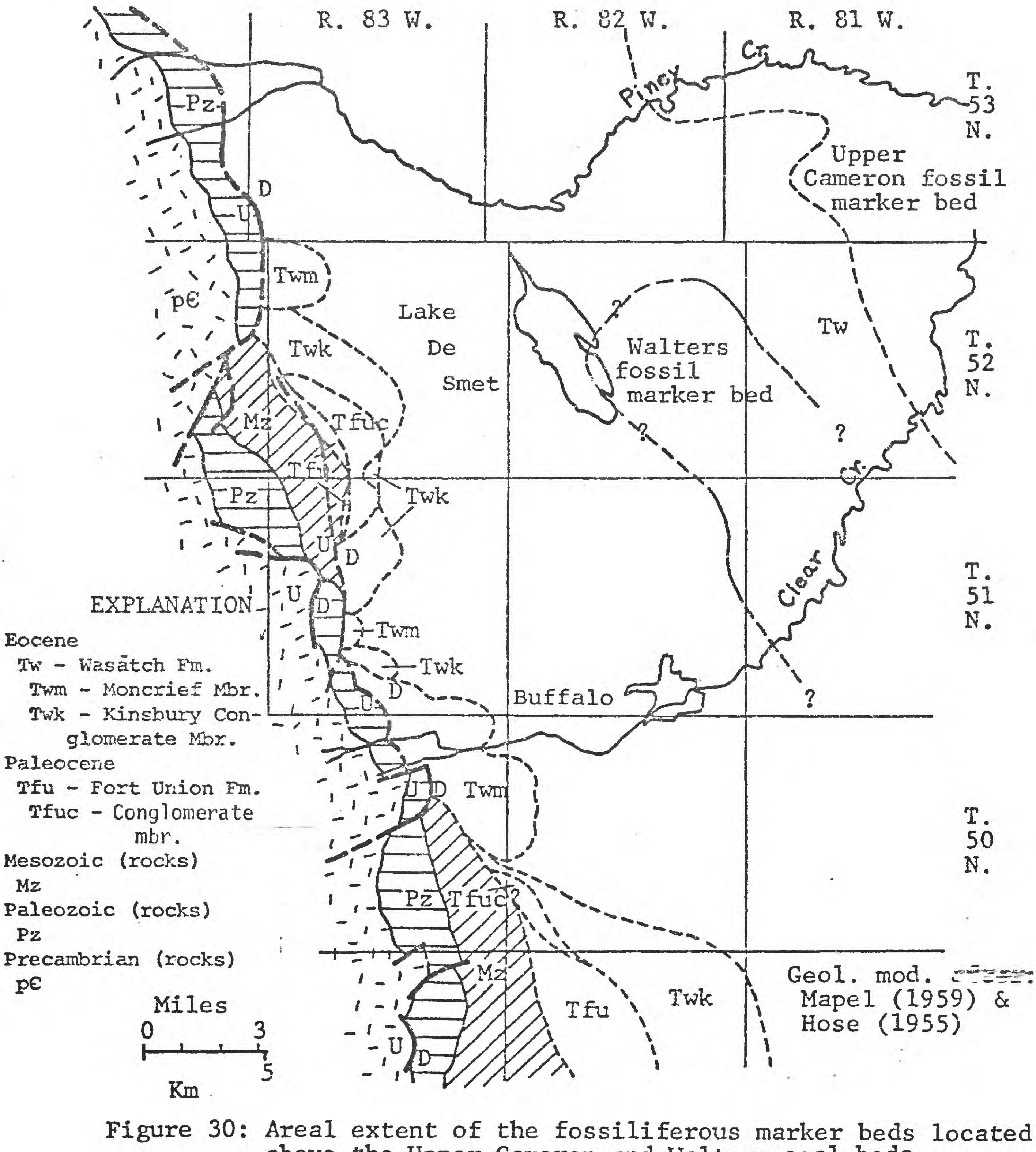


Figure 30: Areal extent of the fossiliferous marker beds located above the Upper Cameron and Walters coal beds.

Unlike the fossil bed above the Upper Cameron coal bed, the fossiliferous mudstone above the Walters coal bed lies variously from 1 m to approximately 15 m above the coal. This fossil bed, which includes gastropods and pelecypods, ranges in thickness from less than 0.3 m to over 7 m. In a deep manmade cut at the southeast corner of Lake De Smet, the fossil bed is split into two beds several meters apart. They occur approximately 1.5 m above what is interpreted to be the uppermost coal split of the Lake De Smet coal bed. The wide variation in thickness of the clastic interval between the coal and the fossil bed leads to two conclusions: (1) coals are not necessarily good units for lateral correlation, particularly when they cannot be walked out and (2) the Walters coal bed may be a series of small discontinuous coal beds rather than a single broad extensive coal bed.

ENVIRONMENTS OF DEPOSITION

General

The wide range of lithologies described for the Fort Union and Wasatch Formations is the result of the environments in which they were deposited. The rapid change from high-energy to low-energy depositional environments was controlled by the intense tectonic activity along the boundary between the basin and uplift blocks. Lateral facies changes reflect the tectonic framework and the instability of the region.

Figure 31.--A 0.6-m clinkered fossiliferous marker bed located above the Walters coal bed. Hammer rests on the base of the fossil bed. NE 1/4 sec. 15, T. 52 N., R. 82 W.

The entire range of lithologies can be related to be an alluvial valley model (LeBlanc, 1972, p. 137). The conglomerate deposits of the conglomerate member of the Fort Union, and the Kingsbury Conglomerate and Moncrief Members of the Wasatch are interpreted to have been deposited as alluvial fans fronting the Bighorn uplift. The distal portions and areas adjacent to the base of the alluvial fans are composed of migrating lobes of braided stream systems. They are characterized by small conglomeratic sandstone lenses and interbedded sandstones, siltstones, mudstones, and thin coals. These coarse deposits spilled onto a broad alluvial plain dominated by meander channels and related levee and crevasse splay systems, swamps, and lakes (fig. 32). The alluvial plain environments are characterized by very fine to medium grained sandstones, siltstones, mudstones, claystones, and thick coals.

Channel systems trend perpendicular to the mountain front west of the Lake De Smet coal bed and parallel to the mountain front (and to the axis of the basin) east of the Lake De Smet coal bed. These conclusions coincide with Seeland's (1976, p. 63; fig. 33) interpretation of the major Eocene paleodrainage pattern for the Powder River Basin. Coals within the study area form marginally to the channels.

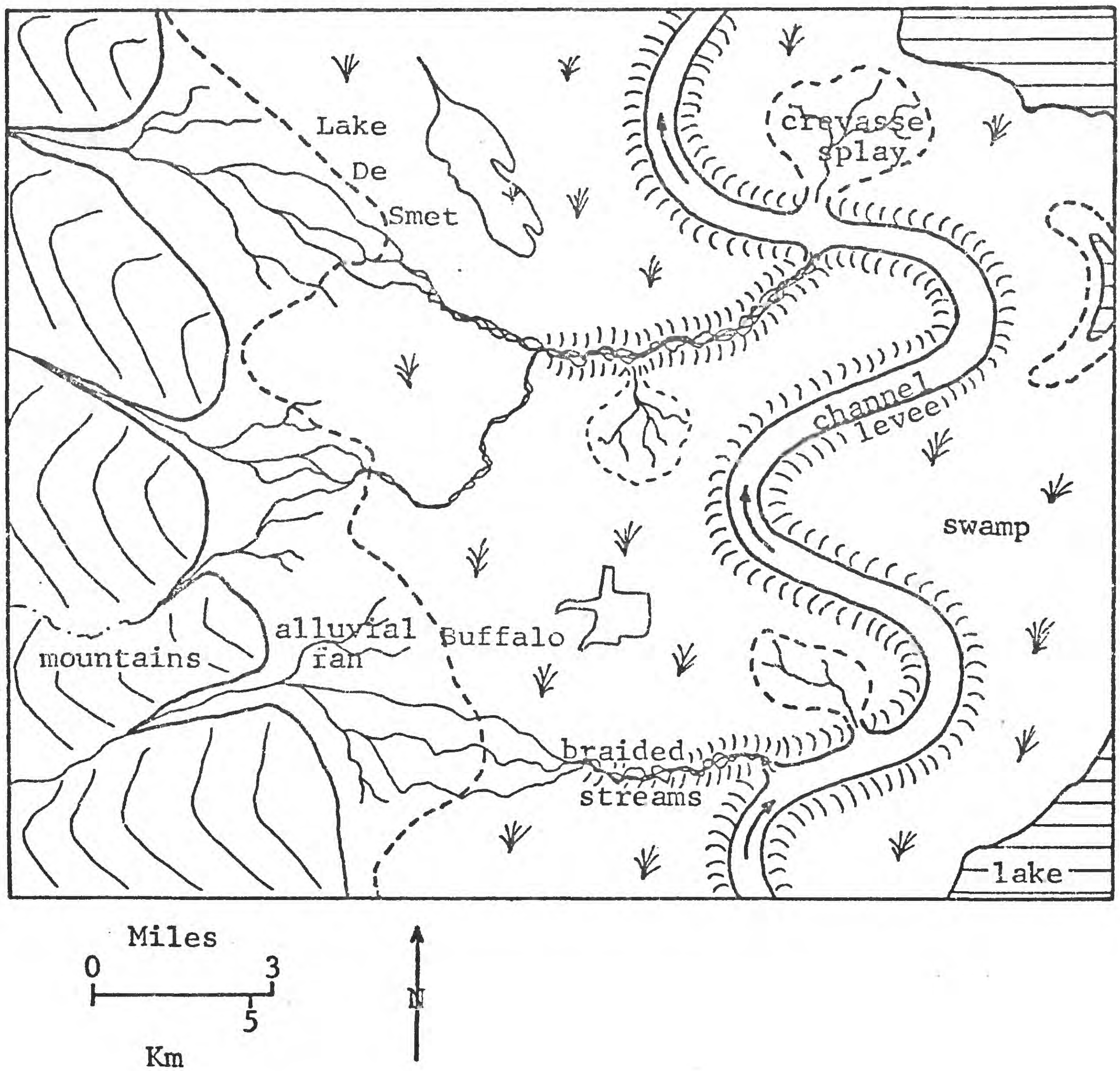


Figure 32: Schematic diagram of environments in the Buffalo-Lake De Smet area during the Eocene. Buffalo and Lake De Smet are superimposed on the diagram.

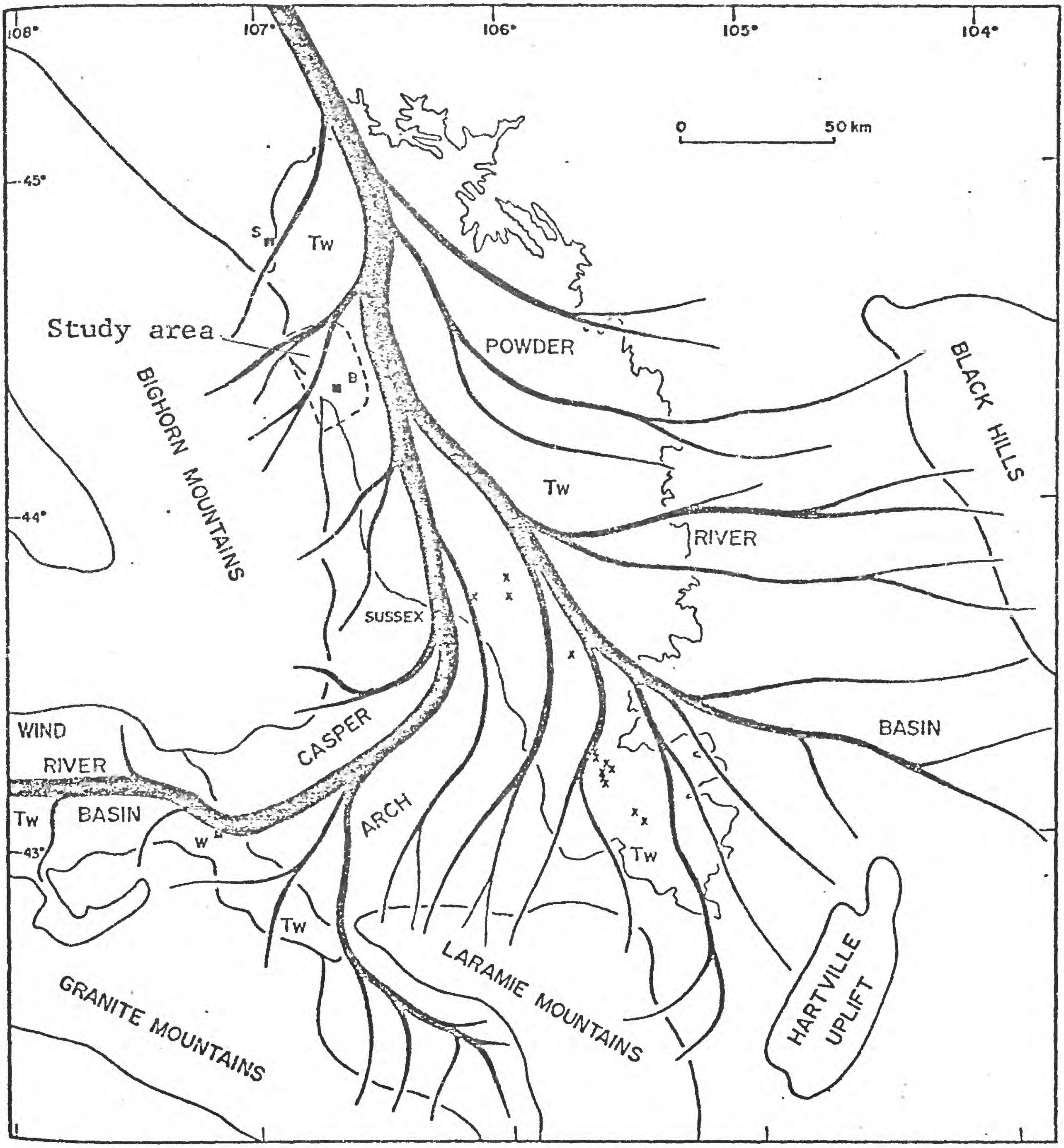


Figure 33: Interpretative diagram of the Eocene paleodrainage for the Powder River Basin. Tw = Wasatch Formation; B = Buffalo; S = Sheridan. From Seeland, 1976.

Alluvial fan environment

The pebble to boulder conglomerates adjacent to the mountain front are interpreted to be alluvial fan deposits. Many of the features observed in the field and discussed below have been well documented in summaries of alluvial fan deposits by Bull (1972, p. 80-82) and McGowan and Groat (1971, p. 8-41).

1. Local, poorly sorted, massive boulder conglomerates contain silt- to pebble-sized matrix material. These deposits flank the Bighorn Mountains and can be equated with lower proximal and upper mid-fan facies. Conglomerates of this depositional setting include the Fort Union outcrops at the north and south ends of Mowry Basin and the Moncrief deposits at the mouth of Clear Creek and at Moncreiffe Ridge.
2. Grain size and thickness of the conglomerate beds decrease and the volume percentage of the sandstones increases away from the massive conglomerate outcrops (that is, away from the apex of the fan). This pattern is best observed in the Kingsbury in a basinward direction and in the conglomerate member of the Fort Union laterally along the mountain front. With massive conglomerates of the Fort Union at the north and soutn ends of Mowry Basin grading into lenticular conglomerate, sandstone, siltstone, and mudstone beds, it is apparent that several coalescing alluvial fan deposits characterize this depositional sequence. Poor exposures prevent detailed study of most of the Kingsbury deposits; however, similar depositional patterns suggest that the Kingsbury, likewise, is a complex system of overlapping alluvial fan deposits. Moncrief deposits suggest two large alluvial fans (one at Clear Creek, the other at Moncreiffe Ridge) that do not coalesce with one another.

3. Proximity to the mountain front provided an area of abundant coarse clastics and high local topographic relief.

4. Oxidation of iron-bearing minerals to hematite resulted in reddish beds in the proximal and mid-fan facies. Oxidation is more prominently displayed in the fine-grained units than in the coase-grained units. Oxidized deposits decrease in volume and eventually disappear toward the base of the fan.

5. Scour and fill features are identifiable where conglomerate beds predominate (proximal and mid-fan ares) (fig. 34).

6. The conglomerates were deposited largely by fluvial processes. This conclusion is based upon the clast-supported nature of the conglomerate and upon the sand and pebble matrix. Units which have conglomerate beds at their base and which show grain-size trends that become finer upward are interpreted to be the result of braided stream systems operating on the distal reaches of the alluvial fans.

7. A small radial drainage pattern displays a paleocurrent direction roughly perpendicular to the mountain front (figs. 36, 38).

Figure 34.--Scour and fill structures in massive conglomerate beds of the conglomerate member of the Fort Union Formation at Castle Rock. Outcrop is approximately 10 m high. NE 1/4 sec. 19, T. 52 N., R. 83 W.

Figure 35.--Poorly sorted sandstones of the braided channel deposits west of the Lake De Smet coal Bed. NE 1/4 sec. 28, T. 51 N., R. 82 W.

Braided stream environments

The braided channel systems (fig. 35) associated with the distal portions of alluvial fans are interpreted to extend beyond the base of the alluvial fans into the coal-bearing strata (fig. 32). These braided systems are represented by the coarse sandstones, siltstones, mudstones, and thin coals west of the Lake De Smet coal bed. Models and descriptions of braided stream deposits from recent sediment studies are not as easily applied as are those for alluvial fan or deltaic environments. Some of the characteristics listed below have been frequently cited, while others have been infrequently observed or reported or are in opposition to generally accepted criteria used to identify braided stream deposits:

1. Figure 13 demonstrates repeated sequences of units becoming finer-grained upward. A gradual coarsening of some sandstones may occur near the top of the unit. Pettijohn (1975, p. 549) notes a general absence of upward decreasing grain size in most braided stream deposits.
2. Irregular scour surfaces occur within the channel deposit as well as at the base.
3. Channel sandstones generally become finer grained upward. A few channel deposits display increasingly coarse upward grain-size trends, while others maintain a constant grain size throughout the sandstone. Weimer and Erickson (1976, p. 127-137) noted that each genetic unit within the upper and lower members of the Lyons Formation (Permian), interpreted as fluvial braided channel deposits, becomes finer grained upward.
4. Channel sandstones are very poorly sorted. Alternating layers of coarse- and fine-grained detritus in adjacent cross-bed laminations reflect fluctuating water energies (fig. 35).

5. Trough cross-stratification is the dominant sedimentary structure. Ripple trough cross-stratification is common near the top of the channel deposit.

6. Interbedded yellowish-orange sandstone and greenish-gray siltstone and mudstone sequences, observed above, below, and lateral to the channel deposits, are interpreted to be levee and crevasse splay deposits. Coleman (1969, p. 230-232) reports numerous levee and crevasse splay deposits in the Brahmaputra River alluvial plain.

7. Large volumes of siltstone and mudstone and minor concentrations of brown shale rich in plant remains and coal are present. This is contrary to virtually every reported modern or ancient analogue. Smith (1970, p. 3010) and Pettijohn (1975, p. 549-550) cite the absence of significant amounts of silt and clay as a criterion for identifying braided stream deposits.

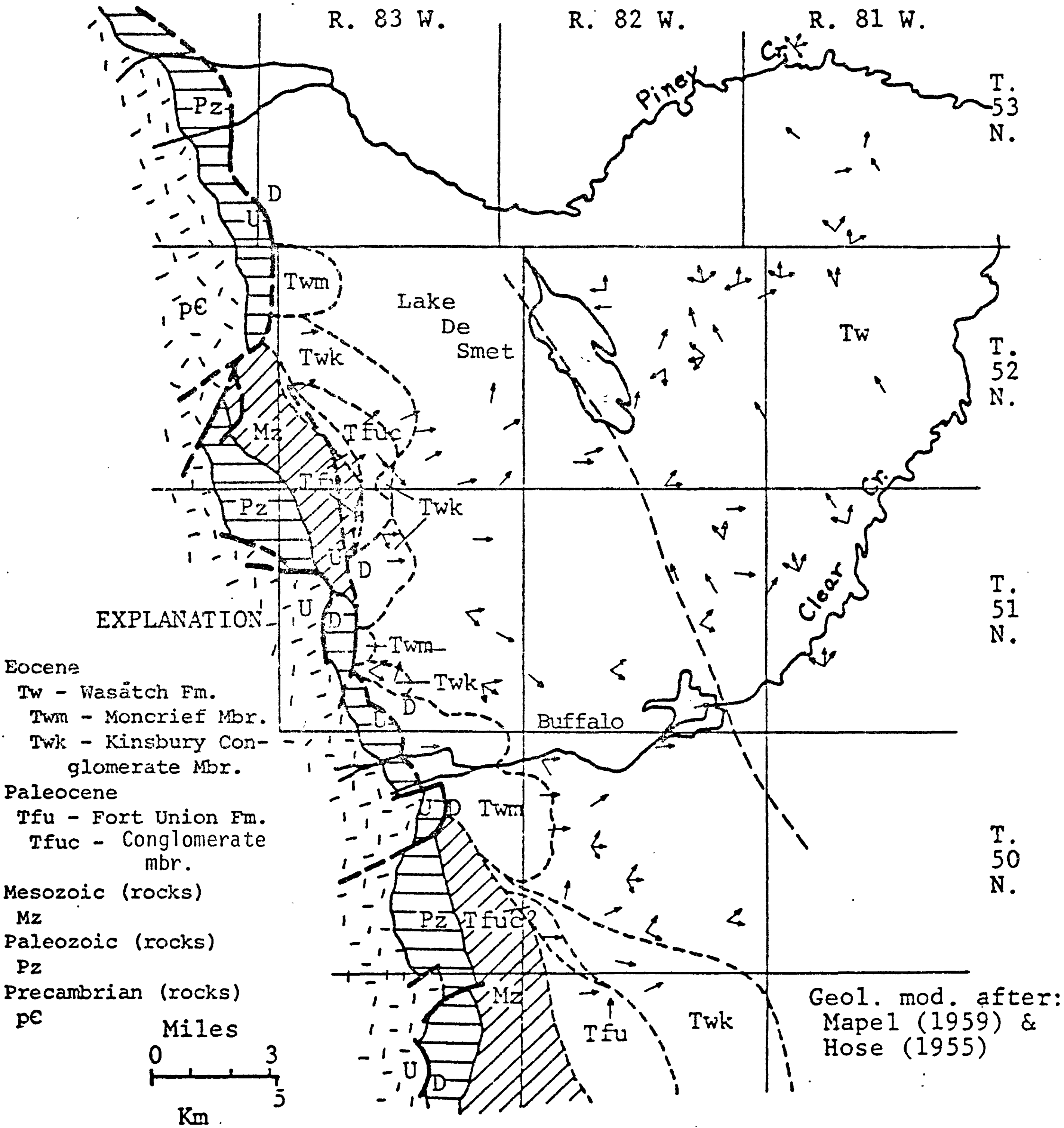


Figure 36: Map displays representative paleocurrent direction readings (arrows) obtained largely from cross strata. Readings west of the dashed line show easterly drainage of the alluvial fan and braided stream environments. Readings east of the dashed line show a north-northwest drainage pattern for the alluvial plain environments.

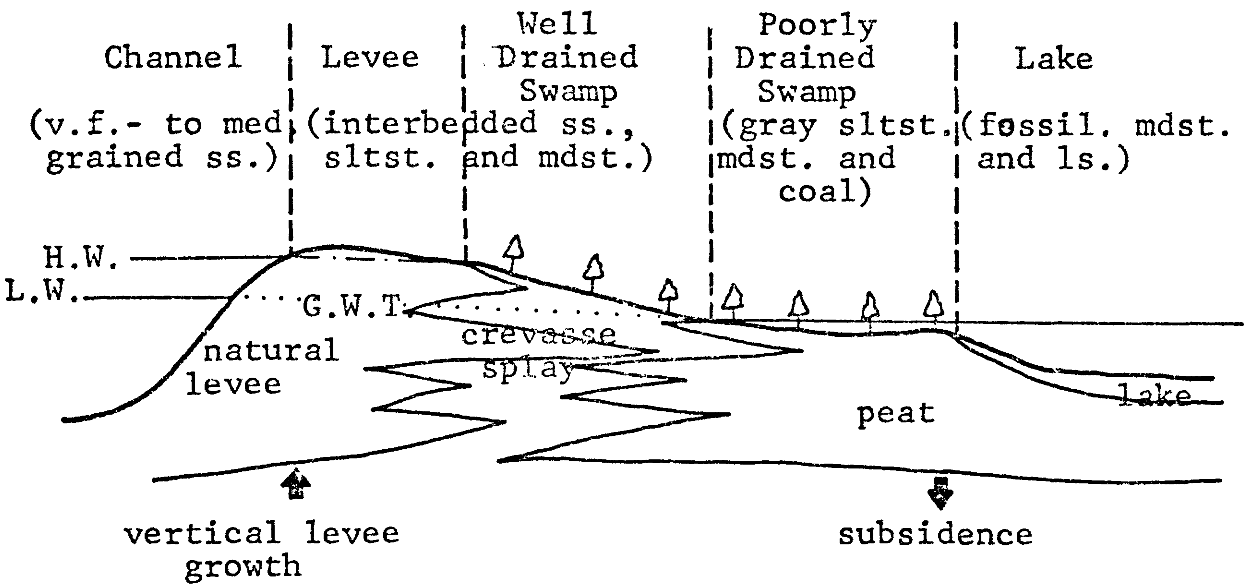
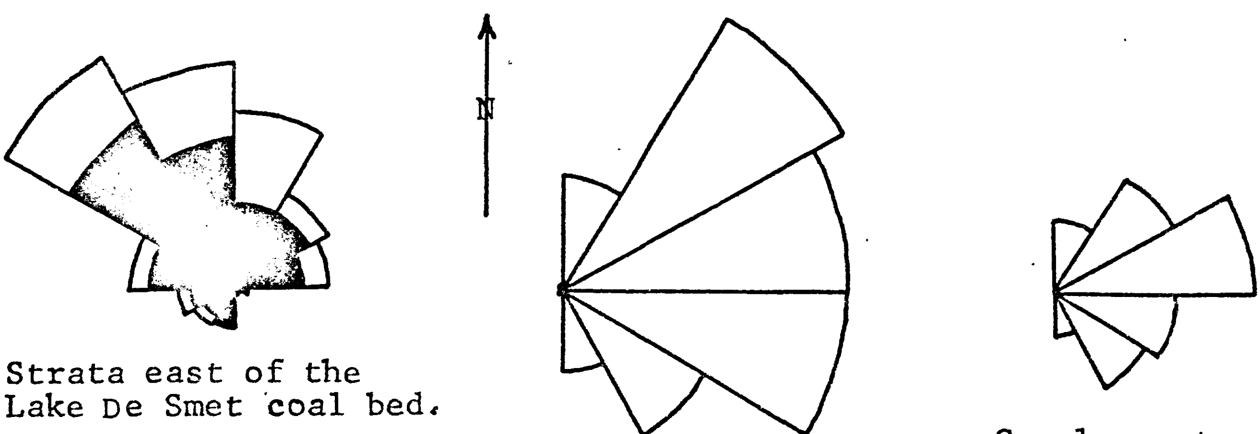


Figure 37: Environments of deposition interpreted for lithologies described for the alluvial plain facies. H.W. = flood stage water level. L.W. = normal water level. G.W.T. = ground water table. Modified from Weimer (1973, p. 71).



Strata east of the Lake De Smet coal bed.

Shaded area = Healy-Walters clastic interval.

130 measurements.

Strata west of the Lake De Smet coal bed excluding cgls.

129 measurements.

Conglomerates west of Lake De Smet coal bed.

71 measurements.

Figure 38: Rose diagrams for transport directions in the study area.

The key to identifying this environment as one characterized by braided stream processes is with the channel deposits. The poor sorting of the sandstones and the irregular scour surfaces which cut into the channel and adjacent levee deposits suggest irregular fluvial energies and high sediment transport accompanied by frequent channel shifting. These features are common in modern braided stream environments.

Levee, crevasse splay, and swamp deposits are also present. As depicted in figure 32, the alluvial fans are interpreted to have spilled onto an alluvial plain. The braided stream systems operating in the distal regions of the alluvial fans fingered out onto the alluvial plain where they were rapidly engulfed. Between the stream channels, swamps flourished. The alluvial fans built outward in a manner resembling that of deltas. The alluvial fans periodically shifted their depocenters to satisfy the dynamics required to transport and deposit the sediment loads. These shifts of depocenters, combined with subsidence, resulted in the formation of the interbedded sequences that are identified as levee, crevasse splay, and swamp deposits (fig. 37).

Alluvial valley environments

Wasatch sediments east of and including the Lake De Smet coal bed consist of meander channel, levee, crevasse splay, paludal, and lacustrine deposits (fig. 32). The pattern of increasingly finer grained sediments upward (depicted in fig. 25), as well as the range of environments, is one commonly attributed to alluvial valley or upper deltaic systems where meandering streams flow. However, the last vestiges of the short-lived Cannonball Sea exited from the northern Powder River Basin during the Paleocene (Mallory, 1972, p. 234-237). The location of the sea in geographic relationship with the Powder River Basin during the Eocene is unknown. The Paleocene and Eocene Golden Valley Formation in North Dakota is lithologically similar to the Wasatch Formation in the Powder River Basin. Hence, during the Eocene, the Powder River Basin may have been the site of either the upper reaches of a vast deltaic complex or, more likely, a partially closed interior basin, characterized by alluvial valley environments, which narrowed at the north end, channeling its waters north onto an alluvial or deltaic plain. In either case, economic coal deposits thin and disappear to the south (Keefer and Schmidt, 1973). The study area is on the flank of the upper reaches of this vast, poorly drained alluvial plain.

The thick, very fine to medium-grained sandstones which show one to four genetic units are interpreted to be meander channel complexes. Meandering of the stream resulted in broad scour surfaces at the base of each unit. Direction of sediment transport varies with each unit from east to southwest, with the basin's principal paleodrainage system trending north-northwest (figs. 36, 38).

Levee and crevasse splay deposits form adjacent to the channels (figs. 32, 37). The characteristic lithologies of both types of deposits are interbedded yellowish-orange sandstones and greenish-gray siltstones and mudstones. Allen (1965a, p. 146; 1965 b, p. 571), Coleman (1969, p. 231), Jacob (1973, p. 1043), and Weimer (1973, p. 71), in various studies of ancient and modern sediment and stratigraphic sequences, have interpreted similar deposits displaying vertical alternation between coarse and fine sediments to be levee and crevasse splay deposits. Weimer (1973, p. 71-72) reported that crevasse splay channels exhibit scour surfaces and generally coarser grained sequences close to the main channel, while their distal portions become finer grained and merge with lacustrine or bay deposits and are virtually indistinguishable from them. Local concentrations of logs at the base of sandstone units may indicate crevasse splay channel locations. However, limited outcrops prevented verification of this interpretation in the Buffalo-Lake De Smet area.

Crevasse splays are the sites of more rapid rates of sediment accumulation than are levees. Growth of levees generally keeps pace with the rate of subsidence while crevasse splays build subdelta complexes adjacent to the channels during peak flow periods. Modern studies of the Mississippi River delta region indicate rapid lateral and vertical growth of crevasse splay deltas (Morgan, 1970, p. 113). Hence, evidence of rapid accumulation of thick sediment sequences, such as tree trunks buried in their growth positions, may well indicate sites of crevasse splay deposits. Jacob (1973, p. 1042) describes buried tree trunks in interbedded coarse and fine sediments in the Tongue River Formation of western North Dakota, but he attributes burial to rapid vertical growth of the levees. Climbing ripple stratification, another indicator of rapid sedimentation, is common in both environments, and results from peak flow periods which effect both environments. Decrease in flow energy away from the channel produces rapid sedimentation, particularly when the suspended load is high, thus creating an excellent environment for the formation of climbing ripple stratification.

Flanking the levees and crevasse splays are the flood basins, whose principal enviroments are swamps and lakes (figs. 32, 38). Dark-gray clays, carbonaceous shales, and coals were deposited in poorly drained swamps where the depositional interface was continuously under water. Fossiliferous mudstones and limestones indicate numerous freshwater lakes. The areal extent of many of these beds indicates that the flood basin between channels often covered hundreds of square kilometers.

The cyclic repetition of these alluvial plain deposits indicates shifting of the channel systems into and out of the study area. When the stream channel was diverted to the east, swamps and lakes formed in the region previously occupied by the channel. The thickness of the coals, in some instances more than 12 m, suggests that the life of any particular environment in a given area was not always a short one.

TECTONICS AND SEDIMENTATION

Conglomerates and tectonics

Structural deformation and vertical facies changes in Upper Cretaceous and lower Tertiary sediments record the history of the Laramide Orogeny along the east flank of the Bighorn Mountains. During Late Cretaceous time, regional epeirogenic uplift resulted in the gradual retreat of the Cretaceous sea. Marine deposits were replaced by lower alluvial plain and deltaic deposits. Continued uplift created gentle warping of the crust, thus producing topographically low highlands which began to provide local detrital sources. This pattern of tectonic and sedimentary activity continued into Paleocene time.

Isopach maps (figs. 39, 40, 41) by Curry (1971, p. 57-59) suggest a sudden change in tectonic and sedimentation patterns in Paleocene time. The first evidence of local sediment thickening in the Buffalo area (Curry, 1971, p. 58) is recorded in Lebo-equivalent Fort Union strata (fig. 40). Deposition, with local thickening in the Buffalo-Lake De Smet area, continued into the early Eocene. Outcrop exposures of stacked lower Fort Union ferruginous sandstones (p. 15) at Mowry Basin support the interpretation that the region was tectonically unstable during their deposition.

Correlating Fort Union outcrops with the subsurface interpretations of Curry (1971) is tenuous at best. The palynomorph identifications from the lower member of the Fort Union in sec. 30, T. 50 N., R. 82 W. imply that the conglomerate member of the Fort Union and the sampled strata are roughly time-equivalent with the upper portion of the Tongue River Member (Leffingwell, 1966, pl. 1) (fig. 5) mapped in the northern and eastern portions of the Powder River Basin. Whether Paleocene strata of still earlier age exist in the study area has not been determined.

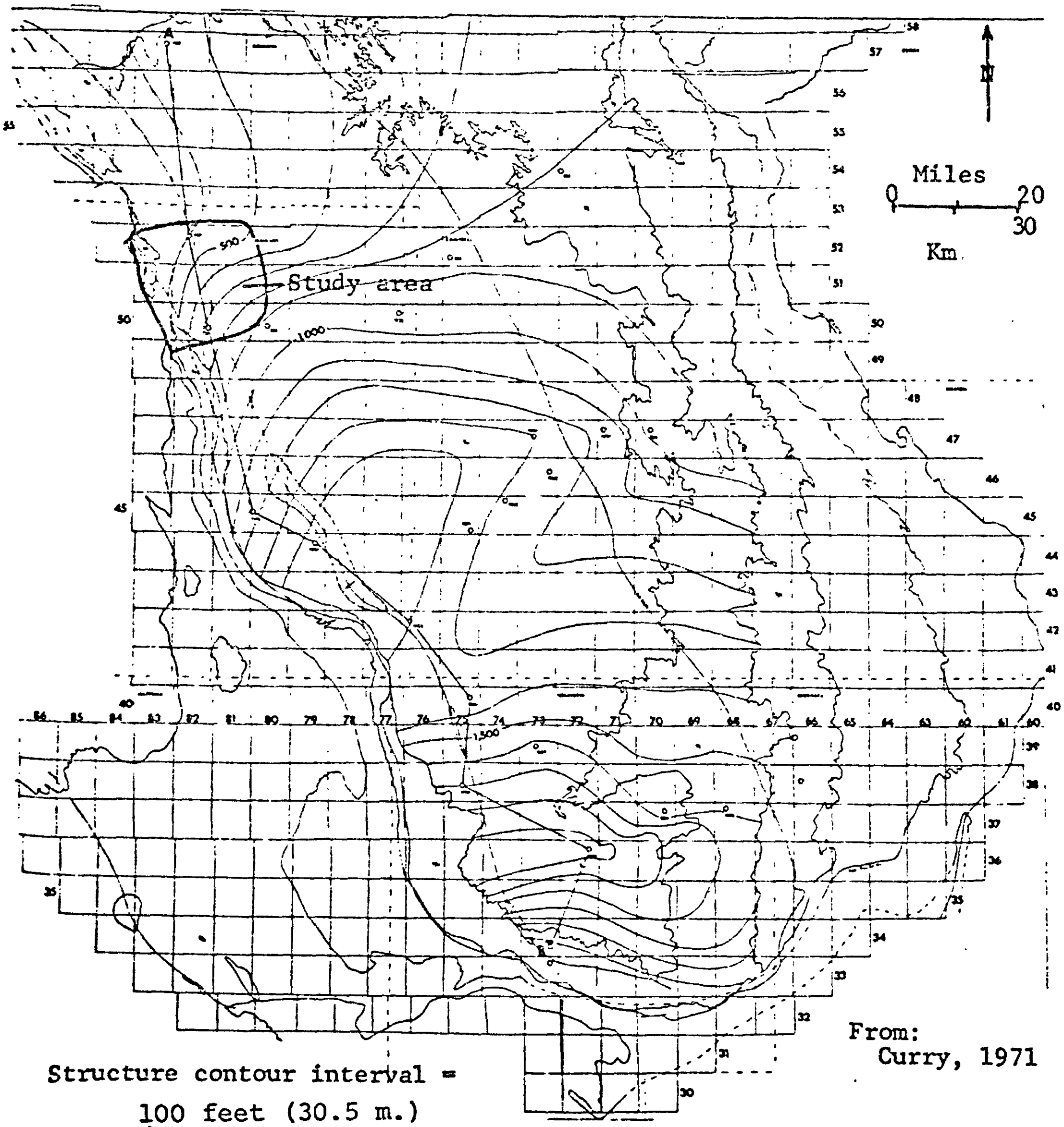


Figure 39: Isopach map of the Tullock Member of the Fort Union Formation. No apparent thickening occurs in the Buffalo-Lake De Smet area.

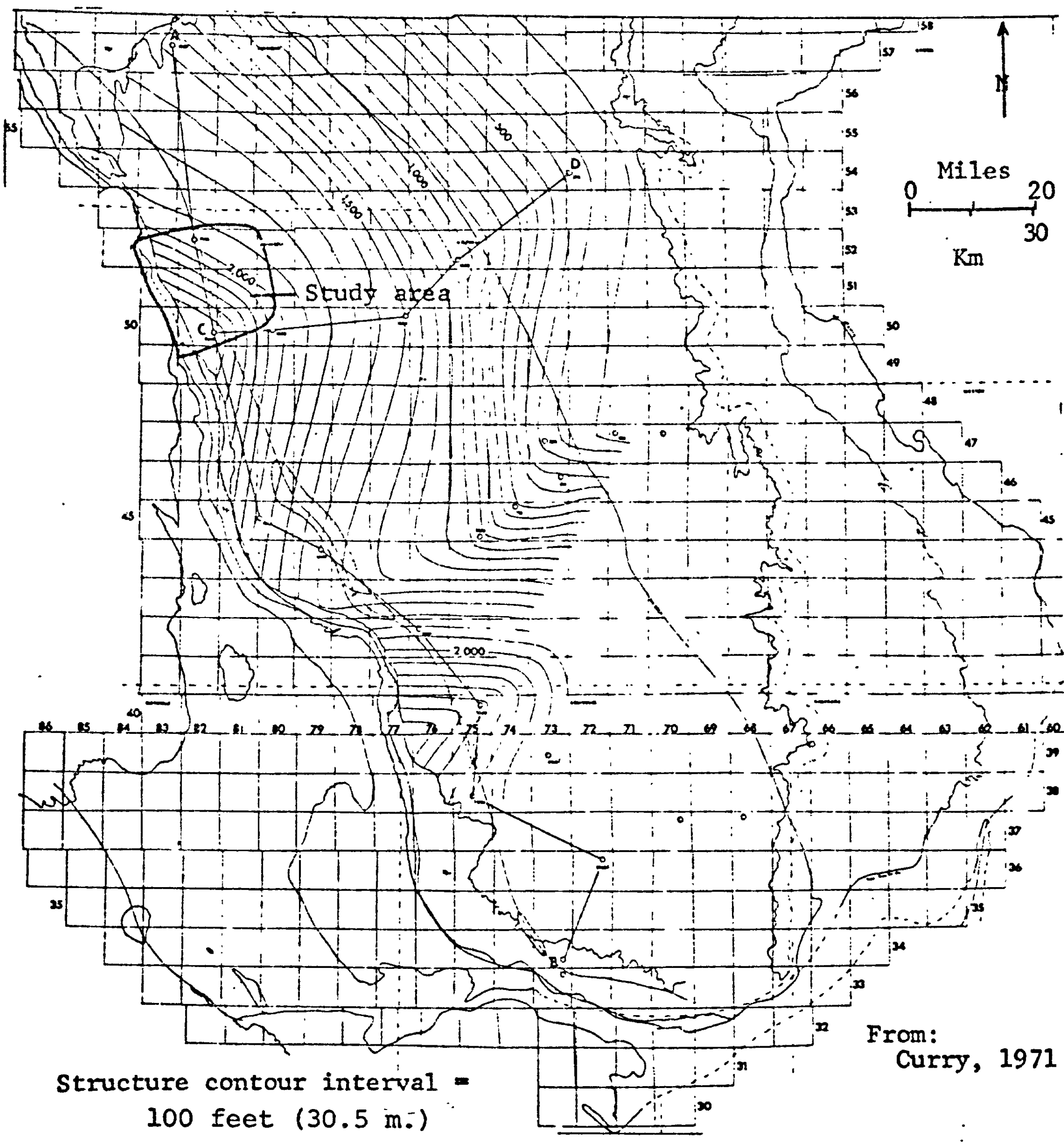


Figure 40: Isopach map of the Lebo Shale Member of the Fort Union Formation. This records the first local thickening of lower Tertiary sediments in the Buffalo-Lake De Smet area.

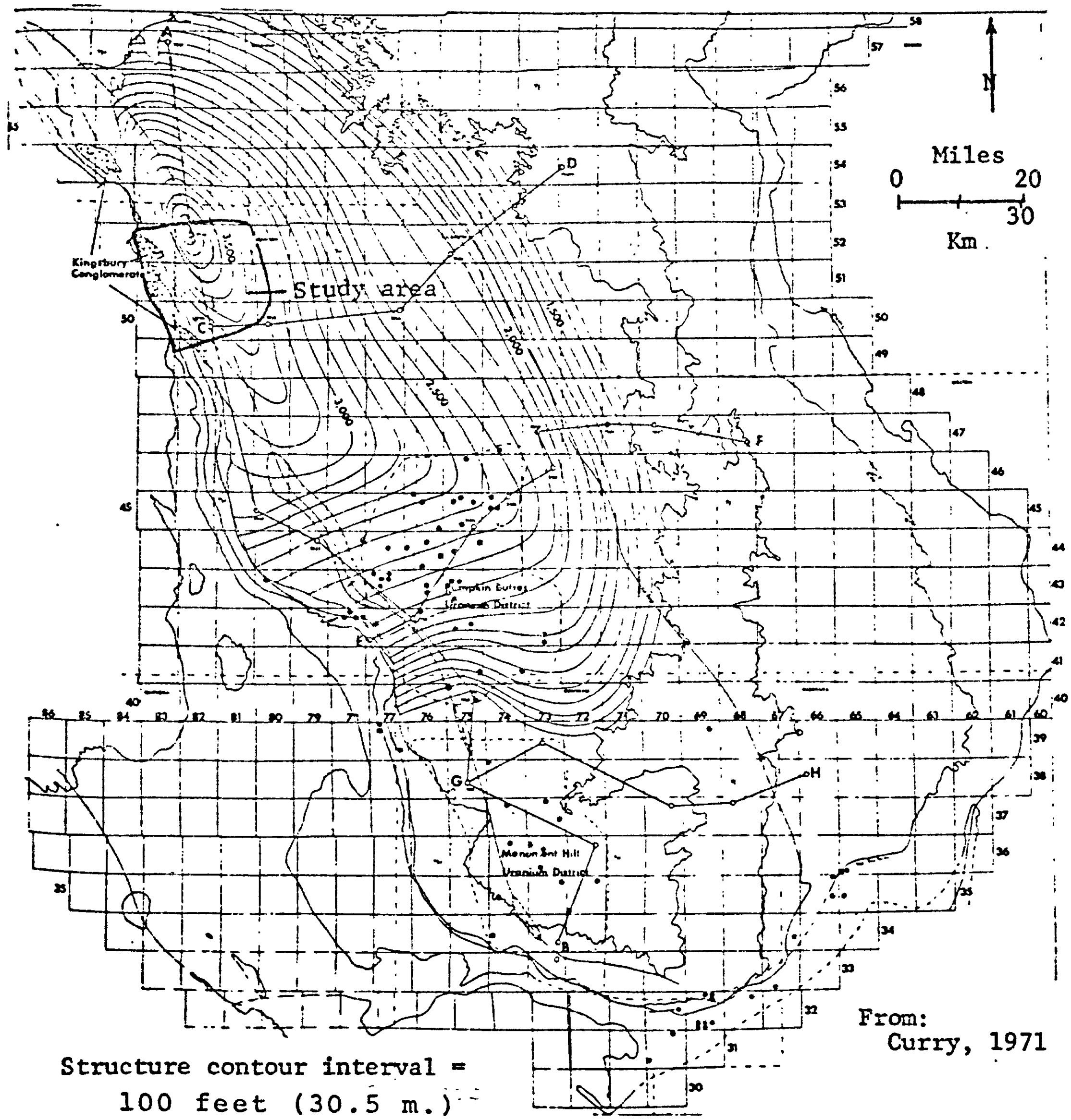


Figure 41: Isopach map of the Wasatch Fm. and the Tongue River Mbr. of the Fort Union Fm. Significant sediment thickening exists in the Buffalo-Lake De Smet area.

Figure 5 and plates 1 and 2 suggest at least three major episodes of strong tectonism during the Laramide Orogeny. Each episode, which recorded a major pulse of uplift and basin downwarp activity, produced increasingly steeper dipping sedimentary deposits (including the most recent conglomerate sequence) along the mountain front, erosion, and subsequent deposition of a new conglomerate facies.

Tectonics along the uplift-basin margin play a key role in the occurrence and distribution of these conglomerates. Several associations between structure and conglomerate occurrences can be made:

1. Conglomerates occur where structural relief between the uplift and basin blocks is greatest.

2. Subsidence and accompanying deposition of Fort Union and Wasatch strata (fig. 4) were greatest in the Buffalo-Lake De Smet area.

3. The greatest Bighorn Mountains flank deformation, including the local thrust faults, occurs west of the Buffalo-Lake De Smet area.

4. A direct association is observed between the location of the Moncrief Member and the thrust faults (pl. 1).

5. Bull (1972, p. 76) hypothesizes that conglomerates resting on upturned older deposits have their greatest thicknesses in the mid-fan area and are products of tectonically active environments.

The role tectonics played in the formation of the Moncrief deposits is more easily understood and interpreted than its role in the formation of conglomerates in the Kingsbury and in the Fort Union. Deformation of the mountain flank prior to Moncrief deposition created anticlinal structures at Mowry Basin and Kingsbury Ridge whose axes were oriented at large (but less than perpendicular) angles to the Bighorn uplift's margin (pl. 1). Structural evidence is best preserved east of Mowry Basin in Wasatch strata interpreted to be older than Moncrief. Strata equivalent to the Moncrief in the coal-bearing facies of the Wasatch do not display comparable deformation. The high local topographic relief at the time of Moncrief deposition is partly the result of this deformational episode.

The anticlinal structures at Mowry Basin and Kingsbury Ridge may identify faults along which movement occurred during and after deposition of lower Tertiary sediments. Weimer and Land (1972, p. 296-297) demonstrated that such movements would display a strong influence on local depositional patterns. As a result of their stratigraphic study of the Lyons Formation near Golden, Colo., Weimer and Land concluded that the thickest and coarsest sediments were in the graben blocks and thinner, finer grained sequences were deposited on the horst blocks. In the study area, the sites of Moncrief deposition are between the anticlines or, in other words, in locations of projected graben structures. Significantly, thrust faults exist opposite the graben structures, perhaps because of the relatively greater vertical displacement between the uplift and basin blocks.

Similar evidence to describe the tectonic and topographic controls during the deposition of the Kingsbury and conglomerates in the Fort Union cannot be generated. Limited outcrops, erosion, and the inability to establish a suitable datum prevent detailed reconstructions. However, speculative interpretation suggests that the locations of these Tertiary deposits are also determined by mountain front tectonic patterns. The best examples are the structural and depositional patterns displayed near Kingsbury Ridge. An east-northeast linear trend can be traced from where the North Fork of Crazy Woman Creek debouches from the mountains to Kingsbury Ridge midway between the anticlinal and synclinal axes. This linear trend can be projected eastward to T. 50 N., R. 80 W., where it ties into an east-northeast fault mapped by Mapel (1959). Thicker coals, as well as several local coal beds, occur north of this fault. The coarsest and thickest Kingsbury deposits are along and to the north of the linear trend. The interpretation is that an active east-northeast-trending fault with the north side down was active during the Eocene and that the Kingsbury and the thicker coals thus were deposited in the graben block. The subsequent anticline developed as the result of later movement along the same fault. Fault block relationships between uplift and basin structures suggest relatively greater displacement between opposing uplift and basin blocks opposite graben structures (fig. 42).

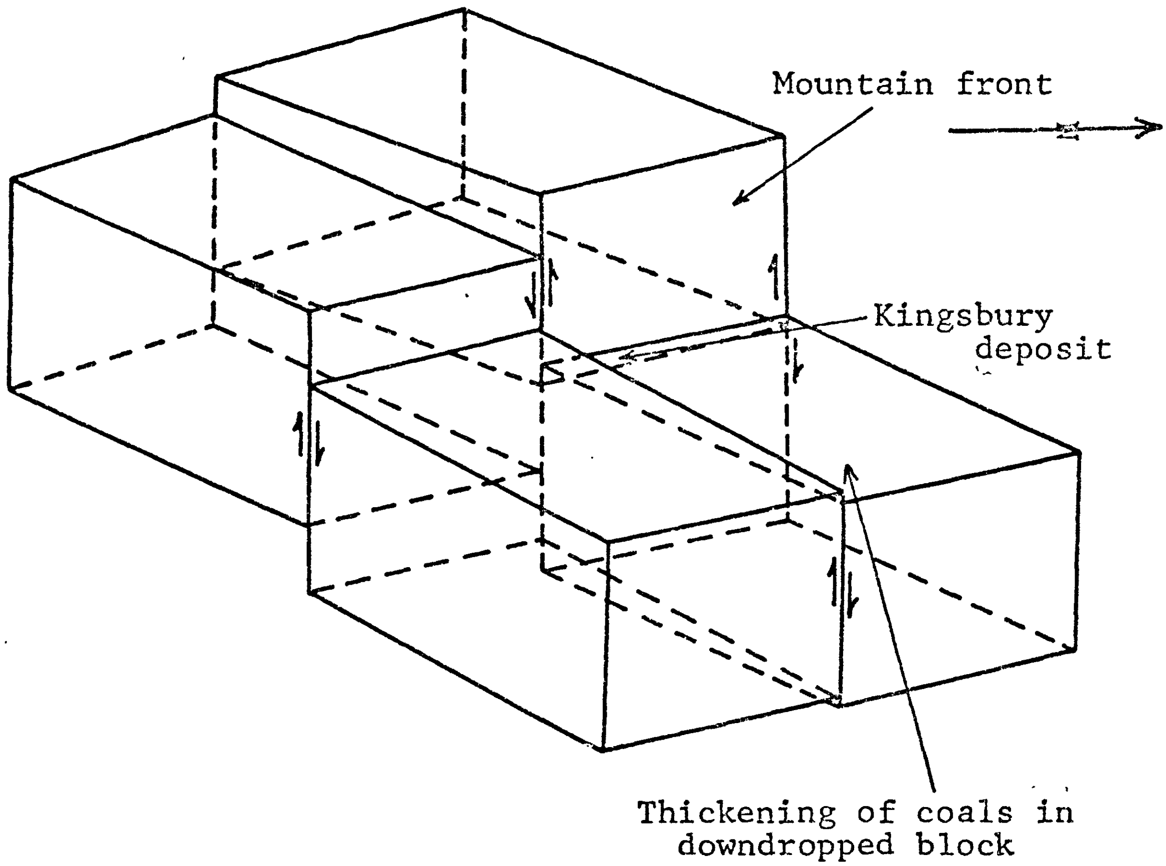


Figure 42.--Schematic diagram illustrating interpreted relative movements of basement fault blocks along the uplift-basin margin in the vicinity west of and including Kingsbury Ridge during the Eocene. Kingsbury Conglomerate Member and thicker coal deposits form in the basin graben fault block.

Coals and tectonics

Coal deposits are very sensitive to sedimentary and tectonic influences. Weimer (1977, p. 10) summarized several geologic factors which control the formation and thickness of coal deposits. His factors include: (a) fresh, clear water conditions with little or no detrital influx; (b) the accumulation of land-derived organics; (c) a balance between the ground water-table and the depositional interface such that the swamp does not dry up, thus permitting oxidation of the organics, or that the water does not become so deep that a lake forms; (d) a favorable climate where abundant vegetation is produced; and (e) a persistence of these conditions in time and space. The last factor implies that sedimentation must equal subsidence for the swamp to continue to flourish.

Given these constraints, some of the problems encountered in interpreting and recreating the depositional environment can be understood. The thickness of the Lake De Smet coal bed suggests an extremely long period of continuous peat deposition. Weimer (1977, p. 10) suggests a compaction factor of 1.5 m of peat to produce 0.3 m of bituminous coal. If one assumes 30-60 m of coal for the Lake De Smet coal bed, then 150-300 m of peat were deposited. Weimer (1977, p. 10) cited a 1970 study of the Klang-Langat delta of Malaysia by Coleman, Gagliano, and Smith, in which the rate of peat accumulation was determined to be 0.10 m of peat per century. Frazier and Osanik (1969, p. 78) reported 0.15 m of peat accumulation per century in the Mississippi delta. Assuming 0.15 m of peat accumulation per century and assuming comparable accumulation rates, the life of the Lake De Smet coal swamp was 100,000-200,000 years.

The disposal of the coarse clastics shed from the uplift poses a problem since no channel has been identified which would divert the clastics around or through the swamp forming the Lake De Smet coal bed. Drill data do indicate one area, sec. 10, T. 51 N., R. 82 W., where no coal was deposited (figs. 16, 17). Unfortunately, no lithologic or mechanical logs are available, and the drill data in this area are of poor quality. A channel to the north or south of the study area may be an alternate explanation.

Structural relationships suggest that the Lake De Smet coal bed is correlative with the finer grained sediments immediately below the Moncrief Member (fig. 5). If a constant 1°-5° dip is assumed for the Moncrief and equivalent strata from the mouth of Clear Creek to Buffalo, the base of the Moncrief can be projected to the upper portion of the Lake De Smet coal bed. If this correlation is valid, a combination of increased tectonic activity and increased coarse sediment influx can be inferred to have terminated the Lake De Smet coal swamp.

A unique feature of the Lake De Smet coal bed is its relatively straight, linear orientation parallel to the axis of the basin and its proximity to the Bighorn uplift, which was shedding coarse clastics. One possible explanation establishing its position and length may be a postulated subsurface fault which does not cut the Tertiary sediments (fig. 43). Foster, Goodwin, and Fisher (1969), utilizing seismic data, proposed such a subsurface fault along the length of the Powder River Basin from Casper to north of Buffalo. The hypothetical fault plane is 6-30 km eastward from the mountain front, and near Buffalo the fault may have separation of nearly 1220 m. However, its position relative to the Lake De Smet coal bed is not known. Such a feature, active during the Laramide Orogeny, would affect local depositional patterns.

Relationships between tectonics and depositional patterns in the coal-bearing strata are not well established or understood. A few faults cut the coal-bearing strata (pl. 1) (Mapel, 1959). The graben drilled by the U.S. Geological Survey and also by an oil company north of Lake De Smet revealed post-depositional displacement. Increased dips along the east shore of Lake De Smet apparently resulted from drag along a fault. A few east-northeast faults can be traced for short distances in outcrops. These, too, appear to be post-depositional.

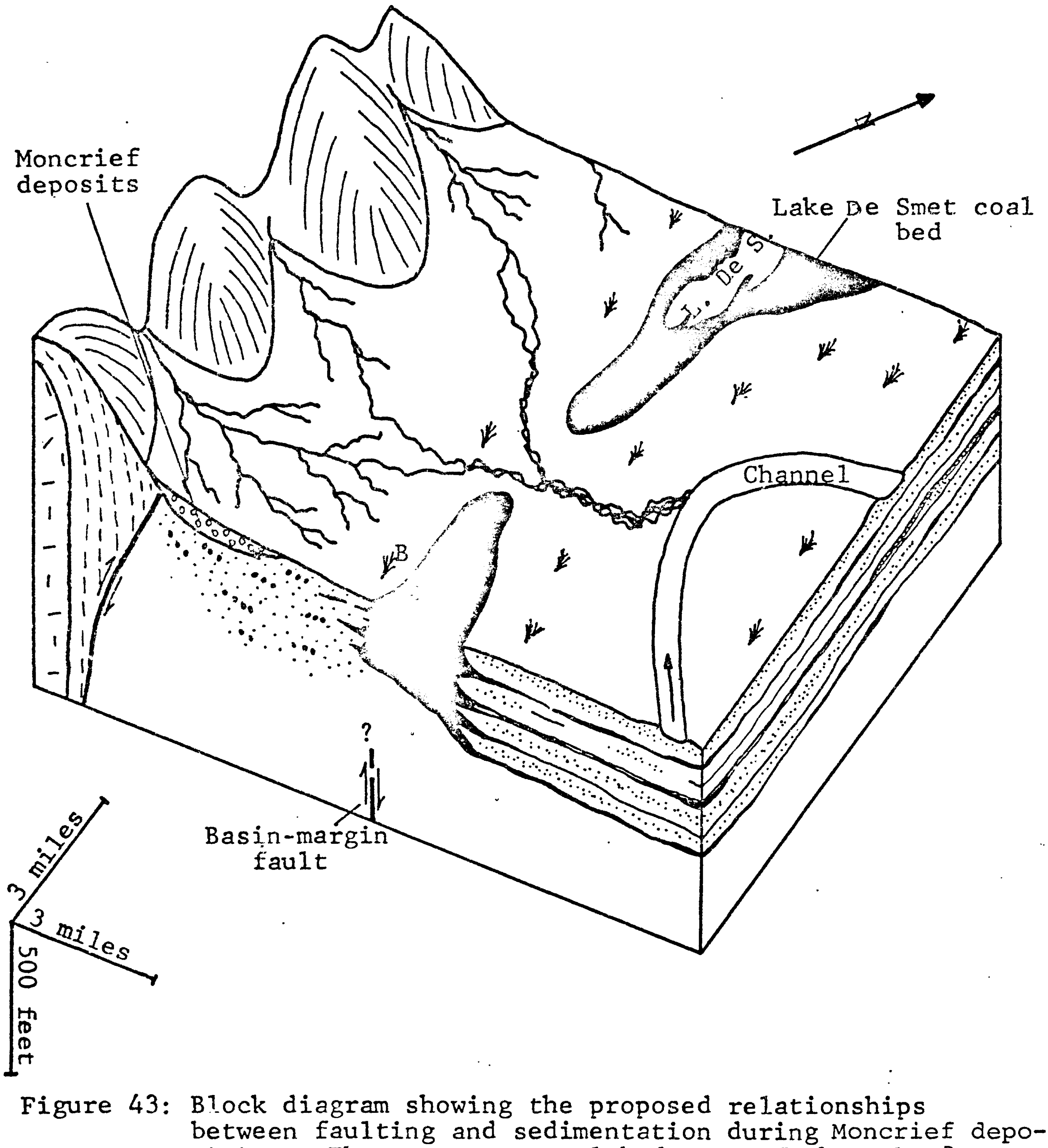


Figure 43: Block diagram showing the proposed relationships between faulting and sedimentation during Moncrief deposition. The uppermost coal bed east of the Lake De Smet coal bed is the Healy. B = Buffalo; L. De S. = Lake De Smet.

Lack of outcrops and of close surface and subsurface controls prevent an analysis of the effects of differential compaction among the various lithologies. One obvious anticlinal structure was mapped in sec. 15, T. 52 N., R. 82 W., immediately south and nearly perpendicular to an east-northeast-trending fault system. The anticline may be due to tectonic stress or to a differential compaction feature formed in a manner similar to one described by Law (1976) in the Gillette, Wyo., area.

The structures Mapel superimposed on the coal beds similarly are difficult to evaluate. In T. 50 N., R. 80 W., a fault and a paralleling synclinal structure in the downdropped block are closely associated. However, it is suggested that these structures may have resulted from both differential compaction features and post-depositional tectonic movements.

Utilizing Mapel's data (1959), isopach maps of the Murray, Lower Cameron, Upper Cameron, and Schuman coal beds and of the clastic interval between the Lower and Upper Cameron coal beds were made in order to study the vertical and lateral thickness changes (figs. 44, 45, 46, 47, 48). These data cover an area northeast and east of the study area. Rapid changes in thicknesses of coal beds are evident and local thickening within successive coal sequences are vertically offset. The significance of these changes and offsets in the frame of regional tectonics is uncertain because the isopached area is small. It would appear the local tectonics were relatively stable, with differential compaction of the varying lithologies providing the main control on the depositional patterns. Thick clastic wedges, in time, would constitute local highs as a result of differential compaction, thus shunting a succeeding fluvial invasion into a region formerly occupied by a coal swamp.

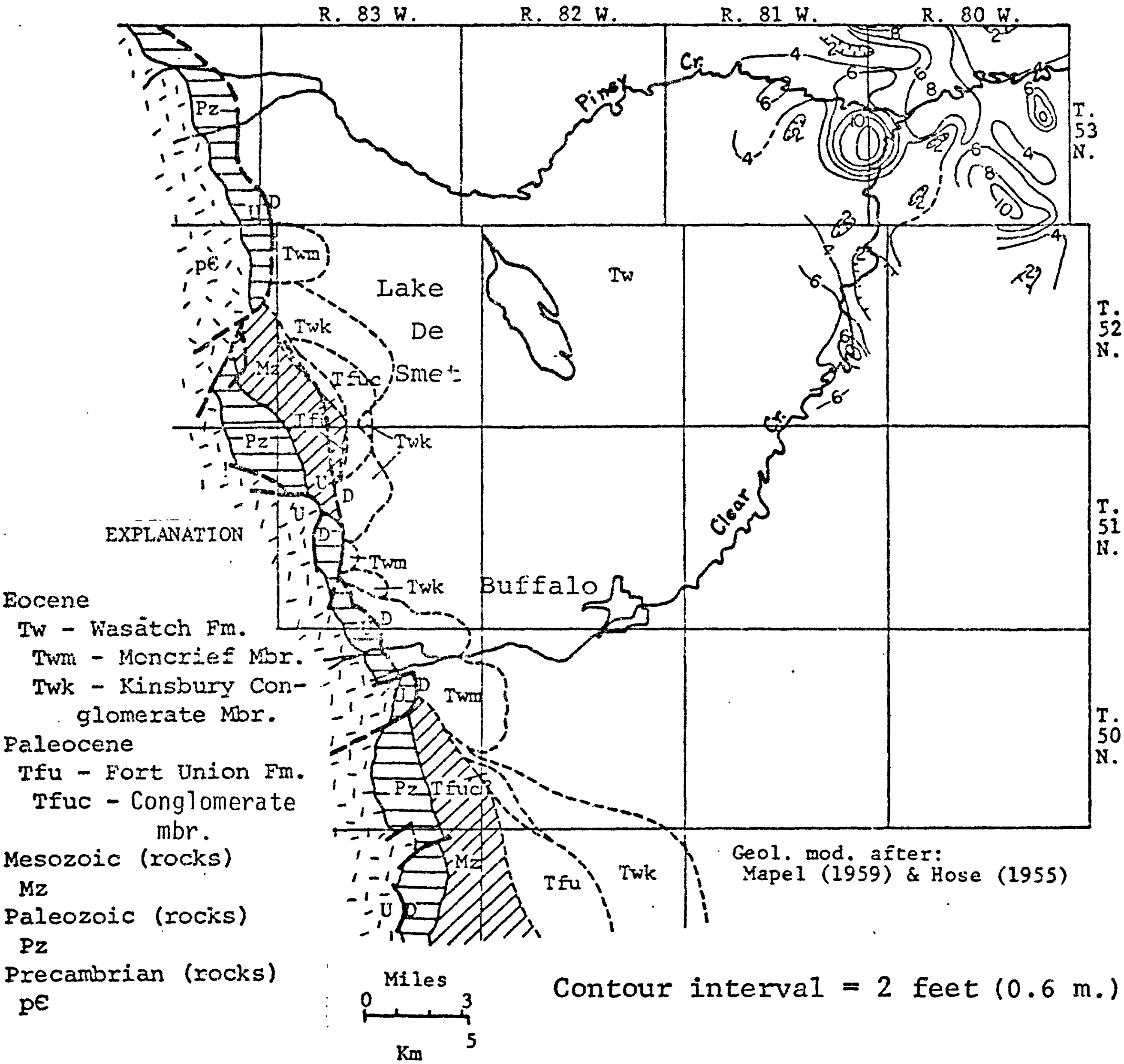
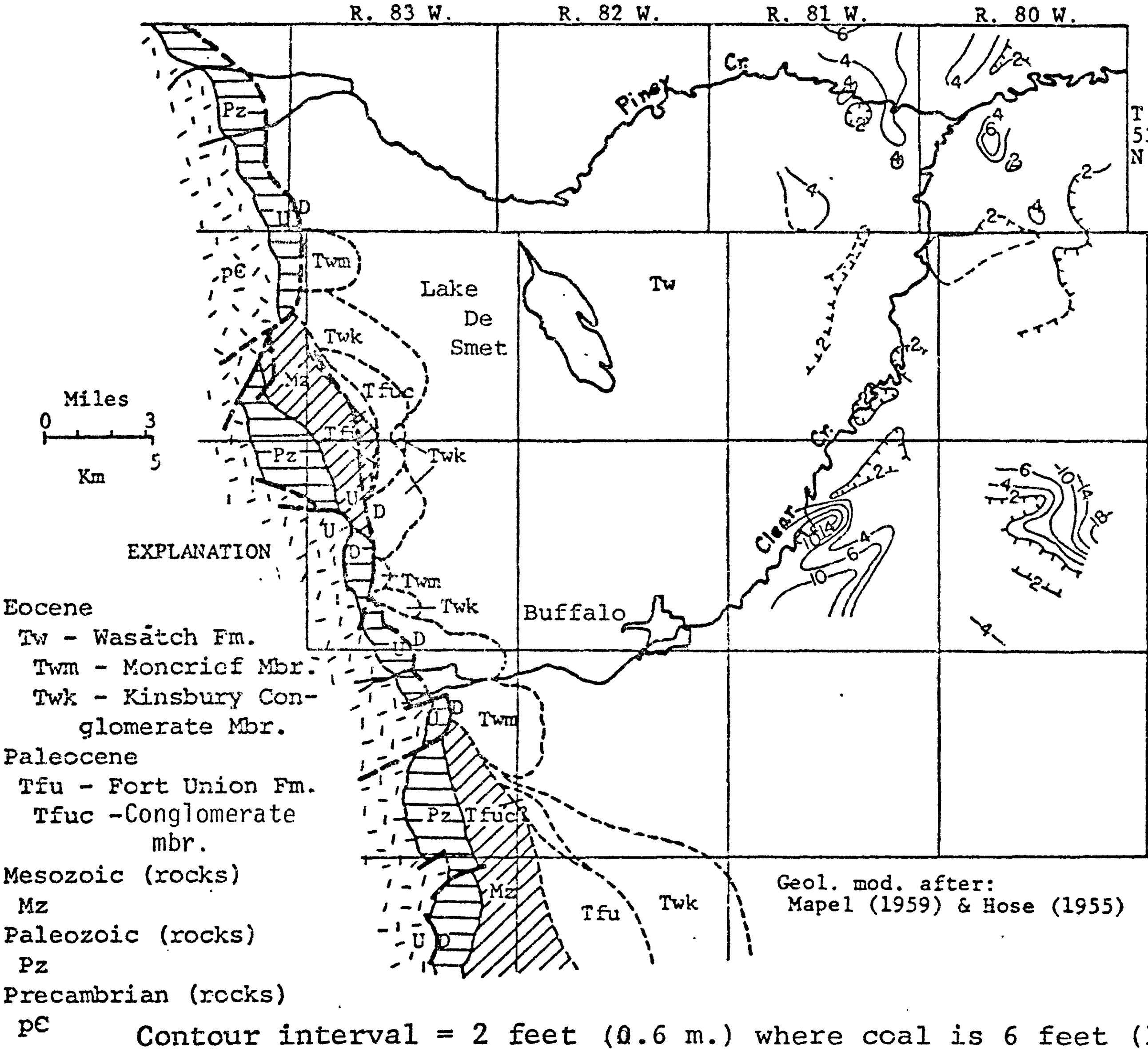


Figure 44: Isopach map of a portion of the Murray coal bed.



Contour interval = 2 feet (0.6 m.) where coal is 6 feet (1.8 m.) or less in thickness.
= 4 feet (1.2 m.) where coal is greater than 6 feet (1.8 m.) in thickness.

Figure 45: Isopach map of a portion of the Lower Cameron coal bed.

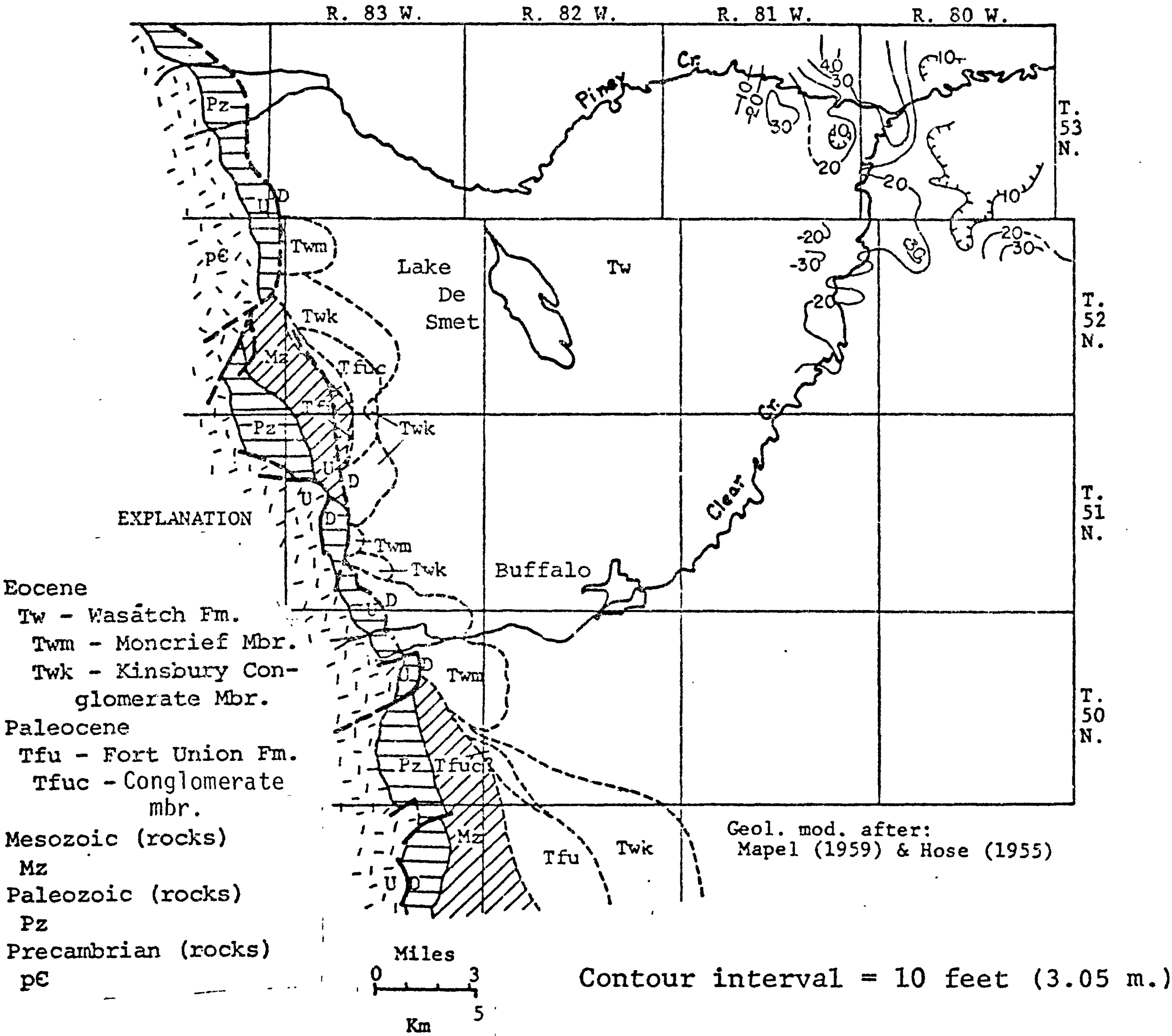


Figure 46: Isopach map of the clastic interval between the Lower Cameron and Upper Cameron coal beds.

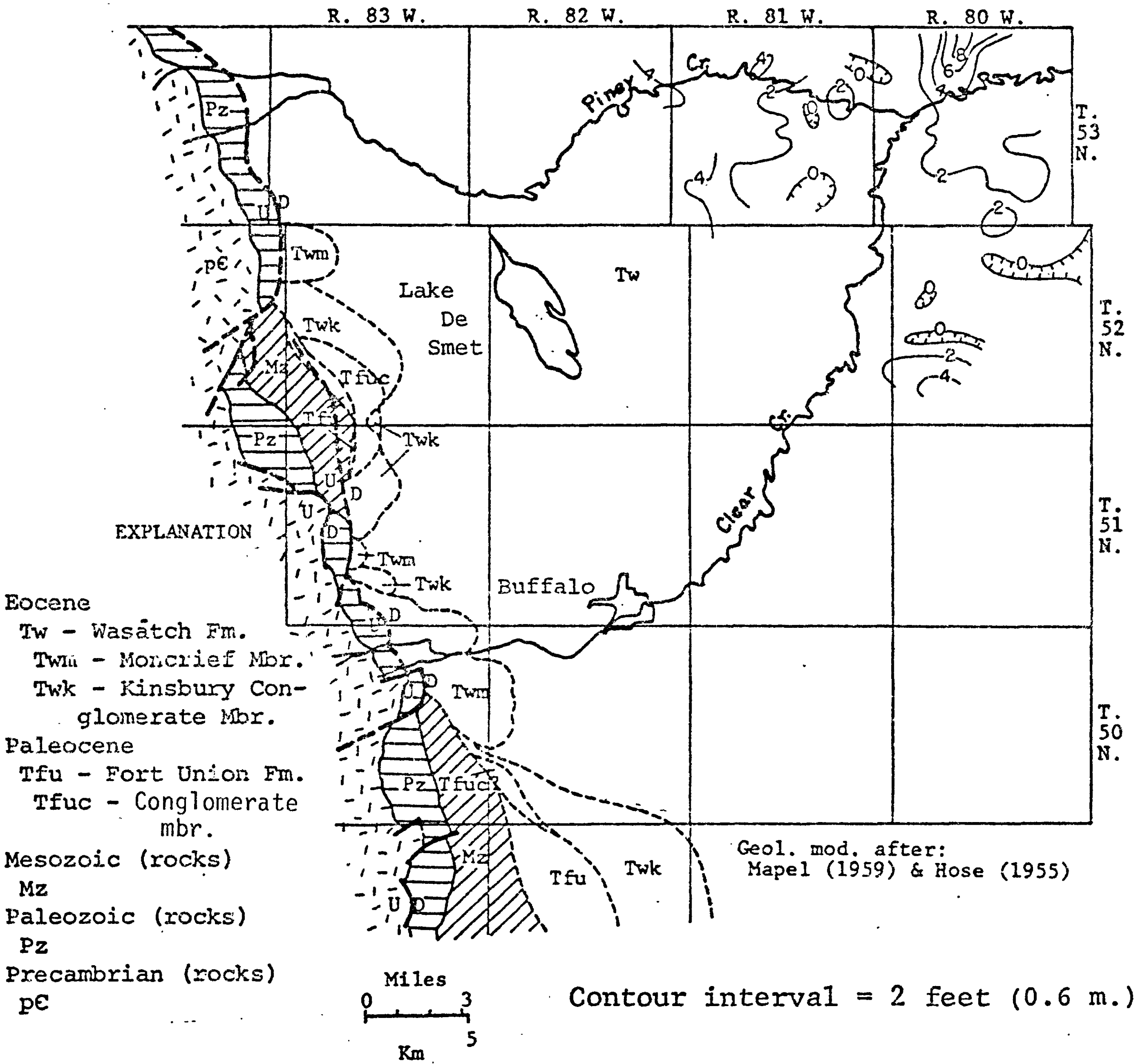
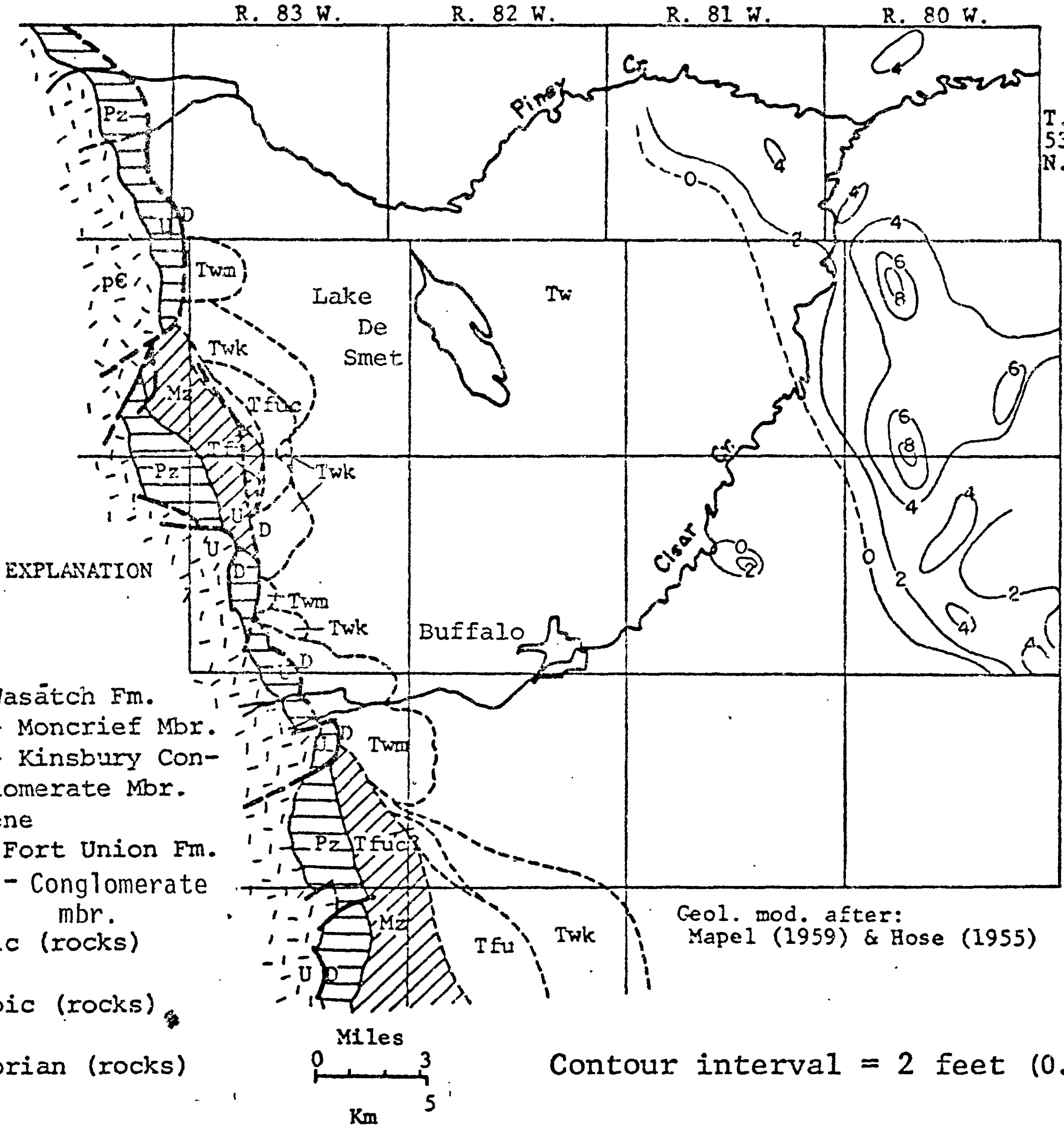


Figure 47: Isopach map of a portion of the Upper Cameron coal bed.



Eocene
- Tw - Wasatch Fm.
  - Twm - Moncrief Mbr.
  - Twk - Kinsbury Conglomerate Mbr.

Paleocene
- Tfu - Fort Union Fm.
  - Tfuc - Conglomerate mbr.

Mesozoic (rocks)
- Mz

Paleozoic (rocks)
- Pz

Precambrian (rocks)
- pЄ

Contour interval = 2 feet (0.6 m.)

Figure 48: Isopach map of a portion of the Schuman coal bed.

Figures 46 and 47 display an interesting pattern. Little or no coal in the Upper Cameron horizon was deposited where the clastic sequence between the Lower and Upper Cameron coal beds is the thickest. Conversely, thick coals are present where the clastic interval is thinnest. This pattern suggests that the Upper Cameron coal bed may be a back-levee swamp with the channel and levee deposits represented by the thick clastic sequence. Coal swamps flanked the thick clastic wedge on both its east and west margins, as shown by the thick coals.

CONCLUSIONS

1. The presence of boulder conglomerates adjacent to an uplift with laterally correlative coal deposits a few kilometers away is not a relationship unique to the Buffalo-Lake De Smet area. Knight (1951, p. 50-51) reported 4115 m of conglomerates of alluvial fan origin in the Ferris, Hanna, and Wind River Formations along the northern edge of Hanna Basin, Wyoming. The Eocene Wind River Formation possesses boulders up to 3 m in diameter but grades laterally into coal-bearing strata 6 km away. The Eocene conglomerates unconformably overlie older conglomerates, but the unconformity disappears basinward where both the Ferris, Hanna, and Wind River strata are lithologically comparable. Field evidence suggests that thrust faulting on the uplift side of the conglomerates began prior to the deposition of conglomerates in the Wind River and continued during and after their deposition. Descriptive similarities between the two areas are striking.

2. The depositional environment of the Wasatch in the Buffalo-Lake De Smet area is that of an alluvial fan complex adjacent to a mountain uplift that fronts directly onto a poorly drained alluvial plain.

3. The coals formed in a back-levee or flood basin swamp marginal to leveed channels in an alluvial valley environment.

4. The Lake De Smet coal bed is along the western margin of an alluvial plain. To the west are small lenses of conglomeratic sandstones representing braided channels emanating from the alluvial fans. To the east, thick broad sheets of very fine to medium-grained sandstones represent meander channel deposits.

5. The Lake De Smet coal bed's thickness and its linear orientation parallel to the trend of the basin may mark the location of a subsurface fault of large separation. It is postulated that the fault was active during Eocene time and played a prominent role in the origin of the Lake De Smet coal sequence.

6. The Lake De Smet coal bed splits eastward into five major, mappable, potentially economic coal beds. From oldest to youngest, these coal beds include the Ucross, Murray, Cameron, Healy, and Walters.

7. Braided stream deposits are characterized by levee and paludal deposits. Normally, braided stream deposits are not characterized by these fine-grained sequences of sediment. However, an unstable tectonic environment coupled with shifting alluvial fan depocenters served to preserve many fine-grained deposits.

8. Palynomorph identifications indicate the Lake De Smet coal bed is early Eocene in age.

9. Palynomorph identifications indicate a late Paleocene age for the upper portions of the lower member and for the conglomerate member of the Fort Union Formation.

10. Structural evidence and analogy to other Laramide depositional sequences suggest that the Moncrief is Eocene and is an upper conglomerate member of the Wasatch Formation.

11. The location of the Moncrief conglomerates is interpreted to be a result of block-fault movements. The conglomerates were deposited on the downdropped blocks. Deformation prior to the Moncrief deposition formed anticlines which are interpreted to have formed in response to movement of basement blocks. The Kingsbury Conglomerate Member of the Wasatch and conglomerate member of the Fort Union are inferred to have similar origins.

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