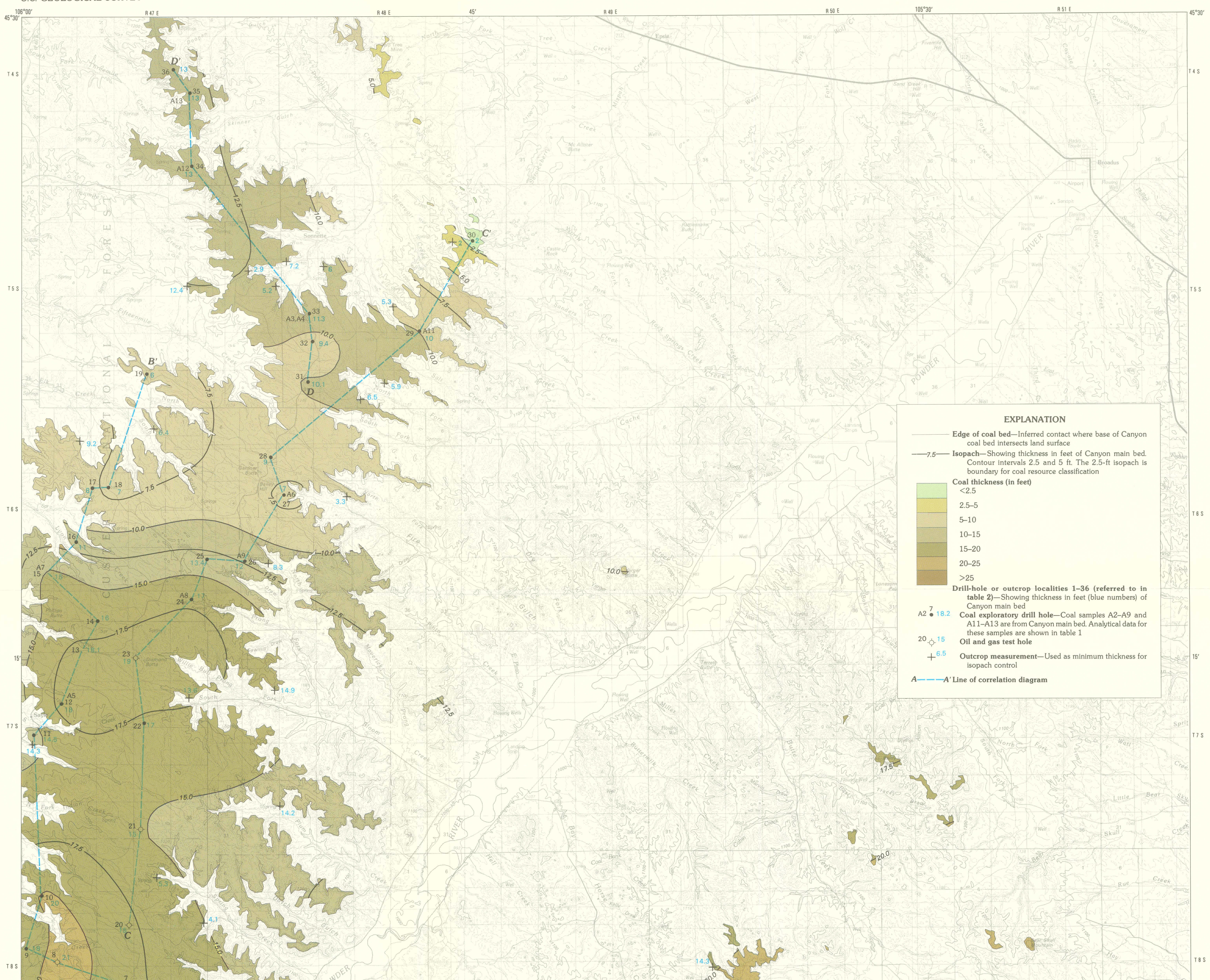
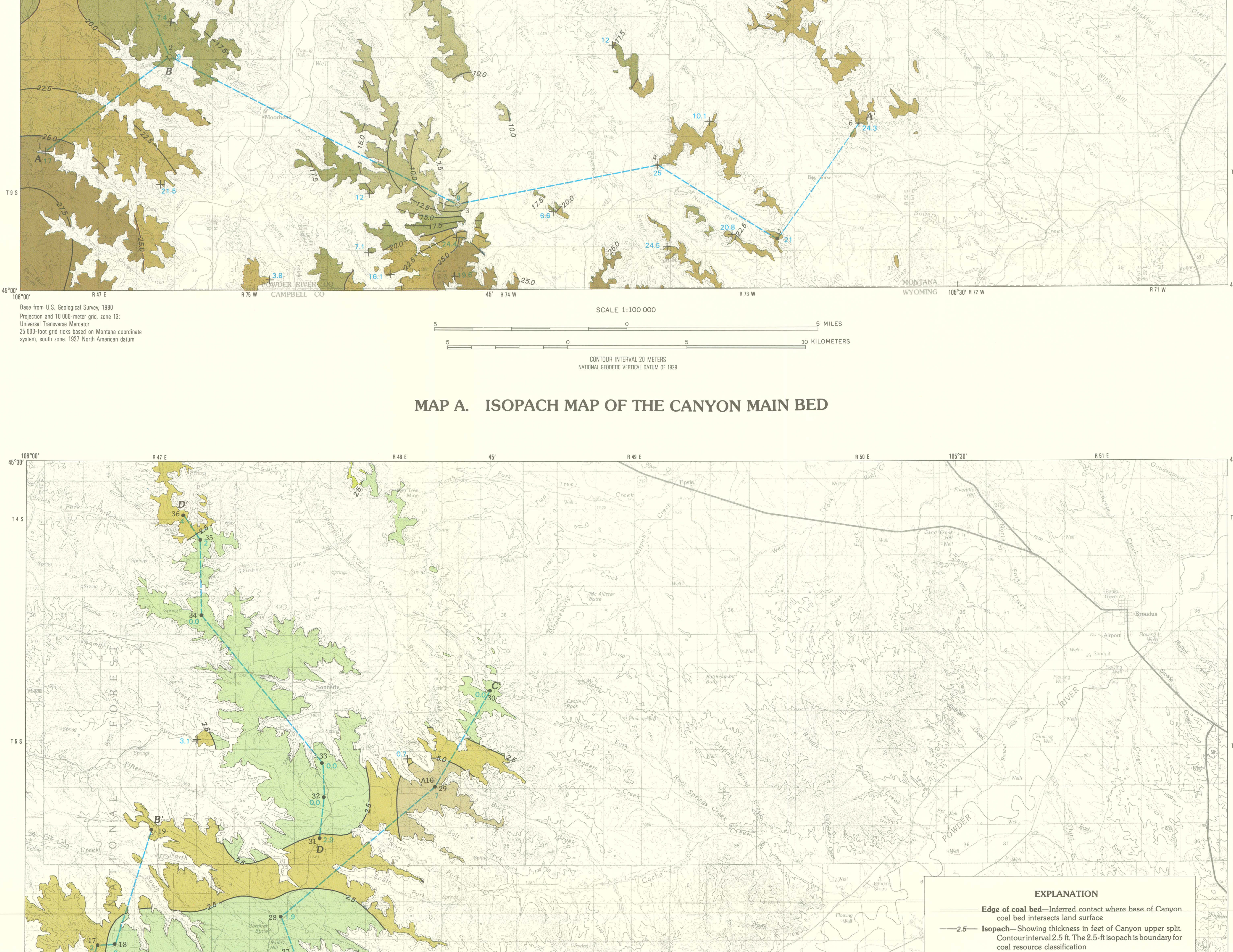


MAP A. ISOPACH MAP OF THE CANYON MAIN BED



Color design by Virginia D. Scott
Graphic design by Thomas L. Loesch
Cartography by Bill Ary
Manuscript approved for publication August 19, 1991

MAP B. ISOPACH MAP OF THE CANYON UPPER SPLIT

CONVERSION FACTORS

Multiply	By	To obtain
inches (in)	2.54	centimeters (cm)
feet (ft)	0.3048	meters (m)
miles (mi)	1.609	kilometers (km)

MAPS AND DIAGRAMS SHOWING THICKNESS AND MORPHOLOGY OF THE PALEOCENE CANYON COAL BED IN THE NORTHERN POWDER RIVER BASIN, WESTERN PART OF THE BROADUS 30′ × 60′ QUADRANGLE, MONTANA AND WYOMING

By
Laura R.H. Biewick
1994

INTRODUCTION

The study area is in the west half of the Broadus 30′ × 60′ quadrangle, in southeastern Montana and northernmost Wyoming (fig. 1), where the Canyon coal bed crops out on the eastern flank of the Powder River Basin. The Canyon coal bed is defined here to include the Canyon main bed and its upper split. It is one of 19 coal beds or zones in the Tongue River Member of the Paleocene Fort Union Formation (fig. 2) in the Broadus quadrangle. The Canyon coal bed generally thickens to the south and thins and splits to the north (maps A, B; correlation diagrams *A–A′, B–B′, C–C′, D–D′*). The Canyon main bed meets the coal-resource thickness criteria in all but a very small northeastern area (less than one square km, map A). This study is an outgrowth of the Coal Folio Program to map and evaluate coal resources.

Based on analytical data of four samples recorded in the National Coal Resources Data System (NCRDS) and nine samples in Matson and Blumer (1973), the apparent rank of the Canyon coal bed in the study area is subbituminous C coal and lignite A. Heat of combustion for these samples ranges from 7,200 Btu/lb to 8,796 Btu/lb on a moist, mineral-matter-free basis (American Society for Testing and Materials, 1978). Mean sulfur content is 0.5 percent (range, 0.2 to 1 percent); mean ash content is 5 percent (range, 3.3 to 7.8 percent, table 1).

ACKNOWLEDGMENTS

Marguerite McLellan (U.S. Geological Survey) made field investigations and worked with the author on coal correlations. Mike Kernodle (U.S. Geological Survey) provided the programs that convert ISM (Interactive Surface Modeling, software of Dynamic Graphics, Inc.) files to ARC/INFO (software of Environmental Systems Research Institute, Inc.) coverages. Carl Rich (U.S. Geological Survey) assisted in the use of ARC/INFO to construct the coal isopach maps (maps A, B).

PREVIOUS INVESTIGATIONS

By correlating coal beds, several authors have reconstructed the stratigraphic framework of the Fort Union Formation for much of the Powder River Basin (Culbertson and others, 1979; Kent and others, 1980; Pierce and Molnia, 1985; Hardie and Van Gosen, 1986; Culbertson, 1987; McLellan and Biewick, 1988; Pierce and others, 1990; and McLellan and others, 1990). In the Broadus quadrangle, McLellan and Biewick (1988) showed an interlocking network of closely spaced correlation diagrams illustrating the stratigraphic framework and the extent of the coal beds in the Fort Union Formation. Matson and Blumer (1973) published several maps of the Canyon coal bed in southeastern Montana as part of their investigations of strippable coal deposits. Isopach, structure, and thickness-of-overburden maps of the Canyon coal bed have been published for the Birney 30′ × 60′ quadrangle to the west (Robinson and Culbertson, 1984a, b) and for the Recluse 30′ × 60′ quadrangle to the south (Kent and Munson, 1978a, b; fig. 1). Isopach maps of the Knobloch and Wall coal beds in the Birney quadrangle can be found in Culbertson and Saperstone (1987a, b). Biewick and McLellan (1990) showed trends of thickening, thinning, and splitting, and areas of coal resources (thickness greater than 2.5 ft) of the Flowers-Goodale coal resource unit in the Birney and Broadus quadrangles.

This study has revealed minor inconsistencies in some of the earlier coal-bed names. Local beds of limited distribution that have previously been assigned to the Canyon coal zone (McLellan and Biewick, 1988) are not included in this study because they have not been shown to merge with the Canyon coal bed.

METHODOLOGY

The identification and correlation of the Canyon coal bed are based on interpretations of the geophysical logs of drill holes in and adjacent to the study area, supplemented by surface mapping. All data were entered into the NCRDS USTRAT (U.S. stratigraphic) data base. Of the 33 drill holes studied, 27 are coal exploration holes drilled by the Montana Bureau of Mines and Geology or the U.S. Geological Survey (table 2). These holes provide the most reliable data on the coal beds in this area; most are in the valleys and tributaries of the Powder River and Otter Creek, where the Canyon coal bed is at a shallow depth (less than 450 ft). The remaining drill holes used are oil and gas test holes for which available geophysical logs are adequate to determine thicknesses and depths of the Canyon coal bed. Preference was given to log suites that include gamma-ray and formation-density logs that allow positive identification of coal, because the coal is less radioactive and less dense than the adjacent rocks. Coal, sandstone, and limestone all may have similarly high resistivity, therefore; the electrical-resistivity log is only used to determine coal thickness where the log can be correlated with a suite of logs from a nearby drill hole that includes gamma ray or formation density logs (Wood and others, 1983, p. 46–62). Gamma-ray logs are available for 50 percent of the oil and gas holes and 89 percent of the coal exploration holes. Formation-density logs are available for 44 percent of the coal exploration holes. Table 2 shows which logs are available for each drill hole.

Surface data were taken from published and unpublished U.S. Geological Survey maps (McLellan and Biewick, 1987a, b; 1988, 1989a, b; 1990). Coal thickness at the outcrop may be less reliable than in the nearby subsurface because coal exposed in outcrop commonly oxidizes slowly during weathering and because slumping of overburden may conceal the true top of the bed (Robinson and Culbertson, 1984b). For these reasons, thickness measurement of a coal bed in a surface exposure is accepted only as a minimum coal thickness to control the isopachs. Elevations of the base of the coal measured at outcrops were used, along with those calculated on geophysical logs, to generate a structure map of the base of the coal bed. The inferred edge-of-coal-bed line on the map was located by determining where the structural surface of the base of the coal intersects the ground surface as shown on the 1:100,000-scale topographic map. The location of the edge-of-coal-bed line is subject to local error because in many places along its outcrop, the Canyon coal bed has burned, baking and fusing the overlying rocks into a resistant reddish rock called clinker. The edge of the clinker, which indicates the lateral extent of coal burning, is not everywhere evident on the surface. Although the amount of coal burned is unknown, it is probably negligible (Robinson and Culbertson, 1984b) and not significant when calculating coal resources.

The data used to generate the maps were retrieved from the NCRDS, and the edge-of-coal-bed line was digitized using ISM on a Prime 9650 minicomputer. The correlation diagrams (*A–A′, B–B′, C–C′, D–D′*) were assembled using the program STRATS (Boger, 1986), and the coal isopach maps (maps A, B) and perspective diagrams (figs. 3–6) were generated using ISM, on Prime 9650 and 9955 minicomputers and on a Silicon Graphics Iris 4D/70GT workstation. Files containing the coal isopach lines generated in ISM were transferred into ARC/INFO on a Prime 9955 minicomputer, to create the final isopach maps (maps A, B).

THE CANYON COAL BED

The Paleocene Fort Union Formation consists of, in ascending order, the Tullock Member, the Lebo Shale Member, and the Tongue River Member. All of the coal beds shown in the accompanying maps, correlation diagrams, and figures occur in the Tongue River Member. The Tongue River, which partly intertongues with the Lebo Shale, is locally more than 1,800 ft thick and consists of interbedded sandstone, siltstone, shale, occasional thin lenses of limestone, and thick, persistent beds of coal.

The Canyon coal bed is in the upper part of the Tongue River Member (fig. 2). It is split into two beds in much of the Broadus quadrangle (maps A, B; correlation diagrams *A–A′, B–B′, C–C′, D–D′*). The Canyon coal bed consists of the Canyon main bed where it is a single bed or where it is split by a parting and the upper split. Where a parting is present the thicknesses of the underlying and overlying coal beds are added together and treated as one coal bed (the Canyon main bed). A parting is defined as a layer of noncoal material in a coal bed that does not exceed the thickness of the coal in either the directly underlying or overlying benches (Wood and others, 1983). In most areas, the main bed is free of identifiable partings, but locally the coal is split by a few feet of shale (correlation diagrams *A–A′, B–B′*). Where a layer of noncoal material exceeds the thickness of either the underlying or overlying coal benches, the coal bed is considered to have split into the main bed and the upper split. The upper split appears to merge laterally with the main bed in the south (maps B; correlation diagrams *A–A′, B–B′*) but not in the north (correlation diagrams *C–C′, D–D′*). The Canyon coal bed is thickest (19 to greater than 27.5 ft) where the main bed is combined with the upper split in the southwestern and southeastern parts of the study area (map A; correlation diagram *A–A′*; delineated by merge line on map B). The upper split is present in much of the study area, where it ranges in thickness from greater than 1 to 7 ft; elsewhere, the upper split pinches out, is cut out, or merges with the main bed (map B; correlation diagrams *A–A′, B–B′, C–C′, D–D′*). The Canyon coal bed extends west into the Birney quadrangle, north into the Powderville quadrangle, and south into the Recluse quadrangle (fig. 1).

The perspective diagrams (figs. 3–6) are included for visualizing the variation in coal thickness (figs. 3, 4) and morphology (figs. 5, 6) of the coal beds. Figures 3 and 4 depict thickness values transformed to appear as a three-dimensional surface. Figures 5 and 6 are three-dimensional diagrammatic depictions of the external structure of the coal beds. The mesh perspectives drawn on the coal thickness (figs. 3, 4) have a vertical exaggeration of 687. Those showing the morphology of the coal beds (figs. 5, 6) have a vertical exaggeration of 30.

The 2.5-ft isopach marks the minimum thickness of subbituminous coal that is considered to be a coal resource by the U.S. Geological Survey (Wood and others, 1983; maps A and B). Areas of zero coal thickness on the upper split isopach map (map B) and perspective diagram (fig. 4) show where the coal has pinched out or was cut out (zero thickness shown in parentheses on the Canyon upper split isopach map). The Canyon coal bed, although laterally extensive, appears to be thickest along northwest-southeast and east-west axes in the Birney quadrangle (Robinson and Culbertson, 1984b) and in an east-west orientation in the Broadus (maps A, B; correlation diagrams *A–A′, B–B′, C–C′, D–D′*) and Recluse 30′ × 60′ quadrangles (Kent and Munson, 1978b). The Canyon coal bed extends from west to east more than 60 mi (fig. 1; McLellan, 1992).

DEPOSITIONAL SETTING

Three depositional models for the late Paleocene of the Powder River Basin have been proposed. Ayers and Kaiser (1984) and Ayers (1986) have suggested that the sediment of the Fort Union Formation in the study area records a history of paludal, fluvial-deltaic, and lacustrine sedimentation from deltas that prograded westward from the Black Hills and filled Lake Lebo, which occupied the basin axis (fig. 7). Ayers and Kaiser (1984) showed an east-west, sand-rich belt at about the Wyoming-Montana State line that they separated into a Decker delta that provided fill from the northwest and a Moorhead delta that filled the basin from the east (fig. 7).

A model for the Tongue River Member of the Fort Union Formation of Paleocene age combined with the overlying Wasatch Formation of Eocene age (Flores, 1981, 1983; Flores and Ethridge, 1985; and Warwick and Stanton, 1988) suggests that the coal formed from peat that accumulated in swamps of a northward-draining, trunk-tributary system (fig. 8). Flores and Ethridge (1985) and Seeland and others (1988) proposed that the deltas of Ayers (1986) are the western and eastern parts of a single sand-rich fluvial axis carrying debris from the northern part of the Bighorn uplift eastward past the northern end of the Black Hills uplift to the Cannonball sea (fig. 9). Seeland and others (1988) proposed that, based on paleocurrents of the Tongue River Member, paleoslope and paleostream flow were generally eastward toward the Cannonball sea in the northern Powder River Basin (fig. 9).

Based on interlocking cross sections in the northern and central Powder River Basin, McLellan (1992) proposed that the distribution of thick Paleocene coal beds and host sedimentary rocks represent many long-lived, peat-forming swamps that covered hundreds of square miles, virtually undisturbed by major drainage channels. Subsidence of the Powder River Basin, accompanied by tectonic uplift of the Black Hills, the Weldon-Brockton-Froid fault system, and the Cedar Creek anticline (fig. 10), blocked drainage systems, intermittently creating widespread peat-forming swamps. The region of the Ashland, Coalwood, and Birney-Broadus coal fields (fig. 1) remained a relatively stable, flat, interdeltaic plain during Paleocene time, accumulating peat beds interbedded with clastic sediment. Most sediment of the Lebo Shale and Tongue River Members came from the Black Hills to the east (McLellan, 1992).

In the study area, the Canyon coal bed was deposited as peat in a swamp on a flood plain in Paleocene time, as described by Robinson and Culbertson (1984b) for the Birney quadrangle to the west. The rock layer that splits the coal bed is probably the result of sediment deposition on the peat bog, caused by a breached levee during the flooding of a large river somewhere to the north (Robinson and Culbertson, 1984b). After deposition of this clastic sediment ("crevasse splays"), the swamp reestablished itself and continued the deposition of peat to form the Canyon upper split (correlation diagrams *A–A′, B–B′, C–C′, D–D′*).

The strata overlying the Canyon coal bed consist of sandstone, siltstone, shale, coal, carbonaceous shale, limestone, and ironstone. Lithofacies and depositional environments for the stratigraphic interval of the middle and upper part of the Tongue River Member (fig. 2) have been described by Flores (1981, 1983) from studies in and adjacent to the study area.

RECOMMENDATIONS FOR FURTHER STUDY

Delineation of other major coal beds in the study area and adjoining quadrangles would show where coal deposition occurred through time, would provide coal and overburden thickness boundaries necessary for coal resource availability calculations, and would result in improved understanding of the depositional environments of the Tongue River Member of the Fort Union Formation. The computer files used to formulate the data here could be used for automated resource appraisal of the Canyon coal bed.

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Table 1. *Analytical data*

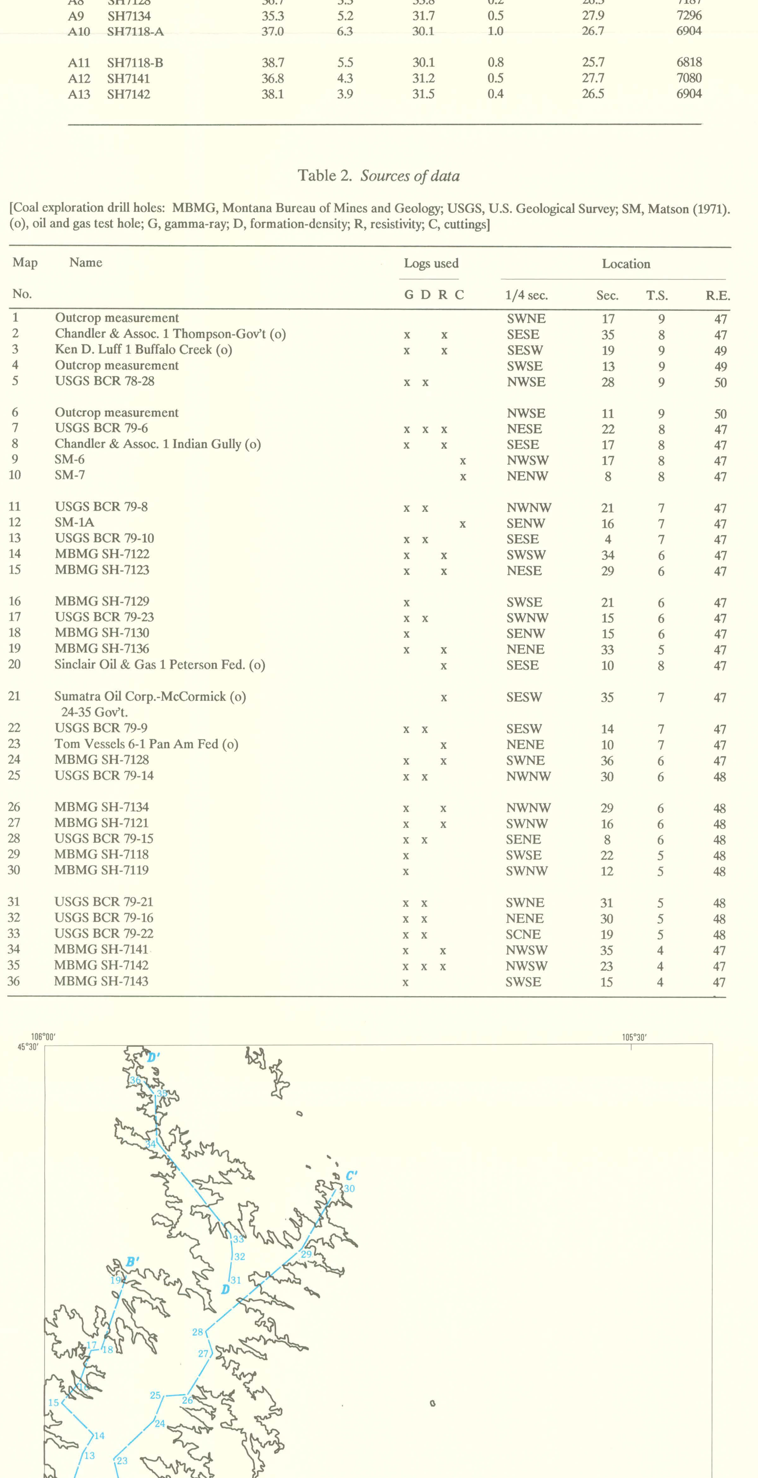
[All values are in percent except Btu/lb and are reported on an as-received basis]

Map ID	Point ID	Moisture	Ash	Fixed carbon	Total sulfur	Volatile matter	Btu/lb
A1	79BR-6-1	27.8	6.7	32.1	0.7	33.4	8161
A2	79BR-6-2	28.7	4.0	31.6	0.3	35.7	8203
A3	79BR-22C-A	29.4	7.8	31.3	0.5	31.5	7705
A4	79BR-22C-1	28.9	5.9	34.6	0.7	30.6	7881
A5	SM-1A	29.7	4.0	36.4	0.3	29.9	8070
A6	SH7121	37.0	4.1	31.4	0.3	27.5	7138
A7	SH7123	34.4	3.7	33.3	0.3	28.5	7455
A8	SH7128	36.7	3.3	33.8	0.2	26.3	7187
A9	SH7134	35.3	5.2	31.7	0.5	27.9	7296
A10	SH7118-A	37.0	6.3	30.1	1.0	26.7	6904
A11	SH7118-B	38.7	5.5	30.1	0.8	25.7	6818
A12	SH7141	36.8	4.3	31.2	0.5	27.7	7080
A13	SH7142	38.1	3.9	31.5	0.4	26.5	6904

Table 2. *Sources of data*

[Coal exploration drill holes: MBMG, Montana Bureau of Mines and Geology; USGS, U.S. Geological Survey; SM, Matson (1971). (o), oil and gas test hole; G, gamma-ray; D, formation-density; R, resistivity; C, cuttings]

Map No.	Name	Logs used G	D	R	C	Location 1/4 sec.	Sec.	T.S.	R.E.
1	Outcrop measurement					SWNE	17	9	47
2	Chandler & Assoc. 1 Thompson-Gov't (o)	x		x		SESE	35	8	47
3	Ken D. Luff 1 Buffalo Creek (o)	x		x		SESW	19	9	49
4	Outcrop measurement					SWSE	13	9	49
5	USGS BCR 78-28	x	x			NWSE	28	9	50
6	Outcrop measurement					NWSE	11	9	50
7	USGS BCR 79-6	x	x	x		NESE	22	8	47
8	Chandler & Assoc. 1 Indian Gully (o)	x		x		SESE	17	8	47
9	SM-6				x	NWSW	17	8	47
10	SM-7				x	NENW	8	8	47
11	USGS BCR 79-8	x	x			NWNW	21	7	47
12	SM-1A				x	SENW	16	7	47
13	USGS BCR 79-10	x	x			SESE	4	7	47
14	MBMG SH-7122	x		x		SWSW	34	6	47
15	MBMG SH-7123	x		x		NESE	29	6	47
16	MBMG SH-7129	x				SWSE	21	6	47
17	USGS BCR 79-23	x	x			SWNW	15	6	47
18	MBMG SH-7130	x				SENW	15	6	47
19	MBMG SH-7136	x		x		NENE	33	5	47
20	Sinclair Oil & Gas 1 Peterson Fed. (o)			x		SESE	10	8	47
21	Sumatra Oil Corp.-McCormick (o) 24-35 Gov't.			x		SESW	35	7	47
22	USGS BCR 79-9	x	x			SESW	14	7	47
23	Tom Vessels 6-1 Pan Am Fed (o)			x		NENE	10	7	47
24	MBMG SH-7128	x		x		SWNE	36	6	47
25	USGS BCR 79-14	x	x			NWNW	30	6	48
26	MBMG SH-7134	x		x		NWNW	29	6	48
27	MBMG SH-7121	x		x		SWNW	16	6	48
28	USGS BCR 79-15	x	x			SENE	8	6	48
29	MBMG SH-7118	x				SWSE	22	5	48
30	MBMG SH-7119	x				SWNW	12	5	48
31	USGS BCR 79-21	x	x			SWNE	31	5	48
32	USGS BCR 79-16	x	x			NENE	30	5	48
33	USGS BCR 79-22	x	x			SCNE	19	5	48
34	MBMG SH-7141	x		x		NWSW	35	4	47
35	MBMG SH-7142	x	x	x		NWSW	23	4	47
36	MBMG SH-7143	x				SWSE	15	4	47



INDEX MAP SHOWING LINES OF CORRELATION DIAGRAMS AND NUMBERED SOURCES OF DATA (SEE TABLE 2) USED TO CONSTRUCT THE DIAGRAMS

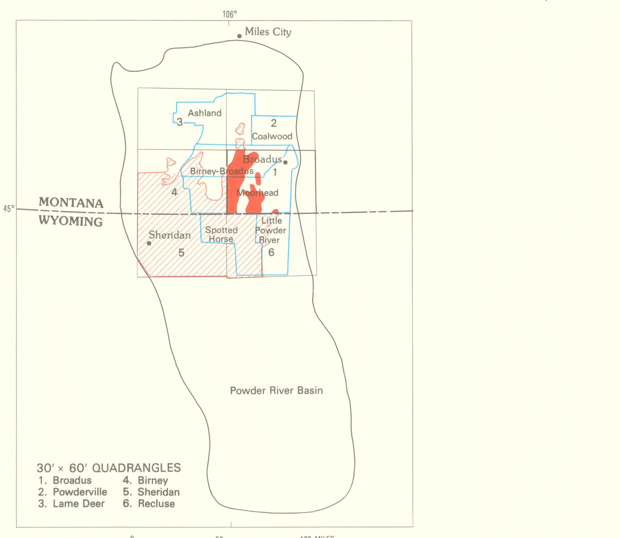


Figure 1. Index map showing the generalized location of the Canyon coal bed in the study area (solid red) and outside the study area (red lines), coal fields in and adjacent to the study area (outlined in blue), and the Broadus 30′ × 60′ quadrangle and adjoining quadrangles in the Powder River basin.

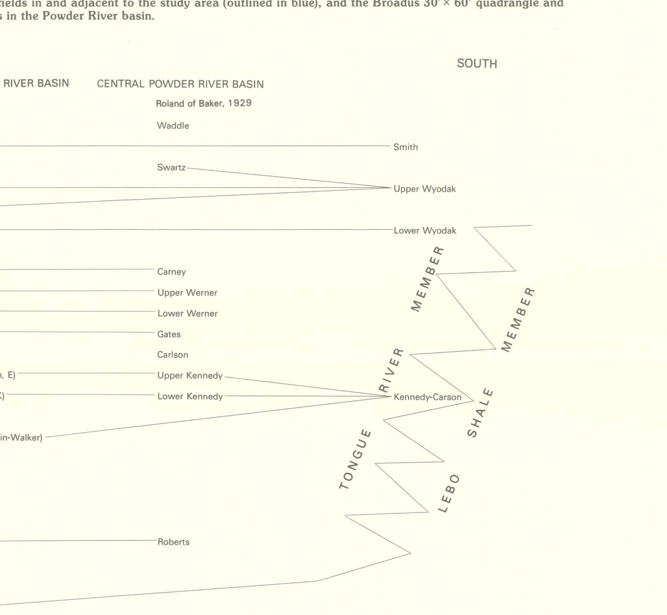


Figure 2. Schematic section showing stratigraphic position and names of coal beds in the Tongue River Member of the Fort Union Formation and the relation of the Lebo Shale Member to the Tongue River Member. Names in parentheses are names used in other reports. From McLellan (1992).

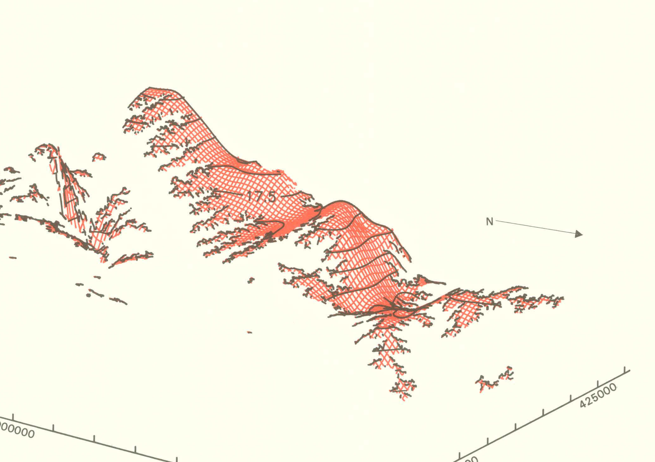


Figure 3. Mesh perspective of the thickness of the Canyon main bed. Area shown is the same as that shown on map A. Contour interval 2.5 ft. Universal Transverse Mercator coordinates are shown.

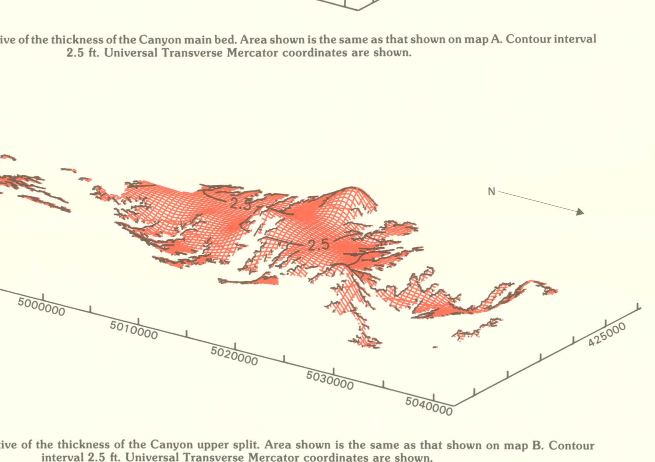


Figure 4. Mesh perspective of the thickness of the Canyon upper split. Area shown is the same as that shown on map B. Contour interval 2.5 ft. Universal Transverse Mercator coordinates are shown.

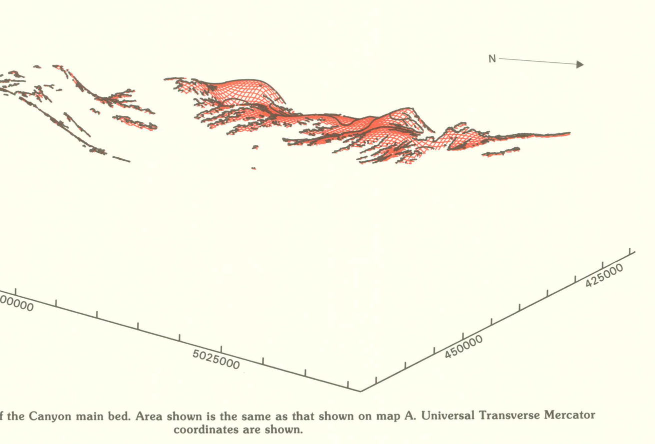


Figure 5. Morphology of the Canyon main bed. Area shown is the same as that shown on map A. Universal Transverse Mercator coordinates are shown.

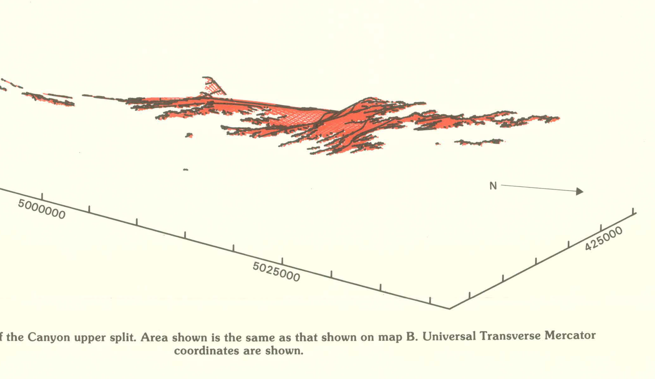


Figure 6. Morphology of the Canyon upper split. Area shown is the same as that shown on map B. Universal Transverse Mercator coordinates are shown.

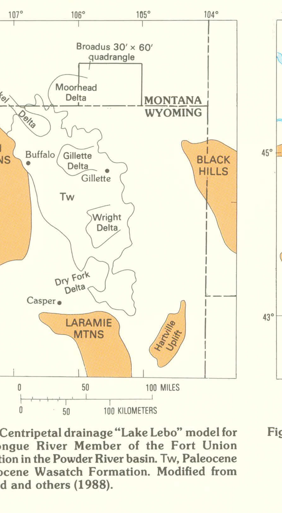


Figure 7. Centripetal drainage "Lake Lebo" model for the Tongue River Member of the Fort Union Formation in the Powder River basin. Tw, Paleocene and Eocene Wasatch Formation. Modified from Seeland and others (1988).

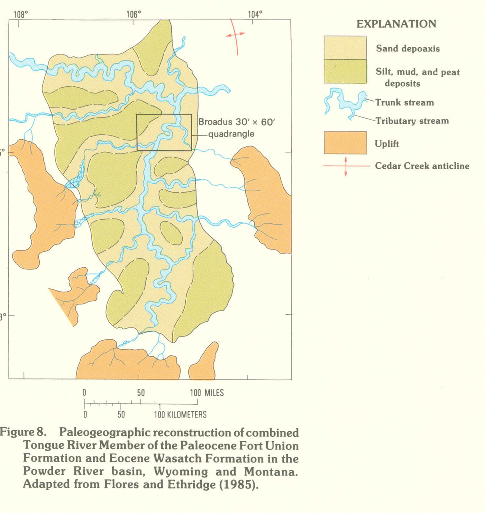


Figure 8. Paleogeographic reconstruction of combined Tongue River Member of the Paleocene Fort Union Formation and Eocene Wasatch Formation in the Powder River basin, Wyoming and Montana. Adapted from Flores and Ethridge (1985).

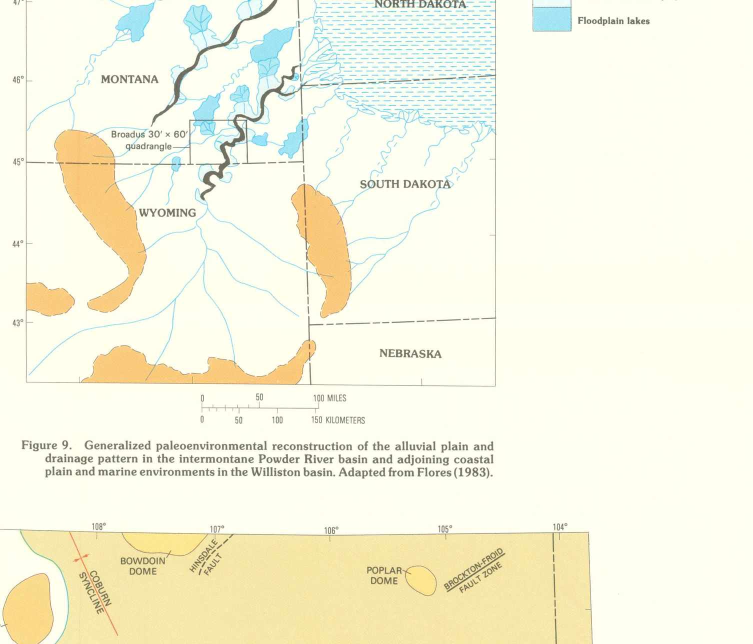


Figure 9. Generalized paleoenvironmental reconstruction of the alluvial plain and drainage pattern in the intermontane Powder River basin and adjoining coastal plain and marine environments in the Williston basin. Adapted from Flores (1983).

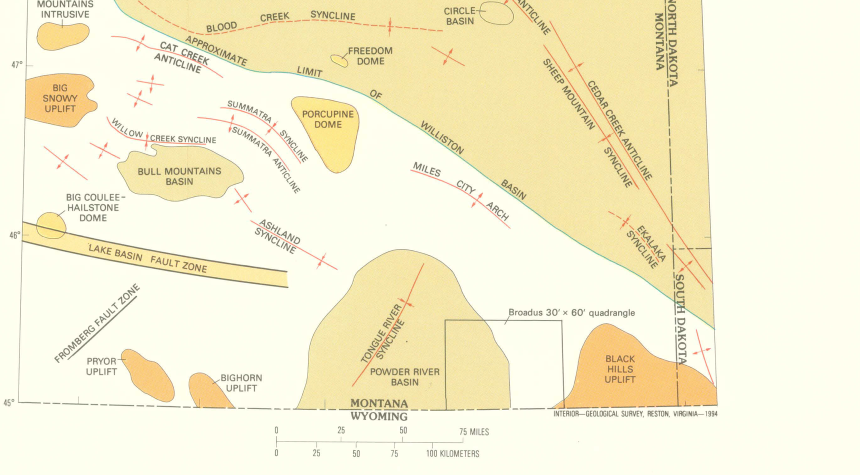


Figure 10. Generalized structural features of eastern Montana. Modified from Stoner and Lewis (1980).

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