UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Use of geophysical logs in recognizing depositional environments in the Tongue River Member of the Fort Union Formation, Powder River Area, Wyoming and Montana

By

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conformity with U.S. Geological Survey editorial standards.

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ABSTRACT

The environmental conditions under which rocks in the Paleocene Tongue River Member of the Fort Union Formation were deposited in the Powder River area, Wyoming and Montana, can be determined using geophysical logs with some limitations. It is widely recognized that gamma ray and density logs are useful in identifying thickness and stratigraphic position of coal beds. In addition, gamma ray and electrical resistivity logs can be used to infer conditions of transportation and deposition of sandstones, siltstones, and other rock types. In particular, intensity responses of the gamma ray and resistance logs provide a clue to variations of grain size such as fining-upward and coarsening-upward characteristics of fluvial channel and crevasse splay deposits, respectively. These signatures in the geophysical logs are readily observed for some beds; for other beds however, the depositional conditions are difficult to determine because the beds do not produce clear-cut log-response patterns. Thus, analysis of the environments of deposition of detrital rocks in drill holes can be made more accurate by a study of stratigraphically equivalent intervals in outcrops near drill-hole sites.

INTRODUCTION

Geophysical logs of drill holes have long been utilized by the petroleum industry in interpretation of environments of deposition of sedimentary rocks based on response patterns of resistivity and spontaneous potential electric logs. Early works on analyzing depositional facies from electric logs relied mainly on interpreting the profiles of the amplitude curves of these logs (Harms, 1966; Fisher and others, 1969). Deflections on the resistivity log are indirectly related to grain size; therefore, the log responses provide considerable insight into the internal characteristics and, by inference, the genesis of sandstone bodies. Fisher and others (1969) identified fluvial channel sandstones by their bell-shaped resistivity profile. In addition, they recognized crevasse splay deposits, which are upward-coarsening sequences, by their inverted, Christmas-tree-like spontaneous potential profiles. The spontaneous potential curve reflects not only changes in grain size but also increases or decreases in the amount of sandstone compared to shale and thicknesses of individual sandstone beds. Thus, "rules of thumb" can be established to characterize the electric log profiles and these are useful in delineating potential hydrocarbon reservoir rocks.

In the 1970's, there was a proliferation of geophysical borehole measurements utilized in coal exploration, which included gamma ray, density, sonic, neutron, and caliper logs. The descriptions and usefulness of these geophysical measurements to coal exploration are described in Davis (1977) and Vaninetti (1981). Siemers (1978) reported that coal, which has the lowest density of the rocks commonly found in coal-bearing sequences, has the highest gamma-ray count rate. In contrast, siderite, which has the highest density among the rocks commonly found in coal-bearing sequences, has the lowest gamma-ray count rate. Very low and very high responses in density log, therefore, are keys to subsurface identification of coal and siderite, respectively. The matching of responses in gamma-ray logs with paleoenvironmental conditions was successfully performed by Miller and Moore (1980). They suggested that responses in the gamma-ray log reflect degrees of paleoenergy levels during deposition of detrital rocks. That is, shales and mudstones, which were deposited in quiet water under very low energy conditions, contain clay minerals and altered feldspars that emit gamma rays and give a high response. In contrast, siltstones and sandstones, which were deposited in moving water under higher energy conditions, contain less clay and have a correspondingly lower response. Thus, differences in deflection in the gamma ray log are crude reflections of the relative amounts of radioactive clays. The above "rules of thumb" were applied in recognizing depositional conditions in geophysical logs of the Paleocene Tongue River Member of the Fort Union Formation in the Powder River area, Wyoming and Montana (Fig. 1).

The geophysical investigation was a part of an overall program to evaluate the quality and petrography of the Tongue River Member coals. Geophysical logs made in five drill holes were used in the study. The holes were drilled in the summer of 1980 by the U.S. Geological Survey. They were rotary drilled to depths ranging from 215 to 595 ft. Coal beds ranging in thickness from 1 to 32 ft were cored together with the roof and floor rocks in each of 5 offset holes (see appendix). Drill cuttings were described to determine the lithology of the coal-bearing rocks. Gamma ray, density, single-point resistance, and caliper logs were run for each hole (see appendix) to determine the thickness and stratigraphic position of the coal beds as well as to provide information for interpreting the conditions under which rocks associated with the coals were deposited. High resolution density and gamma-ray logs were run for selected thick coal beds to record detailed

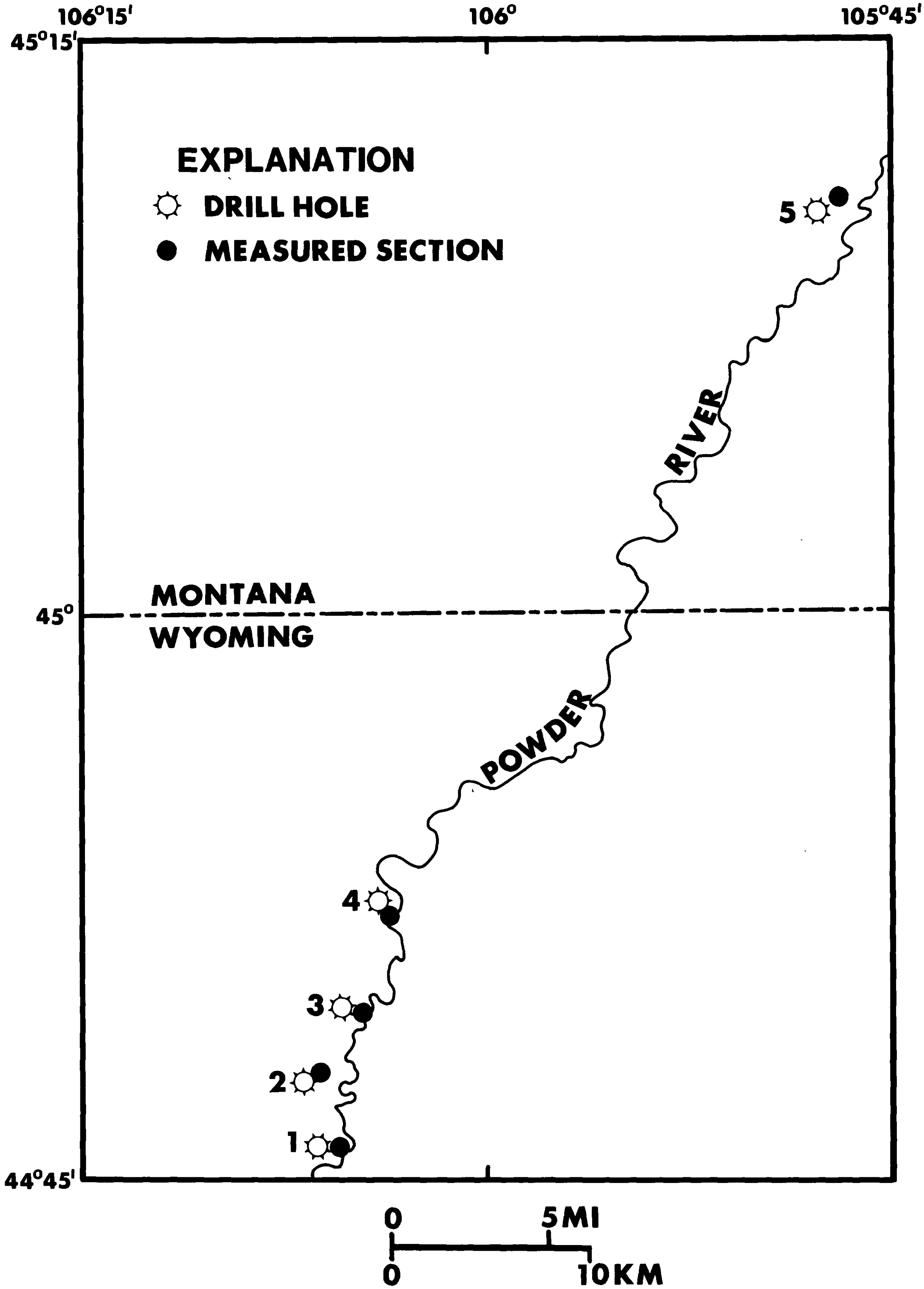


FIG. 1 INDEX MAP OF THE STUDY AREA SHOWING LOCATIONS OF DRILL HOLES AND NEARBY MEASURED SECTIONS IN THE POWDER RIVER AREA, WYOMING AND MONTANA

variations in the response related to porosity and content of mineral matter.

Recognition of depositional conditions by using the geophysical logs was aided by a previous study of stratigraphic sections measured near the drill hole sites (Flores, 1979, 1980, 1981). The measured sections were located from 550 to 1800 ft away from the drill hole sites. Each measured section included descriptions of the thickness, lithology, grain size, internal structures, trace fossil and megafossil contents, and nature of contacts of individual beds. These descriptions provided information on the environmental conditions of deposition of the rock types found in the drill site.

GEOLOGICAL SETTING

The stratigraphic interval that was penetrated by the drill holes included the upper 1100 ft of the Paleocene Tongue River Member of the Fort Union Formation, which consists of interbedded nonmarine sandstone, siltstone, shale, limestone, ironstone, carbonaceous shale, and coal. The sandstone makes up the bulk of the sequence and includes fluvial channel, crevasse splay, and overbank deposits. The least common rock type is ironstone, which occurs as lenses and concretions in overbank, lacustrine, crevasse, and channel floor deposits. Flores (1981) subdivided the Tongue River Member into two major depositional types: an upper sequence of 450 ft thick lacustrine-floodplain dominated deposits and a lower sequence of 1100 ft thick fluvial-channel dominated deposits (Fig. 2).

The lacustrine-floodplain dominated deposits are characterized by abundant freshwater mollusk fossil-bearing limestone interbedded with lake delta, crevasse splay, and fluvial channel sandstone and siltstone. Thin coals are associated with this facies. These coals are usually impure containing abundant carbonaceous shale interbeds and they show a high degree

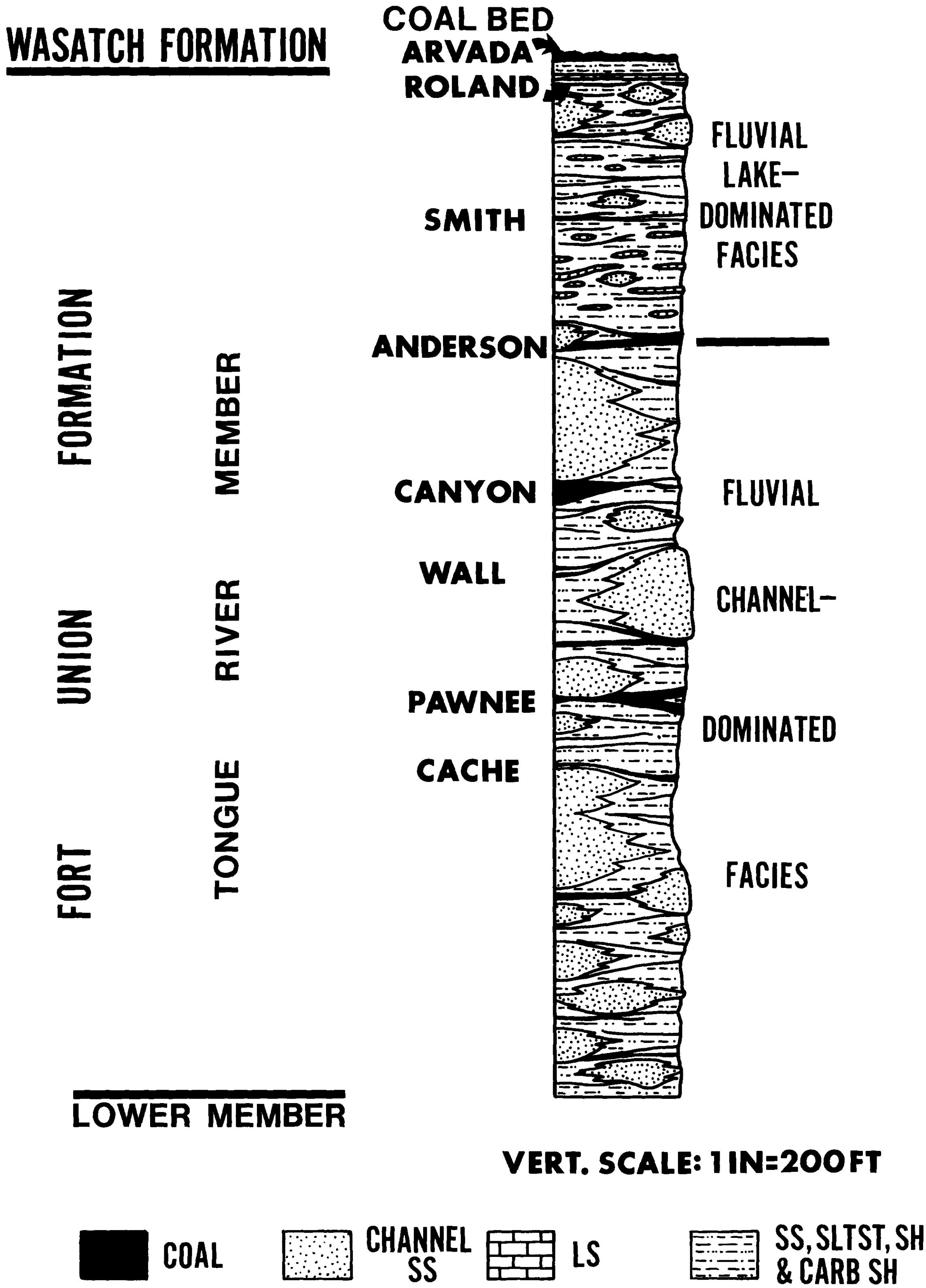


FIG.2 COMPOSITE STRATIGRAPHIC COLUMN SHOWING DISTRIBUTION OF ROCK TYPES, STRATIGRAPHIC POSITION OF COAL BEDS, DEPOSITS OF THE TONGUE RIVER MEMBER AND ITS CONTACTS WITH THE LOWER MEMBER OF THE FORT UNION FORMATION AND THE EOCENE WASATCH FORMATION

of splitting, merging and diverging of individual beds. The fluvial-channel dominated facies is characterized by abundant fluvial channel deposits associated with crevasse splay and overbank deposits. Lacustrine type deposits are not as common in this facies as in the lacustrine-floodplain facies. In addition, thick relatively homogeneous coal beds are associated with the fluvial-channel dominated facies. These thick coals are commonly burned back in the outcrop and the product consists of baked or fused, reddish rock called clinker that includes the coal ash and altered roof rocks.

The drill holes penetrated a total of 6 named coals (Olive, 1957; Bryson and Bass, 1973) that include from youngest to oldest the Smith, Anderson, Canyon, Wall, Pawnee, and Cache coals. Their stratigraphic positions are shown in Figure 2. Other coal beds that were penetrated probably represent locally occurring beds or splits from the named coals. The Pawnee coal is the thickest penetrated bed, as much as 32 ft and the Smith coals are the thinnest, as much as 5 ft thick.

LITHOLOGIC CALIBRATION OF GEOPHYSICAL LOGS

The most useful lithologic guides in the combination of geophysical logs run are the gamma ray, density, and resistance logs. The use of the resistance log as a guide to determination of lithologies, however, was limited because it was run only below fluid level. In order for all three geophysical logs to be used as lithologic guides, they were carefully calibrated by detailed comparison with drill cuttings and cores. The first step is to establish drill-cutting-to-log depth corrections at several distinct lithologic boundaries such as coals and surrounding detrital rocks.

Figures 3 to 7 compare the gamma-ray, density, and resistance logs with sample logs and core descriptions. Coals, carbonaceous shales, and shales are easily identifiable using the gamma-ray log owing to their relatively very low

EXPLANATION (For figures 3 to 9, inclusive)

LITHOLOGY

- COAL
- SANDSTONE
- SILTSTONE
- SHALE
- CARBONACEOUS SHALE
- LIMESTONE
- GRAVEL
- CLINKER

INTERNAL STRUCTURE

- FESTOON CROSSBED
- RIPPLE LAMINATION
- ROOT MARKS
- MOLLUSK FOSSILS

C CHANNEL

L LEVEE

CS CREVASSE SPLAY

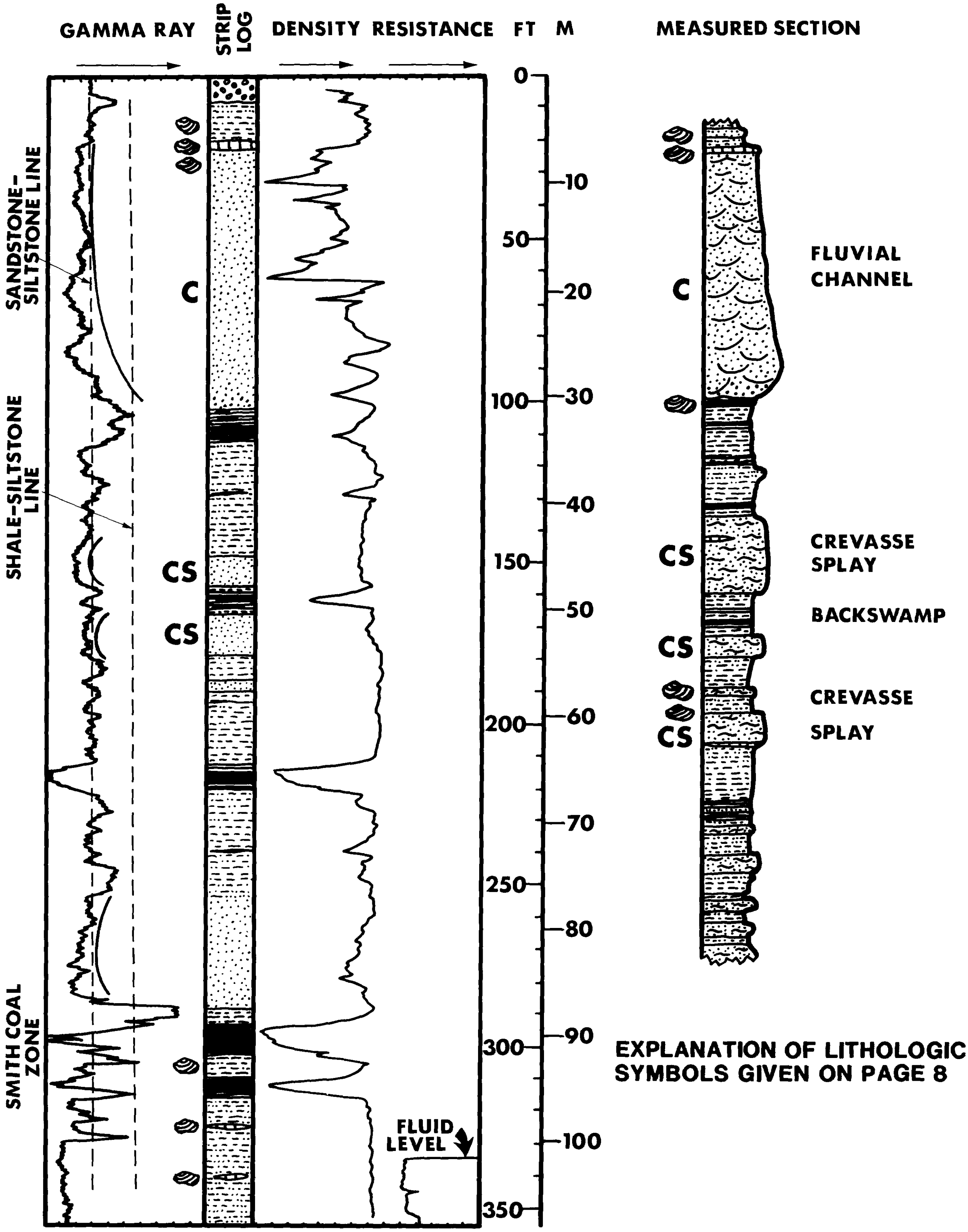


FIG. 3 GEOPHYSICAL AND SAMPLE LOGS OF DRILL HOLE 1A AND NEARBY MEASURED SECTION

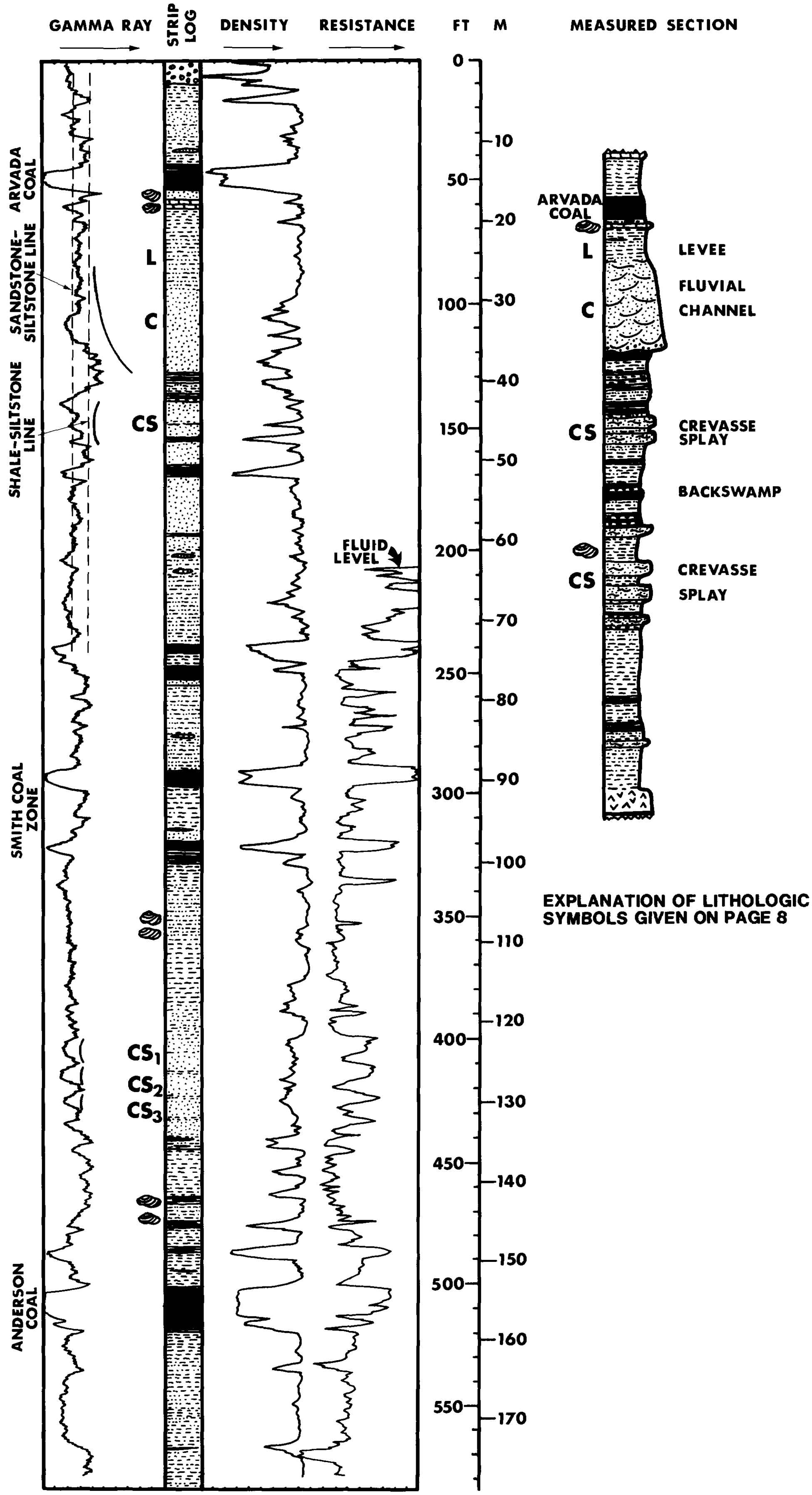
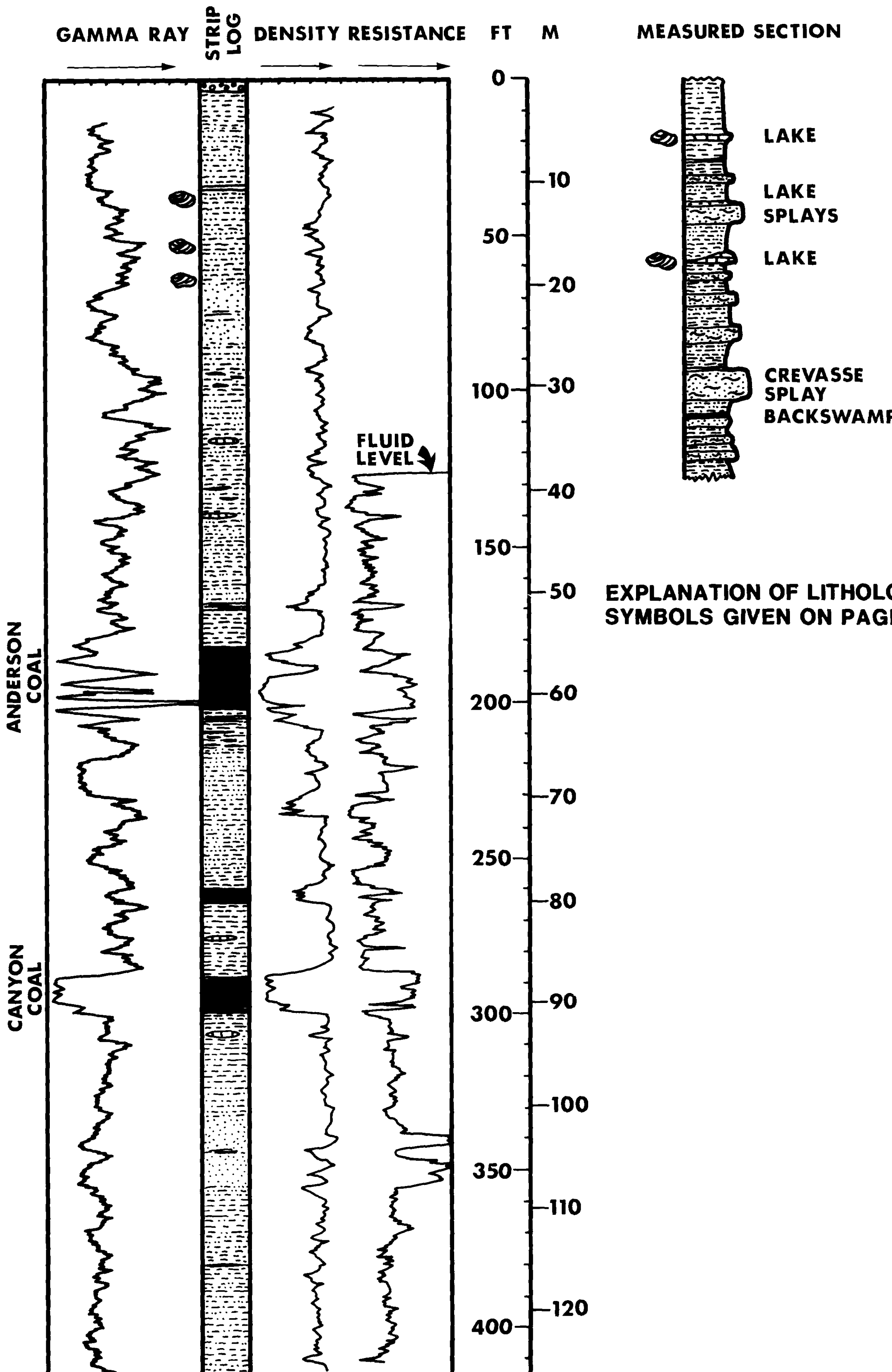
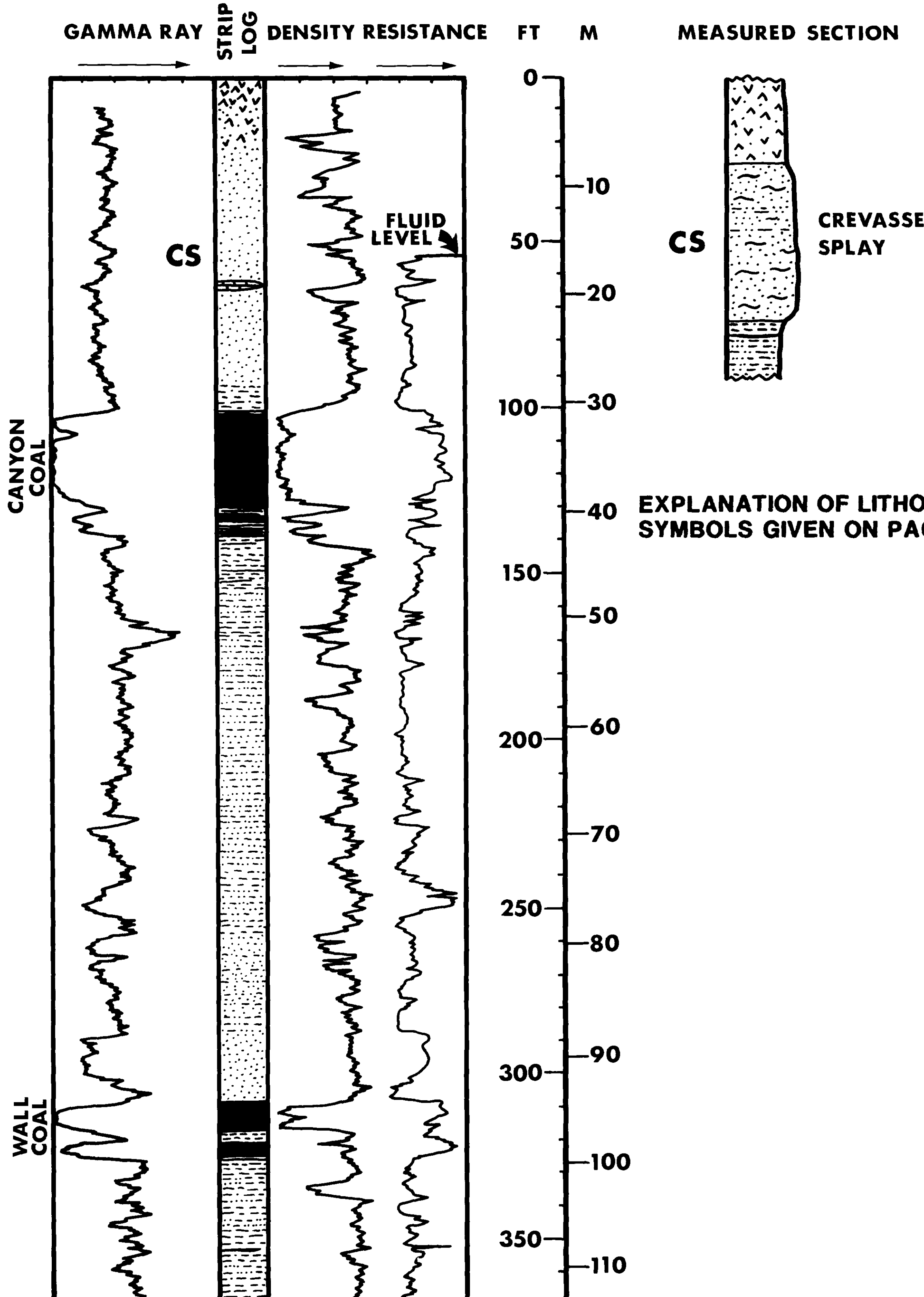


FIG. 4 GEOPHYSICAL AND SAMPLE LOGS OF DRILL HOLE 2A AND NEARBY MEASURED SECTION



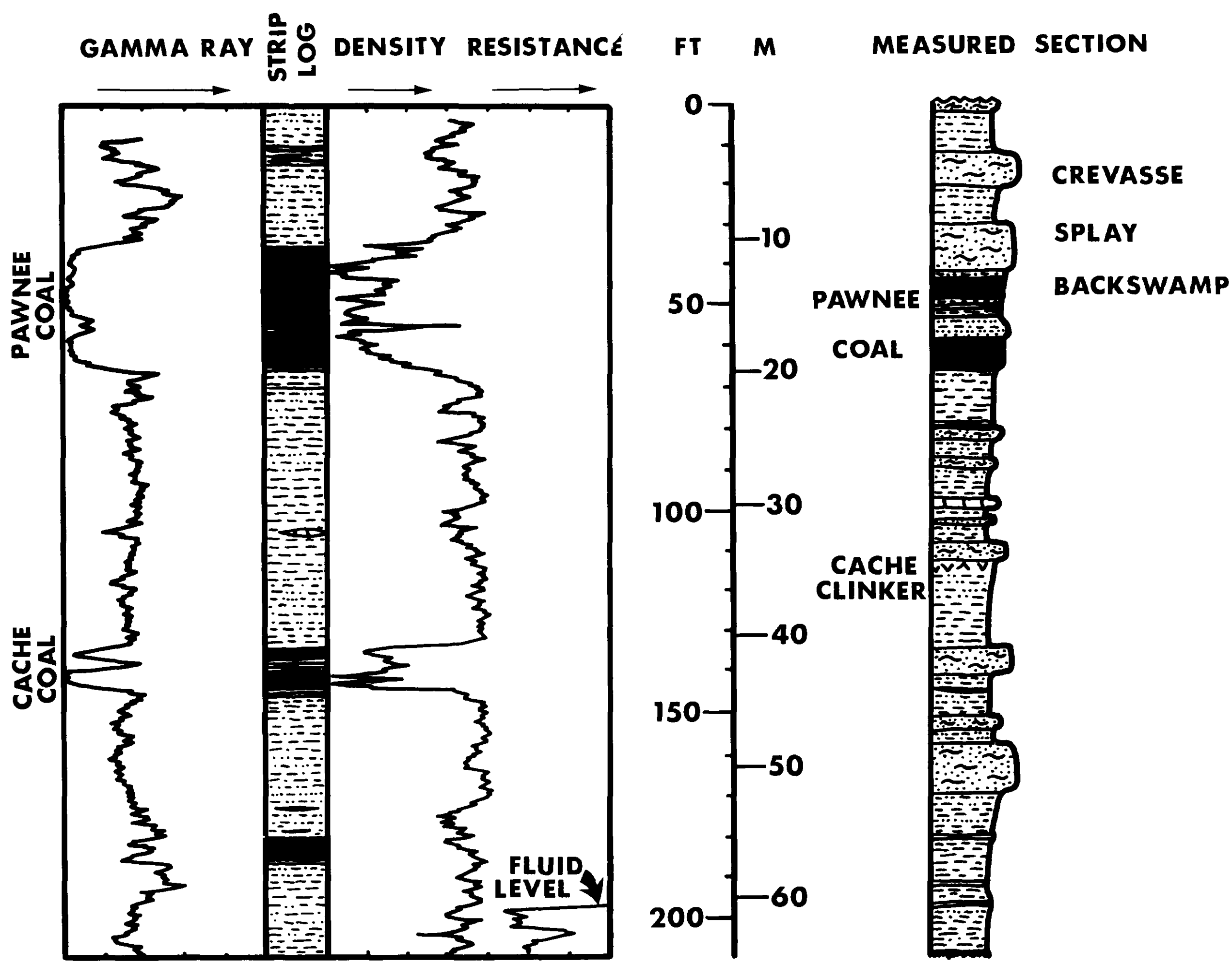
EXPLANATION OF LITHOLOGIC SYMBOLS GIVEN ON PAGE 8

FIG.5 GEOPHYSICAL AND SAMPLE LOGS OF DRILL HOLE 3A AND NEARBY MEASURED SECTION



EXPLANATION OF LITHOLOGIC SYMBOLS GIVEN ON PAGE 8

FIG.6 GEOPHYSICAL AND SAMPLE LOGS OF DRILL HOLE 4A AND NEARBY MEASURED SECTION



EXPLANATION OF LITHOLOGIC SYMBOLS GIVEN ON PAGE 8

FIG. 7 GEOPHYSICAL AND SAMPLE LOGS OF DRILL HOLE 5A AND NEARBY MEASURED SECTION

and high intensity responses, respectively. Sandstones, siltstones, and limestones show moderately higher and lower intensities of gamma ray responses, respectively, than those of the coals, carbonaceous shales, and shales. Positive identification of coal beds is supported by the density log, which usually exhibits very low intensity response in coals. The resistance log is particularly useful in cross checking occurrences of sandstones and interpreting their genetic types by determining their fining-upward (fluvial channel) and coarsening-upward (crevasse splay) grain size characteristics.

The strip logs in Figs. 3 to 7 constructed from descriptions of the drill cuttings (see appendix), display downhole variations of the lithologic units. Visual inspection of the vertical variations of the lithologic units and their log responses permit delineation of vertical lines showing grain size boundaries (shale-siltstone and siltstone-sandstone) of the detrital rocks. These grain size boundaries are plotted onto the gamma ray log allowing differentiation of dominantly shale, siltstone, and sandstone units. In addition, smooth curve lines have been drawn at various places on the gamma-ray logs, which represent averaging of corresponding irregular gamma curves. The smooth curves show in a simplified way deflection patterns that characterize different kinds of sandstone deposited in particular paleoenvironments (e.g. channel and crevasse splay). The gamma-ray log characteristics, therefore, permit generalized interpretation of the paleoenergy levels of the corresponding rocks (McGowen, 1978; Miller and Moore, 1980). That is, the bulk occurrence of grain types (e.g. clays, silts, and sands) is a direct measure of their mode of transport and deposition. In fluvial settings, the sands are transported mainly as bedload and traction load in contrast to the clays and silts, which are transported mainly as suspended load. The chances are that the sands were deposited in high paleoenergy settings such as in channels and crevasse splays and the finer-grained detritus were deposited in quieter paleoenergy settings such as in overbank, floodplain, and lake environments. Thus, the key to understanding the depositional facies of the detrital rocks associated with the coal is their grain size distribution.

The patterns of responses in the gamma ray and density logs can also be correlated with the lithologies of the cores as displayed in Figures 8 and 9. These logs were run at high resolution in order to pick out subtle changes in the physical and chemical properties of the coals. As shown in Figure 8, the gamma ray and density logs of the Anderson and Canyon coals depict pronounced variation in responses where there are shale and carbonaceous shale impurities in the coals. However, in Figure 9, similarly pronounced variation in the response in the gamma ray and density logs are present in apparently homogeneous coal of the Pawnee and Cache coal beds. The variation in the response in logs of these coals probably may be explained by the variations in their ash content (Fishel and Mayer, 1978).

RECOGNITION OF DEPOSITIONAL ENVIRONMENTS

Six depositional modes were recognized in outcrops near the drill holes (Fig. 1): fluvial channel, crevasse splay, overbank-levee, lacustrine delta, lake, and backswamp deposits. Each of these kinds of deposits are identified in Figures 3 through 7.

Direct correlation of these kinds of deposits is possible between the outcrop and laterally equivalent intervals in the drill holes. For example, in Figure 3 the fluvial channel sandstone (C) in the upper part of the measured section can be correlated with a similar deposit in the drill hole. An overbank-levee deposit (L) overlie a fluvial channel deposit and is well developed above the channel sandstone (C) in the upper part of the measured

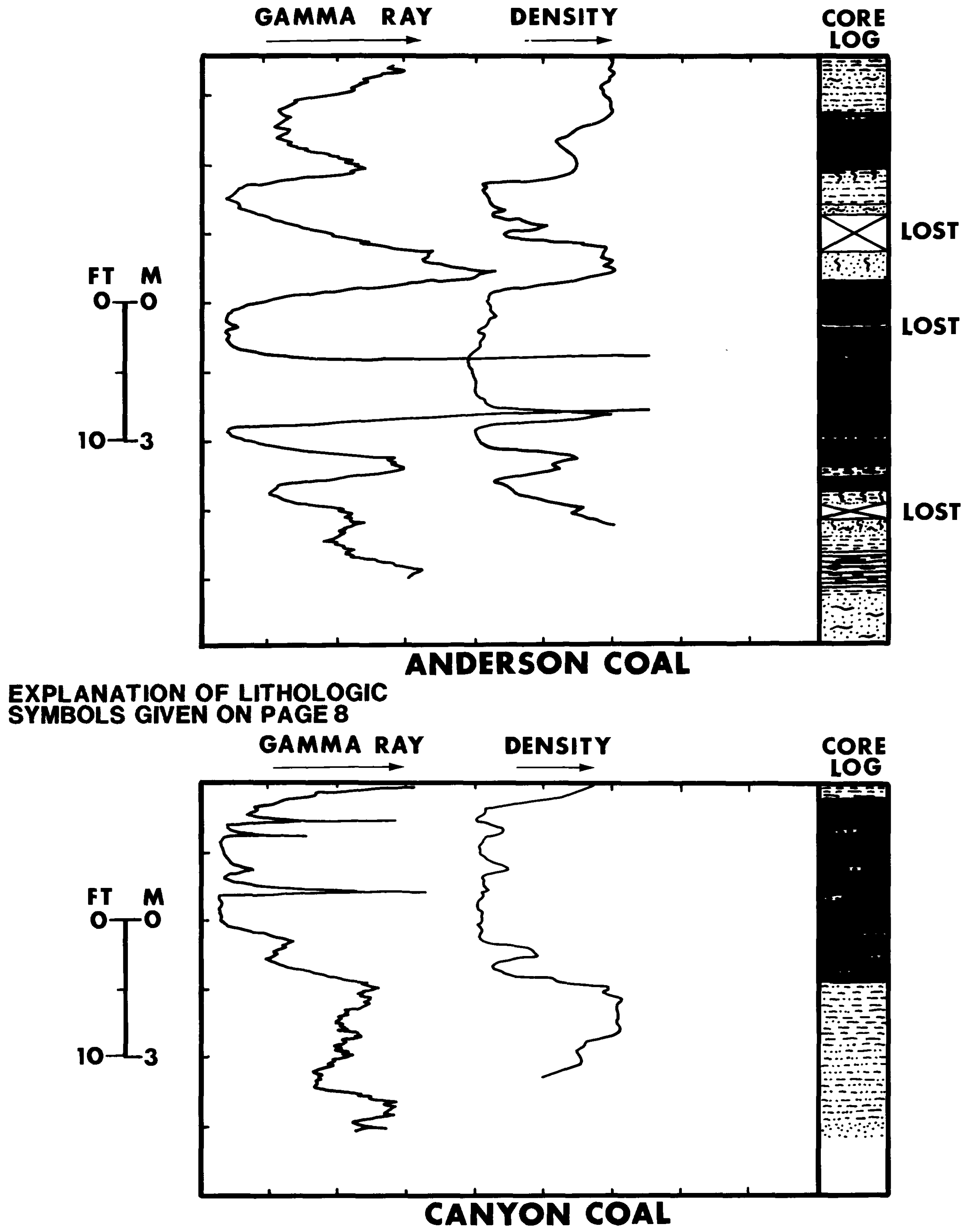
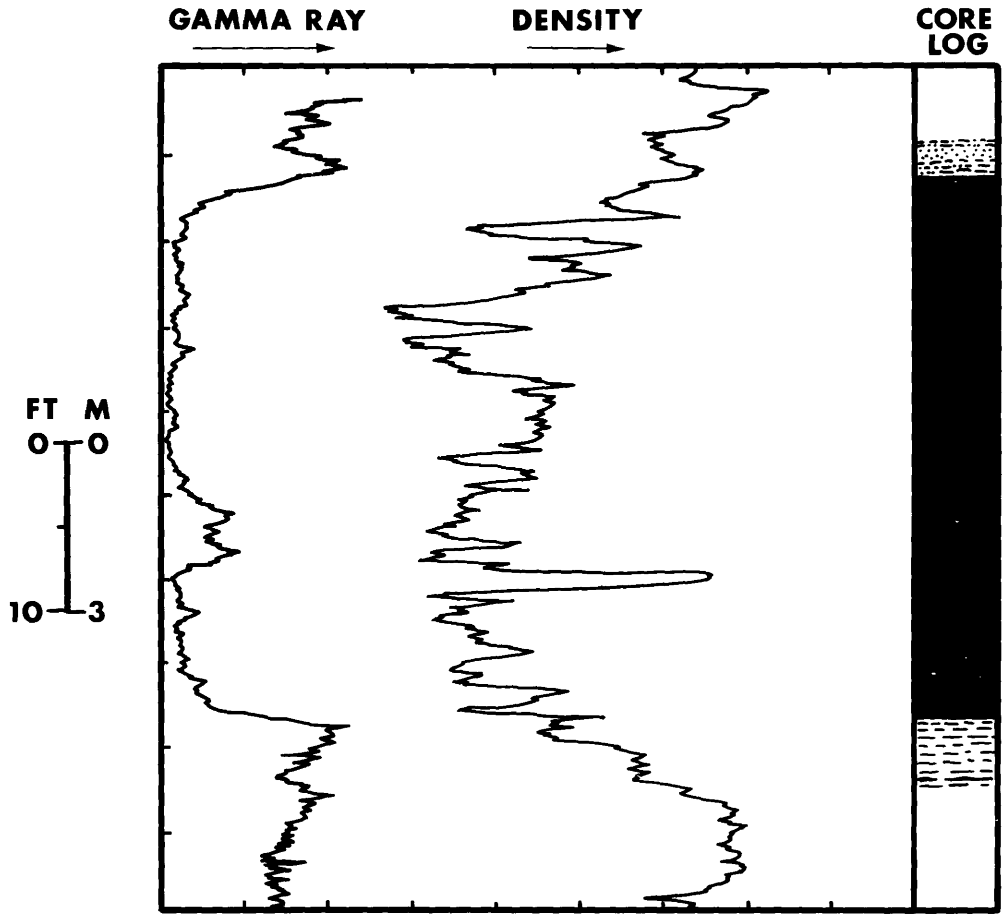
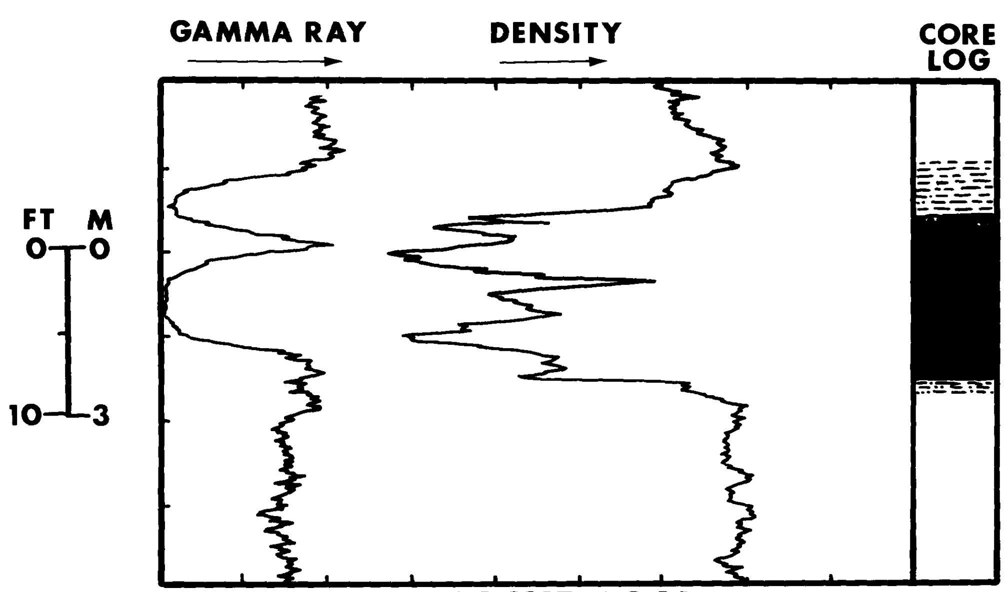


FIG. 8 HIGH RESOLUTION DENSITY AND GAMMA RAY LOGS AND CORE DESCRIPTION OF THE ANDERSON (DRILL HOLE 3A) AND CANYON (DRILL HOLE 4A) COALS AND ADJACENT ROOF AND FLOOR ROCKS



PAWNEE COAL

EXPLANATION OF LITHOLOGIC SYMBOLS GIVEN ON PAGE 8



CACHE COAL

FIG. 9 HIGH RESOLUTION DENSITY AND GAMMA RAY LOGS AND CORE DESCRIPTION OF PAWNEE AND CACHE COAL BEDS (DRILL HOLE 5A) section plotted in Figure 4. The channel-levee deposit, which is a fining-upward sequence, is seen in the simplified gamma ray curve as a line that is concave upward in its lower part and that straightens upward (see Figs. 3 and 4). Crevasse splay sandstones (CS) are well developed in the measured sections illustrated in Figures 3 and 4. The crevasse splay sandstones are recognizable in the corresponding sample and geophysical logs. The gamma ray curve has a roughly rectilinear or "boxlike" profile with rounded corners (Figs. 3 and 4). Diagnostic gamma-ray profiles, however, are not readily apparent in all the logs, perhaps due to the gradational basal and upper contacts of most of the sandstone. Compound curves are well displayed where there are stacked coarsening-upward crevasse splay deposits as shown by beds CS_1, CS_2, CS_3, in Figure 4. In this example, the gamma-ray log tapers toward the middle of each of the crevasse splay sandstones, resulting in a vertical profile of rotated V's that are stacked one atop another.

Perhaps the most diagnostic guide to recognition of depositional environments of the rock types in the subsurface is the presence of freshwater mollusk fossils in the drill samples. Similar occurrences of freshwater mollusk fossils in the measured sections (Figs. 3, 4, and 5) record accumulations in ponded aerated waters in the floodplains of streams. The association of these fossiliferous horizons with coarsening-upward sequences of shale, siltstone, and sandstone (Figs. 3 and 4) suggests accumulation in lacustrine delta settings. In contrast, the occurrence of the mollusk fossils in limestone (Figs 3, 4, and 5) indicates deposition in a lake. Perhaps the measured section in Figure 5, which contains mollusk-bearing limestones and coarsening-upward deposits, represents vertically stacked lake and lacustrine delta sequences. Furthermore, the absence of well-developed coal beds in this sequence attests to the presence of deep-water and well-drained conditions at the time of deposition of the sediments. In areas of the floodplain where poorly drained backswamps formed uninterrupted by overbank-crevasse processes, thick coals, such as the Anderson, Canyon, Wall, Pawnee, and Cache, accumulated.

Although close correlation of beds was possible between outcrops and the subsurface, as partly illustrated in Figures 3 thru 6, correlations could not be made between outcrops and the drill hole in the Bloom Creek locality (Fig.7). In this locality, the drill hole is about 1800 ft away from the measured section or almost twice as far as it was between drill holes and the outcrops at the other localities indicating that the fluvial environments in the Fort Union Formation are highly variable.

The depositional environments of the rock types recognized from the subsurface and outcrop provided only a vertical or one-dimensional arrangement of the depositional packages of the Tongue River Member. Studies of three-dimensional distributions of these depositional packages based on closely-spaced measured sections in the vicinity of the five drill hole sites show that they are temporally areally interrelated (Flores, 1980, 1981). An idealized depositional model showing the temporal areal distribution of the fluvial channel, crevasse splay, overbank-levee, lake, and backswamp and their deposits is depicted in Figure 10. The depositional model can be divided into environmental settings that differ in water energy conditions. An environmental setting that consists of channelized and sheet flows (channel and crevasse splay) are major areas of deposition of mainly coarse detrital rocks such as sandstones. In an environmental setting that consists of standing bodies of water such as lakes and submerged areas of the floodplain, fine detrital rocks, such as shales, settled and limestones precipitated. In transitional settings between these milieu, such as overbank-levee and

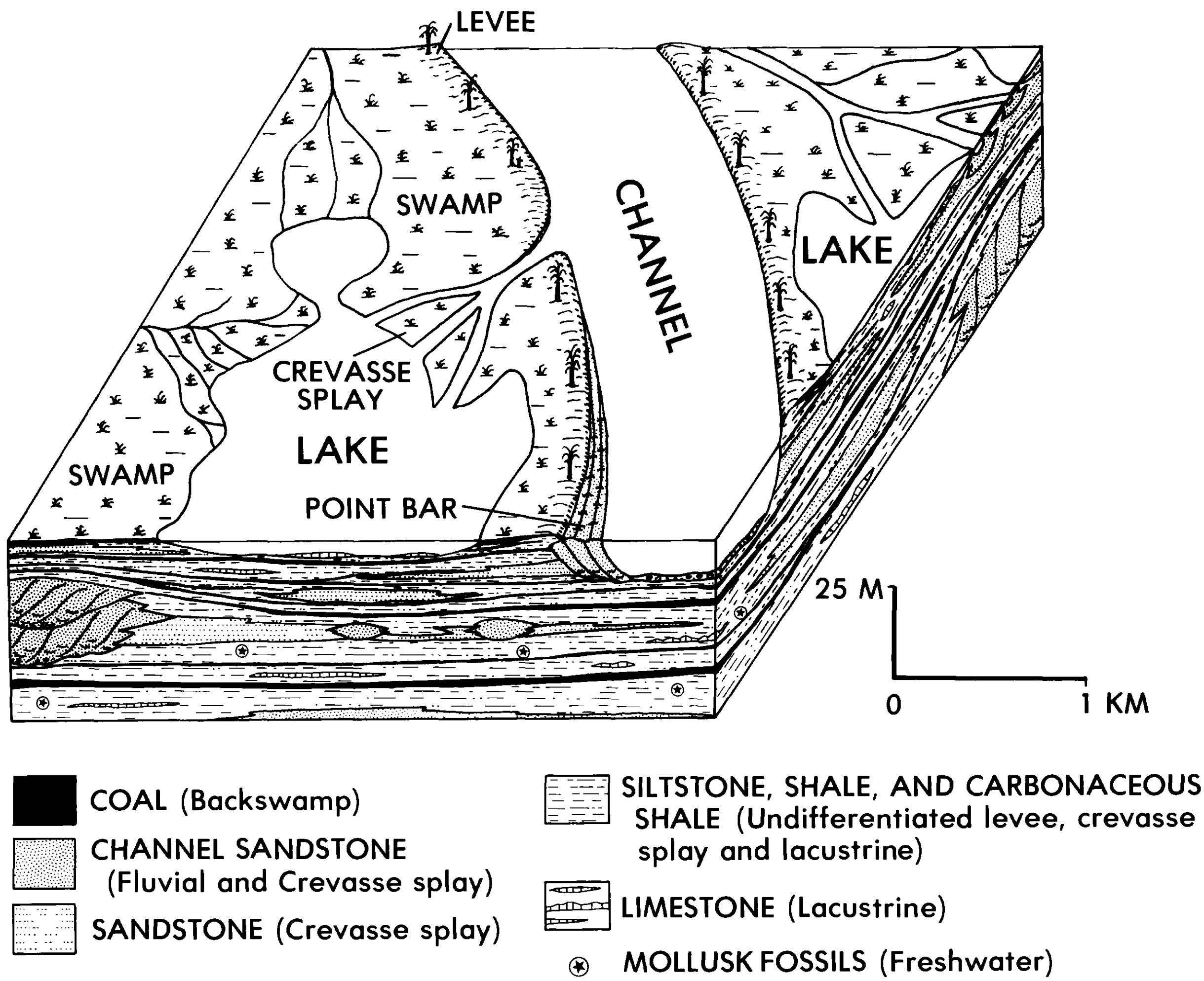


FIG. 10 DEPOSITIONAL MODEL SHOWING TEMPORAL AREAL DISTRIBUTION OF FLUVIAL ENVIRONMENTS AND THEIR DEPOSITS

crevasse margins, intermediate grain-size detrital rocks, such as siltstones, accumulated. These breakdowns of the fluvial environments can therefore be utilized as guides to recognition of specific modes of deposition of detrital rocks as delineated by the shale-siltstone and siltstone-sandstone textural lines plotted on the gamma-ray log in Figures 3 and 4.

CONCLUSION

Geophysical measurements in the form of gamma-ray, density, and resistance logs can be used with some limitations in identifying depositional settings of rocks in the Tongue River Member of the Fort Union Formation in the Powder River area, Wyoming and Montana. Not all genetic types of deposits, however, fit nicely into predetermined log patterns, so a certain amount of subjectivity is involved in the log interpretation. The properties of detrital rocks that are measured or interpreted from the logs are the texture and grain size. Vertical changes of grain size such as fining-upward (fluvial channel) and coarsening-upward (crevasse splay) are best reflected in electrical resistivity logs. However, when the electrical resistivity log is not available, the next most reliable measure of grain size is the gamma ray log. The grain size of the detrital rocks is, in turn, directly related to the paleoenergy conditions of transport and deposition.

Where possible, interpretation of the modes of deposition from geophysical logs should be complimented by sedimentological analysis of equivalent outcrop sequences near the drill hole sites. Outcrops provide better opportunities than drill samples or cores to study the lithology, internal structures, grain size, trace fossil and megafossil content, and nature of contacts of the rock types, and can guide the interpretation of the logs in nearby holes.

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U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole Cabin Creek 1A Elev. 3850 feet Total depth 355 feet

Location SW 1/4 SW 1/4 Sec. 2, T. 55 N., R. 77 W.

County Sheridan State Wyoming Quadrangle Cabin Creek SE

Drilled by USGS Driller Steve Grant Hole size 5/8 inches

Date started 7/23/80 Date completed 8/1/80 Geologist R. M. Flores

Remarks: Sample log modified to conform to geophysical logs and to core samples from hole Cabin Creek 1B

Depth interval (feet)			
From	To	Thickness	Lithologic Description
0	10	10	Gravel, sandy, and silty (alluvium)
10	15	5	Sandstone, gray, silty, with mollusk fossil fragments
15	20	5	Shale, gray, silty, with mollusk fossil fragments
20	23	3	Limestone, gray, with mollusk fossil fragments
23	105	82	Sandstone, buff, very fine grained, with mollusk fossil fragments at the top
105	110	5	Shale, dark gray, carbonaceous
110	115	5	Coal
115	155	40	Siltstone, gray, coal stringers at 120 and 154
155	160	5	Sandstone, gray, fine grained
160	165	5	Shale, dark gray, carbonaceous, with coal stringers
165	166	1	Shale, gray
165	179	14	Sandstone, light gray, fine to medium grained, clay parting at 175
179	215	36	Shale, gray to light brown, silty
215	220	5	Coal and carbonaceous shale
220	290	70	Sandstone, gray, silty, with coal stringer at 240
290	302	12	Coal and carbonaceous shale
302	303	1	Shale, gray, with coal stringers
303	305	2	Coal
305	310	5	Shale, gray
310	315	5	Coal and carbonaceous shale
315	355	40	Siltstone, gray, with fossiliferous limestone stringers at 323 and 340, with shale parting throughout

U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole Cabin Creek 1B Elev. 3850 feet Total depth 322.5 feet

Location SW 1/4 SW 1/4 Sec. 2, T. 55 N., R. 77 W.

County Sheridan State Wyoming Quadrangle Cabin Creek SE

Drilled by USGS Driller Steve Grant Hole size 5/8 inches

Date started 7/23/80 Date completed 8/1/80 Geologist R. M. Flores

Remarks: Hole is 20 ft east of Cabin Creek 1A

Cored intervals (in feet)

Core No.	From	To	Length of cored interval
1	289	303	14
2	303	310.6	7.6
3	310.6	322.5	11.9

Depth interval (feet)

From	To	Thickness	Core Description
289.0	289.6	0.6	Lost
289.6	293.6	4.0	Shale, dark gray, silty
293.6	294.1	0.5	Lost
294.1	294.4	0.3	Siltstone, gray to brown, with carbonaceous shale stringers near the base
294.4	294.8	0.4	Coal and carbonaceous shale
294.8	302.5	7.7	Coal, black, hard, with sandstone lenses at 295.3 and 301.7, cleat fracture at 299.2. UPPER SMITH BED
302.5	302.6	0.1	Shale, dark gray, carbonaceous shale
302.6	303.0	0.4	Coal and carbonaceous shale
303.0	304.1	1.1	Coal, black, hard, cleat fracture
304.1	304.3	0.2	Shale, gray, with coal stringers
304.3	305.7	1.4	Shale, dark gray, carbonaceous
305.7	308.5	2.8	Shale, gray to brown, with coal stringers at 305.4 and 305.7, mollusk fossil fragments at 306.7, 306.9, 307,3, and 307.8

Hole No. Cabin Creek 1B

Depth interval (feet)

From	To	Thickness	Core Description
308.5	310.6	2.0	Lost
310.6	311.7	1.2	Shale, gray to brown, with carbonaceous shale stringers throughout
311.7	311.8	0.1	Shale, dark gray, carbonaceous
311.8	312.5	0.7	Shale, gray to brown
312.5	317.5	5.0	Coal, black, hard, with clay lenses from 312.7 to 312.8, cleat fractures at 313.1, 313.7, 316.7, and 317.2. LOWER SMITH BED
317.5	320.1	2.6	Sandstone, gray, silty to very fine grained, with ripple laminations
320.1	322.5	2.4	Lost

U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole Cabin Creek 2A Elev. 3940 feet Total depth 595 feet

Location SE 1/4 NE 1/4 Sec. 27 , T. 56 N., R. 77 W.

County Sheridan State Wyoming Quadrangle Cabin Creek SE

Drilled by USGS Driller Steve Grant Hole size 5/8 inches

Date started 7/1/80 Date completed 7/23/80 Geologist R. M. Flores

Remarks: Sample log modified to conform to geophysical logs and to core samples from hole Cabin Creek 2B

Depth interval (feet)			
From	To	Thickness	Lithologic Description
0	5	5	Gravel, sandy, with clay lenses (alluvium)
5	31	26	Sandstone, gray to brown, fine grained, clay lense at 17
31	48	17	Shale, gray, silty, limestone stringer at 39
48	60	12	Shale, dark gray, carbonaceous, coal lenses near the base
60	63	3	Sandstone, gray, fine grained
63	66	3	Limestone, gray, with mollusk fossil fragments
66	97	31	Shale, gray, silty, with mollusk fossil fragments, sandstone lenses from 85 to 97
97	128	31	Sandstone, light gray, very fine to medium grained, fining-upward sequence
128	130	2	Shale, dark gray, carbonaceous
130	132	2	Shale, dark gray, carbonaceous, with coal lenses throughout
132	137	5	Siltstone, light gray
137	139	2	Shale, dark gray carbonaceous
139	140	1	Siltstone, light gray, clayey
140	143	3	Sandstone, light gray to gray, very fine grained
143	145	2	Sandstone, light gray, very fine grained, calcareous
145	154	9	Sandstone, gray, very fine grained
154	157	3	Shale, dark gray, carbonaceous, with coal lenses throughout
157	167	10	Shale, gray, silty, with calcareous siltstone lens at 164
167	170	3	Coal, dirty, with carbonaceous shale lenses
170	205	35	Sandstone, light gray, very fine grained, with carbonaceous shale stringer at 195, with shale lens at 200, with limestone stringers at 201 and 205
205	240	35	Siltstone, light gray, with limestone lens from 206-208, sandy from 230-240
240	242	2	Coal, dirty, with carbonaceous shale lenses
242	248	6	Shale, dark gray, carbonaceous
248	253	5	Coal, dirty, with carbonaceous shale lenses

Depth interval (feet)			
From	To	Thickness	Lithologic Description
253	255	2	Sandstone, gray to brown, fine grained
255	291	36	Sandstone, light gray, silty to fine grained, with clay lens at 265, with limestone lens at 276
291	300	9	Coal
300	316	16	Shale, light gray, silty, with coal stringer at 315
316	320	4	Sandstone, gray to brown, very fine grained, with shale lenses throughout
320	328	8	Coal, dirty, with carbonaceous shale lenses
328	337	9	Shale, gray, silty
337	340	3	Siltstone, gray, calcareous, well indurated
340	356	16	Shale, light gray, silty
356	357	1	Siltstone, gray, calcareous, with mollusk fossil fragments
357	389	32	Shale, light gray, with mollusk fossil fragments near top
389	445	56	Sandstone, gray to brown, fine to medium grained, with shale parting at 405, with coal stringer at 444
445	467	22	Shale, gray
467	470	3	Shale, dark gray, carbonaceous, with coal lenses
470	477	7	Shale, gray to brown, silty, with mollusk fossil fragments
477	479	2	Coal, with mollusk fossil fragments
479	509	30	Shale, gray to brown, silty with coal stringers at 480, 485, and 494
509	523	14	Coal
523	595	72	Siltstone, gray, with shale and sandstone lenses throughout

U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole: Cabin Creek 2B Elev. 3940 feet Total depth 527 feet

Location: SE 1/4 NE 1/4 Sec. 27, T. 56 N., R. 77 W.

County: Sheridan State: Wyoming Quadrangle: Cabin Creek SE

Drilled by: USGS Driller: Steve Grant Hole size 5/8 inches

Date started: 7/1/80 Date completed: 7/23/80 Geologist: R. F. Flores

Remarks: Hole is 20 ft northeast of Cabin Creek 2A

Cored intervals (in feet)

Core No.	From	To	Length of cored interval	Core No.	From	To	Length of cored interval
1	47.0	52.0	5	5	489.0	495.0	6
2	52.0	66.0	14	6	495.0	506.0	11
3	293.0	307.0	14	7	506.0	513.0	7
4	323.0	333.6	10.6	8	513.0	527.0	14

Depth interval (feet)

From	To	Thickness	Core Description
47.0	47.2	0.2	Shale, gray
47.2	48.0	0.8	Shale, gray, silty
48.0	48.2	0.2	Shale, dark gray, with organic laminations
48.2	49.3	1.1	Shale, dark gray, silty, carbonaceous, with coal lens at 48.7
49.3	51.9	2.6	Coal, black, hard, with shale lens at 49.4, with bands of pyrite from 49.7 to 49.7 and 50.9 to 51.8, with cleat fractures at 49.8, 50.6 and 50.8. ARVADA BED
51.9	52.0	0.1	Lost
52.0	58.0	6.0	Coal, black, hard, with carbonaceous shale lens at 52.2, 55.3, and 55.4, cleat fractures at 55.6, 56.0, 57.0, 57.4, and 57.9. ARVADA BED

Depth interval (feet)			
From	To	Thickness	Core Description
58.0	60.1	2.1	Coal and carbonaceous shale, with disseminated pyrite at 58.6, with fractures at 59.0, 59.2, and 59.7
60.1	61.9	1.8	Siltstone, gray, clayey, with shale lenses 61.3 to 61.6, with coal and carbonaceous shale lenses from 61.7 to 61.9
61.9	63.0	2.1	Sandstone, gray, fine grained, with ripple laminations, with mollusk fossil fragments
63.0	66.0	3.0	Lost
293.0	294.7	1.7	Lost
294.7	295.6	0.9	Shale, dark gray, carbonaceous, with fractures from 295.1 to 295.4
295.6	303.4	7.8	Coal, black, hard, with shale lenses at 296.3 and 296.6, with cleat fractures at 296.1, 297.7, 299.6, 300.8, 301.5, and 302.6. UPPER SMITH BED
303.4	303.7	0.3	Shale, gray, with coal stringers at 303.6
303.7	303.9	0.2	Shale, dark gray, carbonaceous
303.9	307.0	3.1	Shale, gray to brown, with coal stringers at 305.2, 305.4, 305.6, 305.8, 306.1, and 306.5
323.0	323.4	0.4	Shale, dark gray, carbonaceous
323.4	328.1	4.7	Coal, black, hard, with cleat fractures at 323.5, 323.8, 324.0, 324.3, 324.5, and 326.5, with resin lenses at 327.1. 327.6, and 327.7, with pyrite bands from 325.1 to 325.2. LOWER SMITH BED
328.1	331.5	3.4	Shale, gray, silty, with carbonized rootlets at 331.5
331.5	333.6	2.1	Lost
489.0	489.7	0.7	Shale, light gray, silty, with carbonaceous shale stringers
489.7	490.5	0.8	Lost
490.5	490.7	0.2	Shale, light gray, silty, with carbonaceous shale stringers
490.7	491.3	0.6	Shale, dark gray, carbonaceous
491.3	495.0	3.7	Coal, black, hard, with cleat fractures from 492.0 to 492.7 and at 493.8, 494.5
495.0	495.5	0.5	Shale, light gray, silty
495.5	496.6	1.1	Coal, black, hard, with shale partings at 495.7, 495.9, and 496.0
496.6	497.3	0.7	Siltstone, gray, clayey
497.3	502.6	5.3	Shale, light gray, with coal stringers at 498.1, 499.6, 499.8, and 500.2, with carbonized rootlets at 498.3.
502.6	506.0	3.4	Lost
506.0	506.1	0.1	Coal, black, hard

Depth interval (feet)			
From	To	Thickness	Core Description
			ANDERSON BED
506.1	506.9	0.8	Lost
506.9	513.0	6.1	Coal, black, powdery, with bands of pyrite at 510.2 and 511.3, with cleat fractures from 507.2 to 507.8 and at 508.5, 510.1
513.0	517.9	4.9	Coal, black, bony, with bands of pyrite at 514.5, 516.3, 516.9, and 517.2, with cleat fractures at 513.6, 514.1, and 514.7, with shale lenses from 517.3 to 517.5
517.9	518.3	0.4	Coal and carbonaceous shale
518.3	518.6	0.3	Shale, gray to brown
518.6	522.3	3.7	Coal, black, bony, with resin lenses at 518.9, 519.2, and 521.7, with cleat fractures at 519.6, 520.5, 521.6, and 521.8
522.3	522.6	0.3	Shale, dark gray, carbonaceous with coal stringers
522.6	523.2	0.6	Shale, gray, silty
523.2	523.8	0.6	Sandstone, light gray, very fine grained with ripple laminations, with carbonized rootlets
523.8	527.0	3.2	Lost

U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole Cabin Creek 3A Elev. 3652 feet Total depth 417 feet

Location SE 1/4 SE 1/4 Sec. 14, T. 56 N., R. 77 W.

County Sheridan State Wyoming Quadrangle Cabin Creek SE

Drilled by USGS Driller Steve Grant Hole size 5/8 inches

Date started 6/18/80 Date completed 6/25/80 Geologist R. M. Flores

Remarks: Sample log modified to conform to geophysical logs and to core samples from hole Cabin Creek 3B

Depth interval (feet) From	To	Thickness	Lithologic Description
0	3	3	Gravel, sandy, (alluvium)
3	15	12	Shale, gray, silty, trace of gypsum
15	35	20	Siltstone, gray to brown, with shale parting at 25, with carbonaceous shale stringer at 34
35	65	30	Siltstone, gray, clayey, with mollusk fossil fragments throughout
65	91	26	Siltstone, light gray, sandy, with carbonaceous shale stringers at 75 and 87
91	100	9	Siltstone, dark gray, clayey, with coal stringers
100	115	15	Siltstone, gray with clay partings
115	140	25	Shale, gray, silty, with limestone lenses at 118 and 139, with coal stringers at 130 and 137
140	168	28	Siltstone, gray to brown, clayey
168	169	1	Coal, bony
169	183	14	Shale, gray to brown, silty
183	201	18	Coal, with shale partings from 185 to 187
201	217	16	Shale, gray, with coal stringers, with carbonaceous shale stringers
217	245	28	Siltstone, gray, with limestone lens near the top
245	260	15	Siltstone, gray, clayey
260	265	5	Coal, bony, with carbonaceous shale stringers
265	288	23	Shale, light gray, with limestone lens at 276
288	299	11	Coal
299	336	37	Shale, gray, silty, with limestone lens at 305
336	355	19	Sandstone, gray, fine grained, calcareous, with coal stringer at 345
355	415	60	Shale, gray, silty, with ironstone nodule and coal stringer at 380
415	417	2	Lost

U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole Cabin Creek 3B Elev. 3652 feet Total depth 305 feet

Location SE 1/4 SE 1/4 Sec. 14, T. 56 N., R. 77 W.

County Sheridan State Wyoming Quadrangle Cabin Creek SE

Drilled by USGS Driller Steve Grant Hole size 5/8 inches

Date started 6/18/80 Date completed 6/25/80 Geologist R. M. Flores

Remarks: Hole is 20 ft southeast of Cabin Creek 3A

Cored intervals (in feet)

Core No.	From	To	Length of cored interval	Core No.	From	To	Length of cored interval
1	173.0	186.0	13	5	211.0	221.0	10
2	186.0	192.1	6.1	6	255.0	267.0	12
3	192.1	205.0	12.9	7	277.0	291.0	14
4	205.0	211.0	6	8	291.0	305.0	14

Depth interval (feet) From	To	Thickness	Core Description
173.0	173.6	0.6	Shale, black, carbonaceous, silty
173.6	174.7	1.1	Sandstone, light gray, medium grained, with ripple laminations
174.7	176.6	1.9	Siltstone, dark gray, sandy near the top, with carbonaceous shale lenses near the base
176.6	180.7	4.1	Coal, black, bony, with shale lens at 177.4, with cleat fractures at 172.2 and 180.5
180.7	183.5	2.8	Siltstone, gray, with carbonized rootlets near the top, with shale lenses near the base
183.5	184.0	0.5	Sandstone, gray, very fine grained, wtih ripple laminations defined by clay particles
184.0	186.0	2.0	Lost

Depth interval (feet)			
From	To	Thickness	Core Description
186.0	186.8	0.8	Lost
186.8	188.6	1.8	Sandstone, gray, very fine grained, with carbonized rootlets at 187.5, with ripple laminations
188.6	192.0	3.4	Coal, black, with shale lenses throughout, with cleat fractures lined with pyrite at 190.8
192.0	192.1	0.1	Lost
192.1	200.0	7.9	Coal, black, hard, with cleat fractures throughout, with heavy dessiminated pyrite at 196.6. ANDERSON BED
200.0	200.1	0.1	Shale, black, carbonaceous (radioactive unit - see geophysical log)
200.1	202.5	2.4	Coal, black, hard, with cleat fracture and pyrite at 202.0, with resin lenses throughout
202.5	202.9	0.4	Shale, black, carbonaceous, with coal lenses
202.9	203.9	1.0	Coal, black, hard, with shale lenses near the top, with resin lenses throughout, with band of pyrite at 203.9
203.9	205.0	1.1	Shale, gray, silty, with carbonized rootlets
205.0	205.9	0.9	Lost
205.9	207.4	1.5	Sandstone, gray, very fine grained, clayey near the base, with pyrite nodules throughout, with ripple laminations, with carbonized rootlets
207.4	208.2	0.8	Shale, gray, silty, with carbonaceous shale lenses near the base
208.2	211.0	2.8	Shale, black, carbonaceous, with coal stringers from 208.7 to 209.1, 209.4 to 209.5, and 209.8 to 210.6
211.0	211.5	0.5	Shale, black, carbonaceous, with coal lenses
211.5	212.0	0.5	Sandstone, gray, very fine grained, with shale lenses
212.0	219.8	7.8	Sandstone, light gray, very fine grained, with carbonaceous shale lenses at 217.1, 217.5 and 219.3, with band of pyrite at 218.1, with ripple laminations
219.8	221.0	1.2	Lost
255.0	256.0	1.0	Shale, dark gray
256.0	257.2	1.2	Shale, black, carbonaceous, with coal lenses throughout
257.2	258.1	0.9	Coal, black, with carbonaceous shale lenses. LOCAL BED
258.1	258.3	0.2	Coal, black, bony, with cleat fractures
258.3	261.1	2.8	Coal, black, with carbonaceous shale lenses from 259.7 to 259.9, with bands of pyrite at 258.4, 259.0 and from 259.4 to 259.7

Depth interval (feet)			
From	To	Thickness	Core Description
261.1	263.0	1.9	Shale, gray, with carbonaceous shale lens at 262.1, with carbonized rootlets near the top
263.0	263.2	0.2	Shale, gray, silty, with carbonized rootlets
263.2	264.6	1.4	Shale, gray, with carbonaceous shale lenses
264.6	266.3	1.7	Shale, gray, silty, with carbonaceous shale lens at 263.1
266.3	267.0	0.7	Shale, gray, with carbonaceous shale lenses throughout
277.0	277.2	0.2	Lost
277.2	281.1	3.9	Shale, gray, with carbonaceous shale lenses near the base
281.1	291.0	9.9	Coal, black, with shale lenses near the top, with bands of pyrite at 281.7, 281.8, and 283.9, with cleat fractures near the base. CANYON BED
291.0	294.4	3.4	Coal, black, with disseminated pyrite at the top, with shale lenses at 292.7 and 293.7, with cleat fractures from 292.1 to 292.5
294.4	299.0	4.6	Shale, light gray, silty
299.0	305.0	6.0	Siltstone, gray, clayey, calcareous and indurated from 299.0 to 299.8, sandy near base

U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole Cabin Creek 4A Elev. 3560 feet Total depth 375 feet

Location SW 1/4 SW 1/4 Sec. 31, T. 57 N., R. 76 W.

County Sheridan State Wyoming Quadrangle Cabin Creek SE

Drilled by USGS Driller Steve Grant Hole size 5/8 inches

Date started 8/6/80 Date completed 8/15/80 Geologist R. M. Flores

Remarks: Sample log modified to conform to geophysical logs and to core samples from Hole Cabin Creek 3B

Depth interval (feet)			
From	To	Thickness	Lithologic Description
0	10	10	Gravel, sandy, with clinker in the lower part (alluvium)
10	99	89	Sandstone, buff, very fine grained, coarsens downwards, with calcareous stringers from 67 to 70, with shale lenses near the base, with clinker from 10 to 25
99	100	1	Coal, powdery
100	101	1	Sandstone, gray, very fine grained
101	136	35	Coal, powdery, with carbonaceous shale lenses throughout but concentrated from 129 to 132, hard coal from 120 to 125
136	270	134	Shale, light gray, silty, with carbonaceous shale lenses and carbonized rootlets from 146 to 151, with limestone lenses from 246 to 250
270	308	38	Sandstone, light gray, fine grained
308	325	17	Coal
325	375	50	Shale, light gray, silty, with coal stringers at 353

U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole Cabin Creek 4B Elev. 3560 feet Total depth 329.4 feet

Location SW 1/4 SW 1/4 Sec. 31, T. 57 N., R. 76 W.

County Sheridan State Wyoming Quadrangle Cabin Creek SE

Drilled by USGS Driller Steve Roberts Hole size 5/8 inches

Date started 8/6/80 Date completed 8/15/80 Geologist R. M. Flores

Remarks: Hole 25 ft southeast of Cabin Creek 4A

Cored intervals (in feet)

Core No.	From	To	Length of core recovered	Core No.	From	To	Length of core recovered
1	95.0	110.0	15	4	310.0	324.6	14.6
2	110.0	125.0	15	5	325.0	329.4	4.4
3	125.0	138.7	13.7				

Depth interval (feet)

From	To	Thickness	Core Description
95.0	97.4	2.4	Siltstone, gray, with shale partings, with ripple laminations
97.4	98.5	1.1	Shale, gray, with carbonaceous shale lenses throughout
98.5	98.9	0.4	Shale, gray, with abundant carbonaceous shale lenses near the base
98.9	99.05	0.15	Shale, black, carbonaceous
99.05	100.9	1.85	Siltstone, gray, with abundant carbonaceous shale lenses near the base
100.9	110.0	9.1	Coal, black, hard, with shale lens at 101. CANYON BED
110.0	125.0	15	Coal, black, hard, with resin lens at 113.9, with cleat fractures lined by pyrite throughout
125.0	128.1	3.1	Coal, black, hard, with pyrite along cleat fractures throughout

Depth interval (feet)			
From	To	Thickness	Core Description
128.1	128.3	0.2	Shale, black, carbonaceous, with coaly stringers
128.3	130.65	2.35	Shale, gray, silty, with carbonaceous shale lenses, with carbonized rootlets from 130.1 to 130.4
130.65	131.2	0.55	Shale, black, carbonaceous, with coal stringers
131.2	134.1	2.9	Coal, black, hard
134.1	135.8	1.7	Shale, black, carbonaceous, with coal stringers throughout but concentrated at 134.85
135.8	136.4	0.6	Coal, black, hard
136.4	136.65	0.25	Coal and carbonaceous shale
136.65	138.7	2.05	Shale, black, carbonaceous, with coal stringers from 137.3 to 137.35
310.0	310.3	0.3	Shale, gray, with carbonaceous shale lenses
310.3	316.85	6.55	Coal, black, hard. WALL BED
316.85	317.0	0.15	Coal and carbonaceous shale lenses
317.0	317.4	0.4	Coal, black, hard
317.4	318.95	1.55	Shale, black, carbonaceous, with coal stringers throughout, with gray shale lenses from 318.4 to 318.5
318.95	324.6	5.65	Coal, black, hard
325.0	325.2	0.2	Siltstone, gray, with carbonaceous shale lenses
325.2	325.55	0.35	Shale, black, carbonaceous
325.55	326.1	0.55	Shale, gray, silty, with carbonaceous shale lenses at 325.65
326.1	326.4	0.3	Shale, black, carbonaceous
326.4	326.9	0.5	Shale, gray, silty, with carbonaceous shale lenses
326.9	327.05	0.15	Shale, black, carbonaceous
327.05	329.4	2.35	Shale, gray, silty, with carbonaceous shale lenses throughout, with carbonized rootlets from 328.8 to 329.2

U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole Bloom Creek 5A Elev. 3480 feet Total depth 215 feet

Location NW 1/4 NW 1/4 Sec. 1, T. 8 S., R. 48 E.

County Powder River State Montana Quadrangle Bloom Creek

Drilled by USGS Driller Steve Roberts Hole size 5/8 inches

Date started 8/16/80 Date completed 8/18/80 Geologist R. M. Flores

Remarks: Sample log modified to conform to geophysical logs and to core samples from hole Bloom Creek 5B

Depth interval (feet) From	To	Thickness	Lithologic Description
0	5	5	Siltstone, gray, sandy
5	10	5	Shale, dark brown, with carbonaceous shale lenses
10	15	5	Shale, black, carbonaceous, with coal lenses
15	20	5	Shale, gray, with siltstone and coal lenses
20	35	15	Shale, gray, silty, with coal lenses from 20 to 25 and from 30 to 35
35	65	30	Coal
65	70	5	Coal and carbonaceous shale
70	105	35	Shale, gray, with siltstone lenses from 75 to 85
105	110	5	Limestone, gray, with shale lenses
110	120	10	Shale, gray, calcareous near the base
120	125	5	Shale, gray, silty, with limestone lenses
125	130	5	Siltstone, gray, calcareous
130	135	5	Shale, gray, silty
135	140	5	Coal and carbonaceous shale
140	145	5	Coal
145	150	5	Shale, black, carbonaceous, with gray shale lenses
150	160	10	Shale, gray, silty
160	165	5	Siltstone, gray, with shale lenses near the top
165	170	5	Sandstone, gray, very fine grained
170	180	10	Siltstone, gray, with coal stringers throughout
180	188	8	Coal and carbonaceous shale
188	190	2	Sandstone, gray, very fine grained, with shale lenses near the top
190	205	15	Shale, gray, silty
205	210	5	Shale, dark gray, with coal stringers throughout
210	215	5	Shale, gray, silty

U.S. GEOLOGICAL SURVEY
Branch of Coal Resources

Hole Bloom Creek 5B Elev. 3480 feet Total depth 143.6 feet

Location NW 1/4 NW 1/4 Sec. 1, T. 8 S., R. 48 E.

County Powder River State Montana Quadrangle Bloom Creek

Drilled by USGS Driller Steve Roberts Hole size 5/8 inches

Date started 8/16/80 Date completed 8/18/80 Geologist R. M. Flores

Remarks: Hole 25 ft northeast of Bloom Creek 1A

Cored intervals (in feet)

Core No.	From	To	Length of cored interval	Core No.	From	To	Length of cored interval
1	30	42.9	12.9	4	130	143.6	13.6
2	42.9	56.2	13.3				
3	56.2	67.9	11.7				

Depth interval (feet)

From	To	Thickness	Core Description
30.0	30.2	0.2	Siltstone, gray, with carbonaceous shale lenses
30.2	30.7	0.5	Siltstone, dark gray, sandy, with ripple laminations
30.7	31.65	0.95	Siltstone, gray, with coal stringers at 30.9, with ripple laminations marked by organic matter near the top
31.65	31.7	0.05	Coal, black, bony. PAWNEE BED
31.7	42.9	11.2	Coal, black, with shale lenses at 31.75, 32.9, and 32.85
42.9	56.2	13.3	Coal, black, with some gypsum throughout, with abundant pyrite nodules at 57.7, with bands of pyrite throughout
56.2	63.7	7.5	Coal, black, with shale stringers from 61.4 to 61.6, with gypsum and pyrite nodules throughout
63.7	63.9	0.2	Shale, black, carbonaceous

Hole No. Bloom Creek 5B Page 2 of 2

Depth interval (feet)			
From	To	Thickness	Core Description
63.9	67.9	4.0	Shale, gray, silty, with carbonaceous shale lenses from 67.2 to 67.3 and near the base, with coal stringer at 67.6
130.0	133.4	3.4	Shale, gray, silty
133.4	143.05	9.65	Coal, black, hard, with shale lens at 133.45, 136.7, 137.05, and 137.1, with carbonaceous shale lens at 135.0, with pyrite lenses from 137.1 to 137.8, with resin stringers from 140.65 to 140.85, with gypsum throughout. CACHE BED
143.05	143.6	0.55	Siltstone, gray, with carbonaceous shale lenses