Coal Resources and Cenozoic Geology of the Girard Coal Field, Richland County, Montana

GEOLOGICAL SURVEY BULLETIN 1310

Prepared as part of the Department of the Interior program for the development of the Missouri River basin

Coal Resources and Cenozoic Geology of the Girard Coal Field, Richland County, Montana

By GEORGE E. PRICHARD *and* EDWIN R. LANDIS

GEOLOGICAL SURVEY BULLETIN 1310

Prepared as part of the Department of the Interior program for the development of the Missouri River basin

A study of an area of 1,000 square miles in easternmost Montana bounded by the Missouri and Yellowstone Rivers

GOVERNMENT PRINTING OFFICE, WASHINGTON : 1975

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, ***Secretary***

GEOLOGICAL SURVEY

V. E. McKelvey, ***Director***

Library of Congress Cataloging in Publication Data
Prichard, George Edwards, 1916-
Coal resources and Cenozoic geology of the Girard coal field, Richland County, Montana.
(Geological Survey Bulletin 1310)
"Prepared as part of the Department of the Interior program for the development of the Missouri River basin."
Bibliography: p.
Supt. of Docs. No.: I 19.3:1310
1. Coal mines and mining–Montana–Richland Co. 2. Geology, Stratigraphic–Cenozoic.
I. Landis, Edwin Robert, 1926- joint author. II. Title. III. Series: United States Geological Survey Bulletin 1310.
QE75.B9 No. 1310 [TN805.M9] 557.3'08s [553'.2'0978623]
74-16471

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 – Price $2.60 (paper cover)
Stock Number 024-001-02615-5

CONTENTS

Page

Abstract 1
Introduction 1
  Previous surveys and reports 2
  Present investigation 4
Stratigraphy 5
  Tertiary System 5
    Paleocene Series 5
      Tongue River Member of the Fort Union Formation 6
    Miocene or Pliocene Series 9
      Flaxville Gravel 9
  Quaternary System 12
    Pleistocene Series 12
      Cartwright Gravel 12
      Crane Creek Gravel 14
      Early Wisconsin(?) drift 16
        Ground moraine 19
        Stratified drift 19
        Melt-water and diversion-channel deposits 20
        Eskers 20
        Kames 20
    Pleistocene and Holocene alluvium 21
      Flood-plain terraces and flood-channel alluvium 21
Structure 22
Geomorphology 22
  Valley of the Yellowstone River 22
  Valley of the Missouri River 25
  Glaciation 25
  Postglacial landscape changes 28
Economic geology 29
  Oil and gas 29
  Coal 29
    Physical and chemical properties 29
    Burning of the coal beds 38
    The coal beds 39
    Mining 43
    Estimation and classification of coal resources 44
    Summary of resource estimates 47
    Township descriptions 56
References 87

ILLUSTRATIONS

PLATE 1. Geologic map of the Girard coal field . . . . . In pocket
2. Graphic sections of coal beds in T. 26 N., Rs. 55—58 E., and in T. 27 N., Rs. 55—57 E., Girard coal field . . . . . In pocket

			Page
FIGURE	1.	Index map showing location of the Girard coal field	2
	2-8.	Photographs showing:	
		2. Tongue River Member of the Fort Union Formation	7
		3. Flaxville Gravel capping the Tongue River Member	10
		4. Flaxville Gravel	11
		5. Relations of glacial till to the Cartwright Gravel and the Tongue River Member	13
		6. Crane Creek Gravel overlain by till	15
		7. Glacial erratic	18
		8. Melt-water channel in the Cartwright Gravel	21
	9.	Structure contour map of the Williston basin	23
	10-12.	Photographs showing:	
		10. Wind Gap at Sioux Pass	27
		11. Pust coal bed	37
		12. Clinker, Burns Creek	39
	13-32.	Graphic sections of coal beds:	
		13. T. 21 N., R. 56 E	57
		14. T. 21 N., R. 57 E	58
		15. T. 21 N., R. 58 E	60
		16. T. 22 N., R. 56 E	62
		17. T. 22 N., R. 57 E	63
		18. T. 22 N., R. 58 E	64
		19. T. 23 N., R. 56 E	67
		20. T. 23 N., R. 57 E	68
		21. T. 23 N., R. 58 E	68
		22. T. 23 N., R. 59 E	69
		23. T. 24 N., R. 56 E	70
		24. T. 24 N., R. 57 E	72
		25. T. 24 N., R. 58 E	73
		26. T. 24 N., R. 59 E	74
		27. T. 24 N., R. 60 E	76
		28. T. 25 N., R. 55 E	78
		29. T. 25 N., R. 56 E	80
		30. T. 25 N., R. 58 E	82
		31. T. 25 N., R. 59 E	82
		32. T. 26 N., R. 59 E	85

TABLES

			Page
TABLE	1.	Coal fields whose locations are shown in figure 1	3
	2.	Nonglacial surficial deposits of the Girard coal field	12
	3.	Oil and gas exploration test wells in the Girard coal field	30
	4.	Classification of coals by rank	36
	5.	Proximate analyses of coal from the Girard coal field and selected analyses from adjoining fields	40
	6.	Ultimate analyses of coal samples from the Girard field	42
	7.	Correlation of coal beds in Girard and adjoining coal fields	42
	8.	Estimated original resources of coal in Girard field	48
	9.	Summary of estimated originals resources by township and class	55
	10.	Summary of estimated resources of individual coal beds	55

CONVERSION TO METRIC SYSTEM

In this report the main units of measurement are short tons, miles, square miles, feet, inches, and British thermal units. These and other units may be converted to the metric system by multiplying by the following factors:

English unit *To convert*	*Multiply by*	*Metric unit* *To obtain*
Acres	0.4047	Hectares (ha).
Acre-feet	1.233×10^{-3}	Cubic hectometres (hm^3).
Btu	0.252	Kilogram calories.
Cubic feet	0.0283	Cubic metres (m^3).
Feet	0.3048	Metres (m).
Inches	2.54	Centimetres (cm).
Miles	1.609	Kilometres (km).
Square miles	2.59	Square kilometres (km^2).
Short tons	0.9072	Metric tonnes (t).

COAL RESOURCES AND CENOZOIC GEOLOGY OF THE GIRARD COAL FIELD, RICHLAND COUNTY, MONTANA

By George E. Prichard and Edwin R. Landis

ABSTRACT

The Girard coal field in easternmost Richland County, Mont., is an area of about 1,035 square miles bounded on two sides by the Missouri and Yellowstone Rivers. The field contains estimated original resources of 5,107.4 million tons of lignite. Measured and indicated resources in beds 5–10 feet thick total 388.8 million tons, and measured and indicated resources in beds more than 10 feet thick total 155.9 million tons. One coal bed in a single township contains estimated measured and indicated resources in the more than 10-foot-thick category of more than 50 million tons, and much of this coal is overlain by less than 200 feet of overburden.

The coal is ranked as lignite *A*, with heat content ranging between 7,000 and 8,000 Btu/lb on the moist mineral-matter-free basis. The average ash content is about 8 percent, and the average sulfur content is about 0.7 percent. Twenty-eight townships in the coal field contain estimated resources of lignite. A very large part, about 87 percent, of the estimated resources are inferred because of lack of data about thickness and continuity of the coal beds underlying broad interstream divides and gravel-capped upland terraces.

Bedrock throughout the coal field is the coal-bearing Tongue River Member of the Fort Union Formation of Paleocene age. The Tongue River is extensively mantled by 15 mapped Tertiary and Quaternary surficial units related to (1) the various stages in the geologic history of the Yellowstone and Missouri Rivers, and (2) the advance and retreat of continental glaciers of Wisconsin age.

INTRODUCTION

The Girard coal field, named for a community center (and former post office) near the center of the field, is an area of about 1,035 square miles in eastern Richland County, Mont. It is bounded on the north by the Missouri River, on the east by the Montana–North Dakota line, and on the southeast by the Yellowstone River. The area adjoins the Culbertson coal field to the north, the Fort Peck and the Richey-Lambert fields to the west, and the Sidney field to the south and east. The Girard field is near the center of the Fort Union region of the Great Plains coal province, which extends from central North Dakota to the Bighorn and Musselshell Rivers in Montana and from northeastern Wyoming into Canada. The locations of the Girard field and of other fields in the Great Plains province that are described in bulletins of the U.S. Geological Survey are shown in figure 1 and listed in table 1.

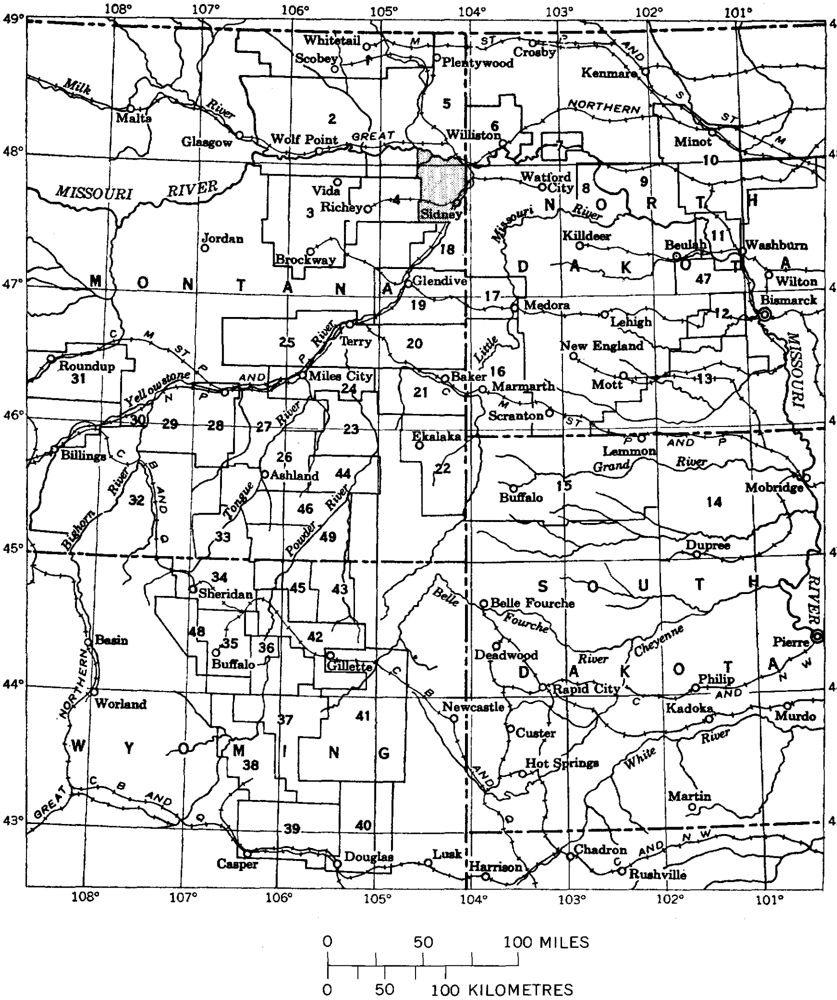

FIGURE 1.—Index map showing the Girard coal field (patterned) and its relation to other coal fields in Montana and adjoining States. Numbers refer to the field names given in table 1.

PREVIOUS SURVEYS AND REPORTS

The area included in the Girard coal field (pl. 1) has been surveyed and subdivided by the U.S. Bureau of Land Management. The guide meridians, standard parallels, and eight townships were surveyed in 1881–83; the remaining townships in the field were surveyed in 1899–1908. Parts of T. 26 N., Rs. 57, 58, and 59 E., and of T. 27 N., Rs. 56, 57, 58, and 59 E., were resurveyed in 1947. The land subdivision corners were marked with pits, or stones, or iron pipes with bronze caps, but many of the markers have been destroyed. Most of the section lines

TABLE 1.—*Coal fields whose locations are shown in figure 1, and number of the U.S. Geological Survey Bulletin describing the geology of the field*

No. in fig. 1	Field	Geological Survey Bulletin	No. in Fig. 1	Field	Geological Survey Bulletin
1	Scobey	751-E	26	Ashland	831-B
2	Fort Peck	381-A	27	Rosebud	847-B
3	McCone County	905	28	Forsyth	812-A
4	Richey-Lambert	847-C	29	Tullock Creek	749
5	Culbertson	471-D	30	Southwest of Custer	541-H
6	Williston	531-E	31	Bull Mountain	647
7	Nesson Anticline	691-G	32	Big Horn County	856
8	Fort Berthold	726-D	33	Northward extension of Sheridan	806-B
9	Fort Berthold	381-A, 471-C	34	Sheridan	341-B
10	Minot	906-B	35	Buffalo	381-B
11	Washburn	381-A	36	Barber	351-I
12	New Salem	726-A	37	Pumpkin Buttes	806-A
13	Cannonball River	541-G	38	Sussex	471-F
14	Standing Rock and Cheyenne River	575	39	Glenrock	341-B
15	Northwestern South Dakota	627	40	Lost Spring	471-F
16	Marmarth	775	41	Gillette	796-A
17	Sentinel Butte	341-A	42	Powder River	381-B
18	Sidney	471-D	43	Little Powder River	471-A
19	Glendive	471-D	44	Coalwood	973-B
20	Terry	471-D	45	Spotted Horse	1050
21	Baker	471-D	46	Birney-Broadus	1072-J
22	Ekalaka	751-F	47	Square Buttes	1076
23	Mizpah	906-C	48	Buffalo-Lake De Smet	1078
24	Miles City	341-A	49	Moorhead	1338
25	Little Sheep Mountain	531-F	50	Girard	1310

where roads have been built were retraced by the county surveyor of Richland County, and the intersections of these roads were used as section-corner locations for this map.

That part of the Girard field south of the 48th parallel, near the center of T. 26 N., is included in the topographic map of the Glendive quadrangle, which was published in 1909. The scale of the Glendive topographic map is 1:250,000 and the contour interval is 50 feet; consequently, many of the surface features are either greatly generalized or not shown on the map. Triangulation stations, marked by concrete monuments, have been established in the area by the U.S. Coast and Geodetic Survey, and the stations that were established by the U.S. Missouri River Commission have been resurveyed and are described. Standard elevations have been determined by first- or second-order leveling by the U.S. Coast and Geodetic Survey, and these elevations along the railroads and highways are marked by standard disks set in concrete. Many of the bench marks established by the U.S. Geological Survey about 1900, shown on the Glendive topographic map, have been destroyed. A general highway and transportation map of Richland County was published in 1936 by the Montana State Highway Department in cooperation with the Bureau of Public Roads of the U.S. Department of Agriculture. Maps showing culture, drainage, and land subdivisions have been prepared by the Richland County Surveyor's office at several different times.

Although the general geology of the Girard field has been described by several geologists, none of the published reports includes a detailed description of either the geology or the coal resources. Thom and Dobbin (1924), Leonard (1911, p. 533-543), and Brown (1948, p. 1270–1272) have discussed the general aspects of stratigraphy in eastern Montana and adjacent areas. In a study of the geomorphology and glacial geology of eastern Montana and adjoining areas, Alden (1932) described the general geologic history and some of the surface features in this area. Howard (1960) described the Cenozoic history of a large area, which included the Girard coal field, in northeastern Montana and northwestern North Dakota. The broad structural features of eastern Montana have been described by Clapp, Bevan, and Lambert (1921, p. 18–24), and Thom and Dobbin (1924). Parts of the field are included in studies of the ground-water resources of the Missouri River in northeastern Montana (Swenson, 1955) and of the lower Yellowstone River (Torrey and Kohout, 1956).

PRESENT INVESTIGATION

This report on the geology and coal deposits in the Girard coal field was prepared as a part of the Department of the Interior program for the development of the Missouri River basin. The information in this report was gathered during an investigation conducted by the U.S. Geological Survey as a part of the systematic survey for the purpose of classifying public lands and determining their mineral resources and geologic features. The report includes descriptions of the thickness and areal distribution of the coal beds, an estimate of the resources in these beds, and information on the geography, geologic structure, and stratigraphy of the area. Geological, structural, and cultural features of the Girard coal field are shown on the planimetric map (pl. 1).

Fieldwork in the northern part of the area was done during the summer of 1950 by the authors, assisted by William J. Hail, Jr., and K. William Brett; during the summer of 1951 the southern part of the area was mapped by the authors, assisted by Charles A. Sandberg. Howard R. Smith was the operator of a jeep-mounted power auger that was used during part of the summer of 1951. A map of the northern part of the area was published in 1955 by the authors, but it does not include as much coal resource information as the present report. The authors revisited the area in September 1964 to check revisions of stratigraphic nomenclature.

The authors wish to express their appreciation for the aid and cooperation of G. E. Brennan, Richland County Surveyor, and the coal-mine owners and operators in the area. Mapping in part of the area was materially aided by information obtained from geophysical survey shot-hole logs that were loaned by the Texas Company.

Aerial photographs at a scale of approximately 1:20,000, taken in

1949, were used as base maps in the field. The locations of geologic contacts, coal bed outcrops, and other features were marked on the photographs, and the data were transferred by means of a Saltzman projector to a base map. The base was compiled from a planetable triangulation net that included 12 U.S. Coast and Geodetic Survey triangulation stations and from township plats of the Bureau of Land Management. Elevation control in the field surveys was based on bench marks established by the U.S. Coast and Geodetic Survey.

STRATIGRAPHY

TERTIARY SYSTEM

PALEOCENE SERIES

Rocks that crop out in the Girard field are part of a thick sequence of beds called the Fort Union or Great Lignite group by Meek and Hayden (1862, p. 433). The beds were named for exposures near old Fort Union on the north side of the Missouri River near the mouth of the Yellowstone River. Weed (1893) described the Fort Union Formation near Livingston, Mont., and correlated it with the beds exposed at the mouth of the Yellowstone River. Brown (1938) established that the base of the Fort Union Formation marks the boundary between the rocks of Mesozoic and Cenozoic age in Montana and North Dakota. The area underlain by the rocks of Paleocene age is shown on a map by Brown (1949).

In eastern Montana and western North Dakota, the Paleocene Series is synonymous with the Fort Union Formation. In the immediate vicinity of the Girard coal field, the Fort Union is divided into three units, called, in ascending order, the Lebo Shale Member, the Tongue River Member, and the Sentinel Butte Member. Differentiation of the members is based chiefly on color differences, though persistent lignite beds or carbonaceous shale zones have been used in some places. In general, the Lebo is medium to dark gray and brown, so-called "somber colored"; the Tongue River is light gray to light grayish yellow; and the Sentinel Butte is "somber colored." Locally, this color differentiation is excellent, but on a regional basis color has been an unsatisfactory criterion. The rocks of Tertiary age in the northern Great Plains contain a distinctive suite of nonopaque heavy minerals, but, thus far, subdivision of the Paleocene rocks on the basis of major mineralogic and lithologic differences is not feasible (Denson and Chisholm, 1971, p. C119). Leffingwell (1970) found that the boundary between two recognizable palynological assemblages occurs in the lower part of the Fort Union Formation and concluded that the lower part of the Tongue River Member was older in northwestern South Dakota and central North Dakota than the lower part of the Tongue River in northeastern Wyoming.

On the basis of very tenuous coal-bed correlations with other areas in eastern Montana and western North Dakota, it seems possible that a very small part of the Fort Union in the extreme northwestern part of the Girard field might be the lateral correlative of the Lebo Shale Member. Parker (1936), who mapped the adjacent Richey-Lambert coal field, placed the Lebo–Tongue River contact about 125 feet below the D coal bed of the Girard field, but Thom and Dobbin (1924) placed the Lebo–Tongue River contact in the Sidney field (Stebinger, 1912) about 40 feet above the D coal bed of that field, which may be the D bed of the Girard field. However, no strata that satisfied the color criterion were observed in the Girard field, so the Lebo is not recognized in the field.

The Sentinel Butte Member is present in many places in western North Dakota, and Brown (1962, p. 15) stated that "at the original type locality of the Fort Union formation in the hills on the north side of the Missouri River opposite the mouth of the Yellowstone only the highest beds of the formation can be seen and all or nearly all of these belong to the Sentinel Butte member." Thom and Dobbin (1924) placed the Tongue River–Sentinel Butte contact at the K coal bed of the Sidney field (Stebinger, 1912). The K bed of the Sidney field cannot be definitely correlated with any bed of the Girard field but would be near the stratigraphic position of a nonpersistent local bed that is about 170 feet above the L bed of the Girard field. If this is a valid correlation a few small areas in the northeastern part of the Girard field might be underlain by correlatives of the Sentinel Butte Member of the Fort Union.

TONGUE RIVER MEMBER OF THE FORT UNION FORMATION

A sequence of shale, sandstone, and coal beds exposed in the Tongue River valley, Wyoming, was defined by Taff (1909, p. 129) as the Tongue River coal group. Thom and Dobbin (1924, p. 495), in a regional stratigraphic study, correlated the Tongue River coal group with the Tongue River Member in eastern Montana as follows (the reference in brackets is substituted for an original footnote):

> It is well exposed along Tongue River between Carneyville, Wyoming, and Brandenburg, Montana, and along the Yellowstone between Burns, Montana, and Buford (Fort Union), North Dakota. * * * The top of the member as here defined is placed beneath bed K of the Sidney field [Stebinger, 1912], * * *. The base of the member is placed beneath the light-colored coal-bearing rocks which characteristically form a marked clinker-capped escarpment rising above lowlands or badlands developed from the somber Lebo shale.

The Tongue River strata (fig. 2) consist of light-yellow to yellowish-gray lenticular massive and, in part, crossbedded sandstone and siltstone interbedded with light-gray clay-shale, along with a few thick lignite beds of wide extent and many lenticular thin lignite beds. The sandstone and siltstone commonly occur in thick beds that form prominent ledges. Zones of bench-forming calcareous concretions are present

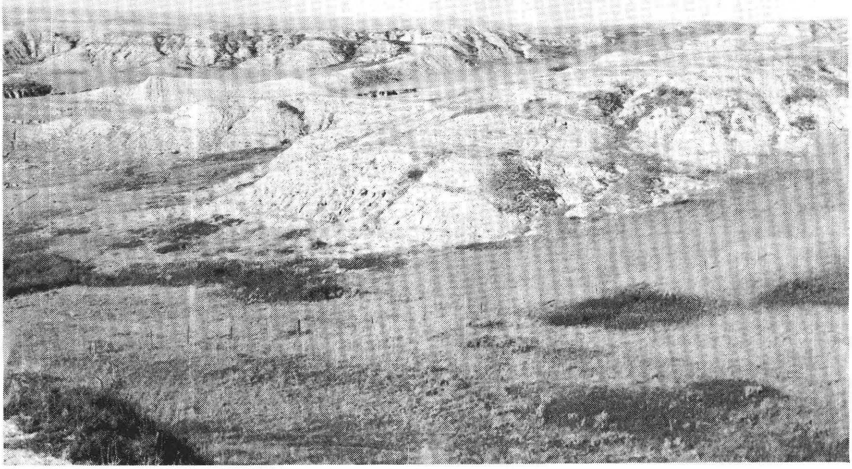

FIGURE 2.—Tongue River Member of the Fort Union Formation north of the Missouri-Yellowstone drainage divide. View is toward the west, from the SW¼ sec. 28, T. 25 N., R. 56 E.

at irregular intervals, and many of the sandstone beds contain round ferruninous concertions generally less than 1 inch in diameter. The ferruginous concretions may occur as individual concretions, or joined together like beads on a string, or in grapelike clusters. Cylindrical, loglike sandstone concretions are common in the lower part of the Tongue River Member and are well exposed in the badlands along the Missouri River. Silicified tree stumps, about 1 foot in diameter and as much as 2 feet long, are scattered over the surface in the western part of T. 23 N., R. 56 E. Though most lithologic units are not of wide extent, some of the thicker coal beds have been traced for many tens of miles, and most correlations within the unit are based on the assumption that the coal beds are the most reliable datum.

The following measured section is probably representative of the lithologies of the Tongue River Member.

Measured section in the S½SE¼ sec. 13, T. 26 N., R. 59 E.

	Feet
Fort Union Formation	
Tongue River Member (in part—230.3 ft)	
Shale, clay, gray, slightly carbonaceous; contains parts of silicified tree stumps; overlain by ground moraine	2.0
Shale, clay, gray	3.0

Measured section in the S½ SE¼ sec. 13, T. 26 N., R. 59 E.—Continued

	Feet
Fort Union Formation—Continued	
Tongue River Member (in part—230.3 ft)—Continued	
Sandstone, light-brown; interbedded with medium-gray sandy clay shale	6.5
Sandstone, light-gray, clayey, concretionary, slightly calcareous	1.5
Shale, clay, light-gray to yellowish-gray	18.0
Shale, coaly, medium-gray	3.0
Shale, clay, light-gray, gypsiferous	1.0
Coal, bony (local bed)	2.0
Shale, clay; carbonaceous in part; medium to light gray	6.5
Coal, bony	.4
Sandstone, light-gray to yellowish-gray, fine-grained; interbedded with yellowish-gray sandy clay shale	11.5
Shale, carbonaceous, brown; coaly in part	1.6
Shale, clay, interbedded light-gray and yellowish-gray	3.0
Shale, clay, sandy, light-gray, calcareous	7.0
Shale, carbonaceous, coaly	1.6
Sandstone, weathered reddish-brown, fine-grained; small nonoxide nodules common	4.5
Sandstone, clayey, light-gray; scattered silicified tree stumps	15.0
Shale, clay, gray; interbedded with yellow-brown fine-grained sandstone	34.0
Sandstone, light-gray, fine-grained, thin-bedded	6.0
Sandstone, very light gray, fine-grained, massive	10.0
Shale, clay, medium-gray; coal lenses as much as 1 inch thick	1.0
Sandstone, clayey, yellow-brown, fine-grained	9.0
Shale, clayey, medium-gray; interbedded with brown coaly carbonaceous shale	3.5
Coal, bony, with a few thin clay shale partings	2.0
Shale, clay, medium-gray	1.0
Sandstone, clayey, yellow-brown, medium-grained	4.0
Shale, carbonaceous, coaly, medium-gray	.3
Sandstone, yellow-brown; interbedded with yellowish-gray clay shale	5.0
Shale, carbonaceous, coaly, medium-gray	.4
Shale, clay, light-gray; interbedded with yellowish-gray clayey sandstone	5.5
Concretion, iron-oxide, sandy and clayey, calcareous	1.5
Shale, clay, light-gray; interbedded with yellowish-gray clayey sandstone	6.0
Concretion, iron-oxide, sandy	.5
Shale, clay, light-gray	6.0
Sandstone, very light gray, very fine grained to fine-grained; contains gastropods	5.0
Shale, carbonaceous, coaly, medium-gray to brown	.5
Shale, clay, light-gray	1.0
Sandstone, light-gray to yellowish-gray, very fine grained	40.0

At a few localities, freshwater mollusks are present in clay shale beds, and fossil plants are common throughout the Tongue River. Petrified wood is locally abundant, mostly as broken scattered pieces but sometimes in a shattered loglike or stumplike form. According to Brown (1952, p. 91), the plant fossils suggest "a considerably moister and milder climate than that prevailing in the region today."

A repetitive, somewhat cyclic alternation of lithologic units in parts of the Fort Union has been reported in some areas (Gerhard, 1963). There is no clearcut pattern to the sedimentary sequence in the Girard field, except that the beds in the lower part of the exposed sequence are commonly thicker and, though lenticular, may be slightly more persistent than the beds in the upper part. The type of sediments incorporated in the Tongue River indicate deposition in terrestrial flood plain, marsh, and swamp environments. According to Brown (1962, p. 92), "the basin receiving the Fort Union sediments was unstable, standing still for a time while vegetable material accumulated, then subsiding and permitting the incipient lignite to be buried beneath muds or sands; and so on until several thousand feet of strata with coal seams were laid down * * *."

The exposed strata of the Tongue River Member in the Girard field are about 835 feet thick.

MIOCENE OR PLIOCENE SERIES

FLAXVILLE GRAVEL

The Flaxville Gravel was named by Collier and Thom (1918) for exposures near the town of Flaxville, on the Scobey branch of the Great Northern Railway, in Daniels County, Mont. Vertebrate fossil fragments were collected by Collier and Thom (1918, p. 180–181) at many places and were identified by J. W. Gidley, who stated that "the beds from which these fragments were collected can not be older than Miocene or younger than lower Pliocene." All of Collier and Thom's fossil localities are north of the Missouri River and, to the author's knowledge, fossils have not been found in the Flaxville elsewhere. Colton (1962, p. 254) changed the unit name to Flaxville Formation in the Otter Creek quadrangle, about 25 miles north of the Girard coal field "because the supposedly distinctive gravel is actually a minor part of the unit." However, the name Flaxville Gravel is retained in the Girard coal field because gravel is, by far, the most prominent and recognizable constituent of the unit, regardless of the exact size distribution of materials at any particular place.

The Flaxville Gravel caps remnants, called the Flaxville plateaus, of a formerly extensive erosion surface, termed the "Flaxville plain" (fig. 3). Alden (1932) correlated the Flaxville plain, which he also called the No. 1 bench, over large parts of eastern and central Montana and adjoining parts of Wyoming. Howard, Gott, and Lindvall (1946) described some gravels in northwestern North Dakota that are similar to the Flaxville and suggested possible correlation. In northeastern Montana, the Flaxville overlies rocks ranging in age from Late Cretaceous to Paleocene. South of the limit of continental glaciation, the Flaxville Gravel is overlain by a few inches of soil or eolian material, but north of the glacial limit the Flaxville is commonly covered by glacial drift that increases in thickness to the north and northeast. The Flaxville

FIGURE 3.—Flaxville Gravel capping the Tongue River Member of the Fort Union Formation. View is toward the north from Burns Creek in the SE¼ sec. 30, T. 21 N., R. 56 E.

plateaus, near the southern limit of glaciation (pl. 1) and in a few other areas as well (Howard, 1960, pl. 1), often were not overridden by the continental glaciers but acted as resistant barriers that channeled or directed ice movement, stream diversions, and melt-water flow. As a result, glacial deposits sometimes nearly or completely surrounded individual plateaus and covered the sides and lapped up onto the top in places but apparently never completely covered the plateau. Two types of Flaxville plateaus—those capped by glacial deposits and those that are not—are present in the report area.

The Flaxville Gravel on and near the Missouri-Yellowstone drainage divide is composed largely of pebbles and cobbles of various igneous and metamorphic rocks in a matrix of fine to coarse sand. Brown iron-stained quartzite is the most abundant component of the gravel. According to Howard (1960, p. 17), the inclusion of many igneous rocks, largely andesitic, is diagnostic of Flaxville Gravel related to the ancestral Yellowstone River drainage, because the Flaxville Gravel within the ancestral Missouri River drainage is composed almost entirely of quartzite and chert. The constituents of the Flaxville are well rounded and are commonly coated with a hard brown iron-oxide patina. Agate—both the milky gray type with dendritic inclusions and the brown and gray banded type—silicified wood, chert, and quartz are minor constituents in the Flaxville in the report area. In places, the

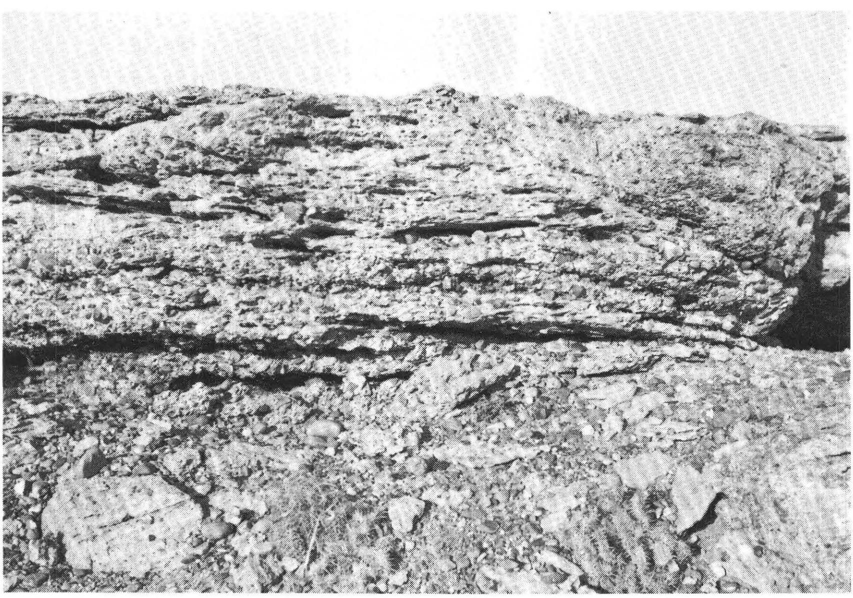

FIGURE 4.—Flaxville Gravel cemented by calcite to form a hard moderately resistant conglomerate. Cobbles are as much as 8 inches across. Near W¼ cor. sec. 13, T. 24 N., R. 57 E.

Flaxville is cemented by calcium carbonate and crops out in resistant ledges (fig. 4). The topographic position of the Flaxville relative to younger nonglacial surficial units in the Girard field is shown in table 2.

Collier and Thom (1918, p. 181-182) listed thicknesses of Flaxville Gravel in excess of 80 feet, but the thickness in the Girard coal field is generally on the order of 20 to 30 feet.

The Flaxville was previously shown by Prichard and Landis (1955) as terrace deposit 7 on a map of the north half of the Girard coal field.

TABLE 2.—*Elevations, thicknesses, and correlations of nonglacial surficial deposits of the Girard coal field*

Map Symbol (pl. 1)	Average distance above Yellowstone River (ft)	Range in thickness (ft)	Correlation with terminology of Alden (1932)	Correlation with terminology of Howard (1960)
Tf	700	10-80	Flaxville Gravel: No. 1 bench	Flaxville Gravel.
Qc4	625(?)	10-25(?)	No. 2 bench	Cartwright Gravel.
Qc3	600	10-25		
Qc2	300	10-50		
Qc1	80	5-20		
Qcc	50	5-15	No. 3 bench	Crane Creek Gravel.
Qt2	20		Alluvium	Pleistocene (Mankato Stade) to Holocene silt, slope wash, eolian sand, loess, and alluvium.
Qt1	12			
Qal	0-10			

QUATERNARY SYSTEM

PLEISTOCENE SERIES

CARTWRIGHT GRAVEL

The first use of the name Cartwright Gravel was by Howard (1958, p. 578) and formal presentation followed shortly thereafter (Howard, 1960, p. 19). The unit is named for exposures about 5 miles east of the Montana-North Dakota boundary, near the edge of the Yellowstone valley about 5-6 miles north of the community of Cartwright in northwestern McKenzie County, N. Dak. The type exposures are about 8 miles northeast of Fairview and about the same distance southeast of Nohly, both of which are in the northeastern corner of the Girard coal field. The Cartwright is considered to be Pleistocene in age (Howard, 1960, p. 21).

The Cartwright Gravel was deposited by the preglacial Missouri and Yellowstone Rivers and their tributaries on an erosional surface called the Missouri Plateau peneplain by Howard (1958, p. 576; 1960). The Missouri Plateau peneplain of northeastern Montana and northwestern

North Dakota was called the No. 2 bench by Alden (1932), who correlated the surface and related deposits over large parts of central and eastern Montana and adjoining parts of Wyoming. Jensen (1951), Jensen and Varnes (1964), and Colton (1951) mapped deposits they called the Wiota Gravel in areas north of the Missouri River, near Fort Peck in Valley County and near Plentywood in Sheridan County. The Wiota Gravel is possibly a correlative of the Cartwright Gravel of the Girard coal field.

In northeastern Montana the Cartwright Gravel overlies units ranging in age from Cretaceous to Paleocene and is overlain by thin soils and eolian material in areas south and west of the limit of glaciation and by drift in the area that was covered by the continental glaciers (fig. 5). In the Girard coal field the Cartwright is largely confined to the broad upland area between the Missouri-Yellowstone drainage divide and the Yellowstone River valley.

According to Howard (1960, p. 19), the Cartwright, like the Flaxville, has identifiable Missouri River and Yellowstone River facies. Both facies are composed largely of quartzites, but the Yellowstone River

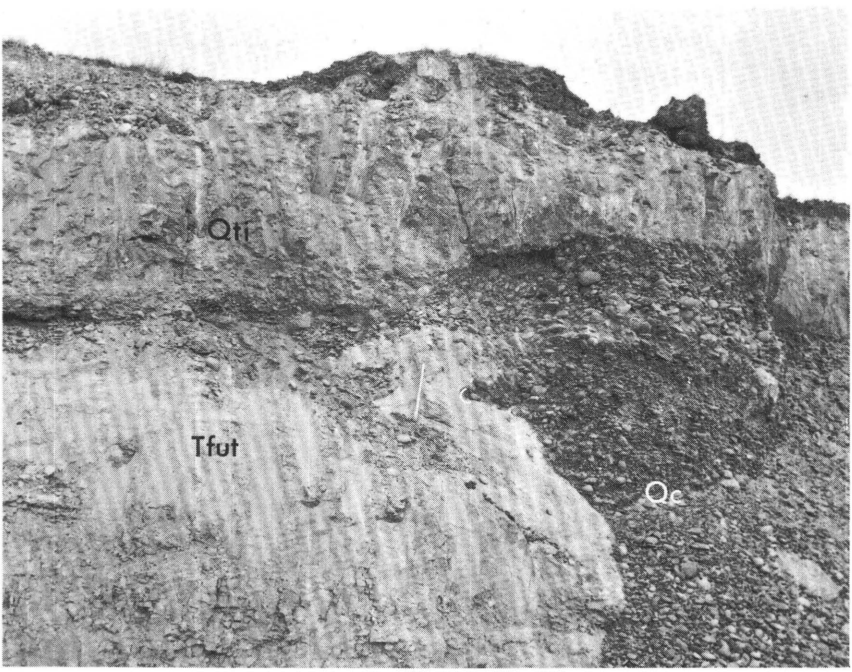

FIGURE 5.—Glacial till (Qti) on Cartwright Gravel (Qc) and the Tongue River Member of the Fort Union Formation (Tfut). Till is 5 feet thick; gravel fills a channel and ranges in thickness from 0.2 to 4.5 feet. (Steel tape is 1 ft long.) NW¼NE¼ sec. 27, T. 20 N., R. 57 E., a few miles south of the Girard coal field.

facies also contains appreciable quantities of igneous rocks, which are largely extrusive, and abundant to sparse amounts of chert, agate, quartz, and petrified wood. Only quartzite, quartz, and chert are abundant lithic elements in the Missouri River facies. The Cartwright Gravel is lithologically very similar to the older Flaxville Gravel, and part may be reworked Flaxville material. However, the Cartwright commonly contains more locally derived materials, such as clinker and soft sandstone from the Fort Union Formation, than the Flaxville, and it also reportedly contains more plutonic igneous rock types, including some granite (Howard, 1960, p. 19) and a few fragments of limestone (Alden, 1932, p. 57).

In the Girard coal field the Cartwright Gravel was mapped on four distinct terrace levels in most parts of the area (table 2) but was not differentiated in a few parts because of uncertain correlation. The gravel at the different levels is lithologically similar, and differentiation is based on relative topographic position.

The Cartwright is 35–40 feet thick at the type locality but ranges in thickness from 5 to 50 feet in the Girard coal field.

CRANE CREEK GRAVEL

The Flaxville and Cartwright Gravels were deposited by the ancestral Yellowstone and Missouri Rivers and are preserved on the plateaus and broad interstream uplands between the present valleys of the Yellowstone River and the Missouri River. In contrast, the Crane Creek Gravel in the Girard coal field is confined to the present valley of the Yellowstone River and the mouths of several of the larger tributaries, including Sears, Crane, Fox, and Lone Tree Creeks. According to Howard (1960, p. 22), the Crane Creek Gravel is pre-Wisconsin Pleistocene (Yarmouth Interglaciation) in age.

The Crane Creek Gravel was deposited on a rock bench cut into the Tongue River Member of the Fort Union Formation. In the Girard coal field the gravel is overlain by thin deposits of silt, eolian material, and glacial material of diverse origin, such as outwash, inwash, reworked (?) fine-grained till, and small quantities of pebble and cobble till (fig. 6). On the sides of the Yellowstone valley, the Crane Creek Gravel is mantled by silty and clayey slope wash and colluvial deposits of undetermined thickness but of limited extent. A gravel deposit on the north side of the Missouri River was correlated with the Crane Creek by Howard (1960, p. 22), but equivalent deposits were not found on the south side of the Missouri in the Girard coal field.

The Crane Creek Gravel resembles the older Flaxville and Cartwright Gravels, and the Crane Creek Gravel was probably in large part derived from the older deposits, especially from the Cartwright Gravel. Dissection of the Flaxville plain had probably been accomplished to nearly its present extent before the beginning of the Crane erosion cycle

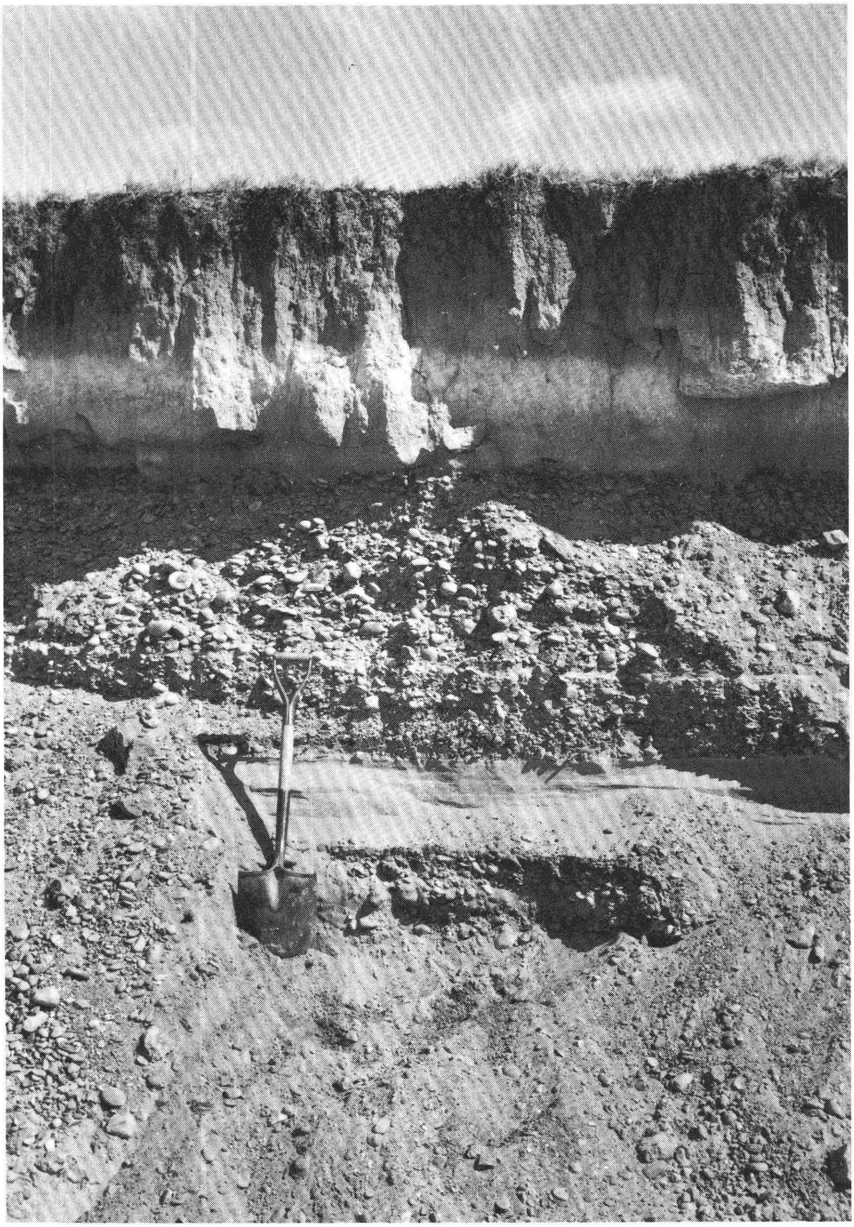

FIGURE 6.—Crane Creek Gravel overlain by till. Thickness of gravel exposed is 8 feet. A sand lens about 10 inches thick is at about the level of the shovel handle. Exposed in a sand and gravel quarry in the NE¼NW¼ sec. 19, T. 22 N., R. 59 E.

(Howard, 1960) that resulted in downcutting by the Yellowstone River and tributaries, and development of the strath upon which the Crane Creek Gravel was deposited. In the Girard coal field, downcutting by the larger tributaries of the Yellowstone resulted in dissection of the Missouri Plateau peneplain and removal of large quantities of Cartwright Gravel that were subsequently spread across the Crane terrace by the Yellowstone River.

Though the pebble and cobble lithic assemblage is similar to that of the older gravel units in the area, the Crane Creek Gravel contains more basic extrusive igneous rocks and slightly more rock types of local derivation. Though exposures are inadequate for valid comparison, the Crane Creek seems to contain considerably more fine clastics, silt, and sand than do the older gravels, but it also contains more large cobbles. The unit is not poorly sorted, however, because individual beds, or crossbeds, are commonly fairly well sized. Pebble analyses by Howard (1960, p. 22 and fig. 11) show little difference between a sample from near the limit of glaciation and another from within the glaciated area. He stated (p. 22–23) that, "Except for a few pebbles of dolomite such as occur in the glacial drift and a few pebbles of granite and metamorphic foliated rocks, the histograms differ little from each other or from the histograms of higher and older gravels beyond the reach of the ice or glacial melt waters."

Though the Crane Creek Gravel deposits may exceed 30 feet in thickness in places, the average thickness is probably about 15 feet. The apparent thickness may be considerably greater near the valley walls because of overlying slope wash and colluvium.

EARLY WISCONSIN (?) DRIFT

The most widespread surficial deposit in the Girard coal field is the glacial drift sheet that is present over a large part of the upland area between the Yellowstone and Missouri Rivers. The drift is considered to be of early Wisconsin(?) (Iowan or Tazewell Stade) age by Howard (1960, p. 35–36). Alden (1932, p. 87) had previously assigned an age of Iowan or Illinoian(?) to the drift. To the authors' knowledge, no direct evidence for the age exists, and the dating is based on local stratigraphic relations and considerations of regional geologic history.

On a map of northeastern Montana, Colton, Lemke, and Lindvall (1961) showed the approximate limits of three glacial advances or readvances, not necessarily of stade rank. Two of the limit lines closely parallel each other along the limit of glaciation in the southwestern part of the Girard coal field. Lemke, Laird, Tipton, and Lindvall (1965) briefly discussed these advances or readvances and the criteria used to differentiate deposits assignable to each. No attempt has been made to show the limits of the second glacial advance in the Girard field, but a very large part of all the glacial drift mapped in the field would be assigned to advance 2 of Lemke, Laird, Tipton, and Lindvall (1965). They suggested that advance 1 is of early Wisconsin (Iowan) age and that advance 2 is of early or late Wisconsin age. In the absence of any definitive evidence, the glacial drift in the Girard field is all considered to be early Wisconsin, with the provision that subsequent work may show that part of it is younger.

In the Girard coal field the early Wisconsin(?) drift overlies all the older Cenozoic units (figs. 5, 6) and is the surface material over a large part of the field, although it is overlain in some places by a few inches of eolian and humic material. The drift has been separated into five map units.

Drift may be classified by composition and topographic form. Compositionally, drift may be classed as till or as stratified drift, or a mixture of both. Till is a massive clay and silt deposit containing scattered pebbles and cobbles deposited directly by a glacier and is "the non-size-sorted end member of a series whose opposite end member is well-size-sorted stratified drift" (Flint, 1957, p. 109).

Till is made up of glacially transported material derived from both local and far-removed sources. Howard (1960, table 1) presented pebble analyses of three till samples from the Girard coal field that show that the till contains from 13 to 74 percent of locally or nearby derived materials. An isopleth map of Flaxville-type silica-rich rocks (Howard, 1956, fig. 5) indicates that the pebbles in the till along the southeast side of the Yellowstone-Missouri drainage divide are derived chiefly from the Flaxville and Cartwright Gravels, whereas pebbles in the till north of the divide are chiefly from more distant sources. In addition to the difference in pebble analyses, the till north of the divide is generally much thinner and contains a smaller percentage of material in the sand- to pebble-size range. These two differences are probably both partially attributable to differences in available supply of Flaxville-type gravels. The till ranges in color from dark brown and medium dark gray to very light gray, and in some places, where largely derived from the local bedrock, it is yellowish gray.

Though no quantitative measurements were made, clay and silt size material comprise most of the till. The most striking aspect of the till, however, is the cobbles and boulders that are present in, and litter the surface of, the till in many parts of the area (fig. 7).

Most of the till in the mapped area is included within the glacial unit mapped as ground moraine. Some till is probably included as a minor constituent in other mapped glacial units, and much thin till, or till of unknown or uncertain thickness, is not shown on the map. For instance, drift is shown overlying the Crane terrace in only a few small areas, but thin deposits of glacial material overlie the Crane Creek Gravel in most areas.

Stratified drift includes two groups of deposits differentiated by their presumed relationship to the glacial ice at the time of deposition. Proglacial deposits are theoretically accumulated beyond the effects of direct contact with ice, while ice-contact features owe part or all of their

FIGURE 7.—Glacial erratic in SW¼ sec. 3, T. 25 N., R. 59 E. Boulder 11 feet long of calcitic dolomite, showing hackly surface due to differential weathering.

form and composition to the fact that they were deposited in immediate contact with wasting ice (Flint, 1957, p. 136).

The proglacial sediments of the Girard coal field consist of silt, sand, and gravel deposited as outwash, inwash, and partly to wholly glacial melt-water and diversion-channel deposits. Outwash deposits accumulate where streams originating from melting of ice change gradient at or near the terminus of the glacier. Inwash deposits are made up of material moved from beyond the terminus toward the glacier by melt-water or stream water and owe their existence and location to the presence of the ice. In practice, the presence of inwash is usually conceded on philosophical grounds, but differentiation is seldom feasible. By definition, all proglacial sediments are well sized sorted, but the range in material size and topographic form is great. Very rapid aggradation commonly occurs in a limited area close to the terminus of a retreating or stagnant glacier, resulting in thick crossbedded outwash deposits that choke drainageways. The finer grained material is carried greater distances and sometimes travels many miles before being deposited. A large but unknown percentage of the material deposited in some of the melt-water and stream-diversion channels is the downstream fine-grained continuation of outwash deposits. In addition to the sediments related to streams, many proglacial deposits accumulated in quiet bodies of water—ponds or lakes caused by the presence of glacial ice, or by glacial deposits, such as outwash. Lake and pond deposits accumulated in such diverse forms as sheetlike deposits and deltas. Both types of lake and pond deposits are present in the Girard coal field.

Ice-contact features are classified according to form and supposed relationship to the ice at time of deposition. Eskers, long sinuous ridgelike forms, are believed to have been deposited in tunnels at the base of the ice; kames and kame terraces were deposited on or against the glacial ice and assumed rounded hill-like or terracelike shapes when the ice melted. Both kames and eskers in the Girard coal field are largely made up of strongly crossbedded sand- to cobble-size Flaxville- and Cartwright-type material mixed with some unsorted till in slumped masses of limited extent.

Ground Moraine

Most of the glacial drift was deposited as ground moraine; "an accumulation of drift having a constructional topographic expression in detail that is independent of the surface underneath it, and having been built by the direct action of the glacier ice" (Flint, 1957, p. 130). In most of the Girard coal field, the ground moraine is composed of till and has a smooth flat to hummocky surface. In a few parts of the area, oriented low ridges and rounded masses are present but are not differentiated on the map. Some of these are shown by Colton, Lemke, and Lindvall (1961), who classed them as fluted till plains and ice-crack moraines. North of the Missouri-Yellowstone drainage divide, the drift is thin and patchy and, in general, reflects the underlying bedrock topography. The drift north of the drainage divide is commonly only a few inches to a few feet thick, and the areas mapped as ground moraine may include areas of very thin drift or no drift except scattered glacial erratics; conversely, some areas of relatively thick drift of limited areal extent may not be delineated.

South of the Missouri-Yellowstone drainage divide, the ground moraine reaches thicknesses of more than 50 feet, and, though it reflects in a general way the gross topography of underlying units, more of the landscape elements are related to the moraine, and over large areas the older units are completely masked.

Stratified Drift

The material mapped in the Girard coal field as stratified glacial drift is composed largely of undifferentiated proglacial sediments, but some ice-contact deposits are included in places where separate mapping was not feasible. Outwash forms by far the largest part, both in bulk and in area, of the stratified drift.

The large area of stratified drift that lies mostly in the southeastern part of T. 23 N., R. 56 E., is outwash composed largely of Flaxville-type sand, pebbles, and cobbles. The outwash mass, which was identified as a pitted valley train by Howard (1960, p. 33), may be more than 50 feet thick in places. The outwash mass thins at its southeast end, where it is overlain by an esker and terminates abruptly on the northwest in a very poorly defined delta. The deposits mapped as stratified drift along Sears Creek and Crane Creek, in the southeastern part of T. 21 N., R. 57 E., and the western part of T. 21 N., R. 58 E., consist largely of sand and silt as much as 50 feet thick. The stratigraphic relations of the sand bodies are obscure, and it is possible that the sand is not a proglacial sediment but is a much older deposit, related to the Cartwright Gravel, that fills a channel cut in the bedrock.

Many other proglacial deposits, particularly small bodies of outwash and lake and pond deposits, are not shown on the map because they are too thin or too small, or their extent could not be determined. For example, no lake deposits are shown on the map, although thin patchy deposits of silty and clayey material are present in areas, such as the Yellowstone valley, that were occupied by glacial lakes. Some of the material mapped as melt-water and diversion-channel deposits was undoubtedly deposited in small lakes or ponds. Along the edge of the bluffs of the Yellowstone valley are small deposits of sand and gravel that are mapped with the ground moraine but may be outwash, possibly deltas built out into a glacial lake. Instead of being proglacial features, some of these small gravel deposits may be the remnants of ice-contact features, such as kames or kame terraces.

Melt-Water And Diversion-Channel Deposits

The glacial melt-water and stream-diversion channels, which are prominent geomorphic features of the Girard coal field, contain clay and silt deposits in places. Some of these deposits are composed solely of proglacial sediments that accumulated in ponds or small lakes or as the downstream fine-grained extensions of outwash deposits. Some of the channel deposits are solely of fluvial origin, and the materials were derived from both distant and nearby sources; this type of material might be considered to be inwash. Though no deposits of indisputable eolian origin were seen, some wind-transported material may be present. From the foregoing it should be obvious that this map unit includes material of complex origin, featuring fine grain size and a common depositional site (fig. 8).

Eskers

Eskers are long sinuous sand and gravel ridges that are generally considered to have been deposited by glacial melt water flowing in channels or in tunnels under the stagnant or wasting terminal part of a glacier. Two eskers, both composed largely of cross-stratified Flaxville-type sand and gravel, were mapped in the Girard coal field. One esker is developed at the upper end of a body of outwash that chokes a preglacial stream valley, and the other begins on a bench covered by Cartwright Gravel and terminates at a preglacial stream valley a short distance away. This esker is surrounded by ground moraine and may be underlain by till.

Kames

Kames are rounded hill-like masses of chaotically cross-stratified sand, pebbles, and cobbles that are generally believed to have been

FIGURE 8.—Melt-water channel cut as much as 25 feet into the Cartwright Gravel. View is toward the southwest from the NW¼NE¼ sec. 6, T. 22 N., R. 56 E.

deposited on top of stagnant or receding glacial ice by melt-water streams. Subsequent melting of the ice deposited the material on the underlying ground surface, preserving at least part of the internal structure. Kame terraces—terracelike bodies of stratified drift deposited by melt water between the edges of the glacial ice and confining ground surfaces, such as the sides of a valley—were not mapped in the Girard coal field. However, some of the small mounds of Flaxville-type sand and gravel with glacial erratics that are present along the buffs on the west edge of the Yellowstone valley may be the remnants of kame terraces, though as mentioned previously, some of them may be the remains of small outwash deltas. These deposits are mapped with the adjoining ground moraine because of their small size.

PLEISTOCENE AND HOLOCENE ALLUVIUM

FLOOD-PLAIN TERRACES AND FLOOD-CHANNEL ALLUVIUM

Alluvium along the Yellowstone and Missouri Rivers and along the principal tributaries are the most recent deposits in the Girard area. The alluvium is mapped only where its extent is great; it is not shown in most of the small valleys, although it is present in most and is of considerable thickness in some, especially in the small valleys north of the Missouri-Yellowstone divide. The alluvial deposits consist of clay, silt, and fine to coarse sand along most of the small streams, but along the rivers and their principal tributaries the alluvium contains a considerable quantity of gravel and boulders derived from terrace deposits. Alluvium as much as 30 feet thick is exposed in the steeply cut banks along the entrenched stream valleys, and it may be 100 feet or more thick in the Yellowstone Valley.

All the material shown as alluvium is younger than the early Wisconsin(?) glacial deposits in the area and most of it is of Holocene age. Included with the alluvium of the stream valleys is silt, slope wash, eolian sand, and loess that Howard (1960, p. 55–57) suggested to be probably of Pleistocene (Mankato Stade) age.

The alluvium in the Missouri River valley was mapped as one unit, but the alluvium in the Yellowstone valley was differentiated into three units—two flood-plain terraces and the alluvium in the flood channel (table 2).

STRUCTURE

The Girard coal field is on the western flank of the Williston basin (fig. 9), a structural depression that was first named and defined by Thom and Dobbin in 1924. In the northwestern part of the Girard field Fort Union beds dip to the northeast; in the central part the beds dip to the east; and in the Yellowstone valley along the eastern side of the coal field, the beds again dip to the northeast. Although the direction of dip is not constant, the dip averages about 25 feet per mile over the entire coal field, and the structural relief is about 750 feet. Structure contours at an interval of 50 feet have been drawn on the base of the Prittegurl coal bed, which ranges from 450 to 520 feet above the base of the Tongue River Member. Because the intervals between coal beds are not constant, a few errors probably were introduced when elevations determined on higher coal beds were extrapolated to the Prittegurl bed.

Structures with closures of more than 50 feet were not found in the area, and, though several vague noselike features are present, the subsurface significance of these features cannot be determined with the available data.

GEOMORPHOLOGY

The evolution of the present landscape of the Girard field began after deposition of the Fort Union Formation on broad flood plains adjoining a shallow sea northeast of the area. Presumably, the rocks of the Fort Union Formation that were deposited in the Girard field represent a major part of the Paleocene Epoch. Rock units of Eocene and Oligocene age overlie the Fort Union in nearby areas but have been eroded from the Girard field without leaving any record of their former presence.

VALLEY OF THE YELLOWSTONE RIVER

The Flaxville Gravel of Miocene or Pliocene age was deposited on a generally smooth surface developed on the Fort Union Formation by the

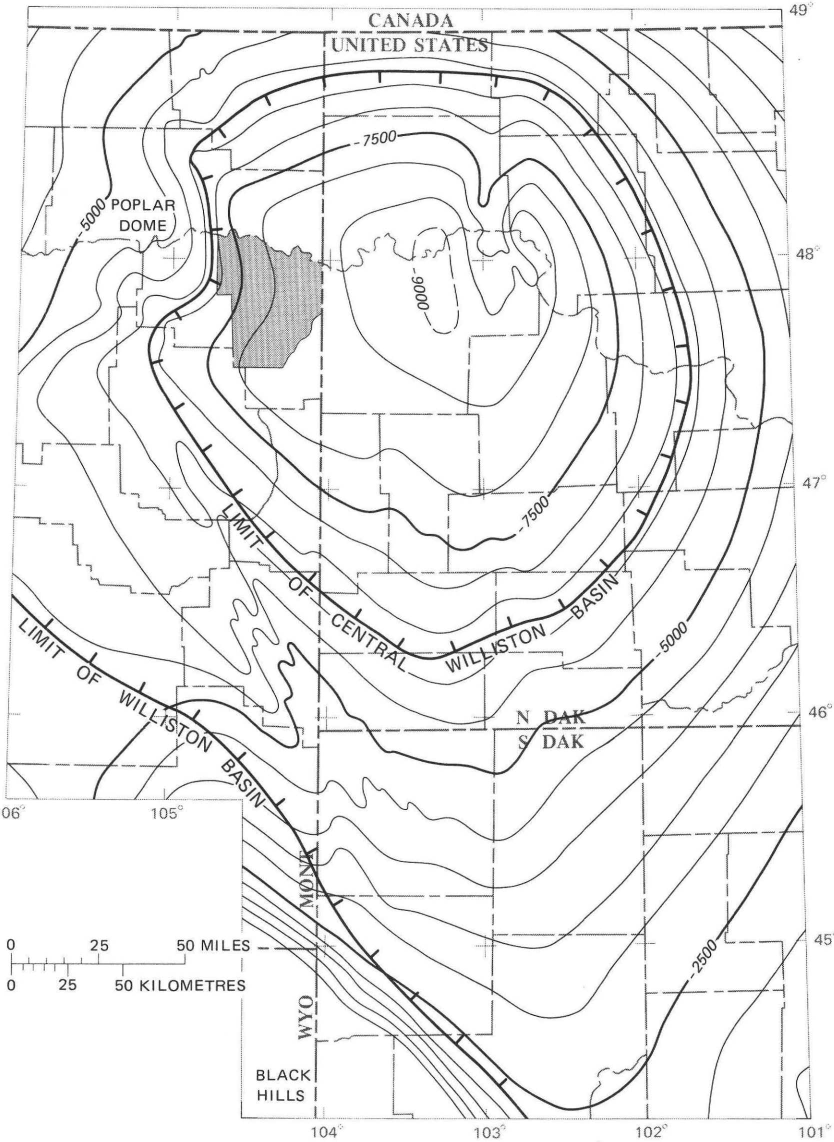

FIGURE 9.—Structure contours of the Williston basin and location of the Girard coal field (patterned). Contours drawn at 500-foot intervals on base of Mississippian rocks; dashed where inferred. From Sandberg (1962).

ancestral Yellowstone River. This surface of erosion is called the Flaxville plain, or the No. 1 bench of Alden (1932).

After deposition of the Flaxville Gravel, the Yellowstone River began, or continued, a southeastward lateral shift that continues, with interruptions but no apparent large reversals, to the present. Downward cutting accompanied the lateral shifting, the Flaxville plain was dissected, and the present form and position of most of the Flaxville plateaus were probably established. Lateral shifting, accompanied at times by aggradation and at other times by episodes of downcutting, resulted in development of the surface called the Missouri Plateau peneplain by Howard (1960) and the No. 2 bench by Alden (1932). The Cartwright Gravel that covers this surface was deposited during four recognizable time periods of aggradation, each of which was terminated by accelerated downcutting. During development of this terraced gravel-covered surface, the major southeastward-flowing tributaries of the Yellowstone River assumed positions roughly coincident with those they now occupy.

Development of the Missouri Plateau peneplain and deposition of the Cartwright Gravel thereon ended with increased downcutting, resulting in entrenchment of the Yellowstone River into the valley that, with some modifications, it occupies today. This period of downcutting, called by Howard (1960) the Crane erosion cycle, ended with lateral planation of the Fort Union Formation within the entrenched valley and deposition of the Crane Creek Gravel. Howard (1960, p. 70) believes that regional history considerations "require that the Crane erosion cycle be no younger than the Yarmouth interglacial stage."

By the end of the Crane erosion cycle, the major landscape features of that part of the Girard coal field southeast of the Missouri-Yellowstone drainage divide were formed, and subsequent events added only a few new features and masked and slightly modified the older ones.

According to Howard (1960, p. 70), the Crane erosion cycle was interrupted or terminated by advance of a continental glacier of Illinoian(?) age; followed by an erosion cycle, which Howard called the deep-trench cycle, that began during the Sangamon Interglaciation and resulted in incision of the main valley of the Missouri River to as much as 140 feet below the Crane Creek Gravel. Howard (1960, p. 72) stated, "In the absence of evidence to the contrary, it is assumed that the oldest of the valley fills is early Wisconsin(?) in age. As additional information on the deep fill and the bedrock profile becomes available, it may develop that the deep trench was only partly eroded prior to the early Wisconsin(?) glaciation and was completed subsequently." Howard had very few data regarding depth to bedrock in the Yellowstone valley, but a well supplying water to the town of Fairview was reported to have penetrated bedrock at a depth of about 95(?) feet. No information is available about the type of material overlying the bedrock and underlying the flood plain and the channel alluvium of post-Wisconsin age.

VALLEY OF THE MISSOURI RIVER

While the north-northeast flowing preglacial Yellowstone River was shifting laterally southeastward, depositing the Cartwright Gravel (a quantitatively insignificant amount was deposited by the tributaries of the Yellowstone) and periodically forming terraces by cutting down into the Fort Union, the northeast-flowing, preglacial Missouri River was apparently following the same pattern. Flaxville, Cartwright, and Crane Creek Gravels deposited by the pre-Illinoian (Howard, 1960), or pre-Tazewell (Lemke and others, 1965) Missouri River are present north of the Girard field, but none was definitely identified in the mapped area. A very small deposit of Flaxville Gravel caps an isolated butte just north of the Missouri-Yellowstone drainage divide in sec. 27, T. 25 N., R. 56 E., but the divide has been dissected and moved southeastward by streams tributary to the Missouri River, and this gravel is believed to have been deposited by the ancestral Yellowstone River. Cartwright Gravel may once have capped some of the smoother remnants of the Missouri Plateau peneplain north of the drainage divide, but if ever present it has been removed or covered by glacial drift. No deposits definitely correlated with the Crane Creek Gravel were found north of the Missouri-Yellowstone drainage divide, but Howard (1960, pl. 1) mapped a small deposit on the north side of the Missouri River.

GLACIATION

Glacial ice advanced southwest and southward from Canada and covered most of the area of the Girard coal field. Only the plateaus capped by Flaxville Gravel in the western part of the field—between Fox Creek and North Fork Burns Creek and between Fox Creek and North Fork Fox Creek—were not overridden by the ice mass. The ice sheet may have been relatively thin by the time it reached the Girard field because the materials deposited by it are thinner and topographically less prominent than they are farther north. In addition to the material derived from as far north as the Canadian Shield, the ice scooped up or bulldozed some of the bedrock and surficial deposits that were present in the area and incorporated them in the deposits made by glacial processes. Some of the different types and forms of glacial deposits originated during the advance of the ice, but the majority of the preserved deposits and landscape features attributable to glaciation probably originated during stagnation and recession of the ice. Many of the ice-marginal, diversion, and melt-water channels undoubtedly originated during the advance of the ice and were used again during recession, but most of the deposits in the channels are probably attributable to the recession period.

Howard (1960) recognized only one advance and one retreat of ice of early Wisconsin age in the Girard field, but Colton, Lemke, and Lindvall (1961) and Lemke, Laird, Tipton, and Lindvall (1965) believed that there were two significant Wisconsin age ice advances over the area. The younger advance extended almost as far southward as the older one, and deposits and landscape features attributable to the older advance were presumably destroyed, buried, or modified. In any event, no differentiation of deposits or features has been attempted in this report and if two advances did occur, almost all the observable results of glaciation of the area are attributable to the younger advance.

The ice that covered the Girard field was probably of lobate or tongue-like form at its margin; a central, thicker part occupied the valley of the Yellowstone River and probably advanced and receded in a relatively orderly fashion. The edge of the ice mass on the uplands away from the Yellowstone valley assumed a very pronounced scalloped and lobed form as the thin ice advanced and receded around and over the dissected Flaxville plateaus and the Missouri Plateau peneplain.

South of the Missouri-Yellowstone drainage divide, direction of ice movement ranged from north to northwest, as the ice followed the existing drainage pattern, but the resultant direction of ice movement was about parallel to the Yellowstone valley and normal to the southeast-flowing tributaries of the Yellowstone River. The positions of the melt-water and stream-diversion channels shown on plate 1 indicate a progressive recession to the northeast, probably a mirror image of the advance. The major tributaries were dammed by ice in their lower courses, while the upper courses held impoundments of various size and duration, the deeper ones of which could overflow southward in channels cut through the interstream divides. Most of the larger channels were probably initiated during the ice advance and reused during recession. Some of the larger ones, such as the set of channels between Fox Creek and North Fork Burns Creek and the channel in secs. 10, 11, and 12, T. 22 N., R. 56 E., may have been used for a long period of time, during advance, stagnation, and recession, without appreciable interruption. Other channels, such as the long one between North Fork Fox Creek and Lone Tree Creek (and its obvious extension for several miles up North Fork Lone Tree Creek) were probably used for long periods during both advance and recession, but a short interruption in use probably occurred during the glacial maximum. The largest melt-water and stream-diversion channels are at the place where the Missouri Plateau peneplain abuts steeper slopes underlain by the Fort Union along the sides of the higher areas, which are held up by Flaxville Gravel lying on remnants of the Flaxville plain. The change in slope probably slowed the ice advance, and the melt waters and diverted streams were able to erode the Fort Union rocks more easily than the Cartwright Gravel.

During the advance and retreat of the glacial ice, many stream diversions took place. Most were of minor, transitory nature, and their occurrence is largely inferred because little or no record is preserved in the landscape. Other diversions were of longer duration, were probably repeated during both advance and retreat, and resulted in major landscape modification. Most of the major streams abandoned the diversion channels when they were no longer under the direct influence of ice and resumed their former courses, leaving large valleys which, at present, have no permanent streams (fig. 10). However, a few of the streams could not resume their preglacial courses because the older valley had become choked with glacial drift, or because they had eroded a new outlet or course that was at a lower elevation than the older one. The large outwash deposit in the southeastern part of T. 23 N., R. 56 E., dammed and choked the preglacial valley of North Fork Fox Creek, and the impounded water in the headwaters of the stream, now called Meadow Fork Fox Creek, cut a new course through the Fort Union Formation at a low point in the stream divide between North Fork Fox Creek and Fox Creek and is now a tributary of the latter. No definitive information such as drill-hole logs is available, but it seems possible that North Fork Lone Tree Creek flowed sutheast through secs. 8 and 9, T. 23 N., R. 58 E., to the present course of the tributary that joins Lone Tree Creek in sec. 25, T. 23 N., R. 58 E., instead of turning abruptly southwest and south in sec. 7, T. 23 N., R. 58 E.

North of the Missouri-Yellowstone drainage divide the glacial drift

FIGURE 10.—Sioux Pass, a wind gap about 120 feet deep cut by a melt-water stream in the NW¼ sec. 14, T. 25 N., R. 57 E.

deposits are thinner than they are south of the divide, possibly because there was much less surficial material, like the Cartwright Gravel, readily available for incorporation into the drift. Proglacial deposits are less abundant north of the divide and the melt-water and stream-diversion channels are less in number and, with few exceptions, shorter and shallower. Stream valleys, which by inference were probably major courses for diverted streamflow and melt-water flow, show few signs of such use and even fewer deposits attributable to glacial agencies. Most of the glacial deposits seem to have been plastered on the preexisting topography, depressions were filled, and, consequently, the thickness of the glacial deposits may change abruptly. In general, the glacial ice had less effect on the land surface north of the Missouri-Yellowstone drainage divide than it did south of the divide. The northern land surface appears to reflect a relatively swift advance by ice that carried small quantities of material from distant sources and larger quantities of locally derived Fort Union sediment. A quiet ice-locked period was followed by a relatively swift retreat.

The present valley of the Missouri River bordering the Girard field is composed of segments of two different ages. A narrow part of the valley, containing a slightly meandering river, lies between broader valley segments containing a river flowing in tight-looped meanders. According to Alden (1932, p. 58), the ancestral preglacial Missouri River flowed northeastward to Hudson Bay but was diverted to an easterly and southeasterly course by an ice sheet "at either the Nebraskan or the Kansan stage of glaciation." Howard (1960, p. 66) assigns a Kansan age to the diversion, which caused the Missouri to assume a course that used the present valley to near Culbertson (T. 28 N., R. 56 E.). From Culbertson, the river followed a curving course northward to the vicinity of the town of Bainville (T. 28 N., R. 58 E.), where it turned south and joined the present valley in the eastern part of T. 27 N., R. 58 E., from there, it flowed southeastward to join the Yellowstone. The narrow part of the present valley, from the northeastern part of T. 27 N., R. 56 E., to the east side of T. 27 N., R. 58 E., is of most recent origin, and according to Howard (1960, p. 85), "The apparent absence(?) of glacial till within the present trench to the south of the [Culbertson-Bainville] channel suggests that it was formed during withdrawal of the early Wisconsin(?) ice."

POSTGLACIAL LANDSCAPE CHANGES

After retreat of the ice sheet northward beyond the Missouri River, stream erosion was renewed, and inequalities in the surface, such as the Flaxville plateaus, were reduced. As pointed out by Howard (1960, p. 70), speaking of northeastern Montana and northwestern North Dakota in general, "The Crane erosion cycle has not yet propagated itself throughout the drainage system; the headwaters of many streams are still flowing at the Missouri peneplain level." Flood-plain and flood-channel alluvium were deposited in both the Missouri and Yellowstone River valleys following the retreat of the early Wisconsin glacier. This alluvial fill is as much as 95 feet thick near Fairview in the Yellowstone valley and thicker in parts of the Missouri valley. According to Howard (1960, p. 72), an unknown part of this fill is probably of early Wisconsin age.

Two other continental glaciers entered Montana and North Dakota from Canada, but neither extended as far south as the Girard coal field. Some eolian silt and other materials were deposited in the Girard field during and (or) after these glaciations, designated middle Wisconsin and Mankato by Howard (1960, table 3), but these deposits are too thin to be shown on the map.

A badlands area that parallels the narrow, younger part of the Missouri valley on the north edge of the Girard field is the only major postglacial erosional landscape change in the area. Minor changes are the removal of thin glacial drift from some of the ridges and valley slopes, the removal or burial of glacial and postglacial deposits in the major stream valleys and diversion channels, and a small amount of headward erosion by minor streams into the remnants of the Flaxville plateaus and the Missouri Plateau peneplain.

ECONOMIC GEOLOGY

OIL AND GAS

Table 3 describes oil and gas exploration test wells that were drilled in the Girard coal field prior to March 1, 1971. As indicated in the table, considerable quantities of oil have been discovered in rocks of Paleozoic age, at depths of 9,000–13,000 feet. The surface structure delineated by use of the coal beds of Paleocene age reveals few, or no, clues to reasons for the oil and gas accumulations at depth.

COAL

PHYSICAL AND CHEMICAL PROPERTIES

Coal, according to Schopf (1956, p. 527), is "a readily combustible rock containing more than 50 percent by weight and more than 70 percent by volume of carbonaceous material, formed from compaction or induration of variously altered plant remains similar to those of peaty deposits. Differences in the kinds of plant materials (type), in degree of metamorphism (rank), and range of impurity (grade), are characteristics of the varieties of coal." Although classification of coals by type and grade is done in some areas for special applications, the most widely used classification systems are those based on rank.

The position of a coal within the metamorphic series, which begins with peat and ends with graphocite, is dependent upon the temperatures and pressure to which the coal has been subjected and the

TABLE 3.—*Oil and gas exploration test wells in the Girard coal field, March 1, 1971*

[Init. prod.: D&A, initial production: dry and abandoned; prod. zone: producing zone; SD, shut down]

Company	Well name	Section	Date completed	Elevation (ft)	Depth (ft)	Remarks (Unit tops and producing zones (in ft) from oil industry reports)
			T. 21 N., R. 57 E.			
Target Oil	1-27 NPRR	SE¼SE¼, 27	11- 5-69	2,251	5,560	Tops: Greenhorn Ls., 4,270; Dakota Ss., 5,560; Init. prod.: D&A.
	1-25 NPRR	SE¼SE¼, 25	12-13-69	2,016	5,353	Tops: Greenhorn Ls., 4,165; Dakota Ss., 5,036; Init. prod.: D&A.
			T. 22 N., R. 56 E.			
McAlester Fuel; Placid Oil.	1-A Burgess	SE¼NE¼, 4	9-29-64	2,546	12,410	Tops: Greenhorn Ls., 4,522; Mission Canyon Ls., 9,016; Winnipeg Fm., 12,390; Init. prod.: D&A.
King Resources	1 Quilling	NW¼NE¼, 8	2- 2-70	2,416	11,890	Tops: Charles Fm., 8,091; Mission Canyon Ls., 8,823; Red River Fm., 11,714; Init. prod.: D&A.
			T. 23 N., R. 57 E.			
Woods Petroleum	1 Coon	NE¼SE¼, 1	6-11-69	2,323	12,578	Tops: Greenhorn Ls., 4,533; Mission Canyon Ls., 9,084; Red River Fm., 12,293; Init. prod.: D&A.
Miami Oil Producers	1 Coon	NE¼SW¼, 2	7-21-69	2,520	12,700	Tops: Muddy Ss. Mbr., Thermopolis Sh., 5,316; Mission Canyon Ls., 9,269; Red River Fm., 12,444; Init. prod.: D&A.
Jack Grynberg; U.S. Smelting, Refining, and Mining.	1 Sawyer	SW¼NE¼, 4	11-13-62	2,444	7,535	Tops: Pierre Sh., 1,862; Greenhorn Ls., 4,652; Madison Gp., 8,924; Init. prod.: D&A.
Miami Oil Producers	1 Larson	SE¼NE¼, 12	11-30-68	2,351	12,438-12,454	Tops: Muddy Ss. Mbr., Thermopolis Sh., 5,102; Mission Canyon Ls., 9,072; Red River Fm., 12,250; Prod. zone: Red River Fm., 12,438-12,454.
King Resources	1 Putnam	NW¼SE¼, 20	11-11-69	2,546	12,438	Tops: Eagle Ss., 3,313; Greenhorn Ls., 4,646; Mission Canyon Ls., 9,159; Red River Fm., 12,208; Prod. zone: Interlake Fm., 11,900-11,924; Red River Fm., 12,356-12,405.
King Resources; U.S. Smelting, Refining, and Mining.	1 Obergfell	SW¼SW¼, 21	7-14-70	2,542	12,570	Tops: Greenhorn Ls., 4,650; Mission Canyon Ls., 9,162; Red River Fm., 12,269; Prod. zone: Red River Fm., 12,306-12,445.

T. 23 N., R. 58 E.

Pennzoil United	1 Johnson	NW¼NW¼, 4	11-21-68	2,388	12,650	Tops: Eagle Ss., 3,326; Greenhorn Ls., 4,650; Mission Canyon Ls., 9,164; Red River Fm., 12,388; Prod. zone: Red River Fm., 12,508-12,547.
	2 Johnson-4	SE¼NW¼, 4	2-15-69	2,373	9,735	Tops: Eagle Ss., 3,318; Greenhorn Ls., 4,643; Lodgepole Ls., 9,703; Prod. zone: Charles Fm., 9,024-9,578.
	1 Sorenson	SW¼NE¼, 4	3-24-69	2,378	12,745	Tops: Greenhorn Ls., 4,665; Mission Canyon Ls., 9,218; Red River Fm., 12,427; Prod. zone: Mission Canyon Ls., 9,078-9,360.
	1 Johnson-5	NE¼NE¼, 5	9-12-69	2,402	12,671	Tops: Greenhorn Ls., 4,630; Mission Canyon Ls., 9,164; Red River Fm., 12,370; Prod. zone: Red River Fm., 12,504-12,570.
Woods Petroleum	1 Dynneson	SE¼NW¼, 7	8-13-68	2,330	12,560	Tops: Greenhorn Ls., 4,551; Mission Canyon Ls., 9,058; Red River Fm., 12,216; Prod. zone: Red River Fm., 12,396-12,472.
	1-A Dynneson	SE¼SE¼, 7	8-18-69	2, 342	12,606	Tops: Greenhorn Ls., 4,577; Mission Canyon Ls., 9,127; Red River Fm., 12,316; Init. prod.: D&A.
	2 Dynneson	SE¼SW¼, 7	10-25-68	2,280	12,464	Tops: Greenhorn Ls., 4,508; Mission Canyon Ls., 9,028; Red River Fm., 12,187; Init. prod.: D&A.
	2-A Dynneson	SW¼NE¼, 7	5- 9-69	2,272	12,486	Tops: Greenhorn Ls., 4,515; Mission Canyon Ls., 9,008; Red River Fm., 12,183; Prod. zone: Red River Fm., 12,366-12,422

T. 23 N., R. 59 E.

Pennzoil United	1 Leo	SW¼SE¼, 4	9- 2-70	2,173	12,810	Tops: Greenhorn Ls., 4,425; Mission Canyon Ls., 9,125; Red River Fm., 12,433; Prod. zone: Red River Fm., 12,616-12,704.
Wendell C. Flynn	1 Beagle Land and Livestock.	NE¼SW¼ SW¼, 17.	10-20-58	2,151	13,134	Tops: Greenhorn Ls., 4,410; Mission Canyon Ls., 8,896; Prod. zone: Mission Canyon Ls., 8,965-9,230.
	1 A. S. Hanto	C SW¼ NE¼, 18.	11- 7-60	2,197	9,240	Tops: Greenhorn Ls., 4,400; Prod. zone: Madison Gp., 9,009-9,240.

T. 24 N., R. 57 E.

King Resources; Waef Core; U.S. Smelting, Refining, and mining.	1 Lewis	NW¼NW¼, 10	2- 3-70	2,460	12,620	Tops: Greenhorn Ls., 4,610; Mission Canyon Ls., 9,124; Red River Fm., 12,245; Prod. zone: Red River Fm., 12,418-12,496.
Miami Oil Producers	2 Franz	SE¼SE¼, 17	7-10-69	2,395	12,603	Tops: Greenhorn Ls., 4,560; Mission Canyon Ls., 9,070; Red River Fm., 12,234; Init. prod.: D&A.
	27-1 Johnson	SE¼NW¼, 27	9- 1-69	2,370	12,514	Tops: Greenhorn Ls., 4,563; Mission Canyon Ls., 9,077; Red River Fm., 12,252; Init. prod.: D&A.
	1 Franz	SE¼NE¼, 28	1-22-68	2,442	12,633	Tops: Mission Canyon Ls., 9,099; Red River Fm., 12,292; Init. prod.: D&A.

TABLE 3.—*Oil and gas exploration test wells in the Girard coal field, March 1, 1971*—Contined

Company	Well name	Section	Date completed	Elevation (ft)	Depth (ft)	Remarks (Unit tops and producing zones (in ft) from oil industry reports)
			T. 24 N., R. 58 E.			
Kerr McGee Corp.	1 Berndt.	SW¼SW¼, 12	5-10-69	2,202	12,816	Tops: Mission Canyon Ls., 9,144; Red River Fm., 12,480; Init. prod.: D&A.
Consolidated Oil and Gas.	13-24-5811 Henderson.	NE¼SW¼, 13	3- 7-69	2,205	9,625	Tops: Greenhorn Ls., 4,489; Mission Canyon Ls., 9,118; Prod. zone: Mission Canyon Ls., 9,120-9,150.
	13-24-5815 Ullman.	SW¼NW¼, 13	1-30-69	2,214	12,810	Tops: Greenhorn Ls., 4,504; Mission Canyon Ls., 9,129; Red River Fm., 12,400; Prod. zone: Red RiverFm., 12,585-12,639.
	13-24-58-1 Clough.	SW¼SE¼, 13	5-27-69	2,160	12,803	Tops: Greenhorn Ls., 4,428; Mission Canyon Ls., 9,080; Red River Fm., 12,334; Prod. zone: Red River Fm., 12,560-12,540.
	14-24-18-1 Berry.	SE¼NW¼, 14	6- 4-69	2,310	12,905	Tops: Greenhorn Ls., 4,600; Mission Canyon Ls., 9,243; Red River Fm., 12,516; Init. prod.: D&A.
	14-24-58-1 Henderson.	NE¼NE¼, 14	7-18-69	2,230	12,760	Tops: Greenhorn Ls., 4,508; Mission Canyon Ls., 9,138; Red River Fm., 12,434; Init. prod.: D&A.
Rutledge Exploration Rudman, Dorfman, and Cantina.	1NPRR- Bentson Unit.	C SE¼, 19	2-22-63	2,363	9,436	Tops: Greenhorn Ls., 4,652; Mission Canyon Ls., 8,988; Prod. zone: Mission Canyon Ls., 9,046-9,389.
Paul F. Rutledge	1 T S Bentson .	SW¼NW¼, 29	2-17-62	2,428	9,586	Tops: Greenhorn Ls., 4,696; Prod. zone: Madison Gp., 9,062-9,135, 9,207-9,575.
Miami Oil Producers	1-A Dynneson .	C SW¼, 29	7- 6-68	2,480	12,785	Tops: Greenhorn Ls., 4,733; Mission Canyon Ls., 9,336; Red River Fm., 12,410; Prod. zone: Red River Fm., 12,601-12,614.
Sun Oil-Phillips Petroleum	2 Dynneson .	CSW¼ SW¼ 29	June 1954	2,492	9,744	Tops: Greenhorn Ls., 4,751; Prod. zone: Madison Gp., 9,128-9,220.
Miami Oil Producers	1-B Dynneson .	SE¼SE¼, 30	9-20-68	2,510	12,835	Tops: Mission Canyon Ls., 9,270; Red River Fm., 12,470; Prod. zone: Red River Fm., 12,659-12,676.
Sun Oil-Phillips Petroleum.	1-Dennis Dynneson.	SW¼SE¼, 30	10-26-55	2,501	12,683	Tops: Greenhorn Ls., 4,759; Red River Fm., 12,477; Prod. zone: Madison Gp., 9,130-9,210, 9,254-9,280, 9,310-9,350.
Mimi Oil Producers ..	1 Allison	NE¼NE¼, 31	11-15-68	2,427	12,780	Tops: Mission Canyon Ls., 9,192; Red River Fm., 12,386; Prod. zone: Red River Fm., 12,575-12,596.
Sun Oil	1 Dynneson ...	NE¼SW¼, 32	4-18-64	2,398	12,648	Tops: Mission Canyon Ls., 9,224; Red River Fm., 12,385; Init. prod.: SD.
Miami Oil Producers	1 Dynneson-C .	NW¼NW¼, 32	4- 8-68	2,478	12,720	Tops: Greenhorn Ls., 4,730; Mission Canyon Ls., 9,238; Red River Fm., 12,418; Prod. zone: Red River Fm., 12,607-12,638.
Pennzoil United	1 Jensen Unit ..	SW¼SW¼, 33	6- 5-69	2,407	12,724	Tops: Greenhorn Ls., 4,645; Mission Canyon Ls., 9,200; Red River Fm., 12,378; Prod. zone: Red River Fm., 12,565-12,582.
Sun Oil	1 J. W. Johnson	SW¼SE¼, 33	6- 3-59	2,426	9,501	Tops: Greenhorn, Ls., 4,678; Prod. zone: Charles Fm., 9,080-9,246.

Rutledge, Rudman, and Dorfman.	1 Peterson-Justice-Christiansen Unit.	NW¼NW¼, 34	11- 1-62	2,366	9,500	Prod. zone: Madison Gp., 9,138-9,454.
			T. 24 N., R. 59 E.			
Pennzoil United	1 Henderson ..	NW¼SE¼, 7	10-13-70	2,216	12,750	Tops: Greenhorn Ls., 4,498; Mission Canyon Ls., 9,155; Red River Fm., 12,450; Init. prod.: D&A.
Consolidated Oil and Gas.	1 East Fairview Unit.	SE¼ NE¼, 12	1-10-71	2,152	12,903	Tops: Greenhorn Ls., 4,462; Mission Canyon Ls., 9,190; Red River Fm., 12,610; Init. prod.: D&A.
	1 Ft. Gilbert Unit.	NW¼NW¼, 32	10-29-70	2,073	12,707	Tops: Greenhorn Ls., 4,356; Mission Canyon Ls., 9,017; Red River Fm., 12,317; Prod. zone: Red River Fm., 12,502-12,512.
			T. 25 N., R. 56 E.			
King Resources	1 Dayton	NE¼SE¼, 23	10-21-69	2,450	12,640	Tops: Greenhorn Ls., 4,589; Mission Canyon Ls., 9,179; Red River Fm., 12,374; Prod. zone: Mission Canyon Ls., 9,036-9,384.
			T. 25 N., R. 58 E.			
Superior Oil; Consolidated Oil and Gas.	1 Christiansen	NE¼NW¼, 13	10-31-67	2,096	13,069	Tops: Greenhorn Ls., 4,417; Red River Fm., 12,341; Prod. zone: Red River Fm., 12,492-12,565.
	1 Vanderhoof-A	SE¼NE¼, 13	6-16-67	2,131	12,737	Tops: Greenhorn Ls., 4,480; Red River Fm., 12,368; Prod. zone: Winnipegosis Fm., 11,414-11,442; Red River Fm., 12,552-
Consolidated Oil and Gas.	1-B Christiansen	SE¼NE¼, 14	5-1b17-68	2,165	12,865	Tops: Red River Fm., 12,472; Prod. zone: Red River Fm., 12,671-12,722.
	1-A Hunter	NE¼SE¼, 14	2-17-68	2,195	12,840	Tops: Mission Canyon Ls., 9,086; Red River Fm., 12,471; Prod. zone: Red River Fm., 12,619-12,675.
Southern Union Production: Consolidated Oil and Gas.	1 Hunter	SW¼SE¼, 23	6-22-66	2,187	13,272	Tops Mission Canyon Ls., 9,118; Red River Fm., 12,480; Init. prod.: Temp. abandoned.
Consolidated Oil and Gas.	1 Bruijord.	SW¼NE¼, 25	12-30-66	2,126	12,850	Tops: Greenhorn Ls., 4,405; Red River Fm., 12,454; Init. prod.: Temp. abandoned.
	2 Brujord.	NE¼NW¼, 25	12- 1-67		12,795	Init. prod.: Temp. abandoned.
Kerr-McGee Corp ..	1 Maeleata	SW¼SE¼, 28	3-10-66	2,314	12,903	Tops: Mission Canyon Ls., 9,232; Red River Fm., 12,562; Init. prod.: D&A.
Miami Oil Producers	1 Larry Tveit ...	NW¼NW¼, 30	1-25-68	2,396	12,958	Tops: Mission Canyon Ls., 9,268; Red River Fm., 12,574; Init. prod.: D&A.

TABLE 3.—*Oil and gas exploration test wells in the Girard coal field, March 1, 1971*—Continued

Company	Well name	Section	Date completed	Elevation (ft)	Depth (ft)	Remarks (Unit tops and producing zones (in ft) from oil industry reports)
			T. 25 N., R. 59 E.			
Superior Oil	1 Vanderhoof-B-	SW¼NW¼, 18	1-18-68	2,101	12,675	Tops: Greenhorn Ls., 4,450; Red River Fm., 12,367; Prod. zone: Red River Fm., 12,516-12,580.
	1 Vanderhoof Unit-C.	NE¼SW¼, 18	5-22-68	2,063	12,637	Tops: Greenhorn Ls., 4,413; Red River Fm., 12,330; Prod. zone: Red River Fm., 12,480-12,540.
Consolidated Oil and Gas.	22-25-5916 La Bonte.	SE¼SE¼, 22	10-23-68	1,987	1,500	Init. prod.: Temp. SD.
Tenneco Oil	1 Engen, et al	NW¼NW¼, 29	10-16-70	2,185	12,875	Tops: Greenhorn Ls., 4,498; Mission Canyon Ls., 9,147; Red River Fm., 12,518; Prod. zone: Red River Fm., 12,671-12,722.
Consolidated Oil and Gas	2 Young Heirs	SW¼SW¼, 30	7-21-68	2,208	13,191	Tops: Red River Fm., 12,487; Prod. zone: Red River Fm., 12,666-12,716.
	1 Young Heirs	NW¼NE¼, 31	5- 9-68	2,208	12,850	Tops: Mission Canyon Ls., 9,187; Red River Fm., 12,502; Prod. zone: Red River Fm., 12,691-12,723.
	3 Young Heirs	SW¼NW¼, 32	10-17-68	2,165	12,745	Tops: Red River Fm., 12,496; Init. prod.: D&A.
			T. 26 N., R. 57 E.			
King Resources	1 McGinnis	SW¼NE¼, 34	12-10-69	2,314	12,700	Tops: Mission Canyon Ls., 9,102; Red River Fm., 12,393; Init. prod.: D&A.
			T. 26 N., R. 58 E.			
Continental Oil	1 Trudell	SW¼SW¼, 17	9-29-70	2,067	12,929	Tops: Winnipegosis Fm., 11,235; Init. prod.: D&A.
Pel-Tex Petroleum	1 Federal	NW¼SE¼, 31	2-12-68	2,175	12,725	Tops: Greenhorn Ls., 4,487; Red River Fm., 12,420; Init. prod.: Temp. abandoned.
Continental Oil	1 Grosvold-35	SW¼NW¼, 35	4- 1-70	2,136	12,788	Tops: Greenhorn Ls., 4,495; Red River Fm., 12,470; Prod. zone: Red River Fm., 12,650-12,660.
	Grosvold-35	NW¼SW¼, 35	9-16-70	2,106	12,731	Tops: Red River Fm., 12,401; Prod. zone: Red River Fm., 12,550-12,609.
			T. 26 N., R. 59 E.			
Union Texas Petroleum.	1 UTP Johnson	NW¼ SE¼, 31	7-6-68	2,123	12,952	Tops: Greenhorn Ls., 4,480; Red River Fm., 12,568; Init. prod.: D&A.

duration of time of subjection. Because it is by definition largely derived from plant material, coal is composed mostly of carbon, hydrogen, and oxygen, along with smaller quantities of nitrogen, sulfur, and other elements. The increase in rank of coal as it undergoes progressive metamorphism is indicated by changes in the proportions of the coal constituents—the higher rank coals have more carbon and less hydrogen and oxygen than the lower ranks.

Various schemes for classifying coals by rank have been proposed and used, but the system employed in the United States is that presented in the "Standard Specifications for Classification of Coals by Rank," adopted by the American Society for Testing and Materials (1969, table 1).

The rank of the coal in the Girard field and in nearby areas is lignite *A*. The fresh lignite is a brownish black to black, and it has a brown streak or powder. It has a subconchoidal fracture, and a surface transverse to the bedding commonly has a banded appearance, owing to the alternation of bright and dull layers. Locally, all the beds contain shale, clay, or sand partings, but these partings are more common and comprise a larger part of a bed where the thickness is less than 5 feet. In many beds the original texture of the woody material is preserved, and the lignite is tough rather than brittle. The lignite rapidly loses moisture—as much as 35 percent—when exposed to air, and the surface becomes dull and covered with small cracks. Slacking proceeds rapidly, and within a few months the exposed lignite is reduced to a fine powder. At all exposures, or under thin overburden where the coal is not kept moist by ground water, the coal is slacked to a fine powder or to small grains, or both, for several feet back from the outcrop, but, under thick overburden, the slacking may not extend more than a few feet back from the exposed face (fig. 11). Lignite from the fresh face in a mine is commonly massive and tough.

Two standardized forms of coal analyses—the *proximate analysis* and the *ultimate analysis*—are generally used in the world today, though sometimes only the less complicated and less expensive *proximate analysis* is made. The analyses are described as follows (U.S. Bureau of Mines, 1965, p. 121–122):

The *proximate analysis* of coal involves the determination of four constituents: (1) water, called moisture; (2) mineral impurity, called ash, left when the coal is completely burned; (3) volatile matter, consisting of gases or vapors driven out when coal is heated to certain temperatures; and (4) fixed carbon, the solid or cakelike residue that burns at higher temperatures after volatile matter has been driven off. *Ultimate analysis* involves the determination of carbon and hydrogen as found in the gaseous products of combustion, the determination of sulfur, nitrogen, and ash in the material as a whole, and the estimation of oxygen by difference.

Most coals are burned to produce heat energy, so the heating value of the coal is an important property. The heating value (calorific value) is commonly expressed in British thermal units (Btu) per pound. Ad-

TABLE 4.—*Classification of coals by rank* [1]

[From American Society for Testing and Materials (1969, table 1)]

Class	Group	Fixed carbon limits, percent (dry, mineral-matter-free basis)		Volatile matter limits, percent (dry, mineral-matter-free basis)		Calorific value limits, Btu per pound (moist,[2] mineral-matter-free basis)		Agglomerating character
		Equal or greater than	Less than	Greater than	Equal or less than	Equal or greater than	Less than	
I. Anthracitic	1. Meta-anthracite	98	...	...	2	...	...	Nonagglomerating.
	2. Anthracite	92	98	2	8	...	...	
	3. Semianthracite[3]	86	92	8	14	...	...	
II. Bituminous	1. Low volatile bituminous coal	78	86	14	22	...	...	Commonly agglomerating.[5]
	2. Medium volatile bituminous coal	69	78	22	31	...	...	
	3. High volatile *A* bituminous coal	...	69	31	...	[4]14,000	...	
	4. High volatile *B* bituminous coal	...	...	...	...	[4]13 000	14 000	
	5. High volatile *C* bituminous coal	...	...	...	...	11 500 10 500	13 000 11 500	 Agglomerating.
III. Subbituminous	1. Subbituminous *A* coal	...	...	...	...	10 500	11 500	Nonagglomerating.
	2. Subbituminous *B* coal	...	...	...	...	9 500	10 500	
	3. Subbituminous *C* coal	...	...	...	...	8 300	9 500	
IV. Lignitic	1. Lignite *A*	...	...	...	...	6 300	8 300	
	2. Lignite *B*	...	...	...	...		6 300	

[1]This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 percent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.

[2]Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[3]If agglomerating, classify in low-volatile group of the bituminous class.

[4]Coals having 69 percent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[5]It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high volatile *C* bituminous group.

FIGURE 11.—Pust coal bed at an abandoned entry at the Pickering mine, NW ¼ sec. 29, T. 21 N., R. 58 E.

ditional tests are sometimes made, particularly to determine the caking, coking, and other properties, such as tar yield, which affect classification or utilization.

Analyses of coal from the Girard field and, for comparison, analyses of coals from adjoining fields are given in table 5. Proximate analyses are given in three forms, marked A, B, and C. Form A gives the composition and heating value of the sample as received in the laboratory and closely approximates the composition of the coal in the mine. Form B gives the calculated composition and heating value of the dry coal. Form C gives the approximate composition and heating value of the dry combustible matter. Coal does not exist in nature with the composition shown by the forms B and C, but these forms are valuable for the purpose of comparison. The volatile matter in each analysis was determined by the modified method, in which gradual heating in an electric furnace prevented mechanical loss of particles and steam. All analyses were made by the U.S. Bureau of Mines.

The ultimate analyses of the coal samples from three mines in the area are given in table 6.

Data for germanium and ash in samples from 10 localities in the Girard field are reported by Stadnichenko, Murata, Zubovic, and Hufschmidt (1953, p. 34).

BURNING OF THE COAL BEDS

Clinker formed by the burning of coal beds along their lines of outcrop is conspicuous in the badlands north of the Missouri-Yellowstone drainage divide and along the valley of North Fork Burns Creek in the southwestern part of the field (fig. 12). The ignition of the coal beds has been ascribed to lightning, to prairie fires, and to the activities of man; however, most of the fires probably started as a result of spontaneous combustion. The presence of clinker fragments in the terrace gravels and the presence of unaltered ground moraine lying directly upon thick masses of clinker indicate that some of the beds must have burned before the advance of the ice sheet into this area.

The appearance of the clinker depends on the lithology of the rocks above the burning coal bed, the intensity of the heat, and the rate of cooling of the clinkered rock. Rogers (1917) described the physical and mineralogical changes that occur in rocks affected by the burning of coal beds. Generally, the clinker is pink, red, or purplish red, but it may be mottled or banded with yellow, green, or black. As the burning progresses back from the outcrop, the baked and fused overburden collapses on the unaffected underlying strata; thus, the base of the clinker coincides, stratigraphically, with the base of the coal bed and is a fairly reliable mapping horizon. The limit of burning of a coal bed is assumed to coincide with the extent on the surface of the clinker formed by the burning.

The extent of burning back from the outcrop is limited only by the lack of circulating air to supply essential oxygen. Extensive burning of thick beds, as in the northwestern part of this field, is possible where

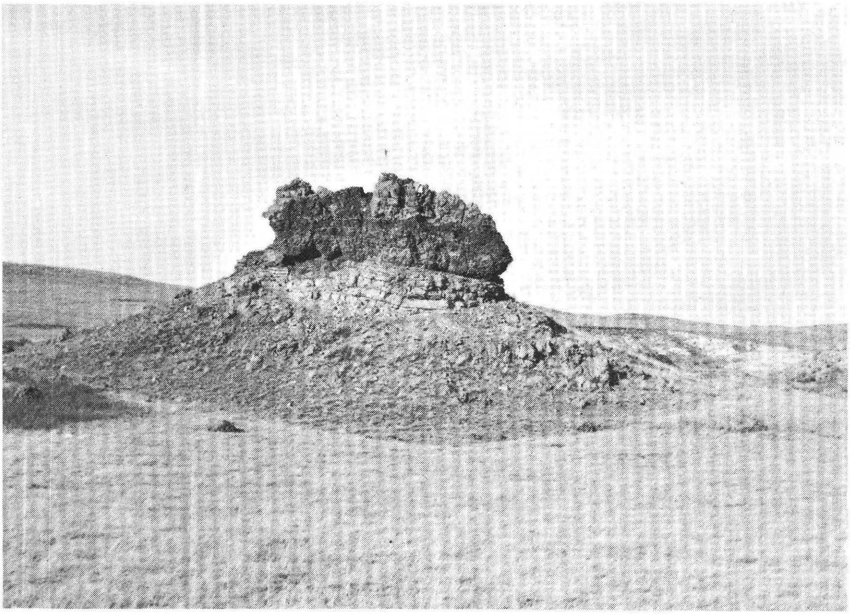

FIGURE 12.—Clinker about 20 feet thick capping a butte near North Fork Burns Creek, formed by burning of the Pust coal bed, sec. 30, T. 21 N., R. 56 E.

the progressive collapse of the overburden opens fissures that permit circulation of air. Overlying beds of sandstone, siltstone, and shale locally are baked and fused for as much as 60 feet above the burned coal bed. In the steep bluffs along the Missouri River, where the lines of outcrop of the coal beds are nearly straight and the overburden is commonly more than 100 feet thick, the coal beds have burned along most of their lines of outcrop. In small stream valleys where headward erosion has exposed the coal bed beyond the clinker, the limit of burning is as much as 50 feet back from the clinker outcrop on the face of the bluff.

THE COAL BEDS

Coal beds that crop out in the Girard coal field occur in the Tongue River Member of the Fort Union Formation. The outcrop of each coal bed is shown by a line on the geologic map (pl. 1). Although the strata dip slightly, the outcrop lines of the coal beds closely follow the contour of the surface and on the map resemble contour lines. Numbers along the outcrop lines indicate localities where thicknesses were measured, and corresponding numbers identify graphic sections of the coal beds at these localities (pl. 2; figs. 13-32). A few of the sections were measured by means of drilling with a jeep-mounted power auger.

Coal beds that occur in the lower part of the Tongue River Member are more continuous and generally thicker than those in the upper part. The principal coal beds vary in thickness along the outcrop, and the intervals between them are not everywhere constant. The thin beds in the

TABLE 5.—*Proximate analyses of coal from three mines in the Girard coal field and five selected analyses from adjoining fields*

[Analyses are in percent except where indicated]

Name of mine, location, and name of bed	Rank of coal[1]	U.S. Bureau of Mines lab. sample No.	Form of analysis [2]	Moisture	Volatile matter	Fixed carbon	Ash	Sulfur	Heating value (Btu)
Girard coal field									
Jennison, sec. 17, T. 27 N., R. 56 E., F bed.	Lignite *A*	[3]D-57773	A	38.9	24.9	29.1	7.1	0.4	6,540
			B	....	40.7	47.7	11.6	.7	10,710
			C	....	46.1	53.9	....	.8	12,120
O'Conner, sec. 9, T. 26 N., R. 57 E., H bed.	... do	[3]D-57776	A	41.5	24.6	27.2	6.7	.7	6,270
			B	....	42.1	46.4	11.5	1.1	10,730
			C	....	47.6	52.4	....	1.3	12,120
Crosby, sec. 20, T. 25 N., R. 56 E., H bed.	... do	[3]D-57772	A	38.2	26.7	27.6	7.5	.8	6,670
			B	....	43.3	44.6	12.1	1.4	10,790
			C	....	49.3	50.7	....	1.5	12,290

Coal fields adjoining Girard coal field									
Elvirio, sec. 12, T. 24 N., R. 54 E., Lower Elvirio bed.	Lignite *A* ...	[4]A-65451	A	38.3	25.7	30.0	6.0	0.5	6,710
			B	....	41.6	48.6	9.8	.8	10,880
			C	....	46.1	53.9	....	.9	12,060
Lane, sec. 26, T. 23 N., R. 53 E., Lane bed.	...do	[4]A-65454	A	36.5	26.9	30.0	6.6	.9	7,150
			B	....	42.4	47.2	10.4	1.4	11,250
			C	....	47.4	52.6	....	1.5	12,560
Otto Pust, sec. 28, T. 22 N., R. 55 E., Pust bed.	...do	[4]A-65453	A	38.3	25.4	30.3	6.0	.5	6,880
			B	....	41.1	49.2	9.7	.8	11,140
			C	....	45.6	54.4	....	.9	12,340
Chimney Rock, sec. 11, T. 20 N., R. 56 E., Pust bed.	...do	[5]D-75580	A	33.7	27.3	32.2	6.8	.5	7,090
			B	....	41.1	48.7	10.2	.7	10,690
			C	....	45.8	54.2	....	.8	11,910
Savage (Knife River), sec. 22(?), T. 20 N., R. 57 E., Pust bed.	...do	([6])	A	37.4	41.6	45.8	12.6	.7	6,630
		([7])	A	37.1	39.5	47.6	12.9	1.3	6,590
		([8])	A	37.9	40.9	48.9	10.2	.8	6,660

[1]Standard specifications for classification of coals by rank (American Society for Testing and Materials Designation D 388-66).
[2]A, as received; B, moisture free; C, moisture and ash free.
[3]This report.
[4]Parker (1936).
[5]Culbertson (1954).
[6]Aresco, Haller, and Abernethy (1962).
[7]Aresco, Janus, and Walker (1965).
[8]Aresco and Janus (1967).

TABLE 6.—*Ultimate analyses of coal samples from the Girard field*

Mine and coal bed	U.S. Bureau of Mines lab. sample No.	Form of analysis[1]	Ash	Sulfur	Hydrogen	Carbon	Nitrogen	Oxygen
O'Conner mine, Prittegurl bed.	D-57776	A	6.7	0.7	7.1	37.2	0.7	47.6
		B	11.5	1.1	4.2	63.5	1.2	18.5
		C	....	1.3	4.7	71.8	1.4	20.8
Crosby mine, Prittegurl bed.	D-57772	A	7.5	.8	6.8	39.6	.7	44.6
		B	12.1	1.4	4.2	64.0	1.1	17.2
		C	....	1.5	4.7	72.9	1.3	19.5
Jennison mine, Lower Elvirio bed.	D-57773	A	7.1	.4	6.8	39.0	.6	46.1
		B	11.6	.7	4.0	63.9	1.1	18.7
		C	....	.8	4.5	72.3	1.2	21.2

[1]A, as received; B, moisture free; C, moisture and ash free.

upper part of the Tongue River Member are lenticular; consequently, their correlation over a large area is commonly uncertain. Although the outcrop line of a thin bed is continuous on the map, the line may actually represent several discontinuous thin beds that occur at slightly different stratigraphic positions. Very lenticular or discontinuous beds are designated as local beds even though beds may be present at the same, or very nearly the same, stratigraphic position in other parts of the Girard field or in nearby areas.

The following tabulation lists the coal beds recognized in the northern and southern parts of the Girard field and postulated correlations with the coal beds mapped in coal fields adjoining the Girard field. Some of the suggested correlations are extremely tenuous and may subsequently prove to be incorrect, but the general stratigraphic relations are believed to be valid (table 7).

TABLE 7.— *Correlation of coal beds in the Girard and adjoining coal fields*

Fort Peck field (Smith, 1909)	Culbertson field (Beekly, 1912)	Richey-Lambert field, eastern part (Parker, 1936)	Sidney field (Stebinger, 1912)	Girard coal field (this report)	
				Northern part	Southern part
	H bed		K bed	Local beds	Local beds.
	G bed			L bed	Gardner bed.
			J bed		Local bed.
	Unnamed beds.			K bed	K bed.
	F bed	Prittegurl bed.	I bed	H bed	Prittegurl bed.
					Local bed.
G bed	E bed	Pust bed	H bed	G bed	Pust bed.
F bed	DD bed	Elvirio bed	G bed	F bed	Sears bed.
			Local bed.		
E bed	CC bed		F bed	E bed.	
		Budka bed.			
D bed	D bed	Lane bed	E bed	D bed.	
C bed	C bed.				
B bed.	B bed.				
A bed	A bed.				

MINING

Coal has been mined on a small scale in the Girard field for domestic use since the earliest settlement of the area. For many years coal beds were the only source of fuel, and the ranchers took coal from most of the easily accessible outcrops. Prospect pits and abandoned mines are common throughout the coal field. Mines in the field produced about 14,000 tons of coal during 1950, and about 11,000 tons during 1951. The use of coal for space heating has decreased in recent years because of increased use of natural and liquid petroleum gases in both urban and rural parts of this area.[1]

The largest mine in the field in 1951, the Jennison mine, in the NW¼ sec. 17, T. 27 N., R. 56 E., had been in operation since 1941. One adit, about 1,500 feet long, and two shorter ones extended along the lower part of the F bed into the hillside. Coal was mined from rooms, drifts, and the adit face in the lower 7 feet of the bed, leaving about 5 feet of coal in the roof. Electrically self-propelled mine trucks hauled the mechanically loaded coal from the face to the tipple. Although the mine was in operation throughout the year, the maximum production rate of about 100 tons per day was sustained only during October and November.

The Crosby mine, in the SE¼ sec. 20, T. 25 N., R. 56 E., consisted of one adit which extended about 600 feet into the H bed. The lower 6 feet of the coal bed was mined, leaving the upper 4 feet in the roof. Small mine cars were loaded, pushed along the tracks, and unloaded at the entry by hand. Most of the mining was done during the fall and winter, but a small quantity of coal was mined during the spring and summer. According to the operator, the average annual production in 1950 was about 2,000 tons.

The Bemer mine, in the NW¼ sec. 18, T. 27 N., R. 56 E., was opened in 1948, and consisted of one drift that extended about 400 feet into the lower part of the F bed. Only the lower 6 feet of the coal bed was mined, and the upper part, 8–9 feet thick, was left as the roof. Loading, moving the mine cars, and unloading the coal at the entry was done by hand. The owner estimated that about 500 tons of coal was produced from this mine in 1951.

The O'Connor mine in the SE¼ sec. 9, T. 26 N., R. 57 E., was privately owned, and all coal taken from the mine during 40 years of operation was used by the owners. It consisted of one drift extending into the H bed, which is about 6 feet thick, and the total thickness of the coal was mined.

Although no coal was mined after April 1950, the Park mine, in the NW¼ sec. 18, T. 27 N., R. 56 E., one-fourth mile north of the Bemer mine, produced about 900 tons of coal during the first part of 1950. The

[1]As of December 31, 1970, no mines were listed as producing coal in the Girard field. (E. J. Cox, U.S. Geological Survey, oral commun., 1971; Hansen, 1971).

Allen mine (loc. 602) in sec. 21, T. 21 N., R. 58 E., near Crane, increased production from 21 tons in 1950 to 174 tons of coal in 1951. During 1950, the Sorenson mine (loc. 614) in sec. 26 T. 21 N., R. 57 E., produced 121 tons of coal by strip mining in the valley of Sears Creek. In addition to these small mines, several other small mines and prospects were operated intermittently and supplied a small quantity of coal for domestic use. All mining in the field has been by either tunneling or stripping, except a shaft mine at Fairview, in the SE¼NW¼ sec. 8, T. 24 N., R. 60 E., which was operated successfully for many years before being flooded in 1939.

A strip mine operated by the Knife River Coal Mining Co. in T. 20 N., R. 57 E., about 4.5 miles west of Savage, is about 4 miles south of the southern boundary of the Girard field. The mine opened in 1955 to supply fuel for the Lewis and Clark Steam Electric Generating Station near Sidney, which is specifically designed for fuels produced in the area. The bed mined is the Pust. The Breezy Flat strippable lignite deposit in which this strip mine is located was investigated and described by Culbertson (1954).

ESTIMATION AND CLASSIFICATION OF COAL RESOURCES

Preparation of a coal reserve estimate involves certain procedures and definitions, discussed in detail by Averitt (1969, p. 14–30), that have been established in an attempt to standardize, insofar as possible, coal-resource appraisals in the United States. As used in this report, the term "coal resources" is defined as that part of the total amount of coal in the ground that has been determined to be present by mapping and (or) exploration and that can be quantitatively evaluated according to selected and specified parameters.

The coal characteristics that are commonly used in classifying coal resources are the rank, grade, and weight of the coal, the thickness and areal extent of the coal beds, and the thickness of the overburden. The rank of the coal in the Girard field has been discussed previously in the section on physical and chemical properties.

Grade or quality classification of coals is generally based upon the quantity of ash, sulfur, and other deleterious constituents that are important in determining the utilization potential. A tabulation of 642 typical mine, tipple, and delivered samples of coals in the United States by Fieldner, Rice, and Moran (1942) shows that the samples ranged in ash content from 2.5 to 32.6 percent and averaged 8.9 percent and ranged in sulfur content from 0.3 to 7.7 percent and averaged 1.9 percent. In comparison, samples from the Girard field and adjacent areas range in ash content from 6.0 to 12.9 percent and average 8.2 percent and range in sulfur content from 0.4 to 1.3 percent and average 0.7 percent. Thus, the coals of the Girard field and surrounding area are lower in ash and much lower in sulfur than most coals in the United

States—a factor of importance in view of increasing concern about air pollution during combustion of solid and liquid fuels.

The weight of coal ranges considerably with differences in rank and ash content. In areas such as the Girard field where true specific gravities of the coals are unknown, an average specific gravity value based on many determinations in other areas is used to express the weight of the coal for resource estimation calculations. The average weight of lignite is taken as 1,750 tons per acre-foot—a specific gravity of 1.29.

Because of the important relation of coal-bed thickness to utilization potential, most coal resource estimates prepared by the U.S. Geological Survey are tabulated according to three thickness categories. For lignite the categories are as follows: Thin, 2.5–5 feet; intermediate, 5–10 feet; and thick, more than 10 feet. About 13 percent of the estimated resources of the Girard field are in the thin category, about 62 percent are of intermediate thickness, and about 25 percent are in the thick category. This distribution may be affected by (1) the reluctance of resource estimators to project information for thin beds very far from points of measurement, and (2) the tendency of the lignite to slack upon weathering; because of this tendency a thin bed is much less likely to be noticed everywhere at its outcrop than a thicker coal bed, and the presence of thin beds is more likely to go undetected. The distribution does, of course, also reflect the fact that the coal beds of Tertiary age in the northern Great Plains include a larger percentage of coal in beds more than 5 feet thick than is present in the coal-bearing rock sequences in other parts of the United States. For example, Averitt (1969, fig. 5 and p. 37) showed the distribution of the estimated resources of 21 States as 44 percent in beds in the thin category, 27 percent in the intermediate category, and 29 percent in the thick category.

Coal-bed thicknesses used in calculating resource estimates were derived from both isopach maps and weighted average thicknesses. Bed-thickness maps were prepared where the distribution of data allowed meaningful thickness maps but in some areas, particularly of isolated and widely spaced outcrop data, weighted average thicknesses of coal beds in the area were derived. The outcrops of coal beds 1.5 or more feet thick are shown on the map but the resources in beds with a weighted average thickness of less than 2.5 feet are not included in the summary total.

Within the Girard field the thicker beds, particularly the F, H, G, and Prittegurl beds, are more than 2.5 feet thick for linear distances of more than 15 miles. Probable correlation of these beds in neighboring coal fields, such as the Richey-Lambert field (Parker, 1936), increases the traceable extent of these beds several fold. The thinner beds, such as the K, L, and Gardner beds, seem to be intermittently present over areas comparable to the thicker beds but are not generally continuous for distances of more than 5 miles, either because each of the beds is so thin it does not crop out or because each one locally thins to extinction and, thus, may be regarded as a series of discrete lenses at about the same stratigraphic level. In some nearby areas, channels that cut into or through the coal beds have been filled by younger beds of the Tongue River Member or the much younger glacial deposits of Pleistocene age. In the Girard field, channeling of the coal beds was observed only in a few places, but channels probably are as prevalent as in other areas north of the limit of glaciation. The problem of determining the extent of subsurface burning of the coal beds is discussed in another section of this report.

Coal resources are commonly divided into categories based on the thickness of overburden, in feet, as follows: 0–1,000, 1,000–2,000, and 2,000–3,000. The estimated coal resources of the Girard field are all at depths of less than 1,000 feet, so overburden thickness categories are not used. Thinner overburden categories are used in some areas in order to categorize coal resources for special uses or situations, such as strip-mining potential. Lack of sufficient detailed information precludes categorization of the estimated resources of the Girard field for strip-mining potential, but a considerable portion of the known coal in some areas is overlain by less than 200 feet of overburden.

Coal resources are also commonly classified according to the abundance and reliability of the data upon which the estimates are based. In general, most measured and indicated resources estimated for the Girard field are contained in bodies of coal within one-half mile of points of information. Inferred resources are contained in bodies of coal whose inner boundaries are generally bodies of measured and indicated resources and whose outer boundaries are based largely on projection of information on the basis of geologic inference, but generally no more than 2 miles from points of observation. About 13 percent of the estimated coal resources of the Girard field is in the measured and indicated class, and the remainder, about 87 percent, is in the inferred class. Reasons for the relatively large percentage of estimated resources in the inferred class are (1) most of the data points are located on irregular dissected outcrops whose geometry does not allow large areas of measured and indicated coal to be outlined; and (2) most of the inferred resources are located under the interstream divides and gravel-capped terraces, where there are no reliable drill-hole data.

Another classification of coal resources is based on the distinction between original, remaining, and recoverable resources. Original resources are the resources in the ground before the beginning of mining operations and include coal that has been mined and lost in mining, coal that is in the weathered zone near the outcrop, and coal that is under cultural features, such as roads, railroads, and pipelines. The estimated coal resources of the Girard field are calculated as original resources because very little coal has been removed by past mining.

For every ton of coal produced in mining, a certain amount of coal is left unmined, in pillars, roof, or floor; is discarded as undersize; is lost in washing; or is unrecoverable due to the presence of cultural features or other mining in the area. The ratio of the coal actually produced to the sum of 1) the coal actually produced and 2) the coal lost in mining or unrecoverable is expressed in percentage as the recoverability factor. For areas where precise information is unavailable or inadequate, the Geological Survey has adopted a standard recoverability factor of 50 percent. Thus, for every ton of coal produced another ton of coal is lost, and the remaining resources of such an area are the original resources minus twice the reported amount of coal produced in the area. Information about past production in the Girard field is completely inadequate, and no attempt is made in this report to derive a remaining resource estimate for the field. However, the past production is insignificant compared with the original resource estimate so the remaining resource is for all practical purposes the same as the original resource.

The recoverability factor discussed in the preceding paragraph is applied to convert remaining resources to recoverable resources. If the commonly used recoverability factor of 50 percent is applied, the recoverable resources are one-half the remaining resources.

SUMMARY OF RESOURCE ESTIMATES

The estimated original coal resources of the Girard field total 5,107.4 million short tons, of which 688.2 million tons is classed as measured and indicated resources and 4,419.2 million tons is classed as inferred (table 8). Coal beds 2.5–5 feet thick make up 649.3 million tons of the total estimated resources, beds 5–10 feet thick make up 3,158.3 million tons, and beds more than 10 feet thick make up 1,299.8 million tons. Measured and indicated resources in beds more than 5 feet thick total 544.7 million tons.

Table 9 summarizes the estimated original resources of the Girard field by township and by reliability of data classes. Resources were estimated in 28 townships, but only inferred resources were estimated in three of the townships. The township with the most estimated resources is T. 26 N., R. 57 E., with a total of 425.2 million tons, but T. 27 N., R. 56 E., has the most measured and indicated resources with 104.6 million tons in that class. Six of the townships contain more than 300 million tons of estimated resources and 10 townships contain more than 30 million tons of measured and indicated resources.

The H and F coal beds of the northern part of the Girard field contain over one-half of the estimated original resources of the whole field (table 10) and the H bed alone contains over 30 percent of the total estimated resources. The estimated resources of the F bed might total even more than the H bed if more were known about the areal extent of the bed

TABLE 8.—*Estimated original resources, in millions of short tons, of coal in the Girard field*

Coal beds	Reserves of coal in beds of thickness shown								Total reserves			
	Measured and indicated				Inferred							
	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Total (measured and indicated)	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Total (inferred)	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Grand total
T. 21 N., R. 56 E.												
K		3.4		3.4						3.4		3.4
Prittegurl					15.4			15.4	15.4			15.4
Pust				36.3			273.4	273.4			309.7	309.7
Township total		3.4	36.3	39.7	15.4		273.4	288.8	15.4	3.4	309.7	328.5
T. 21 N., R. 57 E.												
Prittegurl	11.6			11.6	52.7			52.7	64.3			64.3
Pust			27.8	27.8			188.1	188.1			215.9	215.9
Sears						25.5		25.5		25.5		25.5
Township total	11.6		27.8	39.4	52.7	25.5	188.1	266.3	64.3	25.5	215.9	305.7
T. 21 N., R. 58 E.												
Prittegurl	11.3			11.3	0.9			0.9	12.2			12.2
Pust		2.1	32.1	34.2			3.7	3.7		2.1	35.8	37.9
Sears		14.0		14.0		89.4		89.4		103.4		103.4
Township total	11.3	16.1	32.1	59.5	0.9	89.4	3.7	94.0	12.2	105.5	35.8	153.5

T. 22 N., R. 56 E.												
K		1.4		1.4						1.4		1.4
Prittegurl	3.6	5.3		8.9	70.8			70.8	74.4	5.3		79.7
Township total	3.6	6.7		10.3	70.8			70.8	74.4	6.7		81.1
T. 22 N., R. 57 E.												
K	4.0			4.0	14.0			14.0	18.0			18.0
Prittegurl	2.9	23.6		26.5		99.4		99.4	2.9	123.0		125.9
Township total	6.9	23.6		30.5	14.0	99.4		113.4	20.9	123.0		143.9
T. 22 N., R. 58 E.												
K	6.0	2.9		8.9	30.0			30.0	36.0	2.9		38.9
Prittegurl	7.9			7.9	21.1			21.1	29.0			29.0
Local					8.3			8.3	8.3			8.3
Township total	13.9	2.9		16.8	59.4			59.4	73.3	2.9		76.2
T. 23 N., R. 56 E.												
K	1.4			1.4					1.4			1.4
Prittegurl	2.7	3.5		6.2	13.4			13.4	16.1	3.5		19.6
Local	.3			.3					.3			.3
Township total	4.4	3.5		7.9	13.4			13.4	17.8	3.5		21.3
T. 23 N., R. 57 E.												
Gardner	0.9			0.9	18.8			18.8	19.7			19.7
Local					1.2			1.2	1.2			1.2
Township total	0.9			0.9	20.0			20.0	20.9			20.9

TABLE 8.—*Estimated original resources, in millions of short tons, of coal in the Girard Field*—Continued

Coal beds	Reserves of coal in beds of thickness shown.								Total reserves			
	Measured and indicated				Inferred							
	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Total (measured and indicated)	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Total (inferred)	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Grand total
T. 23 N., R. 58 E.												
Gardner	1.0			1.0	16.6			16.6	17.6			17.6
Local	4.9			4.9	47.5			47.5	52.4			52.4
Township total	5.9			5.9	64.1			64.1	70.0			70.0
T. 23 N., R. 59 E.												
Gardner	0.4	15.4		15.8		26.4		26.4	0.4	41.8		42.2
Prittegurl	1.3	3.0		4.3	34.1			34.1	35.4	3.0		38.4
Township total	1.7	18.4		20.1	34.1	26.4		60.5	35.8	44.8		80.6
T. 24 N., R. 56 E.												
K	0.4			0.4					0.4			0.4
Prittegurl	1.0	22.6		23.6		74.5		74.5	1.0	97.1		98.1
Township total	1.4	22.6		24.0		74.5		74.5	1.4	97.1		98.5
T. 24 N., R. 57 E.												
Prittegurl		3.8		3.8		84.2		84.2		88.0		88.0
Local beds	2.7	3.8		6.5	31.5			31.5	34.2	3.8		38.0
Township total	2.7	7.6		10.3	31.5	84.2		115.7	34.2	91.8		126.0

T. 24 N., R. 58 E.												
Gardner	...	...	...	...	...	26.8	...	26.8	...	26.8	...	26.8
Local beds	1.7	0.4	...	2.1	0.3	.8	...	1.1	2.0	1.2	...	3.2
Township total	1.7	0.4	...	2.1	0.3	27.6	...	27.9	2.0	28.0	...	30.0
T. 24 N., R. 59 E.												
Gardner	1.3	29.4	...	30.7	...	80.6	...	80.6	1.3	110.0	...	111.3
Local	...	...	...	...	...	9.1	...	9.1	...	9.1	...	9.1
Township total	1.3	29.4	...	30.7	...	89.7	...	89.7	1.3	119.1	...	120.4
T. 24 N., R. 60 E.												
Gardner	...	...	...	...	...	0.7	...	0.7	...	0.7	...	0.7
Local	...	3.7	...	3.7	...	5.1	...	5.1	...	8.8	...	8.8
Township total	...	3.7	...	3.7	...	5.8	...	5.8	...	9.5	...	9.5
T. 25 N., R. 55 E.												
H	1.4	2.3	...	3.7	...	0.3	...	0.3	1.4	2.6	...	4.0
F	2.2	6.9	...	9.1	...	167.2	...	167.2	2.2	174.1	...	176.3
E	0.3	...	...	0.3	...	...	...	...	0.3	...	...	0.3
Township total	3.9	9.2	...	13.1	...	167.5	...	167.5	3.9	176.7	...	180.6
T. 25 N., R. 56 E.												
Local beds	2.7	...	...	2.7	...	...	...	...	2.7	...	...	2.7
H	0.6	15.4	...	16.0	...	182.2	...	182.2	0.6	197.6	...	198.2
F	...	...	...	...	...	85.4	...	85.4	...	85.4	...	85.4
Township total	3.3	15.4	...	18.7	...	267.6	...	267.6	3.3	283.0	...	286.3

TABLE 8.—*Estimated original resources, in millions of short tons, of coal in the Girard field*—Continued

Coal beds	Reserves of coal in beds of thickness shown.								Total reserves			
	Measured and indicated				Inferred							
	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Total (measured and indicated)	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Total (inferred)	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Grand total
T. 25 N., R. 57 E.												
H	...	...	...	...	...	255.3	...	255.3	...	255.3	...	255.3
Township total	...	...	...	...	...	255.3	...	255.3	...	255.3	...	255.3
T. 25 N., R. 58 E.												
H	...	...	...	...	...	241.7	...	241.7	...	241.7	...	241.7
Township total	...	...	...	...	...	241.7	...	241.7	...	241.7	...	241.7
T. 25 N., R. 59 E.												
H	...	...	...	...	...	220.7	...	220.7	...	220.7	...	220.7
Township total	...	...	...	...	...	220.7	...	220.7	...	220.7	...	220.7
T. 26 N., R. 55 E.												
H	...	0.2	...	0.2	...	...	...	...	...	0.2	...	0.2
F	7.5	10.6	...	18.1	...	200.2	...	200.2	7.5	210.8	...	218.3
Township total	7.5	10.8	...	18.3	...	200.2	...	200.2	7.5	211.0	...	218.5

T. 26 N., R. 56 E.												
H	0.3	24.8	...	25.1	...	40.2	...	40.2	0.3	65.0	...	65.3
G	8.4	...	...	8.4	24.5	1.6	...	26.1	32.9	1.6	...	34.5
F	...	...	...	...	...	...	298.2	298.2	...	...	298.2	298.2
Township total	8.7	24.8	...	33.5	24.5	41.8	298.2	364.5	33.2	66.6	298.2	398.0
T. 26 N., R. 57 E.												
H	0.8	62.2	...	63.0	...	180.3	...	180.3	0.8	242.5	...	243.3
G	3.9	13.7	...	17.6	85.0	18.4	...	103.4	88.9	32.1	...	121.0
F	...	...	...	...	...	60.9		60.9	...	...	60.9	60.9
Township total	4.7	75.9	...	80.6	85.0	198.7	60.9	344.6	89.7	274.6	60.9	425.2
T. 26 N., R. 58 E.												
K	0.9	...	...	0.9	...	...	...	...	0.9	...	...	0.9
H	2.3	27.4	...	29.7	...	165.8	...	165.8	2.3	193.2	...	195.5
G	...	6.1	...	6.1	...	130.7	...	130.7	...	136.8	...	136.8
Township total	3.2	33.5	...	36.7	...	296.5	...	296.5	3.2	330.0	...	333.2
T. 26 N., R. 59 E.												
Local beds	0.2	...	...	0.2	...	...	...	...	0.2	...	...	0.2
H	...	...	...	...	...	116.5	...	116.5	...	116.5	...	116.5
Township total	0.2	...	...	0.2	...	116.5	...	116.5	0.2	116.5	...	116.7
T. 27 N., R. 55 E.												
F	2.5	21.7	7.6	31.8	...	5.3	13.0	18.3	2.5	27.0	20.6	50.1
E	16.8	8.2	...	25.0	...	...	...	...	16.8	8.2	...	25.0
D	...	1.8	...	1.8	...	192.0	...	192.0	...	193.8	...	193.8
Township total	19.3	31.7	7.6	58.6	...	197.3	13.0	210.3	19.3	229.0	20.6	268.9

TABLE 8. —*Estimated original resources, in millions of short tons, of coal in the Girard field*—Continued

Coal beds	Reserves of coal in beds of thickness shown.								Total reserves			
	Measured and indicated				Inferred							
	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Total (measured and indicated)	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Total (inferred)	2.5 to 5.0 feet	5.0 to 10.0 feet	More than 10.0 feet	Grand total
T. 27 N., R. 56 E.												
H	0.8	21.8		22.6		19.4		19.4	0.8	41.2		42.0
G	14.2	7.5		21.7	19.1	12.7		31.8	33.3	20.2		53.5
F	8.4		51.9	60.3			245.7	245.7	8.4		297.6	306.0
Township total	23.4	29.3	51.9	104.6	19.1	32.1	245.7	296.9	42.5	61.4	297.6	401.5
T. 27 N., R. 57 E.												
H		10.2		10.2		3.8		3.8		14.0		14.0
G	2.0	9.7		11.7	0.6	7.3		7.9	2.6	17.0		19.6
F			0.2	0.2			60.9	60.9			61.1	61.1
Township total	2.0	19.9	0.2	22.1	0.6	11.1	60.9	72.6	2.6	31.0	61.1	94.7
Grand total	143.5	388.8	155.9	688.2	505.8	2,769.5	1,143.9	4,419.2	649.3	3,158.3	1,299.8	5,107.4

TABLE 9.—*Summary of estimated original resources by township and class*

[In millions of short tons]

Location		Measured and indicated resources	Inferred resources	Total resources
T. 21 N.,	R. 56 E ...	39.7	288.8	328.5
	R. 57 E ...	39.4	266.3	305.7
	R. 58 E ...	59.5	94.0	153.5
T. 22 N.,	R. 56 E ...	10.3	70.8	81.1
	R. 57 E ...	30.5	113.4	143.9
	R. 58 E ...	16.8	59.4	76.2
T. 23 N.,	R. 56 E ...	7.9	13.4	21.3
	R. 57 E ...	.9	20.0	20.9
	R. 58 E ...	5.9	64.1	70.0
	R. 59 E ...	20.1	60.5	80.6
T. 24 N.,	R. 56 E ...	24.0	74.5	98.5
	R. 57 E ...	10.3	115.7	126.0
	R. 58 E ...	2.1	27.9	30.0
	R. 59 E ...	30.7	89.7	120.4
	R. 60 E ...	3.7	5.8	9.5
T. 25 N.,	R. 55 E ...	13.1	167.5	180.6
	R. 56 E ...	18.7	267.6	286.3
	R. 57 E ...		255.3	255.3
	R. 58 E ...		241.7	241.7
	R. 59 E ...		220.7	220.7
T. 26 N.,	R. 55 E ...	18.3	200.2	218.5
	R. 56 E ...	33.5	364.5	398.0
	R. 57 E ...	80.6	344.6	425.2
	R. 58 E ...	36.7	296.5	333.2
	R. 59 E ...	.2	116.5	116.7
T. 27 N.,	R. 55 E ...	58.6	210.3	268.9
	R. 56 E ...	104.6	296.9	401.5
	R. 57 E ...	22.1	72.6	94.7
Total (rounded)		688	4,419	5,107

TABLE 10.—*Summary of estimated resources of individual coal beds*

Coal bed	Total estimated original resources (millions of short tons)	Percent of total (rounded)
H	1,600	31
F	1,260	24½
Prittegurl	571	11
Pust	564	11
G	365	7
Gardner	219	4½
D	194	4
Sears	129	2½
K	64	1½
E	25	½
Local beds	124	2½

because the F bed is more than 10 feet thick in some areas. More than one-third of the estimated measured and indicated resources in beds more than 10 feet thick are in the F bed.

About 67 percent of the total estimated resources are in the northern part of the coal field. This distribution is at least partly explained by the unequal abundance of information, which is related to the facts that (1) the south half is blanketed by surficial deposits to a much greater degree than the north half, and information on the coal is correspondingly sparse; and (2) even where surficial materials do not conceal the coal-bearing rocks, outcrops of coal-bearing rocks in the south half are more topographically subdued, more weathered, and more covered by vegetation than are the outcrops in the north half.

TOWNSHIP DESCRIPTIONS

T. 21 N., R. 56 E.

(fig. 13)

Pust Coal Bed

The lowermost coal bed exposed in T. 21 N., R. 56 E., crops out in the valley of North Fork Burns Creek and is very extensively burned along the outcrop. Resistant clinker as much as 50 feet thick caps small ridges and pinnacles that are as much as a quarter of a mile from the outcrop. The bed ranges in thickness from 32 feet of coal, at locality 622 to 26.5 feet, with a 14-inch-thick carbonaceous shale parting 14 feet above the base and a 6-inch-thick carbonaceous shale parting 9 feet 9 inches from the top, at locality 625. At locality 624 the bed is a zone of coal, bony coal, bone, and carbonaceous shale more than 45 feet thick.

K Coal Bed

A bed of coal measuring 7.5 feet of coal and bony coal was formerly strip mined at locality 621. This bed is about 35–45 feet above the Prittegurl coal bed.

Unexposed Coal Beds

The Prittegurl coal bed, which is exposed along Fox Creek in T. 22 N., R. 56 E., is believed to underlie the northeastern part of T. 21 N., R. 56 E.

T. 21 N., R. 57 E.

(fig. 14)

Pust Coal Bed

The lowermost coal bed exposed in the township is the Pust coal bed, which is extensively burned at the outcrop along Sears Creek. It ranges in thickness from 12 feet 9 inches, with a 2-inch-thick carbonaceous shale parting 6 feet 9 inches below the top, at locality 614 to 10 feet of coal at locality 620. Several strip mines in secs. 26 and 27 formerly supplied coal to the neighboring landowners. The Pust bed crops out in

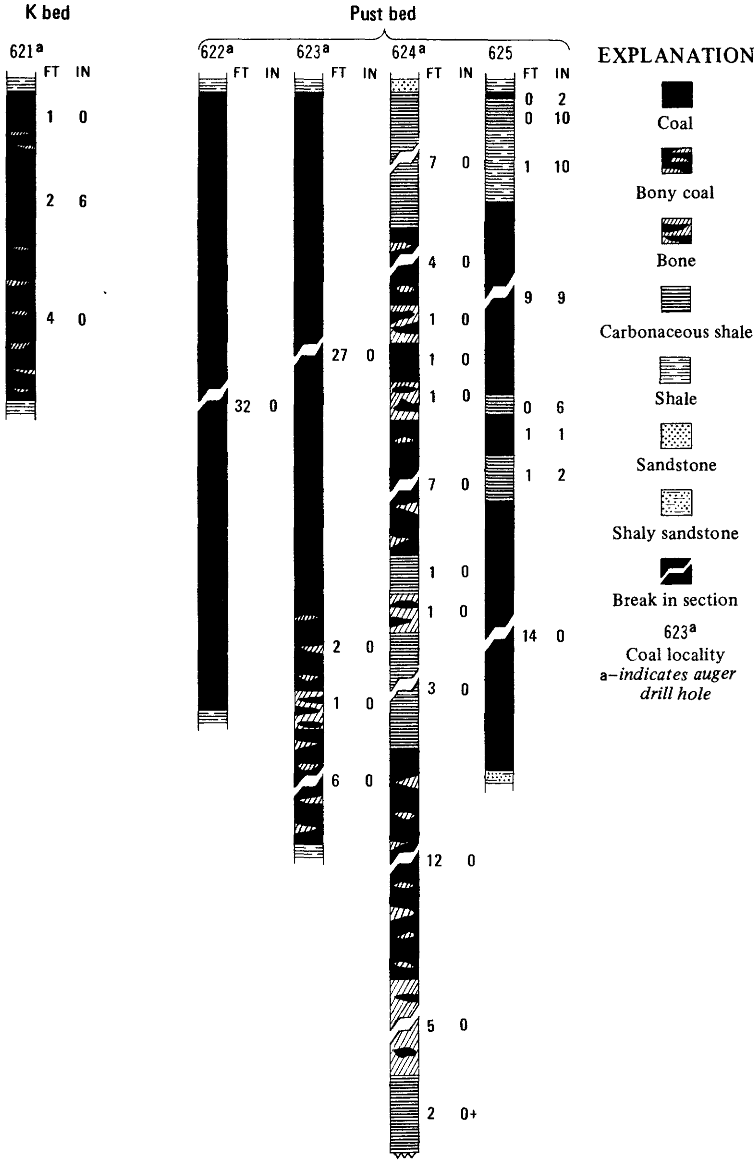

FIGURE 13.—Graphic sections of coal beds in T. 21 N., R. 56 E.

the valley of Dunlap Creek about 1 mile south of the township, and the coal is 10 feet thick in several auger holes and wells within one-half mile of the south boundary of the township. A well in the SE¼SE¼ sec. 29 is reported to have penetrated 10 feet of coal at about the Pust bed horizon, and several other wells within 1 mile are reported to have encountered coal at about the same horizon. The well and auger-hole

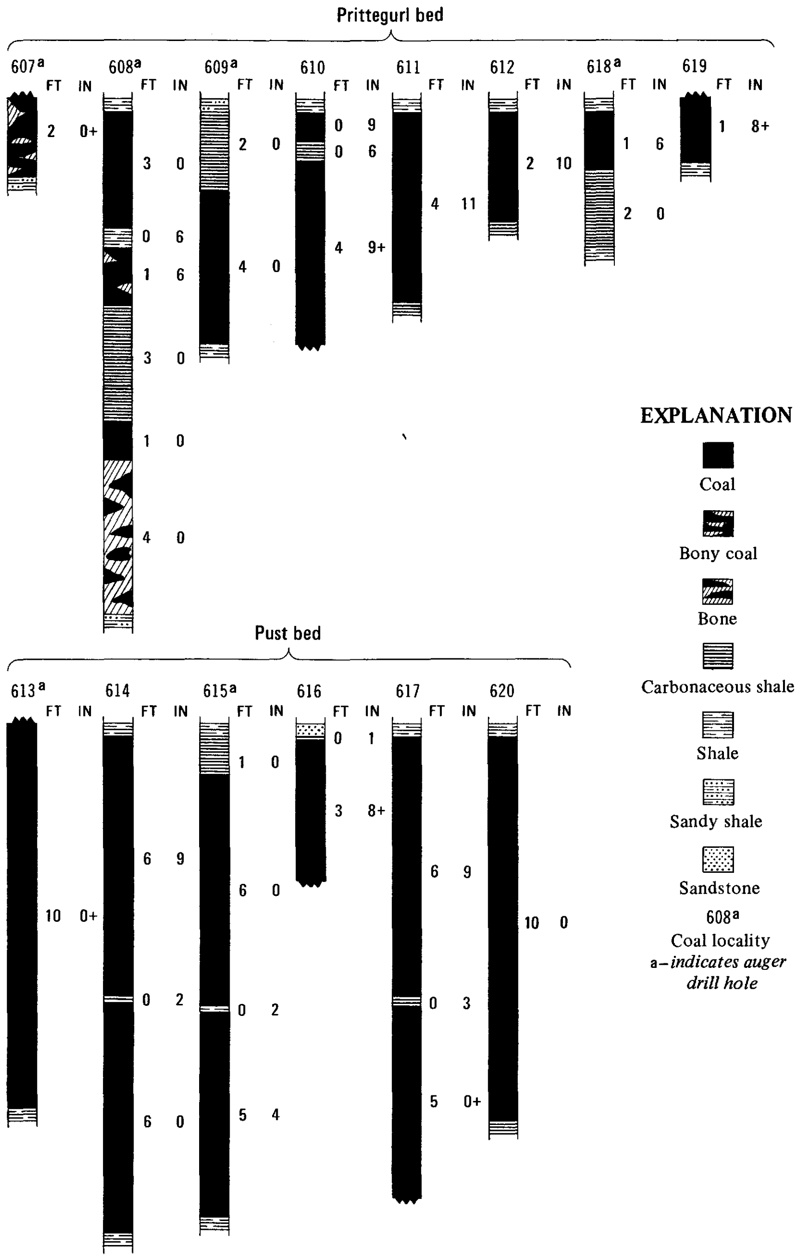

FIGURE 14.—Graphic sections of coal beds in T. 21 N., R. 57 E.

records mentioned above were used as a basis for calculating inferred coal resources over the southwestern part of the township.

Prittegurl Coal Bed

The Prittegurl coal bed, about 100 feet above the Pust bed, is exposed in the valleys of Fox Creek, Crane Creek, Sears Creek, and their tributaries. The coal bed was not mapped in all parts of the township, because of a lack of exposures. At locality 611 the coal bed measures 4 feet 11 inches in thickness, and 13 feet of coal, bony coal, bone, and carbonaceous shale is present at locality 608.

Unexposed Coal Bed

The Sears bed, exposed in sec. 31, T. 21 N., R. 58 E., is 9 feet 3 inches thick at locality 606 and is believed to underlie the southeast corner of T. 21 N., R. 57 E., about 75 feet below the Pust coal bed.

T. 21 N., R. 58 E.

(fig. 15)

Sears Coal Bed

The Sears bed crops out where Sears Creek and Crane Creek empty onto the entrenched valley of the Yellowstone River at the level of the Crane Creek Gravel. The bed ranges in thickness from more than 7 feet at locality 595 under the town of Crane to 10 feet with a 6-inch-thick shale parting 1 foot below the top near the mouth of Sears Creek at locality 605. The Sears bed is about 55–100 feet below the Pust bed in the Sears Creek–Crane Creek area.

Pust Coal Bed

The Pust bed crops out in the steep slopes below the Cartwright Gravel terraces. The bed ranges in thickness from 8 feet 8 inches at locality 600 to about 14 feet in an auger hole at locality 594.

Prittegurl Coal Bed

The Prittegurl bed is present in the northwestern part of the township, but it is concealed by surficial deposits, or perhaps was removed prior to deposition of the surficial deposits, in some parts of the township. The bed ranges in thickness from about 3.5 feet in an auger hole at locality 586 to 4 feet 11 inches at locality 599.

T. 22 N., R. 56 E.

(fig. 16)

Prittegurl Coal Bed

The only mappable coal bed in T. 22 N., R. 56 E., crops out on the south side of Fox Creek valley. The bed ranges in thickness from 7 feet 8 inches at locality 535 to 2 feet of clean coal at locality 537.

Unexposed Coal Beds

The K coal bed is believed to be present about 35–45 feet above the Prittegurl bed in T. 22 N., R. 56 E., but was not mappable at the only

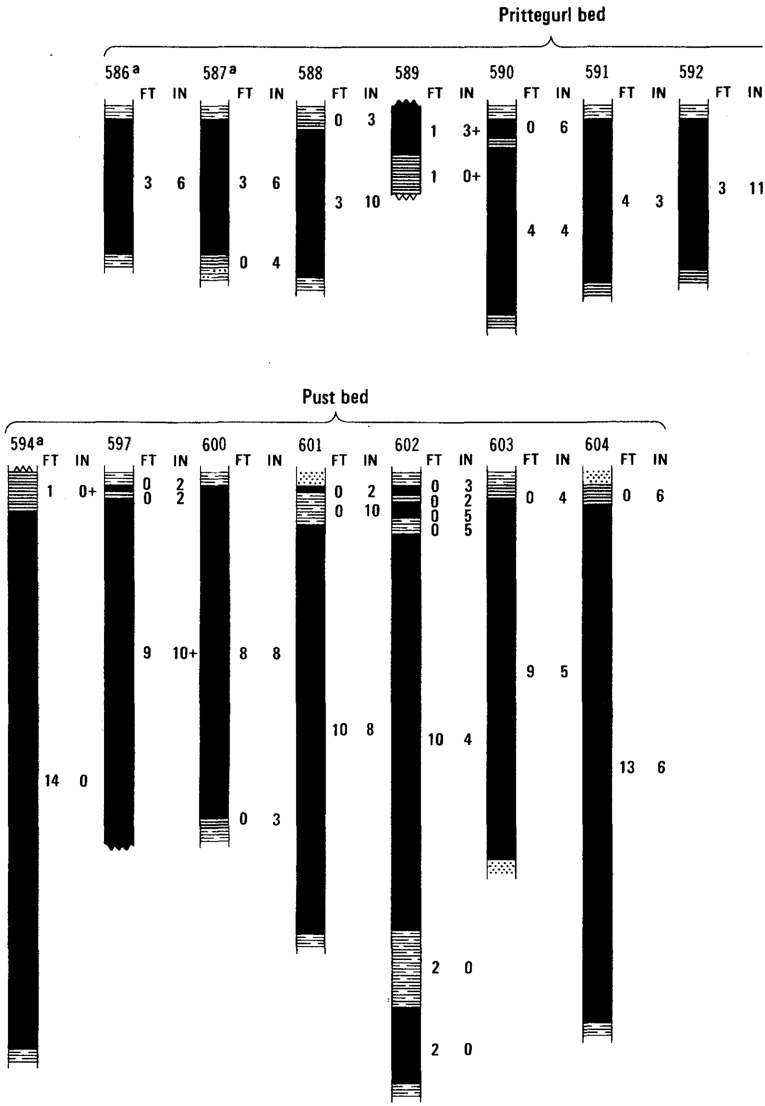

FIGURE 15 (above and facing page).—Graphic sections of coal beds in T. 21 N., R. 58 E.

exposure, in sec. 17, in the township. However, it is 7.5 feet thick in sec. 1, T. 21 N., R. 56 E.

T. 22 N., R. 57 E.

(fig. 17)

PRITTEGURL COAL BED

The lowest coal bed exposed in the township crops out in the valleys of Fox Creek and North Fork Fox Creek, about 100 feet above the Pust

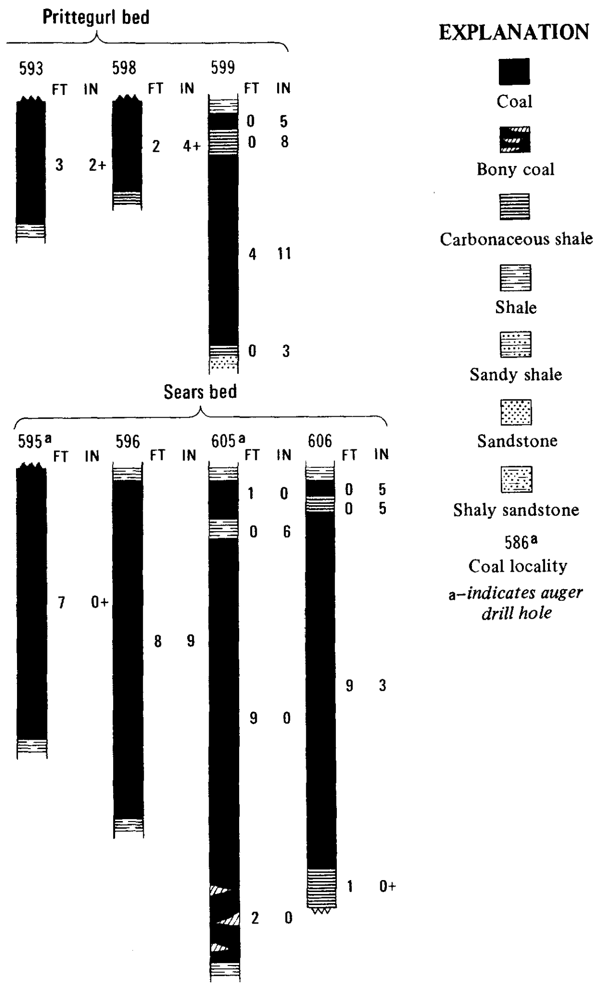

FIGURE 15.—Continued.

coal bed. It usually has a parting near the middle, but in some places the parting is absent. The bed ranges in thickness from 21 feet, with an 11-foot-thick shale and sandstone parting 7 feet above the base, at locality 546 to 3 feet 3 inches at locality 542.

K COAL BED

The coal bed exposed in the valley of North Fork Fox Creek about 120–130 feet above the Pust bed ranges in thickness from 7 feet, with a 2-foot-thick carbonaceous shale parting 4 feet above the base, at locality 540 to 3 feet at locality 543.

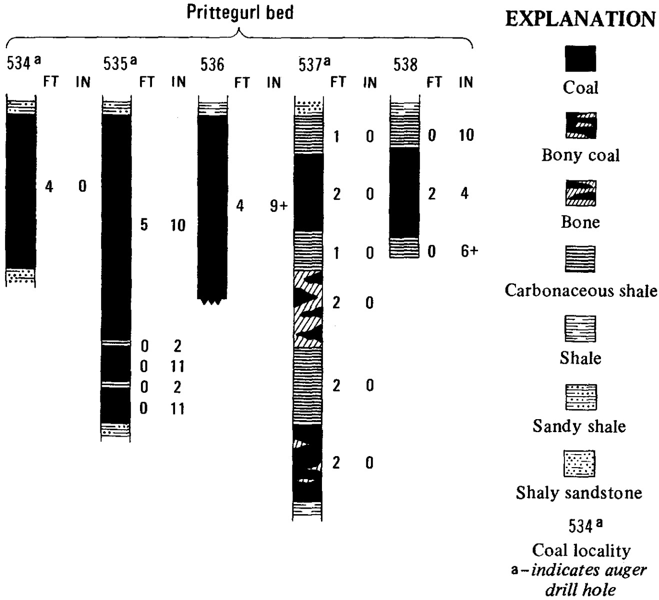

FIGURE 16.—Graphic sections of coal beds in T. 22 N., R. 56 E.

T. 22 N., R. 58 E.

(fig. 18)

SEARS COAL BED

An auger hole at locality 572 near an abandoned prospect or strip pit in the bank of Fox Creek penetrated about 13 feet of coal at a depth of 15 feet. The coal was underlain by 1 foot of shale which was underlain by 7 feet of carbonaceous shale. The coal is probably at the level of the Sears bed but could possibly represent the Pust bed. No resources were estimated for this bed because of lack of data on lateral continuity of the bed.

PRITTEGURL COAL BED

The Prittegurl bed crops out at many places along the sides of Fox Creek and North Fork Fox Creek in the southwestern part of the township. The bed could underlie most of the township but is concealed by surficial deposits in the southern part of the township and is not exposed in the northeastern part. The coal bed ranges in thickness from about 2 feet at several localities to about 4 feet at localities 580, 573, and 576.

K COAL BED

The K bed crops out in the western and northern parts of the township about 35 feet above the position of the Prittegurl bed. The K

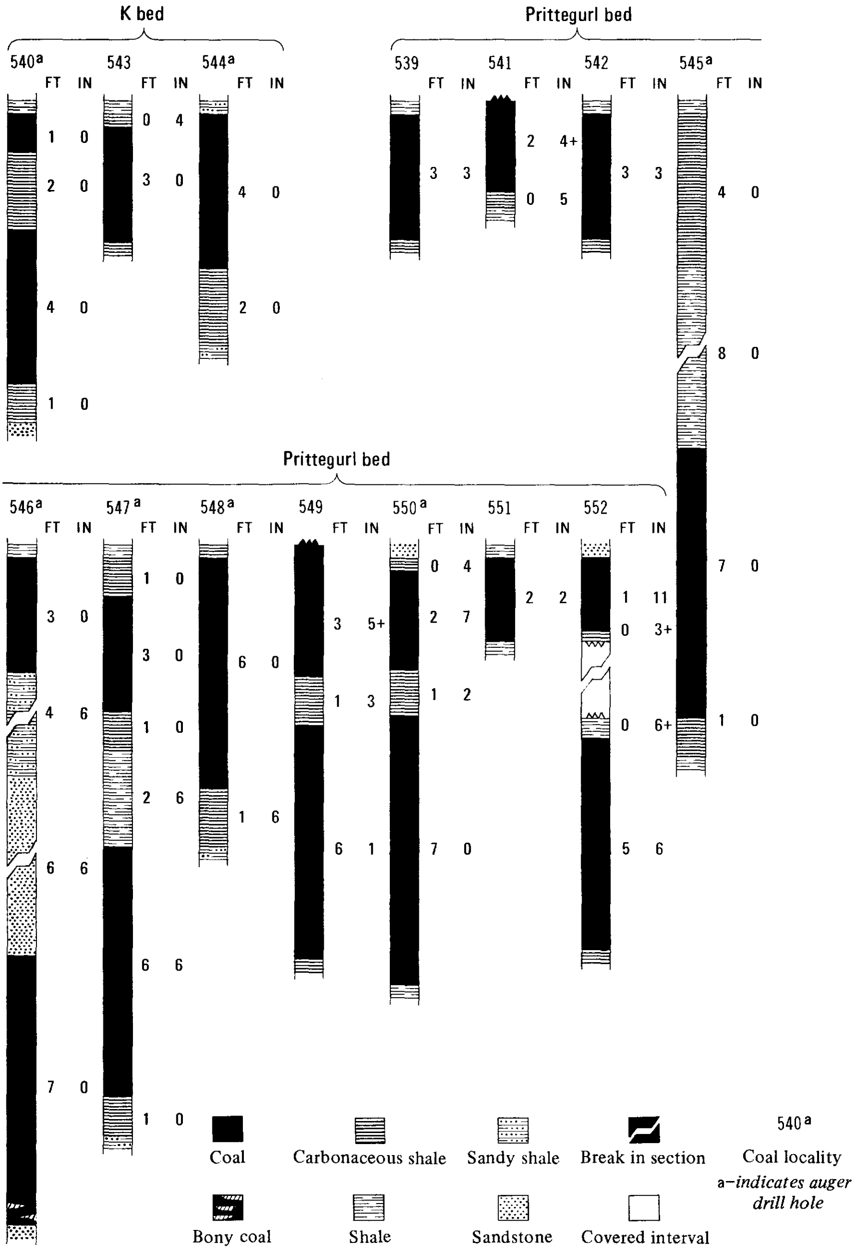

FIGURE 17.—Graphic sections of coal beds in T. 22 N., R. 57 E.

bed is less than 2.5 feet thick at many places but is 5.5 feet thick at locality 553 in the northeastern corner of the township.

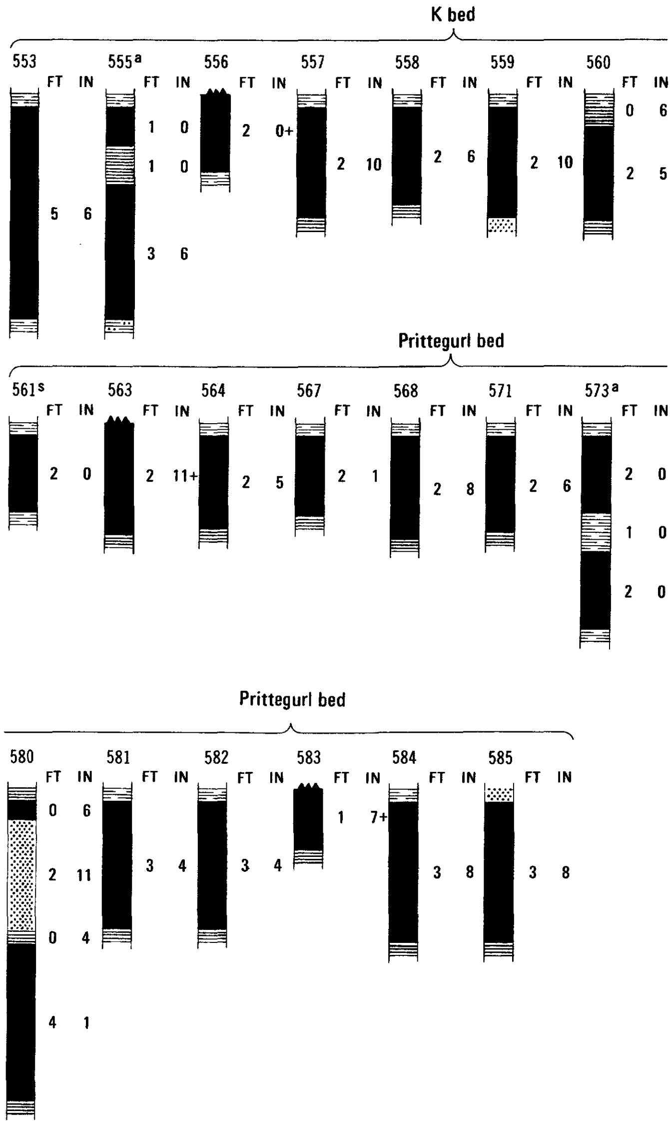

FIGURE 18 (above and facing page).—Graphic sections of coal beds in T. 22 N., R. 58 E.

LOCAL BED

A local bed with eroded top is 1 foot 4 inches thick at locality 554. The bed was not observed elsewhere nearby, and the measured section is not shown in figure 18.

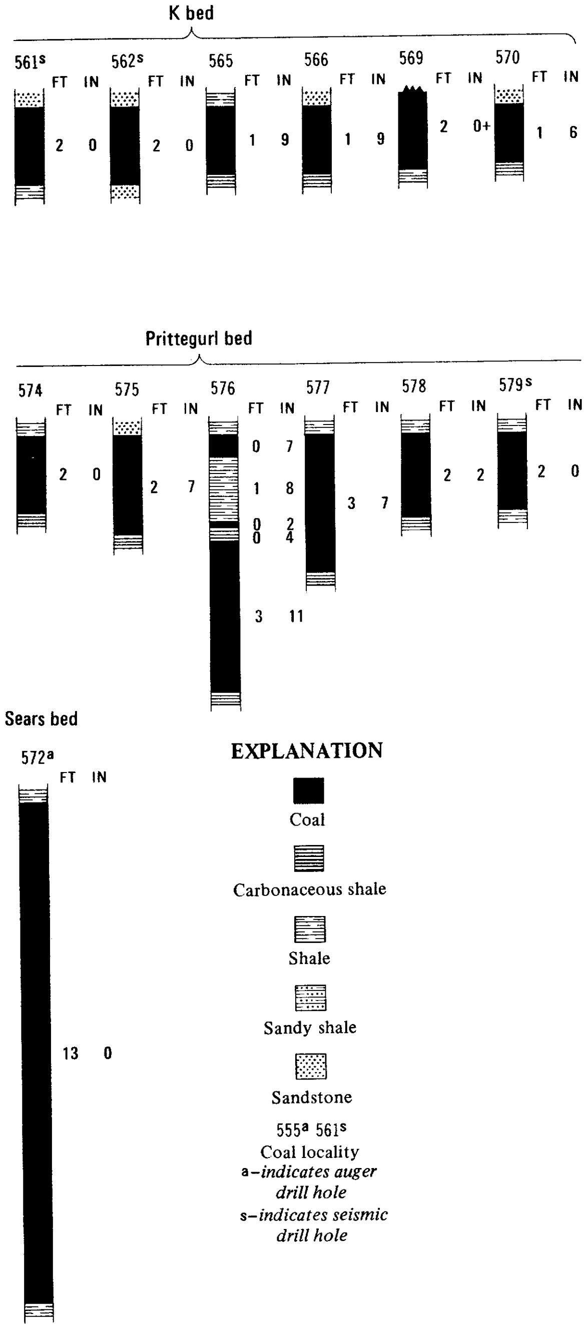

FIGURE 18.—Continued

Unexposed Coal Bed

A local bed exposed in the southern part of T. 23 N., R. 58 E., is assumed to underlie a small area along the northern boundary of T. 22 N., R. 58 E.

T. 23 N., R. 56 E.

(fig. 19)

Prittegurl Coal Bed

The Prittegurl bed is exposed in the northwestern and western parts of T. 23 N., R. 56 E. Where exposed, it is a zone of coal, bony coal, bone, carbonaceous shale, and light-gray shale in which the thickness of coal ranges from 4 feet at locality 525 to 1 foot 10 inches in the largest of three coal beds within the zone at locality 532. The bed could not be traced over the rest of the township.

K Coal Bed

The coal bed lying 55–65 feet above the Prittegurl bed in the northern part of T. 23 N., R. 56 E., has been correlated with the bed lying at a similar position in T. 24 N., R. 56 E. It ranges in thickness from 3 feet at locality 528 to 1 foot 11 inches at locality 529. The bed can be traced over much of the northwestern part of T. 23 N., R. 56 E., but seldom attains a thickness of more than 1.5 feet. It could not be traced over the southern part of the township.

Local Bed

The top of a bed containing 3 feet of coal within a zone of more than 7 feet of carbonaceous shale is exposed in a roadside ditch at locality 530. On the basis of comparative elevations, this bed is believed to be about 35 feet lower than the Prittegurl bed and does not correlate with any other exposed bed in the township.

T. 23 N., R. 57 E.

(fig. 20)

Gardner Coal Bed

At locality 523 the Gardner bed measures 3 feet 3 inches of coal in a cutbank along South Fork Lone Tree Creek. The coal bed is burned along the outcrop, but no extensive clinkering of the overlying strata has occurred.

Local Coal Bed

At locality 524 a 1.5-foot-thick bed of coal is exposed on the north side of a ridge. On the south side of the ridge the coal is less than 1.5 feet thick. The abandoned mine in sec. 35 is on the same coal bed, and about 3 feet of coal is reported to have been mined there. However, no such thickness of coal was found on either side of the drainage divide between North Fork Fox Creek and South Fork Lone Tree Creek.

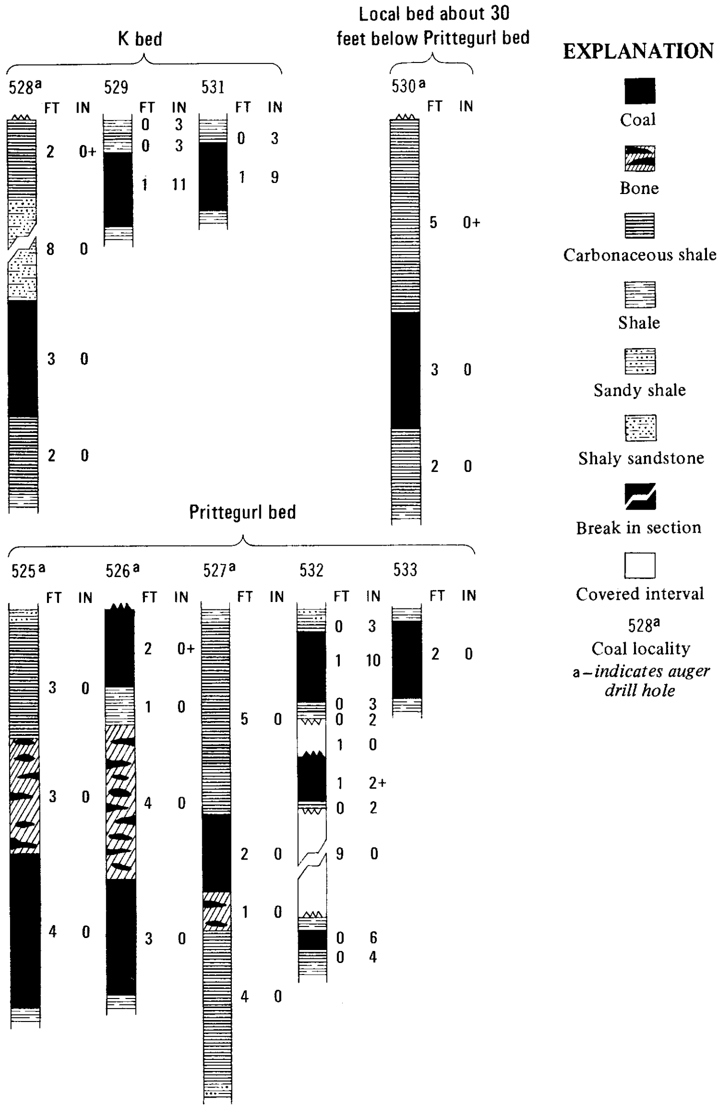

FIGURE 19.—Graphic sections of coal beds in T. 23 N., R. 56 E.

T. 23 N., R. 58 E.

(fig. 21)

K COAL BED

The K bed crops out in the southeastern part of the township but is less than 2.5 feet thick.

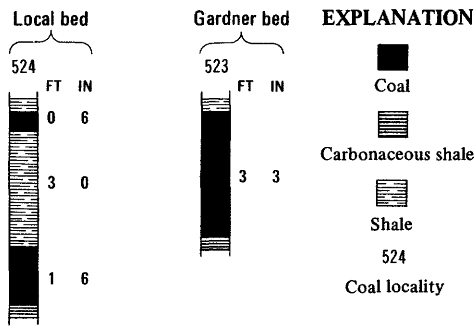

FIGURE 20—Graphic sections of coal beds in T. 23 N., R. 57 E.

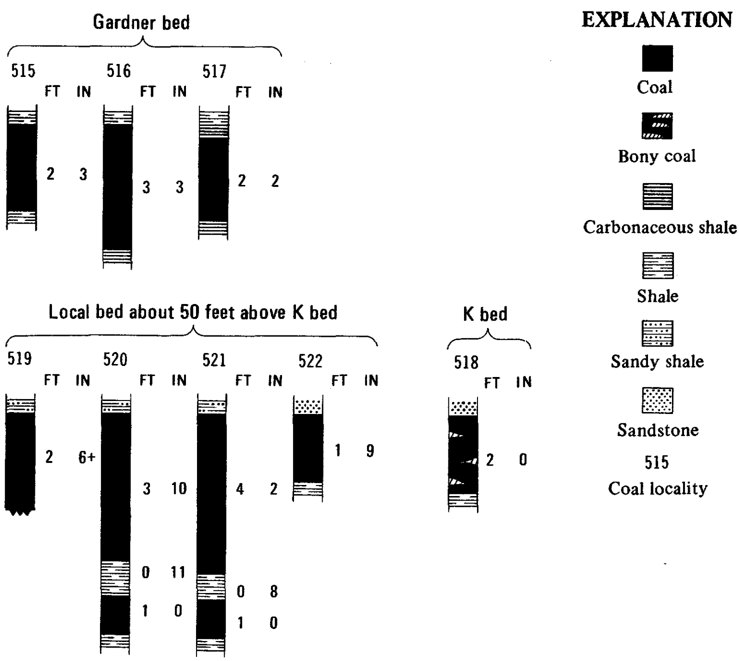

FIGURE 21.—Graphic sections of coal beds in T. 23 N., R. 58 E.

LOCAL COAL BED

A local bed about 50 feet above the K bed contains 5 feet 2 inches of coal at locality 521 and more than 2.5 feet at two other localities in the southern part of the township.

GARDNER COAL BED

The Gardner bed crops out along the valley of Lone Tree Creek in the western part of the township. The bed ranges in thickness from 2 feet 2

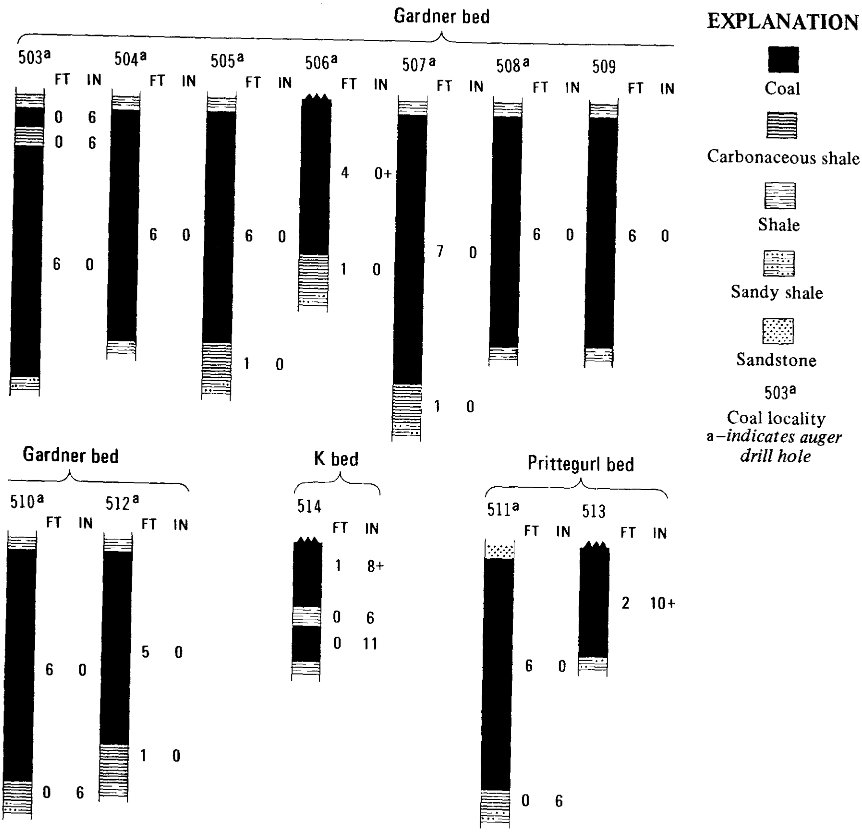

FIGURE 22.—Graphic sections of coal beds in T. 23 N., R. 59 E.

inches to 3 feet 3 inches. The bed is also believed to underlie the northeastern part of the township but does not crop out there.

T. 23 N., R. 59 E.

(fig. 22)

PRITTEGURL COAL BED

The Prittegurl bed is about 6 feet thick at locality 511 and is more than 2 feet 10 inches thick at an incomplete exposure at locality 513. The bed probably underlies much of the northwestern part of the township.

K COAL BED

The K bed crops out in the southwestern part of the township and contains 2 feet 7 inches of coal at locality 514. However, no resources were estimated for the K bed in the area because the bed seems to be generally less than 2.5 feet thick in this area.

GARDNER BED

The Gardner bed underlies a large area in the northwestern part of

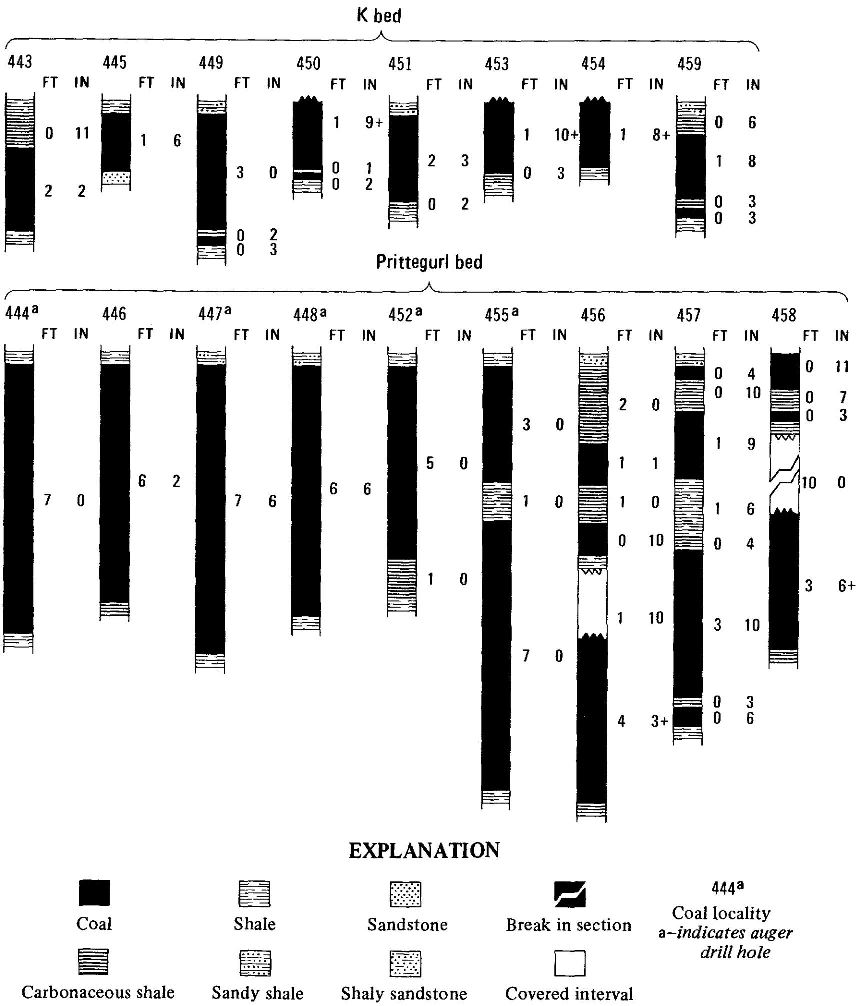

FIGURE 23.—Graphic sections of coal beds in T. 24 N., R. 56 E.

the township. The bed ranges in thickness from more than 4 feet in an auger hole at locality 506 to about 7 feet in an auger hole at locality 507.

T. 24 N., R. 56 E.
(fig. 23)

PRITTEGURL COAL BED

The lowermost coal bed exposed in T. 24 N., R. 56 E., crops out north of the Missouri-Yellowstone drainage divide near the heads of the northwestward-flowing tributaries of East Charlie Creek and is burned extensively along the outcrop. The bed could not be traced south of the Missouri-Yellowstone drainage divide in T. 24 N., R. 56 E.

K Coal Bed

This bed, about 60 feet above the Prittegurl bed, is burned at the outcrop at various places in the township but does not develop any large clinker deposits. The bed ranges in thickness from less than 1.5 feet to 3 feet 5 inches with a 2-inch-thick carbonaceous shale parting 3 feet below the top at locality 449. The bed is easily traced on the north side of the Missouri-Yellowstone drainage divide, but south of the divide the outcrop is difficult to find on the gentle grass-covered slopes.

Unexposed Coal Beds

The F coal bed, which is 5 feet thick in sec. 1, T. 24 N., R. 55 E., does not crop out in T. 24 N., R. 56 E., but is probably present about 200 feet below the Prittegurl bed. A local bed that is exposed in T. 25 N., R. 56 E., is probably present in the northern part of the township.

T. 24 N., R. 57 E.

(fig. 24)

Prittegurl Coal Bed

The lowermost coal bed exposed in T. 24 N., R. 57 E., is 6.5 feet thick at locality 469 (sec. 22) and is believed to be the Prittegurl bed.

K Coal Bed

The K coal bed is exposed in the valley of North Fork Lone Tree Creek and ranges in thickness from 2.5 feet at locality 467 to 1.5 feet at locality 465. The bed thins eastward from the measured localities. No reserves were estimated for the K bed.

Local Coal Bed About 40 Feet Above The Prittegurl Bed

The coal bed exposed at locality 475 in section 34 measures 1.5 feet of coal and may be the K bed. However, the coal bed could not be traced far enough to make correlation possible with any other coal bed in the township.

Local Coal Bed About 80 Feet Above The Prittegurl Bed

The local bed exposed about 80 feet above the Prittegurl bed in sections 13, 20, 21, 27, 28, and 34 ranges in thickness from less than 1.5 to 5 feet of coal at locality 463.

Local Coal Bed About 115 Feet Above The Prittegurl Bed

The coal bed about 115 feet above the Prittegurl bed in sections 13 and 24 contains 2 feet of coal at locality 462 but thins rapidly to the west and could not be traced westward from locality 461.

Local Coal Bed About 235 Feet Above The Prittegurl Bed

The coal bed exposed around the bases of the Flaxville Gravel-capped buttes in secs. 13, 14, and 23 could not be traced over any other part of the township but may correlate with the Gardner coal bed, which is exposed in the townships to the east. It ranges in thickness from 2.5 feet at locality 464 to 6 feet of coal at locality 470.

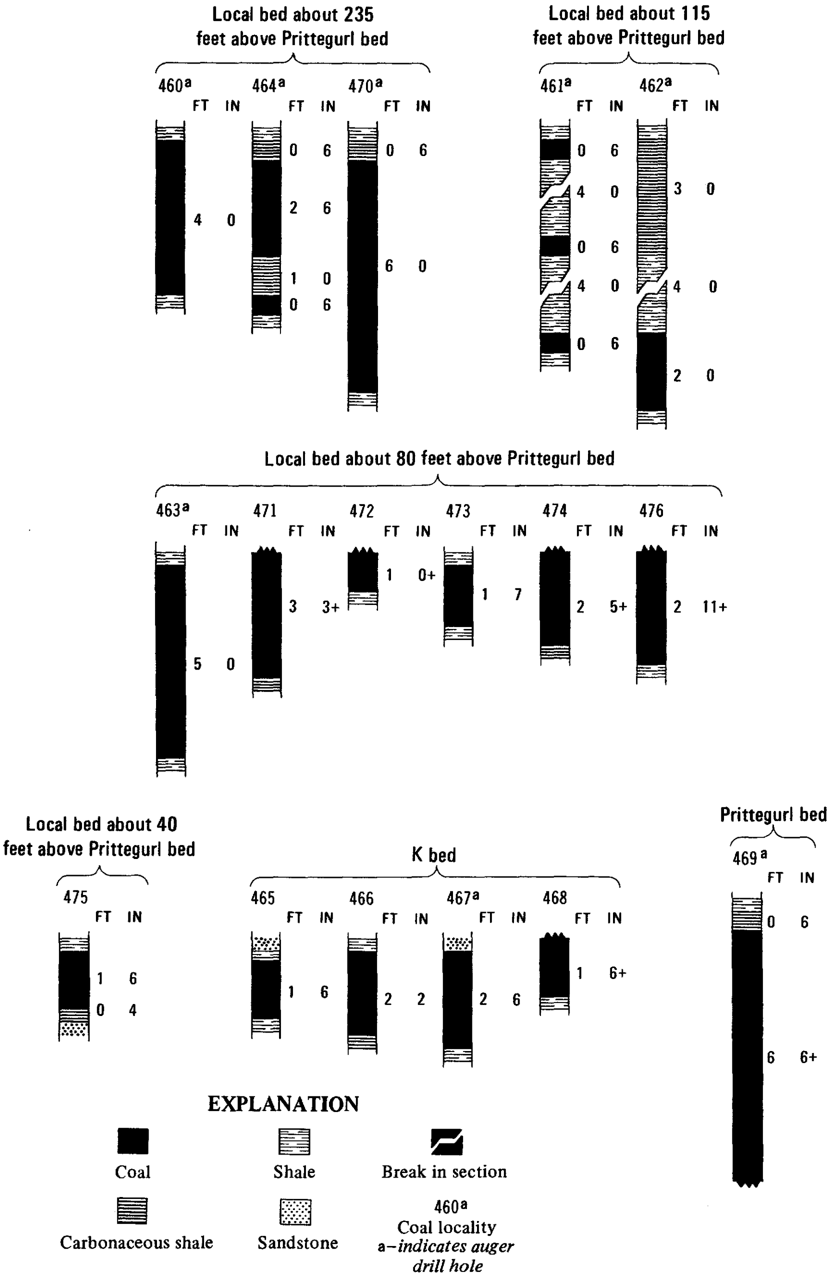

FIGURE 24.—Graphic sections of coal beds in T. 24 N., R. 57 E.

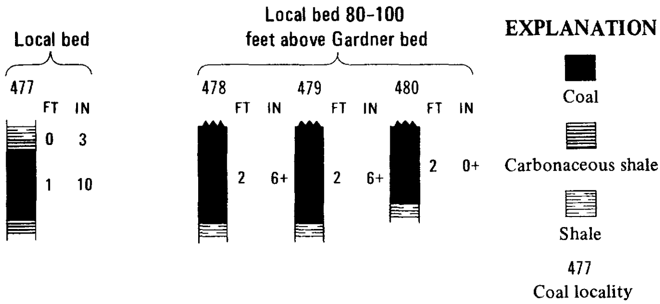

FIGURE 25.—Graphic sections of coal beds in T. 24 N., R. 58 E.

T. 24 N., R. 58 E.

(fig. 25)

LOCAL COAL BED ABOUT 80 FEET ABOVE THE PRITTEGURL BED

A local bed that is about 5 feet thick in an auger hole at locality 463 in T. 24 N., R. 57 E., extends at least a short distance into this township though the bed is not exposed.

GARDNER COAL BED

The Gardner bed underlies several square miles, and perhaps more, of the southeastern part of the township. No measurements of the coal bed were obtained, but abandoned mines and prospects mark the location of the bed along the valley of First Hay Creek.

LOCAL COAL BED ABOUT 80–100 FEET ABOVE THE GARDNER BED

This coal bed crops out south of First Hay Creek about 80–100 feet above the level of the Gardner bed. Three measurements of the bed, all incomplete because of weathered or eroded tops, indicate that the bed is a minimum of 2 feet thick.

LOCAL BED IN NORTHERN PART OF TOWNSHIP

A thin bed of uncertain stratigraphic position contains 1 foot 10 inches of coal at locality 477 in section 9.

T. 24 N., R. 59 E.

(fig. 26)

PRITTEGURL COAL BED

Three auger holes, two in the valley of First Hay Creek and one in the Yellowstone valley along the course of Second Hay Creek, penetrated coal or coaly material at about the same level. At locality 485 the wet muddy soft coaly material was overlain directly by gravel. At localities 488 and 499 2–10 feet of shale intervened between the coaly material

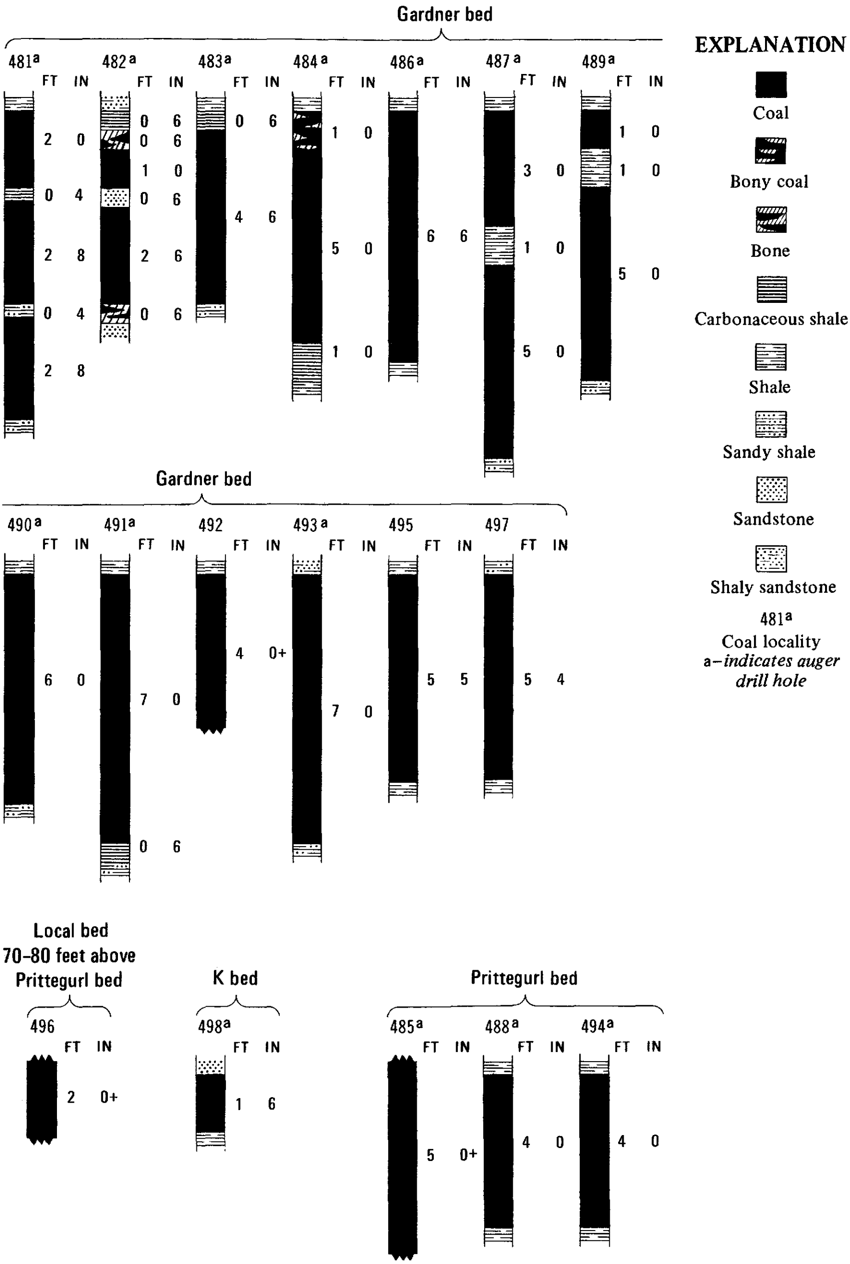

FIGURE 26.—Graphic sections of coal beds in T. 24 N., R. 59 E.

and water-soaked alluvium, and the coaly fragments which were returned by the auger were hard and woody, though very wet. In all three localities sample recovery was very poor, and the thickness of the coaly material was estimated on the basis of bit performance. No resources were estimated for this bed, but it is about at the stratigraphic level of the Prittegurl bed.

K Coal Bed

A coal bed correlated with the K bed is present in an auger hole at locality 498 but is only 1.5 feet thick.

Local Coal Bed 70–80 Feet Above The Prittegurl Bed

A bed more than 2 feet thick was examined at locality 496, but the bed could not be traced or identified laterally, so no resources were estimated for the bed.

Gardner Coal Bed

The Gardner bed is present along the valleys of First and Second Hay Creeks. The bed was observed and measured at 13 localities, but 10 of these localities were tested by auger holes because the bed does not crop out for long distances. However, much of the southern and eastern parts of the township are probably underlain by the Gardner bed.

Local Coal Bed About 20-30 Feet Above The Gardner Bed

A local bed that seems to be present at a stratigraphic level about 20–30 feet above the Gardner bed probably extends into the northeastern part of T. 24 N., R. 59 E., although it is not exposed in the township.

T. 24 N., R. 60 E.

(fig. 27)

Gardner Coal Bed

The Gardner bed is probably present in the northwestern part of the township.

Local Coal Bed About 20-30 Feet Above The Gardner Bed

A bed that seems to be about 20–30 feet above the stratigraphic level of the Gardner bed was observed at three localities, two of which are auger holes. The thickness ranged from about 4 to 6 feet. This bed could possibly be the Gardner.

Local Coal Bed About 130 Feet Above The Gardner Bed

A bed about 2 feet thick was observed in an auger hole at locality 500. No resources were estimated for the bed.

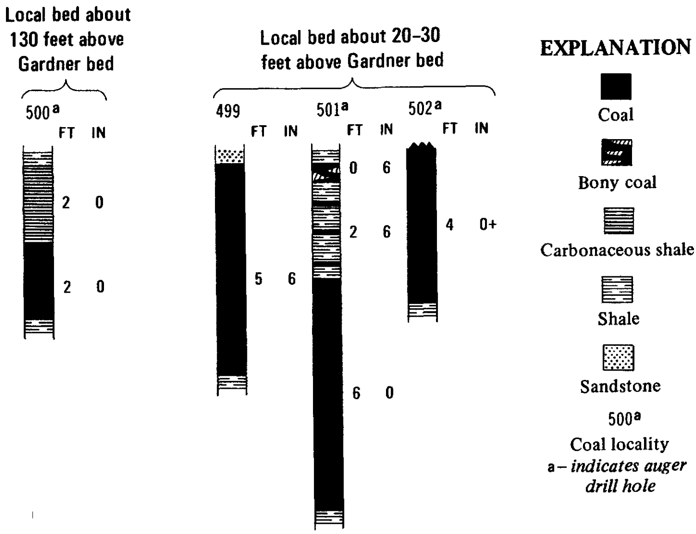

FIGURE 27.—Graphic sections of coal beds in T. 24 N., R. 60 E.

T. 25 N., R. 55 E.

(fig. 28)

E COAL BED

The lowermost coal bed exposed in T. 25 N., R. 55 E., crops out along East Charlie Creek about 270 feet above the base of the Tongue River Member of the Fort Union Formation. More than 5 feet of clean hard coal with 8 inches of carbonaceous shale near the middle was measured above the flooded part of an abandoned mine at locality 423 and represents only the upper part of the bed. At locality 422, about one-eighth mile to the north, the coal bed is more than 7 feet thick but is mostly bony coal. South of locality 429 and west of East Charlie Creek, the E coal bed is represented by carbonaceous shale.

F COAL BED

The F coal bed, which is about 75 feet above the E bed and 185 feet below the H coal bed, crops out near the tops of the ridges in the western part of the area but is commonly burned or is concealed by soil or alluvium. Generally, this bed is less than 2.5 feet thick, but at localities 431, 432, and 440 the coal ranges in thickness from 2 feet 10 inches to more than 6 feet, and at locality 434, in sec. 27, two 4-foot-thick benches of coal separated by a 2-foot-thick parting of carbonaceous shale were found in an auger hole. At locality 435, in sec. 28, about 3 feet of gray shale separates a lower bench of bone from an upper bench of coal.

H Coal Bed

Bed H is about 185 feet above the base of the F coal bed and is burned along most of its outcrop in the southeastern part of the township. At locality 433, only 3 feet 2 inches of coal was found, but at locality 442, 10 feet of coal was found in an auger hole. In secs. 2, 13, 24, and 36, clinker resulting from burning of this coal bed has been taken for use as road metal to surface the county roads.

K Coal Bed

A coal bed 47 feet above the H bed was found to be 1 foot 11 inches thick at locality 441, in sec. 36. It is correlated tentatively with the K coal bed that is exposed in townships to the northeast and east.

Unexposed Coal Beds

The D coal bed has an upper bench about 8 feet thick, separated by 8 feet of sandstone and shale from a lower bench about 3 feet thick. It is 130 feet below the E coal at locality 102, sec. 7, T. 27 N., R. 55 E., and may be present below the surface in T. 25 N., R. 55 E. The C coal bed, which is about 250 feet below the E bed, crops, out along the Missouri River valley about 15 miles northwest of this area.

T. 25 N., R. 56 E.

(fig. 29)

H Coal Bed

The outcrop of the H coal bed is marked in most of the township by clinker resulting from the burning of the coal. This bed is 570 feet stratigraphically above the base of the Tongue River Member and is the lowermost coal bed exposed in the township. A section measured by means of a jeep-mounted power auger at locality 409 shows the coal to be 10 feet thick only a few feet from a clinker outcrop, and about 1 mile to the north, at locality 388, the coal is 3 feet 5 inches thick. Because of the extensive burning, the lenticular character of the bed is not very well illustrated. The Crosby mine, at locality 392, in sec. 20, supplied domestic fuel in this area during the fall and winter.

K Coal Bed

The K coal bed, 45–55 feet above the H bed, is 3 feet 2 inches thick at locality 411 but is thinner at other localities where it was measured.

Local Beds

Local beds 80, 110, 130–140, and 170–180 feet above the H bed are exposed at many localities in the township. At most localities the beds are less than 2.5 feet thick.

T. 25 N., R. 57 E.

No coal beds are exposed in this township. However, the H coal bed crops out 1 mile west of sec. 6 and is concealed by alluvium in a valley north of sec. 5. The H coal bed underlies this township at a minimum depth of 200 feet.

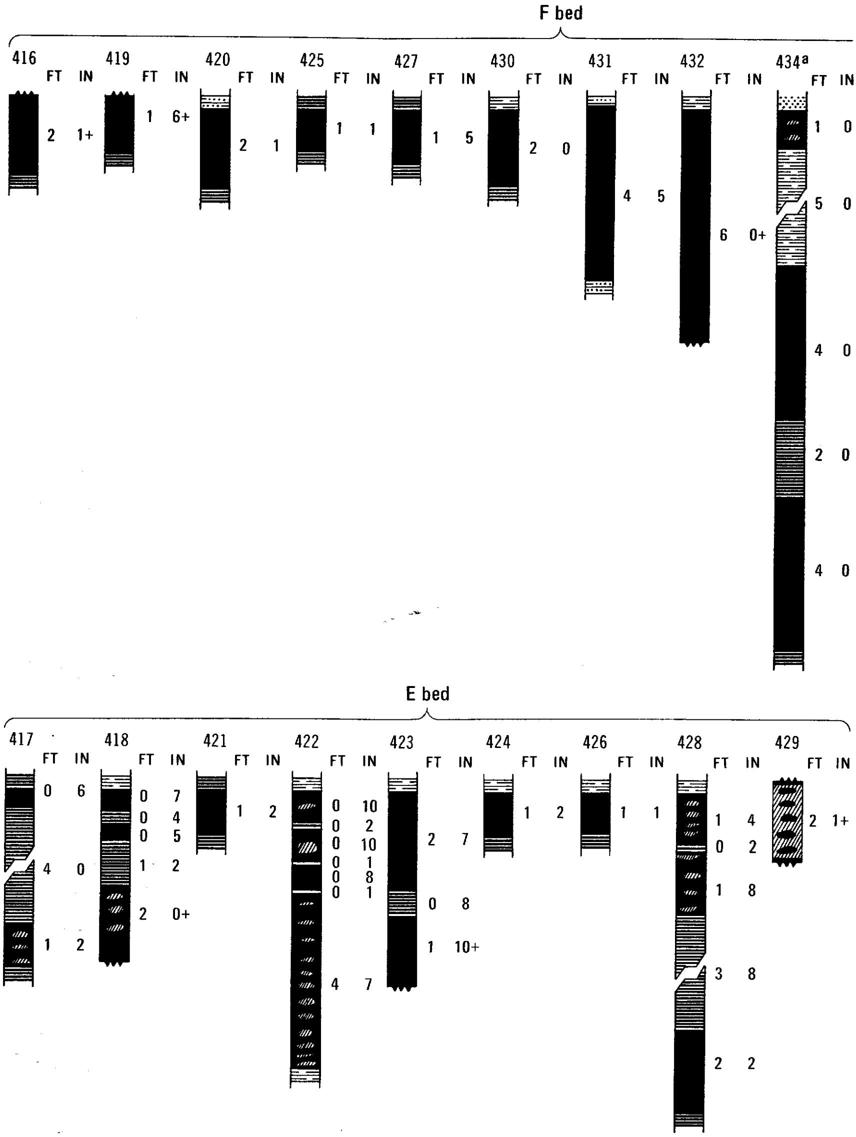

FIGURE 28 (above and facing page).—Graphic sections of coal beds in T. 25 N., R. 55 E.

T. 25 N., R. 58 E.

(fig. 30)

No coal beds of commercial value are exposed in this township; however, the H coal bed may be present at a depth of about 200 feet. The thin discontinuous L coal bed, about 200 feet above the H bed, was mapped between widely separated localities. At locality 377, the coal is 2 feet 5 inches thick, which is the maximum in this township.

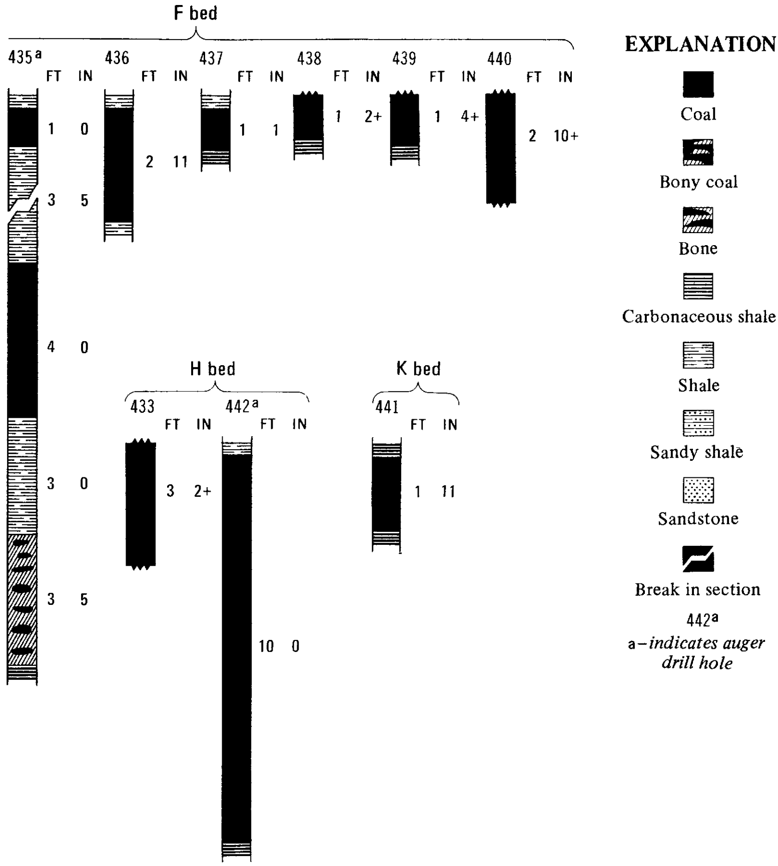

Figure 28.—Continued.

T. 25 N., R. 59 E.

(fig. 31)

No coal beds of commercial value are exposed in this township; however, the H coal bed may be present at a depth of about 200 feet below the L coal bed. Two local beds, about 25 and about 80 feet below the L bed, are exposed in the township but are less than 2.5 feet thick at all the localities where they were measured.

T. 26 N., R. 55 E.

(pl. 2)

E Coal Bed

The E coal bed, which crops out at the base of a divide at locality 168, in sec. 31, is the lowermost coal bed exposed in this township. At locality 168 there is less than 2 feet of coal in a carbonaceous shale more than 7 feet thick. The E bed is very lenticular as illustrated by the fact that,

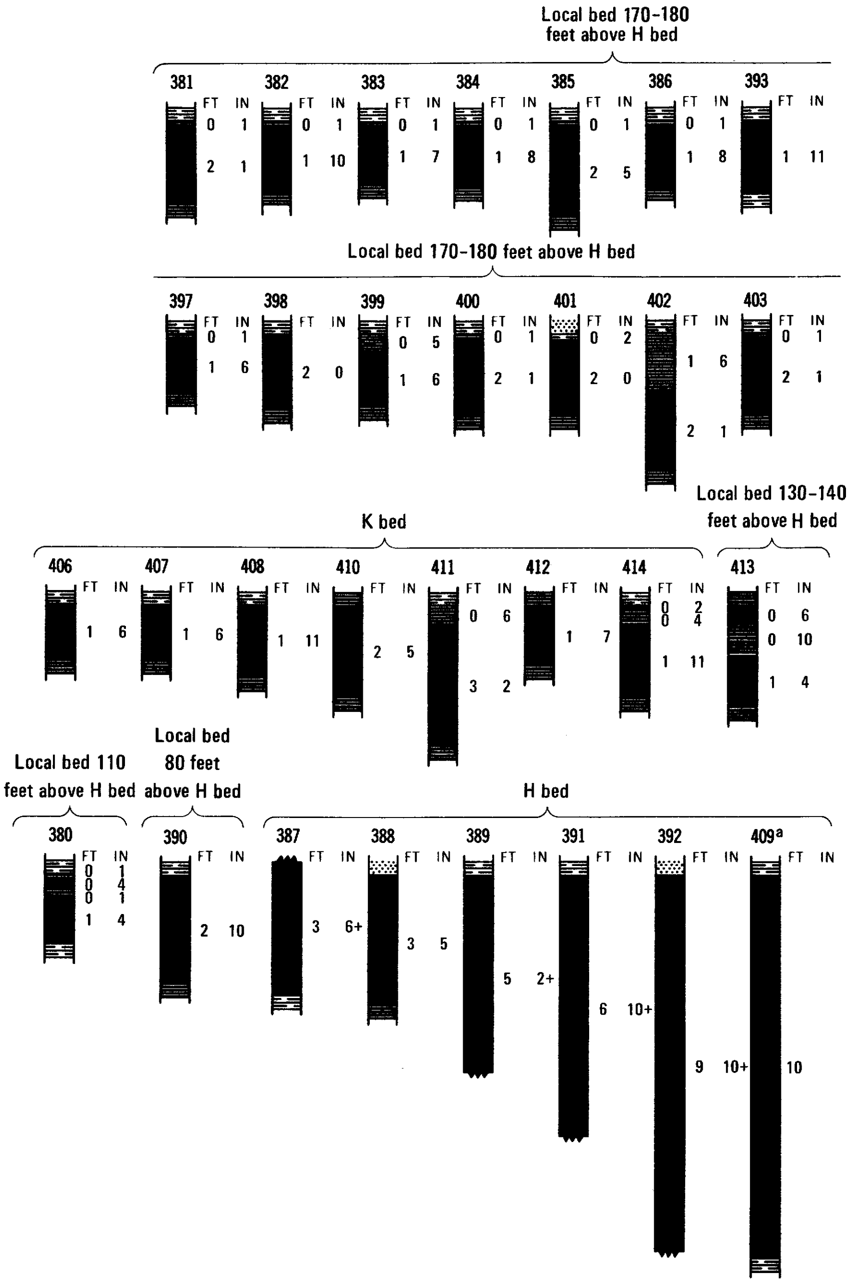

Figure 29 (above and facing page).—Graphic sections of coal beds in T. 25 N., R. 56 E.

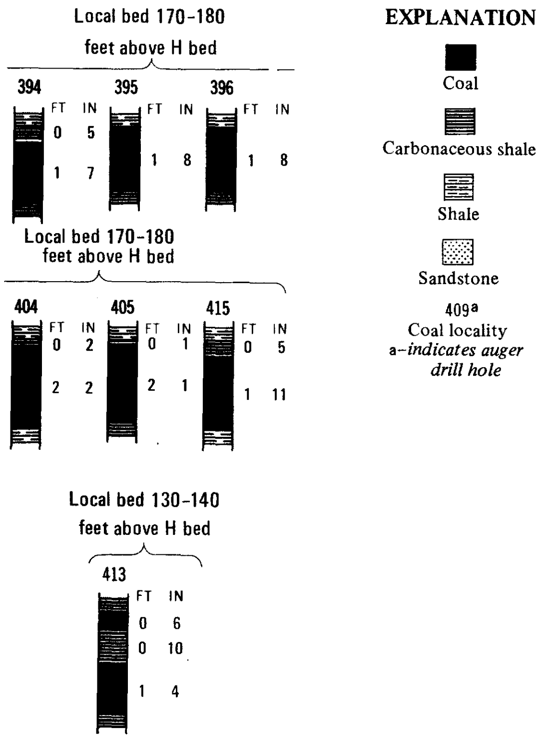

FIGURE 29.—Continued.

in the adjoining township about 2 miles to the south, the coal bed is more than 7 feet thick.

F COAL BED

The upper bench and the lower bench of the F bed are mapped separately in the western part of this township where only the lower bench has burned along most of the outcrop. The coal in the lower bench has an average thickness of about 5 feet, and the upper bench has an average thickness of about 3 feet. The shale between the two benches ranges in thickness from about 14 to 31 feet. Clinker, resulting from burning of the coal, is common along most of the F bed in this township.

G COAL BED

In this township, the G coal bed, which is about 135 feet above the lower bench of the F bed, has many shale partings and is much thinner than at exposures to the northeast and east. The coal has a maximum thickness of 2 feet 7 inches at locality 147 and crops out only on the

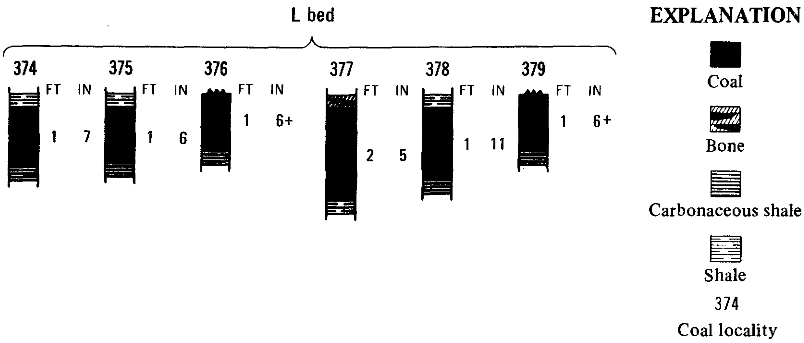

FIGURE 30.—Graphic sections of coal beds in T. 25 N., R. 58 E.

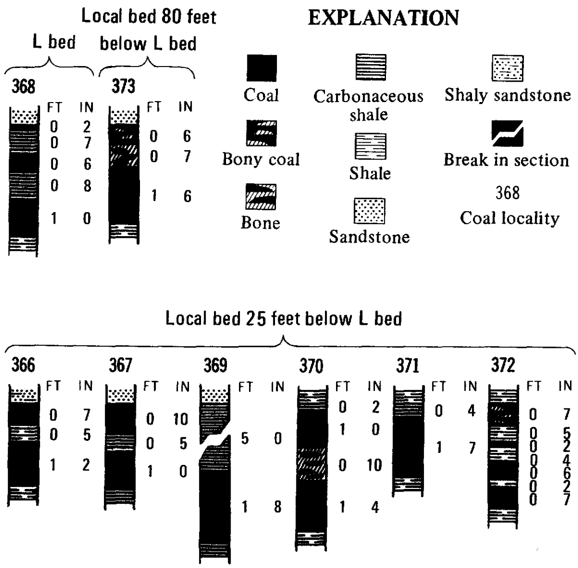

FIGURE 31.—Graphic sections of coal beds in T. 25 N., R. 59 E.

ridges in the eastern part of the township. The bed was not mapped in section 22 near locality 164 because it is very thin and may be absent locally. Localities 163 and 166, both on the G bed near locality 164, are not shown graphically or on the geologic map because the coal bed is less than 1 foot thick.

H COAL BED

In this township the H coal bed was found at only two localities, both at the tops of ridges. At localities 161 and 165 the coal is more than 4 feet thick, but a true thickness could not be measured at either locality because of slumping. At locality 165 the area underlain by the H bed is too small to be shown on the geologic map.

LOCAL COAL BED

An uncorrelated coal bed of uncertain stratigraphic position was measured at locality 171. This bed may be near the position of the G bed.

T. 26 N., R. 56 E.
(pl. 2)

G COAL BED

The G coal bed, which is the lowermost bed exposed in this township, crops out along the lower slopes of the ridges except in the southeastern part of the township. Shale partings in the coal decrease in number and thickness in the north-central part of this township. At localities 187, 188, and 190, the coal is more than 4 feet thick.

H COAL BED

The H coal bed, which is 75 feet above the G bed, crops out near the tops of the ridges but is extensively burned along the outcrop or is concealed by soil or alluvium. Coal 11 feet thick was found at locality 174 in an auger hole, but the maximum thickness found at a surface exposure was at locality 192, where the coal is 9 feet thick. The extensive burning along the outcrop is an indication of the purity and thickness of the bed.

LOCAL BEDS

Two local beds, both less than 2.5 feet thick, were measured at localities 172, 173, and 191. The beds are about 120 and 160 feet above the H bed.

T. 26 N., R. 57 E.
(pl. 2)

G COAL BED

The G coal bed, which is the lowermost bed exposed in this township, crops out along the lower slopes of the ridges and at the base of the Missouri River bluff in the northern part of the township. Shale partings, which are numerous in areas to the west, are not present in the G bed in this area, and the average thickness of the coal is about 5 feet. Clinker is common along most of the bed in this area.

H COAL BED

The H coal bed, which is 72 feet above the G bed, is burned extensively along the outcrop near the tops of the ridges in the northern part of this township. The coal ranges in thickness from about 5 feet to 9 feet 2 inches and has very few partings or impurities.

K COAL BED

The K coal bed, about 60 feet above the H bed, is present over much of the township but is less than 2.5 feet thick.

L Coal Bed

The L bed, less than 2.5 feet thick, was measured at six localities in the township.

Local Beds

Four local beds, which are less than 2.5 feet thick almost everywhere, were measured in the township. The beds are about 65 and 80–90 feet above the K bed and 35–40 and 45–55 feet above the H bed.

T. 26 N., R. 58 E.

(pl. 2)

G Coal Bed

The G coal bed, which is concealed east of sec. 8 by alluvium, crops out along the base of the river bluff in secs. 6, 7, and 8. At locality 306, neither the top nor the bottom of the bed could be reached in a flooded abandoned mine. At locality 305, in sec. 6, the coal is more than 6 feet thick with no partings. Inasmuch as the G bed has increased in thickness and purity from west to east, it probably underlies the entire township south of the Missouri River.

H Coal Bed

The H bed crops out in the western and northern parts of this township. The bed has many shale partings that were not present in exposures west of this township. East of sec. 9 the H coal bed is concealed by the alluvium of the Missouri River. The coal ranges in thickness from 1 foot 4 inches at locality 352 to 7 feet at locality 312.

K and L Coal Beds

The K coal bed, which is 50 feet above the H bed, was mapped for use in structure control. The L bed was mapped for the same purpose.

Local Beds

Two local beds, one 120–130 feet above the L bed and the other 170–190 feet above the L bed, were measured in the township. The bed 170–190 feet above the L bed is more than 4 feet thick at both the localities (338 and 339) where it was examined, but it underlies only a small area and was not mapped.

T. 26 N., R. 59 E. (FRACTIONAL)

(fig. 32)

A local bed 170–190 feet above the L bed is the only bed in the township that is known to be more than 2.5 feet thick. A thin local bed 120–130 feet above the L bed was measured at four localities, and the L coal bed, less than 2.5 feet thick, was mapped for use in carrying structure control into this township.

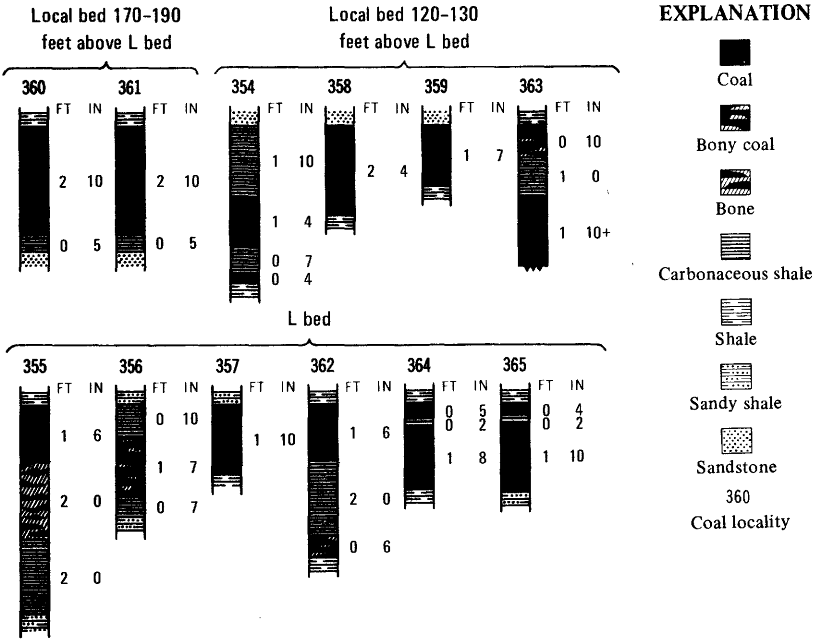

FIGURE 32.—Graphic sections of coal beds in T. 26 N., R. 59 E.

T. 27 N., R. 55 E. (FRACTIONAL)

(pl. 2)

The lowermost coal bed exposed in T. 27 N., R. 55 E., crops out in the northwest corner of the area at the base of the Missouri River bluff. At locality 102 a lower bench of coal, 2 feet 9 inches thick, is separated by 8 feet of sandstone and shale from the upper bench of bony coal, about 8 feet thick.

E COAL BED

The E coal bed, which is 130 feet above the D bed, crops out along the lower slopes of the ridges and is commonly burned or is concealed by alluvium and thick soil. This coal bed is lenticular, and the coal ranges in thickness from 2 feet 7 inches at locality 107 to 7 feet 2 inches at locality 135. No inferred reserves were estimated for the E bed because the bed thins rapidly to the east and southeast.

F COAL BED

The F coal bed has a greater average thickness than any other bed in the area, but the coal is rarely exposed because of the extensive burning along the outcrop in this township. An upperbench of coal, about 3 feet thick, is about 25 feet above the lower bench of clean hard coal, which ranges in thickness from 3 feet 6 inches at locality 108 to 11 feet 8 inches at locality 122.

G Coal Bed

The G coal bed, which is 155 feet above the F bed, is exposed near the eastern boundary on the highest hills at localities 105 and 124, where it is about 2 to 3 feet thick. Measurements in T. 27 N., R. 56 E., show that the bed thickens to the east. No reserves were estimated in the township.

T. 27 N., R. 56 E. (FRACTIONAL)

(pl. 2)

E Coal Bed

The E bed crops out at the base of the river bluff in sec. 7 and extends only half a mile eastward before it is concealed by alluvium. At localities 21 and 22, the E bed is 75 feet below the F bed, and the coal is about 3 feet thick. Doubts exist about the persistency of this bed in a southerly and southeasterly direction; therefore, no reserves were estimated for the E bed.

F Coal Bed

The F coal bed is the most important bed in the township. Its average thickness is more than 11 feet. An upper bench of lenticular bony coal is separated from the lower part of the bed by 8–31 feet of shale and sandstone beds. The F bed, which is about 75 feet above the E bed and about 140 feet below the G coal bed, is burned along most of its outcrop, and the clinker resulting from the burning forms a prominent red band along the steep side of the Missouri River valley. The Park, Bemer, and Jennison mines were operating on a commercial scale on this bed in 1950. Coal from the Jennison mine was sold for industrial use in Sidney and as far north as Plentywood, and at each mine coal was sold for local domestic use.

G Coal Bed

The G coal bed, which crops out on the valley slopes about 140 feet above the F bed, is commonly burned or is concealed by thick soil or alluvium. The coal ranges in thickness from less than 3 feet to more than 4 feet.

H Coal Bed

Clinker, resulting from the burning of the H bed, crops out near the tops of the high ridges in the southern one-half of this township. The H coal bed crops out about 85 feet above the G bed and is extensively burned along the outcrop. At locality 65 the coal is 8 feet 8 inches thick, but the average thickness is about 6 feet.

LOCAL BEDS

Local beds above the H coal bed have less than 2.5 feet of coal and are not considered to be commercially valuable.

T. 27 N., R. 57 E. (FRACTIONAL)

(pl. 2)

F COAL BED

The lowermost coal bed in T. 27 N., R. 57 E., is covered by slide debris and alluvium but is exposed at locality 57, in sec. 24, T. 27 N., R. 56 E., about one-half mile to the west, where the coal bed is more than 8 feet 4 inches thick.

G COAL BED

The G coal bed, which is about 145 feet above the F bed and about 72 feet below the H coal bed, crops out in the side of the valley above the alluvium but is commonly burned at the outcrop. The coal ranges in thickness from 3 feet 7 inches at locality 3 to 7 feet 1 inch at locality 10.

H COAL BED

Bed H is about 72 feet above the G coal bed and about 47 feet below the K bed and is burned along most of its outcrop in this fractional part of the township. At locality 2, in sec. 19, more than 8 feet 5 inches of coal was found, but because of slumping this is not an exact measurement of the coal. The extent of burning is an indication of the purity and persistent thickness of the bed.

K COAL BED

The K bed is less than 2.5 feet thick in this township.

LOCAL BEDS

Two local beds less than 2.5 feet thick were measured at four localities in the township.

REFERENCES

Alden, W. C., 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174, 133 p.

American Society for Testing and Materials, 1969, 1969 book of ASTM standards, with related material—Part 19, Gaseous fuels; coal and coke: Am. Soc. Testing and Materials, 484 p.

Aresco, S. J., Haller, C. P., and Abernethy, R. F., 1962, Analyses of tipple and delivered samples of coal (collected during the fiscal year 1961): U.S. Bur. Mines Rept. Inv. 6086, 41 p.

Aresco, S. J., and Janus, J. B., 1967, Analyses of tipple and delivered samples of coal (collected during the fiscal year 1966): U.S. Bur. Mines Rept. Inv. 6904, 43 p.

Aresco, S. J., Janus, J. B., and Walker, F. E., 1965, Analyses of tipple and delivered samples of coal (collected during the fiscal year 1964): U.S. Bur. Mines Rept. Inv. 6622, 38 p.

Averitt, Paul, 1969, Coal resources of the United States, January 1, 1967: U.S. Geol. Survey Bull. 1275, 116 p.

Beekly, A. L., 1912, The Culbertson lignite field, Valley County, Montana: U.S. Geol. Survey Bull. 471–D, p. 319–358.

Brown, R. W., 1938, The Cretaceous–Eocene boundary in Montana and North Dakota [abs.]: Washington Acad. Sci. Jour., v. 28, no. 9, p. 421–422.

______1948, Correlation of Sentinel Butte shale in western North Dakota: Am. Assoc. Petroleum Geologists Bull., v. 32 no. 7, p. 1265-1274.

______1949, Paleocene deposits of the Rocky Mountains and plains: U.S. Geol. Survey Prelim. Map.

______1952, Tertiary strata in eastern Montana and western North and South Dakota, *in* Billings Geol. Soc. Guidebook, 3d Ann. Field Conf., 1952: p. 89–92.

______1962, Paleocene flora of the Rocky Mountains and Great Plains: U.S. Geol. Survey Prof. Paper 375, 119 p.

Clapp, C. H., Bevan, Arthur, and Lambert, G. S., 1921, Geology and oil and gas prospects of central and eastern Montana: Montana Univ. Bull., Bur. Mines and Metallurgy Ser. 4, 95 p.

Collier, A. J., and Thom, W. T., Jr., 1918, The Flaxville gravel and its relation to other terrace gravels of the northern Great Plains: U.S. Geol. Survey Prof. Paper 108–J, p. 179–184.

Colton, R. B., 1951, Geology of the Otter Creek quadrangle, Montana: U.S. Geol. Survey open-file report, 32 p.

______1962, Geology of the Otter Creek quadrangle, Montana: U.S. Geol. Survey Bull. 1111–G, p. 237–288.

Colton, R. B., Lemke, R. W., and Lindvall, R. M., 1961, Glacial map of Montana east of the Rocky Mountains: U.S. Geol. Survey Misc. Geol. Inv. Map I–327.

Culbertson, W. C., 1954, Three deposits of strippable lignite west of the Yellowstone River, Montana: U.S. Geol. Survey Bull. 995–H, p. 293–332.

Denson, N. M., and Chisholm, W. A., 1971, Summary of mineralogic and lithologic characteristics of Tertiary sedimentary rocks in the Middle Rocky Mountains and the northern Great Plains, *in* Geological Survey research 1971: U.S. Geol. Survey Prof. Paper 750–C, p. C117–C126.

Fieldner, A. C., Rice, W. E., and Moran, H. E., 1942, Typical analyses of coals of the United States: U.S. Bur. Mines Bull. 446, 45 p.

Flint, R. F., 1957, Glacial and Pleistocene geology: New York, John Wiley & Sons, 553 p.

Gerhard, L. C., 1963, Cyclic deposition of lower Fort Union Formation in eastern Montana: Compass, v. 40, no. 2, p. 88–96.

Hansen, Miller, compiler, 1971, Directory of mining enterprises for 1970 with a list of coal mines, 1970 *and a section on* The mineral industry of Montana in 1970, by F. V. Carrillo, W. N. Hale, and M. A. McComb: Montana Bur. Mines and Geology Bull. 82, 59 p.

Howard, A. D., 1956, Till-pebble isopleth maps of parts of Montana and North Dakota: Geol. Soc. America Bull., v. 67, no. 9, p. 1199–1206.

______1958, Drainage evolution in northeastern Montana and northwestern North Dakota: Geol. Soc. America Bull., v. 69, no. 5, p. 575–588.

______1960, Cenozoic history of northeastern Montana and northwestern North Dakota, with emphasis on the Pleistocene: U.S. Geol. Survey Prof. Paper 326, 107 p. [1961].

Howard, A. D., Gott, G. B., and Lindvall, R. M., 1946, Late Wisconsin terminal moraine in northwestern North Dakota [abs.]: Geol. Soc. America Bull., v. 57, no. 12, pt. 2, p. 1204–1205.

Jensen, F. S., 1951, Preliminary report on the geology of the Nashua quadrangle, Montana: U.S. Geol. Survey open-file report, 37 p. [1952].

Jensen, F. S., and Varnes, H. D., 1964, Geology of the Fort Peck area, Garfield, McCone, and Valley Counties, Montana: U.S. Geol. Survey Prof. Paper 414-F, p. F1-F49.

Leffingwell, H. A., 1970, Palynology of the Lance (Late Cretaceous) and Fort Union (Paleocene) Formations of the type Lance area, Wyoming, *in* Kosanke, R. M., and Cross, A. T., Symposium on palynology of the Late Cretaceous and early Tertiary, San Francisco, Calif., 1966: Geol. Soc. America Spec. Paper 127, p. 1–64.

Lemke, R. W., Laird, W. M., Tipton, M. J., and Lindvall, R. M., 1965, Quaternary geology of northern Great Plains, *in* The Quaternary of the United States: Princeton, N.J., Princeton Univ. Press, p. 15–27.

Leonard, A. G., 1911, The Cretaceous and Tertiary formations of western North Dakota and eastern Montana: Jour. Geology, v. 19, no. 6, p. 507-547.

Meek. F. B.. and Havden. F. V.. 1862. Descriptions of new Lower Silurian [primordial], Jurassic, Cretaceous, and Tertiary fossils, collected in Nebraska, * * *, with some remarks on the rocks from which they were obtained: Acad. Nat. Sci. Philadelphia Proc., 1861, v. 13, p. 415–447.

Parker, F. S., 1936, The Richey-Lambert coal field, Richland and Dawson Counties, Montana: U.S. Geol. Survey Bull. 847–C, p. 121–174.

Prichard, G. E., and Landis, E. R., 1955, Geology of the northern part of the Girard coal field, Richland County, Montana: U.S. Geol. Survey Coal Inv. Map C-24.

Rogers, G. S., 1917, Baked shale and slag formed by the burning of coal beds: U.S. Geol. Survey Prof. Paper 108–A, p. 1–10.

Sandberg, C. A., 1962, Geology of the Williston basin, North Dakota, Montana, and South Dakota, with reference to subsurface disposal of radioactive wastes: U.S. Geol. Survey Rept. TEI–809, 148 p.

Schopf, J. M., 1956, A definition of coal: Econ. Geology, v. 51, no. 6, p. 521–527.

Smith, C. D., 1909, The Fort Peck Indian Reservation lignite field, Montana: U.S. Geol. Survey Bull. 381–A, p. 40–59.

Stadnichenko, Taisia, Murata, K. J., Zubovic, Peter, and Hufschmidt, E. L., 1953, Concentration of germanium in the ash of American coals—A progress report: U.S. Geol. Survey Circ. 272, 34 p.

Stebinger, Eugene, 1912, The Sidney lignite field, Dawson County, Montana: U.S. Geol. Survey Bull. 471–D, p. 284–318.

Swenson, F. A., 1955, Geology and ground-water resources of the Missouri River valley in northeastern Montana *with a section on* The quality of the ground water, by W. H. Durum: U.S. Geol. Survey Water-Supply Paper 1263, 128 p. [1956].

Taff, J. A., 1909, The Sheridan coal field, Wyoming: U.S. Geol. Survey Bull. 341, p. 123–150.

Thom, W. T., Jr., and Dobbin, C. E., 1924, Stratigraphy of Cretaceous-Eocene transition beds in eastern Montana and the Dakotas: Geol. Soc. America Bull., v. 35, no. 3, p. 481–505.

Torrey, A. E., and Kohout, F. A., 1956, Geology and ground-water resources of the lower Yellowstone River valley between Glendive and Sidney, Montana, *with a section on* Chemical quality of the water, by H. A. Swenson: U.S. Geol. Survey Water-Supply Paper 1355, 92 p.

U.S. Bureau of Mines, 1965, Mineral facts and problems: U.S. Bur. Mines Bull. 630, 1118 p.

Weed, W. H., 1893, The Laramie and the overlying Livingston formation in Montana, with report on flora by F. H. Knowlton: U.S. Geol. Survey Bull. 105, 68 p.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1975—677-309/37