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Field Trip Guidebook

ECONOMIC GEOLOGY OF THE PENNSYLVANIAN SYSTEM IN SOUTHWEST MISSOURI

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INTRODUCTION

Development of the coal, petroleum, and tar sand resources of the Pennsylvanian System in southwestern Missouri has been a principal factor in the cultural and economic growth of this largely rural area. Oil was discovered in the mid-1890's near the town of Stotesbury in Vernon County. Tar sand has been recovered locally from sandstone outcrops for asphalt road paving since the early 1930's. Prior to that time, the viscous tar was recovered for lubricating machinery. Coal has been mined for local use since the area was settled, and was commercially produced as early as the mid-1800's. From 1926 to 1935, the Mindenmines district outproduced all other districts in the state.

The energy crisis of the 1970's brought about a resurgence of exploration drilling and mineral resource production in the region. Construction of two large coal-fired power plants in northwestern Jasper County and Linn County, Kansas set the stage for the modern coal mining industry in southwestern Missouri. Two large surface coal mines (Pittsburg & Midway Coal Mining Company's Empire and Midway mines) were opened in Barton County and southwestern Bates County, respectively, to supply coal for these mine-mouth power plants. Smaller coal mines were soon opened to supply the power plants with coal on the spot market. Rising oil prices and new technology for enhanced oil recovery made the heavy oil resources of Vernon and Barton County economically recoverable. In 1984, half of Missouri's oil production was from Vernon County. Tar sand resources also became economically attractive during this period.

Despite declining oil and coal production in the late 1980's, Barton and Vernon Counties contain a wealth of mineral resources. New technology for utilizing high-sulfur coal and a recent trend to move away from a dependency on a foreign oil supply, may provide the key to future development of the area's mineral fuels resources.

The principal focus of this field trip is the coal, petroleum and tar sand resources of the Atokan and Desmoinesian strata in southwestern Missouri. Field trip participants will examine the stratigraphy of five economic coal beds and the associated strata. Two active coal mines, one active heavy oil operation, and an abandoned tar sand quarry will be visited. The field trip ends with a discussion of the virgin prairie resources of southwestern Missouri. The preservation of Missouri's virgin prairie in the vicinity of coal mining activity has become a recent issue in striking a balance between developing the state's mineral resources and protecting the environment.

ECONOMIC GEOLOGY

The average thickness of the Pennsylvanian strata throughout much of Barton and Vernon Counties is 200 feet with an average regional dip of 3^{o} to 5^{o} north-northwest. Desmoinesian rocks are exposed at the surface throughout most of the region. Along major rivers and their tributaries, erosion has exposed the older rock units of the Krebs Subgroup and Atokan Series. Erosional remnants or mounds rising as much as 120 feet above the surrounding topography are interesting geologic features typical to this area. The thick marine limestone beds of the Blackjack Creek and Higginsville Formations (Fort Scott Subgroup) are some of the youngest Pennsylvanian units preserved on the crests of these mounds. Structural displacement and erosional patterns may explain the origin of these mounds; however, more data is needed before a general geologic history of the mounds can be determined.

In Barton and Vernon Counties, coal has been mined from the Riverton, Rowe, Drywood, Weir, Mineral, Fleming, Croweburg, Verdigris, Mulky, and Bandera Formations. In the past three decades, most coal production in Barton and Vernon Counties has been from the Rowe, Drywood, Mineral, Fleming and Croweburg coal beds. Production from the Atokan sequence has been insignificant in recent years, but prior to the mid 1970's, it was locally important in central Barton County. The Atokan has attracted recent attention because of its potential for low-sulfur coal resources.

The heavy oil and tar sand resources are present in the lower Cherokee sandstones of the Bluejacket and Warner Formations. This part of the stratigraphic section is a complex depositional environment, which has been the focus of stratigraphic studies for many years (Wells, 1977, 1979; Tomes, 1986; Howe, 1961, 1988; Nuelle, 1990, 1991). The absence of persistent marker beds in this part of the section, the lenticular nature of the coal beds, and the complexity of the fluvio-deltaic environment, have hindered the development of the mineral resources in this region.

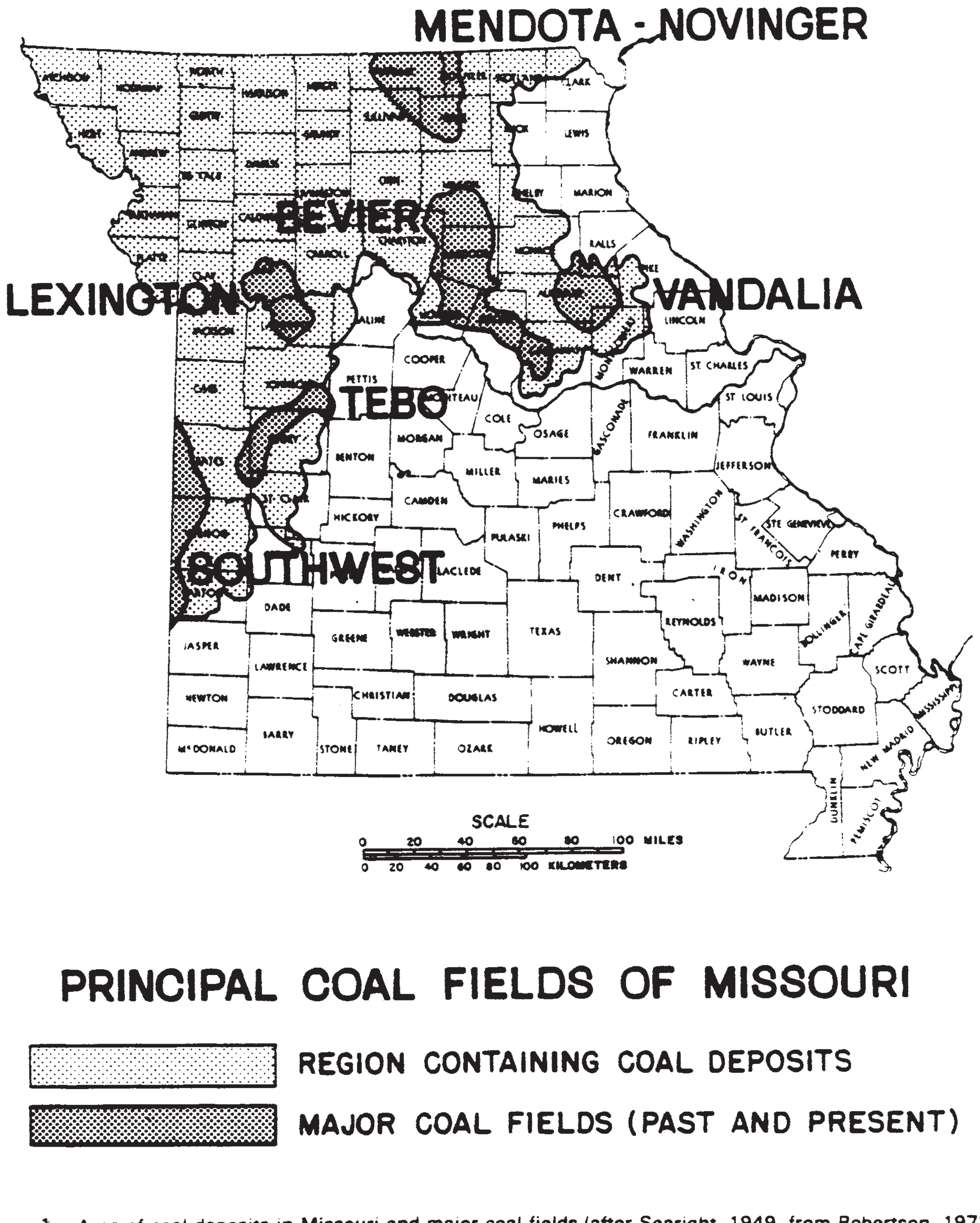


Figure 1. Area of coal deposits in Missouri and major coal fields (after Searight, 1949, from Robertson, 1973).

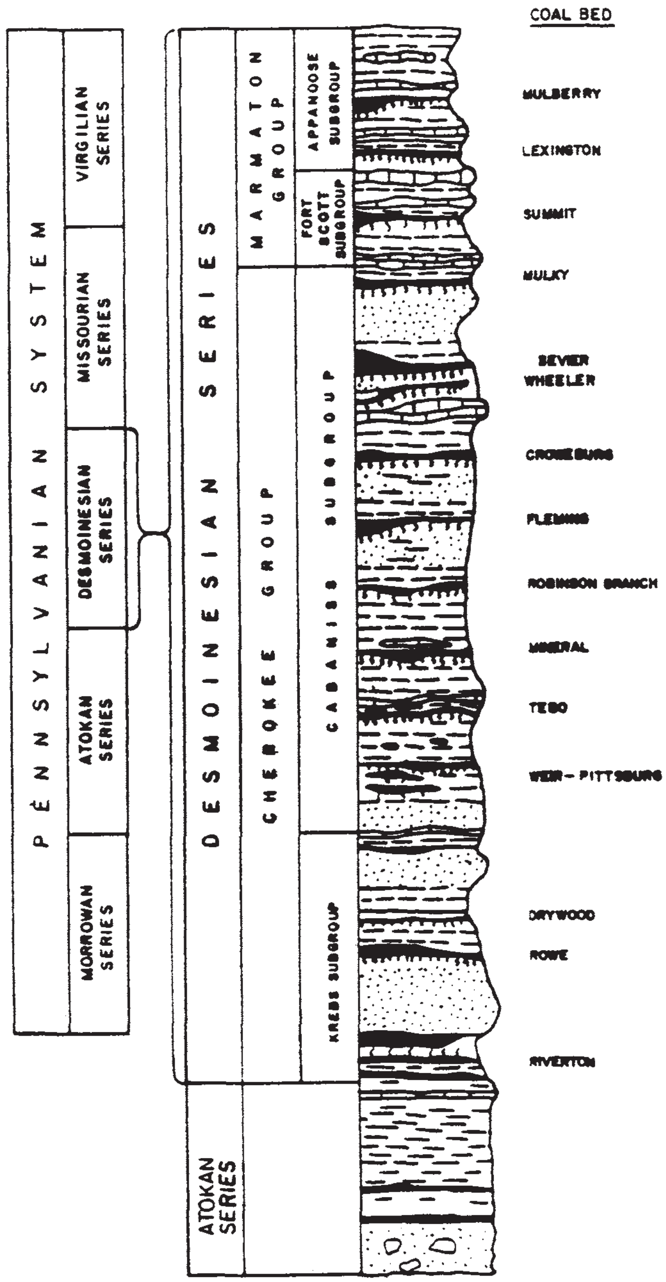


Figure 2. Stratigraphy of principal coal beds of Missouri. Modified from Robertson (1971).

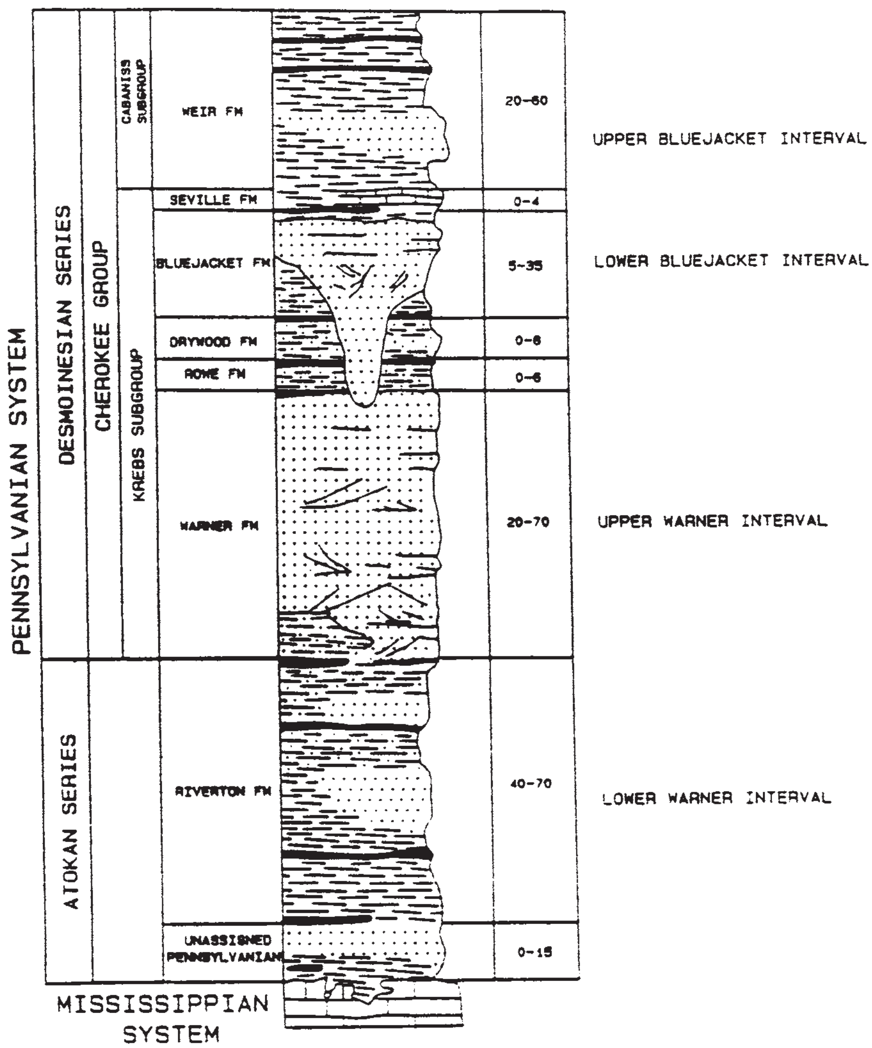
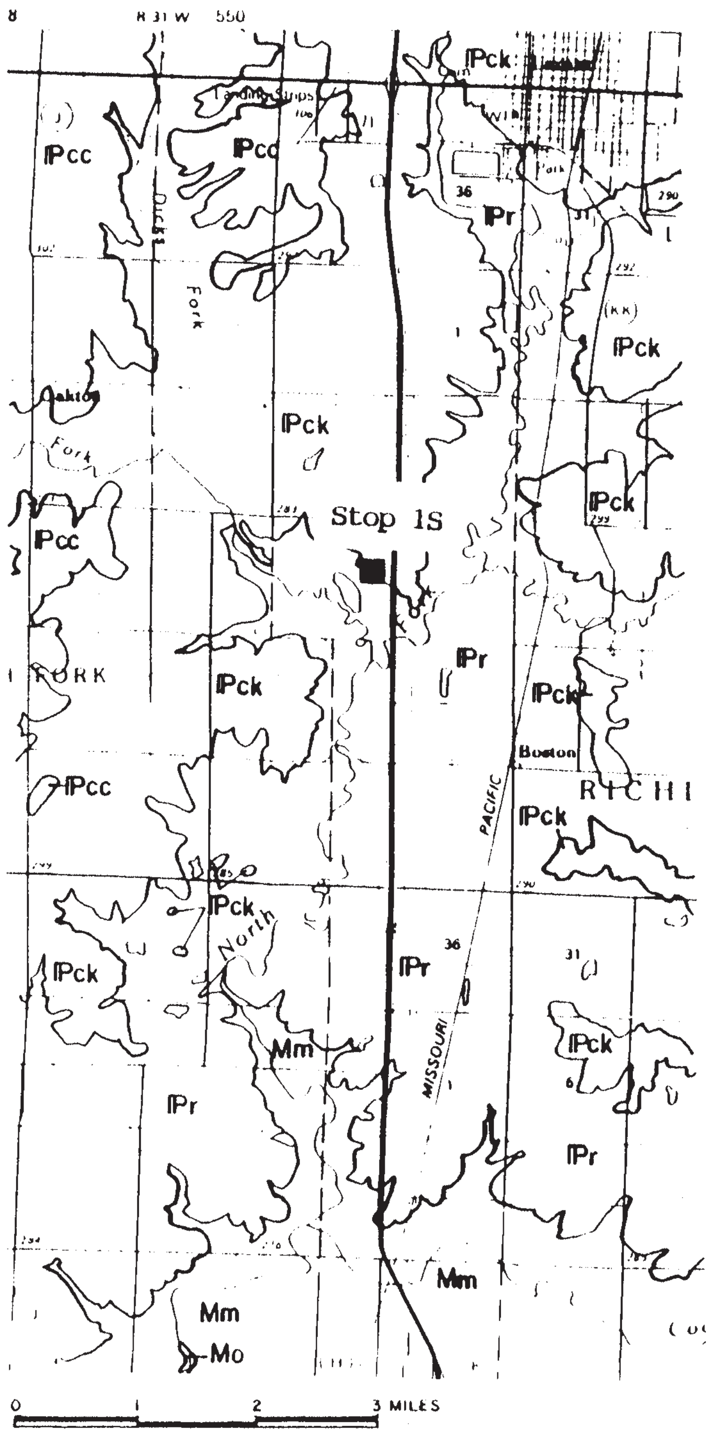


Figure 3. Generalized geologic column of lower Desmoinesian and Atokan strata in southwest Missouri (from Netzler, 1990).



LEGEND FOR GEOLOGIC MAP

Pmm Map unit

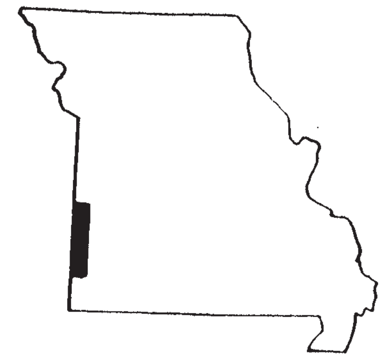
Contact inferred

(A) Fault, inferred, ball and bar on the downthrown side. Letter in parenthesis refers to discussion in text.

CORRELATIONS OF MAP UNITS

System	Series	Group	Subgroup	Formation	Map Unit
Pennsyvanian	Desmoinesian	Marmaton	Appanoose	Bandera Pawnee	Pmm
				Labette	Pmb
			Fort Scott	Higginsville Little Osage Blackjack Creek	
		Cherokee	Cabaniss	Exello Mulky Lagonda Bevier Verdigris Croweburg Fleming Robinson Branch Mineral Scammon Tebo Weir	Pcc
			Krebs	Seville Bluejacket Drywood Rowe Warner	Pck
				Undifferentiated Riverton-Warner	Pu
				Riverton	Pr
	Atokan				
Mississippian	Chesterian			Carterville	Mc
	Meramecian			St. Louis Salem Warsaw	Mm
	Osagean			Burlington-Keokuk	Mo

INDEX MAP



INDEX MAP OF GEOLOGIC MAPS

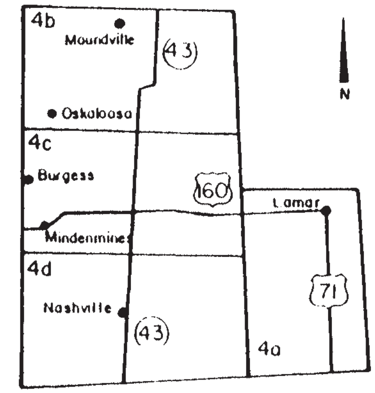


Figure 4a Geologic map of the southern part of the Southwest Field in Missouri (from Smith, Work, and Robertson, 1990).

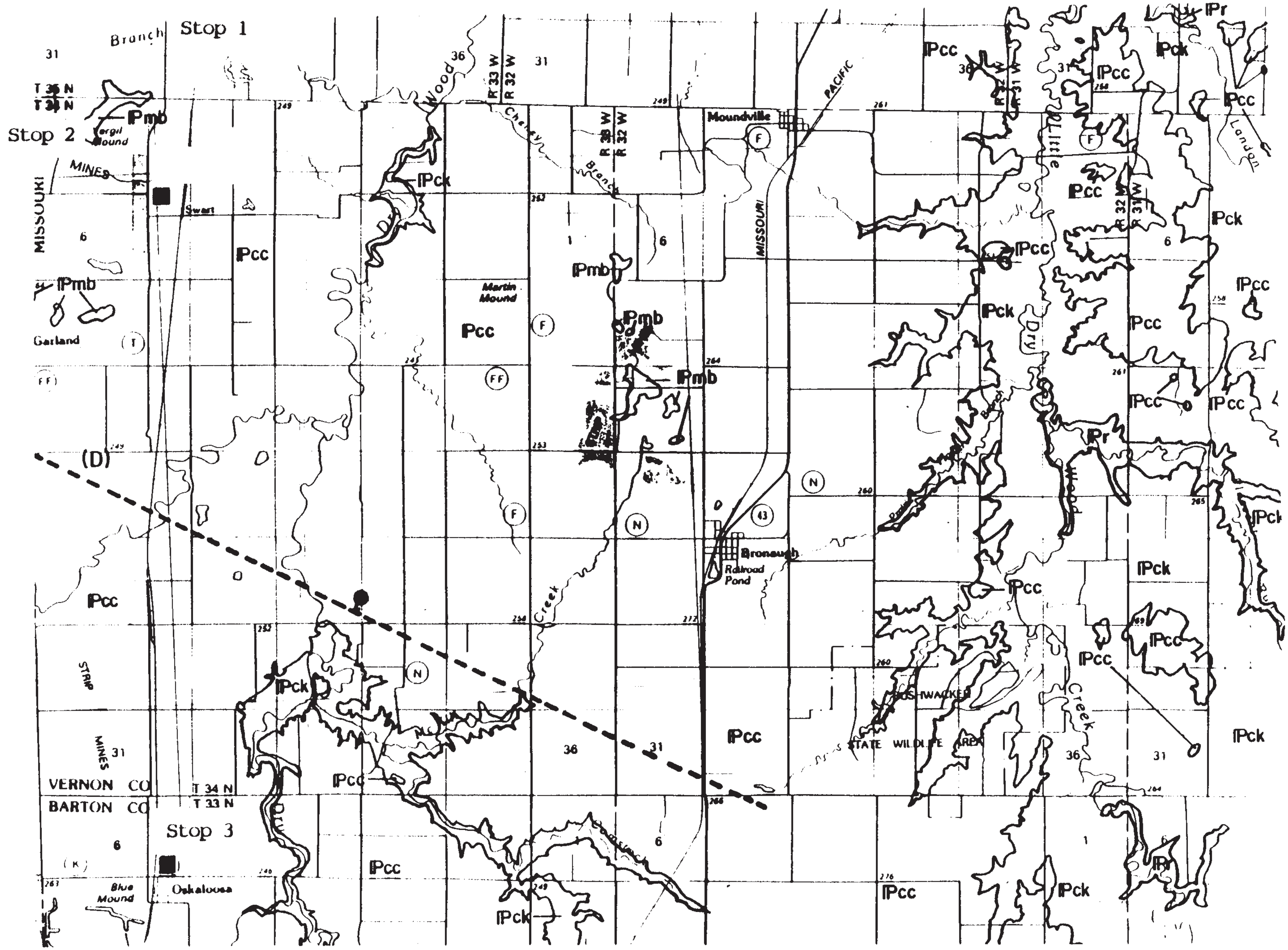


Figure 4b. Geologic map of the southern part of the Southwest Field in Missouri (from Smith, Whitfield, and Nuelle, 1990).

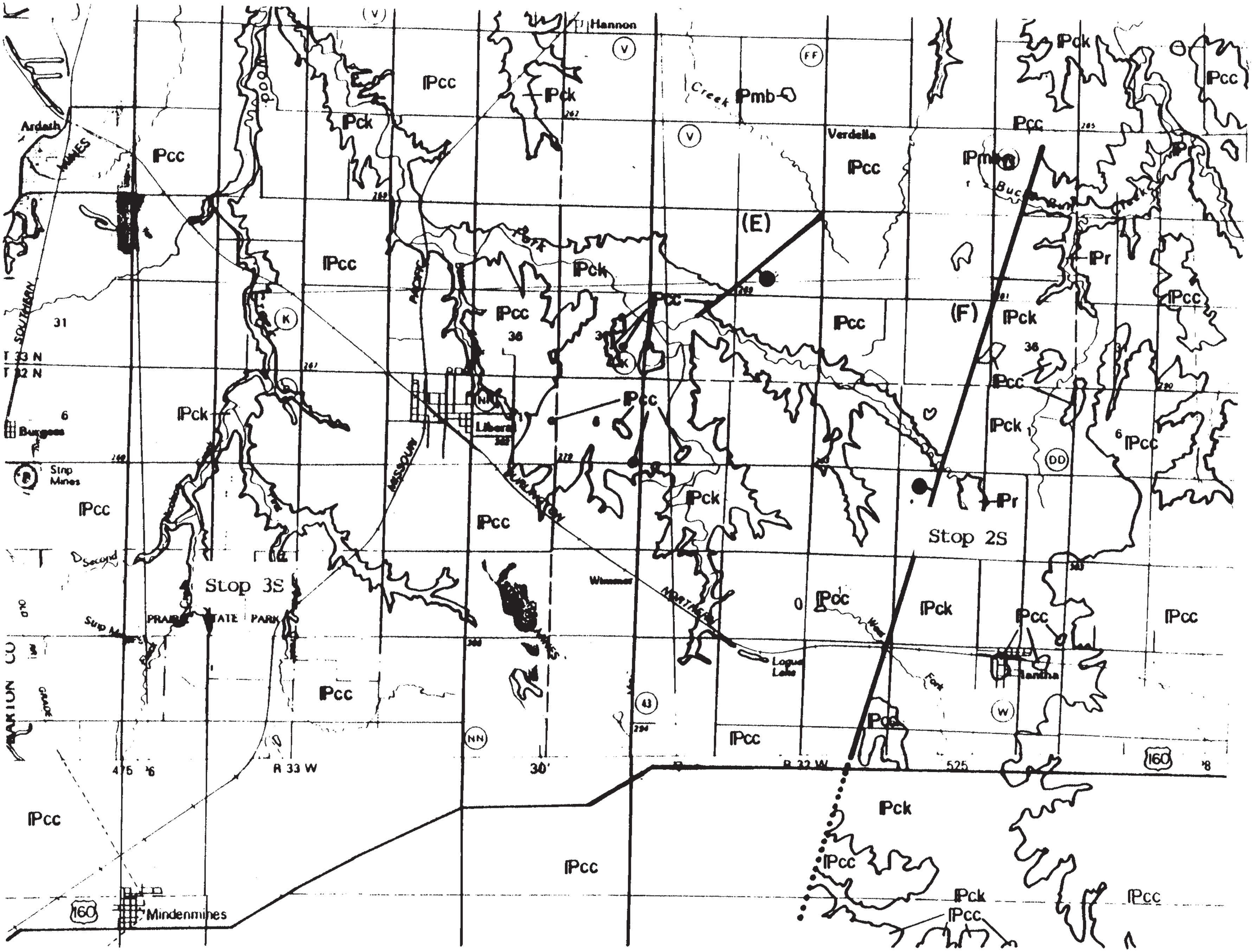


Figure 4c. Geologic map of the southern part of the Southwest Field in Missouri (from Smith, Whitfield, and Nuelle, 1990).

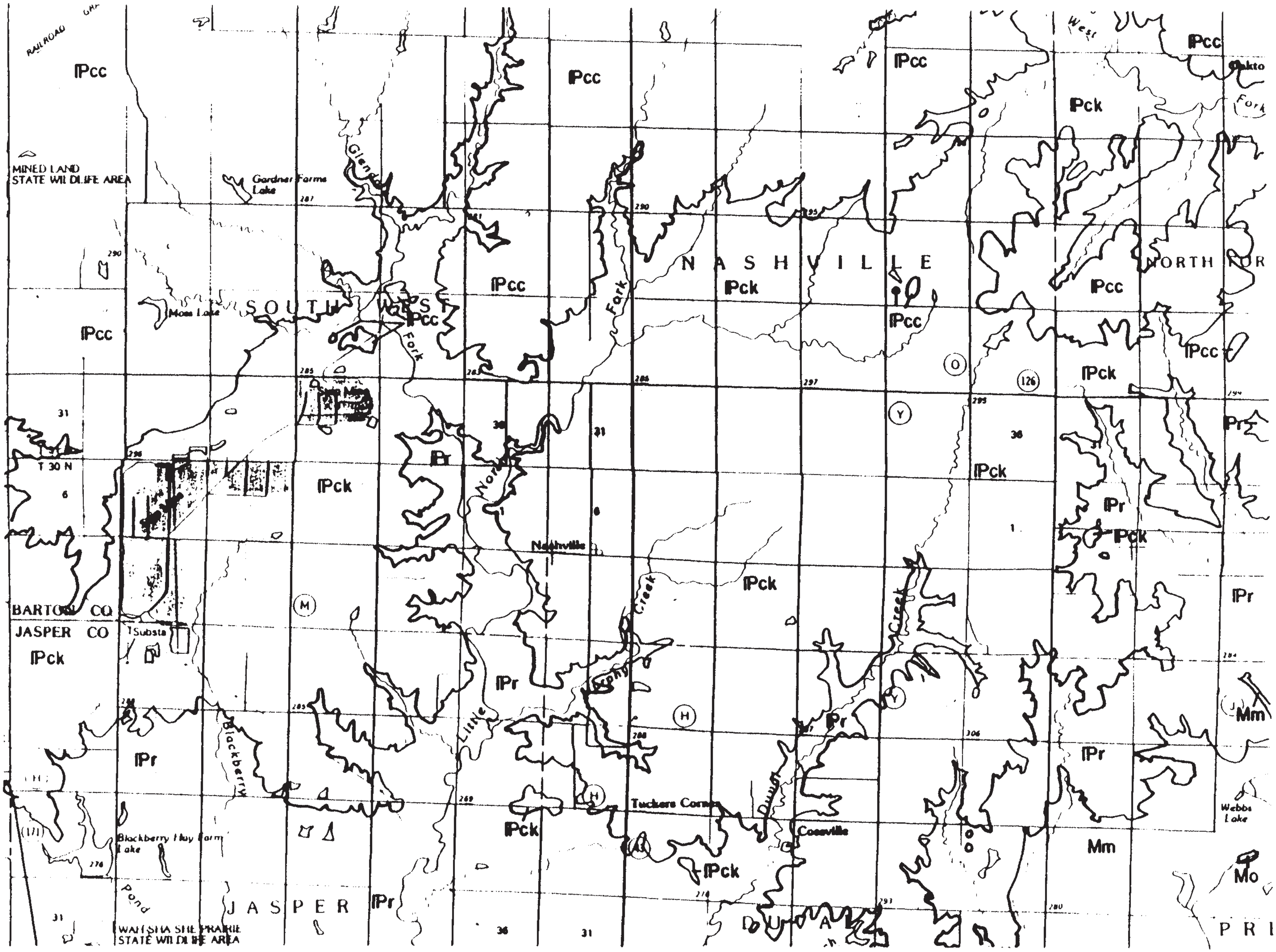


Figure 4d. Geologic map of the southern part of the Southwest Field in Missouri (from Smith, Work, and Robertson, 1990).

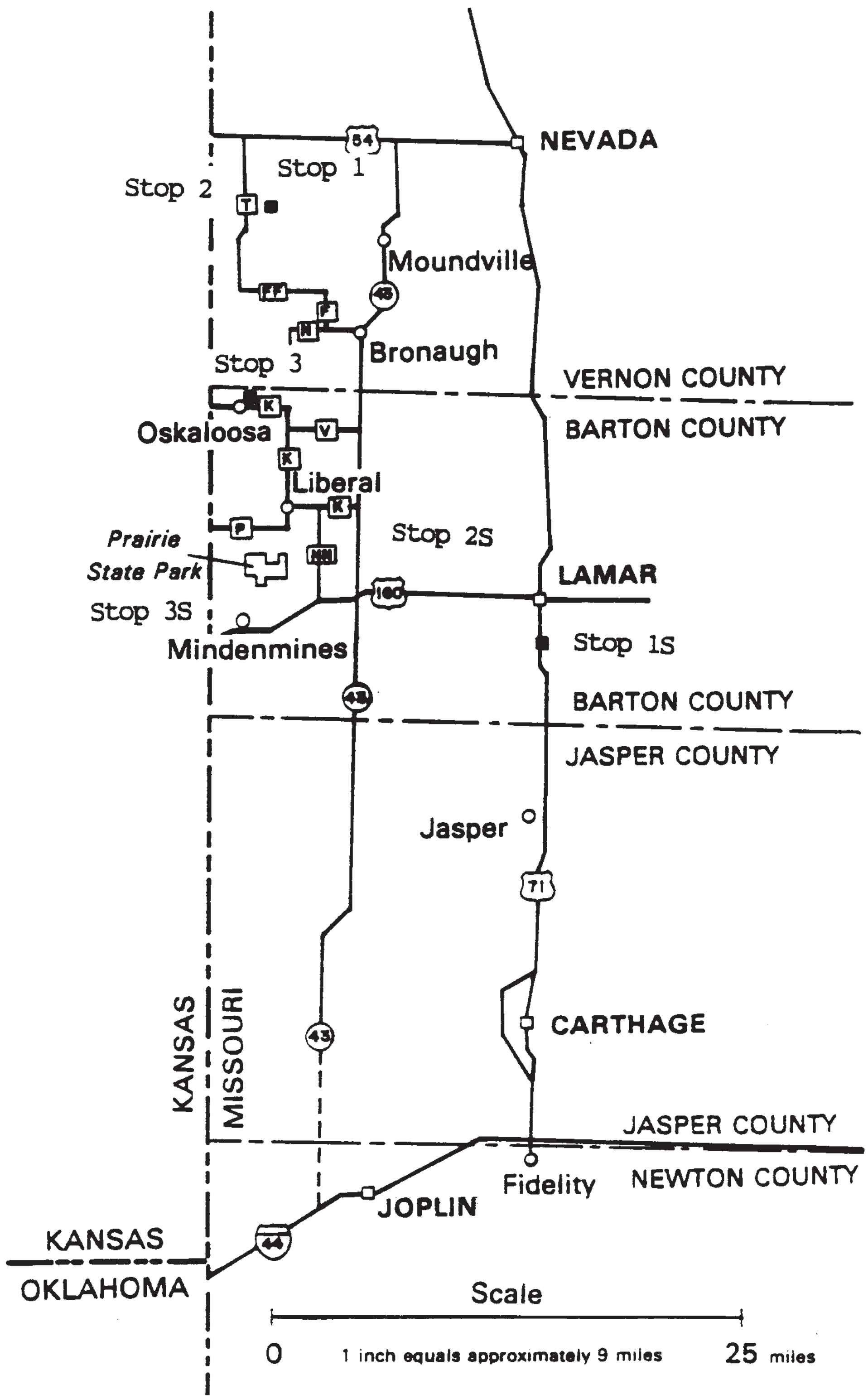


Figure 5. Field trip route

Roadlog---Friday, September 27, 1991

Mileage			
From	To	Interval	
0.0	0.0	0.0	Comfort Inn parking lot Nevada, Missouri. TURN RIGHT (WEST) on U.S. Hwy 54.
0.0	0.8	0.8	Stoplight (Centennial Ave.)
0.8	1.1	0.3	Overpass.
1.1	1.8	0.7	Jct. County Rds. BB & W.
1.8	2.4	0.6	Cottey College Established 1884.
2.4	4.1	1.7	Little Drywood Creek.
4.1	6.0	1.9	Jct. U.S. Hwys. 54 & 43.
6.0	8.4	2.4	Coal crops out on right. (Rowe or Drywood Fm.)
8.4	8.9	0.5	Abandoned strip mine.
8.9	9.0	0.1	Big Drywood Creek Abandoned strip mine.
9.0	10.0	1.0	Jct. County Road H.
10.0	10.6	0.6	Outcrop, Bluejacket sandstone.
10.6	12.8	2.2	Outcrop, shale of Rowe or Drywood Formations.
12.8	13.2	0.4	Railroad overpass.
13.2	14.0	0.8	Junction County Road T TURN LEFT (SOUTH) ON T.
14.0	14.2	0.2	Railroad tracks.
14.2	14.4	0.2	Clayton Christian Church.
14.4	15.8	1.4	Abandoned strip mine on right, Mulky coal mined.
15.8	16.6	1.2	Junction County Road KK.
16.6	17.0	0.4	Oil tanks on left.

Stop 1

Carmel Energy, Inc.
W 1/2 Sections 28, 33, T.35 N., R.33 W.
Vernon County, Missouri

Carmel Energy, Inc., located near Deerfield in western Vernon County (W 1/2 Sections 28, 33, T.35 N., R.33 W.), is one of three operations producing "heavy oil". Since 1978, Carmel Energy has produced over 550,000 barrels of oil and remains the largest commercial "heavy oil" project in the state.

Production of the "heavy oil" is accomplished by injecting a super- heated mixture of steam, nitrogen, and carbon dioxide into the producing horizon. Carmel Energy patented this process under the name Vapor Therm Process. At its peak production in 1984, Carmel Energy produced between 10,000 and 12,000 barrels per month. However, because of the sharp decrease in the value of oil in the mid-1980's, Carmel Energy curtailed steam flooding. Today, production averages about 5,000 barrels per year.

Production at this locality is from the "Eastburn Sandstone". This localized sandstone body, which was tentatively named by Carmel Energy, lies stratigraphically between the Warner and the Bluejacket Formations at a depth of approximately 100 feet. Most likely, the "Eastburn Sandstone" is a localized channeling of the Bluejacket Sandstone through the Rowe-Drywood Formations or a facies change within the Rowe-Drywood Formations. Wells (1979) subdivides the Bluejacket and Warner Formation into an "upper" and "lower" zone to accommodate observed facies changes in the Krebs Subgroup. These zones are not formally recognized in the stratigraphic nomenclature of Missouri.

AREAL GEOLOGY

Prominent structural features (McCracken, 1971) include the Schell City-Rich Hill Anticline in extreme northeastern Vernon County, the Swarts-Garland Dome (T.34 N., R.33 W.), the northwest extension of the Chesapeake Fault, the Lamar Syncline, and most notably the Bourbon Arch (Ebanks and James, 1974). Within Missouri, regional dip of Pennsylvanian strata is to the west, northwest from 3-5°. Tomes (1986) reports that the thickest sandstone sequences are on the downthrown sides of faults and in the synclinal axes.

Sandstones of the Atokan and Lower Desmoinesian Series have been described as major reservoirs of "heavy oil" in western Missouri. The sandstones of the Warner and Bluejacket Formations and the "Eastburn Sandstone" are the principal targets for exploration.

The Warner Formation consists mainly of sandstone. In places, a conglomerate zone lies at its base which grades upward into sandstone with interbedded silt and shale zones. Average thickness of the formation is between 30 to 40 feet. The sandstone is predominately quartz, well rounded, fine to medium-grained, with some beds containing abundant amounts of mica. The bedding is commonly more massive than the Bluejacket and cross-bedded. Siderite, pyrite, iron and clay nodules are prevalent. The sandstone is oil bearing or impregnated with tar throughout most of the county.

The Drywood and Rowe Formations consist of shale, siltstone and localized coal beds. The contact between the two formations is not readily identifiable on electrical logs.

The "Eastburn Sandstone" described by Bradshaw (1985) consists of a basal conglomerate which contains limestone, siderite, and unidentifiable pebbles replaced by pyrite. The basal conglomerate grades upward into a fine-grained sandstone which contains parallel and cross-bedded sequences. This sequence grades upward into silty shales. Average thickness of the production unit is 20 feet. The lower 12 to 16 feet is more permeable and has an average porosity of 25 percent. API gravity of the produced oil ranges from 20-23^{o}.

The overlying Bluejacket Formation is upwards of 25 feet thick and lies at a depth of approximately 60 feet. The Bluejacket is oil bearing, but considered a poor reservoir. Low porosity, grain size, sorting and permeability combine to make the Bluejacket a poor producer. Very fine-grained sandstone, gray shale, and lenses of siltstone are characteristic of the formation.

Western Missouri reserve estimates range from a few million to an estimated 1.9 billion barrels of oil in place (Wells, 1979). Recovery rates of around 50% have been obtained from recent "heavy oil" operations in Vernon County. If favorable economic conditions prevail and secondary and tertiary recovery techniques are successful, then substantial quantities of near surface "heavy oils" can be commercially recovered.

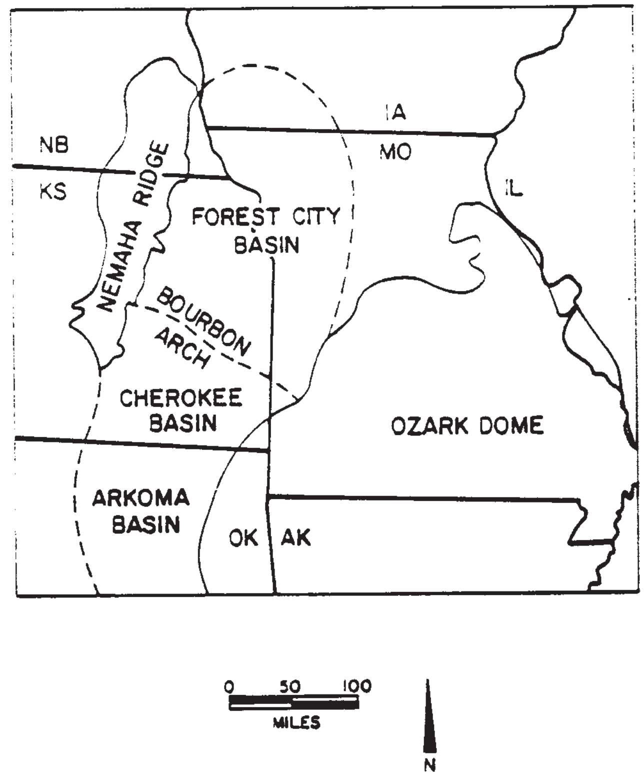


Figure 7. *Structural features of mid-continent (after Tomes, 1986).*

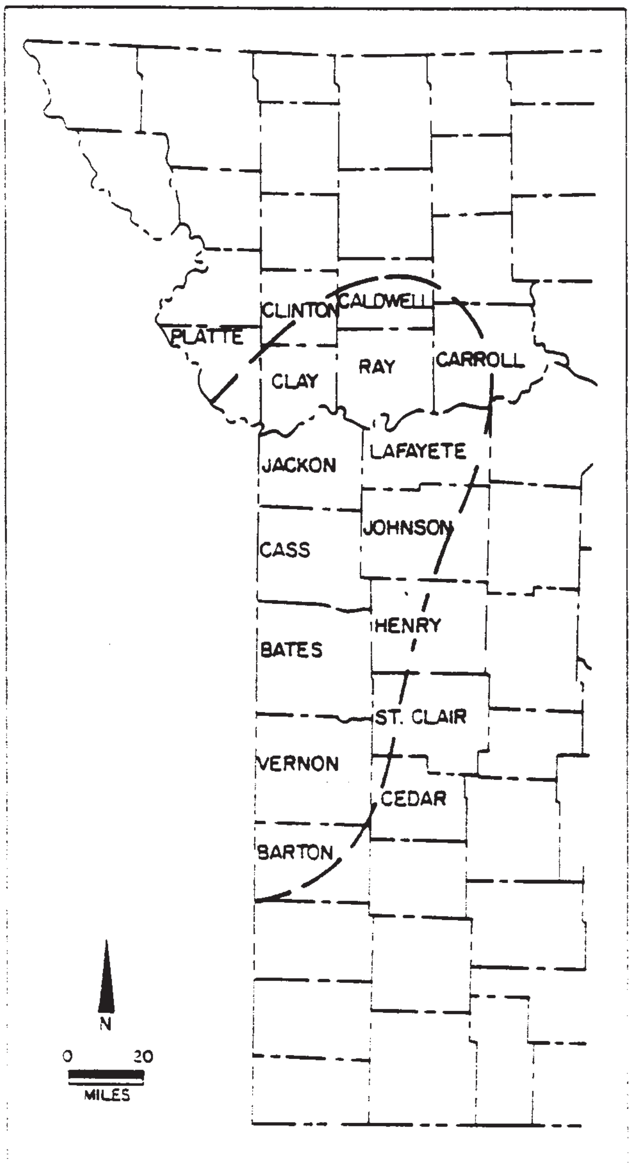


Figure 6. *Map of heavy oil occurrences in Missouri (after Wells, 1979).*

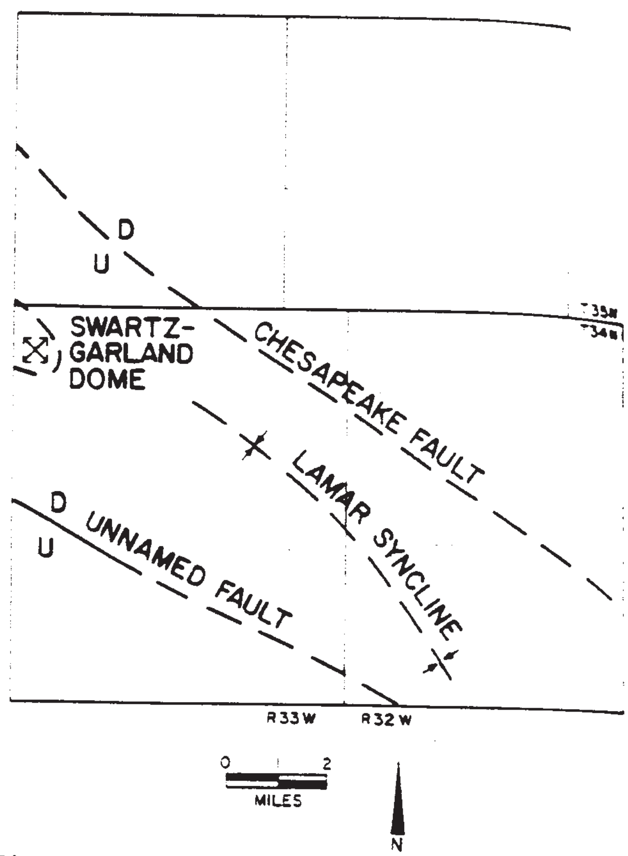


Figure 8. *Structural features of southwest Vernon County, Missouri (Tomes, 1986).*

Mileage			
From	To	Interval	
17.0	17.5	0.5	Abandoned pump jacks.
17.5	17.9	0.4	Operating pump jacks of Carmel Energy Co., Inc.
17.9	18.0	0.1	Bridge.
18.0	18.2	0.2	TURN LEFT (EAST). Entrance to Carmel Energy Co., Inc. STOP 1.
18.2	19.0	0.8	Abandoned strip mines Croweburg coal mined.
19.0	19.4	0.4	Abandoned strip mine. Formerly operated by Bill's Coal Company. Croweburg and Mineral coal beds were mined.
19.4	20.1	0.7	Gravel road. TURN RIGHT (WEST) on gravel road.
20.1	21.5	1.4	Kansas-Missouri state line. TURN RIGHT (NORTH).
21.5	21.7	0.2	Gray shale of the Verdigris Formation exposed in ditch.
21.7	21.9	0.2	Gravel road.
21.9	22.0	0.1	Abandoned strip pit.
22.0	22.3	0.3	Abandoned pit and equipment of Bill's Coal Company.
22.3	22.7	0.4	Mined and reclaimed area of Caylor Construction Co.
22.7	22.9	0.2	Mine entrance, Mary Jane #1 Mine, Caylor Construction Co. STOP 2.
22.9	25.7	2.8	Return to County Road T.
25.7	26.4	0.7	Reclaimed land and final pit, Caylor Construction Co.

Stop 2

CAYLOR CONSTRUCTION CO.
NW 1/4, Section 5, T. 34 N, R. 33 W
Vernon County, Missouri

The mine is in the NW 1/4, Section 5, T. 34 N., R. 33 W., south of Swart in the southwestern corner of Vernon County. Caylor Construction Co. began mining in Missouri in 1985 on the leases of Bill's Coal Co., which ceased mining when the insurance company that held their reclamation bonds declared bankruptcy. The headquarters of Caylor Construction Co. is in Ottawa, Kansas. In 1989, annual production was 81,985 tons. The mine currently employs seven people. All production is from the Croweburg and Mineral beds which average 30.4 and 38.1 cm (12 and 15 in) thick, respectively. The Fleming bed is present in the pit but is too thin to be recovered at this locality. Output from the mine is crushed and sized at a small, portable, washing plant. No advanced coal-cleaning methods are employed.

AREAL GEOLOGY

The regional dip is approximately 3^0 to the northwest. The Mulky coal bed has been mined on the crest of the two mounds in the area (Figure 9). The smaller mound in the southern part of Section 6 trends east-west and has a maximum relief of 60 feet. The larger one, Vergil Mound, lies approximately 1 1/2 miles northwest of the mine and has been protected from erosion by the thick limestone of the Blackjack Creek Formation (caprock of the Mulky coal bed). This limestone is the equivalent of the Lower Fort Scott Limestone in Kansas.

The Croweburg and Mineral beds have been extensively mined in tandem in western Missouri for the past three decades. The stratigraphic section measured in the highwall of the mine (Figure 10) shows the relationship between the Mineral, Fleming and Croweburg beds that is typical for western Missouri. The Croweburg is one of the most persistent coals in the Western Region of the Interior Coal Province in terms of thickness and lateral extent. It is correlated with the Whitebreast coal seam in Iowa and the Colchester No. 2 seam in Illinois (Howe, 1956). In Vernon County, local miners named it the "One-Foot" bed because of its persistent thickness in the region. In north-central Missouri the Croweburg bed averages 18 inches thick.

The caprock of the Croweburg bed is the Ardmore Limestone Member of the Verdigris Formation. The "Lower" Ardmore Limestone is the uppermost unit exposed in the highwall of the mine. It is characterized by the dark-gray to black shale and large flat limestone concretions. The "Upper" Ardmore Limestone is .6 m (2 ft) thick, massive and weathers along joint planes into large rhomboidal blocks. Its informal name is the "Diamond Rock". The distinctive lithology and weathering characteristics of the Ardmore make it an important stratigraphic marker in both the outcrop and subsurface.

The distribution of the Fleming bed in the highwall is characteristic of its distribution in Missouri and Kansas. The Fleming has been mined at various localities in western Missouri where it reaches a thickness of up to one foot. In other localities, the Fleming bed is represented by a thin coal smut. The identification of the lower two beds in the highwall was made on the basis of stratigraphic sections described by previous workers at Bronaugh, Missouri, and Arma, Kansas (Searight, 1955; Howe, 1956). In Henry County, Missouri, an interval between the horizons of the Fleming and Mineral coal beds is present (Robinson Branch Formation) which contains a locally persistent coal bed and sequence of gray shale. The Fleming coal bed is often mistaken for the Robinson Branch coal and the underlying, thicker coal miscorrelated as the Fleming. However, at this locality, the Robinson Branch Formation is not present. The Mineral bed is 38.1 to 50.8 cm (15 to 20 in) thick in Barton and Vernon Counties.

COAL QUALITY

The following proximate analyses were taken from a coal sampling program conducted by the Missouri Division of Geology and Land Survey in 1980 (Smith and Deason, 1982). Channel samples were collected from the highwall of Bill's Coal Company in NW 1/4, Section 6, T. 34 N., R. 33 W. The results of these analyses closely correspond to those published by Wedge and Hatch in 1980. The following ash fusion temperatures and free swelling indices were taken from their report.

CROWEBURG		MINERAL	
Moisture	4.46*	Moisture	7.20
Ash	11.75	Ash	15.64
Volatile Matter	37.64	Volatile Matter	35.54
Fixed Carbon	46.15	Fixed Carbon	41.62
Heat Value	11,463 Btu	Heat Value	10,372
Sulfur	3.33	Sulfur	4.64
Forms of Sulfur		Forms of Sulfur	
Sulfide	2.14	Sulfide	3.35
Sulfate	0.11	Sulfate	0.21
Organic	1.08	Organic	1.08
Free Swelling Index 8.0		Free Swelling Index 7.0	
Ash Fusion Temperature, ^{0}C		Ash Fusion Temperature, ^{0}C	
Initial Deformation	1095	Initial Deformation	1105
Softening	1130	Softening	1150
Fluid	1160	Fluid	1180

*Values are given in weight-percent per pound of coal. Analyses were performed on an as-received basis.

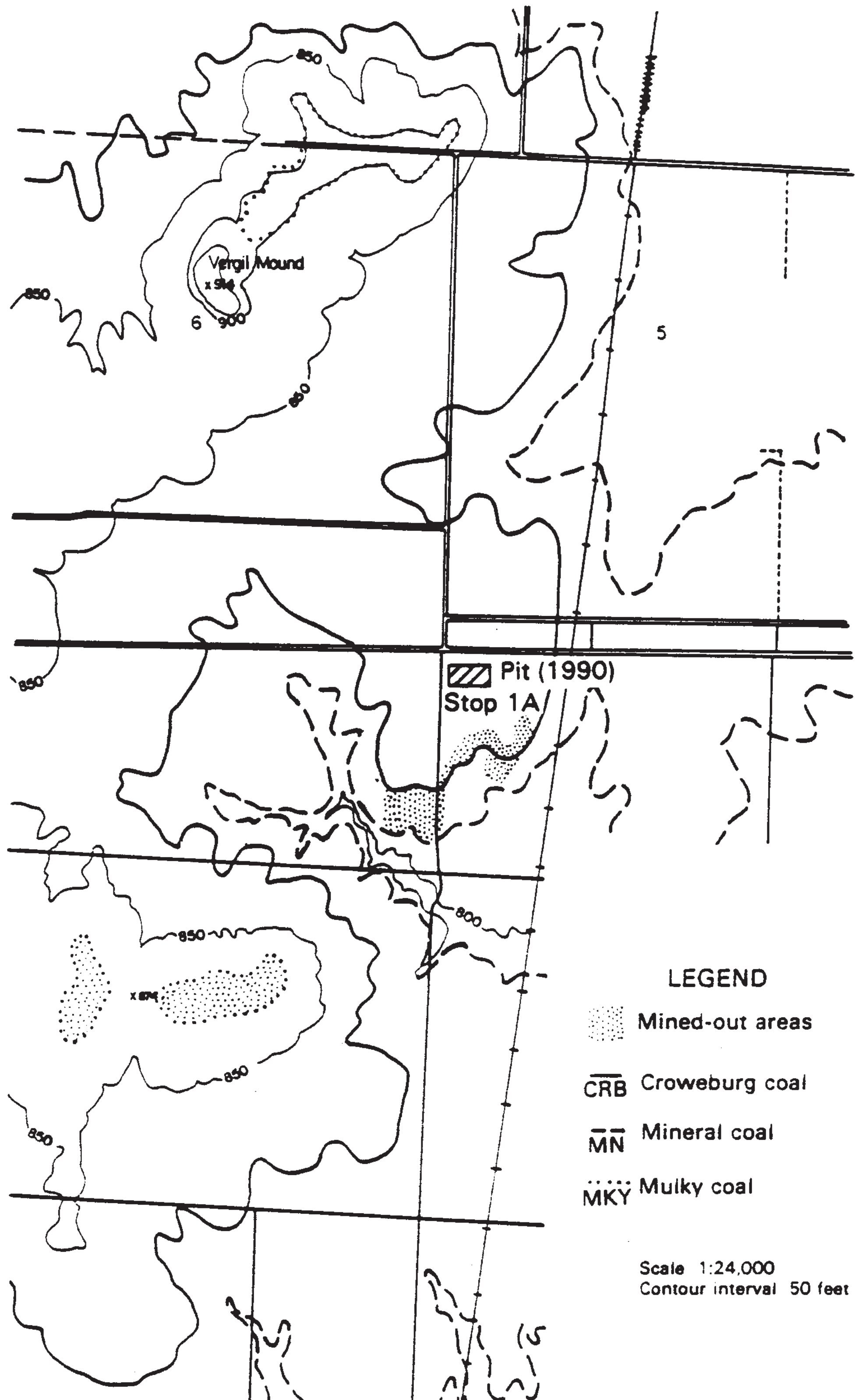


Figure 9. Caylor Construction Co. Stop 1A

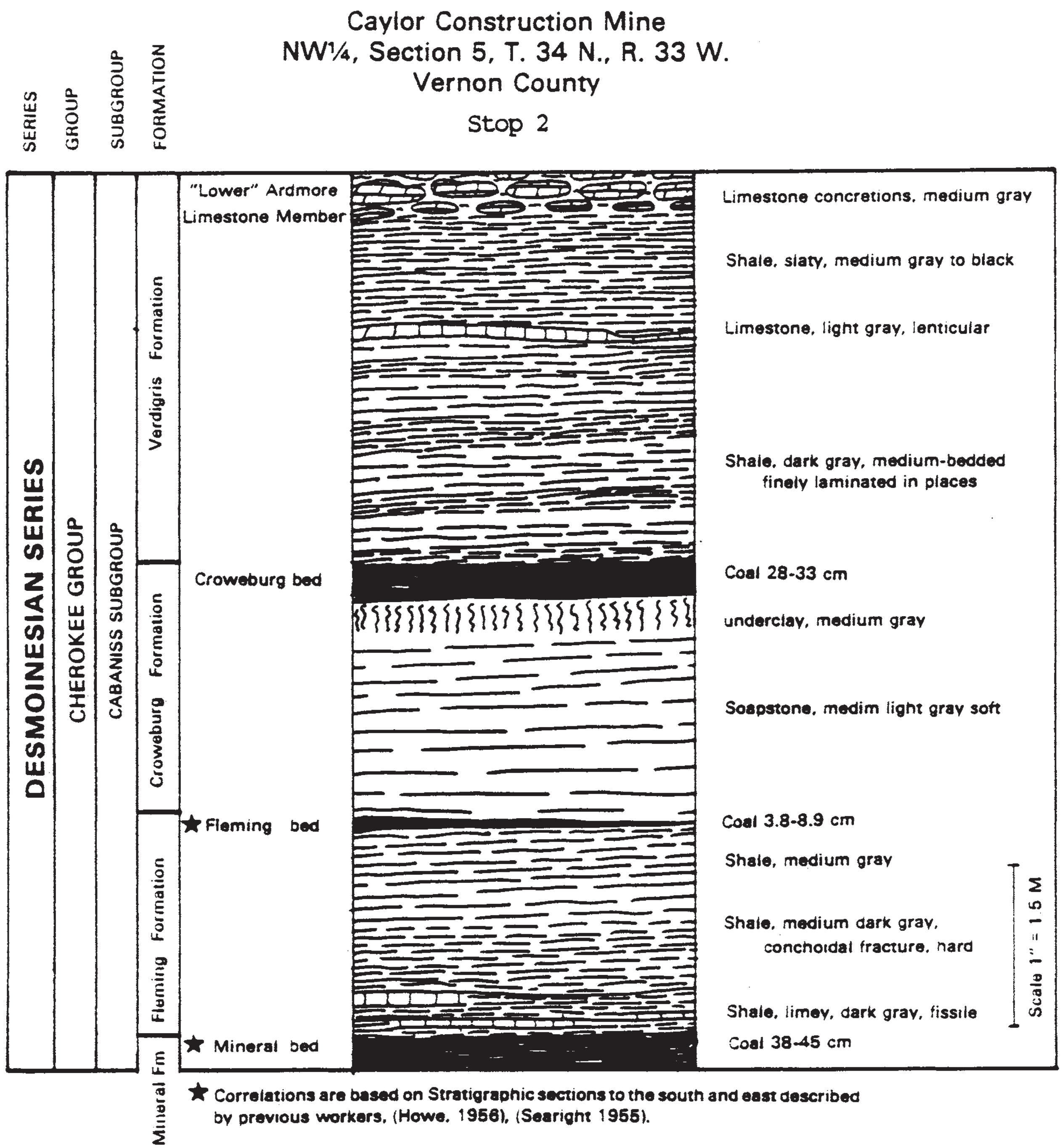


Figure 10. Stratigraphic section measured at the higwall of Caylor Construction Co. mine. Stratigraphic classification and nomenclature follow Searight and Howe, (1961).

Mileage			
From	To	Interval	
26.4	26.7	0.3	Gravel road.
26.7	27.7	1.0	Junction County Roads FF & T. TURN LEFT (EAST) on FF.
27.7	27.9	0.2	Railroad tracks.
27.9	30.0	2.1	Creek.
30.0	32.1	2.1	Junction County Roads F & FF. TURN RIGHT (SOUTH) on F.
32.1	34.1	2.0	Junction County Roads N & F. TURN LEFT (EAST) on N.
34.1	35.7	1.6	Abandoned strip mines. Mineral and Croweburg coals mined.
35.7	36.3	0.6	Railroad tracks.
36.3	36.4	0.1	Junction U.S. Hwy 43 and County Road N. TURN RIGHT (SOUTH) on Hwy 43.
36.4	39.4	3.0	Barton/Vernon County Line.
39.4	40.8	1.4	Bridge.
40.8	41.4	0.6	Junction County Road V & U.S. Hwy 43. TURN RIGHT (WEST) ON County Road V.
41.4	42.5	1.1	Railroad tracks.
42.5	45.4	2.9	Junction County Roads K & V. TURN RIGHT (NORTH) on K.
45.4	46.4	1.0	TURN LEFT (WEST) on K.
46.4	47.3	0.9	Drywood Creek.
47.3	48.6	1.3	TURN RIGHT (NORTH). Mine office, Alternate Fuels, Inc. STOP 3.
48.6	56.4	7.8	Return to U.S. Hwy 43.

TURN LEFT (NORTH) on U.S. Hwy. 43. Return to Nevada (23 miles).

Stop 3

ALTERNATE FUELS MINE
SE 1/4, Section 6, T. 34 N., R. 33 W.
Barton County, Missouri

The Alternate Fuels mine near Oskaloosa in the northwest corner of Barton County (SE 1/4, Section 6, T. 34 N., R. 33 W.) will represent Missouri's first significant production from the Weir-Pittsburg bed in Barton County since the early 1940's. Until recently, most coal explorationists believed extensive exploitation of the Weir-Pittsburg in the early 1900's had largely exhausted the original resource base of that seam in Missouri. However, an extensive exploration drilling program conducted in 1985 by Alternate Fuels confirmed the presence of sizeable Weir-Pittsburg reserves in Vernon and Barton Counties.

Projections call for initial production (Summer 1990) from the Weir-Pittsburg bed near the southeast corner of Section 6 (Figure 7b) with plans for tandem recovery of lesser--but significant--amounts of the Croweburg, Mineral, and Wheeler beds (average thickness 45.7, 30.5, and 45.7 cm, respectively) as mining progresses westward toward Blue Mound.

Production, which is expected to peak at 300,000 tons, is largely committed to Kansas City Power & Light Co.'s La Cygne power plant in Linn County, Kansas.

AREAL GEOLOGY

The mine lies near the base of a long mound which extends north and slightly northeast across Sections 31, 6 and 7 in Townships 33 and 34. The highest point is Blue Mound, where maximum topographic relief is 36.5 m (120 ft). The mound is an erosional remnant similar to those found throughout Vernon and Barton Counties. It has been protected from erosion by the resistent sandstone of the Chelsea Member (Scammon Formation). The crest of Blue Mound is underlain by the thick limestone of the Blackjack Creek Formation.

The regional dip is approximately 4^{o} to the southwest. The general dip along the mound is expressed by the pattern of strip mining in the southwest quarter of Section 7. Two faults trending northwestsoutheast traverse the area on either side of Blue Mound. Offset is approximately 40 feet and the Mineral coal bed is displaced. Two small synclines affect the distribution of the Weir-Pittsburg bed in Sections 7 and 8 and in Sections 5 and 6.

Much of the surface mining in this area was conducted prior to 1926. According to Greene and Pond (1926), the Weir-Pittsburg bed reached a maximum thickness of 1.2 m (4 ft). The stratigraphic section (Figure 8) was compiled from drill records provided by Alternate Fuels, Inc. and shows the nature of the strata above the Weir-Pittsburg coal bed.

The Tebo coal may be recovered at this locality if mining proves economically feasible in terms of coal bed thickness and quality. The Tebo was the largest producing bed in Henry County where it averaged 0.6 m (2 ft) thick. The Tebo is overlain by the Tiawah Limestone Member, an important, persistent, marker bed, which is a dark gray, very dense limestone averaging 15.2 cm (6 in) thick in Vernon County. In Henry County it is a maximum of 45.7 cm (18 in) thick.

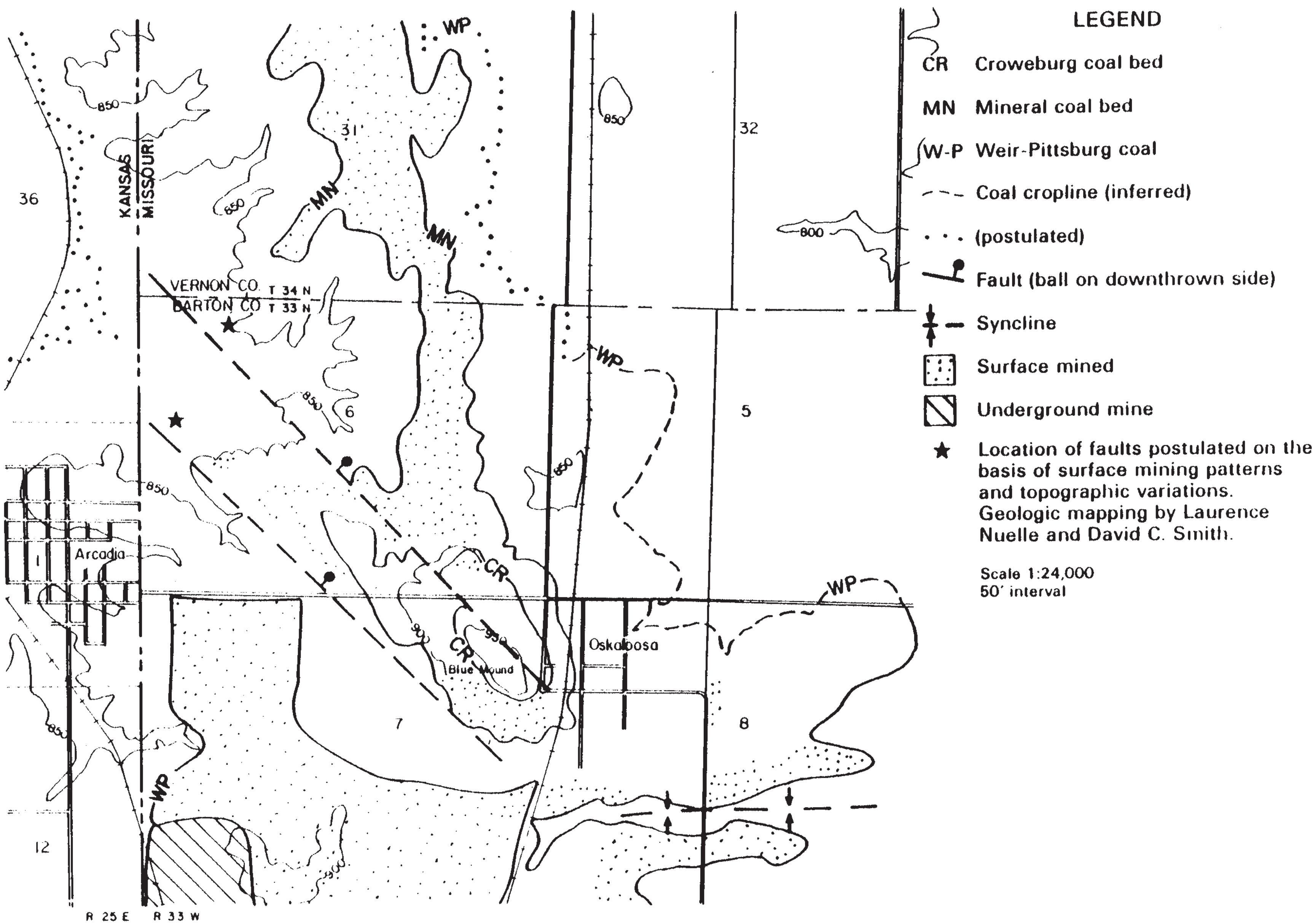


Figure 11. Stop 3, Alternate Fuels Mine, NE¼, Sec. 6, T. 34 N., R. 33 W. Barton Co., Missouri.

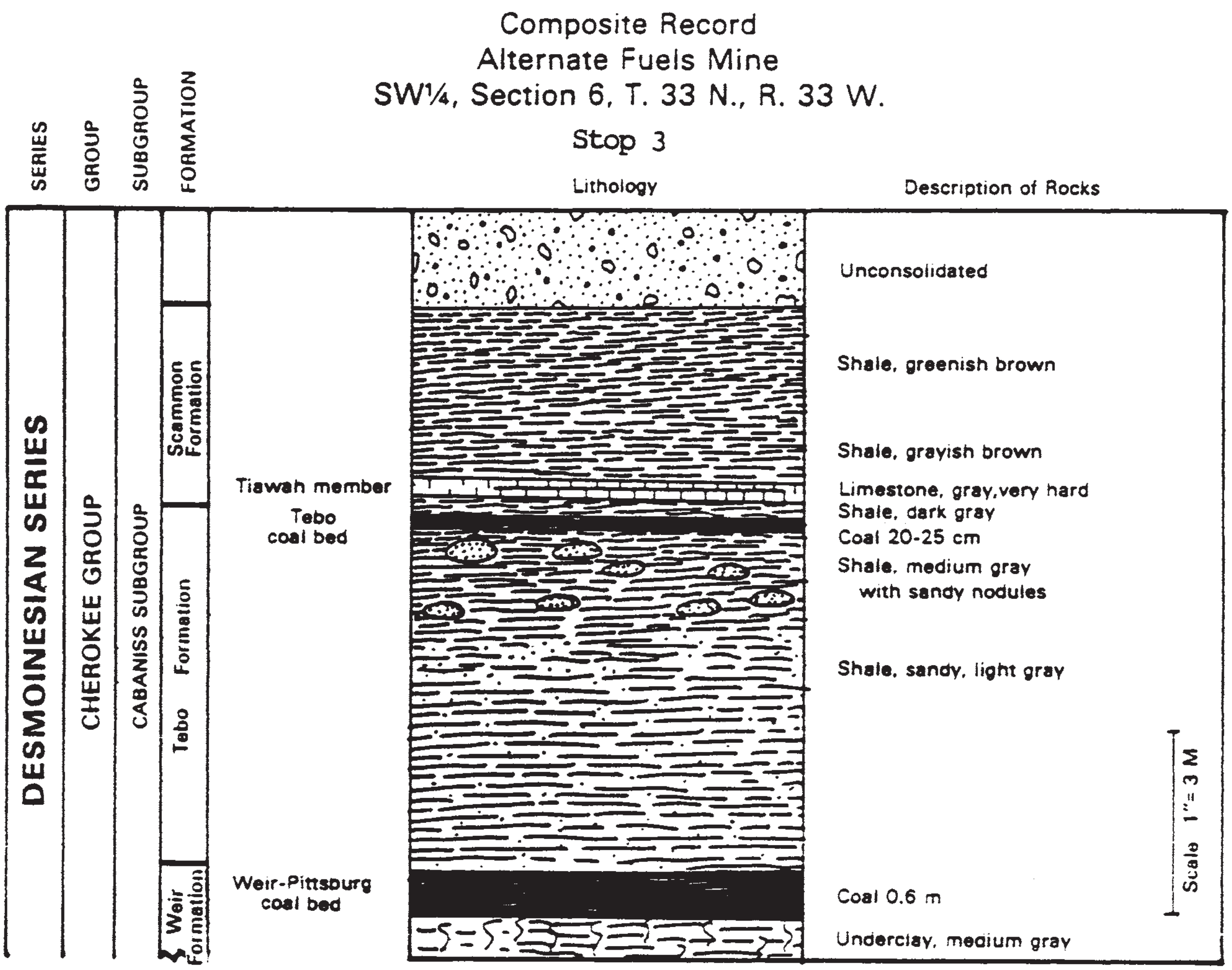


Figure 12. Strata above the Weir-Pittsubrg coal bed.

Roadlog---Saturday, September 28, 1991

Depart from Comfort Inn in Nevada. Travel south on U.S. Hwy 71 to Lamar. This roadlog begins at the junction of U.S. Highways 160 and 71 on the western edge of Lamar in Barton County.

Lamar, county seat of Barton County, is the birthplace of Harry S. Truman, thirty-third president of the United States. The Trumans occupied a 1 1/2 story house, which was built around 1881. It is a State Historic Site and is listed on the National Register of Historic Places. The house has been restored and redecorated with furnishings from the period of the Truman's occupancy. The Site is maintained by the Missouri Department of Natural Resources, Division of Parks, Recreation and Historic Preservation.

	Mileage		
From	To	Interval	
0.0	0.0	0.0	Junction U.S. Hwy 160 & 71. Stay on U.S. 71, traveling south.
0.0	2.0	2.0	CAUTION! SLOW DOWN! APPROACHING TURN THAT IS NOT MARKED!
2.0	2.5	0.5	TURN RIGHT (WEST) on old U.S. Hwy 71. Follow curve to left and go south.
2.5	4.0	1.5	Outcrop of Warner and Riverton Fms. STOP 1S.
4.0	8.0	4.0	Return to Lamar (Jct. U.S. Hwy 160 & 71). TURN LEFT (WEST) on U.S. Hwy 160.
8.0	10.9	2.9	Junction County Road J.
10.9	13.4	2.5	Junction County Roads W & O.
13.4	14.1	0.7	Bridge.
14.1	18.0	3.9	Jct. U.S. Hwys 160 & 43. TURN RIGHT (NORTH) on U.S. Hwy 43.

Stop 1S

ROAD CUT IN RIVERTON AND WARNER FORMATIONS
U.S. Highway 71
NE 1/4, SE 1/4, Sec. 14, T.31N., R.31W., Barton County

Rocks from the uppermost Riverton Formation to the lower part of the Warner Formation are exposed at this roadcut, 6 km (4 mi) south of Lamar (Figure 7a). The Riverton Formation contains five coals which have been numbered sequentially from the oldest (1) to the youngest (5). At this locality, coal 4 is exposed (Figure 12). Coal 3 is just below the road level, some 2.4 m below coal 4. Coals 3 and 4 have been mined locally throughout the area. In the past, these two coals were thought to be the Rowe and Drywood coals and resources were assigned to those coals. However, recent work has proved the coals to be in the Riverton.

Coals 3 and 4 are examples of typical thin, high-sulfur Western Interior basin coals. They formed on a lower delta plain and were inundated by marine waters after deposition. Thus, marine water sulfate was available for formation of pyrite, resulting in a high-sulfur coal.

The interval from coal 4 to coal 5, including coal 5, is missing, probably due to scouring and subsequent deposition of Warner sandstone. Unit 6 is a thin interval of sandstone and shale that disconformably overlies the Riverton. The unit is thinly to thickly laminated, contains organic debris and plant stem impressions on bedding planes, and is ripple-marked.

Overlying the interbedded sandstone and shale is channel-fill sandstone of units 7 and 8. Warner sediments grade upward from lower distributary channel settings to upland fluvial settings. The time of Warner deposition was that of a prograding delta and of scouring and channel-fill. Thus, Warner rock units preserved, at any one locality, is dependent on the amount of scouring and replacement by younger Warner sediments.

Unit 9 is similar to Unit 6. It consists of interbedded sandstone and shale and may represent another interdistributary environment. The distributary channels probably changed courses several times allowing interdistributary sediments to be deposited several times in a stratigraphic section. Unit 9 was probably also derived from another distributary channel.

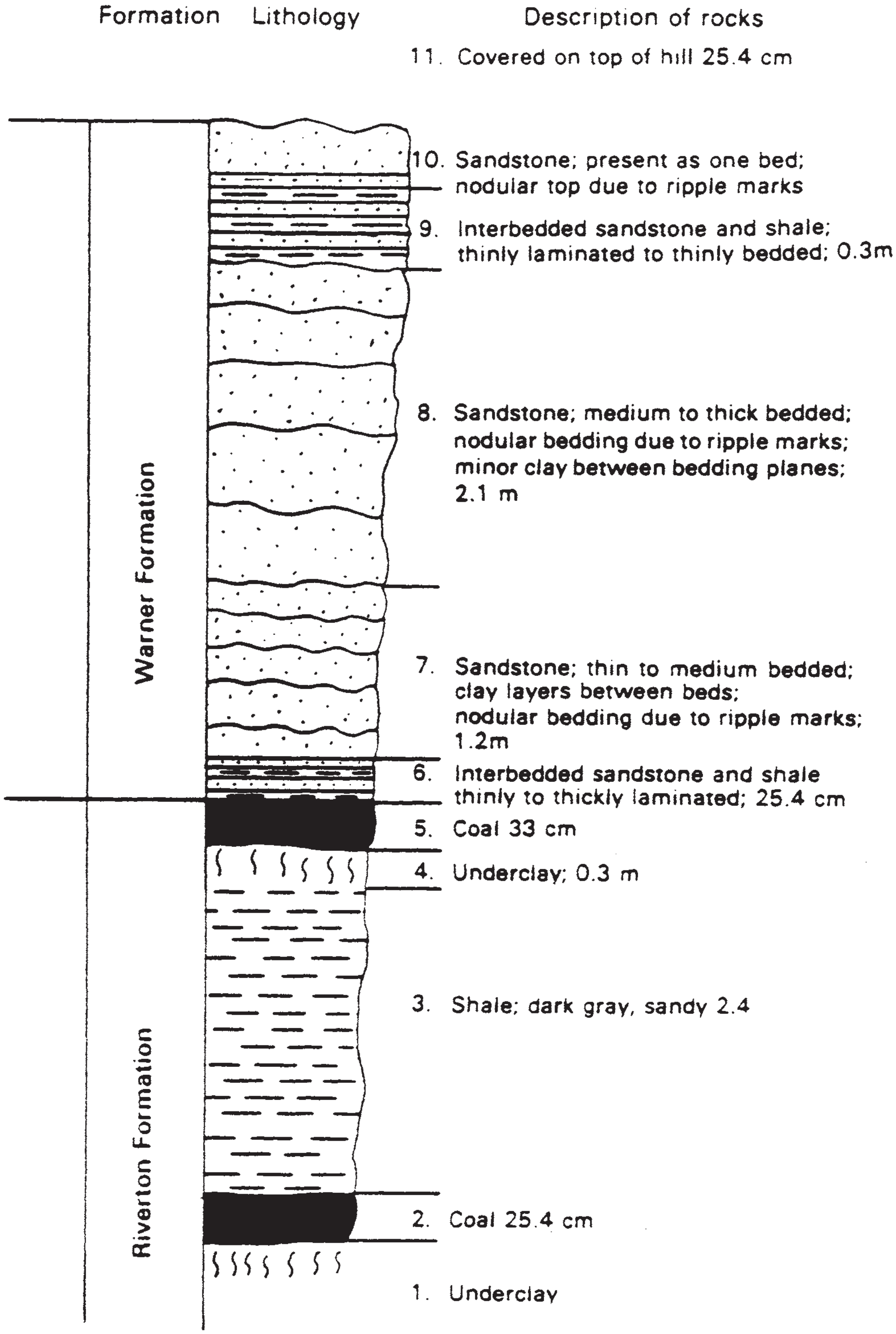


Figure 13. Section exposed at stop 2. Modified from Smith (1975). Unit 2 is the unnamed coal 3 in the Riverton and unit 5 is the unnamed coal 4. At this location, only the interval from the upper part of unit 3 through unit 10 can be observed.

18.0	18.6	0.6	Weir-Pittsburg mined in abandoned strip pits to the west. The nature of the Pennsylvanian strata is shown in the electric log of DOE-TS No. 14.
18.6	20.4	1.8	Railroad overpass.
20.4	20.8	0.4	Junction Hwy 43 and gravel road. TURN RIGHT (EAST) on gravel road.
20.8	24.3	3.5	Abandoned strip pit of Bold Ark Oil Co. STOP 2S.
24.3	27.8	3.5	Return to U.S. Hwy 43. TURN RIGHT (NORTH) on U.S. Hwy 43.
27.8	29.7	1.9	Jct. Hwy 43 and County Road K. TURN LEFT (WEST) on County Road K.
29.7	31.7	2.0	Jct. County Roads NN and K. City of Liberal on left.
31.7	32.2	0.5	Railroad tracks.
32.2	32.6	0.4	Railroad tracks.
32.6	33.1	0.5	Small mound.

Road traverses small mound underlain by Warner sandstone. Much of the flat-lying country is developed on the Riverton Formation, which is less resistant to erosion than the Warner sandstone.

33.1	33.7	0.6	TURN LEFT (SOUTH) on County Road P.
33.7	34.0	0.3	Type locality of the Drywood coal bed on west side of road.
34.0	34.7	0.7	TURN RIGHT (WEST) on County Road P (follow paved road).
34.7	35.4	0.7	Bridge, Nicholson Creek.
35.4	35.7	0.3	TURN LEFT (SOUTH) on gravel road opposite the sign for Prairie State Park.
35.7	36.9	1.2	Entrance to picnic area on right side of road. Park on gravel road. STOP 3S.

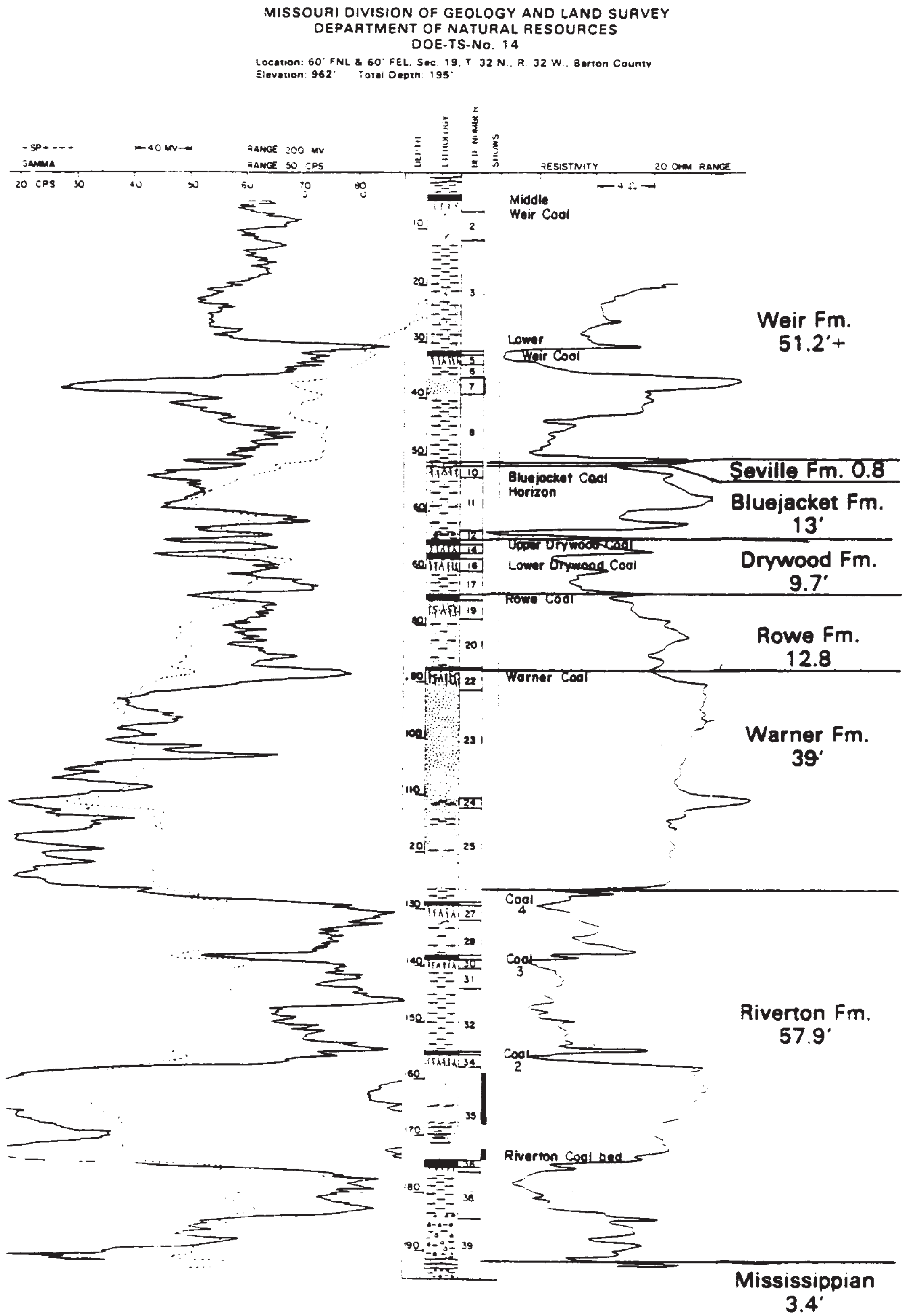


Figure 14. Geophysical log of DOE-TS No. 14 showing the nature of the Pennsylvanian strata in the area. (Modified from Wells, 1979-Correlations by Smith and Nuelle, 1987).

Stop 2S

Bold-Ark Oil Company
SE 1/4, Section 11, T.34 N., R.32 W.
Barton County, Missouri

The Bold-Ark Oil Company quarry near Iantha in central Barton County (SE 1/4, Section 11, T.34 N., R.32 W.) is one of several operations that produced "bituminous sandstone". The quarry operated on a pilot basis through the spring of 1987. Forecasted annual production was estimated at approximately 10,000 tons of "bituminous sand", supplemented by the additional recovery of 5700 barrels of crude oil.

The retort process initially begins by directly heating the crushed "bituminous" sandstone with propane. After continued heating by produced flue gases, the sandstone is passed through a water-cooled condenser, drained, and stockpiled. The cooling water is recycled.

Operated through 1987, the quarry employed nine individuals. The equipment included: one retort plant, one bulldozer, a front-end loader and a dump truck. Approximately 15 acres were disturbed during plant operation.

Production was from the Bluejacket Formation. The formation averages 15 feet thick at the quarry, with approximately 10 to 20 feet of overburden in place. The asphalt produced on site contained 24 gallons of released crude oil/ton of crushed sandstone. Additional oil was added to meet construction specifications for use on county roads and private drives.

Western Missouri "bituminous" sandstone quarries produced for a few years. Due to the unfavorable economics of recovery and the "low-load limit" of the "bituminous" sandstone in asphalt construction specifications, sandstone production has ceased and the quarries have filled with water.

AREAL GEOLOGY

Wells (1977) suggested that recovery of the "bituminous" sandstone is possible in areas where the sandstone lies near the surface. The quarries operated in Pennsylvanian sandstones of the Warner and Bluejacket Formations. These tabular sandstones are interpreted to be part of a prograding upper deltaic plain/lower alluvial valley; with meandering distributary channels building on a high-constructive lobate delta (Wells, 1977; Tomes, 1986). Features apparent in this depositional sequence include: channels, point bars, natural levees, crevasse splays, and longshore bars.

Core drilling in the mid-1970's demonstrated the discontinuous nature of the sandstone bodies. Thicknesses ranged from just a few feet to upwards of 100 feet. The more persistent Bluejacket Formation sandstone is a thin-bedded, fine-grained sandstone, or siltstone. Average thickness is 15 to 20 feet. Where the sandstone is well developed, medium-grained sand with intermediate to massive bedding occurs. Occasional cross-bedding is noted in core samples.

The Warner Formation sandstone includes sandstone, siltstones, and silty shales. The thickness is approximately 30 to 40 feet. The predominately quartz sand is fine to medium-grained, and more rounded than the overlying Bluejacket sandstone. The bedding is commonly more massive than the Bluejacket, and cross-bedded. Siderite, pyrite, iron and clay nodules are prevalent.

Oil or "bitumen" occurrences are present in both the Warner and Bluejacket Formations. While fair shows of oil occur at depth in western Vernon and Barton Counties, development of the "bitumen" zones are exposed or lie near the surface in central and eastern Vernon and Barton Counties. The low gravity of the "bitumen" is credited to meteoric flushing of the reservoir during or immediately after emplacement of the hydrocarbon, hence increasing the amount of microbial action. This bacterial biodegradation is caused by the oxidation of the hydrocarbon. Long chain aliphatic and paraffinic compounds are most susceptible.

No bituminous sandstone quarries are currently operating in western Missouri, and no future operations are planned.

Stop 3S

PRAIRIE STATE PARK

Prairie State Park was originally purchased by the Missouri Nature Conservancy to preserve a portion of the vast original prairie grassland that once covered much of the state of Missouri. The Nature Conservancy purchased 1500 acres in 1979. As funds became available, the property was purchased by the Missouri Department of Natural Resources, Division of Parks, Recreation and Historic Preservation. The park was dedicated in 1980 and today it contains 2558 acres.

Three sections of the park are preserved as Missouri natural areas because of their high-quality features. Two are recognized as the state's best examples of undisturbed tall grass prairie and feature more than 200 species of native wildflowers. The third features a high-quality prairie headwaters stream that forms deep pools as it meanders throughout the prairie. Three hiking trails and an overnight backpack campground have been developed for visitors to appreciate the diverse fauna and flora of the prairie grassland.

Nine American bison were brought to Prairie State Park in 1982. The herd now numbers 28 and continues to grow. This herd is the only one in the state free to roam on its native prairie habitat.

The Visitors' Center was dedicated June 11, 1988 and contains interpretive displays of a prairie stream, prairie wildlife and fauna. The Center has a display on the local history of the area which includes the coal mining industry. Field trip particpants will enjoy the historic photos and miners' tools of Barton County's early coal mining history.

****

Return to Nevada (42 miles): Take gravel road south from the Park to U.S. Hwy 160. Turn left (east) on Hwy. 160 and go approximately 16 miles to U.S. Hwy 71 at Lamar. Go north on Hwy 71 to Nevada (26 miles). Buses will return to Comfort Inn parking lot.

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STRATIGRAPHY OF BASAL PENNSYLVANIAN ROCK UNITS (BURGNER, RIVERTON, AND WARNER FORMATIONS, AND UNASSIGNED ROCK UNITS) IN THE MISSOURI PORTION OF THE JOPLIN 1^{o} x 2^{o} QUADRANGLE

by

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ABSTRACT

A refined geologic column of late Atokan and early Desmoinesian rocks shows the stratigraphic distribution of associated coal beds. Small amounts of Burgner Formation coal were mined from downdropped karst blocks in Mississippian bedrock of the Tri-state zinc district; the coal is restricted to sinkholes and has no economic reserves. North of the district, Mississippian and older bedrock is overlain by a basal Pennsylvanian section, not assigned to a formation, of shale, sandstone, and conglomerate; a thin coal rarely caps the section.

The Riverton Formation overlies the basal section and consists of shale, sandstone, and coal. There are five persistent coals, all of which are seldom exposed at any one place; also, there are two less persistent coals and other coals of local extent. Warner Formation sandstone and shale represent fluvial-deltaic sediments, some of which fill scours in the underlying Riverton Formation. The Warner Formation, capped by a thin coal, is overlain in ascending order by the Rowe, Drywood, and Bluejacket Formations.

An unnamed succession of shale and sandstone is in scoured contact with the Riverton Formation and interfingers with the Warner, Rowe, and Drywood Formations. The succession consists of thinly to thickly laminated shale with isolated sandstone ripples, discontinous sandstone laminae, and thin to medium beds of sandstone; sedimentary structures are indicative of a tidal mudflat.

INTRODUCTION

In recent years, Pennsylvanian rocks in southwest Missouri have been evaluated for heavy oil, tar sand, and coal potential. The units onlap the Ozark dome and extend along the northern rim of the Tri-state zinc district into Kansas and then southward into Oklahoma along the district's western rim. This paper is a summary of Nuelle (1990) and was developed during an evaluation of low-sulfur coal resources in Dade County, Missouri, and coal resource studies of the Joplin 1^{o} x 2^{o} quadrangle (Fig. 1).

COALS OF UNCERTAIN STRATIGRAPHIC POSITION

Burgner Formation

The Burgner Formation occurs as downdropped strata in karsted Mississippian rocks near Webb City (Fig. 2). The formation is of uncertain stratigraphic position because contacts with other Pennsylvanian rocks have not been documented. Burgner Formation shale and coal is overlain by 5 m of limestone that

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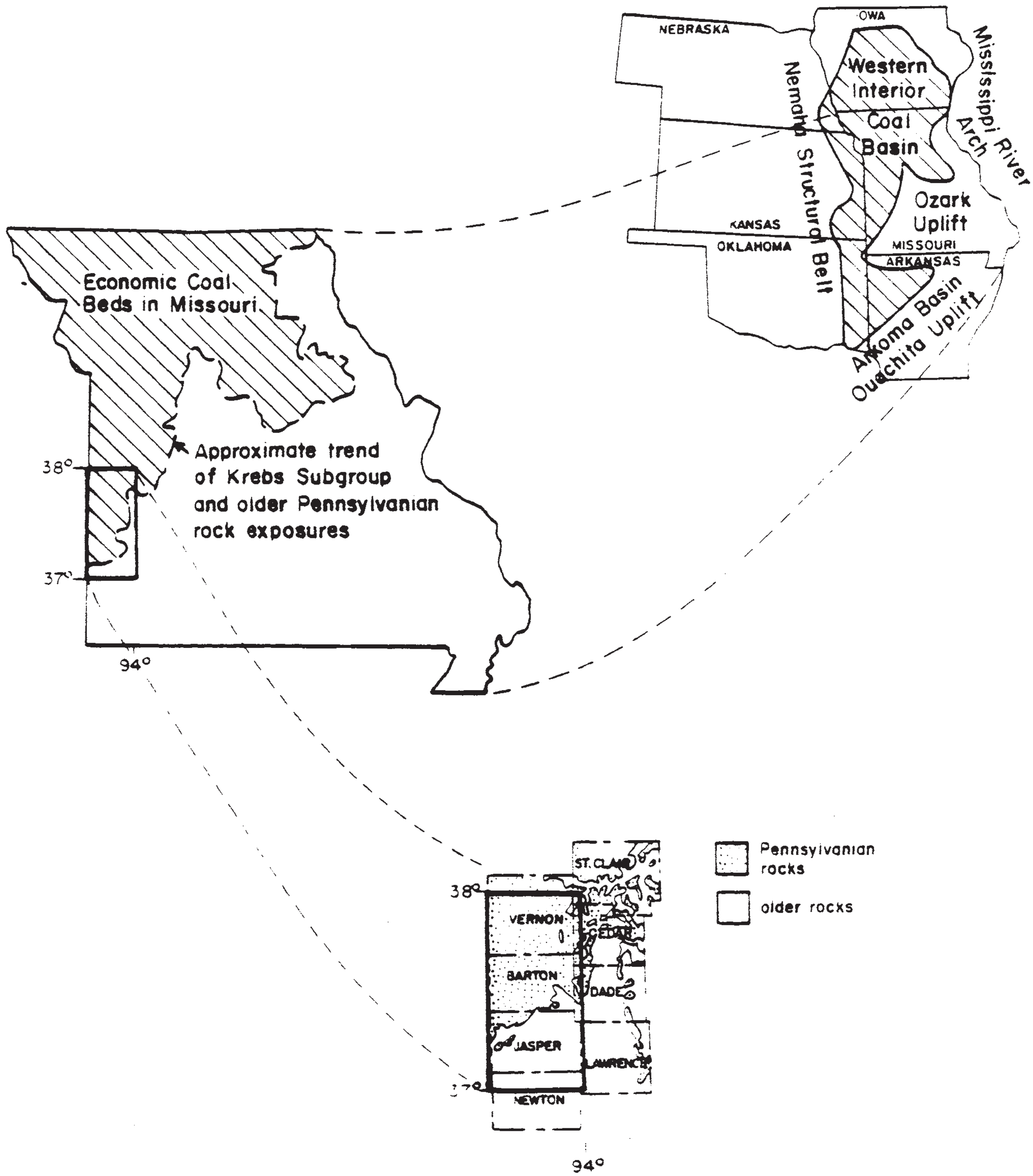

Figure 1. Location of report region showing its setting relative to Missouri coal distribution and to the Western Interior coal basin.

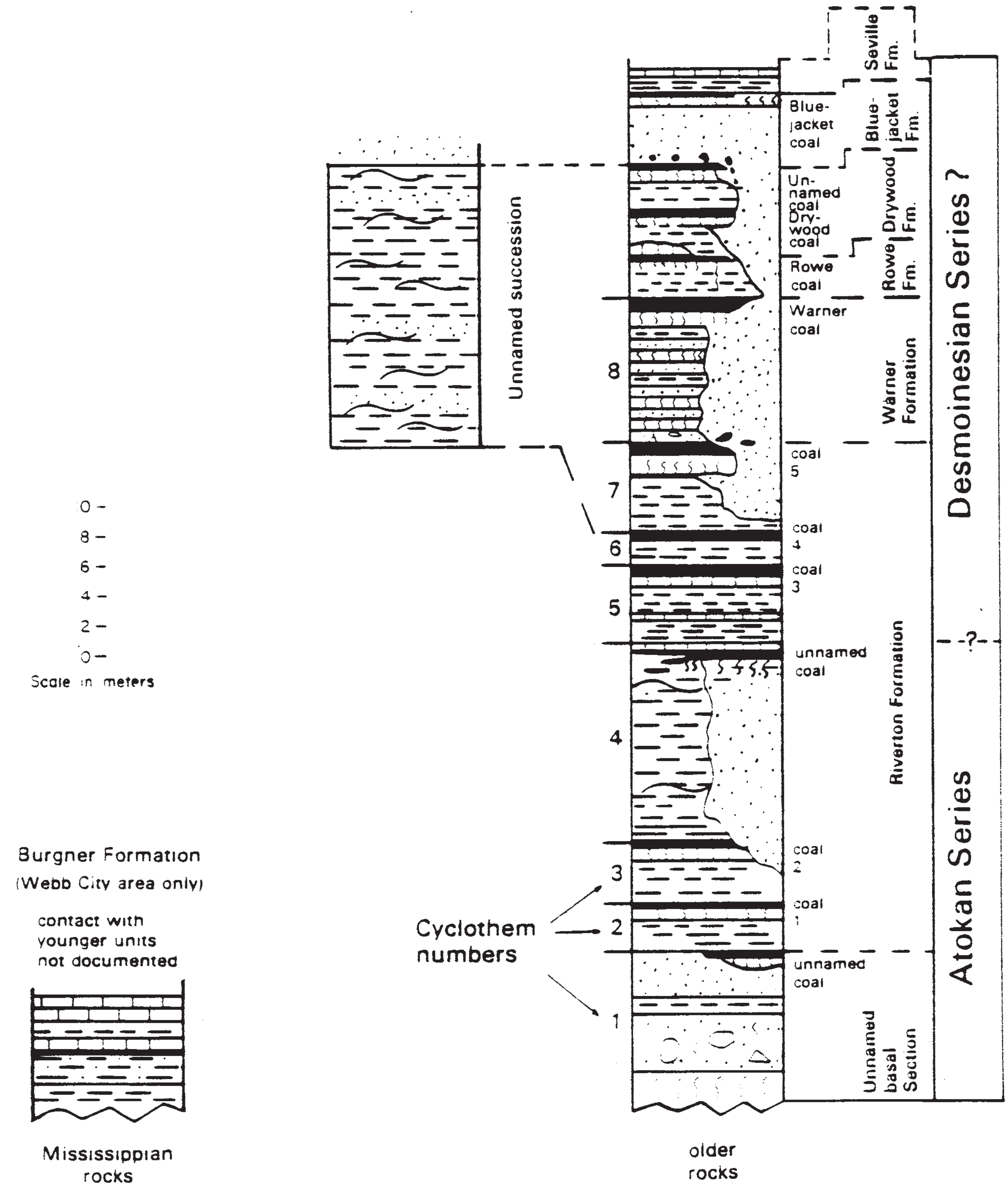

Figure 2. Geologic column of exposed Atokan and lower Desmoinesian rocks, Joplin 1° x 2° quadrangles, Missouri Portion.

has a meter thick shale 3.3 m above its base (Searight and Palmer, 1957). The limestone is Atokan in age as shown by fusulinids (Thompson, 1953), conodonts (T. L. Thompson, personal communication), ammonoids (Unklesbay and Palmer, 1958), and other invertebrates (Searight and Palmer, 1957; and Hoare, 1961). Although Burgner Formation coals reach a combined thickness of 1.5 m and were mined near Webb City, they offer no resource potential because they are limited to sinkholes.

COALS OF KNOWN STRATIGRAPHIC POSITION

General Comment

Correlation of Units. Unit correlations are based on Searight and Howe (1961) as much as possible. More stratigraphic data is now available, and, in many places the section differs from the column of Searight and Howe. Thus, correlations are provisional and formational contacts are shown with dashed lines.
Cyclothems. It is useful to delineate cyclothems to better understand stratigraphic positions of coal beds and to recognize equivalent intervals when one or more coals are absent. Eight cyclothems have been identifed from the base of the Pennsylvanian strata to the top of the Warner Formation (Fig. 2). For an explanation of how the cyclothems were delineated, see Nuelle (1990).
Coal Resource Potential. Coal resources were determined for the U. S. Geological Survey CUSMAP (Conterminous United States Mineral Appraisal Program) evaluation of the Joplin 1^{o} x 2^{o} quadrangle. Resource data will be available in Brady and others (in preparation). Coal resources for the Missouri portion of the quadrangle are also listed in Bostic and others (1990); they differ from the CUSMAP report because coals as thin as 20.3 cm (8 in) were considered.

The Unassigned basal section

Cyclothem 1

The oldest cyclothem is a 0- to 10-m-thick basal Pennsylvanian section of clay, shale, sandstone, and conglomerate (Fig. 2) that rests unconformably on Mississippian, or older, rocks. Many enclosed chert fragments altered to clay and siderite. Coarse, rounded, frosted quartz grains aid in the distinction of these beds from younger units. Basal section rocks are absent at many places, poorly developed at others, and well developed at some. A thin uneconomic coal, up to 15 cm thick, rarely caps the unit. The section is not assigned to a formation; it is not included in the Riverton Formation type-section description and it underlies Riverton Formation shales. The basal section, although poorly understood, clearly records part of a transgressive-regressive cycle.

Riverton Formation

General Comment. The Riverton Formation varies from 3 m thick, where it has been eroded and replaced by younger sediments, to 30 m thick; its average thickness is about 17 m. The lower part is mostly dark-gray thickly laminated shale with lenticular bedded sandstone and discontinous sandstone laminae; it also contains two widespread coals. The upper part is mostly gray shale and clay; it contains three widespread coals. Other Riverton Formation coals are not as extensive as the five major coals.

The five extensive coals are numerically designated 1 through 5, in order of decreasing stratigraphic age. The formation's upper contact is placed at the top of coal 5. If coal 5 is absent, the contact is placed at an abrupt lithologic change. The Riverton Formation grades into the Warner Formation where there is no unconformity.

Cyclothem 2

Dark-gray to black fissile shale forms the basal unit of cyclothem 2 and is the base of the Riverton Formation as used in this report. The shale grades upward into lighter gray shale and then into underclay capped by coal 1 (Fig. 2). Coal 1 is irregular in distribution, thin, and high in sulfur content; the coal offers little economic potential. Cyclothem 2 is generally less than a meter thick.

Cyclothem 3

Cyclothem 3 extends from a black to dark-gray shale above coal 1 to the top of coal 2 (Fig. 2); it is seldom over 3 m thick. The dark shale grades upward into lighter-colored shale and then into an underclay capped by coal 2. In places, only the basal dark shale is present. Cyclothem 3 has no unique rock units and is best identified when coal 2 or its underclay is present. Coal 2 is mostly less than 20 cm thick. In places, the interval between coals 1 and 2 is less than 2.5 cm.

Cyclothem 4

Cyclothem 4 extends from a black to dark-gray shale above coal 2 to a black and gray shale interval sandwiched between two fossiliferous limestone beds that are about 18 m above the base of the Riverton Formation (Fig. 2). Cyclothem 4 contains most of the shale below the Warner Formation and includes most of the "typical" Riverton Formation shales of past workers. The cyclothem is rarely capped by a thin coal.

Quartz wacke to quartz arenite sandstone, containing shale- and wood-pebble conglomerates, is present in the lower part of the cyclothem. The sandstone is up to 12 m thick, but averages 3 to 4.5 m thick (Wells. 1979); in places, coal 2 has been scoured and replaced by the sandstone. This sandstone is in the Lower Warner unit of Wells (1979) and Ebanks (1979).

Much of cyclothem 4 is thickly laminated, dark-gray shale with lenticular bedded sandstone and discontinous sandstone laminae; the unit is up to 12 m thick and is the most notable rock type in the Riverton Formation. Horizontal burrows with circular cross-sections are common; less common are vertical burrows with oval cross-sections. Bedding planes are covered by varying amounts of muscovite and fragmented plant debris. Nodular siderite layers are common; they are medium- to dark-gray, 1 to 15 cm thick, and are generally sandy, hard, and have subconchoidal fracture. Some siderite layers contain pellets, ostracods, brachiopods, wood debris, and shark teeth.

Two thin, fossiliferous limestone units overlie the shale with lenticularly bedded sandstone. They thin northward and pinch out in the southern part of the region where excessive terrigenous sedimentation inhibited limestone development. The lower limestone unit is the top of cyclothem 4 and the upper unit is in the lower part of cyclothem 5; each unit is up to 0.3 m thick and has one to three beds with sharp, scoured contacts. The limestone varies from wackestone to packstone and contains shells and quartz sand grains in a lime mudstone matrix. The limestone becomes ferruginous and red with increasing sand content toward the pinchout line; north of the pinchout, siderite layers occur in intervals equivalent to the limestone units.

Cyclothem 5

Cyclothem 5 extends from the base of a black fissile shale above the lower limestone unit to the top of coal 3; it is about 5 m thick and is mostly shale and clay. The cyclothem basal shale grades upward into lighter-colored shale which in turn grades into underclay capped by coal 3; minor siltstone and sandstones is present.

One noteworthy rock type is the upper limestone unit mentioned previously. Another is that of a black fissile shale that grades upward into a calcareous dark-gray shale. The shales separate the two limestone units and each is less than a half meter thick. Both shales contain inarticualte brachiopods. The lower part of the gray shale contains juvenile ammonoids and the upper part contains articulate brachiopods and echinoderm ossicles.

Much of Cyclothem 5 consists of a medium- to dark-gray clayshale and light-gray claystone that overlie the upper limestone unit. The clayshale reaches a thickness of 3 m and grades upward into claystone that forms the underclay of coal 3. The unit contains up to 30 volume percent pellets, many of which converted to siderite or gypsum upon diagenesis.

Cyclothem 6

Cyclothem 6 extends from a black to dark-gray shale above coal 3 to the top of coal 4 (Fig. 2); its thickness varies from a couple of centimeters to over 5 m. Where thin, the interval is mostly black fissile shale with Calamites stem impressions. Where thicker, the interval commonly contains siltstone and claystone with abundant cone-bearing conifer leaves and tree trunk impressions.

Cyclothem 7

Cyclothem 7 extends from the base of a dark-gray shale above coal 4 to the top of coal 5. Generally, most of the interval above coal 4 (and also above coal 3) is missing with scour-fill units replacing the interval. There is no unique rock type in this cyclothem except that of a 1.2 m thick limestone that was reported from an oil test well near Lamar; as this is the only record of the limestone, not much is known about its distribution.

In most of the region, coal 5 is thin and high in sulfur content. At Sylvania, in northwestern Dade County, the coal has been extensively mined and is a meter thick and low to medium in sulfur content.

Warner Formation

Cyclothem 8

The eighth cyclothem extends from a shale above coal 5 to the top of the Warner coal. It is the most incomplete record of a transgressive-regressive cycle because much of the interval above coal 4 was scoured and replaced by sediments of the prograding Warner Formation delta. A black carbonaceous shale above coal 5 is preserved only in a few localities.

The Warner Formation is 3 to 15 m thick. The lower part is interbedded very fine-grained sandstone and claystone; the upper part is largely medium to massive bedded channel-fill sandstone. In many places, the Warner Formation is largely shale and claystone with minor sandstone. Where a coal occurs, the upper contact is placed at the top of the coal (Searight and Howe, 1961). Where the Warner Formation grades into the Riverton Formation or Rowe Formation, correlations of contacts are difficult to impossible.

Much of the Warner Formation is interbedded sandstone, shale, and clay that forms a sequence up to 10 m thick. The sequence consists of couplets of upward fining sandstone beds capped by shale or clay; these probably represent splay sand deposition that culminated with mud deposition. The beds are wavy, thinly laminated to thinly bedded. Sedimentary features include groove marks, load casts, stem impressions, climbing ripples, and microscale cross-beds. Blanket sandstone beds also occur in this sequence and in other parts of the formation.

Perhaps the rock type most associated with the Warner Formation is that of massive cross-bedded sandstone that forms impressive bluffs at various localities. This type of sandstone occurs in channels scoured in older Warner Formation and Riverton Formation units. Shale- and wood-pebble conglomerates are present in many of the channel-fill sandstones; the conglomerates grade upward into very fine-grained sandstones which grade, in turn, to coarse-grained, laminar to large-scale cross-bedded sandstone. Clay occurs interstitally or as seams between sandstone beds. Overall, the sequence coarsens upward due to a decrease of interstitial clay and an increase of grain size. The upward coarsening of grain size resulted from the Warner Formation fluvial system becoming more typical of a middle to upper delta plain setting in which meandering rivers cut deeply into underlying sediments, filling channels with gravel and sand; features include gravel bars, channel abandonment clay (sometimes capped by coal smut), and clay levees. The massive sandstones above coal 5 are the Upper Warner unit of Wells (1979) and Ebanks (1979).

An unusual rock type of the Warner Formation is that of a varved to structureless, variegated to dark gray claystone which has only been observed in northwestern Dade County; it reaches a thickness of 6 m. In places, the clay is carbonaceous; in other places, it is sandy and sometimes interbedded with siltstone. It varies from semi-plastic to hackly. The claystone is provisionally assigned to the Warner Formation and it may represent a lower delta plain lake bed.

Unnamed Succession

East of Lamar, a drill hole intersected an 18 m thick unnamed succession of interbedded clay shale and sandstone (Fig. 2). The succession's lateral and vertical distribution are poorly understood. In places, the succession is distinctly bounded by the Riverton and Warner Formations. In places, it occupies various parts of the upper Riverton Formation to the lower Bluejacket Formation interval; in one drill hole, the succession occupies the entire interval.

The unnamed succession consists of varying ratios of dark-gray to light-gray sandstone and shale. When shale is dominant, sandstone occurs as isolated ripples, convoluted ripples, and thin laminae; when sandstone is dominant, shale occurs as isolated flasers and thin laminae. Flame stuctures, dewatering features, burrows, and sparse fossil shells are present. A gray siltstone parting near the top of the unit contains superbly preserved fern fronds and leaves. The sequence has lithologic features similar to the North Sea tidal mud flats.

A problem with the cyclothem grouping of units arises here. Using Heckel's (1985) time constraints of the duration of transgressive-regressive cycles, two million years could be involved in the deposition of units above the Riverton Formation and below the Bluejacket Formation; this amount of time is unreasonably long for a tidal flat to endure. A possible explanation may be that the unit may represent more than one tidal flat.

Atypical Stratigraphic Sections

In the report area, many stratigraphic sections deviate from the sequences described above. Variations are due to paleogeographic setting and depositional hiatuses. The realization that atypical sections exist should be remembered during investigations so that excessive effort is not exerted in picking formational contacts in places where it may not be possible to do so.

Summary

Rocks below the Warner Formation are poorly exposed and their associated coal beds offer only limited economic coal potential. Coals associated with the Burgner Formation occur as downdropped karst blocks in Mississippian bedrock in the Tri-State zinc district. They were mined in the past, but because they are restricted to sinkholes, they have no potential for today's coal industry. Burgner strata have never been observed in contact with other Pennsylvanian rocks, thus their stratigraphic position is not clear.

Pennsylvnaian rocks are better preserved north of the zinc district where eight cyclothems have been delineated from the base of an unassigned basal Pennsylvanian section below Riverton Formation shales to the top of the Warner Formation. They vary from ideal cyclothems because the region was in a near shore setting during much of the time; erosion during depositional hiatuses was accompanied by scouring and replacement of sediments by channel-fill material.

The unassigned basal Pennsylvanian section of sandstones, conglomerates, and shales, is rarely capped by a thin coal with no resource potential. Five persistent coals are provisionally assigned to the Riverton Formation, and a coal occurs at the top of the Warner Formation. Although Riverton Formation coals have been mined in recent years, they offer only limited resource potential because they are typically thin and high in sulfur content.

During much of Riverton Formation deposition, the region was in a near shore setting oscillating from a marginal marine to a lower delta plain environment during which mostly dark-gray shales were deposited. Deposition of the prograding Warner Formation delta dominated the eighth transgressive-regressive cycle and sedimentation changed from mostly mud to sand.

Warner Formation rock units show a change form lower delta plain sedimentation to middle and upper delta plain sedimentation. Upper delta plain channel-fill sandstones are generally considered typical Warner Formation sandstone by most Pennsylvanian workers, but the Warner Formation also contains much less massive sandstones and a significant amount of clay and shale not generally associated with the Warner Formation.

An unnamed succession of shale and sandstone derived from a tidal mud flat setting occupies the interval from the upper part of the Riverton Formation to the lower part of the Bluejacket Formation. It laterally interfingers with the Warner, Rowe, and Drywood Formations.

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