COAL GEOLOGY OF THE CHELSEA QUADRANGLE IN PARTS OF CRAIG, MAYES, NOWATA, AND ROGERS COUNTIES, OKLAHOMA

By

WALTER ROBIN KEASLER

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Thesis Approved:

Gary F. Stewart
Thesis Adviser

Samuel A. Friedman

John D. Naff

R. N. Donovan

Norman N Durham
Dean of the Graduate College

PREFACE

This thesis is a study of the coal geology in parts of Craig, Mayes, Nowata, and Rogers Counties, Oklahoma. Geologic, structural contour, isopach, and overburden maps were prepared to aid in the description of the geology of the area and in estimation of coal resources.

Prof. Samuel A. Friedman suggested the problem and made suggestions, comments, and criticisms throughout the course of the study. Dr. John D. Naff served on the thesis committee, and provided assistance with the paleontological aspects of the study. I would also like to thank Dr. Naff for being instrumental in developing my interest in the field of Geology.

I especially thank my major advisor, Dr. Gary F. Stewart, for the time spent, and the interest and concern he showed during the course of the study, and during my academic career at Oklahoma State University. I also thank Dr. R. Nowell Donovan for the great amount of general assistance, and moral support he provided.

The Oklahoma Geological Survey provided partial funding for field expenses, and much of the data used in this report. Data was also supplied by the Carbonex, Fuel Dynamics, and Peabody Coal companies. I thank Bob Collins and Joe Podpechan of Carbonex Coal Co., and Rod Monroe and Ted Parsons of Fuel Dynamics for the assistance they personally provided. Thanks are given to Charles E. Williams of Arkoma Coal Corp., who provided an overall insight into the coal industry.

I thank my parents, Bob and Marguerite Keasler, for their understanding and financial support during my academic career. Finally, I would like to thank Ellen for her cooperation and understanding during the past two years.

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ABSTRACT

Rocks that are found in outcrop in the study area include stratigraphic units of the Boggy Formation of the Krebs Group, the Senora Formation of the Cabaniss Group, and the Fort Scott Limestone of the Marmaton Group. These units are part of the Desmoinesian Series, Pennsylvanian System.

Six coals crop out or were penetrated in the subsurface. However, only four coals, the Weir-Pittsburg, Mineral, Croweburg and Iron Post coals of the Senora Formation are of economic importance.

Remaining coal resources in the study area are 9,383,000 short tons of Weir-Pittsburg coal, 9,190,000 short tons of Mineral coal, 16,935,000 short tons of Croweburg coal, and 7,223,000 short tons of Iron Post coal. Of these 7,506,000 short tons of Weir-Pittsburg coal, 7,352,000 short tons of Mineral coal, 13,548,000 short tons of Croweburg coal, and 5,778,000 short tons of Iron Post coal are recoverable.

The Weir-Pittsburg, Mineral, and Iron Post coals in the study area are high sulfur; the Croweburg coal in the study area is low sulfur. These coals are ranked as high volatile A and C bituminous coal. The Weir-Pittsburg, Mineral and Iron Post coals are best suited for electric-power generation and industrial uses. The Iron Post is being sold for use in coking in Texas. The Croweburg coal is best suited for use in coking.

INTRODUCTION

Location

The area under study in this report is approximately 63 sq. mi. located in northeasternmost Rogers County, northwestern Mayes County, southeastern Nowata County, and southwestern Craig County (Fig. 1).

Geologic Setting

The rock units under investigation make up the Cabaniss Group, part of the underlying Krebs Group, and part of the overlying Marmaton Group, all strata of the Desmoinesian Series, Pennsylvanian System. In ascending order the major named rock units are the Boggy Formation, the Senora Formation and the Fort Scott Limestone. Of the Boggy Formation only the siltstones and shales overlying the Taft Sandstone Member crop out in the study area. Rock units within these formations are shown in Figure 2. Of the Fort Scott Limestone, only the Blackjack Creek Limestone Member crops out in the study area. These strata include the commercially valuable Weir-Pittsburg, Mineral, Croweburg and Iron Post coal beds (Fig. 2).

A generalized stratigraphic column representative of the study area and of northeastern Oklahoma is shown in Figure 2; a generalized geologic map of the area is included as Plate 1. Geologic names of outcropping rock units and of the commonly used subsurface equivalents are listed in Table 1.

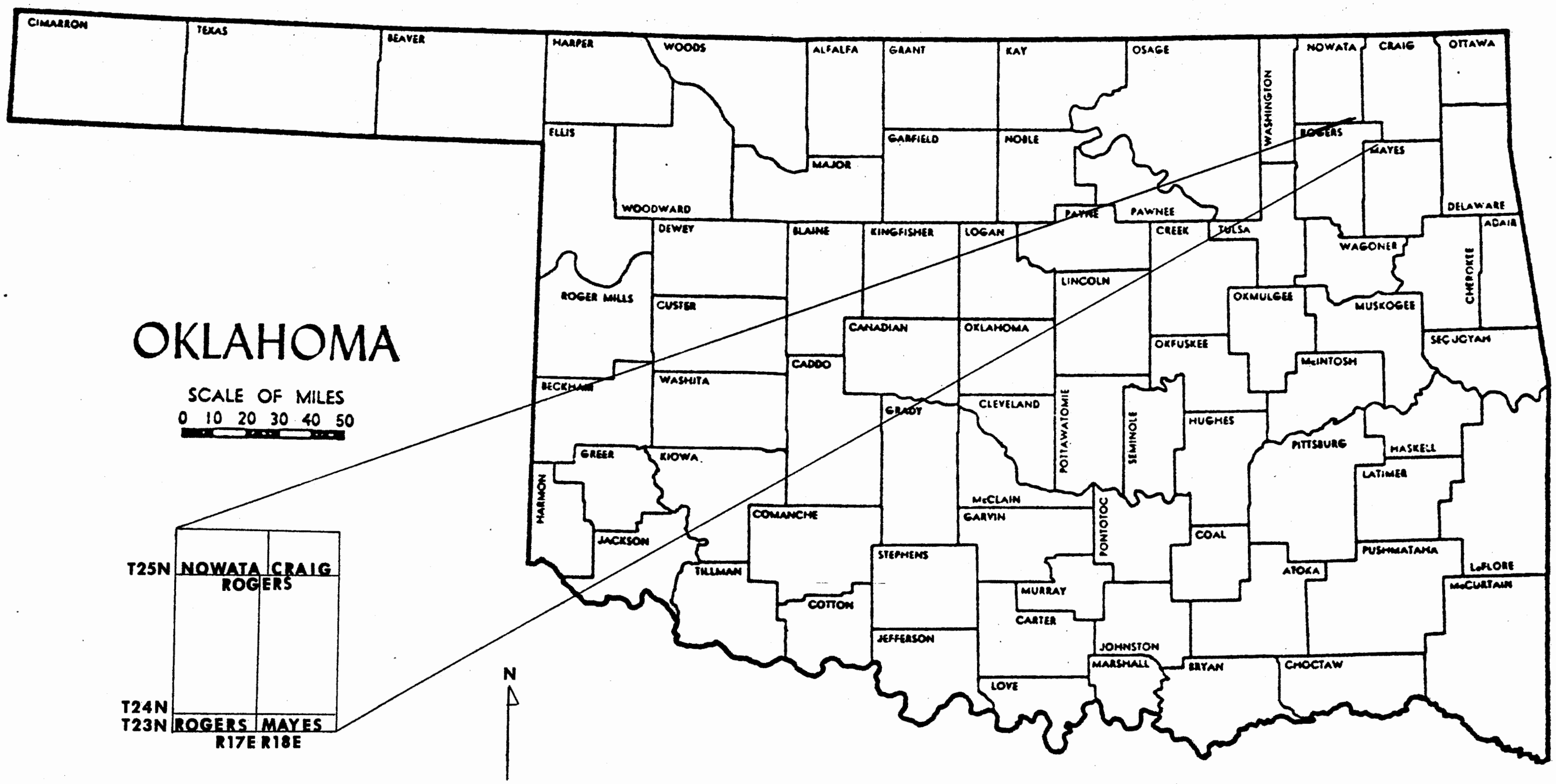

Fig. 1.--Location of the study area

System	Series	Group	Formation	Member	Bed
PENNSYLVANIAN	DESMOINESIAN	MARMATON	Fort Scott Limestone	Blackjack Creek Limestone	
		CABANISS	Senora	Excello Shale Breezy Hill Limestone Lagonda Zone Verdigris Limestone Fleming cap rock Russell Creek Limestone Chelsea Sandstone Tiawah Limestone	Iron Post coal Croweburg coal Mineral coal Tebo coal Weir-Pittsburg coal
			Boggy	Taft Sandstone Inola Limestone Bluejacket Sandstone	Bluejacket coal
		KREBS	Savanna	Dickson Sandstone Doneley Limestone Sam Creek Limestone Spaniard Limestone	Drywood coal Rowe coal
			McAlester	Warner Sandstone	
			Hartshorne		Riverton coal

Fig. 2.--General columnar section of Desmoinesian rocks, northeastern Oklahoma (Partly from Branson, and others, 1965, Pl. 2)

Objectives

The principal objective of this study is to map the coal beds and associated rock units, to determine the distribution, reserves, and suitabilities of the coals for commercial use.

Table 1.--Surface and correlative subsurface names of stratigraphic units in the study area. Modified from Jordan (1957).

Surface name	Subsurface name
Blackjack Creek Limestone Member	Oswego lime
Lagonda Zone Member	Prue sand
Verdigris Limestone Member	Verdigris Limestone
Croweburg coal	Henryetta coal
Chelsea Sandstone Member	Skinner sand
Tiawah Limestone Member	Pink lime
Taft Sandstone Member	Red Fork sand

Procedure

Data for this study were obtained from 363 drillers' logs of coal-test borings (in the confidential file now at the Oklahoma Geological Survey), drillers' logs of oil and gas wells (Oklahoma Corporation Commission Logs), aerial photographs, field mapping and descriptions of outcrops. Analyses of coal were provided by the Oklahoma Geological Survey. Location of data points are shown in Plate 2.

Previous Investigations

Some of the first geological work in the vicinity of the study area was by Ohern (1910), Bloesch (1938), Ireland (1928), and Woodruff and Cooper (1928). Lowman (1932, 1933) discussed the stratigraphy and regional structural history of the "Cherokee" beds in Oklahoma. Oakes (1953) separated the Cherokee into the Krebs and Cabaniss Groups, and described their lithologies and boundaries. At an interstate conference in Nevada, Missouri, 1953, representatives of the geological surveys of Kansas, Missouri, Nebraska, and Oklahoma voted to replace the term "Cherokee" by the Krebs and Cabaniss Groups.

Studies of the Pennsylvanian of northeastern Oklahoma and adjoining states were made by Branson (1954, 1956, 1963, 1964), Frezon and Dixon (1975), Howe (1951, 1956), Pierce and Courtier (1937), and Ware (1955). Huffman (1958) discussed the geology of the flanks of the Ozark uplift.

Theses that dealt with geology in the vicinity of the study area include the work of Lohman (1952), Gruman (1954), and Strong (1961). Austin (1946) mapped and described the Chelsea Sandstone and associated strata. Valderrama (1974) investigated the areal distributions, depositional environments, and source areas of the sediments included in the Skinner stratigraphic interval. Cassidy (1962) described the stratigraphy, petrology, and some aspects of the geochemistry of the Excello Shale Member.

Studies of coal and palynology include papers by Oakes (1944), Bond (1963), Gibson (1961), Ruffin (1961), Wilson and Hoffmeister (1956), and Urban (1962). Wilson (1968a, 1968b, 1976) made inferences about the paleoecology of coal swamps in northeastern Oklahoma based on palynological data collected in papers listed above. Coal and coal reserves of Oklahoma were summarized by Trumbull (1957), and Friedman (1972a, 1972b, 1974, 1976).

STRUCTURAL FRAMEWORK

Regional Structural Geology

The study area is near the western boundary of the Ozark Uplift, adjacent to the Northern Oklahoma Platform (Arbenz, 1956; see also Fig. 3, this report). Strata dip westward and northwestward from the Ozark Uplift at about 50 to 60 ft. per mile (Pl. 3). Faults generally trend northeastward; they are believed to have resulted from tensional forces caused by loading of the Arkoma Basin to the south, and uplift of the Ozark Dome to the east and northeast (Huffman, 1958, p. 89). Reeder (1974, p. 179) believed that most of the faults "were established in Precambrian time and movement continued along them in varying degrees until late in the Paleozoic." Rock units thin northward from the Arkoma Basin across the Northern Oklahoma Platform (Oakes, 1953, p. 1525).

Structural Geology of the Study Area

Structural contour maps of the top of the Mississippian unconformity (Pl. 3), and of the Weir-Pittsburg, Croweburg (Pl. 4), and Iron Post (Pl. 5) coal beds show the local structural geology.

Structure of the study area is difficult to detect by inspection of rocks at the surface. Folds are gentle and observable dips that deviate from the normal dip of 1° to 2° NW may be due to slumping. Also, much of the area is covered by colluvium and alluvium that may be as thick as 30 ft. at some places. Folds and faults may be concealed by

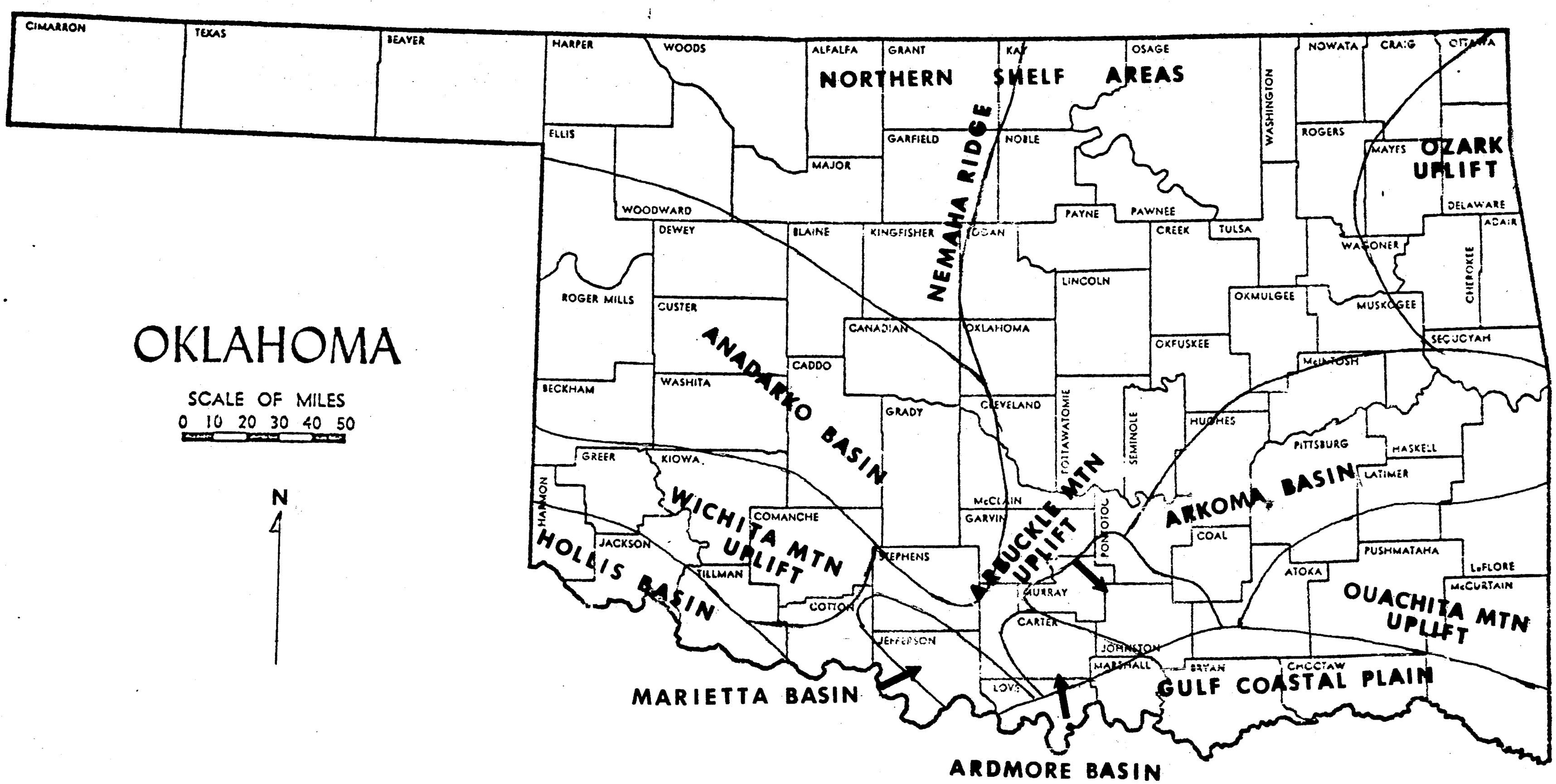

Fig. 3.--Major geologic provinces of Oklahoma (modified from Johnson and Dension, 1973)

these undifferentiated Quaternary deposits.

Lohman (1952) first mapped the area in detail, (1:20,000); he postulated two faults in the study area. Uncommonly straight segments of streams, bedrock elevations, and missing sections of rock were the evidence from which these faults were inferred. However, some of the data compiled in this report tend to reject or alter Lohman's interpretations.

For example, Lohman (1952; Pl. 1) mapped the Booker School fault as extending from Sec. 6, T. 24 N., R. 18 E. northeastward across T. 25 N., R. 18 E. for about 4 miles. "Between Pryor Creek and the outlier capped by Breezy Hill limestone west of Booker School in T. 25 N., R. 18 E., about 65 ft. of section appears to be missing between the base of the Chelsea and the Verdigris limestone" (Lohman, 1952, p. 54). Interpretation of the information from 13 drillers' logs of oil and gas wells in the area does not support this hypothesis. Furthermore, there is no discernible topographic lineament as could be expected. Typically, the Breezy Hill Limestone Member lies about 210 ft. above the base of the Chelsea Sandstone Member in the area. On the outlier mentioned by Lohman, in Sec. 28, T. 25 N., R. 18 E., the Breezy Hill lies at about 900 ft. in elevation, as estimated from the U.S. Geological Survey 7.5' topographic map of the area. Using this same map for elevation estimation, the nearest outcrop of the base of the Chelsea sandstone, almost a mile to the southeast in the same section, is at about 750 ft. If one adds the normal 50-60 ft. of dip to the northwest (see Pl. 3), the base of the Chelsea sandstone should lie at the predicted 210 ft. beneath the Breezy Hill limestone. The present writer therefore has concluded that the Booker School Fault probably does not exist in the study area, and thus it is not shown on the maps of this report.

The Catale Fault was mapped by Lohman (1952; Pl. 1) as extending from Sec. 16, T. 24 N., R. 18 E. southeastward for 3-1/2 miles, with the downthrown side to the southwest (Lohman, 1952, p. 53-54). Logs of recent coal-test borings and logs of oil and gas wells in Sec. 16, T. 24 N., R. 18 E. tend to confirm this fault, but require placement of the downthrown side to the northeast (see Pl. 1, Pl. 3, and Pl. 4). Throw, estimated from displacement of the top of the Mississippian and the top of the Weir-Pittsburg coal bed, is about 40 ft.

Lohman (1952) also mapped the Little Pryor Creek fault, as extending northeastward from Sec. 23, T. 24 N., R. 18 E. at least to Sec. 6, T. 24 N., R. 19 E. "Southwestward the fault apparently terminates against the Catale fault" (Lohman, 1952, p. 53) in Sec. 23, T. 24 N., R. 18 E. He also postulated that this fault may extend farther to the southwest. Although there is little data to demonstrate this extension, a definite lineament trends southwestward from this postulated termination in Sec. 23 to Sec. 33, T. 24 N., R. 18 E.; it follows exactly the trend of the Little Pryor Creek fault. On this basis, the Little Pryor Creek fault is inferred to extend into the study area, as shown on Plate 1.

The Bowlin Spring fault has been mapped (see Pl. 1 and Pl. 3) as extending southwestward from just south of the hamlet of Bowlin Spring, Sec. 28, T. 25 N., R. 18 E., to about Sec. 35, T. 24 N., R. 17 E., where no evidence for its continuation has been found. Northeastward, it continues out of the study area for an unknown distance. Evidence for placement of the fault includes a spring (probably the Bowlin Spring), a definite topographic lineament extending from the SW corner of Sec. 8,

T. 24 N., R. 18 E. to the SW corner of Sec. 27, T. 25 N., R. 18 E., and evidence from drillers' logs of oil and gas wells drilled in Sec. 24, T. 24 N., R. 17 E. on the site of the present Chelsea Cemetery (see Appendix A, logs 1 and 2). Based on data taken from these two drillers' logs, the upthrown side is placed to the northwest with an estimated throw of 40 ft.

Plate 3 shows gentle northwestward dip at the level of the Mississippian-Pennsylvanian unconformity interrupted by a few faults and several gentle folds. A small anticline was mapped (Pl. 3) in Secs. 1, 2, 11, 12, T. 24 N., R. 17 E. The axis of the fold trends northeastward, and the amount of closure is estimated at about 30 ft.

Another inferred anticline is located in Secs. 10, 11, 14, 15, T. 24 N., R. 17 E. This fold trends northwestward, and the amount of closure is almost 80 ft.

STRATIGRAPHY

Rock units that crop out in or near the study area, and Pennsylvanian rocks older than the Senora Formation which were penetrated by wells drilled for oil and gas in the area are shown in Figure 4.

For the purpose of mapping in this study area, the base of the Senora Formation (which is the base of the Cabaniss Group) is defined as the base of the underclay directly beneath the Weir-Pittsburg coal bed. The top of both the Senora Formation and Cabaniss Group is defined as the base of the Blackjack Creek Limestone Member of the Fort Scott Limestone, Marmaton Group (Fig. 4), (Branson and others, 1965, p. 42).

Five extensive coal beds have been recorded in outcrops or in coal-test borings in the study area; they are listed in Table 2. The Weir-Pittsburg, Mineral, Croweburg, and Iron Post coals have been mined, or are being mined in the study area. These coals range in thickness from 0 to 28 in., according to drillers' logs of coal-test borings. The stratigraphic sequence of these coals are associated strata is shown in Figure 4, and is discussed in the following paragraphs.

The Weir-Pittsburg coal is approximately 50 ft. beneath the Tebo coal in Sec. 9, T. 24 N., R. 18 E. where the Weir-Pittsburg coal is being mined. Position of the Tebo coal can be approximated closely by reference to the discontinuous and poorly exposed Tiawah Limestone Member; position of the Tebo can be approximated roughly by reference to the Chelsea Sandstone Member. In several outcrops in the study area, the Chelsea can be observed in paleochannels cut to within a few feet of the position of the Tebo. Accordingly, estimates of the position of the Tebo and Weir-Pittsburg coal beds by projection from the base of the Chelsea would be highly conjectural, because the Chelsea can be shown to thicken and thin a great deal.

Table 2.--Coals present in the study area (see also Fig. 4).

Iron Post coal	(O)	(S)	($)
Unnamed coal	(O)		
Croweburg coal	(O)	(S)	($)
Mineral coal		(S)	($)
Tebo coal	(O)	(S)	
Weir-Pittsburg coal		(S)	($)

(O) Observed in outcrop.

(S) In subsurface.

($) Economically important in the study area.

The Weir-Pittsburg coal was correlated by Lohman (1952, p. 30) with the informally named "Paw-Paw coal". However, the term Paw-Paw also has been used for the Mineral coal in the study area at the Peabody Rogers County No. 1 mine. The section from the Weir-Pittsburg to the Tebo coal

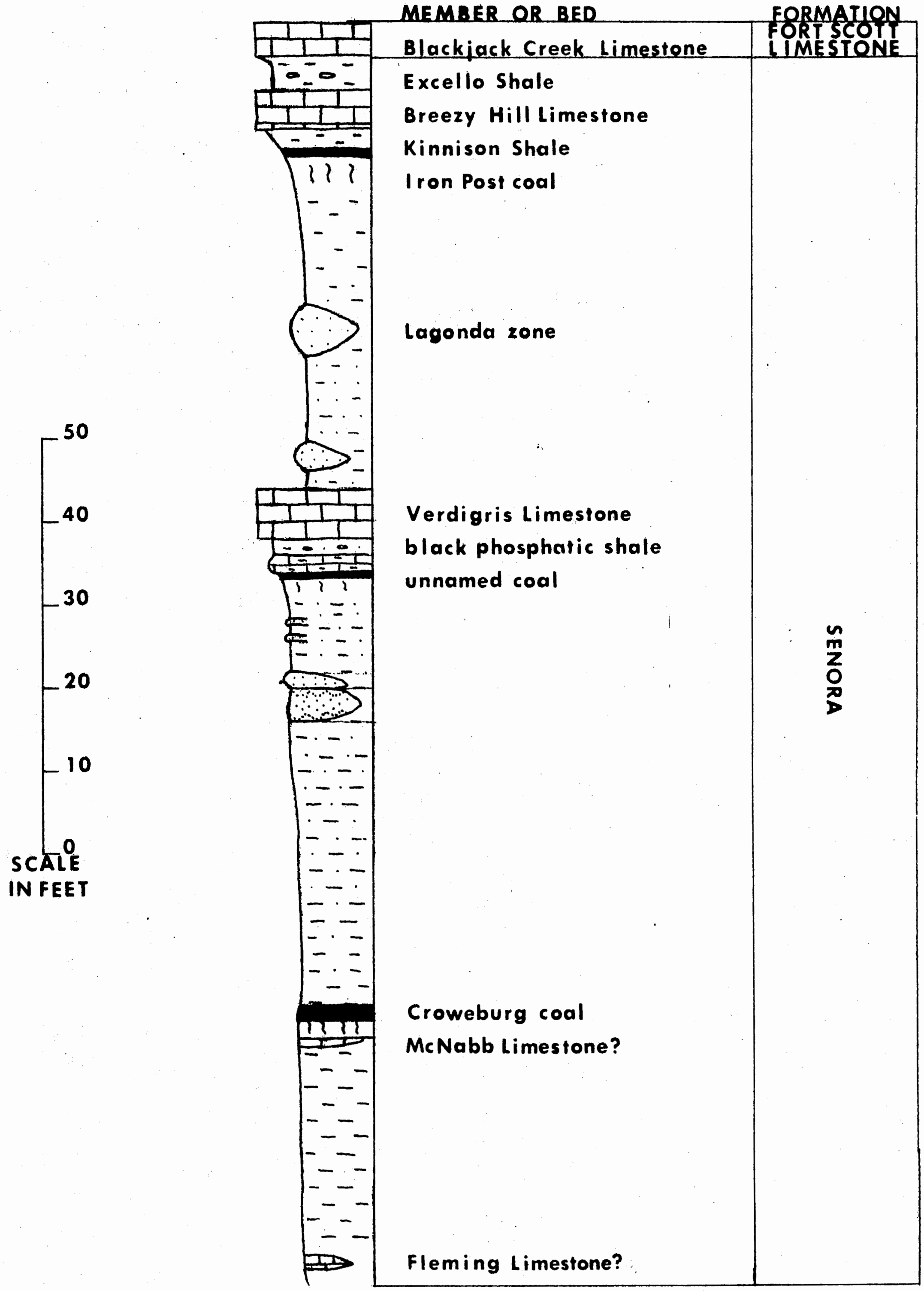

Fig. 4.--Columnar section, Chelsea area, Craig, Mayes, Nowata, and Rogers Counties, Oklahoma

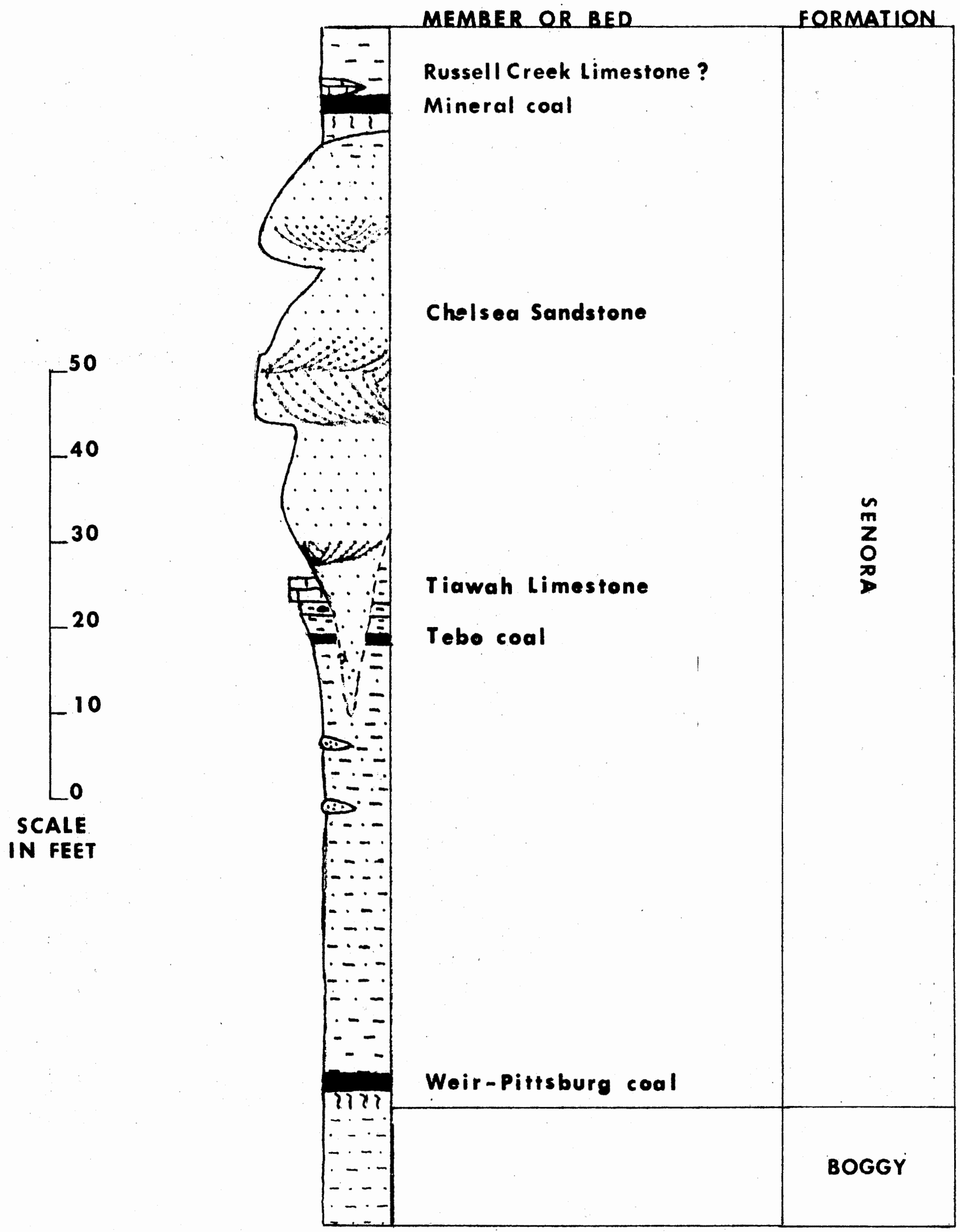

Fig. 4.--(continued)

is dark gray clayey shale grading upward to silty shale, that contains lenticular sandstone at some localities. The Weir-Pittsburg and Tebo coals are traceable into Kansas, where the Tebo is also known as the Pilot coal (Howe, 1956, p. 52).

The Tebo coal underlies a black, phosphatic shale, which Lohman (1952, p. 31, 32) correlated with the black phosphatic shale that lies beneath the Tiawah Limestone Member. This shale appears to extend throughout the study area, and therefore marks the approximate position of the Tiawah. The Tiawah, named by Lowman (1932), was found in outcrop only in a railroad cut in the SW¼,NE¼,SE¼,SW¼, Sec. 36, T. 24 N., R. 17 E., and in a pond in the NW¼,SW¼,SW¼ of the same section. In polished slab the Tiawah is medium gray, sparitic, and contains brachiopods, crinoid stems, and algal filaments. Its weathered surface is sharp, jagged, and moderate orange pink (as determined from the Geological Society of America's rock-color chart).

The Chelsea Member is a massive, cross-bedded, fine-to-medium grained, well sorted, subangular, "salt and pepper", micaceous quartzose sandstone. It ranges in thickness from 0 to at least 60 ft., and forms hills in the terrain east of Chelsea. Generally it consists of a fine- to medium-grained lower unit that underlies terrain covered by oak-hickory forest, and a clayey, fine-grained upper unit that underlies grasslands. Fern impressions and Calamites are common, especially in the lower unit. Westward from Chelsea, Lohman (1952) reported thinning of the unit. However, logs of oil and gas wells indicate that the entire unit is present, but only the upper part is exposed at the surface. As stated above, much of the Chelsea was deposited in channels eroded to the approximate position of the Tebo coal; however it is possible that these channels could have cut through the Tebo and into underlying strata in places (Fig. 4).

Oakes (1953, p. 1525) reported that the Cabaniss Group is unconformable upon the underlying Krebs Group. In northeastern Oklahoma, most observers have placed this unconformity at the base of the Chelsea Sandstone Members (Austin, 1946, Lohman, 1952, Branson, and others, 1965). The evidence for this unconformity is conglomerate near the base of the Chelsea at some localities. However, within the thesis area, the Chelsea is not the base of the Cabaniss Group (Branson and others, 1965, Pl. 2); by definition the Weir-Pittsburg coal bed and overlying strata are between the Chelsea and the top of the Krebs Group. There is little or no evidence to support an unconformity at the base of the Cabaniss Group. It was not observed in the field during the present study, nor is it shown in drillers' logs. In all probability the Cabaniss Group rests conformably upon the underlying Krebs Group in this region.

The interval between the Chelsea Sandstone Member and the Croweburg coal (Fig. 4) is not exposed in its entirety within the study area. From drillers' logs this interval was determined to be about 50 ft. thick, and is mainly shale. This section includes the Mineral coal, which has been mined in the southwestern part of the study area. The Mineral lies about 45 ft. below the Croweburg coal, according to the log of a coal-test boring in the NW¼,NE¼,NW¼, Sec. 1, T. 24 N., R. 17 E (see Appendix A, log 3), and is traceable into Kansas (Howe, 1951, p. 2091). Deposition of sandy sediments may have continued in some parts of the study area; not allowing coal-forming conditions to exist throughout the area. However, data to support or condemn this hypothesis are scarce. Several drillers' logs of oil and gas wells show 1-2 ft.-thick limestones in this interval. These beds may correspond to the Russell Creek Limestone Member and Fleming Limestone Member (Fig. 4), which crop out north of the study area (Branson and others, 1965, p. 38). The Russell Creek overlies the Mineral coal, and the Fleming is reported to lie 5 to 15 ft. above the Russell Creek (Branson and others, 1965, p. 38).

The McNabb Limestone Member (Fig. 4) has been reported as underlying the Croweburg coal and associated underclay at some localities (Oakes, 1944; Wilson and Hoffmeister, 1956). The limestone reported in a driller's log of a coal-test boring (Appendix A, log 4), may be the McNabb; it is 44 ft. above the Mineral coal in the NW¼,NE¼,NE¼,NE¼, Sec. 2, T. 24 N., R. 17 E. Bennison (1972, p. 23) described the McNabb as a 2-to 3-ft.-thick, argillaceous to sandy limestone crowded with large productid and spiriferid brachiopods. Limestone sampled from the rubble of a Croweburg coal mine located in Sec. 36, T. 25 N., R. 17 E. is argillaceous to sandy and contains abundant productid brachiopods, Marginifera, and probably is derived from the McNabb Member.

The Croweburg coal "is the most widespread coal in the United States, and possibly in the world" (Wanless, 1975, p. 41). It has been recorded and mapped in Iowa, Missouri, Kansas, and Oklahoma. It has been correlated with coals in Illinois (Colchester no. 2), Indiana (Coal IIIa), Kentucky (Schultztown), and possibly with the Lower Kittanning coal of the northern Appalachian basin (Wanless, 1975, p. 41, Pl. 17). The Croweburg is the only coal of the Cabaniss Group that can be traced from the Arkoma basin to the platform area of Oklahoma (Branson, 1964, p. 58). Figure 5 shows approximately the original distribution of this coal. Locally, the Croweburg has been referred to as the "Broken Arrow,"

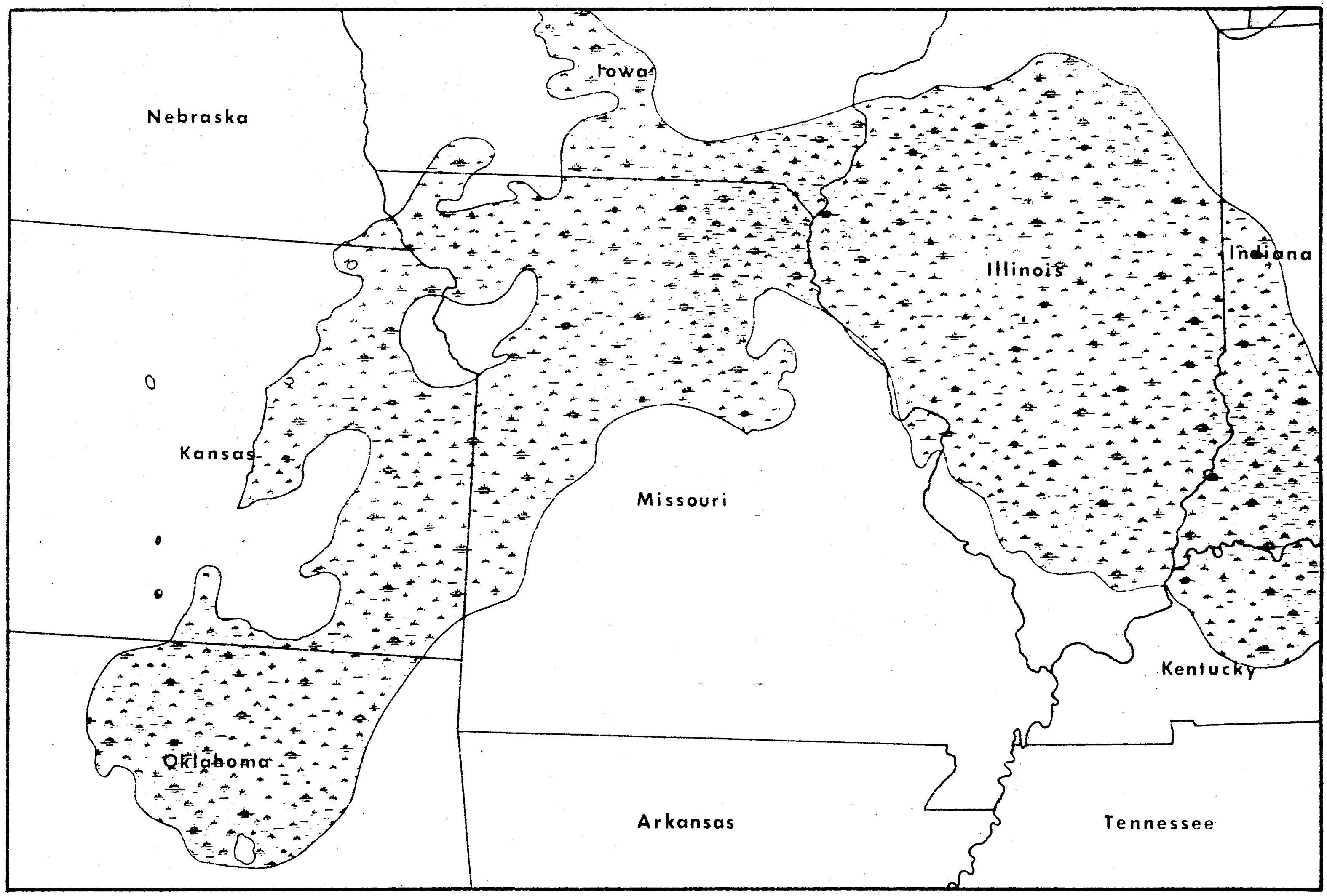

Fig. 5.--Original distribution of the Droweburg and Colchester No. 2 coals (modified from Wanless, 1975, Pl. 17)

(Oakes, 1944, p. 12), "Sequoyah" (Friedman, 1974, p. 32), and "Henryetta" (Wilson and Hoffmeister, 1956, p. 9) coals.

The interval from the Croweburg coal upward to the Verdigris Limestone Member (Fig. 4) is approximately 50 to 60 ft. thick. The section is composed mainly of silty shales, but it contains a 3 to 6-ft., fine-grained sandstone that lies about 20 ft. beneath the Verdigris. This is the upper part of the Skinner interval of the subsurface (Table 1). Eleven feet above this sandstone, a thin, discontinuous coal was observed on the high wall of a reclaimed strip pit at the center of Sec. 15, T. 24 N., R. 17 E. Associated with this coal is a 3.5-ft.-thick underclay containing rootlets. The coal is capped by a unit about 2-ft.-thick that varies from calcareous siltstone to silty limestone.

The Verdigris Limestone Member is a highly useful marker bed at the surface and in the subsurface. It is a 6-ft.-thick, iron-rich, impure biomicrite, in which bryozoa, crinoid stems, foraminifera, gastropods, and ostracods were observed. Algal filaments are also contained in the uppermost 1 foot. Abundant chert, clay, and silt are also present. Directly beneath the Verdigris is a distinctive black shale about 2-ft.-thick.

The section overlying the Verdigris to the Breezy Hill Limestone Member is about 40-ft.-thick. Above the Verdigris is about 18 ft. of medium gray silty shale with dike-like structures of similar shale, stained grayish orange. Howe (1956) interpreted the dike-like structures to be composed of precipitate from ground water that moved within closely spaced joints. The shale section coarsens upward to fine-grained, angular, hematitic sandstone, about 6-ft.-thick; this is the Lagonda zone of the surface, or Prue sandstone of the subsurface (Table 1). Shale composes the remainder of the section upward to the Iron Post coal and its associated underclay (Fig. 4).

Locally, the Iron Post coal bed has been called the "Fort Scott coal," and has been miscorrelated with the true Fort Scott coal, the Mulky coal of Kansas and Missouri (Howe, 1951). Above the Iron Post coal is the Breezy Hill Limestone Member of the Senora Formation, easily mistaken for the lowest bed of the Fort Scott Limestone, the Blackjack Creek Limestone Member (Fig. 4), which is the cap rock of the Mulky coal. The Iron Post coal has not been observed in Kansas (Howe, 1956, p. 84). The Mulky does not extend southwards into Oklahoma, although the Excello Shale Member of the Senora Formation, which occupies the stratigraphic position between the Mulky and the Blackjack Creek limestone in Kansas, is traceable to Claremore, Oklahoma (Howe, 1951, p. 2092).

The Breezy Hill Limestone Member averages about 5 ft. thick in the study area, and is biomicrite. The lower 3 ft. is light gray, limonite-stained, weathers to very light gray, and contains bryozoa and brachiopods. The upper 2 ft. is algal limestone, pale brown to grayish orange in polished slab section, weathering to pale orange and dark yellowish orange. Algal filaments, algal degris, brachiopods, bryozoa, crinoid stems, foraminifera and recrystallized sparite are included. Below the Breezy Hill and above the Iron Post coal bed lies a 2-ft.-thick black shale, named the Kinnison Shale Member by Howe (1951, p. 2090).

The Excello Shale Member lies between the Breezy Hill Limestone Member and the overlying Marmaton Group (Fig. 4). The Excello is black phosphatic shale about 4 ft. thick; it underlies the Fort Scott Limestone conformably. Only the Blackjack Creek Limestone Member of the

Fort Scott Limestone is present in the study area. The Blackjack Creek is a 5-ft.-thick, light-gray, finely crystalline limestone with vugs and fossil cavities filled with coarsely crystalline calcite (Branson and others, 1965, p. 43).

INFERRED DEPOSITIONAL HISTORY

Schopf (1975, p. 30) postulated a tropical, humid climate during the Pennsylvanian throughout the Midcontinent region. An overall marine transgression submerged the Nemaha highlands to the west for the first time during the Pennsylvanian by the end of deposition of the Cabaniss (Frezon and Dixon, 1975, p. 188). This transgression was oscillatory, with minor regressions and transgressions producing rhythmic, coal-bearing, sedimentary sequences.

The Weir-Pittsburg coal bed and its associated underclay conformably overlie the Taft Sandstone Member and associated shales of the Boggy Formation. Hudson (1969) believed that the Taft represents a deltaic complex in southern Osage County (Fig. 1) to the west of the study area. Near the study area, the Taft probably was also deposited as part of a deltaic complex.

Bond (1963, p. 79) reported the relative abundances of spores in the Weir-Pittsburg coal sampled from a mine in Rogers County, south of the study area, being Laevigatosporites, 45 percent, Lycospora, 16.5 percent, and Calamospora, 6.5 percent. Laevigatosporites and Lycospora are interpreted by Wilson (1976) to represent a pioneer stage in the development of a coal swamp. Wilson (1976) also concluded that high-sulfur coals commonly show evidence of relatively thick pioneer stages. The Weir-Pittsburg coal fits this description, as it averages about 6.5 percent sulfur.

Overlying the Weir-Pittsburg coal is a gray, fissile, sparsely fossiliferous, slightly calcareous and pyritic shale. Invertebrate fossils collected by the author from this shale include Euphemites, Nuculana bellastriata, Marginifera, and Rhombopora. Evidence of burrowing was also observed in the shale. This evidence indicates deposition in a paralic, brackish to saline swamp (J.E. Naff, personal communication, 1978).

Terrestrial beds underlying the Weir-Pittsburg coal, and paralic beds overlying it indicate that the coal swamp formed during a marine transgression. I believe that this occurred in a manner similar to that described by Teichmüller and Teichmüller (1975, p. 12): "As with the North Sea at present, the advancing sea pushes a rising groundwater table landwards before it and so in this way a new swamp belt develops."

The paralic shale overlying the Weir-Pittsburg coal is overlain conformably by a nonfossiliferous shale that grades upward into brown, silty shale, which includes lenticular thin beds of sandstone. I believe that these unfossiliferous shales are nonmarine, and that a transgression preceded development of the Tebo coal swamp in a manner similar to that described in the preceding paragraph.

Ruffin (1961) reported the relative abundances of spores in the Tebo coal in Craig County just east of the study area as being Laevigatosporites 51.7 percent, Lycospora 13.6 percent, Calamospora 12.8 percent, and Lophotriletes 5.1 percent. In relative abundances of genera, this assemblage resembles that of the Weir-Pittsburg coal; however Ruffin (1961, p. 92) stated that Lophotriletes microsaetosus "has not been reported with such consistent abundance throughout all levels from any other Desmoinesian coal in Oklahoma." The Tebo coal is only 2 to 3 in.

thick in the study area, and thus samples were not submitted for proximate and ultimate analyses. Pyrite is abundant in hand specimens, suggesting that the Tebo probably is a high-sulfur coal (see Appendix D); it probably was associated with a relatively thick pioneer stage.

The Tebo is overlain by black, phosphatic shale that probably was deposited in near-shore, possibly tidal lagoon environments. The Tiawah Limestone Member, which contains sparite, algal filaments, crinoid stems and brachiopods, overlies the black shale. Algal filaments and crinoid stems are indicative of shallow-marine conditions.

Following the deposition of the Tiawah was a major marine regression or a progradational episode, during which the Chelsea Sandstone Member was deposited. The Chelsea is a fine-to medium-grained sandstone that fines upward, has a sharp basal contact, medium- to large-scale cross-bedding, a small width-to-thickness ratio, and fossil wood fragments concentrated within a few feet of the base. Comparing these criteria with those of Shelton (1973, Table 3), I judge the Chelsea to have been deposited in a deltaic environment, probably on an upper deltaic plain, that trended northeast-southwestwards in the study area. In a regional subsurface study, Valderrama (1974) also assigned a deltaic environment for the Chelsea (which he called "Skinner"), and showed that the regional trend of the Chelsea is northeast-southwest. On the basis of mineralogy, he also concluded (1974, p. 51) that the Chelsea was derived from a "source area dominated by sedimentary rocks, including carbonates."

The Chelsea sandstone fines upward markedly, and at some places in the subsurface is overlain by the Mineral coal and associated underclay. The relative abundances of spores in the mineral were reported by Wilson (1976, p. 22) from Urban's (1962) work as being <u>Laevigatospora</u> 43 percent, Lycospora 7 percent, Densosporites 14 percent, and Florinites 15.5 percent. Densosporites and Florinites are believed by Wilson (1976) to represent a climax stage, where the coal swamp apparently was forested and "was ecologically somewhat stable" (Wilson, 1976, p. 25). Although the Mineral coal is a high-sulfur coal (averaging 3.5 percent) and shows evidence of a relatively thick pioneer stage, it apparently was the first coal of the Senoran formation in the study area to have developed in a swamp that reached the climax stage of development.

The Mineral coal and overlying strata are not exposed in the study area. However, northeast of the study area in Craig County (Fig. 1) the Russell Creek Limestone Member overlies the Mineral coal (Branson and others, 1965) indicating that north of the study area the Mineral coal swamp was inundated by marine water. Perhaps these conditions existed in the study area also.

Shales make up the interval between the Mineral coal and the Croweburg coal. As discussed previously (p. 18), the McNabb Limestone Member may be present in the study area. The McNabb and terrestial beds above the Croweburg coal would indicate that the Croweburg was deposited during regressive conditions. Analyses of spores from two mines just north and south of the study area, (Wilson and Hoffmeister, 1956), show the following abundance: Cirratriradites punctatus, 32 percent, Laevigatosporites minutus, 26 percent, and Florinites antiquus, 13 percent. The low sulfur content of the Croweburg (0.5 percent-0.7 percent) would indicate that the swamp was never in contact with marine or brackish waters, which could have supplied the sulfate ions to form pyrite and marcasite.

A terrestial environment followed development of the Croweburg swamp, as silty shales and sands were deposited in what Valderrama (1974) determined to be another deltaic complex. The source area was probably to the southeast, in the Ouachita region (Valderrama, 1974).

Shales that overlie the Croweburg are overlain by the Verdigris Limestone. Wright (1975, p. 80) postulated a clear, relatively deep marine environment of deposition for the Verdigris in southern Kansas. However, the assemblage of fossils described earlier (p. 20), and a high content of noncarbonate materials suggest that within the study area, the Verdigris was deposited in shallow marine water.

Overlying the Verdigris is the Lagonda sandstone which probably was deposited in a deltaic environment; its source area was to the south, in the Ouachita and Arbuckle Mountains (Wright, 1975, p. 81). North of the study area the Bevier coal swamp developed upon this delta. The Bevier coal was not observed in outcrop or reported in logs of coal-test borings in the study area.

The Iron Post coal swamp developed near the end of deposition of the Senora Formation. Forming in a manner similar to the Weir-Pittsburg, Tebo, and Mineral coals, the Iron Post is high-sulfur coal (3.64 - 3.9 percent). Wilson (1976) reported from Gibson's work (1961) the relative abundances of spores in the Iron Post coal to be Laevigatorsporities 21.4 percent, Calamospora 20 percent, Lycospora 15.7 percent, and Thymospora 12.6 percent.

The overlying Kinnison Shale, Breezy Hill Limestone, and Excello Shale Members probably were deposited during an overall deepening of the water (Cassidy, 1962, p. 62). Crinoid stems, bryozoans, and burrows indicate a shallow-marine environment for the Breezy Hill. The uppermost 2 ft. of the Breezy Hill is an algal limestone, which likewise formed in shallow, clear marine water. Cassidy (1962) believed that the Excello Shale Member was deposited in deep, stagnant water, and no evidence was observed to the contrary during the present writer's research.

ECONOMIC GEOLOGY

In the study area, five companies are developing at least six mines, and new mines are to be opened in the near future (Ted Parsons, Fuel Dynamics, personal communication). Production at selected mines from 1970 to December 1977 is shown in Table 3.

Determination of whether a coal bed can be mined economically depends on (a) grade of coal (measured by content of ash, sulfur, and Btu value), which determines its market use and price, (b) thickness of the marketable coal, and (c) thickness and lithology of the overburden. Coal at depths of more than 100 ft., with an overburden-to-coal ratio greater than 60:1 is considered to be economically nonstrippable (Friedman, 1974, p. 15).

Other factors that may have negative effects on the economics of mining coal include (a) reclamation of the mined-out area, (b) costs of transporting the coal to the buyer, and (c) pollution of nearby streams and ground water by mine waters bearing sulfuric acid, iron oxides, and suspended sediments. For a more complete discussion of the general economics of strip mining, see Averitt (1975) and Friedman (1974).

The average caloric values (Btu) and contents of ash and sulfur of the minable coals in the study area are shown in Table 4. Proximate and ultimate analyses for individual samples are recorded in Appendix B. Results of proximate and ultimate analyses indicate that the Weir-Pittsburg is a high-volative A bituminous coal, the Mineral a high-

Table 3.--Production figures from selected mines (data from S. A. Friedman, 1978, written communication).

COMPANY	COUNTY	COAL	ANNUAL TOTAL SHORT TONS	YEAR
G&P Mining	Nowata	Croweburg	7,010	1977
Carbonex Coal	Rogers	Iron Post & Croweburg (undifferentiated)	147,074	1977
Fuel Dynamics	Rogers	Croweburg	167,700	1977
Hefner&Son*	Rogers	Weir-Pittsburg	110,986	1977
Solar Excavating	Craig	Croweburg	110,610	1977
Shamrock Coal	Rogers	Weir-Pittsburg	83,421	1977
Carbonex Coal	Rogers	Iron Post & Croweburg (undifferentiated)	69,041	1976
Fuel Dynamics	Rogers	Croweburg	136,789	1976
Peabody Coal	Rogers	Croweburg	44,273	1976
Peabody Coal	Rogers	Croweburg	506,810	1975

* Located approximately 1 mile east of study area in sec. 23, T. 24 N. R. 18 E.

Table 4.--Ash, sulfur, volatile matter, and calorific value (Btu) (as received) for coals in the study area. (Samples collected by the author and by S. A. Friedman; analyses by Oklahoma Geological Survey. Values for Mineral coal from Friedman, 1974, p. 19).

	Value	No. of Samples	Range (in percent)
Ash	(percent of proximate analysis)		
Weir-Pittsburg coal	9.9	5	7.6-12.6
Mineral coal	13.9	0	11.0-17.3
Croweburg coal	7.1	6	2.7-9.9
Iron Post coal	9.0	2	8.1-10.0
Sulfur	(percent of ultimate analysis)		
Weir-Pittsburg coal	6.1	5	3.8-8.5
Mineral coal	4.8	0	3.5-5.1
Croweburg coal	0.57	6	0.5-0.7
Iron Post coal	3.9	2	3.9-3.9
Volatile Matter	(percent of proximate analysis)		
Weir-Pittsburg coal	37.7	5	36.6-39.0
Mineral coal	11.0	0	
Croweburg coal	35.6	6	34.2-38.5
Iron Post coal	43.4	2	42.7-44.1
Calorific value (Btu)			
Weir-Pittsburg coal	14,766	5	14,523-14,983
Mineral coal	12,730	0	
Croweburg coal	14,892	6	14,761-14,969
Iron Post coal	14,927	2	14,910-14,943

volatile C bituminous coal, the Croweburg a high-volative A bituminous coal, and the Iron Post a high-volatile A bituminous coal (see standards report by Averitt, 1975, p. 20).

Sulfur and ash contents of the Weir-Pittsburg and Mineral coals in the study area are too high to permit use of the coals in coking. These coals are sold as steam coals, and are used for electric-power generation. Sulfur and ash contents of the Croweburg coal are acceptable to permit use of the coal in coking, and the Croweburg is being marketed as such. Sulfur and ash contents of the Iron Post coal are generally too high to permit use of the coal in coking; however it is being blended with the Croweburg and other coals, for use in Texas as coking coal (R. Collins, Carbonex Co., 1978, personal communication). Otherwise, the Iron Post is best suited for electric-power generation.

Isopach maps of the Weir-Pittsburg and Croweburg coals are shown on Plate 6, and of the Iron Post coal on Plate 7. An isopach map of the Mineral coal was not made because sufficient data were not available. Available records of drill holes show that the Mineral is only about 10 to 12 in. thick; resources were figured from what is considered to be its minimal economical thickness, 12 in. (Friedman, personal communication, 1978). The Mineral has been mined in the southwestern part of the study area (Plate 7).

Boundaries of the Weir-Pittsburg and Croweburg coals are shown on Plates 4, 6, and 8. The boundary of the Mineral can be seen on Plate 9, and that of the Iron Post on Plates 5 and 8.

An overburden isopachous map of the Croweburg coal is shown on Plate 8, an overburden isopachous map of the Mineral coal is shown on Plate 9, and an overburden isopachous map of the Weir-Pittsburg coal is shown on Plate 10. An overburden map of the Iron Post coal was not prepared; maximal overburden in the study area is about 30 ft., which is considered to be less than the economic depth limit (R. Collins, Carbonex Co., 1978, personal communication). Lithology of overburden can be inferred from cross sections on Plate 11.

Estimates of coal resources in the study area are shown in Table 5. Resources were determined using data obtained in coal-test borings, and were classified according to reliability of estimates (see Friedman, 1974, p. 14), thicknesses of coals, and thicknesses of overburden.

The minimal economic thickness of minable coal was taken to be 10 in. for the Croweburg and Iron Post, and 12 in. for the Weir-Pittsburg and Mineral coals. Averitt (1974, p. 23) suggested using 14 in. as the minimal economic thickness for minable coal. This was not done, because within the study area, coals have been mined profitably at the thicknesses specified above (Friedman, 1978, personal communication). Lower limits of 13 in. and 24 in. were used to define the next two higher categories of coal thicknesses for the Weir-Pittsburg and Iron Post, and 12 in. and 18 in. were used for the Croweburg as suggested by Professor Friedman of the Oklahoma Geological Survey, and are shown in Table 5.

Sixty feet of overburden is considered to establish the economic depth limit of the Weir-Pittsburg and Mineral coals, whereas the Croweburg coal, in places where it contains 1 percent or less sulfur, is considered to be minable to depths as great as 100 ft. (Friedman, 1978, personal communication). Overburden categories were set by economic limits existent in the study area, and by practicality of presenting them in map form. Estimates of resources were not made of localities where the coal is either thinner than its presumed minimal economic

Table 5.--Remaining measured, indicated, and inferred coal resources, ordered by thickness of coal and thickness of overburden (in thousands of short tons)

	Thickness (in.) Minimum	Average	Acres	Thousands of Short Tons
MEASURED				
Weir-Pittsburg coal overburden (ft)				
0-20	12+	(22.9)	301	1,034
21-40	13+	(22.9)	178	611
41-60	24+	(25.5)	180	689
Mineral coal overburden (ft)				
0-40	12		932	1,678
41-60	12		394	709
Croweburg coal overburden (ft)				
0-20	10+	(16.8)	1,517	3,823
21-60	12+	(16.8)	1,919	4,836
61-100	18+	(20.8)	1,543	4,814
Iron Post coal overburden (ft)				
0-30	10+	(15.3)	2,285	5,244
INDICATED				
Weir-Pittsburg coal overburden (ft)				
0-20	12+	(22.9)	432	1,484
21-40	13+	(22.9)	211	724
41-60	24+	(25.5)	128	488
Mineral coal overburden (ft)				
0-40	12		972	1,750
41-60	12		548	986

Table 5.--(Continued)

	Thickness (in.) Minimum	Average	Acres	Thousands of Short Tons
INDICATED (Continued)				
Croweburg coal overburden (ft)				
0-20	10+	(16.8)	314	791
21-60	12+	(16.8)	688	1,734
61-100	18+	(20.8)	492	1,535
Iron Post coal overburden (ft)				
0-30	10+		641	1,177
INFERRED				
Weir-Pittsburg coal overburden (ft)				
0-20	12+	(22.9)	644	2,213
21-40	13+	(22.9)	403	1,384
41-60	24+	(25.5)	198	756
Mineral coal overburden (ft)				
0-40	12		1,419	2,554
41-60	12		1,111	2,000
Croweburg coal overburden (ft)				
0-20	10+	(16.8)	24	75
21-60	12+	(16.8)	157	494
61-100	18+	(20.8)	87	271
Iron Post coal overburden (ft)				
0-30	10+	(15.3)	221	506

limit, or where the overburden is thicker than the economic limit.

Original, remaining, and recoverable coal resources are shown in Table 6. The "original resources" category includes all coal equal to or thicker than their designated minimal economic thickness. Production figures for mines, where available, were combined with estimates of production in order to determine the total quantity of coal mined and lost in mining. This quantity was subtracted from the computed original resources to determine remaining resources. To determine recoverable reserves, the average recoverability in strip mining was assumed to be 80 percent (see Averitt, 1975, p. 31). Thus 80 percent of the remaining strippable resources is determined to obtain the strippable recoverable reserves.

Underclays

Dominant minerals in underclays of the study area are kaolinite and illite. Figure 6 is an X-ray scan typical of underclays in the study area. Table 7 shows the results of semi-quantitative analysis of underclays in or near the study area.

Table 6.--Original, remaining, and recoverable (strippable) coal resources in study area (in thousands of short tons).

Weir-Pittsburg coal		Mineral coal	
Original	9,704	Original	9,667
Remaining	9,383	Remaining	9,190
Recoverable	7,506	Recoverable	7,352
Croweburg coal		**Iron Post coal**	
Original	19,362	Original	8,320
Remaining	16,935	Remaining	7,223
Recoverable	13,548	Recoverable	5,778

Grand Total	
Original	47,053
Remaining	42,731
Recoverable	34,184

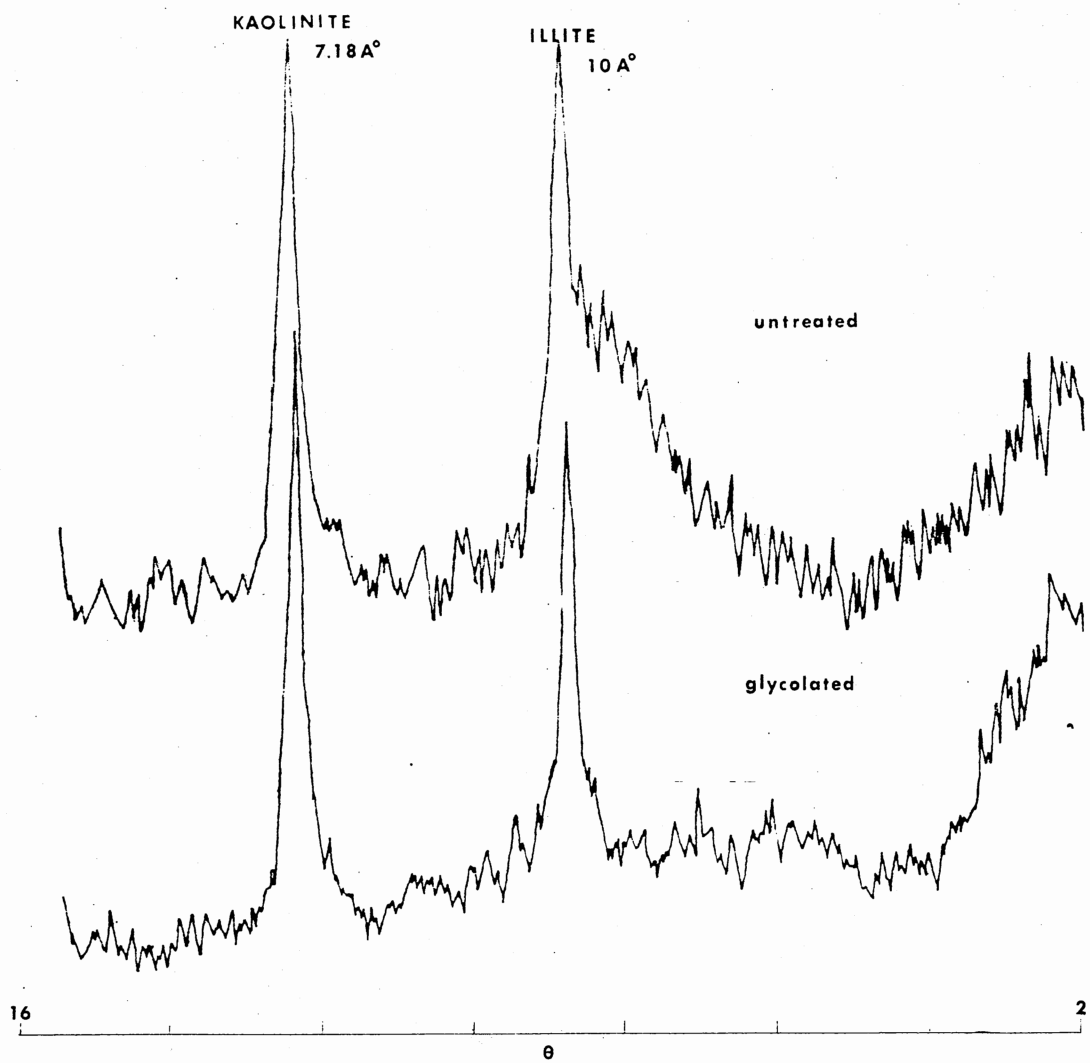

Fig. 6.--X-ray scan of typical underclay in the study area

Table 7.--Semi-quantitative analysis of some underclays in or near the study area. Underclays are listed in sequence, by the name of the coal overlying each.

Location	Sample	Coal	Relative % Illite	Relative % Kaolinite	Relative % Mixed Layer
Sec. 28 T. 25 N. R. 17 E.	1	Croweburg	52.4	35.7	11.9
Sec. 28 T. 25 N. R. 17 E.	2	Iron Post	36.3	46.2	17.5
Sec. 3 T. 24 N. R. 17 E.	3	Iron Post	42.1	40.1	17.8
Sec. 3 T. 24 N. R. 17 E.	4	Iron Post	43.5	44.7	11.8
Sec. 34 T. 25 N. R. 17 E.	5	Croweburg	40.6	43.8	15.6
Sec. 34 T. 25 N. R. 17 E.	6	Croweburg	36.5	53.5	10.2
Sec. 27 T. 25 N. R. 17 E.	7	Croweburg	43.4	40.7	15.9
Sec. 27 T. 25 N. R. 17 E.	8	Croweburg	37.8	40.0	22.2
Sec. 22 T. 25 N. R. 17 E.	9	Iron Post	53.8	26.9	19.2
Sec. 22 T. 25 N. R. 17 E.	10	Iron Post	61.5	25.6	12.9
Sec. 22 T. 24 N. R. 18 E.	11	Tebo	49.3	42.4	8.2
Sec. 22 T. 24 N. R. 18 E.	12	Tebo	35.0	50.0	15.0

CONCLUSIONS

The principal conclusions of this study are as follows:

1) Rocks that are found in outcrop in the study area include stratigraphic units of the Boggy Formation of the Krebs Group, the Senora Formation of the Cabaniss Group, and the Fort Scott Limestone of the Marmaton Group. These units are part of the Desmoinesian Series, Pennsylvanian System.

2) Six coals crop out or were penetrated in the subsurface. However, only four coals, the Weir-Pittsburg, Mineral, Croweburg and Iron Post coals of the Senora Formation are of economic importance.

3) Strata in the study area dip 1° to 2° to the northwest, and folds are gentle.

4) The Cabaniss Group apparently lies conformably upon the underlying Krebs Group in the study area.

5) Sediments of the Cabaniss Group were deposited in or near shallow seas, with the exception of the Excello Shale which was deposited in deeper waters. Coal swamps developed on deltas that were built into the seas repeatedly and that were submerged repeatedly.

6) Remaining coal resources in the study area are 9,383,000 short short tons of Weir-Pittsburg coal, 9,190,000 short tons of Mineral coal, 16,935,000 short tons of Croweburg coal, and 7,223,000 short tons of Iron Post coal. Of these 7,506,000 short tons of Weir-Pittsburg coal, 7,352,000 short tons of Mineral coal, 13,548,000 short tons of Croweburg coal, and 5,778,000 short tons of Iron Post coal are recoverable.

7) The Weir-Pittsburg, Mineral, and Iron Post coals in the study area are high sulfur; the Croweburg coal in the study area is low sulfur. These coals are ranked as high volatile A and C bituminous coal. The Weir-Pittsburg, Mineral and Iron Post coals are best suited for electric-power generation and industrial uses. The Iron Post is being sold for use in coking in Texas. The Croweburg coal is best suited for use in coking.

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APPENDIX A

SELECTED DRILLERS'LOGS OF OIL AND COAL

TEST BORINGS IN THE STUDY AREA

LOG 1

COMPANY	Fulton Oil & Gas Co.
FARM	Morrison No. 4
LOCATION	SE¼SE¼NE¼ Section 24, T. 24 N., R. 17 E.
COUNTY	Rogers
PRODUCTION	Dry
ELEVATION	750 estimated from topographic map
DRILLING COMMENCED	12-12-19
DRILLING COMPLETED	1-10-20

FORMATION	TOP	BOTTOM
Soil	0	4
Sandstone	4	60
Shale	60	65
Limestone	65	69
Sandstone	69	79
Shale	79	127
Sandstone	127	135
Shale	135	227
Sandstone	227	286
Total depth	286	

LOG 2

COMPANY	Fulton Oil & Gas Co.
FARM	Morrison No. 5
LOCATION	NE¼NE¼SE¼ Section 24, T. 24 N., R. 17 E.
COUNTY	Rogers
PRODUCTION	Dry
ELEVATION	750 estimated from topographic map
DRILLING COMMENCED	1-17-20
DRILLING COMPLETED	1-25-20

FORMATION	TOP	BOTTOM
Soil	0	4
Clay	4	16
Shale	16	70
Sandstone	70	130
Shale	130	135
Limestone	135	139
Sandstone	139	160
Shale	160	345
Sandstone	345	349
Shale	349	406
Total depth	406	

LOG 3

COMPANY	Fuel Dynamics
DRILL HOLE	68
LOCATION	NE¼NW¼ Section 1, T. 24 N., R. 17 E.
COUNTY	Rogers
ELEVATION	790 estimated

FORMATION	TOP	THICKNESS
Surface	0.0	5.0
Yellow shale	5.0	6.4
Coal (Croweburg)	11.4	1.5
Fireclay	12.9	4.6
Dark shale	17.5	10.5
Blue shale	28.0	27.5
Coal (Mineral)	55.5	1.0
Fireclay	56.5	3.5
Total depth	60.0	

LOG 4

COMPANY	Fuel Dynamics
DRILL HOLE	59
LOCATION	NE¼NE¼NE¼ Section 2, T. 24 N., R. 17 E.
COUNTY	Rogers
ELEVATION	780

FORMATION	TOP	THICKNESS
Surface	0.0	3.0
Limestone (McNabb?)	3.0	2.0
Shale	5.0	5.0
Dark shale	10.0	5.0
Blue shale	15.0	32.6
Coal (Mineral)	47.6	0.9
Shale	48.5	2.1
Coal (Mineral)	50.6	0.7
Fireclay	51.3	6.0
Total depth	57.3	

APPENDIX B

ANALYSES OF COAL IN

THE STUDY AREA

--Results of proximate analyses, ultimate analyses (sulfur only) and heat-value analyses of coals in the study area. Abbreviations used: M (moisture); AR (as received); MF (moisture-free); VM (volatile matter); FC (fixed carbon); S (sulfur); BTU (British thermal units per pound); AF (ash-free); P (pyrite); SO_x (sulfate); Org. (organic); FSI (free-swelling index).

Coal	Location	Thickness	Field No.	Lab. No.	M(AR)	VM(AR)	VM(MF)	ASH(AR)	ASH(MF)	FC(AR)	FC(MF)	S(AR)	S(MF)	BTU(AR)	BTU(MF)	BTU(MF,AF)	Sulfur P	Sulfur SO_x	Sulfur Org.	FSI
Iron Post	Nowata County NE¼SE¼SE¼SW¼ Sec. 33 T. 25 N., R. 17 E.	15 in.	77C8	1354	1.1	42.2	42.7	9.9	10.0	46.8	47.5	3.8	3.9	13,300	13,453	14,943	2.20	0.05	1.61	7½
Iron Post	Nowata County NE¼SE¼SE¼SW¼ Sec. 33 T. 25 N., R. 17 E.	15 in.	77C9	1355	1.1	43.6	44.1	8.0	8.1	47.3	47.8	3.8	3.9	13,548	13,699	14,910	2.02	0.05	1.75	7½
Weir-Pittsburg	Rogers County Sec. 22 T. 24 N., R. 18 E.		76C86	1311	1.7	36.7	37.4	10.5	10.7	51.1	51.9	6.8	7.0	12,746	12,969	14,523	6.15	0.38	0.44	
Weir-Pittsburg	Rogers County Sec. 22 T. 24 N., R. 18 E.		76C87	1312	1.6	38.4	39.0	7.9	8.1	52.1	52.9	3.8	3.8	13,392	13,613	14,813	3.03	0.11	0.68	
Weir-Pittsburg	Mayes County SE¼NE¼NE¼ Sec. 3 T. 23 N., R. 18 E.	22 in.	77C10	1356	2.2	36.0	36.8	12.3	12.6	49.5	50.6	8.3	8.5	12,497	12,783	14,617	7.50	0.42	0.38	8½
Weir-Pittsburg	Mayes County SE¼NE¼NE¼ Sec. 3 T. 23 N., R. 18 E.	22 in.	77C11	1357	1.7	36.0	36.6	10.1	10.3	52.2	53.1	6.2	6.3	13,135	13,366	14,894	5.68	0.18	0.37	8
Weir-Pittsburg	Rogers County Sec. 9 T. 24 N., R. 18 E.	1.7 ft.	77C13	1359	2.0	37.8	38.6	7.4	7.6	52.8	53.8	4.8	4.9	13,573	13,850	14,983	3.9	0.18	0.75	
Croweburg	Rogers County SW¼ Sec. 3 T. 24 N., R. 17 E.	Upper 8½ in.	76C80	1301	4.2	34.0	35.5	6.8	7.0	55.0	57.5	0.5	0.5	13,154	13,728	14,761	0.03		0.43	
Croweburg	Rogers County Sec. 3 T. 24 N., R. 17 E.	12 in.	77C12	1358	4.8	33.6	35.3	6.6	7.0	55.0	57.7	0.5	0.6	13,233	13,896	14,936	0.05	0.03	0.46	
Croweburg	Rogers County SW¼ Sec. 3 T. 24 N., R. 17 E.	Lower 8½ to 12½ in.	76C81	1302	5.5	32.4	34.2	7.8	8.3	54.3	57.5	0.6	0.6	12,903	13,648	14,883	0.09		0.48	
Croweburg	Nowata County Sec. 36 T. 25 N., R. 17 E.	Upper 7.5 in.	76C74	1295	3.2	37.3	38.5	2.6	2.7	56.9	58.8	0.5	0.5	14,002	14,463	14,857	0.1		0.4	
Croweburg	Nowata County Sec. 36 T. 25 N., R. 17 E.	Lower 7.5 in.	76C75	1295	6.8	33.4	35.8	7.4	7.9	52.4	56.3	0.6	0.7	12,825	13,765	14,945	0.2		0.5	

APPENDIX C

MEASURED SECTIONS

1. Carbonex Coal Co., Strip Mine, SE¼SE¼SW¼ Sec. 33, T. 24 N., R. 17 E.

Description of Unit	Thickness in Ft
Senora Formation	
Breezy Hill Limestone Mbr., upper 1.1 ft. finely crystalline, lower four ft. gray, fossiliferous, very silty.	5.1
Kinnison Shale Mbr., black.	2.0
Iron Post coal.	1.1
Total thickness	8.2

2. Abandoned Strip Mine, E½NE¼ Sec. 15, T. 24 N., R. 17 E.

Description of Unit	Thickness in Ft
Senora Formation	
Breezy Hill Limestone Mbr., fossiliferous, finely crystalline, weathers light gray, very fossiliferous, caps hill.	1.0
Kinnison Shale Mbr., very weathered, gray.	1.0
Iron Post coal, weathered.	1.0
Covered, probably shale.	7.0
Shale, lt. gray.	7.0
Sand, fine grained, angular, hematitic, weathers lit. brown.	5.8
Shale, silty at top, coarsens downward to very fine grained, angular sand, weathers med. gray, dike-like structures of same material at base, dikes weather grayish orange.	18.0
Verdigris Limestone Mbr. (not measured)	
Total thickness	40.8

3. High Wall of Strip Pit, N½NE¼SE¼ Sec. 15, T. 24 N., R. 17 E.

Description of Unit	Thickness in Ft
Senora Formation	
Verdigris Limestone Mbr., finely crystalline, weathers orange-brown, top foot very fossiliferous, middle four feet less fossiliferous, basal one foot very fossiliferous.	6.0
Shale, black, phosphate nodules.	2.3
Shale, very limey, in places an argillaceous limestone.	2.1
Coal.	0.1
Underclay, containing rootlets.	3.5
Shale, silty, interbedded lenticular, thin beds of fine grained sandstone, upper foot flaser bedding, second foot convolute bedding, flaser bedding next foot, lower two feet climbing ripples with some convolute bedding.	7.5
Sand, very fine grained, convolute bedding in the upper 6 inches, weathers grayish orange.	2.1
Sand, fine grained, coarsening upward, convolute bedding in upper foot, climbing ripples, lower 2 feet convolute bedding.	4.5
Shaly siltstone, laminated, climbing ripples, med. lt. gray.	2.0
Total thickness	30.1

4. West of Chelsea Reservoir, South Side of Valley, NE¼SE¼SE¼ Sec. 22, T. 24 N., R. 17 E.

Description of Unit
Senora Formation
Verdigris Limestone Mbr. (not measured).

Covered, probably siltstone.	20.0
Sandstone, fine grained.	3.0
Siltstone, fine downward to a silty shale.	26.0
Covered.	5.0
Croweburg coal, soft weathered.	1.2
Total thickness	55.2

5. Along Cliff, SE¼SE¼SE¼ Sec. 28, T. 25 N., R. 18 E.

Description of Unit	Thickness in Ft
Senora Formation	
Chelsea Sandstone Mbr. (all below)	
Sand, very fine grained, coarsening downward to fine-medium grain, sub-rounded, hematitic, salt and pepper sand, case hardening nodules near top, 30° cross-bedding hear base.	14.0
Sand, fine grained, forms slope.	8.0
Sand, fine to medium grain, sub-rounded, hematitic, salt and pepper sand, 30° cross-bedding.	10.0
Covered, probably silty sand.	12.0
Sand, fine to medium grain, sub-rounded, hematitic, salt and pepper sand 30° cross-bedding, cut out at base.	6.0
Total thickness	50.0

6. Along Slope of Hill on the N-S Road South of the NW Corner of Sec. 10, T. 24 N., R. 18 E.

Description of Unit	Thickness in Ft

Senora Formation	
Chelsea Sandstone Mbr. (not measured)	
Shale, black, phosphatic.	0.6
Shale, lt. brown, weathered.	1.4
Tebo coal.	0.25
Underclay (not measured)	
Shale, coarsening upward to a siltstone, some thin lenticular beds of sand present.	24.0
Total thickness	26.25

7. NE¼NE¼NE¼ Sec. 18, T. 24 N., R. 18 E.

Description of Unit	Thickness in Ft
Senora Formation	
Chelsea Sandstone Mbr., fine-to-medium grain, well sorted, sub-rounded, micaceous, salt and pepper.	5.0
Covered.	1.0
Chelsea Sandstone Mbr., very fine to fine grain, pinkish color at base, white color upper foot.	5.0
Chelsea Sandstone Mbr., fine to medium grained sand, well sorted, sub-angular, salt and pepper appearance, chert pebbles present top of unit, groove and tool marks base of unit, sharp basal contact.	3.7
Shale, black.	0.3
Coal, weathered.	0.3
Shale, weathered, dike-like structures present.	1.5
Total thickness	16.8

APPENDIX D

GLOSSARY OF COAL RELATED TERMS

GLOSSARY OF COAL TERMS

Ash- Inorganic residue remaining after ignition of combustible substances, determined by definite prescribed methods (Friedman, personal communication, 1976).

High volatile coal- Coal with a fixed carbon of less than 69%, and volatile matter equal or greater than 31% measured on a dry, mineral-matter-free basis (Averitt, 1974).

> High volatile A bituminous coal- High volatile coal with a calorific value equal or greater than 14,000 Btu/lb.
>
> High volatile B bituminous coal- High volatile coal with a calorific value equal or greater than 13,000 Btu/lb.
>
> High volatile C bituminous coal- High volatile coal with a calorific value equal or greater than 11,500 Btu/lb.

High-sulfur coal- Coals containing more than 3.0 percent sulfur (Friedman, 1974, p. 23).

Indicated coal resources- Tonnage of coal in the ground based partly on reasonable geologic projection. The points of observation and measurement are about 1 mile apart but may be 1½ miles apart for beds of known continuity (Averitt, 1974).

Inferred coal resources- Tonnage of coal in the ground based on an assumed continuity of coal beds downdip from and adjoining areas containing measured and indicated resources. In general, inferred coal lies 2 miles or more from outcrops or from points of precise information (Averitt, 1974).

Measured coal resources- Tonnage of coal in the ground based on assured coal-bed correlations and on closely spaced observations about one-half mile apart. Computed tonnage judged to be accurate within 20 percent of the true tonnage (Averitt, 1974).

Original resources- Resources in the ground before the advent of mining (Averitt, 1974).

Proximate analysis- In the case of coal and coke, the determination, by prescribed methods, of moisture, volatile matter, fixed carbon (by difference), and ash (Averitt, 1974).

Remaining coal resources- Resources remaining in the ground as of a stated date. Obtained by subtracting production and estimated losses in mining from original resources, or by eliminating mined-out areas as of a stated date in preparing estimated of remaining resources (Averitt, 1974).

VITA

Walter Robin Keasler

Candidate for the Degree of

Master of Science

Thesis: COAL GEOLOGY OF THE CHELSEA QUADRANGLE IN PARTS OF CRAIG, MAYES, NOWATA, AND ROGERS COUNTIES, OKLAHOMA

Major Field: Geology

Biographical:

Personal Data: Born in Beeville, Texas, February 1, 1952, the son of Mr. and Mrs. Robert B. Keasler.

Education: Graduated from Memorial High School, Tulsa, Oklahoma, in May, 1970; received Bachelor of Science degree in Geology from Oklahoma State University in December, 1974; completed requirements for the Master of Science degree at Oklahoma State University in May, 1979.

Professional Experience: Seismologist, Seismograph Service Corporation, 1975; Geologist, Lario Oil Company, Wichita, Kansas, 1976; Graduate Teaching Assistant, Department of Geology, Oklahoma State University, 1977; Geologist, Sun Production, Tulsa, Oklahoma, 1978.