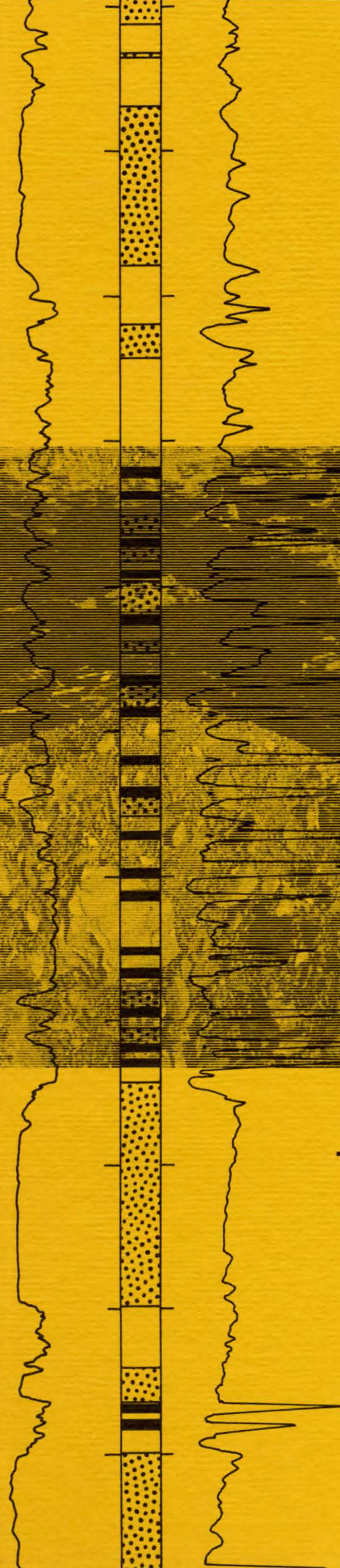


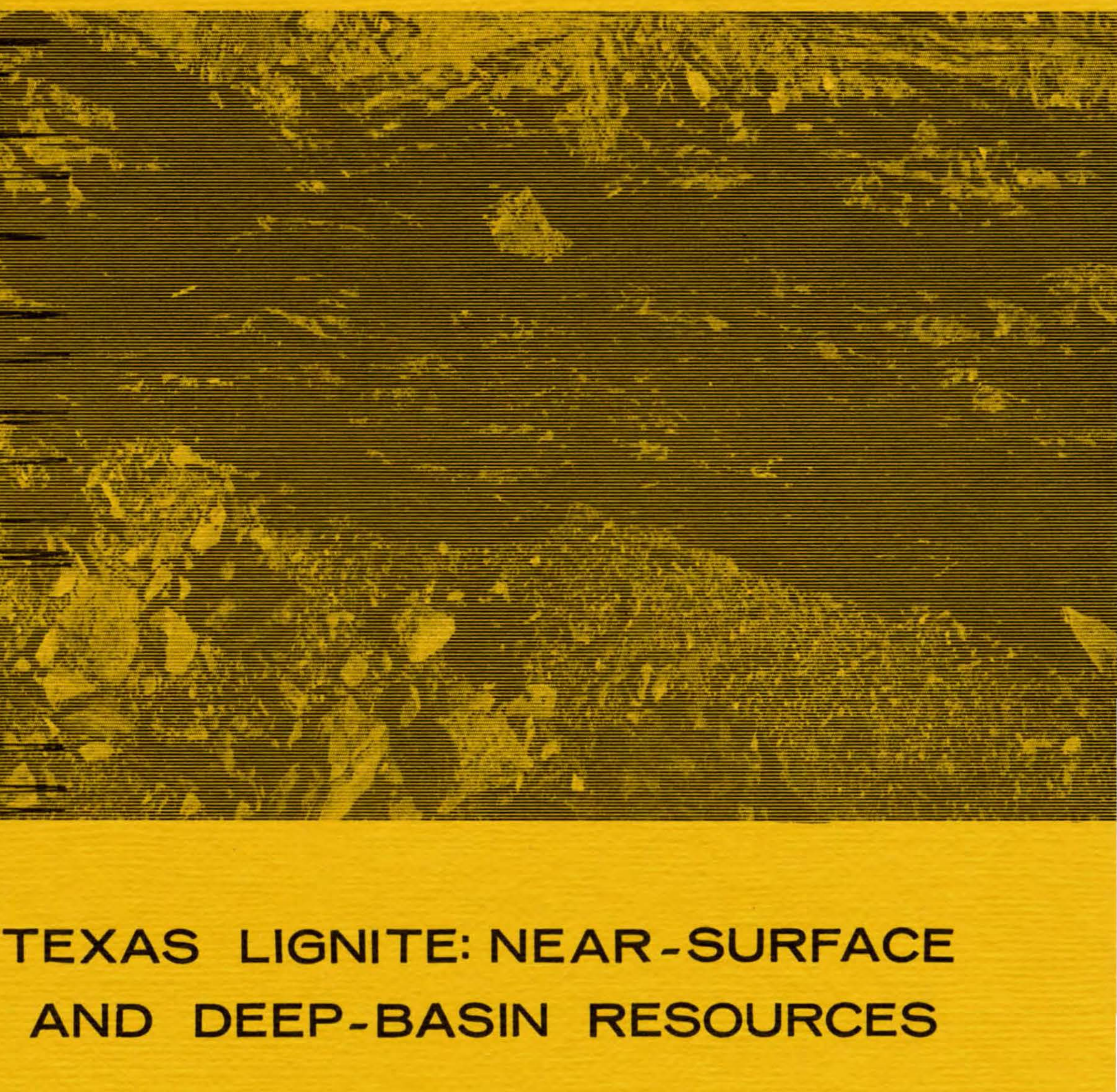
BUREAU OF ECONOMIC GEOLOGY

The University of Texas at Austin

Austin, Texas 78712

W. L. Fisher, Director

Report of Investigations — No. 79



TEXAS LIGNITE: NEAR-SURFACE AND DEEP-BASIN RESOURCES

By W. R. Kaiser 1974

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TEXAS LIGNITE: NEAR-SURFACE AND DEEP-BASIN RESOURCES

W. R. Kaiser

ABSTRACT

Lignite or low-rank coal is a major energy resource in Texas, providing energy since 1850. Prior to 1930, and the advent of abundant natural gas and oil, lignite was a major energy source. Today it is again assuming a substantial role in energy generation with the operation or scheduled construction by 1980 of lignite-fueled, steam-electric plants (up to 1500-megawatt capacities) near Alcoa, Fairfield, Athens, Mt. Pleasant, and Tatum. Future utilization of Texas lignite is likely in the production of synthetic gases, liquid fuels, and chemical feed stocks. Total statewide production of lignite is currently estimated at 8 to 10 million short tons annually.

Texas lignite resources, mainly situated in East and Central Texas north of the Colorado River, are large. Potential statewide resources at depths of less than 200 feet or available to conventional surface mining are estimated at 10.4 billion short tons. To this is added deep-basin lignite, a huge potential resource at depths of 200 to 5,000 feet below the surface, available through in situ recovery methods. More than 100 billion tons have been mapped, equivalent on a Btu basis to 277 billion barrels of oil. Utilization is technically feasible, but future development will depend on energy needs, dwindling fossil-fuel reserves, an unrealized potential of nuclear energy, and the larger question of national energy policy.

Environmental problems connected with the utilization of near-surface lignite are land use and disturbance, air and thermal pollution, water allocation and quality, and waste disposal. At the moment, sulfur oxides and particulates, because of their effect on the respiratory tract, are the air pollutants of prime concern to public health. The environmental impact, except for air pollution, is about the same whether lignite is used in steam-electric plants or gasification plants. Underground gasification poses the potential threat of ground-water contamination and surface subsidence, but avoids major land disturbance and waste disposal problems.

Lignite is found as near-surface and deep-basin deposits throughout the Texas Gulf Coastal Plain. Near-surface lignite occurs in two elongate bands stretching from the Rio Grande (Webb and Starr Counties) to the Red River (Bowie County) and Angelina River (Angelina County). Deep-basin lignite occurs coastward and downdip from the near-surface occurrences. The principal lignite deposits are found in the Wilcox Group (lower Eocene), while deposits of secondary importance in terms of resources and grade are found in the Yegua Formation and Jackson Group (upper Eocene). Lignite occurs as a component facies of ancient fluvial, deltaic, and lagoonal rocks in East, Central and Southeast, and South Texas, respectively. The highest grade and most extensive resources occur north of the Colorado River in the Wilcox Group in East and Central Texas. On a dry basis, sulfur content is 1.0 to 1.4 percent, ash content 12 to 14 percent, and heating value 10,500 to 11,000 Btu per pound. There is a correlation between grade and geologic occurrence: deltaic lignite is the best quality, fluvial lignite is intermediate in quality, and lagoonal lignite is poorest in quality.

INTRODUCTION

Past and Recent Events

Lignite or low-rank coal is a major energy raw material in the State of Texas. Lignite was one of the first mineral resources utilized by early settlers in the State. As early as 1819, L'Héritier indicated a "mine de charbon de terre" in East Texas on a map accompanying a report "Le Champ—d'Asile, tableau topographique et historique du Texas, etc.," published in Paris.

Prior to the advent of natural gas and oil as principal energy raw materials in the State, lignite was a major energy source. During the first third of this century, more than 100 mines operated at one time or another in East Texas. Principal production was during the years from 1910 to about 1930. During the early 1950's when natural gas was widely available, a large lignite mine was opened in Milam County southwest of Rockdale to provide the fuel for power generation used in the processing of aluminum from bauxite. In the past two years, large-scale mines and power plants have been either put into operation or scheduled for operation near Fairfield, Athens, Mt. Pleasant, and Tatum. Lignite is once again assuming a substantial role as a raw material for Texas energy.

The Bureau of Economic Geology and its predecessor, the Geological Survey of Texas, have published several reports on Texas lignite. In 1892, Dumble published the first comprehensive report on Texas lignite. Following this were reports by Phillips in 1902 and 1914, and papers by Stenzel in 1946 and Stenzel and others in 1948. The first comprehensive resource estimates were prepared by Perkins and Lonsdale in 1955. The most recent report, "Lignites of the Texas Gulf Coastal Plain," was prepared by Fisher in 1963. Most of these reports are now out of print.

The present report updates and summarizes information presented in the above reports, emphasizing the geographic distribution, geologic occurrence, resources, grade, and environmental use factors of Texas lignite. Comprehensive subsurface studies conducted by the Bureau of Economic Geology in recent years have indicated exceedingly large volumes of lignite at varying depths in the Texas Coastal Plain. Although below depths for conventional mining and not amenable to immediate utilization, future developments of in situ recovery technology through underground gasification make deep-basin lignite a major potential source of energy. Lignite distribution, occurrence, and resource estimates, as well as factors involved in its recovery, are presented in this report.

Energy Demand: The Role of Texas Lignite

In 1972, 72 quadrillion (72×10^{15}) Btu (British thermal units) of energy was consumed in the United States. That amount was 50 percent more than a decade previous and twice the consumption of 20 years ago. By 1980 the level of consumption is projected to be one-third higher than today. Estimates by the U. S. Bureau of Mines show that consumption in year 2000 will be more than 2.6 times that of 1972. In addition to overall increase in level of consumption, per capita consumption of energy has increased 44 percent in the past 20 years. Most of the growth in energy consumption has been supplied by increased use of oil and natural gas. In recent years almost no increase occurred in the use of coal or lignite despite the fact that coal resources far exceed those of oil and gas combined. In 1920, coal (including lignite) provided more than 80 percent and oil and gas only 16 percent of our total energy. By contrast, in 1972 coal and lignite provided only 17 percent and oil and gas combined accounted for 78 percent of our total energy. At the present time other sources of energy—nuclear, hydroelectric, and geothermal—combine to account for a little more than 5 percent of our total energy supply.

As reserves of oil and natural gas continue to dwindle, the abundant coal resources of this Nation provide the major fuel potential. But problems exist in the utilization of coal or lignite. Principal of these are atmospheric pollution and surface mining. Future developments in the use of coal as an energy source, in the Nation and in Texas, will depend in part on the larger question of national energy policy.

From early days in Texas up to the present, energy from lignite has been viable, despite the discovery and development of immense oil and gas reserves during the past 50 years. In 1954, a large-volume lignite mine was opened at Alcoa in southern Milam County, with the mined lignite used for power generation in the reduction of imported bauxite to aluminum. This mine and power plant (360-megawatt capacity) went into operation at a time when oil and gas supplies were plentiful. At the present time, four large-volume, lignite-fueled, steam-electric plants are scheduled to be in operation by 1980. The first of these, Big Brown (1150 MW) in Freestone County near Fairfield, went into operation in 1971. Three others, Monticello (1150 MW) in Titus County near Mt. Pleasant, Martin Lake (1500 MW) in Rusk County near Tatum, and Forest Grove (750 MW) in Henderson County near Athens, are planned to be in operation by 1975, 1977, and 1979, respectively. Each of these plants will use between 11,000 and 22,000 short tons of lignite per day, or

4 to 8 million tons per year. Other plants of comparable size, though not announced at present, will probably be on line within the next decade. Many areas with substantial lignite reserves are currently held by several companies and will be developed as power sources in the future.

Texas lignite resources, mainly situated in East Texas, are extensive. Resources within 90 feet of the surface and thus available to conventional surface mining were conservatively computed by Perkins and Lonsdale (1955) at 3.3 billion short tons. Recent mapping of lignite lands in the Texas Coastal Plain by the Bureau of Economic Geology indicate approximately 1,000,000 acres possibly underlain by lignite at depths of less than 200 feet. Assuming an average thickness of three to ten feet of minable lignite and a specific gravity of 1.30 or 1.25, a total of 10.4 billion tons of potential resources are indicated. To these resources, within depths of conventional surface mining, may be added the much larger resource of deep-basin lignite occurring at depths from 200 to 5,000 feet below the surface. More than 100 billion short tons have been mapped, equivalent on a Btu basis to 277 billion barrels of oil. Not all the deep-basin lignite nor that near the surface can be recovered. But the magnitude of this energy resource makes it an important and substantial solid-fuel resource for the future.

Acknowledgments

The author benefited from frank discussion of Texas lignite and Eocene sedimentation with W. L. Fisher, Director, Bureau of Economic Geology. His review of the manuscript markedly improved the final product. Craig L. Burton assisted and recorded deep-basin lignite data, prepared preliminary maps, and compiled statistical data. Illustrations were prepared by the Bureau cartographic staff under the direction of James W. Macon. The report was typed by Elizabeth T. Moore, composed by Fannie M. Sellingsloh and Dawn Weiler, and edited by Kelley Kennedy.

GEOGRAPHIC DISTRIBUTION

Definitions

Lignite is a low-rank, brownish-black coal with a high moisture and volatile-matter content and a heating value of less than 8300 Btu/lb (moist, mineral-matter free), that is intermediate in coalification between peat and subbituminous coal. Most lignite contains clearly separable pieces of plant material, is soft, friable, and comparatively porous, and has a low specific gravity.

In this report two kinds of lignite deposits, near-surface and deep-basin, are defined on depth of occurrence. The former occur at 0 to 200 feet below the surface and are exploitable by modern surface-mining methods; the latter occur at 200 to 5,000 feet and are exploitable only by in situ recovery methods.

Distribution

Lignite is found throughout the Texas Gulf Coastal Plain from the Rio Grande to the Red and Sabine Rivers as near-surface and deep-basin deposits. Near-surface lignite occurs within the outcrop of the main lignite-bearing rocks in an irregular area centered on Panola and adjacent counties (Sabine uplift) and two elongate bands: a continuous, northern band stretching from the Rio Grande (Webb County) to the Red River (Bowie County); and a parallel coastward, discontinuous band from the Rio Grande (Starr County) to the Angelina River (Angelina County) (fig. 1). For ease of discussion, subregions are outlined based on geologic occurrence (discussed in the next section). The continuous northern band is divided into three subregions: South, Webb County northeast through Caldwell County; Central, Bastrop County north through Freestone County; and East, Henderson County northeast through Bowie County, plus the Sabine uplift area. The discontinuous, coastward band has two subregions: South, Atascosa, La Salle, McMullen, Starr, and Zapata Counties; and Southeast, Fayette County northeast through Angelina County (fig. 1).

Two large areas of deep-basin lignite have been outlined downdip and coastward from the near-surface lignite. The principal area occurs in central and eastern Texas as a broad arc which widens gradually from Gonzales County northeast to Cherokee County where it splits and wraps

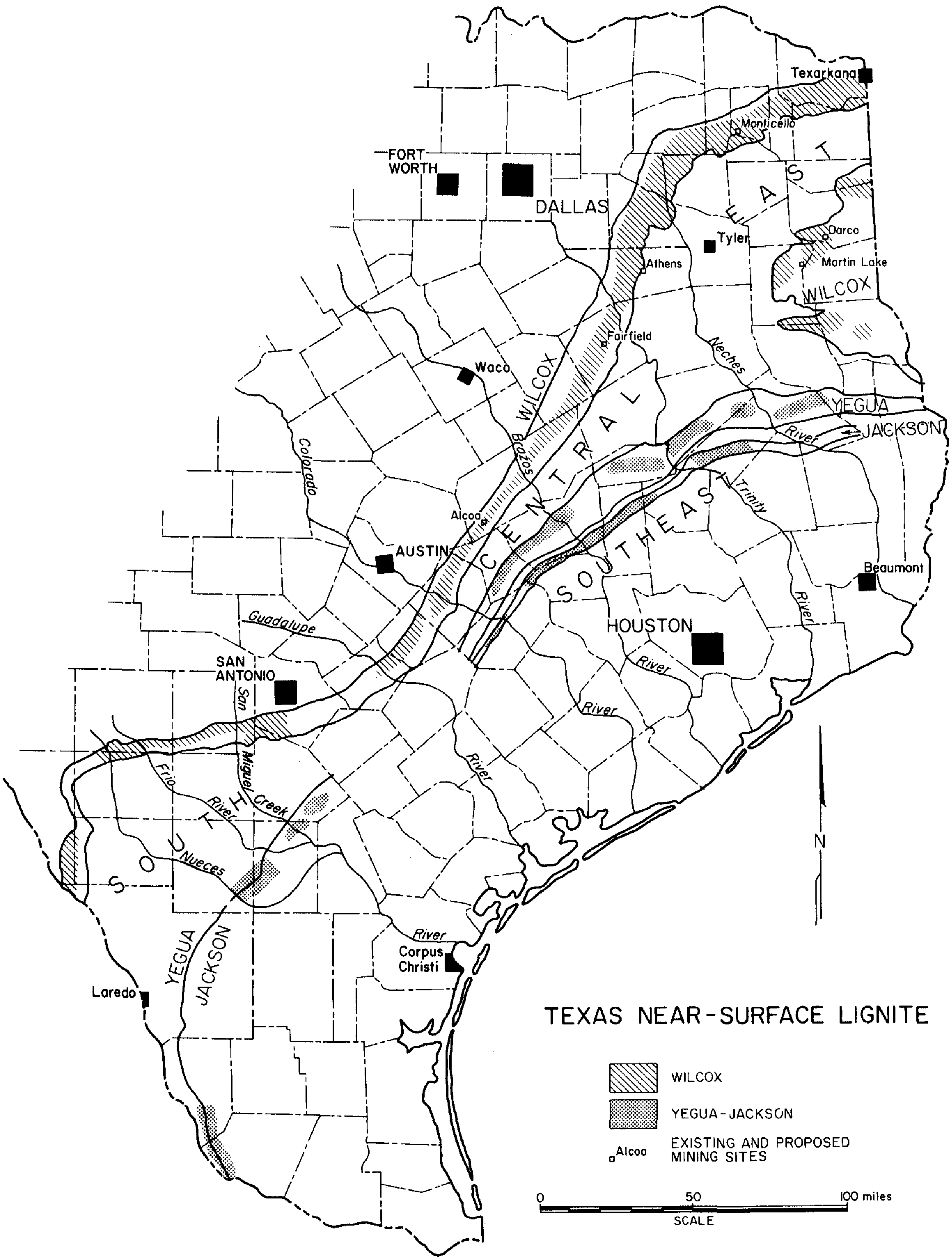


Figure 1. Distribution of Texas near-surface lignite.

around the north and south flanks of the Sabine uplift (fig. 2). In South Texas, an elongate band extends from the junction of Starr, Zapata, and Jim Hogg Counties to central McMullen County. Six comparatively small, isolated areas, two in South Texas and four in Southeast Texas, have also been delineated with the largest located in Washington County (fig. 2).

GEOLOGIC OCCURRENCE

Lignite is widely distributed in several lower Tertiary (Eocene) rock units of the Texas Gulf Coastal Plain. Many of these lignite deposits are in seams too thin (less than 3 or 4 feet thick) or too small areally to be commercially significant. The principal commercial lignite deposits are found in the lower Eocene Wilcox Group, while deposits of secondary importance are found in the upper Eocene Yegua Formation and Jackson Group (table 1; Fisher, 1963).

Lignite occurs as a component facies of ancient fluvial, deltaic, and lagoonal rocks (Fisher, 1968; McGowen, 1968). Commercial deposits of fluvial lignite occur only in the Wilcox Group. Deltaic lignite occurs primarily in the Wilcox Group with smaller occurrences in the Yegua and Manning Formations (Fisher and McGowen, 1967; Fisher, 1969; Fisher and others, 1970). Lagoonal lignite occurs with equal abundance in the Wilcox Group, Indio Formation (west of the Frio River, Indio equals Wilcox), Yegua Formation, and Jackson Group.

Fluvial Lignite

Fluvial lignite occurs in East Texas in the Wilcox Group at several stratigraphic horizons. It is a component facies of the Mt. Pleasant fluvial system (Fisher and McGowen, 1967). The pattern of sedimentation is cyclic—that is, multistacked, thick, fining-upward sequences or fluvial cycles (fig. 3, well Q-101). Lignite is associated with the fine-grained upper part (overbank deposits) of these cycles (Dumble, 1892, fig. 8, p. 133; Fisher, 1964, fig. 8, p. 167). In most cases, commercial lignite deposits occur between paleochannels or in interchannel areas (fig. 4).

Fluvial lignite has a high percentage of woody material. Dumble (1892, p. 163) reports stumps in growth position and tree trunks (16 to 20 feet by 18 to 20 inches) in this lignite. Its low sulfur content (1.0 ± 0.4 percent[1]), dominantly woody composition (Fisher, 1968), and palynoflora support forested, fresh-water swamps as sites of accumulation (Nichols and Traverse, 1971).

Apparently, commercial deposits in the Mt. Pleasant fluvial system formed as backswamp peats on broad, isolated floodplains separated by stabilized meanderbelts. The Mississippi River alluvial plain is a good Holocene analogue. On the alluvial plain, swamps and peats occur between meanderbelts established by major ancient and modern Mississippi River courses (Frazier, 1967, figs. 7 and 8, p. 298–299), for example, between Bayou Teche and the Mississippi River or Bayou Teche and intervening, upstream ancient courses (fig. 5). The relationship of swamps to channels on the Mississippi alluvial plain is similar to that of the Wilcox lignites and channels (figs. 4 and 5). Frazier and Osanik (1969) describe backswamp peats up to 20 feet thick, composed of cypress-gum vegetation, flanking natural-levee ridges (fig. 6). Swamps persist because peat accumulation keeps pace with subsidence and are sufficiently far from active channels to be free of vegetation-inhibiting influxes of sediment. Evidently, Wilcox swamps were similarly located for the lignites are moderately low in ash (13.8 ± 5.6 percent).

Deltaic Lignite

Deltaic lignite occurs in Central Texas in the Wilcox Group and in Southeast Texas in the Yegua and Manning Formations (figs. 7, 8, and 9). Lignites occurring in the Calvert Bluff Formation of the Wilcox Group are by far the most important; lignites in the lower part of the Wilcox Group (Hooper Formation) are too thin and discontinuous to be commercially significant. Wilcox lignite is a component facies of the Rockdale delta system (Fisher and McGowen, 1967), Yegua lignite an unnamed delta system (Fisher, 1969), and Manning lignite the Fayette delta system (Fisher and others, 1970). Lignite is associated with three sedimentation patterns: alternating distributary channel and interdistributary deposits; repetitive coarsening-upward, delta-front sequences; and

[1] All analyses cited in text on dry basis.

Table 1. Stratigraphic occurrence of Texas lignite.

		East, Southeast, and Central Texas	South Texas	
OLIGOCENE		Catahoula Group		
EOCENE SERIES	Jackson Group	Whitsett Formation	upper	
		Manning Formation*	middle	
		Wellborn Formation	lower*	
		Caddell Formation		
	Claiborne Group	Yegua Formation*	upper Yegua*	
		Cook Mountain Formation		
		Stone City Formation	Laredo Formation	
		Sparta Sand		
		Weches Formation		
		Queen City Sand	El Pico Clay	
		Reklaw Formation	Bigford Formation	
		Carrizo Sand	Carrizo	
	Wilcox Group*	Calvert Bluff Formation*		
		Simsboro Sand	lower Wilcox* Group	Indio* Formation
		Hooper Formation		
		Midway Group		

*main lignite occurrences.

terminology from: Barnes, 1967, 1970, 1974b; Eargle, 1968; Renick, 1936.

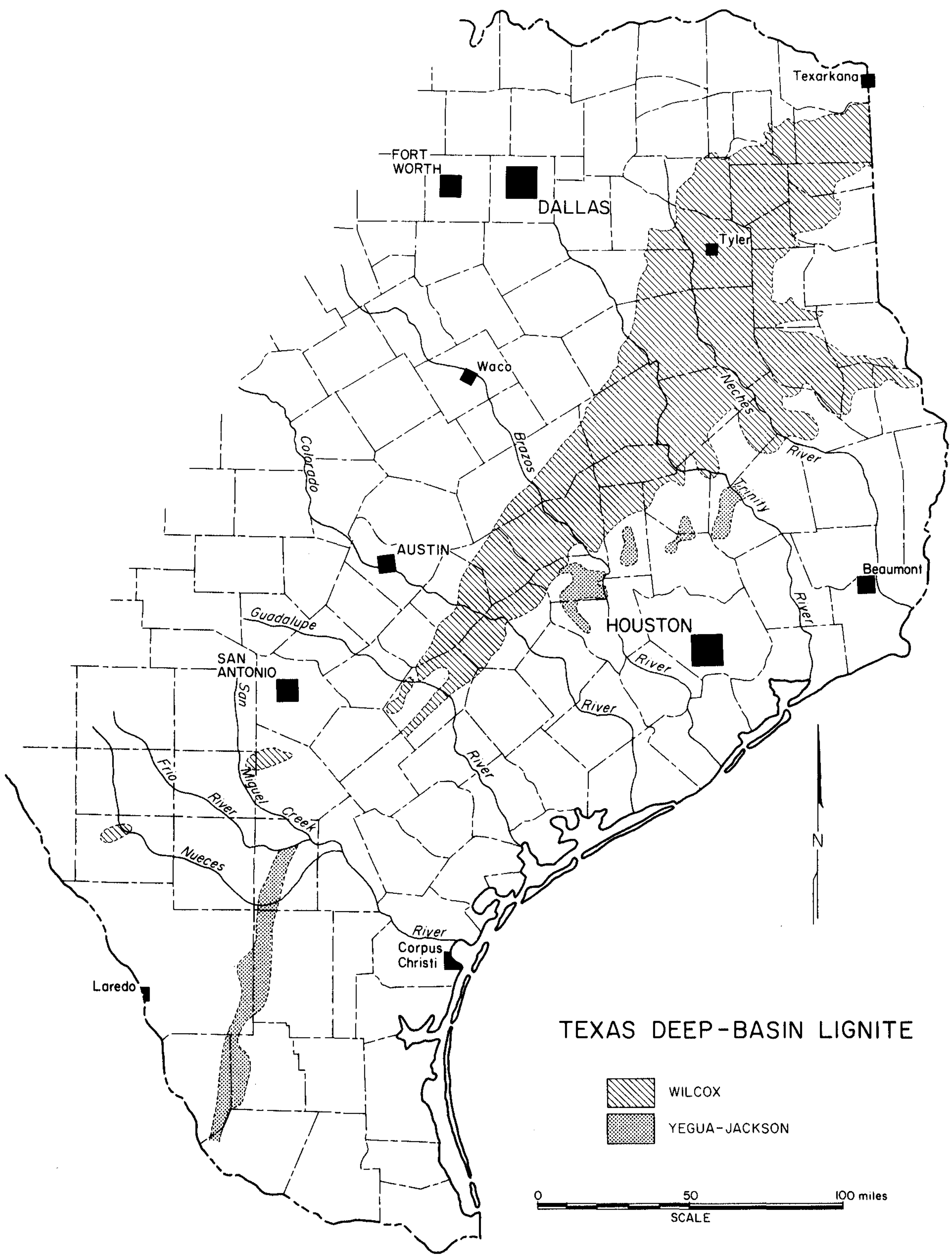


Figure 2. Distribution of Texas deep-basin lignite.

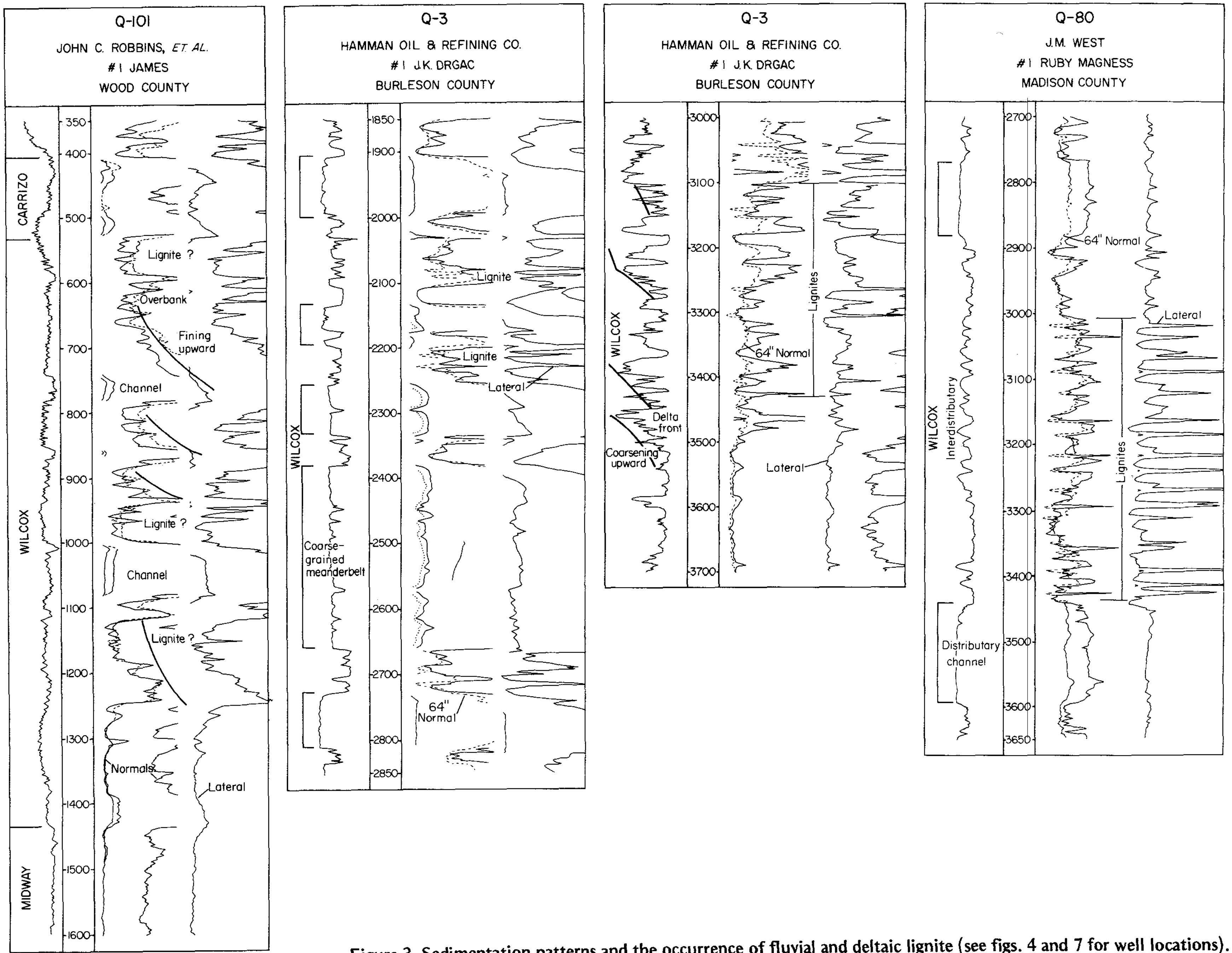


Figure 3. Sedimentation patterns and the occurrence of fluvial and deltaic lignite (see figs. 4 and 7 for well locations).

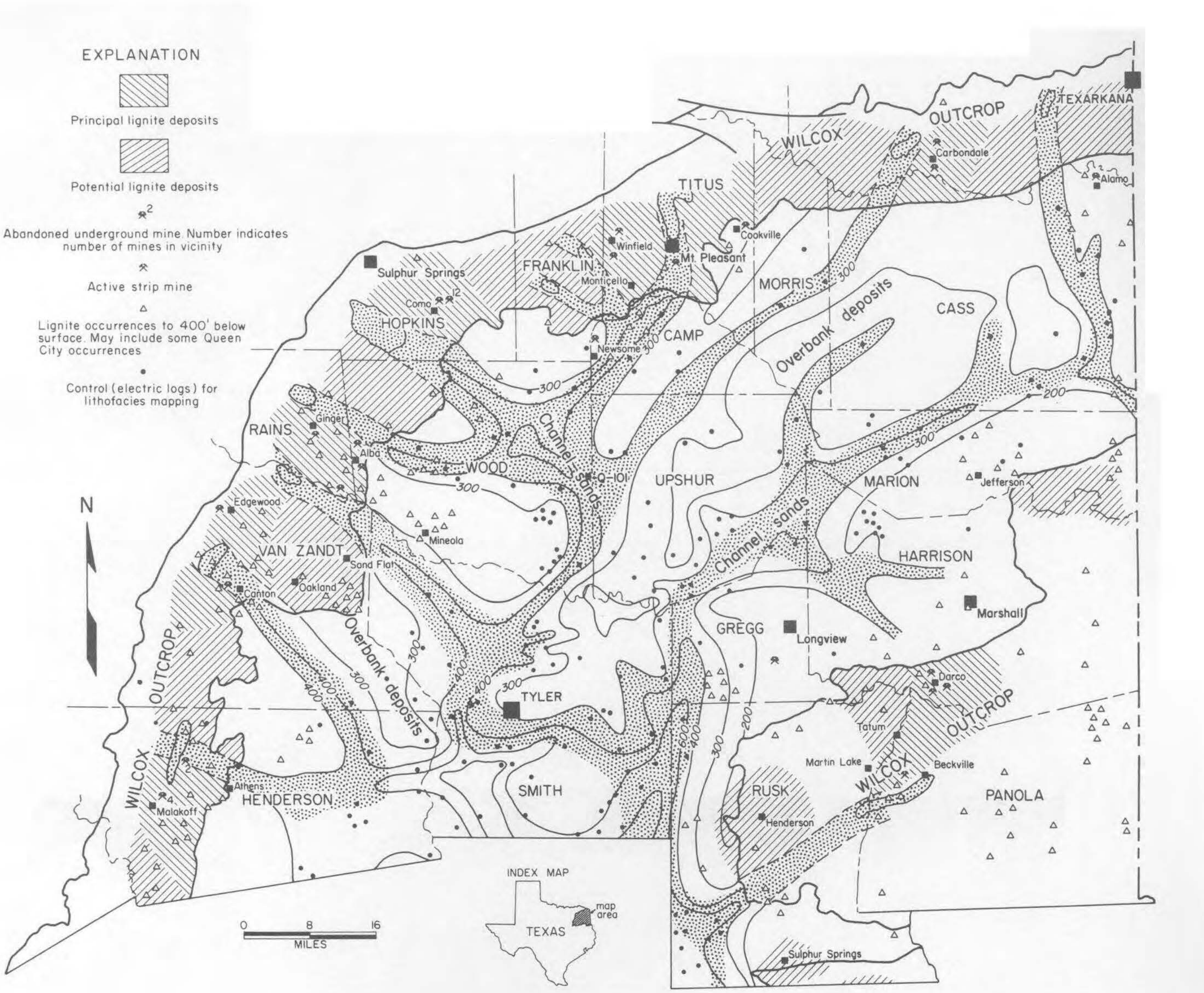


Figure 4. Distribution of East Texas Wilcox lignite. Wilcox outcrop from Darton and others, 1937; lithofacies mapping from Fisher and McGowen, 1967; lignite occurrences from Perkins and Lonsdale, 1955.

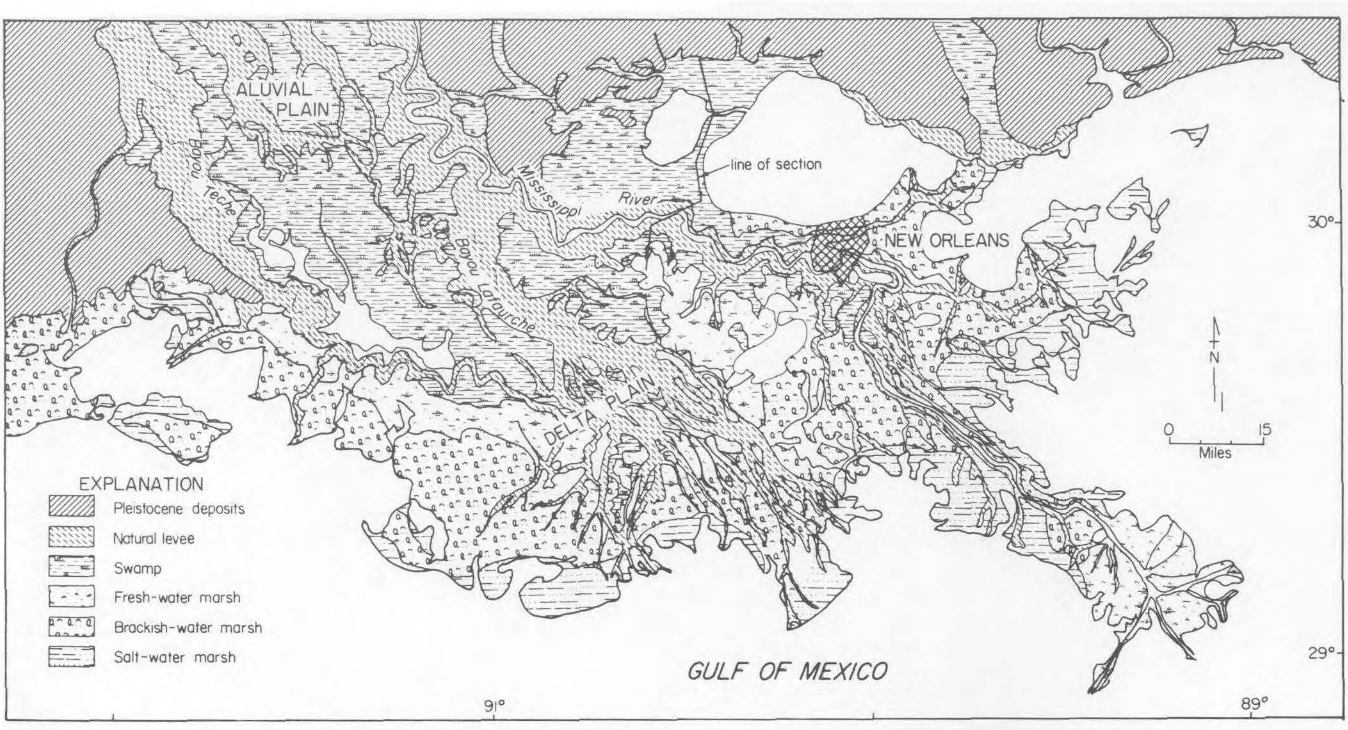


Figure 5. Swamp and marsh zonation of Mississippi delta and lower alluvial plain; from Frazier and Osanik, 1969.

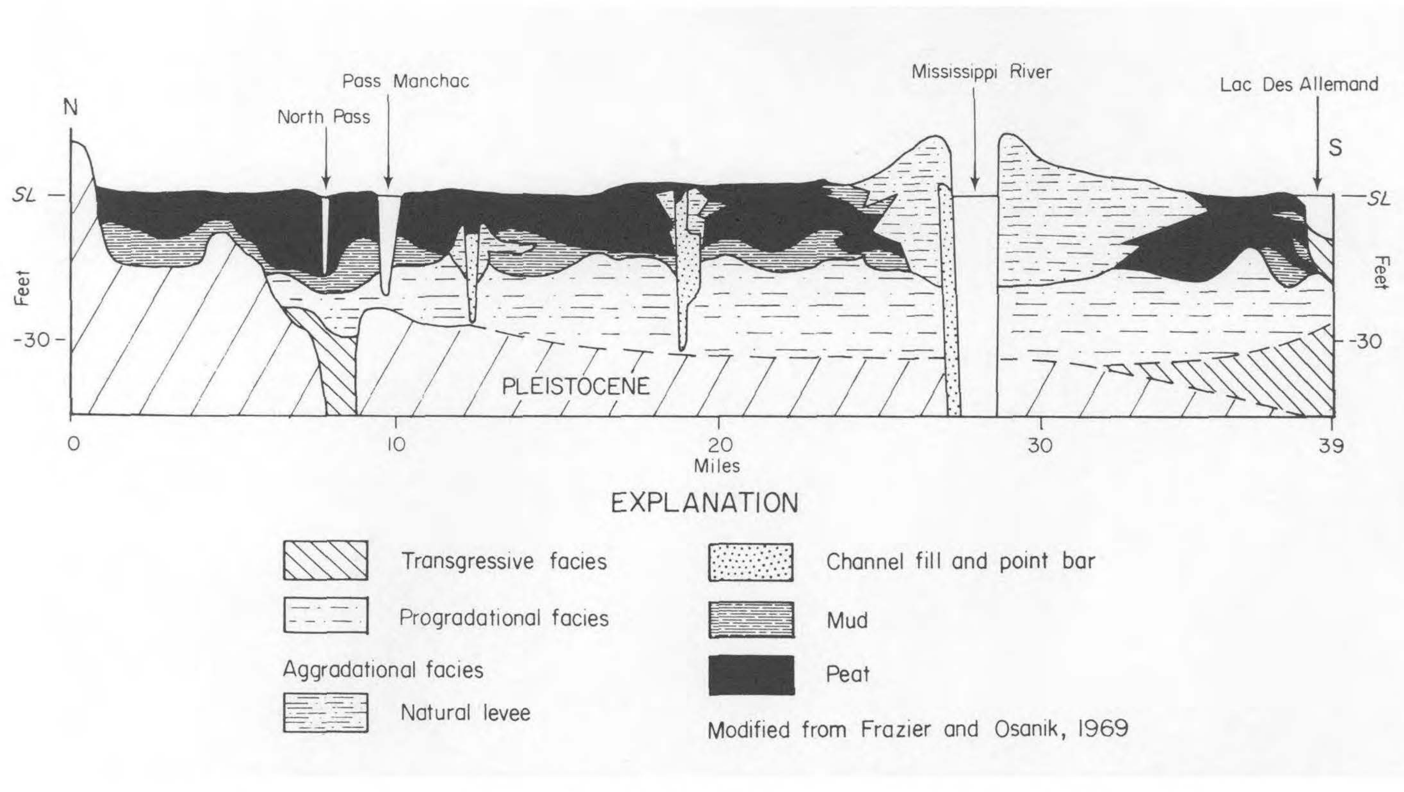


Figure 6. Cross section through Mississippi River backswamp peat (see fig. 5 for location).

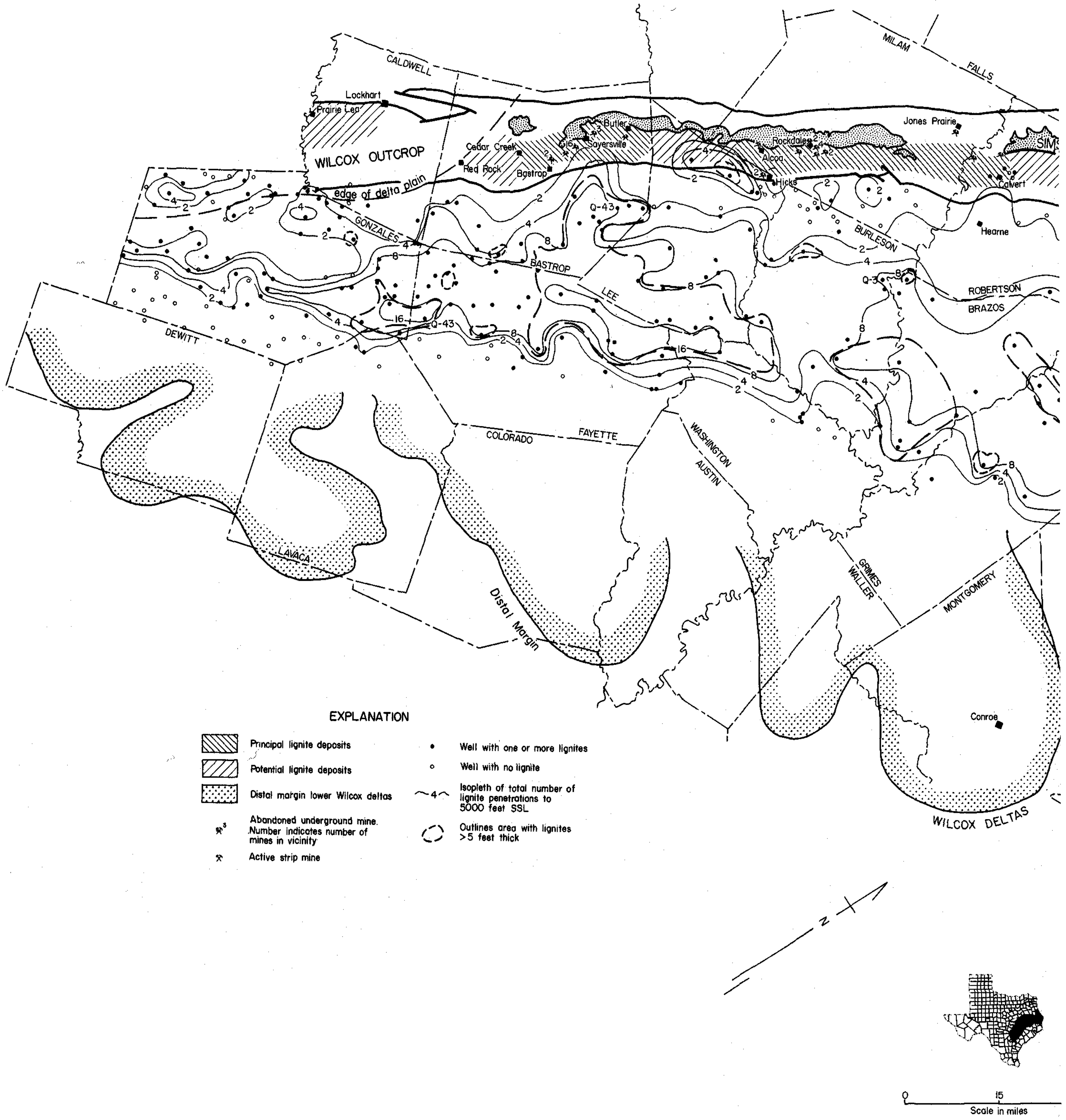


Figure 7. Distribution of Central Texas Wilcox lignite. Hooper, Simsboro, and Calvert Bluff outcrop lower Wilcox deltas from Fisher and McGowen, 1967.

, Simsboro, and Calvert Bluff outcrop from Barnes, 1970, 1974a, and 1974c; distal margins of

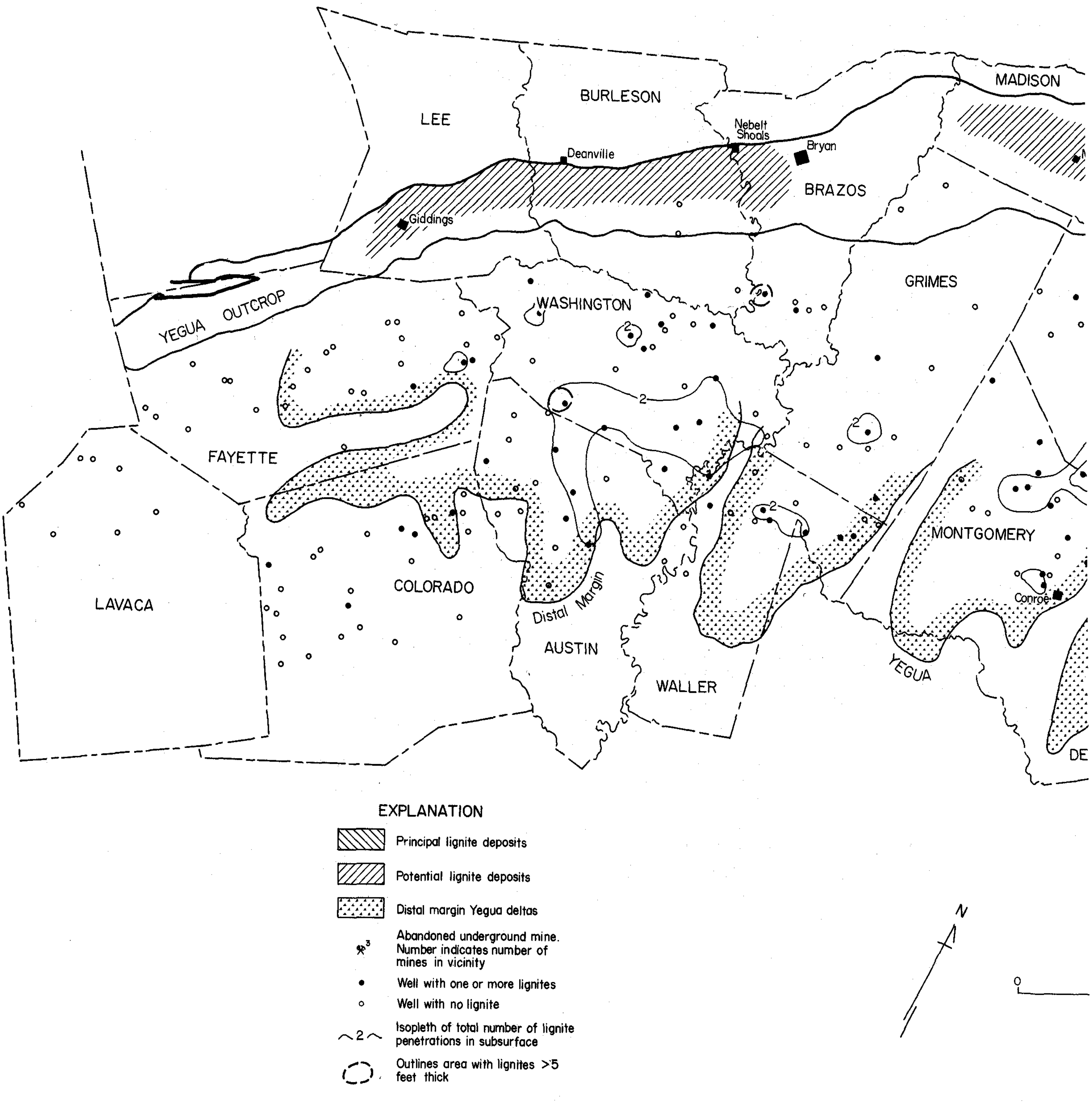
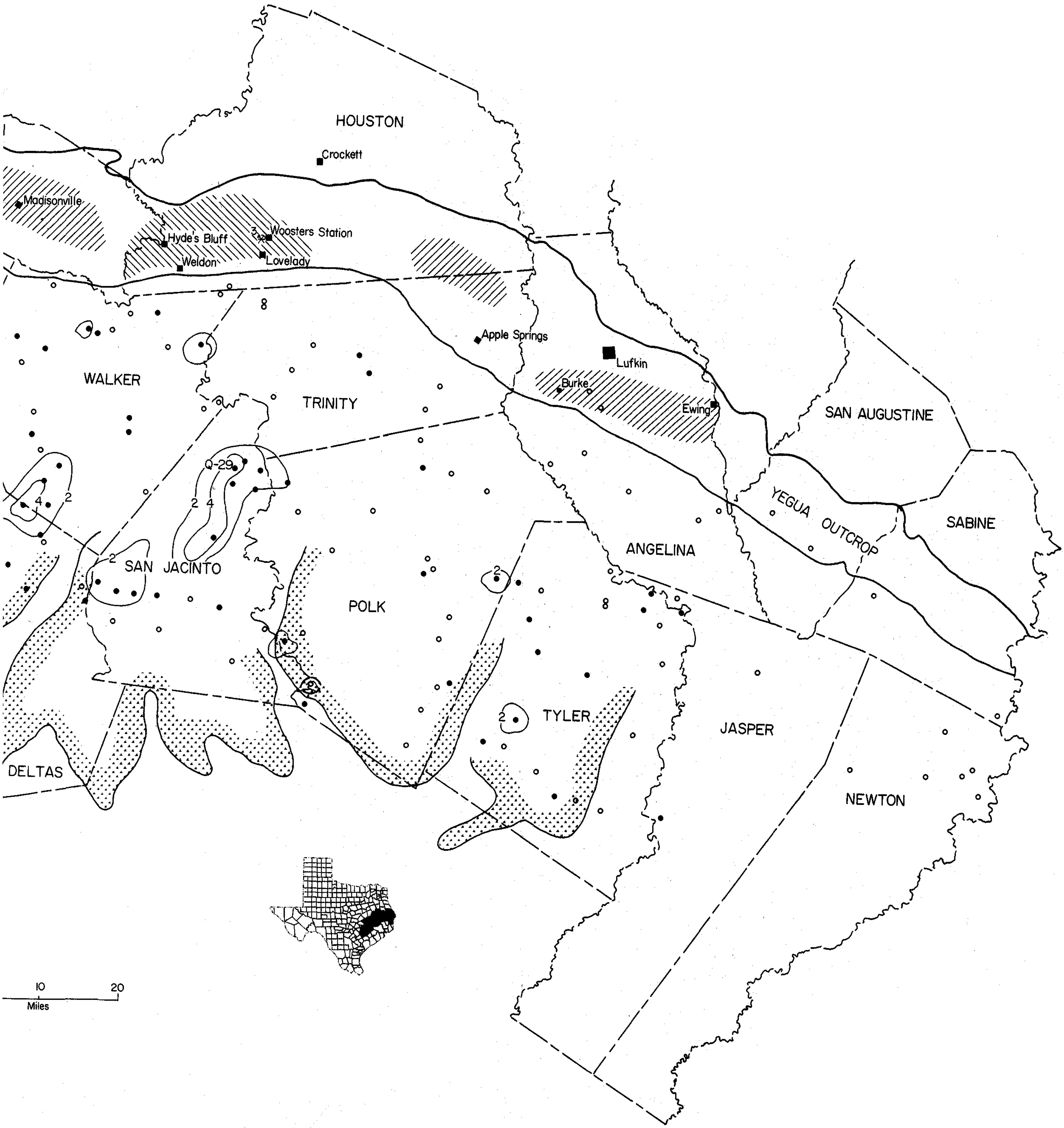


Figure 8. Distribution of Southeast Texas Yegua lignite. Yegua outcrop fr
(Bur. Econ. Geology work map).



p from Barnes, 1967, 1968, and 1974a; distal margins of Yegua deltas from Fisher

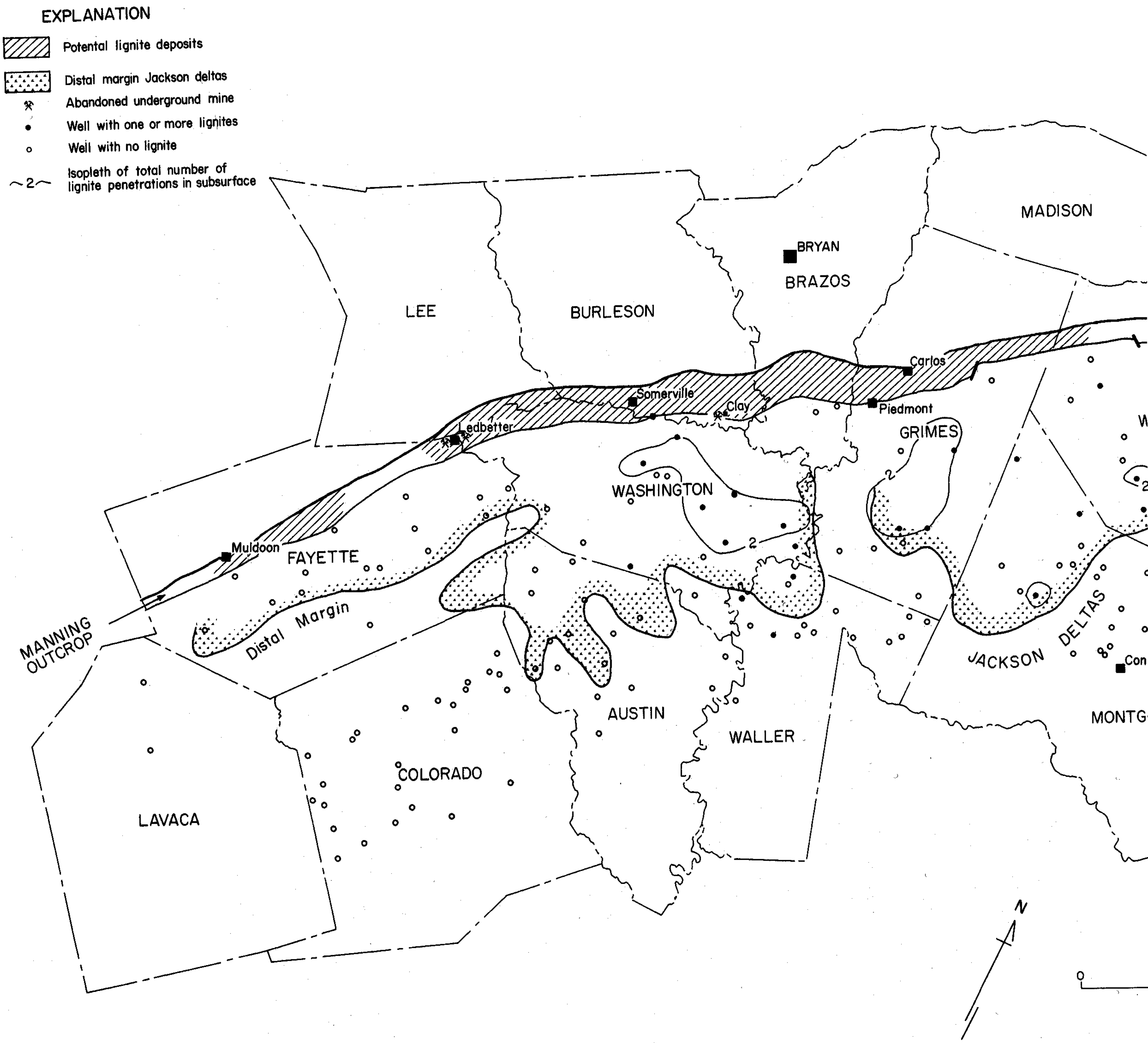


Figure 9. Distribution of Southeast Texas Jackson (Manning) lignite. Manni
deltas from Fisher and others, 1970.

e. Manning outcrop from Barnes, 1967, 1968, and 1974a; distal margins of Jackson stacked coarse-grained meanderbelt deposits (fig. 3). The thickest, most extensive lignites are associated with delta-plain, interdistributary deposits (fig. 3, well Q-80). The other occurrences are not commercially significant.

Deltaic lignite is primarily nonwoody reflecting a marsh origin (Fisher, 1968), though the presence of rather abundant woody material indicates peat accumulation in marshes high on the delta plain. For example, the palynoflora of the main lignite seam at Alcoa in Milam County indicates that fresh-water marsh and hardwood swamp conditions alternated (Atlee and others, 1968), suggesting a location on the highest part of the delta plain. Modern analogues are taken from the Mississippi delta plain, a Holocene analogue of the Wilcox Rockdale delta system (Fisher, 1969). The Mississippi delta marshes show a zonation from fresh to brackish to saline gulfward (fig. 5). Peat is most extensively developed on that part of the delta plain away from the contaminating effects of active distributaries and inland from the destructive effects of the Gulf or roughly coincident with fresh and brackish marshes. Within that setting peats accumulate in two ways. One is a marsh peat accumulating between the distributary channels of an actively prograding delta lobe (fig. 10; Fisk, 1960; Frazier and Osanik, 1969). These interdistributary peats have limited lateral extent, a high detritus and sulfide content (Fisk, 1960; Coleman and Smith, 1964), and commonly occur in clusters of 3 to 6 beds separated by thin mud units. The other case is a marsh peat located on an abandoned, inactive delta lobe in which peat accumulation keeps pace with delta foundering (fig. 10). These blanket peats have wide lateral extent (up to 200 sq mi), spreading across several abandoned distributary channels, a tabular shape, and a low detritus content (Coleman and Smith, 1964).

Fisher and McGowen (1967) and McGowen (1968) interpreted areally extensive Wilcox lignites (i.e., blanket peats) to be a regional, landward facies of marine delta destruction, while correlating laterally restricted lignites with constructional interdistributary environments. Commercial Wilcox and Yegua-Jackson deltaic lignites probably formed as blanket peats. Grade, composition, and size of the Wilcox commercial lignites are closely analogous with modern blanket peats, as revealed by low ash (12.2 ± 3.3 percent), moderate sulfur (1.4 ± 0.7 percent), tabular shape, and wide extent (up to 10 miles).

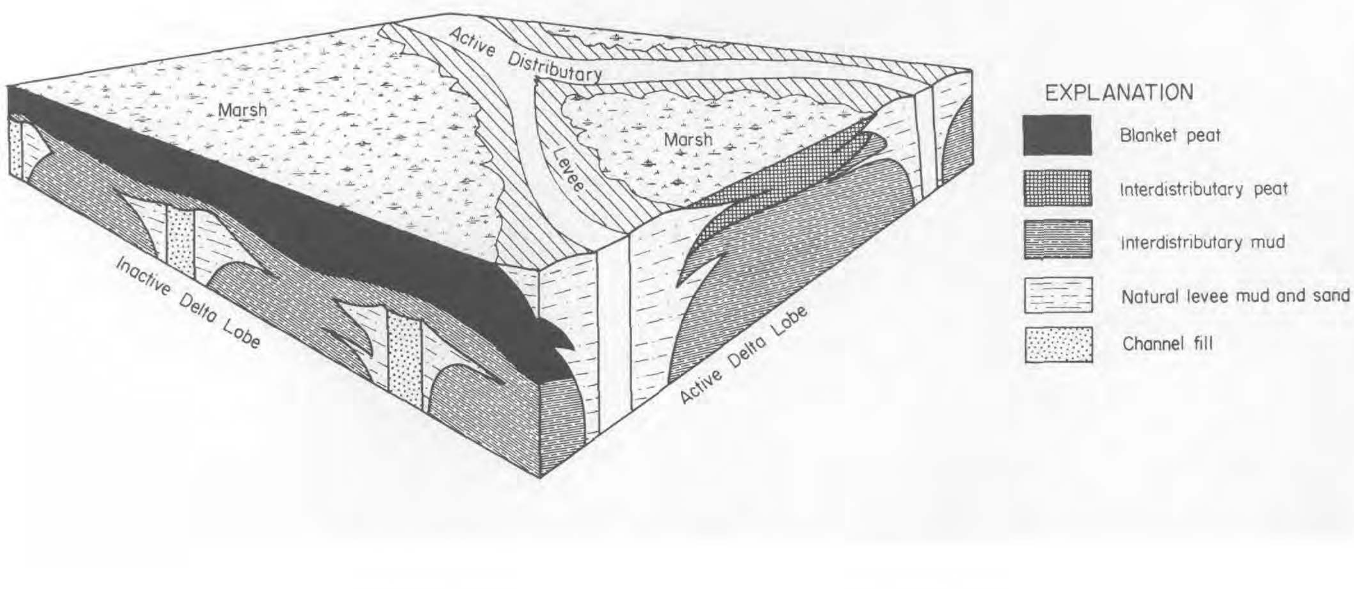


Figure 10. Modern deltaic peats: blanket vs. interdistributary peat.

Lagoonal Lignite

Lagoonal lignite occurs primarily in South Texas in the Wilcox Group, Indio Formation, upper Yegua Formation, and lower Jackson Group, and secondarily in East Texas in the Wilcox. Wilcox and Yegua-Jackson lignite are about equally abundant, but the Wilcox lignite is superior in quality. Upper Eocene lignite is grouped as Yegua-Jackson because in South Texas there is no well-defined, easily recognized rock-stratigraphic marker separating the two units (fig. 11, well Q-276).

Wilcox and Indio lignite in South Texas is a component facies of the Indio lagoon-bay system and in East Texas of the Pendleton lagoon-bay system (Fisher and McGowen, 1967). Yegua-Jackson lignite is a component facies of Yegua and Jackson barrier bar-strandplain systems (Fisher, 1969; Fisher and others, 1970). The pattern of sedimentation is one of multistacked progradational or coarsening-upward barrier- and strandplain-beach sequences in which the lignites are associated with inland or updip lagoonal muds (fig. 11). Regionally the lignites lie updip (landward) of the axes of the ancient barrier bar-strandplain systems (figs. 12 and 13), reflecting their lagoonal origin.

Lagoonal lignite has a high sulfur content (Yegua-Jackson 1.9±0.8; Wilcox 1.7±0.5 percent) suggesting a salt marsh origin, while its high ash content (Yegua-Jackson 40.8±14.3; Wilcox 16.5±8.3 percent) indicates frequent introduction of clastic material. Modern analogues are found, though peat is not extensively developed, as a component environment of regressive, linear clastic shorelines. For example, in the Texas Gulf Coast barrier bar-lagoon system, peats are generally absent while on the Nayarit coast (western Mexico), abundant but thin marsh peats are accumulating in a strandplain-lagoonal system (Curray and others, 1969). Despite the secondary role of peats in both environments, they illustrate the sedimentary framework of lagoonal peat (lignite) accumulation. Figure 14, based on the Texas and Mexico examples, shows the component facies of a progradational, barrier-strandplain beach sequence. The resulting coarsening-upward sequence, capped by peat-bearing lagoonal sediments, is closely analogous to those seen in the Eocene (fig. 11).

NEAR-SURFACE DEPOSITS

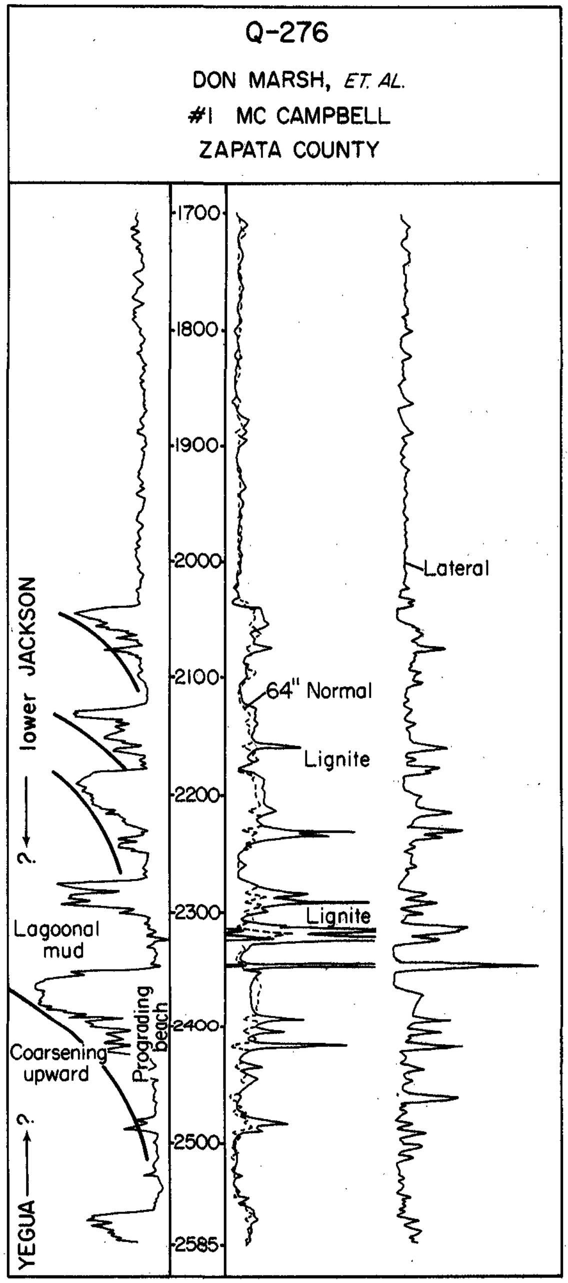
The most important and highest grade lignite deposits occur in the Wilcox Group north of the Colorado River. Deposits of secondary importance occur in the Yegua Formation and Jackson Group, with the best deposits in these units also found north of the Colorado River. In the following discussion the Wilcox and Yegua-Jackson lignite are treated separately. They are discussed by geographic areas, as previously outlined, reflecting the dominant geologic occurrence: East Texas (fluvial), Central and Southeast Texas (deltaic), and South Texas (lagoonal). Much of the material for this section comes from Fisher (1963).

Wilcox Group

East Texas.—The principal deposits are located in southern Titus County, south-central Hopkins County, southwestern Wood and southeastern Rains Counties, Van Zandt County, western Henderson County, southern Harrison and northwestern Panola Counties, and northwestern Shelby and northeastern Nacogdoches Counties (figs. 4 and 7; table 2). All deposits are fluvial lignite except those of Shelby and Nacogdoches Counties, which are lagoonal lignite.

In the past all mining was by undergound room-and-pillar methods through shafts 50 to 150 feet deep. The Malakoff district, in western Henderson County, was the most important of the old mining districts. At one time or another 14 mines were active in the district, yielding some of the largest tonnages in the State. In the Alba district of southwestern Wood County, 17 mines were active from 1890 to 1946, and in the Como district of south-central Hopkins County, 12 mines were active from 1901 to 1946.

Currently lignite is being strip-mined in southern Harrison County at Darco by ICI America, Inc., for the manufacture of activated carbon. Two large strip mines are scheduled for operation by Texas Utilities Company (Industrial Generating Company) at Winfield in west-central Titus County, and Beckville in northwestern Panola



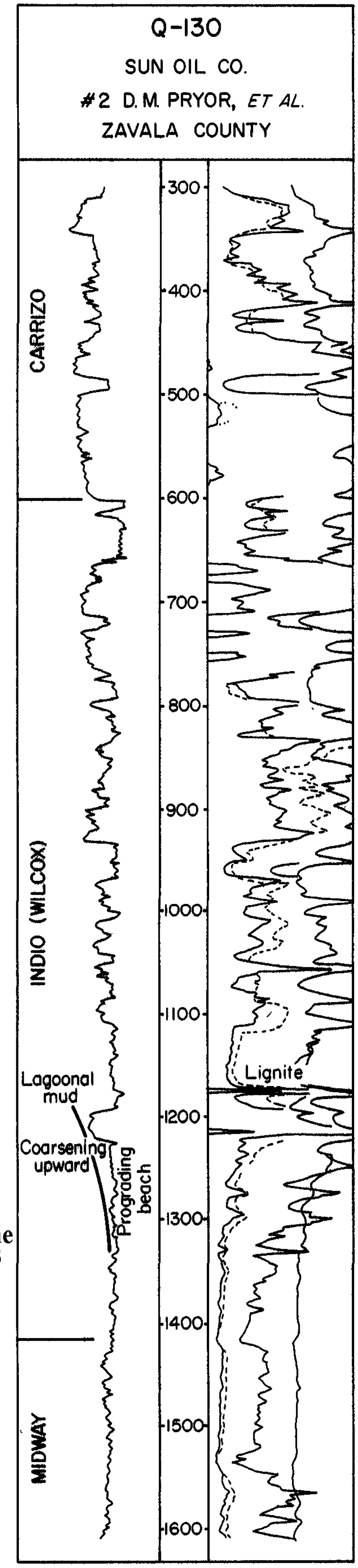


Figure 11. Sedimentation patterns and the occurrence of lagoonal lignite (see figs. 12 and 13 for well locations).

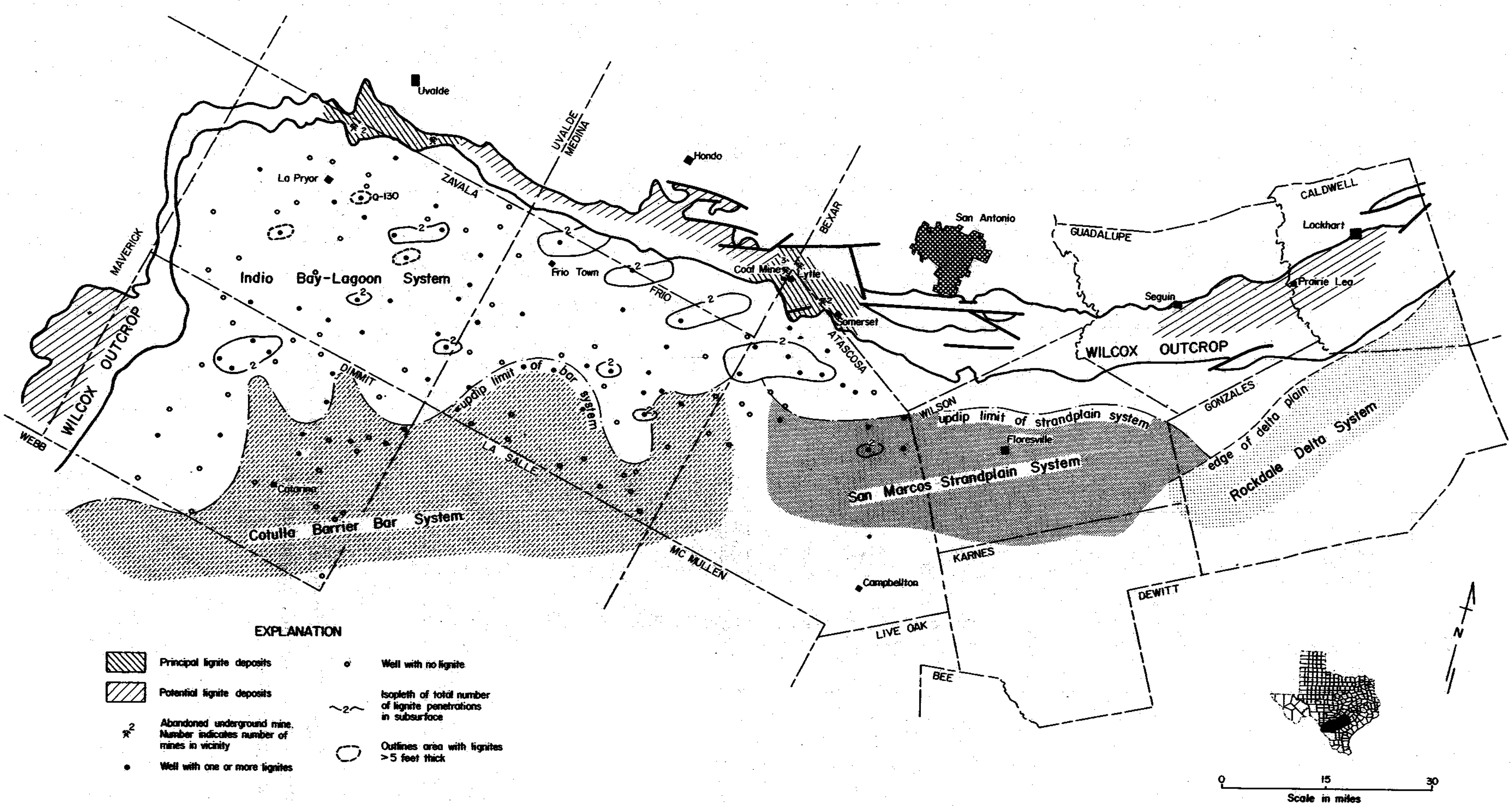


Figure 12. Distribution of South Texas Wilcox lignite. Wilcox outcrop from Darton and others, 1937; Wilcox depositional systems from Fisher and McGowen, 1967.

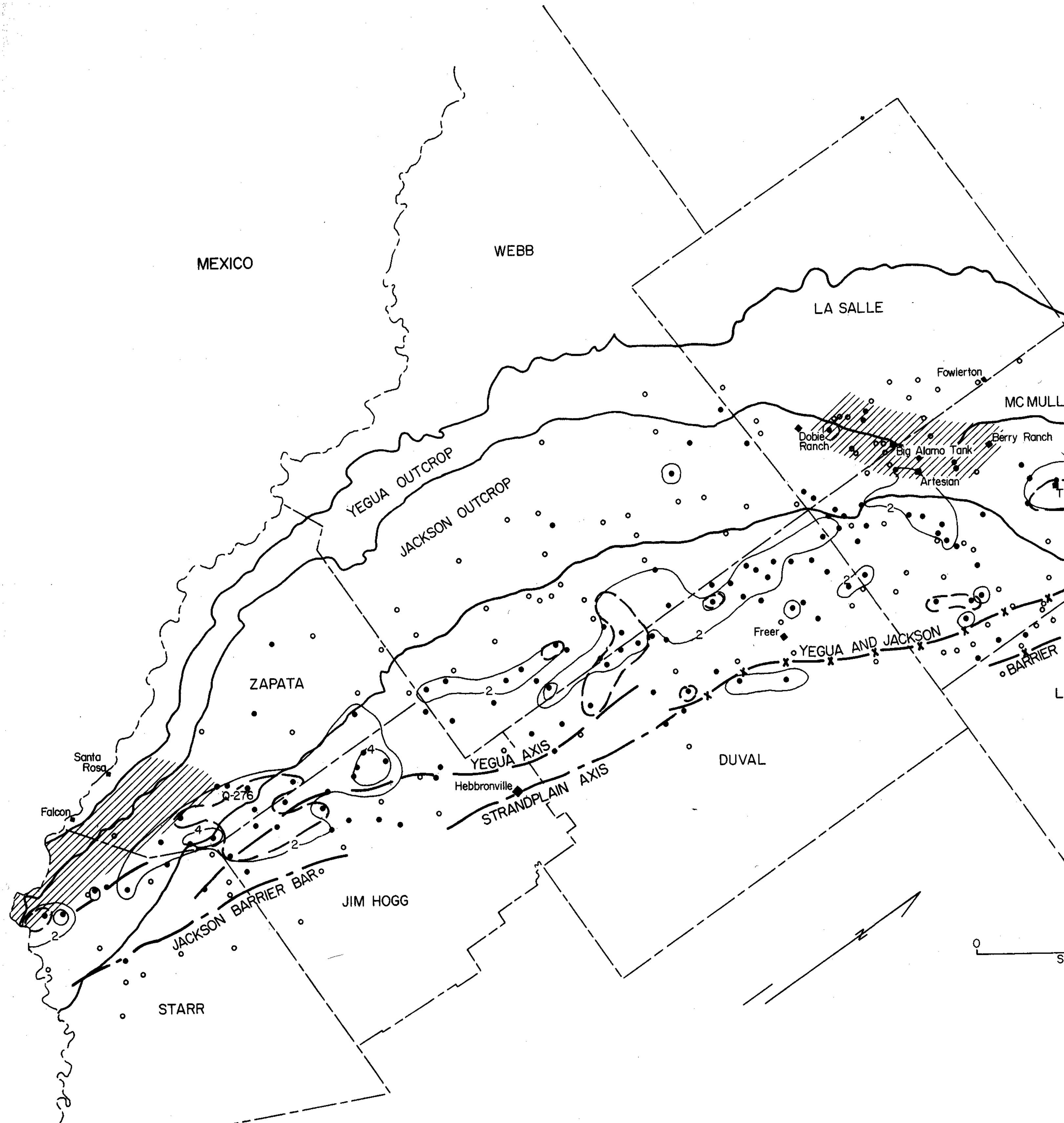
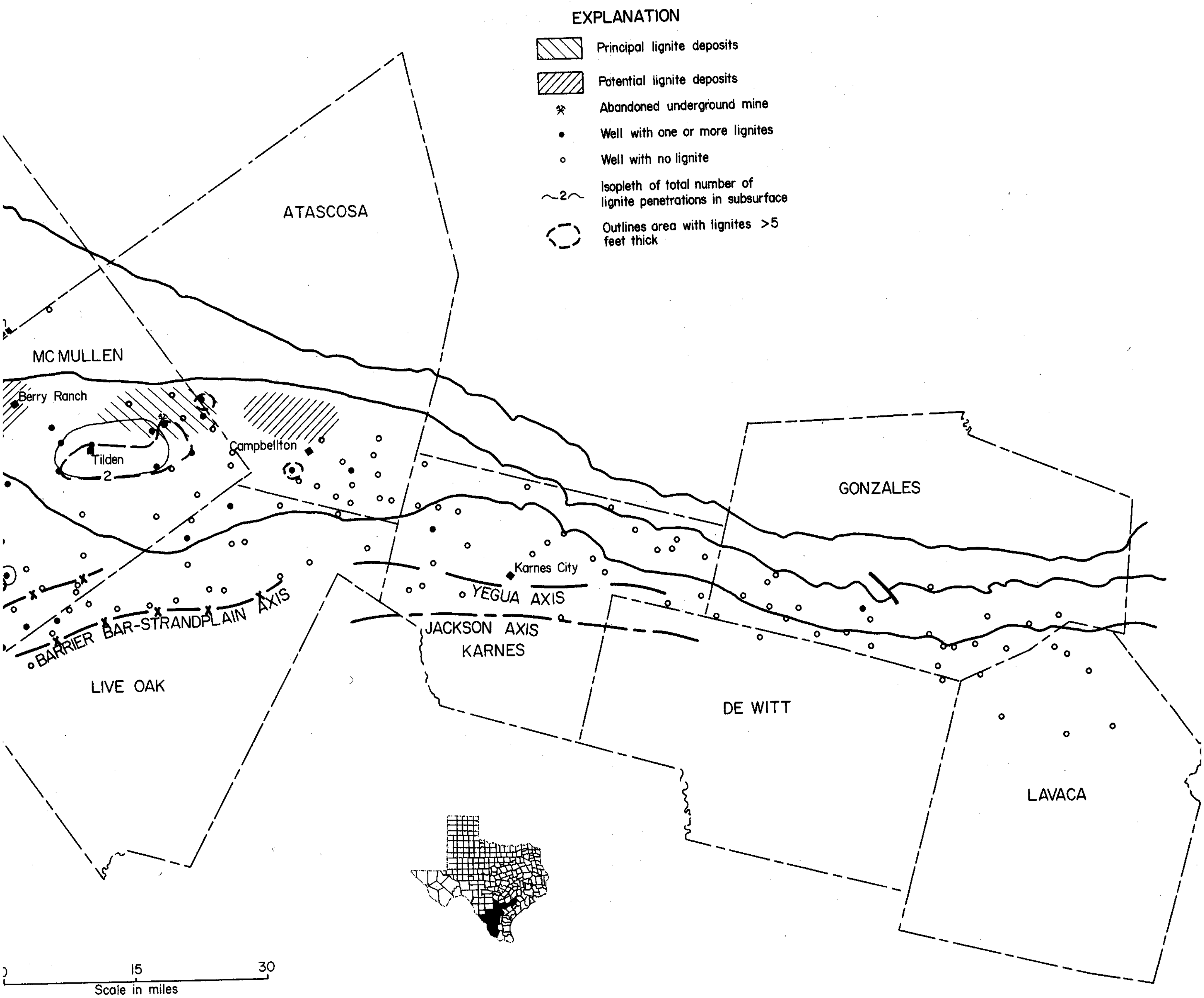
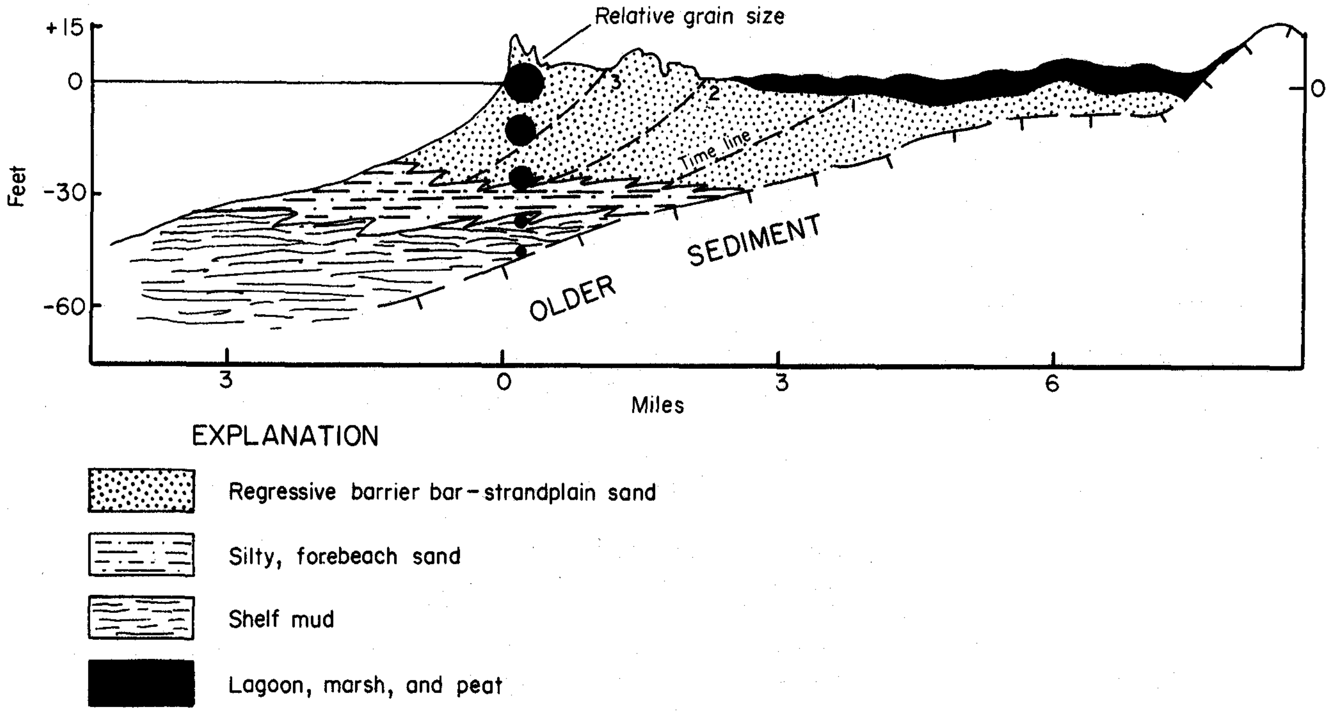


Figure 13. Distribution of South Texas Yegua-Jackso
Yegua-Jackson barrier bar-strandplain axes from Fisher and oth



/egua-Jackson lignite. Yegua and Jackson outcrop from Darton and others, 1937; Barnes, in preparation; isher and others, 1970; Fisher (Bur. Econ. Geology work maps).



Adapted from Curray, and others, 1967; Bernard and others, 1970

Figure 14. Holocene prograding beach sequence.

County, to supply lignite for steam-electric plants. Mining is expected to begin about 1974 and 1976, respectively. Texas Power and Light Company has scheduled its Forest Grove plant in Henderson County for 1979 operation, though mining is expected to begin before that time.

Potential lignite deposits (table 3) are shown on figure 4. They have been outlined with regard to inferred interchannel position, previous production, and reported outcrop and well occurrences (Dumble, 1892; Adams and others, 1927; Fisher, 1963). The key to finding new lignite deposits is the paleochannels. Exploratory drilling should be preceded by a thorough lithofacies and stratigraphic study aimed at delineating the Wilcox channels. Drilling then should be concentrated in the interchannel areas. Potential resources are estimated at 5,085 million tons (table 4).

Central Texas.—The principal deposits are deltaic lignite located in Freestone County, northern Robertson County, southern Milam County, and northern Bastrop County (fig. 7 and table 2). In the past the lignite deposits of Milam County have been the most important and most exploited lignite in Texas. At least 34 different companies have operated mines in the past 80 years with the Rockdale district being the most important of the old mining districts. In Bastrop County from 1886 to 1944, approximately 25 mines have been active at one time or another. Mining centered largely along the Missouri-Kansas-Texas Railroad between Sayersville and Bastrop and along the Southern Pacific Railroad in the vicinity of Butler. Today two large strip mines, operated by Industrial Generating Company at Alcoa (southern Milam County) and Fairfield (Big Brown operation, northern Freestone County), are producing lignite for steam-electric plants (fig. 7).

Commercial lignites occur in the lower Calvert Bluff Formation directly overlying the Simsboro Sand (fig. 15). Simsboro sands in the outcrop are interpreted as coarse-grained meanderbelt deposits (McGowen and Garner, 1970), while in the subsurface both coarse-grained and fine-grained meanderbelt deposits are present (fig. 15). The

Table 2. Principal lignite deposits.

County	Group or Formation	Location	Thickness[1] (feet)	Facies
Anderson	Calvert Bluff	concentrically around the Palestine salt dome 5 miles west-southwest of Palestine	7.5	deltaic
Atascosa	lower Wilcox	northern part; vicinity of Lytle	5.5	lagoonal
Bastrop	Calvert Bluff	vicinity of Butler, divide area between Big Sandy and Piney Creeks from Sayersville to Bastrop, and Cedar Creek east of FM 20	4-10	deltaic
Bexar	lower Wilcox	Medina-Atascosa line to Somerset area	4.5-6	deltaic
Bowie	Wilcox	south-central part in Carbondale area; Sulphur River	3-13	fluvial
Freestone	Wilcox	southern corner and belt 3 x 12 miles trending northeast from Fairfield (Big Brown steam plant and strip mine)	5-12	deltaic
Harrison	Wilcox	astride the Sabine River from State Hwy. 43 to Eight Mile Creek (Darco area)	5-10	fluvial
Henderson	Wilcox	north and east of Malakoff within 6.5-mile radius; Caney Creek (site of T.P.&L. Forest Grove steam plant, 6 miles northwest of Athens)	7-12	fluvial
Hopkins	Wilcox	southeastern part; vicinity of Como	5.5-8.5	fluvial
Houston	Yegua	southwest part from Lovelady area to Trinity Rivers; Wooters Station	2-6	deltaic
Lee	Calvert Bluff	extreme northeastern part in vicinity of Hicks	4-6	deltaic
McMullen	Yegua-Jackson	north-central part, San Miguel Creek area, 8 miles north of Tilden	5-8	lagoonal
Medina	lower Wilcox	just west of Lytle at the old community of Coal Mine	5-8	lagoonal
Milam	Calvert Bluff	from the southern corner northeast to the Brazos River; Alcoa (Industrial Generating Co. active strip mine), and Rockdale vicinities	7-16	deltaic
Nacogdoches	Wilcox	extreme northeastern part in Garrison area	4.5	lagoonal

[1]maximum expected thickness of individual seams

Table 2 (continued)—

County	Group or Formation	Location	Thickness[1] (feet)	Facies
Panola	Wilcox	northwestern part; Beckville area (site of Industrial Generating Co. strip mine)	5-15	fluvial
Rains	upper Wilcox	southeastern part; vicinity of Ginger	3-10	fluvial
Robertson	Calvert Bluff	west-central part north of Calvert in general area of Brazos River; Little Brazos River and Walnut Creek	3-12	deltaic
Shelby	Wilcox	vicinity of Timpson and Stockman	4-6.5	lagoonal
Titus	Wilcox	southern half; vicinity of Winfield (site of Industrial Generating Co. strip mine), Mt. Pleasant, Cookville	4-11	fluvial
Uvalde	Indio	southeastern part; east of Leona River to west of Nueces River	5-10	lagoonal
Van Zandt	Wilcox	Canton and Edgewood areas	5-12	fluvial
Wood	Wilcox	extreme western edge; Alba-Hoyt district	8-13	fluvial
Zavala	Indio	northwestern part; astride the Nueces River	3-10	lagoonal

Simsboro marks the culmination of a major progradational or regressive phase which began in the lower Hooper Formation. Note the multistacking of coarsening-upward, progradational delta-front sequences in the Hooper (fig. 15). The thin and discontinuous nature of the Hooper lignites is readily explained in terms of accumulation as interdistributary peats during active deltation or progradation. Following Simsboro deposition sedimentation slowed and on foundering older deltas, extensive lignites accumulated as delta-plain blanket peats during lower Calvert Bluff deposition. These are the lignites being strip-mined at Big Brown near Fairfield and Alcoa in Milam County. The sedimentology of the remainder of the Calvert Bluff is not clear. In the Bastrop County and Leon County areas the lignite sequence (delta-plain deposits) appears, based on electric-log patterns, to be overlain by distributary channel deposits and/or delta-front sequences (fig. 15). The latter signal the start in the upper Calvert Bluff of a second major progradational phase. Deltaic deposition closes the Wilcox which is, in turn, in outcrop unconformably overlain by braided stream deposits of the Carrizo Sand (Claiborne Group).

Potential lignite deposits (table 3) are shown on figure 7. They have been outlined with regard to inferred stratigraphic occurrence in the lower Calvert Bluff Formation, reported outcrop and well occurrences (Dumble, 1892; Fisher, 1963), and projection from deep-basin occurrences. The value of the latter as a clue to near-surface occurrences is well illustrated in figure 7. Note the fingerlike projection in eastern Bastrop County pointing updip to the Sayersville-Bastrop district, an important old mining district. Another similar projection in western Houston County points

Table 3. Potential lignite deposits.

County	Group or Formation	Location	Thickness[1] (feet)	Facies
Anderson	Calvert Bluff	extreme northwestern corner	4-8	deltaic
Angelina	Yegua	east-west across central part from Burke to Ewing	4-7	deltaic
Atascosa	Yegua-Jackson	west of Campbellton; Metate Creek, La Parita Creek	5-8	lagoonal
Bastrop	Calvert Bluff	south of Cedar Creek to Red Rock area	4-8	deltaic
Bowie	Wilcox	western one-third and eastern one-third parts	2-10	fluvial
Brazos	Yegua	northwestern part (Nebelt Shoals, Brazos River)	3-5	deltaic
	Manning	outcrop band from Brazos River to Navasota River	3-10	deltaic
Burleson	Yegua	Deanville-Davidson Creek area, Nebelt Shoals, and outcrop band from Yegua Creek to Brazos River	3-5	deltaic
	Manning	Somerville to Brazos River	2-5	deltaic
Caldwell	lower and middle Wilcox	belt running northeast from San Marcos River to Clear Fork of Plum Creek	2-4	lagoonal
Camp	Wilcox	northern part; vicinity of Newsome	4-5.5	fluvial
Cass	Wilcox	vicinity of Alamo	5-12	fluvial
Dimmit	Indio	extreme western edge	2-5	lagoonal
Fayette	Manning	Colorado River southwest to the vicinity of Muldoon and south of Ledbetter	3-8	deltaic
Franklin	Wilcox	southern half (Crutcher mine)	2-8	fluvial
Freestone	Calvert Bluff	Teague-Freestone area northeast to Fairfield-Turlington area	5-12	deltaic
Gregg	Wilcox	southeastern part	2-5	fluvial
Grimes	Manning	Piedmont-Carlos area northeast to county line	3-10	deltaic
Guadalupe	lower and middle Wilcox	belt extending northeast from Seguin to San Marcos River	2-4	lagoonal
Harrison	Wilcox	Marshall area	6-12	fluvial
Houston	Yegua	southeastern part east of Piney Creek to Cochino Bayou	2-5	deltaic
LaSalle	Yegua-Jackson	southeastern part in the Dobie Ranch-Big Alamo Tank area	2-5	lagoonal

[1] maximum expected thickness of individual seams

Table 3 (continued)–

County	Group or Formation	Location	Thickness[1] (feet)	Facies
Lee	Calvert Bluff	northern part	2-10	deltaic
	Yegua	southwestern part in Giddings area northeast to Yegua Creek	4-6	deltaic
	Manning	extreme southeastern edge to county line	2-5	deltaic
Leon	Calvert Bluff	extreme northwestern corner; Evansville and Bear Grass areas	6-11	deltaic
Limestone	Calvert Bluff	southeastern corner	2-10	deltaic
Madison	Yegua	east-west belt across central part from Shepard Creek to Larrison Creek	2-10	deltaic
Marion	Wilcox	southeastern part from Jefferson east to Arkansas line	2-3	fluvial
Maverick	Indio	extreme southeastern edge	2-5	lagoonal
McMullen	Yegua-Jackson	western part from Berry Ranch southwest to Artesian and county line	2-5	lagoonal
Medina	lower Wilcox	westward from Coal Mine to county line	5-8	lagoonal
Morris	Wilcox	northern quarter	2-8	fluvial
Nacogdoches	Wilcox	from Lynn Flat to Garrison	4-6	deltaic?
Robertson	Calvert Bluff	from Calvert northeast to Headsville	3-10	deltaic
Rusk	Wilcox	5- to 8-mile radius of Henderson, vicinity of Sulphur Springs, and extreme northeastern corner	3-6	fluvial
Shelby	Wilcox	Center area	4-6	lagoonal
Starr	Yegua-Jackson	extreme western corner	2-8	lagoonal
Trinity	Yegua	northeastern part from county line to Apple Springs area	2-5	deltaic
	Manning	from county line east to Groveton area	4-9	deltaic
Uvalde	lower Wilcox	Leona River east to county line	2-8	lagoonal
Van Zandt	Wilcox	eastern part; Oakland and Sand Flat areas, southwest corner	2-10	fluvial
Walker	Manning	extreme western edge (Kelso Creek) and eastern edge (Chalk Creek)	2-10	deltaic
Washington	Manning	northwestern part from western tip to junction of Lee, Burleson, and Washington Counties	2-6	deltaic
Wood	Wilcox	belt northwest from Quitman to northwestern corner	5-10	fluvial
Zapata	Yegua-Jackson	from Falcon to Santa Rosa eastward to midcounty	2-8	lagoonal

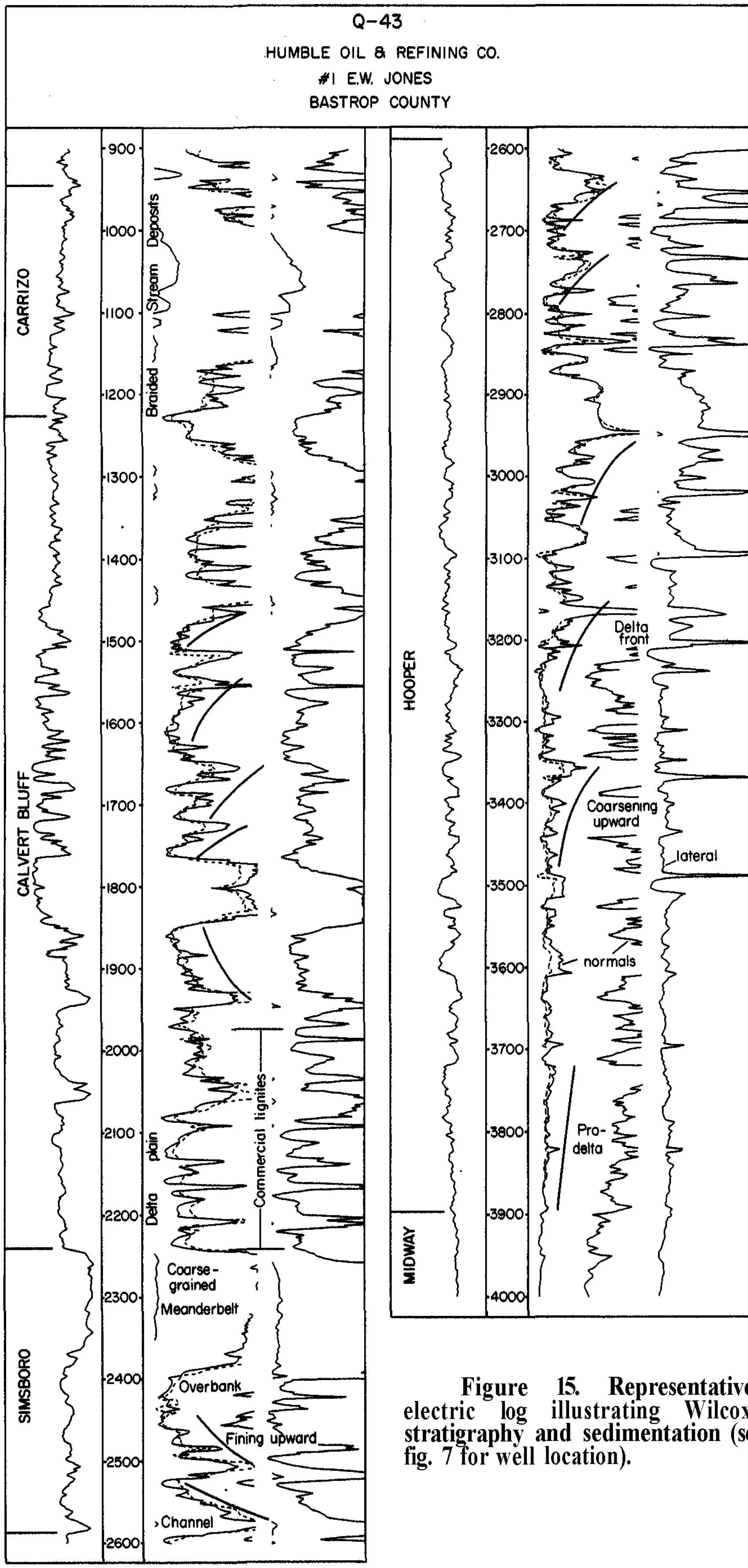


Figure 15. Representative electric log illustrating Wilcox stratigraphy and sedimentation (see fig. 7 for well location).

updip to the Fairfield area, the site of Industrial Generating Company's Big Brown operation.

In prospecting for new lignite deposits, one should locate the Simsboro Sand (Barnes, 1970, 1974a) and concentrate exploratory drilling immediately southeastward in the strike valleys of the Calvert Bluff Formation. Potential resources are estimated at 2,846 million tons (table 4).

South Texas.—The principal deposits are lagoonal lignite located at the junction of Medina, Bexar, and Atascosa Counties and in south-central Uvalde and north-central Zavala Counties (fig. 12 and table 2). The most important mining districts were Lytle (four abandoned mines) and Somerset (two abandoned mines).

Potential lignite deposits (table 3) are shown on figure 12. They have been outlined with regard to inferred stratigraphic occurrence in the lower Wilcox Group and Indio Formation (fig. 11), reported outcrop and well occurrences (Dumble, 1892; Plummer, 1932, fig. 36, p. 575; Maxwell, 1962; and Fisher, 1963), and projection from deep-basin occurrences. The areas outlined in Maverick and Medina Counties are based primarily on the projection, parallel to the Cotulla barrier-bar system, of deep-basin occurrences to the outcrop.

New lignite deposits should be sought in a band adjacent to the mapped Wilcox-Midway contact, since lignites of commercial thickness occur in the lower Wilcox above the Midway Group. Though the lignites are sufficiently thick, they are discontinuous, making it difficult to find the reserves necessary to support most mine-mouth operations. Because of their high sulfur content (1.7 ± 0.5 percent), these lignites are not attractive at the moment for direct combustion as boiler fuel. Furthermore their ultimate potential for gasification or as boiler fuel is lessened by insufficient water resources. Despite the drawbacks of questionable reserves, poor quality, and a short water supply, recent exploratory drilling has been conducted in Caldwell, Medina, Uvalde, and Maverick Counties by at least three companies. Potential trendwide resources are estimated at 676 million tons (table 4).

Yegua Formation and Jackson Group

Southeast Texas.—Lignite of this area is of deltaic origin. Yegua lignite occurs primarily in the lower part of the formation, but is known to occur throughout the formation. The only Yegua lignite that has been commercially exploited is located in southwestern Houston County (fig. 8 and table 2). At Wooters Station, 2 miles north of Lovelady, three mines were operated from 1901 to 1930. Jackson (Manning Formation) lignite has been mined at Ledbetter (1905 to 1908) in Fayette County, just north of Ledbetter in Washington County, at Clay in Burleson County, and at Groveton in Trinity County (fig. 9).

Potential lignite deposits (table 3) are shown in figures 8 and 9. They have been outlined with regard to inferred stratigraphic position, minor previous production, reported outcrop and well occurrences (Dumble, 1918; Deussen, 1924, p. 75–80; Plummer, 1932, p. 676 and 698; and Fisher, 1963), and projection from deep-basin occurrences. Areas off the Yegua and Jackson delta complexes, east of Angelina County and south of Fayette County, are not prospective. In either case the transition is to decidedly more marine sediments, or in other words to environments less favorable to lignite accumulation.

Yegua lignite deposits rank second in importance behind those of the Wilcox Group, being less extensive and of slightly poorer grade. Manning lignite is of lesser importance and is characterized by high ash and sulfur (greater than 1.5 percent) content. Based on grade and resources the Yegua lignite has the best potential for future utilization. Yegua lignite mined at Wooters Station is comparable in grade to commercial Wilcox lignite. Manning lignite cannot be utilized without new sulfur technology to remove SO_2 from stack gases, relaxation of the air pollution standards, or extensive coal gasification. Potential resources in the Yegua and Manning are estimated at 836 and 550 million tons, respectively (table 4).

South Texas.—In South Texas upper Eocene, lagoonal lignite is grouped as Yegua-Jackson. Normally the marine Caddell Formation (lowermost Jackson) is the marker separating the two units, but at the dip position of lignite occurrence, in association with upper Yegua-lower Jackson beach sandstones, it is absent or not easily recognized (fig. 11). Thus the Yegua-Jackson boundary is picked in an arbitrary manner and can only be established definitely with paleontological data.

The only lignite that has been commercially exploited (as a drilling mud additive) is located in

Table 4. Near-surface potential lignite resources.[1]

County	Wilcox	Yegua	Jackson	Yegua-Jackson
Angelina		174		
Atascosa	26			70
Bastrop	447			
Bexar	78			
Bowie[2]	536			
Brazos		39	42	
Burleson		121	85	
Caldwell	76			
Fayette			102	
Franklin	156			
Freestone	967			
Grimes			63	
Guadalupe	82			
Harrison	555			
Henderson	463			
Hopkins	434			
Houston		255		
LaSalle				86
Lee	47	95	41	
Limestone	169			
Madison		132		
Marion	60			
Maverick[3]	129			
McMullen				212
Medina	150			
Milam	813			
Morris	89			
Nacogdoches	90			
Panola	524			
Rains	245			
Robertson	403			
Rusk	275			
Shelby	234			
Starr				33
Titus	444			
Trinity		20	108	
Uvalde	110			
Van Zandt	782			
Walker			17	
Washington			92	
Wood	198			
Zavala	24			
Zapata				33
	8,606	836	550	434

	Amount	Percent
REGIONS		
East Texas[4]	5,085	48.77
Central Texas[5]	2,846	27.30
Southeast Texas[5]	1,386	13.29
South Texas[6]	1,109	10.64
	10,426	100.00
GEOLOGIC OCCURRENCE		
Fluvial	4,709	45.17
Deltaic	4,232	40.59
Lagoonal	1,485	14.24
	10,426	100.00
GEOLOGIC TREND		
lower Eocene (Wilcox)	8,606	82.54
upper Eocene (Yegua-Jackson)	1,820	17.46
	10,426	100.00

[1] in millions of short tons
[2] includes Cass County
[3] includes Dimmit County
[4] 1765 tons/acre-foot in Marion, Harrison, Panola, Rusk, Nacogdoches, and Shelby Counties; 1700 in all others
[5] 1765 tons/acre-foot in all counties
[6] 1700 tons/acre-foot in all counties

north-central McMullen County (fig. 13). Maxwell (1962) assigned this lignite to the Yegua Formation; however, it may just as properly be assigned to the lower Jackson Group. Potential deposits (table 3) are shown on figure 13. Note the well-defined north-northeast trend of the deep-basin lignite occurrences located updip (lagoonward) of the axes of the Yegua-Jackson barrier bar-strandplain systems. The projection of this trend north to the outcrop intersects the outcrop in north-central McMullen and southeastern Atascosa Counties, areas in which lignite of commercial thickness and extent have been reported (Deussen, 1924; Maxwell, 1962; Fisher, 1963). Similarly, projection of the deep-basin trend south points to potential deposits in the Rio Grande area. Prospecting for new reserves should be confined to the outcrop band of upper Yegua-lower Jackson sandstones. Potential trendwide resources are estimated at 434 million tons (table 4). Poor quality (ash 40.8 ± 14.3 and sulfur 1.9 ± 0.8 percent, n = 8), questionable reserves for mine-mouth operations, and insufficient water resources limit the commercial significance of this lignite.

Potential Resources

Several factors influence the calculation of lignite resources and reserves. The most important ones are specific gravity (tons per acre-foot), minimum thickness, maximum overburden, stripping ratio, amount of control data, seam continuity and geometry, and recovery factor. Fisher (1963) cited a specific gravity of 1.2 to 1.4 (1629 to 1904 short tons per acre-foot) for Texas lignites. Stenzel and others (1948) cited a range of 1.16 to 1.46 and an average value of 1.33. In Texas the most frequently used value of minimum thickness is 4 or 5 feet. Maximum overburden and stripping ratio (overburden/seam thickness) are closely tied to technology. The increase in size and efficiency of strip-mining machinery has permitted a steady increase in both values. Already overburden 180 to 185 feet thick is being removed in large-scale operations, thus a maximum value of 200 feet does not seem unrealistic. In Texas removal of 0 to 150 feet of overburden is typical. Between 1946 and 1970, the average national stripping ratio has increased from 6:1 to 11:1 (Averitt, 1970). Averitt suggests that a 30:1 ratio is technically feasible as a maximum for present and near-future strip mining. The most frequently used values in Texas range from 10:1 to 15:1. The influence of the amount of control is obvious. Seam continuity and geometry are best estimated from an understanding of geologic occurrence, for example, blanket vs. interdistributary lignites. For strip mining the recovery factor is about 80 to 85 percent.

The size of an individual lignite seam ranges from 1 to 15 square miles or 7 to 100 million short tons (6-foot continuous bed and 1,765 tons per acre-foot). Several of these, within a 10-mile radius, provide reserves sufficient for the operation of a lignite-fueled, mine-mouth, steam-electric plant or gasification plant. The operating reserves are estimated to be 210 to 280 million tons based on a plant capacity of 6 to 8 million tons per year and a 35-year plant life.

A reliable determination of Texas Coastal Plain lignite resources is seriously hampered by a lack of control. Perkins and Lonsdale (1955) made the first comprehensive estimate of Texas lignite resources. Though they called their estimates reserves, they should properly be termed potential resources (Brobst and Pratt, 1973) for only locally are the data available to calculate reserves or recoverable identified resources: specific bodies of lignite whose existence, location, and size are known. Their estimate is probably a conservative one in that it included only measured and indicated reserves (conditional resources[2]) and not inferred reserves (hypothetical[3] and speculative[4] resources). They calculated a statewide resource of 7.1 billion short tons.

An estimated statewide resource of 10.4 billion short tons has been calculated by the writer (table 4). Guidelines for this estimate were chosen somewhat arbitrarily but rely on geologic occurrence, past and current production, reported outcrop and well occurrences, and projection from deep-basin occurrences. The thickness of lignite assigned varies with the county according to tables 2 and 3. The most subjective element is the fraction of mapped principal and potential lignite areas assumed to be underlain by lignite (figs. 4, 7, 8, 9, 12, and 13). Discussion of the estimates for East and Central Texas, where 76 percent of the State's estimated resources are located (table 4), illustrates the approach.

[2]Resources that may eventually become reserves when conditions of economics or technology are met.

[3]Undiscovered resources reasonably expected in known districts.

[4]Undiscovered resources that may exist in unknown districts.

In East Texas principal and potential lignite areas are outlined between the inferred trends of Wilcox paleochannels (fig. 4). Since lignite occurs at several horizons in the Wilcox Group, almost all the principal and potential acreage was considered prospective, evaluated, and assigned a rating factor. The principal areas were assigned a factor of 1/2, except in Harrison and Panola Counties where 8/10 was used. For potential areas a factor of 1/3 was used in every county. The rating factor reflects the probability that there is lignite within stripping depth (less than 200 feet below the surface), and is based on geologic setting, the regional dip of the lignite-bearing strata, past and current production, and outcrop and shallow well occurrences. In each county the principal and potential acreage was determined and multiplied by the rating factor to give the probable acreage underlain by lignite. Assuming one continuous lignite seam, a thickness is chosen by county for the principal and potential area from tables 2 and 3, respectively. Tonnage is calculated by multiplying the obtained acre-feet by tons per acre-foot. For example, in Wood County the method yields 2,560 principal acres underlain by 10 feet of lignite and 15,149 potential acres underlain by 6 feet of lignite for a total resource of 198 million short tons.

In Central Texas, estimates are more confidently made because lignite occurs at one stratigraphic horizon, the lower one-third of the Calvert Bluff Formation; thus a band adjacent to the Simsboro Sand, one-third of the total width of the Calvert Bluff outcrop belt, is considered prospective (fig. 7). Within this band, rating factors were assigned to principal and potential areas, 3/4 and 1/2 or 1/3, respectively. Calculations were made as described above. In Freestone County, the method yields 40,960 principal acres underlain by 8 feet of lignite and 27,520 potential acres underlain by 8 feet of lignite for a total resource of 967 million tons.

For South Texas Wilcox and Yegua-Jackson the principal and potential rating factors were 1/3 and 1/4, respectively. For Southeast Texas Yegua, the factors were 1/3 and 1/4 or 1/5, respectively. For Southeast Texas Jackson where only potential acreage is outlined, factors of 1/3, 1/4 or 1/5 were assigned.

Grade

Lignite of the highest grade occurs in the Wilcox Group north of the Colorado River; lower grade lignite is found in the Wilcox south of the Colorado River and in the Yegua Formation and Jackson Group. In Southeast Texas, Yegua lignite is superior to Jackson lignite, while South Texas Yegua-Jackson lignite is the State's poorest (table 5; Fisher, 1963).

Southward along the outcrop there is an overall decrease in lignite grade (figs. 16, 17, and 18). Lowest ash and sulfur values are found in lignites of East and Central Texas, with highest values in South Texas lignites. Lignites with heating values of 11,000 to 12,000 Btu/lb are found in the Sabine uplift area and Bastrop County to the Trinity River; values between 10,000 and 11,000 Btu/lb are found in the area from the Trinity River to Bowie County, Zavala to Bastrop Counties, and Fayette and Houston Counties; values less than 10,000 Btu/lb are found in McMullen County. Fixed carbon decreases southward with high values coinciding with high Btu values. Volatile matter also decreases southward with high values coinciding with low ash values.

There is a correlation between grade and geologic occurrence. In table 5, the regions East, Central and Southeast, and South coincide with the occurrence of fluvial, deltaic, and lagoonal lignite, respectively. Fisher (1968) and McGowen (1968, p. 166–167) characterized the differences among the three kinds of lignite in relative terms. Their conclusions are reflected in table 5, but the absolute differences are small. Deltaic lignite is the best quality, fluvial lignite is intermediate in quality, and lagoonal lignite is poorest in quality.

Deltaic lignite has moderate sulfur content, low ash content, high Btu values, moderate volatile-matter content, high fixed-carbon content, and high specific gravity. High Btu values, fixed-carbon content, and specific gravity are a function of a low percentage of woody material and high percentage of marsh plant organics. The moderate sulfur content indicates accumulation in fresh to brackish marshes located seaward of fresh-water swamps. A low ash content reflects minimal contamination by clastic sediment such as on foundering, abandoned delta lobes where following avulsion, sediment is bypassed to a new site of deposition.

Fluvial lignite has low sulfur content, moderate ash content, low to moderate Btu values, high volatile-matter content, moderate fixed-carbon

Table 5. Regional compositional variation of Texas lignite.

	As Received					Dry Basis				
	Volatile matter	Fixed carbon	Ash	Sulfur	Btu/lb	Volatile matter	Fixed carbon	Ash	Sulfur	Btu/lb
Wilcox East[1]	X = 35.70	26.76	9.95	0.81	7,705	X = 47.44	38.50	13.78	1.01	10,482
	S = 6.97	7.54	5.80	0.34	622	S = 7.95	7.80	5.62	0.40	1,014
	N = 89	87	89	82	59	N = 44	44	44	41	49
	C =		0.58	0.42		C =		0.41	0.40	
Wilcox Central[2]	X = 33.82	29.49	9.10	1.00	7,916	X = 47.65	39.64	12.17	1.41	11,033
	S = 5.49	5.66	2.54	0.44	839	S = 7.48	8.88	3.34	0.67	712
	N = 76	76	76	69	68	N = 70	71	70	63	58
	C =		0.28	0.44		C =		0.27	0.48	
Wilcox South[3]	X = 33.51	27.55	15.10	1.66	7,508	X = 49.28	33.03	16.47	1.68	10,979
	S = 9.83	9.47	12.14	0.94	496	S = 11.79	3.79	8.28	0.45	1,086
	N = 17	18	18	16	11	N = 7	7	7	7	8
	C =		0.80	0.57		C =		0.50	0.27	
Yegua-Jackson Southeast[4]	X = 34.89	21.79	10.96	0.83	7,124	X = 51.15	32.17	16.72	1.47	10,594
	S = 5.21	4.41	6.08	0.41	526	S = 6.68	6.58	8.08	0.86	786
	N = 17	16	16	10	10	N = 14	14	14	8	10
	C =		0.55	0.49		C =		0.48	0.59	
Yegua-Jackson South[5]	X = 28.83	21.01	40.84	1.78	6,130	X = 32.35	23.08	40.82	1.93	6,826
	S = 3.68	3.08	6.29	0.72	735	S = 2.80	11.45	14.32	0.79	784
	N = 8	8	8	8	8	N = 8	8	8	8	8
	C =		0.15	0.40		C =		0.35	0.41	

Statewide moisture X = 26.76, S = 8.39, N = 219

X = arithmetic mean
S = standard deviation
N = number of analyses
C = S/X = *coefficient of variation*
See Appendix for individual analyses.
Includes no outcrop samples; includes partially air-dried samples.

[1]east of the Trinity River (except Shelby and Nacogdoches Counties)
[2]between Trinity and Colorado Rivers
[3]*south of Colorado River*
[4]Angelina County (Angelina River) through Fayette County
[5]Atascosa County to Rio Grande

content, and low to moderate specific gravity. The low sulfur content implies a fresh-water origin; the high volatile-matter content is a function of a high percentage of woody material which reflects a swamp environment. Furthermore, during tropical storms swamp vegetation is protected from saline water by a head of fresh water derived from river floodwater and runoff (McGowen, 1968), hence a low-sulfur environment is maintained at all times. Moderate ash content indicates minimal contamination by clastic sediment such as in swamps far from active channels.

Lagoonal lignite has high sulfur content, high ash content, low to moderate Btu values, low to moderate volatile-matter content, low fixed-carbon content, and low to moderate specific gravity. The high sulfur content suggests accumulation in a salt marsh. High ash content is a function of contamination by clastic sediment such as might be washed over and through barrier beaches into associated lagoonal marshes. A slow rate of marsh subsidence relative to rates of organic and clastic sediment accumulation accounts for the thin and discontinuous lagoonal lignites (McGowen, 1968).

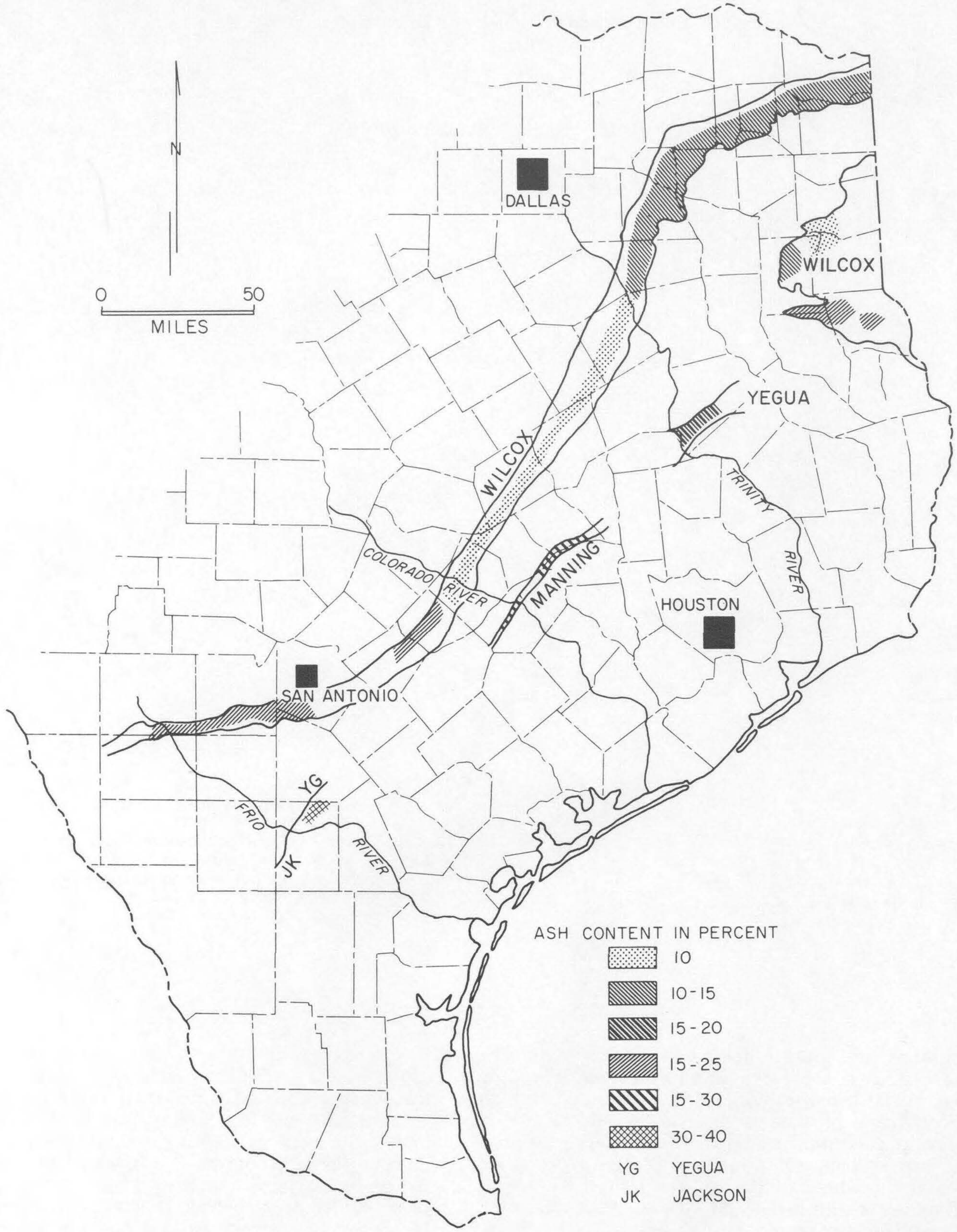


Figure 16. Regional variation in ash content of Texas lignite (as-received basis).

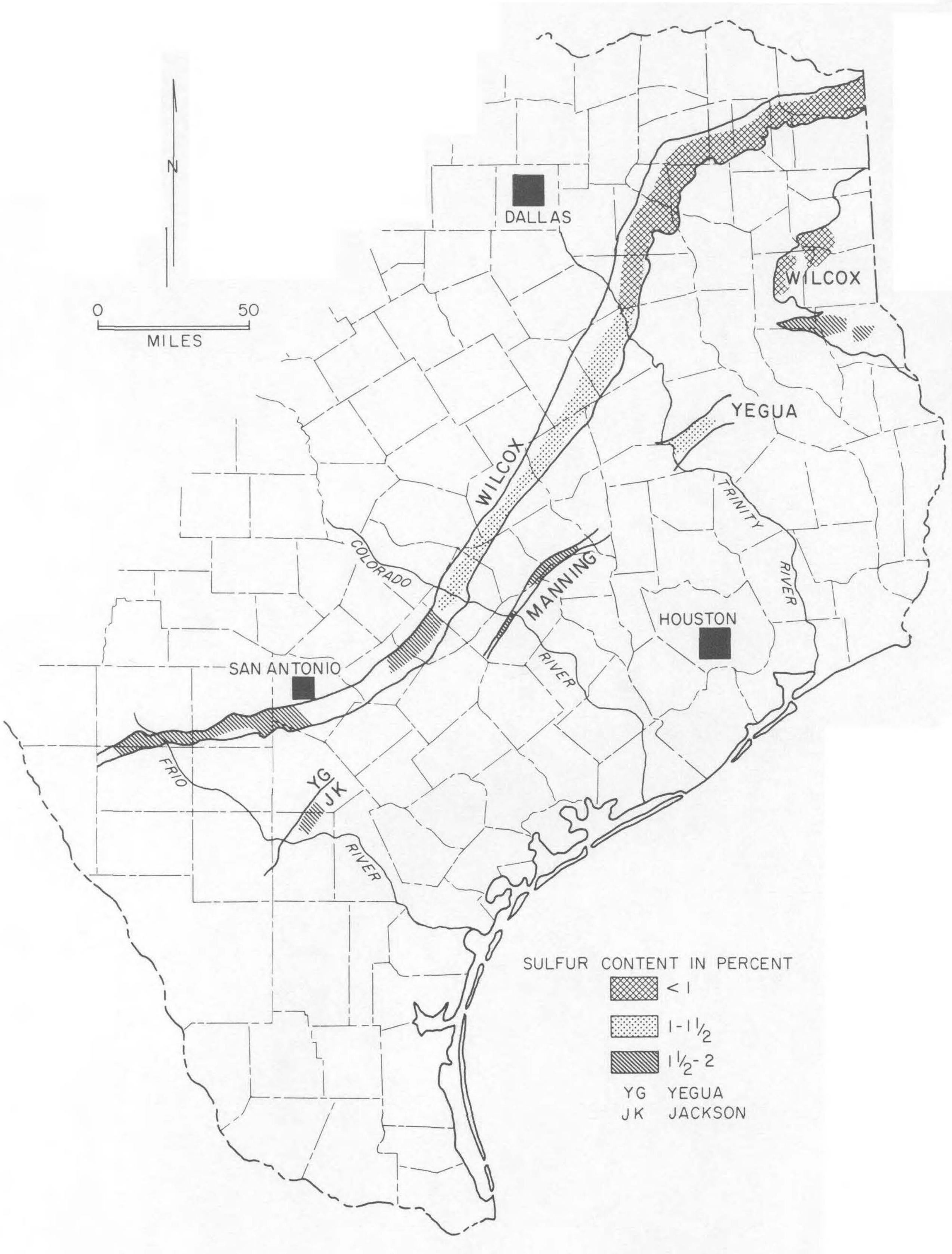


Figure 17. Regional variation in sulfur content of Texas lignite (as-received basis).

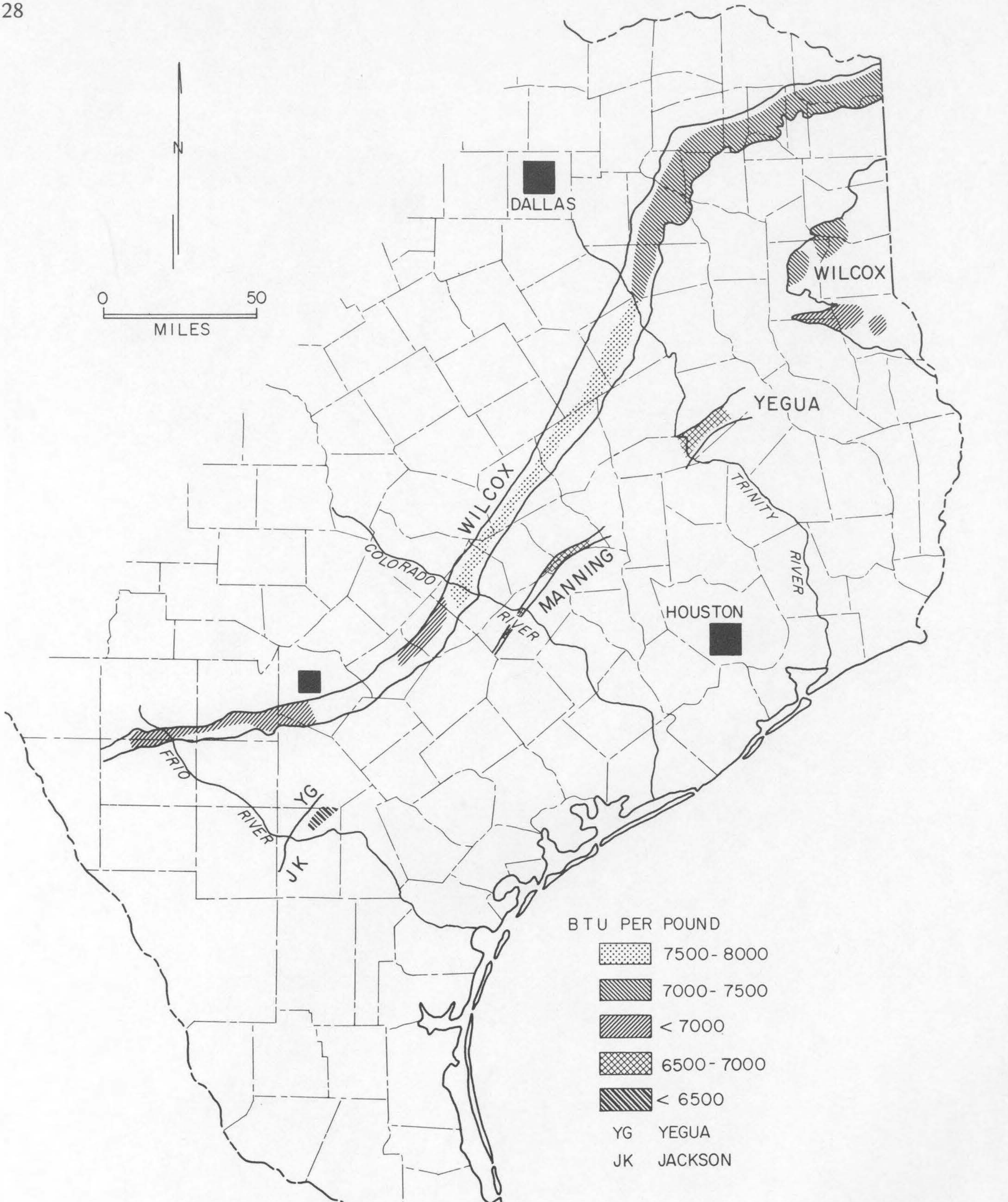


Figure 18. Regional variation in heating value of Texas lignite (as-received basis).

Production

Since about 1890 lignite has been produced by more than 150 operators in at least 35 Texas counties. Reasonably reliable production figures are available from 1892 to 1950 (table 6). From an annual production of less than 15,000 short tons in the late 1880's, lignite production increased to a peak of 1.2 million tons in 1913 and 1918. Annual production averaged about one million tons from 1915 through 1930. From 1930 to 1940 production declined and by 1940 was 606,000 tons annually. By 1950 annual production had dropped to 18,000 tons. Production to 1950 was about 35 million tons. From 1950 to January 1, 1974, production can only be estimated but is set at 50 million tons. Thus total statewide production stands at approximately 85 million tons.

Table 6. Lignite production.

Year	Amount $\times 10^3$ short tons
late 1880's	<15
1890	~15
1895	124
1900	253
1905	392
1910	881
1913	1,181
1915	891
1918	1,187
1920	1,070
1925	826
1927	1,169
1930	750
1935	722
1940	606
1945	80
1950	18
1960	2,000[1]
1970	2,250[1]
1972	4,545
1974	8,000[1]
1980	25,000[2]

[1]estimated from plant capacity
[2]estimated from plant capacity for present and scheduled plants

In 1954 Industrial Generating Company began strip mining at Alcoa; based on plant capacity, annual production is estimated at two million tons. In 1971, the same company began mining at Fairfield where annual production is estimated at six million tons based on plant capacity. Current annual production at Darco (ICI America, Inc.) is about 250,000 tons (R. L. Brandes, Jr., written communication). Total statewide production is currently estimated to be 8 to 10 million tons per year. By 1980, when additional lignite-fueled, steam-electric plants are operational, production is expected to be about 25 million tons annually. Texas at that time will rank among the top ten coal-producing states in the Nation. For comparison, the ninth and tenth ranked states in 1971 produced 9.3 and 8.2 million tons of coal, respectively.

Mining Practice and Utilization

Mining practice.—All of the lignite currently mined in Texas is strip-mined. Modern earthmoving equipment and the availability of large lignite reserves beneath shallow, unconsolidated overburden make surface mining more economical than underground mining. Typically the overburden is removed by draglines (up to 90 cubic-yard buckets) and large shovels. Single units or a combination of different types of equipment are used depending on overburden thickness (Fisher, 1965, p. 282–284). At the Big Brown operation near Fairfield, an electric dragline with a 70-cubic-yard bucket removes the 40 to 50 feet of overburden. An electric power shovel (16-cubic-yard capacity) loads the lignite into 180-cubic-yard trucks for haulage over company roads to the plant. At Alcoa in Milam County, a large conveyor belt is used to transport lignite from primary crushers to the plant site. At the plant the lignite is crushed and sized, then pulverized to less than 0.074 mm and air-fired as a dust.

Stripping is accomplished by removing the overburden and piling it in conical spoil rows covering recently mined-out areas. Pit advance is down the dip or inclination of the lignite seam, with overburden becoming thicker as mining moves downdip. In this method, called area stripping, different capacity and type of stripping equipment can be used at the same time along the same cut. The largest block of unmined lignite is the narrow strip or fender left along the toe of the spoil row to stabilize it and to prevent contamination of the mined lignite. Also a thin blanket of lignite is commonly left on the pit floor to prevent contamination by underlying mud and sand (Fisher, 1965). About 80 to 85 percent recovery is obtained.

Utilization.—By far the largest and most important use of Texas lignite is in lignite-fueled, steam-electric plants. Ash, a byproduct of the combustion, is used as a lightweight road aggregate, cement filler, and an additive in oil-well drilling mud. A small percentage of the State's total lignite production is used to make activated carbon which is used as an absorptive medium or filtering agent.

In the future, major utilization of Texas lignite is likely in the production of synthetic gases, liquid fuels, and chemical feed stocks. The low rank and high moisture content makes lignite very reactive at low temperature and therefore highly desirable for the production of synthetics. Other possible uses of lignite are for cement burning, production of organic chemicals and leonardite, carbonization, and as a source of montan wax and carbon electrode raw material. Possible additional uses of ash are as a portland cement pozzolan, soil stabilizer, and inert filler in asphaltic concrete mixes. The various uses of lignite are summarized in detail in U. S. Bureau of Mines Information Circulars Nos. 7691 (1954a), 7692 (1954b), 8164 (1963), 8234 (1964), 8304 (1966), 8376 (1968), 8471 (1970a), 8488 (1970b), and 8543 (1972).

Environmental Factors

Utilization of Texas lignite raises several environmental problems. The principal ones are land use and disturbance, air and thermal pollution, water allocation and quality, and waste disposal. Except for air pollution, the problems are about the same whether lignite is used in steam-electric plants or gasification plants. Competing claims for land and water allocation will become increasingly knotty problems in the future.

Land and water.—The building of mine-mouth, steam-electric plants or gasification plants requires substantial land. The total acreage that must be leased or purchased commonly exceeds 10,000 acres and includes land for coal reserves, cooling-water reservoir, storage areas, plant facilities, and conveyor belts, truck haul roads or railroad.

Modern steam plants need one to one and one-fourth surface acres of cooling reservoir per megawatt of capacity; generally that means a reservoir of 1,000 to 2,000 acres 10 to 60 feet deep. With flue gas desulfurization a steam plant will require more water than any comparable gasification process (Babu, 1974). A gasification plant producing 250 million cubic feet per day will consume about 10,000 acre-feet of water per year. Already the availability of water is critical in arid South Texas; therefore, in this area lignite exploitation hinges as much on water availability as on lignite reserves.

Pollution.—The principal pollutants generated by solid-fuel burning plants are sulfur oxides (SO_2 and SO_3), nitrogen oxides (NO and NO_2), carbon dioxide (CO_2), carbon particulates (soot), fly ash, and waste heat. Sulfur oxides upon oxidation ultimately yield corrosive sulfuric acid (H_2SO_4) or a sulfate such as ammonium sulfate [$(NH_4)_2SO_4$]. Nitrogen oxides react to yield highly corrosive nitric acid (HNO_3). The effects of particulates (soot and fly ash) largely depend on particle size; very tiny particles (less than 2 microns) are the most troublesome. The effect of carbon dioxide is uncertain, but may have a long-range climatic effect. Waste heat (thermal pollution) is discharged in heated water to cooling reservoirs or vented directly to the atmosphere; its consequences are not fully understood. Waste heat is potentially a large energy source which may be utilized for desalination of water or heating nearby homes.

At the moment, sulfur oxides and particulates are the air pollutants of prime concern to public health because of their effect on the respiratory tract. There is relatively little concern over nitrogen oxides because the lower combustion temperatures and slower quenching rates of stationary plants minimize NO_X emissions and health risks are not well defined. Currently in Texas, stationary plants burning lignite meet two sets of emission standards. Plants permitted before December 1971 meet the following standards: SO_2, 3.0 lbs per million Btu of input; particulates, 0.3 lb; and opacity 30 percent. Plants permitted today must meet standards established by the Environmental Protection Agency: SO_2, 1.2 lbs per million Btu of input; particulates, 0.1 lb; opacity 20 percent; and NO_2, 0.7 lb; there is no standard for SO_3. Plants at Alcoa, Fairfield, and Monticello operate under the less stringent standards while the proposed Martin

Lake and Athens plants must meet the newer standards.

According to the National Academy of Engineering (1970) no sound, economical, commercial process exists for the removal of SO_2 from stack emissions. Up to now the problem has been solved by burning low-sulfur coal or lignite. Under the old standards Texas lignite with less than 1.6 percent sulfur (100 percent SO_2 up stack) could be used; the new standards require lignite with less than 0.6 percent sulfur. Obviously without new sulfur removal technology, a substantial amount of Texas lignite is unsuitable for direct combustion, especially the higher sulfur South Texas lignite. If lignite is used for gasification, sulfur content is much less of a problem. In this case, hydrogen sulfide (H_2S) and carbonyl sulfide (COS) are formed and can be removed by oxidation to elemental sulfur, H_2O, and CO_2 (Haas, 1973) or by low-temperature methanol or carbonate scrubbing.

Particulates are effectively removed (98 to 99 percent) by electrostatic precipitators; however, once removed a problem of disposal exists. A plant burning 6 million tons of Texas lignite will produce about 600,000 tons of ash per year. Some ash can be used as byproducts such as lightweight road aggregate but a substantial amount must be stored or disposed of in pits. Windblown toxic particulates and leachates such as heavy metals and acid water runoff are potential environmental hazards from ash storage areas. In addition to ash, gasification plants will produce water or gas liquor, process effluent containing phenols, ammonia, and certain other toxic compounds that are potential pollutants of fresh water.

Land disturbance.—The environmental effects of surface mining in Texas have been reviewed by Groat (1973). Lignite strip mining in Texas is in its infancy, but as more lignite-fueled steam plants and gasification plants are built, many thousands of acres of land will be disturbed. Stripping alters the land surface and topography, exposing formerly buried rock and soil to the atmosphere. The exposed overburden may yield toxic particulates (dust) and leachates that can pollute streams and surrounding lands. Acid water runoff is a serious problem where the overburden and coal are high in sulfur and the climate warm and humid. To date, acid runoff has not been a problem in Texas because moderately low-sulfur lignite with sulfur-free overburden is being mined.

Quantifying the offensiveness of mined land is impossible. Most unreclaimed mined areas are impenetrable and essentially useless for any purpose. The arguments for and against reclamation have been put in terms of aesthetics and economics. Three factors, within the limits of physical and chemical characteristics of the spoil material, bear on a successful reclamation program: climate, terrain, and land capability. In areas of high to moderate rainfall (East and Central Texas) revegetation occurs rather easily and naturally, while artificial lakes can be shaped for recreation, stock ponds, or homesites. In dry areas (South Texas) reclamation will be more difficult. Revegetation may occur naturally on a time scale that is unacceptable to society (decades or even centuries). It may be impossible, because of insufficient rainfall and alkali soils, to establish any kind of vegetation on some mined land; for example, fifty-year-old mine dumps in the Laredo area are totally devoid of vegetation. Revegetation in South Texas can probably be achieved only with major sustained inputs of water, fertilizer, and management.

Terrain is not a serious limitation to reclamation in Texas as it is in the Appalachian area where reclamation is difficult at best, and the scarred hills and water pollution have combined to create a wasteland. In Texas the lignite occurs in flat to moderately rolling country, a topography easily reproduced by redistribution and remolding of parallel rows of unconsolidated spoil. Furthermore, most of the lignite lands are post oak savannah in the native state. Soils are not markedly different from underlying sediments and rocks; hence topsoils are not much more fertile than overburden. The consequences of surface mining would be much more severe if an area was rich, productive cropland prior to mining.

There is no mine reclamation law in Texas, although operations at Fairfield by Industrial Generating Company include, on a voluntary basis, an extensive reclamation program. Topsoil is not segregated because it is not much more fertile than the overburden. Mined land is returned to the original topography and planted with grasses (Coastal Bermuda and clover) and native trees. Runoff waters are kept on the property and monitored in holding ponds before being allowed to drain into area streams. Maintaining drainage waters at a suitably high pH is not a problem, since the lignite has a moderately low sulfur content and the overburden is low in sulfur.

It is certain that as lignite mining becomes more extensive, land reclamation will be mandatory. Fortunately, the principal lignite deposits are in the eastern part of the State where favorable climate and terrain work for successful reclamation programs. Restrictions currently being debated in federal strip-mining legislation, such as slope prohibitions and mining on federal land, would not affect surface mining in Texas.

DEEP-BASIN DEPOSITS

Deep-basin lignite is a vast potential energy resource that can be tapped through existing in situ recovery methods. Fundamental work on Eocene, lignite-bearing stratigraphic units revealed the presence of extensive lignite in the deep basin, pointing out the relative abundance in various depositional systems (Fisher and McGowen, 1967; Fisher, 1969; Fisher and others, 1970). In these studies no specific attempt was made to outline the occurrence of deep-basin lignite. McGowen (1968, fig. 10, p. 167) and Fisher (Bureau of Economic Geology work maps) made the first generalized maps of deep-basin lignite in the Wilcox Group in Central Texas and Yegua Formation in Southeast Texas. In this study, a systematic effort was made to map in some detail deep-basin lignite in the Wilcox Group, Yegua Formation, and Jackson Group throughout the State. Two important occurrences have been mapped in Central and South Texas (figs. 7 and 13). Lignite in Central Texas occurs in Wilcox rocks and in South Texas in Yegua-Jackson rocks. In terms of potential resources, Wilcox lignite is by far the more important.

Method

The data for this section come exclusively from about 1,500 geophysical logs run in oil and gas wells. About 90 to 95 percent of the logs used were electric logs; the remainder were induction logs. Without a porosity log, lignite cannot be uniquely identified (Bond and others, 1969; Reeves, 1971). An operational definition of lignite was used; its three elements are a sharp resistivity peak or spike, baseline spontaneous potential (SP), and a proper geologic setting. The latter refers to association with log patterns characteristic of fluvial and distributary channels, delta fronts, and barrier beaches.

Lignites are best picked on electric logs. Opposite a lignite the long lateral curve (18 ft. 8 in. spacing) displays a sharp peak or spike and a very low reading (blind zone) immediately below. The long normal curve (64 in. spacing) displays a sharp reversal back toward the baseline in beds thinner than 64 inches (fig. 19). This characteristic allows an easy distinction between beds greater than or less than 5 feet thick.

The induction log is not well suited for the detection of lignite, especially in beds thinner than 5 feet. In the thicker beds conductivity approaches zero and the 16-inch normal and induction curves track (fig. 19). Intuition of the worker and knowledge of the geologic setting are crucial in picking lignites on an induction log.

On each log the total number of lignites greater than and less than 5 feet thick was counted to the base of the stratigraphic interval in question or to 5,000 feet below sea level. Among the lignites counted, 90 to 95 percent were less than 5 feet thick (1.5-5 ft.). Moving updip the picking of lignite becomes increasingly difficult because the interval of interest is charged with fresh and brackish water. The data are presented as a series of isopleth maps in which the total number of lignites was contoured (figs. 7, 8, 9, 12, and 13).

Geologic Occurrence

Wilcox Group.—The largest and most extensive deposits of deep-basin lignite in Texas occur in the Wilcox Group of Central Texas (fig. 7). These deposits coincide with the delta plain of the Rockdale delta system (Fisher and McGowen, 1967). The lignite occurs in rocks here informally referred to as middle and lower Wilcox (fig. 20). Vertically lignites tend to cluster between distributary channel deposits (fig. 3, well Q-80). The thicker (greater than 5 feet), more areally extensive lignites are regarded as blanket lignites. Deep-basin lignites are most numerous and thickest in Madison, Houston, Leon, Lee, Fayette, and Bastrop Counties.

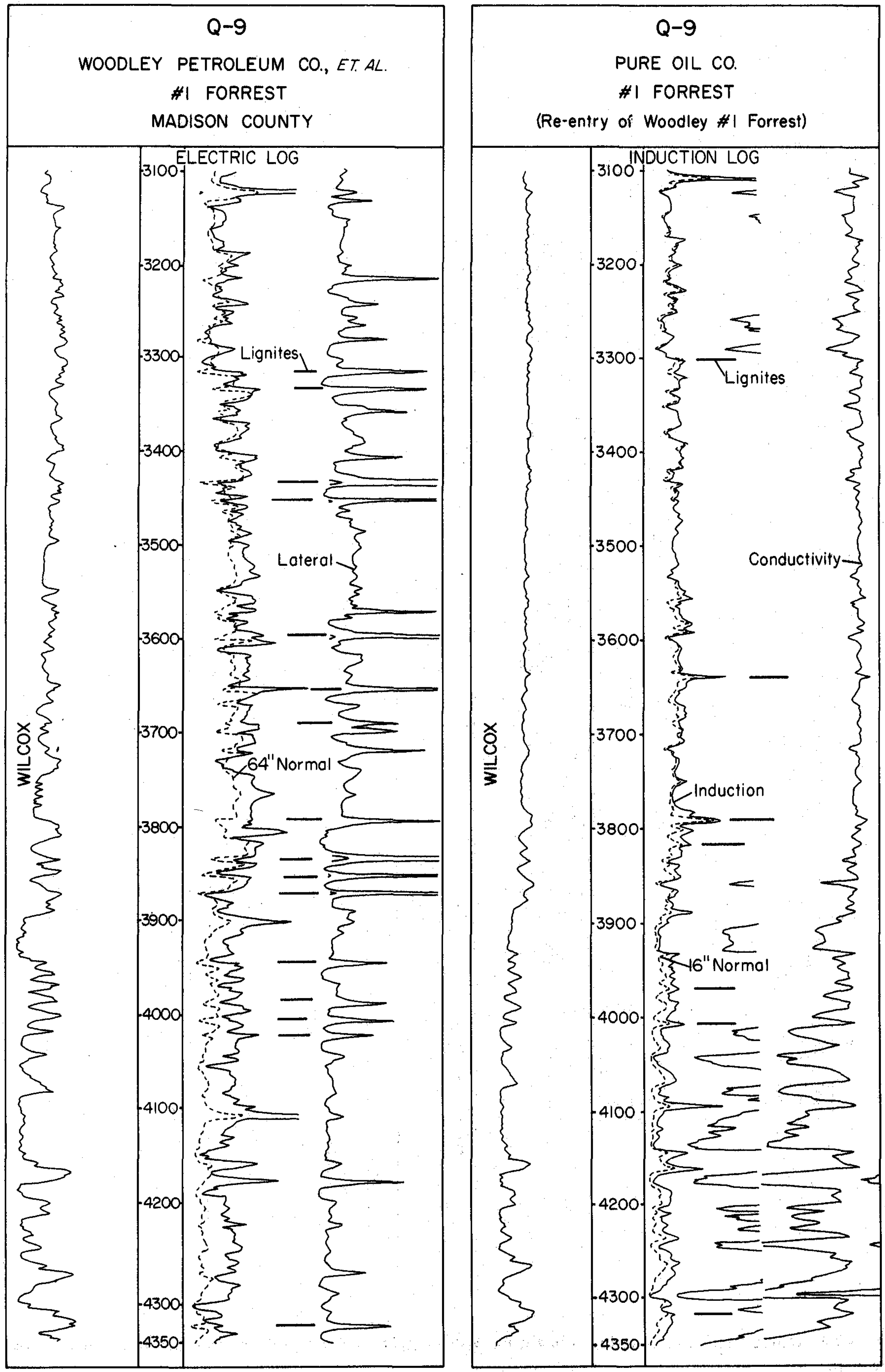


Figure 19. Geophysical log response of lignite: electric log vs. induction log (see fig. 7 for well location).

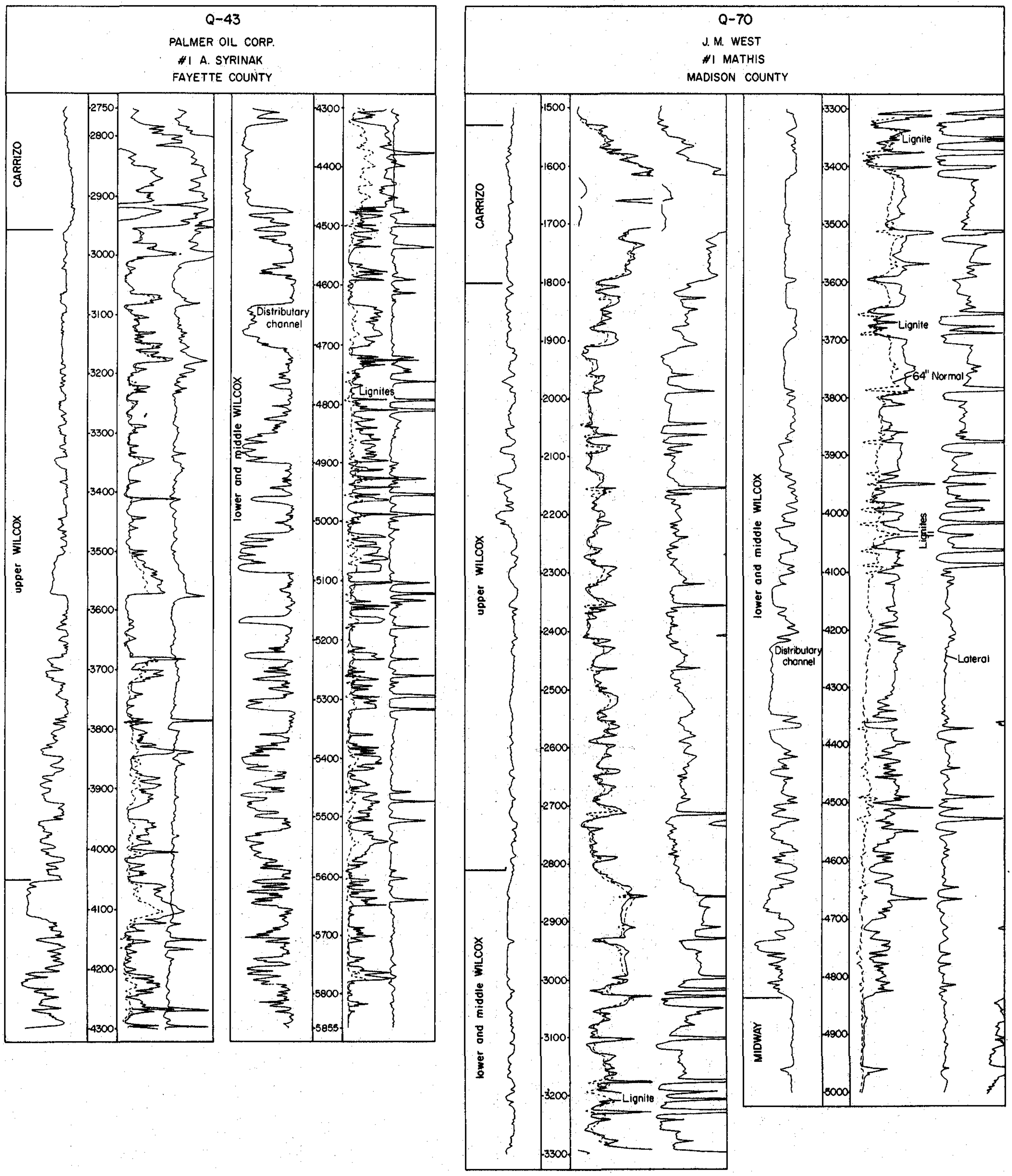


Figure 20. Representative electric logs illustrating Wilcox stratigraphy and deep-basin lignite occurrence (see fig. 7 for well locations).

East Texas lignite occurs as a component facies of the Mt. Pleasant fluvial system (Fisher and McGowen, 1967). Since the Wilcox is charged with fresh water the distribution of deep-basin lignite could not be determined from geophysical logs. However, figure 4 does show some lignite occurrences; for example, at Mineola (Wood County) 15 feet of lignite occurs at 460 feet below the surface, and at Marshall three 6- to 12-foot lignites are reported. Judging by the important deposits at the surface and the large number of lignites reported in the subsurface, this area is believed to hold substantial resources at relatively shallow depths. In South Texas a few small areas of lagoonal lignite are outlined (fig. 12) occurring in the lower Wilcox (fig. 11).

Yegua Formation and Jackson Group.— Compared to the Wilcox Group, deep-basin lignite occurrences in the upper Eocene are of minor importance. Important upper Eocene lignite deposits are located in South Texas in a lagoonal environment associated with sandstones of the upper Yegua and lower Jackson (fig. 11). Only in South Texas have reasonably large areas of lignites greater than 5 feet thick been outlined (fig. 13). In Southeast Texas, upper Eocene lignites occur in a deltaic environment (figs. 8 and 9). The Yegua deposits are the largest, occurring primarily in the lower Yegua (fig. 21); Jackson deposits occur in the upper Jackson.

Potential Resources

Several assumptions have been made in determining Texas deep-basin lignite resources. On the isopleth maps the area within each isopleth was determined letting the isopleth value be the number of lignites within the enclosed area. Lignites outside the two-lignite isopleth are not included. The updip position of this isopleth is only approximate because the intervals of interest are fresh- to brackish-water charged. It is further assumed that all lignites are 2 feet thick and laterally continuous with a specific gravity of 1.30 and 1.25 in the central and southern areas, respectively.

Under the above assumptions, a grand total resource of 112 billion short tons of lignite was calculated (table 7). Not included are probably substantial resources in East Texas which could not be calculated. Huge resources are present in the Wilcox Group. In the Central Texas area, 97

Table 7. Deep-basin potential lignite resources.[1]

	All lignites[2]				Lignites > 5 feet thick			
	East	Central[3]	Southeast[3]	South[4]	East	Central	Southeast	South
Wilcox	No data	104.3		0.8	No data	16.6[5]		
Yegua			2.6					
Jackson			1.0					
Yegua-Jackson				3.4				1.6[6]
			Total = 112.1					

[1]in billions of short tons
[2]assume continuous 2-foot beds
[3]specific gravity = 1.30 or 1,765 tons/acre-foot
[4]specific gravity = 1.25 or 1,700 tons/acre-foot
[5]assume continuous 7-foot beds, specific gravity = 1.30
[6]assume continuous 6-foot beds, specific gravity = 1.25

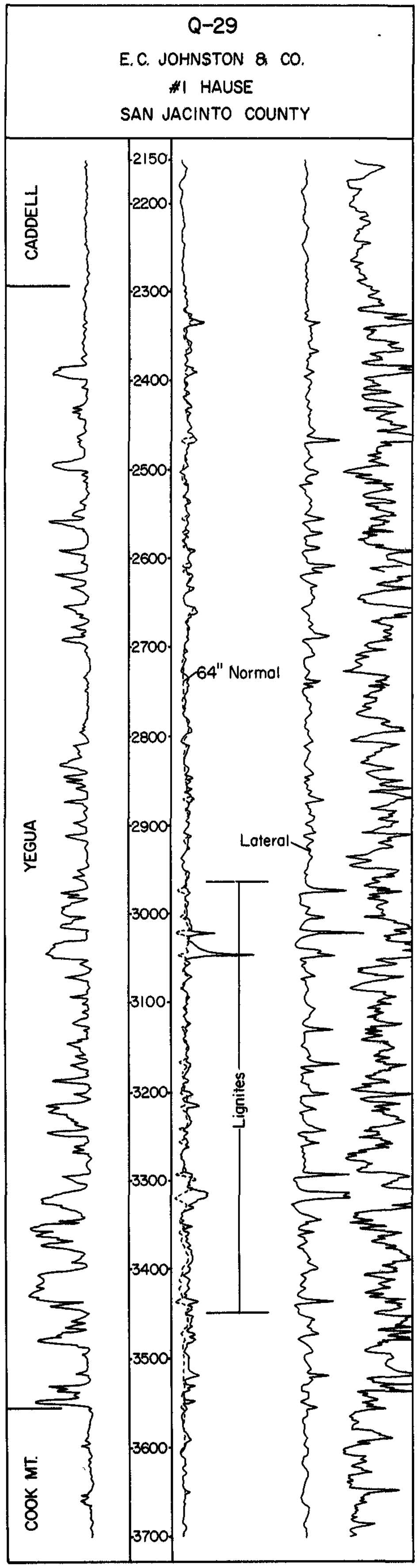


Figure 21. (left) Representative electric log illustrating Yegua stratigraphy and deep-basin lignite occurrence (see fig. 8 for well location).

percent of the resources are in the Wilcox. Not unexpectedly the Wilcox has by far the largest resource of lignites over 5 feet thick, 16.6 billion tons (table 7). The area of greatest potential for thick lignites is in southern Lee and northern Fayette Counties (fig. 7). In Lee County, lignites 10, 20, and 25 feet thick are not uncommon.

This deep-basin lignite is a vast potential energy resource. In equivalent energy terms the Central Texas Wilcox resource of 104 billion tons (table 7) is equal to 288 billion barrels of oil and 1,725 trillion cubic feet of gas.[5] This would meet the Nation's future energy demand for 13 years at the projected 1985 rate of 62 million barrels of oil per day (U. S. Bur. Mines estimate).

Underground Gasification of Coal

Current technology.—Available technology is based on worldwide activity which peaked between 1945 and 1960. Simultaneous experimental work was carried on in Great Britain, Morocco (by the French), Belgium, Italy, U. S. (Gorgas, Alabama), and U.S.S.R. The Russians have been the most active experimenters beginning in 1933 and continuing to 1965 when activity apparently ceased. Only in the U.S.S.R. have industrial plants for underground gasification been installed. Worldwide, there has been little testing of available technology since about 1965. Currently the Union Pacific Corporation and the U. S. Bureau of Mines are conducting a joint project at Hanna, Wyoming begun in late 1972 to test the technology and economics of underground gasification (Schrider and Pasini, 1973). Several private companies and university laboratories are also experimenting or have experimented with underground coal gasification (Higgins, 1972; Raimondi and others, 1973).

The methods reviewed in the literature (Capp and others, 1963; Elder, 1963; Arthur D. Little, Inc., 1972) for carrying out underground gasification are classified as shaft and shaftless methods and rely on combustion, pyrolysis, steam, and hydrogen reactions of coal. Shaft methods require men to work underground to prepare the coal

[5]7,900 Btu/lb lignite, 5.7×10^6 Btu/bbl oil, 950 Btu/ft^3 gas.

seams for gasification. Shaftless methods require no underground work since the coal seams are reached by boreholes.

Three shaft methods have been extensively reported in the literature: chamber, stream, and borehole producer. The chamber method has been superseded by later technology. The stream method has been the most successful, but is best applied to steeply dipping beds. The borehole producer method is best for horizontal or gently dipping beds (fig. 22A). It requires the preparation of parallel, underground galleries spaced about 500 feet apart. From such galleries horizontal boreholes, about 15 feet apart, are drilled from gallery to gallery. Gasification is started by igniting the horizontal boreholes farthest from the general access gallery. Blast (air or air, oxygen, steam mixture) comes down the central inlet shaft or vertical borehole into the inlet gallery and through the boreholes being gasified. Product gases are recovered from shafts or vertical boreholes intersecting offtake galleries. If air is the blast product, gas will be rich in nitrogen. Gasification proceeds toward the general access gallery (fig. 22A).

The basic shaftless method is the so-called percolation or filtration method which involves variation of borehole sizes (normally 10-inch diameter or more), numbers of boreholes, locational patterns, methods of linking, and gasification procedures (fig. 22B). The coal seam is penetrated by long horizontal boreholes or by vertical boreholes spaced 50 to 400 feet apart and located in a geometric pattern of rhombohedrons, rectangles, squares, or concentric circles. If the seam is penetrated by horizontal boreholes, fewer boreholes in the simplest of patterns are necessary (fig. 22C). Gasification takes place between different pairs of linked boreholes with offtake and intake holes depending on the locational pattern and gasification procedure (e.g., forward or backward burning, blast type). For lignites the method can be made to work using only their high natural permeability to link the boreholes. High-rank coals usually require hydraulic or pneumatic fracturing to increase permeability and stimulate gas flow between boreholes. Linkage may also be done by horizontal drilling, electro-carbonization, or filtration by fire.

One Russian percolation installation has been described in detail (fig. 22D; Elder, 1963). Reportedly the plant produced 15.6 billion cubic feet of gas per year using lignite with about 30 percent moisture, 37 percent ash, and a heating value of 4,900 Btu/lb. Boreholes were arranged in squares about 75 feet apart. Each generator was prepared for operation in two stages. First, four boreholes, 75 feet apart, are ignited and linked to each other forming a 225-foot linear fire front. Next, four boreholes 75 feet away are ignited and linked normal to the corresponding borehole in the fire front of the first row. The result is a generator composed of four parallel gasification passages 75 feet long, terminating at right angles at a fire front 225 feet long. Blast gas enters the boreholes in the second row and the product gas is removed from boreholes in the first row. Additional rows of boreholes are successively linked and gasified over the life of the installation (fig. 22D). Thus, for a 1000-megawatt plant the gasification area might be about three miles wide with the gasification direction advancing at right angles over a total distance dependent on plant life, coal recovery, and seam thickness (Arthur D. Little, Inc., 1972, p. 49–51).

Potentially, underground gasification of coal is a cheap source of fuel for electric-power generation and raw material for synthetic gases, liquid fuels, and other chemicals. The methods so far developed have been operated on a substantial scale. They can produce a combustible gas, mainly CO, H_2, and CH_4, of low-Btu value (50–280 Btu/scf), but not on a continuous basis or at a constant Btu value. It is noted that turbines can operate efficiently on gas as low as 120 Btu/scf. Several problem areas remain to be solved involving control of the fire front (location, size, and temperature) or combustion zone, roof collapse, linking of points within the coal seam, leakage of gasifying agent and product gas, and ground-water flow into the reaction zone.

Roof collapse is a problem requiring additional research on pneumatic or hydraulic stowing techniques and the rock mechanics of different overburdens. Utilization of coal's inherent directional properties is a promising approach to combustion-zone control and linkage problems (Komar and others, 1973). By application of backward and forward pressure on selected boreholes, in specific relation to the face and butt cleats, combustion-zone control might be possible. Linkage will be easier parallel to the direction of preferred flow; for example, natural permeability is considerably higher parallel to the face cleat direction. Problems of gas leakage and ground-

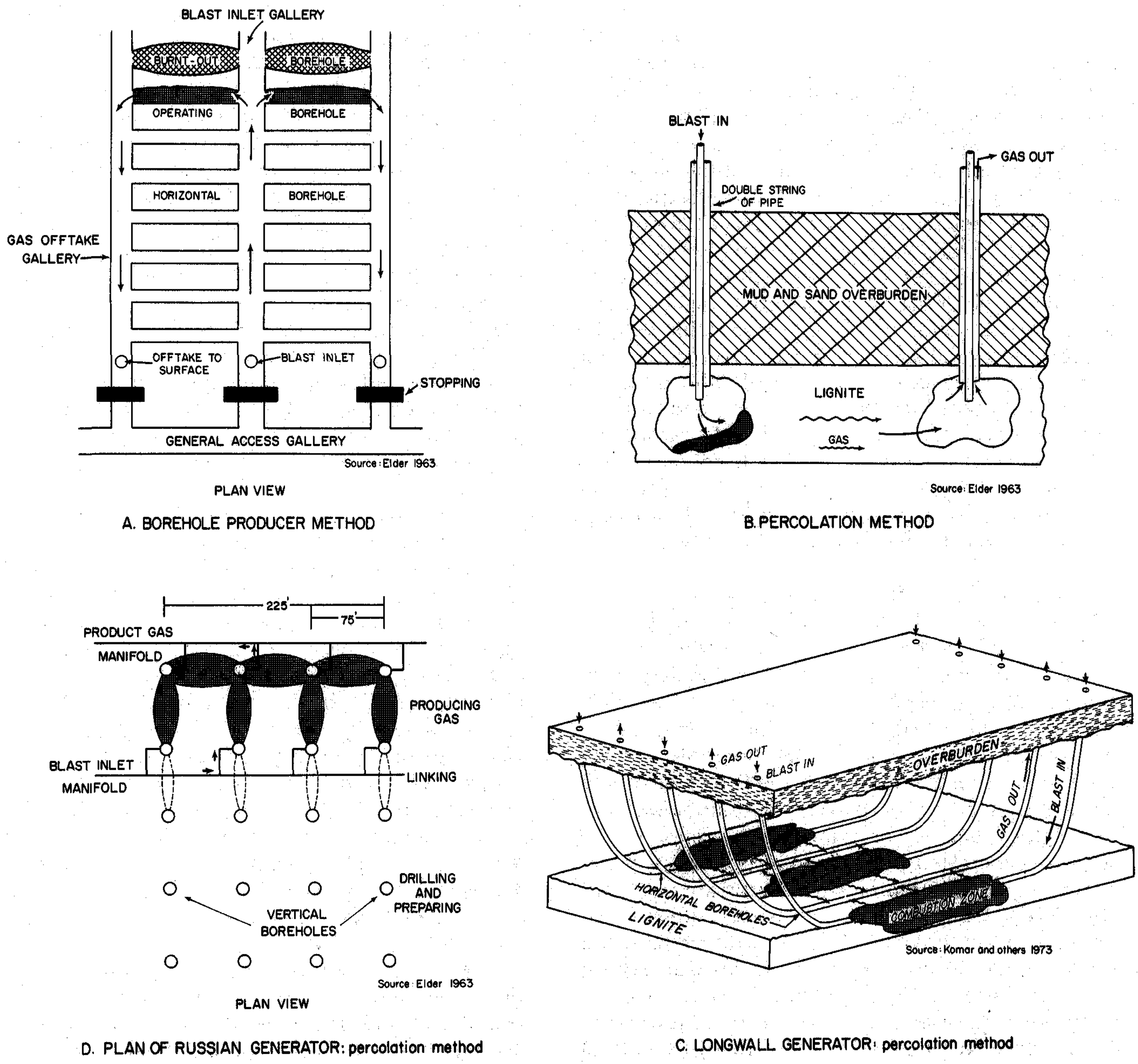


Figure 22. In situ gasification technology applicable to gently dipping coal seams.

water inflow can be moderated by gasifying thick seams roofed and floored by impermeable shale or mud.

Environmental factors.—Underground gasification poses the potential threat of ground-water contamination and surface subsidence. Ground water is subject to pollution by phenols and other toxic compounds (H_2S and NH_3) produced in the gasification zone. Other effects are an increase in water temperature, pH, and dissolved solids. The threat to ground-water aquifers can be effectively minimized by gasifying coal seams below the principal aquifers and employing a well-designed casing program. In Texas the major deep-basin lignite deposits are significantly removed from the principal fresh-water aquifers. Surface subsidence can be avoided by controlling roof collapse, perhaps by pneumatic or hydraulic filling of the voided space. In addition, gasification sites can be located far from existing or potential urban areas where the impact of surface subsidence would be slight. Not clear at this time is what percentage of the effluent gases from in situ gasification will be SO_2 and NO_x, but probably it will depend on O_2 and steam percentage in the blast gas, underground combustion temperature, and sulfur content of the coal. Environmental advantages of in situ gasification are that little or no land is disturbed, ash and waste heat remain underground, and almost no fresh water is consumed.

Economics.—Worldwide active testing of underground gasification technology ceased about 1965 for lack of economic incentive. Prior to the 1970's, tests were conducted in an entirely different energy supply-and-demand situation than exists today. The changed climate has prompted the new tests at Hanna, Wyoming.

Arthur D. Little, Inc. (1972, p. 103–107) reviewed the economics of underground gasification quoting production costs ranging from 40 cents to 300 cents per million Btu. A. D. Little, Inc. postulated the price which a hypothetical power utility would be willing to pay for clean, desulfurized gases leaving the underground gasification site. Optimistically a product gas of 356 Btu/scf could earn as much as 87 cents per million Btu while pessimistically a product gas of 97 Btu/scf could earn as little as 28 cents. Using a pipeline-quality gas production model, a product gas of 343 Btu/scf could earn from 68 cents to 28 cents per million Btu. A realistic estimate of production costs is hampered by the absence of data from candidate underground gasification projects, but is placed at 70 cents to 18 cents per million Btu. Thus it appears that gas from underground gasification can be competitive with alternatives being considered to meet the Nation's future energy needs.

Outlook for Texas.—Two available underground gasification methods are applicable to the gently dipping Texas lignites: borehole producer and percolation. Because of the large amount of underground labor required in construction of galleries and horizontal boreholes, the former method has limited application. Some variation of the percolation method has the most promise, particularly since lignite has high gas permeability making gasification practical without fracing. To date the best success has been in lignite. The depths to which it can be applied are dependent on drilling technology and costs. Current drilling and casing costs ($20.00/foot) probably limit its application to lignite less than 1,000 feet below the surface; however, experimentation has been carried out in Russia in beds as deep as 3,300 feet. Utilization of deeper beds would permit gasification below fresh-water reservoirs and use of higher gasification pressures without risk of excessive leakage.

To date the best results have come from gasification of lignites and coals greater than 5 feet thick (see figs. 7 and 13 for areas of thick lignites in Texas). Gasification of thin seams (3 to 5 feet thick) is practical, but not favorable because of increased heat losses to the country rock and increased moisture content of the seams. Furthermore, for increased efficiency it is necessary to operate in thicker seams with fewer boreholes and increased distances between them. Thick Texas lignites are commonly roofed and floored by clay, shale, and silty shale—an impermeable seal which will reduce ground-water flow into the reaction zone and the threat of ground-water contamination. In addition, roof collapse appears to be less of a problem in shaly rocks. Russian workers have concluded that shaly roof rocks increase the effectiveness and stability of the gasification process, probably by settling down on the mine floor directly behind the burning coal face.

Clearly, available technology favors thick lignites at shallow depths; a number of such deposits in Texas are likely sites for a pilot underground gasification projection. Because the Btu rating of gas from underground gasification is low it will be uneconomical to pipe long distances (greater than 100 miles) without upgrading to pipeline quality. Future exploitation will require the siting of electric-power or synthetic pipeline-quality gas plants at or reasonably close to the underground gasifier. Texas has plentiful reserves available for commercial operations expected to require operating reserves of at least 100 to 150 million tons. It is concluded that the future use of Texas deep-basin lignite will depend on energy needs and dwindling reserves of easily obtained fossil fuels, coupled with unrealized potential of alternative energy supplies, such as nuclear, geothermal, or solar.

CONCLUSIONS

(1) The present energy dilemma is real and immediate. In the years ahead, coal and lignite, in view of our shrinking oil and gas reserves, will play an important role in meeting the Nation's energy needs. Already in Texas conventional near-surface lignite deposits are being extensively utilized for electric-power generation.

(2) Lignite is found as near-surface and deep-basin deposits throughout the Texas Gulf Coastal Plain. Near-surface lignite occurs in two elongate bands stretching from the Rio Grande (Webb and Starr Counties) to the Red River (Bowie County) and Angelina River (Angelina County). Deep-basin lignite, between 200 and 5,000 feet below the surface, occurs coastward and downdip from the near-surface occurrences.

(3) The principal lignite deposits are found in the Wilcox Group (lower Eocene); deposits of secondary importance in terms of resources and grade are found in the Yegua Formation and Jackson Group (upper Eocene). The most important deposits occur north of the Colorado River. Lignite occurs as a component facies of ancient fluvial, deltaic, and lagoonal rocks in East, Central and Southeast, and South Texas, respectively.

(4) In the past all mining was by shallow underground room-and-pillar methods. The most important mining districts were Malakoff (Henderson County), Alba (Wood County), Como (Hopkins County), Rockdale (Milam County), and Bastrop-Sayersville (Bastrop County). Currently lignite is being strip-mined near Fairfield (Freestone County), Alcoa (Milam County), and Darco (Harrison County). Additional strip mines are expected to be operational near Winfield (Titus County), Beckville (Panola County), and Athens (Henderson County) by about 1980.

(5) Potential near-surface resources are estimated at 10.4 billion short tons with about 80 percent of the resources in the Wilcox Group. Operating reserves for a 1,000-megawatt steam-electric plant (35-year life) is estimated at 200 to 250 million tons. Two areas have most promise for new reserves of that size. They are within the Wilcox outcrop in Bastrop through Freestone Counties and in East Texas north and east of Freestone County. Counties that appear to have greatest potential in the latter area are: Harrison, Henderson, Hopkins, Panola, Rains, Rusk, Titus, and Van Zandt.

(6) The highest grade lignite occurs north of the Colorado River in the Wilcox as a component facies of ancient fluvial and deltaic systems in East and Central Texas, respectively. On a dry basis, sulfur content is 1.0 to 1.4 percent, ash 12 to 14 percent, and heating value 10,500 to 11,000 Btu per pound. There is a correlation between grade and geologic occurrence: deltaic lignite is the best quality, fluvial lignite is intermediate in quality, and lagoonal lignite is poorest in quality.

(7) Total statewide production is currently estimated at 8 to 10 million tons annually and is projected to be 25 million by 1980. Nationally, in 1971 the ninth and tenth ranked states had coal and lignite production of 9.3 and 8.2 million tons, respectively. The largest and most important use of Texas lignite is in lignite-fueled, steam-electric plants. The mines at Alcoa, Fairfield, Athens, Winfield, and Beckville do or will supply lignite for such plants. Future utilization is likely in the production of synthetic gases, liquid fuels, and chemical feed stocks.

(8) Environmental problems connected with the utilization of near-surface lignite are land use and disturbance, air and thermal pollution, water

allocation and quality, and waste disposal. The environmental impact, except for air pollution, is about the same whether lignite is used in steam-electric plants or gasification plants. At the moment, sulfur oxides and particulates, because of their effect on the respiratory tract, are the air pollutants of prime concern to public health. There are no climatic or terrain limits to a successful reclamation program in East and Central Texas. Underground gasification poses the potential threat of ground-water contamination and surface subsidence, but avoids major land disturbance and waste disposal problems.

(9) Deep-basin lignite tonnage, a solid-fuel resource for the future, is estimated at more than 100 billion tons. On an equivalent basis, this is equal to 277 billion barrels of oil and 1,660 trillion cubic feet of gas. The most important occurrence is in the Wilcox Group of Central Texas from Fayette County through Houston County.

(10) Underground gasification of coal and lignite is technically feasible. To be on a firm competitive footing the underground gasifier must be able to continuously produce a gas of constant Btu value greater than 120 Btu/scf. Utilization of deep-basin Texas lignite will depend on energy needs and dwindling reserves of easily obtained fossil fuels coupled with unrealized potential of nuclear energy.

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APPENDIX. ANALYSES AND DESCRIPTION OF SAMPLES.[6]

PROXIMATE ANALYSES

Sample Number	As-Received Basis: Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb	Dry Basis: Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
At-1	13.29	59.87	18.53	8.33	—	—	—	—	—	—	—
At-2	16.40	37.04	32.35	14.21	3.00	8599	44.30	36.70	17.00	3.71	10286
Ba-1	27.20	41.28	25.99	4.89	0.64	8114	—	—	—	—	
Ba-2	35.40	36.88	21.22	6.50	0.94	7859	—	—	—	—	—
Ba-3	—	—	—	—	—	—	56.94	32.86	10.20	1.47	12166
Ba-4	37.26	31.85	24.81	6.08	0.57	6416	50.76	39.54	9.70	0.90	10226
Ba-5	24.50	38.02	30.54	6.94	0.64	8779	47.34	40.66	12.00	0.80	10930
Ba-6	10.00	47.00	24.09	18.91	1.80	8114	51.76	26.50	21.75	2.50	9036
Ba-7	24.10	32.60	32.30	11.00	1.10	8090	—	—	—	—	—
Ba-8	32.50	28.96	32.18	6.36	—	7325	42.90	47.68	9.42	—	10852
Be-1	23.64	43.15	23.15	9.70	2.03	8104	56.98	30.32	12.70	2.66	10613
Be-2	14.60	18.00	8.60	58.60	—	—	—	—	—	—	—
Bo-1	10.67	76.41	10.62	1.45	0.85	—	—	—	—	—	—
Bo-2	11.55	37.70	42.30	7.55	0.90	—	—	—	—	—	—
Bo-3	13.68	48.61	26.25	11.46	0.47	10362	55.20	29.84	14.96	0.54	11780
Cal-1	13.06	43.18	36.59	7.17	5.70	—	—	—	—	—	—
Cal-2	8.15	29.06	39.73	23.08	1.33	—	—	—	—	—	—
Cam-1	20.74	37.26	28.60	13.40	—	8416	47.01	36.09	16.90	—	10618
Cas-1	15.80	39.42	39.79	4.99	—	—	—	—	—	—	—
Fa-1	33.80	31.17	23.72	7.25	4.06	6688	49.28	32.90	17.82	1.34	9709
Fa-2	31.12	33.95	22.66	12.27	0.93	8416	33.83	16.78	49.39	5.84	8516
Fa-3	1.20	33.42	16.58	48.80	5.77	—	45.42	35.19	19.39	—	—
Fa-4	19.82	36.45	28.25	15.50	—	—	53.05	18.14	28.81	—	—
Fa-5	27.80	38.31	13.08	20.21	—	—	50.30	27.40	22.30	—	—
Fa-6	33.50	33.45	18.23	14.82	1.41	—	58.50	34.50	7.00	2.40	—
Fa-7	39.00	35.69	21.05	4.28	—	—	56.52	32.48	11.00	—	11110
Fa-8	38.50	34.77	19.99	8.74	—	—	54.50	33.30	12.20	2.70	11222
Fa-9	46.30	—	—	—	—	—	—	—	—	—	—
Fa-10	46.00	—	—	—	—	—	49.04	41.22	9.74	—	—
Fa-11	31.26	23.24	19.80	25.70	—	6000	33.81	28.80	37.39	—	8722
Fa-12	31.50	29.94	28.56	11.00	—	7559	42.25	41.69	16.06	—	11035
Fr-1	26.90	33.80	29.40	9.90	1.65	7714	46.24	40.22	13.54	2.25	10566
Fr-2	23.47	31.83	26.50	18.20	1.92	7481	41.59	34.62	23.79	2.51	9775
Fr-3	25.64	37.16	29.90	7.30	1.24	9195	49.97	40.21	9.82	1.66	12365

[6]Largely from Fisher, 1963.

Sample Number	As-Received Basis: Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb	Dry Basis: Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
Fr-4	27.40	26.53	36.71	9.36	1.39	7977	36.54	50.56	12.90	1.92	10988
Fr-5	27.20	33.23	31.13	8.44	1.40	8056	45.64	42.76	11.60	1.92	11066
Fr-6	31.00	32.09	30.29	6.62	0.86	7560	46.50	43.90	9.60	1.24	10957
Fr-7	23.00	34.40	32.59	10.01	0.95	7903	44.68	42.32	13.00	1.24	10264
Fr-8	33.79	32.01	27.10	7.10	0.68	7435	48.34	40.93	10.73	1.03	11229
Ha-1	14.85	38.52	39.60	6.18	0.85	———	———	———	———	———	———
Ha-2	13.35	42.82	35.67	7.00	1.16	———	———	———	———	———	———
Ha-3	16.40	35.95	44.75	2.30	0.60	———	———	———	———	———	———
Ha-4	10.05	33.31	35.86	18.70	2.08	———	———	———	———	———	———
Ha-5	9.50	41.25	38.90	8.35	2.00	———	———	———	———	———	———
Ha-6	———	———	———	———	———	———	44.20	45.10	10.70	1.00	11200
Ha-7	33.50	30.90	29.70	5.90	0.60	7610	46.40	44.70	8.90	0.90	11440
Ha-7a	21.00	36.70	35.30	7.00	0.70	9040	———	———	———	———	———
Ha-7b	———	———	———	———	———	———	51.00	49.00	———	1.00	12550
Ha-8	33.60	28.90	29.70	7.80	0.50	7380	43.50	44.70	11.80	0.80	11120
Ha-8a	18.30	35.50	36.60	9.60	0.70	9090	———	———	———	———	———
Ha-8b	———	———	———	———	———	———	49.30	50.70	———	0.90	12610
Ha-9	35.80	28.80	28.00	7.40	0.50	7210	44.90	43.50	11.60	0.80	11230
Ha-9a	22.10	35.00	33.90	9.00	0.60	8750	———	———	———	———	———
Ha-9b	———	———	———	———	———	———	50.80	49.20	———	0.90	12700
Ha-10	33.80	28.10	28.80	9.30	0.80	7300	42.40	43.60	14.00	1.20	11030
Ha-10a	20.10	33.90	34.80	11.20	0.90	8820	———	———	———	———	———
Ha-10b	———	———	———	———	———	———	49.30	50.70	———	1.40	12830
Ha-11	33.20	30.90	28.60	7.30	0.50	7800	46.30	42.80	10.90	0.80	11690
Ha-11a	18.20	37.90	35.00	8.90	0.70	9560	———	———	———	———	———
Ha-11b	———	———	———	———	———	———	51.90	48.10	———	0.90	13110
He-1	25.00	34.47	33.25	7.28	———	———	———	———	———	———	———
He-2	25.00	33.59	33.39	8.02	———	———	———	———	———	———	———
He-3	22.50	———	———	———	———	———	54.70	36.30	9.00	0.07	10600
He-4	16.50	39.00	31.30	13.20	1.69	8338	46.71	37.48	15.81	2.02	9986
He-5	12.60	40.20	26.40	20.80	2.27	8338	46.00	30.21	23.79	2.59	9540
He-6	30.60	30.90	30.42	8.00	1.23	7793	44.64	43.83	11.53	1.77	11229
He-7	25.00	36.81	29.89	8.30	0.70	7950	———	———	———	———	———
He-8	24.14	39.49	19.83	16.54	1.08	7578	———	———	———	———	———
He-9	6.80	50.65	37.00	5.55	0.52	———	———	———	———	———	———
He-10	5.70	57.45	29.85	7.00	0.87	———	———	———	———	———	———
He-11	32.75	25.15	14.80	27.30	1.10	———	———	———	———	———	7665
Hop-1	33.87	45.88	3.41	16.84	0.68	6474	69.39	5.16	25.45	1.04	9790
Hop-2	34.00	———	———	———	———	———	39.50	49.38	11.12	1.01	11680
Hop-3	36.64	28.33	27.02	8.01	0.41	6717	———	———	———	———	———
Hop-4	———	———	———	———	———	———	44.70	42.63	12.67	0.64	10600
Hop-5	27.50	35.20	27.30	10.00	0.73	7040	———	———	———	———	———
Hop-6	———	———	———	———	———	———	48.54	37.65	13.81	1.00	9709
Hop-7	10.20	39.92	44.13	5.75	———	———	———	———	———	———	———
Hop-8	22.92	50.28	21.66	5.14	———	———	———	———	———	———	———
Hop-9	23.10	29.96	30.50	16.40	1.38	7481	38.96	39.67	21.37	1.80	9728

Sample Number	As-Received Basis						Dry Basis				
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
Hop-10	17.80	———	———	———	———	———	40.10	38.30	21.60	1.26	9967
Hop-11	30.13	48.75	8.06	13.06	1.99	———	———	———	———	———	9992
Hop-12	28.01	33.49	11.25	27.25	0.72	———	———	———	———	———	7544
Hou-1	32.58	37.02	19.56	10.84	0.56	———	———	———	———	———	———
Hou-1a	21.25	43.25	22.85	12.65	0.65	———	———	———	———	———	———
Hou-2	33.50	39.50	16.25	10.75	0.56	7142	———	———	———	———	———
Hou-2a	20.55	47.20	19.41	12.84	0.67	8534	———	———	———	———	———
Hou-3	34.70	32.23	21.87	11.20	0.79	7056	———	———	———	———	———
Hou-3a	13.40	42.75	29.00	14.85	1.04	9358	———	———	———	———	———
Hou-4	———	———	———	———	———	———	54.91	29.01	16.08	0.83	———
Hou-5	———	———	———	———	———	———	59.40	24.43	16.17	0.84	10741
Hou-6	———	———	———	———	———	———	49.36	33.49	17.15	1.21	10805
Hou-7	33.50	32.34	23.80	10.36	0.63	7267	———	———	———	———	10928
Hou-8	25.58	39.37	25.30	9.75	0.60	7532	———	———	———	———	———
Hou-9	———	———	———	———	———	———	52.90	33.99	13.11	0.80	10120
Hou-10	28.16	43.60	21.02	6.64	0.58	7326	———	———	———	———	———
Hou-11	31.45	30.80	25.60	12.75	———	6410	———	———	———	———	———
Hou-12	12.88	47.57	29.40	10.15	———	———	———	———	———	———	———
Hou-13	30.95	32.84	27.64	8.57	1.43	7855	———	———	———	———	———
Hou-14	36.16	33.16	19.93	10.75	0.40	7518	51.95	31.26	16.79	0.64	10994
Hou-15	41.50	28.90	23.17	6.42	1.38	6605	49.90	39.60	11.00	2.37	11291
Hou-16	13.10	41.65	36.80	7.55	0.90	———	———	———	———	———	———
Hou-17	4.90	40.73	20.93	32.90	0.54	———	———	———	———	———	———
Hou-18	11.80	36.06	32.56	16.70	0.88	———	———	———	———	———	———
Hou-19	4.52	32.91	22.01	40.03	0.48	———	———	———	———	———	———
Hou-20	7.75	40.65	30.95	19.75	0.90	———	———	———	———	———	———
Hou-21	30.70	29.04	29.66	10.60	———	6936	41.90	42.80	15.30	———	10009
Lee-1	12.60	44.75	33.90	8.75	0.63	9774	51.20	38.78	10.02	0.72	11182
Lee-2	16.50	36.07	37.17	8.60	1.66	———	———	———	———	———	———
Lee-3	16.00	———	———	———	———	———	53.54	37.16	9.30	———	———
Leo-1	29.96	41.68	22.24	6.12	0.70	6903	59.50	31.75	8.75	1.00	———
Leo-2	23.11	39.84	29.39	6.78	0.88	8336	———	———	———	———	———
Leo-3	1.80	———	———	———	———	———	62.22	22.78	17.00	———	———
Leo-4	12.80	———	———	———	———	———	56.06	34.94	9.00	———	———
Leo-5	2.60	———	———	———	———	———	62.32	27.58	11.10	———	———
Leo-6	20.00	———	———	———	———	———	58.62	33.68	7.70	1.46	11020
Leo-7	27.00	37.91	27.80	7.21	0.44	7308	51.93	38.07	10.00	0.60	11380
Leo-8	15.71	———	———	———	———	———	45.20	46.30	8.50	———	———
Leo-9	28.20	34.77	24.72	12.31	1.02	7805	44.38	39.28	15.84	1.31	10006
Leo-10	33.00	28.90	29.40	9.70	0.98	8027	43.13	42.39	14.48	1.48	11980
Leo-11	33.00	27.84	30.26	9.00	0.88	8057	41.40	45.16	13.44	1.48	12026
Leo-12	31.50	27.60	34.20	6.70	0.82	8360	40.29	49.38	9.78	1.20	12058
Leo-13	26.50	28.96	28.81	15.73	1.11	6528	39.40	39.20	21.40	1.51	———
Leo-14	19.80	35.74	35.00	9.46	0.90	8494	44.57	43.64	11.80	1.12	10598
Leo-15	23.04	33.72	35.20	8.04	1.29	8697	43.82	45.74	10.44	1.68	11275

Sample Number	As-Received Basis Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb	Dry Basis Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
Leo-16	27.80	31.80	31.70	8.70	1.19	8808	44.04	43.91	12.05	1.65	12196
Leo-17	25.80	33.39	31.91	8.90	1.04	8146	45.00	43.00	12.00	1.40	10980
Leo-18	24.60	32.60	32.70	10.10	0.62	7760	43.24	43.36	13.40	0.82	11221
Leo-19	34.80	29.28	30.25	5.67	1.55	7519	44.90	46.40	8.70	0.84	11533
Leo-20	30.80	30.24	31.76	7.20	0.82	7496	43.70	45.90	10.40	1.12	10832
Leo-21	30.20	28.04	30.18	11.58	—	7538	40.17	43.24	16.59	—	10800
Leo-22	27.30	31.28	30.92	10.50	—	7403	43.02	42.54	14.44	2.71	8980
Leo-23	27.10	30.70	28.80	13.40	—	6546	42.11	39.51	18.38	1.65	12196
Li-1	9.00	34.62	43.84	12.54	1.41	7658	38.04	48.18	13.78	1.54	8416
Li-2	12.00	42.00	32.00	13.00	—	—	—	—	—	—	—
McM-1	12.05	43.62	14.73	29.60	1.71	6652	49.60	16.75	33.65	1.95	7563
McM-2	16.13	41.09	29.88	12.90	1.89	8403	48.99	35.63	15.38	2.25	10019
McM-3	16.55	40.89	27.20	15.36	1.85	8350	49.00	32.59	18.41	2.22	10006
McM-4	15.07	41.59	27.33	16.01	1.28	8665	48.99	32.17	18.84	1.56	10203
McM-5	20.87	41.55	21.48	16.10	1.84	7700	52.61	27.15	20.34	2.32	9731
McM-6	14.14	43.06	28.93	13.87	2.67	8836	50.15	33.69	16.16	3.10	10291
McM-7	10.60	43.72	18.29	27.19	1.23	6610	49.03	20.50	30.47	1.38	7410
McM-8	10.84	41.79	27.63	19.74	1.77	7860	46.87	30.99	22.14	1.99	8816
McM-9	10.06	37.97	7.11	44.86	0.80	5010	42.22	7.91	49.87	0.89	5570
McM-10	8.00	28.50	18.10	45.40	2.20	5610	31.00	19.70	49.30	2.40	6100
McM-11	7.50	21.10	17.00	48.40	2.50	5250	29.20	18.50	52.30	2.70	6570
McM-12	9.00	27.60	19.70	43.20	2.00	5590	30.50	21.70	47.80	2.20	6170
McM-13	10.00	31.60	23.70	34.70	0.80	6720	35.10	26.40	8.50	0.80	7470
McM-14	6.40	27.60	18.50	47.50	2.40	5510	29.40	19.90	50.70	2.60	5890
McM-15	10.50	33.00	25.50	31.00	1.10	7300	36.90	28.50	34.60	1.20	8160
McM-16	8.20	30.10	22.70	39.00	2.30	6430	32.70	24.80	42.50	2.50	7010
McM-17	8.50	31.10	22.90	37.50	0.90	6630	34.00	25.10	40.90	1.00	7240
Me-1	35.30	36.33	28.85	7.52	0.93	—	56.15	32.24	11.61	1.45	12215
Me-2	31.67	24.81	26.49	17.03	3.55	—	—	—	—	—	—
Me-3	32.92	27.42	27.08	12.58	1.46	6840	—	—	—	—	—
Me-4	27.39	35.07	28.16	9.38	0.88	7485	—	—	—	—	—
Me-5	24.36	33.89	25.64	16.11	0.74	7068	44.80	33.89	21.31	0.97	—
Me-6	32.92	27.42	27.08	12.58	1.46	6840	40.88	40.37	18.75	2.18	10197
Me-7	30.77	27.36	28.39	13.48	1.62	7079	—	—	—	—	—
Me-8	28.00	27.50	32.30	12.20	1.60	7580	—	—	—	—	—
Me-9	31.67	24.81	26.49	17.03	3.55	—	—	—	—	—	—
Me-10	34.39	40.31	18.50	6.90	1.20	7536	61.36	28.17	10.47	1.84	11470
Me-11	28.34	41.49	21.63	8.54	0.87	7846	—	—	—	—	—
Me-12	34.29	42.68	24.77	10.15	0.55	8156	55.00	31.91	13.09	1.33	10510
Mi-1	29.94	39.03	21.09	9.94	0.55	6291	55.70	30.09	14.31	0.78	8979
Mi-2	7.30	45.62	36.65	10.43	0.45	10411	49.21	39.53	11.26	0.51	11230
Mi-3	24.20	36.28	30.62	8.90	1.14	7684	47.87	40.39	11.74	—	—
Mi-4	32.00	29.77	29.20	9.03	1.24	7842	43.78	42.94	13.28	1.65	11533
Mi-5	29.07	28.96	24.47	17.60	3.29	7439	40.84	34.49	24.67	4.65	10489

Sample Number	As-Received Basis Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb	Dry Basis Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
Mi-6	31.52	44.49	17.48	6.51	0.93	8046	64.98	25.57	9.45	1.36	11750
Mi-7	35.86	25.50	29.72	7.92	0.87	–––	41.32	46.34	12.34	1.36	–––
Mi-8	35.30	26.22	29.58	8.90	0.76	6898	–––	–––	–––	–––	–––
Mi-9	34.72	34.26	22.73	8.29	1.04	7697	54.02	34.82	11.16	1.60	11792
Mi-10	28.20	–––	–––	–––	–––	–––	45.78	39.15	15.07	–––	–––
Mi-11	32.27	44.30	15.26	8.17	2.31	7383	65.41	22.54	12.05	3.42	10901
Mi-12	33.63	46.78	7.45	12.14	0.99	7359	70.49	11.24	18.27	1.50	11088
Mi-13	36.01	27.95	28.66	7.38	0.77	7132	43.68	44.79	11.53	1.20	11146
Mi-14	31.06	27.67	33.39	7.88	0.99	7870	40.14	48.43	11.43	1.43	11416
Mi-15	35.56	28.91	27.49	8.04	0.75	7870	44.86	42.66	12.48	1.16	–––
Mi-16	32.20	30.11	28.82	8.87	0.88	–––	–––	–––	–––	–––	–––
Mi-17	12.62	37.91	36.21	13.26	0.48	9525	43.38	41.43	15.19	0.54	10900
Mi-18	30.20	33.23	28.84	7.73	0.69	6920	47.60	41.31	11.09	0.98	10030
Mi-19	30.34	34.14	30.66	4.86	0.61	6797	49.00	44.00	7.00	0.87	9957
Mi-20	24.20	33.40	32.30	10.10	1.00	8310	44.00	42.60	13.40	1.30	10960
Mi-20a	11.00	39.20	37.90	11.90	1.20	9750	–––	–––	–––	–––	–––
Mi-20b	–––	–––	–––	–––	–––	–––	50.80	49.20	–––	1.50	12640
Mi-21	33.20	29.30	29.80	7.70	1.30	7550	43.90	44.60	11.50	2.00	11240
Mi-21a	15.30	37.20	37.80	9.70	1.70	9530	–––	–––	–––	–––	–––
Mi-21b	–––	–––	–––	–––	–––	–––	49.60	50.40	–––	2.30	12700
Mi-22	32.00	29.60	31.10	7.30	0.90	7640	43.90	44.60	11.50	2.00	11240
Mi-22a	15.30	37.20	37.80	9.70	1.70	9530	–––	–––	–––	–––	–––
Mi-22b	–––	–––	–––	–––	–––	–––	48.90	51.10	–––	1.50	12600
Mi-23	31.90	29.30	27.90	10.90	1.70	7150	42.90	41.10	16.00	2.50	10490
Mi-23a	14.90	36.60	34.90	13.60	2.20	8930	–––	–––	–––	–––	–––
Mi-23b	–––	–––	–––	–––	–––	–––	51.10	48.90	–––	3.00	12490
Mi-24	20.64	36.24	32.64	10.48	0.70	8262	45.66	41.12	13.22	0.80	10410
Mi-25	29.60	31.50	30.24	8.66	1.00	7593	44.74	42.96	12.30	1.37	10785
Mi-26	16.73	36.09	35.36	11.18	1.26	8695	43.34	42.46	14.20	1.51	10442
Mi-27	13.41	37.03	39.43	10.13	1.36	9582	42.76	45.54	11.70	1.57	11066
Mi-28	29.83	35.46	27.03	7.98	0.88	–––	50.50	38.50	11.00	1.25	–––
Mi-29	32.12	34.30	26.61	6.97	0.82	6690	50.52	39.20	10.28	1.20	–––
Mi-30	32.97	37.09	22.91	7.21	–––	–––	–––	–––	–––	1.18	11551
Mi-31	27.30	27.40	33.55	11.10	0.65	–––	40.33	42.93	15.93	0.80	–––
Pa-1	20.80	52.08	22.67	3.98	0.48	–––	–––	–––	–––	–––	–––
Pa-2	30.24	30.22	32.68	6.89	3.73	8494	43.32	46.82	9.87	5.38	12176
Pa-3	32.81	34.25	24.68	8.26	0.86	7379	50.98	36.73	12.29	1.28	10982
Ra-1	10.78	40.35	36.45	11.45	1.00	–––	–––	–––	–––	–––	–––
Ra-2	9.50	38.70	36.75	14.15	0.90	–––	–––	–––	–––	–––	–––
Ro-1	29.86	51.00	10.00	9.14	0.91	7929	72.72	14.26	13.02	1.30	11305
Ro-2	25.64	35.55	30.28	8.53	0.96	7459	47.80	40.71	11.49	1.29	10030
Ro-3	19.42	43.12	29.46	7.08	0.92	7695	–––	–––	–––	–––	–––
Ro-4	34.33	25.94	30.93	8.80	0.95	7214	39.50	47.10	13.40	1.45	10985
Ro-5	29.62	27.60	29.37	13.41	0.98	7040	–––	–––	–––	–––	–––
Ro-6	23.50	29.07	35.74	11.69	0.82	8089	–––	–––	–––	–––	–––

Sample Number	As-Received Basis						Dry Basis				
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
Ro-7	24.01	29.75	37.74	11.50	0.91	8021	———	———	———	———	———
Ro-8	33.50	26.06	30.38	10.06	0.97	———	39.19	45.68	15.13	1.46	———
Ro-9	30.60	30.19	34.07	5.14	0.86	8938	43.50	49.10	7.40	1.13	11674
Ro-10	25.80	34.40	31.20	8.60	1.24	8416	———	———	———	———	———
Ro-10a	20.34	36.76	31.70	11.20	1.24	9118	———	———	———	———	———
Ro-10b	21.20	32.80	32.10	13.90	1.37	8806	———	———	———	———	———
Ro-10c	18.90	35.52	30.18	15.40	1.37	8775	———	———	———	———	———
Ro-10d	16.50	31.50	24.90	27.10	1.37	7995	———	———	———	———	———
Ro-11	24.20	34.40	30.90	10.50	1.24	8884	———	———	———	———	———
Ro-11a	26.90	32.00	32.80	8.30	1.24	8962	———	———	———	———	———
Ro-11b	20.70	33.10	29.60	16.60	1.24	8572	———	———	———	———	———
Ro-11c	20.10	31.60	31.90	16.40	1.24	9507	———	———	———	———	———
Ro-11d	18.30	29.40	25.90	26.40	1.37	7949	———	———	———	———	———
Ro-12	10.30	38.70	37.60	13.40	1.24	10209	———	———	———	———	———
Ro-12a	14.30	39.10	36.10	10.50	1.37	10162	———	———	———	———	———
Ro-12b	15.10	37.30	35.80	11.80	1.37	9694	———	———	———	———	———
Ro-12c	10.90	35.50	35.30	18.30	1.37	9663	———	———	———	———	———
Ro-12d	12.54	31.36	29.50	26.60	1.37	8650	———	———	———	———	———
Ro-13	29.80	35.54	29.69	5.97	0.77	8129	49.20	42.30	8.50	1.10	11580
Ro-14	31.10	34.02	27.88	7.10	0.65	8500	44.55	45.15	10.30	0.85	11140
Ro-15	29.40	32.12	33.89	4.59	0.73	8110	45.50	48.00	6.50	1.04	11487
Ro-15a	29.40	29.51	32.01	9.08	1.29	———	41.80	45.34	12.86	1.29	10536
Ro-16	35.60	32.24	27.46	4.70	———	———	50.06	42.74	7.30	1.19	11455
Ro-17	31.40	29.36	31.25	7.99	———	———	42.80	45.57	11.64	1.16	11019
Ru-1	16.83	46.33	31.74	5.37	1.09	———	———	———	———	———	———
Ru-2	7.15	45.86	40.56	4.95	1.48	———	———	———	———	———	———
Ru-3	16.55	43.90	25.40	14.15	0.08	———	———	———	———	———	———
Ru-4	13.51	45.36	32.44	8.69	0.88	———	———	———	———	———	———
Ru-5	15.70	4.11	79.14	1.06	———	———	———	———	———	———	———
Ru-6	11.50	43.90	38.04	6.56	2.22	11221	49.60	42.90	7.41	2.51	12680
Sh-1	31.96	39.53	23.05	5.46	1.46	8053	58.10	33.89	8.05	2.16	11837
Sh-2	18.26	43.51	29.53	8.70	2.46	———	———	———	———	———	———
Ti-1	31.24	40.29	21.07	7.40	0.73	6727	58.60	30.64	10.76	1.05	9782
Ti-2	34.50	29.96	29.04	6.50	1.28	7403	45.74	44.34	9.92	1.95	11298
Ti-3	32.16	42.84	15.75	9.25	0.85	———	———	———	———	———	10661
Ti-4	32.27	45.85	14.27	7.62	0.94	———	———	———	———	———	10543
Ti-5	12.03	66.94	13.88	7.15	0.88	———	———	———	———	———	10580
Ti-6	33.44	30.02	24.14	12.40	0.57	6820	45.10	36.27	18.63	0.85	10246
Va-1	27.20	40.90	27.09	4.81	0.48	7682	56.18	37.20	6.62	0.65	10540
Va-2	28.70	———	———	———	———	———	43.90	42.50	13.60	———	———
Va-3	33.47	34.28	23.67	8.85	0.75	———	———	———	———	———	10357
Va-4	33.32	32.79	25.67	6.62	0.81	———	———	———	———	———	10713
Va-5	30.53	34.32	8.41	26.74	1.74	———	———	———	———	———	6692

Sample Number	As-Received Basis: Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb	Dry Basis: Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
Wo-1	29.28	34.02	29.04	6.66	0.57	7238	48.10	41.05	10.85	0.80	10220
Wo-2	15.00	43.61	32.71	8.68	0.94	8789	51.30	38.48	10.22	1.10	10340
Wo-3	25.80	36.55	24.67	12.98	0.61	8095	———	———	———	———	———
Wo-4	28.86	35.96	27.26	7.92	0.50	7996	50.55	38.32	11.13	0.70	11239
Wo-5	31.34	41.18	18.98	8.50	0.57	———	59.98	27.64	12.38	0.83	———
Wo-6	33.71	29.25	29.76	7.28	0.53	7348	44.12	44.89	10.99	0.80	11086
Wo-7	33.98	31.01	27.33	7.68	0.56	———	46.97	41.40	11.63	0.84	———
Wo-8	36.80	28.86	28.09	6.25	0.53	7101	45.66	44.45	9.89	0.84	11236
Wo-9	34.87	29.80	27.69	7.64	0.50	———	45.75	42.52	11.63	0.77	———
Wo-10	33.85	27.50	31.35	7.30	0.51	7497	41.57	47.39	11.04	0.77	11333
Wo-11	36.27	30.58	25.14	8.01	0.51	———	———	———	———	———	———
Wo-12	36.30	30.61	24.90	8.19	0.50	———	———	———	———	———	———
Wo-13	33.43	37.80	18.17	10.60	0.68	———	———	———	———	———	———
Wo-14	34.08	33.15	25.32	7.45	0.49	———	———	———	———	———	———
Wo-15	33.83	38.83	21.90	4.84	0.60	6158	———	———	———	———	———
Wo-16	29.20	36.92	27.02	6.86	0.58	7442	52.14	38.22	9.64	0.81	10510
Wo-17	10.80	41.20	38.92	9.08	0.61	9670	46.18	43.63	10.20	0.68	10840
Wo-18	24.10	36.48	31.92	7.50	1.00	7882	———	———	———	———	———
Wo-19	33.46	31.51	27.44	7.59	0.61	8257	———	———	———	———	———
Wo-20	33.14	30.81	27.39	8.66	0.65	7038	———	———	———	———	———
Wo-21	32.79	29.51	28.94	8.76	0.85	7437	———	———	———	———	———
Wo-22	26.59	30.85	32.71	9.90	0.68	7728	42.00	44.52	13.48	0.92	10520
Wo-23	24.95	32.21	32.06	10.78	0.70	7785	42.92	42.72	14.36	0.95	10598
Wo-24	25.85	35.58	31.30	7.27	0.54	7974	47.99	42.21	9.80	0.73	10754
Wo-25	27.51	33.42	28.12	10.95	0.62	7739	46.10	38.80	15.10	0.85	10676
Wo-26	27.67	32.02	31.06	9.25	0.71	7710	———	———	———	———	———
Wo-27	27.48	32.24	33.01	7.27	0.69	8004	———	———	———	———	———
Wo-28	27.03	33.41	30.25	9.31	0.79	7813	———	———	———	———	———
Wo-29	26.00	32.41	29.63	11.96	0.85	7538	———	———	———	———	———
Wo-30	28.45	33.15	30.56	7.84	0.74	7706	———	———	———	———	———
Wo-31	27.27	34.44	28.69	9.60	0.79	7809	———	———	———	———	———
Wo-32	28.28	31.61	27.16	12.95	0.83	7246	———	———	———	———	———
Wo-33	24.50	31.30	38.00	6.20	0.98	7996	———	———	———	———	———
Wo-34	28.86	35.96	27.26	7.92	0.50	7996	———	———	———	———	———
Wo-35	31.34	41.18	18.96	8.50	0.57	———	———	———	———	———	———
Wo-36	33.71	29.25	29.76	7.28	0.53	7348	———	———	———	———	———
Wo-37	33.98	31.01	27.33	7.68	0.56	———	———	———	———	———	———
Wo-38	36.80	28.86	28.09	6.25	0.53	7101	———	———	———	———	———
Wo-39	34.87	29.80	27.69	7.64	0.50	———	———	———	———	———	———
Wo-40	33.85	27.50	31.35	7.30	0.51	7497	———	———	———	———	———
Wo-41	24.80	32.20	29.20	13.80	1.10	8105	42.83	38.83	18.34	1.46	10780
Wo-42	22.30	33.80	24.60	19.30	1.37	8213	43.50	31.66	24.84	1.76	10570
Wo-43	19.90	33.36	30.04	16.50	1.24	8385	41.90	37.50	20.60	1.54	10470
Wo-44	19.70	34.06	29.94	16.30	1.64	8260	42.41	37.29	20.30	2.04	10290
Wo-45	16.60	29.90	28.50	25.00	1.33	7278	35.85	34.16	29.99	1.81	8727
Wo-46	23.36	30.14	31.40	15.10	1.24	8027	26.94	30.66	30.30	———	———
Wo-46a	26.94	30.66	30.30	12.10	1.85	8260	———	———	———	———	———
Wo-46b	27.56	30.94	29.60	11.90	1.78	8027	———	———	———	———	———

Sample Number	As-Received Basis Moisture	Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb	Dry Basis Volatile Matter	Fixed Carbon	Ash	Sulfur	Btu/lb
Wo-46c	27.70	30.50	29.30	12.50	1.85	7559	—	—	—	—	—
Wo-46d	22.40	29.50	28.80	19.30	1.58	7247	—	—	—	—	—
Wo-47	21.40	35.66	31.44	11.50	1.10	8572	—	—	—	—	—
Wo-47a	22.60	32.20	30.70	14.50	1.03	8104	—	—	—	—	—
Wo-47b	26.70	32.10	28.90	12.30	1.35	7824	—	—	—	—	—
Wo-47c	23.12	33.64	29.04	14.20	1.35	7948	—	—	—	—	—
Wo-47d	22.50	31.24	29.36	16.90	1.20	7637	—	—	—	—	—
Wo-48	23.46	33.60	32.64	10.30	1.10	8343	—	—	—	—	—
Wo-49	16.60	35.60	34.00	13.80	0.96	8837	—	—	—	—	—
Wo-49a	17.46	38.44	28.50	15.60	1.24	8198	—	—	—	—	—
Wo-49b	19.70	34.00	33.00	13.30	1.10	8650	—	—	—	—	—
Wo-49c	20.76	32.64	31.20	15.40	1.24	8182	—	—	—	—	—
Wo-49d	16.26	32.64	32.00	19.10	1.37	8214	—	—	—	—	—
Wo-50	18.90	35.40	35.20	10.50	0.96	9118	—	—	—	—	—
Wo-50a	20.50	34.36	33.74	11.40	1.24	8712	—	—	—	—	—
Wo-50b	16.90	35.60	35.95	11.60	1.24	9090	—	—	—	—	—
Wo-50c	14.10	36.50	36.60	12.80	1.24	9585	—	—	—	—	—
Wo-50d	12.14	34.06	34.70	19.10	1.24	8775	—	—	—	—	—
Wo-51	35.60	45.21	11.60	7.59	0.47	7567	70.21	18.02	11.77	0.73	11751
Wo-52	34.23	41.74	19.85	4.87	0.56	7691	63.47	30.19	6.34	0.86	11694
Wo-53	29.20	—	—	—	—	—	52.14	38.22	9.64	0.81	10510
Wo-54	27.00	35.90	28.70	8.40	1.92	7512	49.18	39.31	11.51	2.63	10290
Wo-55	33.56	27.78	29.67	8.99	0.96	—	—	—	—	—	9977
Za-1	8.37	25.93	36.40	29.30	1.68	8104	28.30	30.72	31.98	1.83	8844
Za-2	6.11	37.30	40.99	15.50	1.97	—	—	—	—	—	11231
Za-3	15.32	—	53.00	11.05	3.02	—	—	—	—	—	11530
Za-4	7.48	28.99	11.64	51.99	0.30	3299	31.20	12.60	56.20	0.32	3566
Za-5	7.99	35.56	24.39	32.06	0.68	6855	38.65	26.51	34.84	0.74	7550
Za-6	5.40	31.85	53.25	9.50	1.52	—	—	—	—	—	11823
Za-7	7.25	39.80	38.45	14.50	2.28	—	—	—	—	—	10860
Za-8	5.90	42.30	34.65	17.15	2.19	—	—	—	—	—	10500

DESCRIPTION OF SAMPLES

Atascosa County

At-1. Mine sample, Kinney mine near Somerset in Bexar County; sample apparently air-dried; Dumble, 1892, p. 185.

At-2. Outcrop sample, submitted Jan. 1914; Franklin ranch, about 15 miles southwest of Christine; B. E. G. no. 1137; no. 1244, Schoch, 1918, pp. 77, 189.

Bastrop County

Ba-1. Mine sample, Bastrop Coal Company; analysis by P. S. Tilson, Houston; no. 5, Phillips and others, 1911, pp. 105, 106.

Ba-2. Mine sample, Glenn-Belto mine, Bishop; no. 1537, Phillips, 1902, p. 51; Phillips and Worrell, 1913, pp. 87, 88.

Ba-3. Mine sample, Glenn-Belto mine, T. M. S. no. 1537; no. 1245, Schoch, 1918, pp. 77, 189.

Ba-4. Mine sample, Independence Mining Company, Phelan; B. E. G. no. 21; no. 21, Phillips and others, 1911, pp. 45, 46; no. 499, Phillips and Worrell, 1913, pp. 202, 203; no. 1246, Schoch, 1918, pp. 77, 189.

Ba-5. Mine sample, Independence Mining Company, Phelan; no. 192, Phillips and Worrell, 1913, p. 97; no. 1248, Schoch, 1918, pp. 77, 189.

Ba-6. Outcrop sample; near Clopton Switch, 6 miles south of Elgin; no. 175, Phillips and Worrell, 1913, p. 97; no. 1247, Schoch, 1918, pp. 77, 189.

Ba-7. Unspecified sample, delivered to U. S. Bureau of Mines; no. 560, Fieldner and others, 1942, p. 38.

Ba-8. Mine sample, submitted by State Purchasing Agent; Sayer mine, McDade; B. I. C. no. 623; no. 1248a, Schoch, 1918, pp. 77, 189.

Bexar County

Be-1. Outcrop sample; Cassin Station, south side of Missouri Pacific Railroad crossing of Medina River; seam, 4.5 feet thick, overburden, 40 to 50 feet; B. E. G. no. 1477; no. 1249, Schoch, 1918, pp. 77, 189.

Be-2. Core sample, submitted; 1/2 mile north of Cassin Station; seam, 14 inches thick at a depth of 164 feet; sample apparently air-dried; B. E. G. no. 1478; no. 1250, Schoch, 1918, pp. 77, 189.

Bowie County

Bo-1. Mine sample, submitted by E. P. Elliot, New Boston; shaft mine, Solomon Poer Headright, Anderson Creek, 7.0 miles south of New Boston; seam, 12 feet thick, overburden, 30 feet; sample apparently air-dried; Dumble, 1892, p. 159.

Bo-2. Second sample from locality Bo-1; Dumble, 1892, p. 159.

Bo-3. Probably outcrop sample, submitted by R. W. Rodgers, Texarkana; locality not known; B. E. G. no. 38; Phillips and others, 1911, p. 123; no. 1251, Schoch, 1918, pp. 77, 189.

Caldwell County

Cal-1. Outcrop sample, submitted by S. J. McDowell; vicinity of Burdett Wells; apparently air-dried; Dumble, 1892, p. 184; no. 1254, Schoch, 1918, pp. 77, 189.

Cal-2. As Cal-1; Dumble, 1892, p. 184; no. 1255, Schoch, 1918, pp. 77, 189.

Camp County

Cam-1. Mine sample, submitted by Hatfield & Clinton; vicinity of Newsome; seam, 5.5 feet thick, overburden, 33 feet; air-dried; B. I. C. no. 646; no. 1255a, Schoch, 1918, pp. 78, 189.

Cass County

Cas-1. Outcrop sample; Stone Coal Bluff on Sulphur River; Dumble, 1892, p. 160; Phillips, 1914, p. 89; no. 1256, Schoch, 1918, pp. 78, 189.

Fayette County

Fa-1. Outcrop sample; Mantoon Bluff, right side of Colorado River, opposite Rabbs Prairie; seam, 18 feet thick; Dumble, 1892, p. 204.

Fa-2. Unspecified sample, Melcher Coal & Clay Company, O'Quinn; B. E. G. no. 23; no. 1261, Schoch, 1918, pp. 78, 189.

Fa-3. Unspecified sample, submitted by J. T. Wright, Temple; 2 miles west of Muldoon; B. E. G. no. 906; no. 1262, Schoch, 1918, pp. 78, 189.

Fa-4. Mine sample, Big Four mine, Ledbetter; upper seam, 7.0 feet thick at a depth of 55 feet; B. E. G. no. 61; no. 1263, Schoch, 1918, pp. 78, 189.

Fa-5. Mine sample, Big Four mine, Ledbetter; lower seam, 7.0 feet at 95 feet; B. E. G. no. 62; no. 1264, Schoch, 1918, pp. 78, 189.

Fa-6. Mine sample, Big Four mine, Ledbetter; seam, 4 feet thick at a depth of 100 feet; B. E. G. no. 157; no. 1265, Schoch, 1918, pp. 78, 189.

Fa-7. Car sample, submitted by Daniel Webster, Ledbetter; B. E. G. no. 181; no. 1266, Schoch, 1918, pp. 78, 189.

Fa-8. Mine sample, Lower Stratum Mining Company, Ledbetter; B. E. G. no. 237; no. 1267, Schoch, 1918, pp. 78, 189.

Fa-9. Mine sample, submitted by T. T. Felder; Lower Stratum Mining Company, Ledbetter; B. E. G. no. 1141; no. 1268, Schoch, 1918, pp. 78, 190.

Fa-10. Mine sample, submitted by T. T. Felder; Lower Stratum Mining Company, Ledbetter; B. E. G. no. 1444; no. 1270, Schoch, 1918, pp. 79, 190.

Fa-11. Well sample; 3 miles north of Flatonia on Texas & New Orleans Railroad; seam, 8 feet thick, overburden, 22 feet; B. I. C. no. 613; no. 1270a, Schoch, 1918, pp. 79, 190.

Fa-12. Outcrop of seam described in Fa-11; B. I. C. no. 614; no. 1270b, Schoch, 1918, pp. 79, 190.

Freestone County

Fr-1. Mine sample, submitted by Wm. Gaines, Austin; shaft no. 2 near Donie; B. E. G. no. 1495; no. 1271, Schoch, 1918, pp. 79, 190.

Fr-2. Well sample, submitted by Wm. Gaines, Austin; hole no. 4 near Donie; no. 1272, Schoch, 1918, pp. 79, 190.

Fr-3. Probably mine sample, submitted by J. M. Bray; vicinity of Donie; B. E. G. no. 1566; no. 1273, Schoch, 1918, pp. 79, 190.

Fr-4. Mine sample, no. 1 from shaft on lease of J. M. Bray, Donie; 3 feet of lower seam beginning at 2.5 feet from bottom; B. E. G. no. 1675; no. 1274, Schoch, 1918, pp. 79, 190.

Fr-5. Mine sample, as Fr-4; 2.5 feet of lower seam beginning at 5.5 feet from bottom; B. E. G. no. 1676; no. 1275, Schoch, 1918, pp. 79, 190.

Fr-6. Mine sample, as Fr-4; 3.5 feet of lower seam beginning at 8.0 feet from bottom; B. E. G. no. 1677; no. 1276, Schoch, 1918, pp. 79, 190.

Fr-7. Outcrop sample; creek about 1 mile northeast of Bray Shaft, Donie; seam, 3 feet 2 inches; B. E. G. no. 1678; no. 1277, Schoch, 1918, pp. 79, 190.

Fr-8. Core sample, Big Brown, TP&L Spl. #10-M, 76′6″ to 81′3″.

Harrison County

Ha-1. Outcrop sample; B. Anderson Headright, Robertson Ferry, Sabine River; no. 704, Dumble, 1892, p. 165.

Ha-2. Outcrop sample; J. T. Ramsdale Headright, Rocky Ford, Sabine River; no. 707, Dumble, 1892, p. 165.

Ha-3. Outcrop sample; Francis Wilson Headright; no. 717, Dumble, 1892, p. 165.

Ha-4. Outcrop sample; Port Caddo Headright, McCathern Creek, Hendricks survey; no. 952, Dumble, 1892, p. 165.

Ha-5. Outcrop sample; J. T. Ramsdale Headright, Rocky Ford, Sabine River; air-dried; Dumble, 1892, p. 165.

Ha-6. Average of mine samples; Darco Works of Atlas Chemical Industries, Inc.; G. H. Scheffler, letter dated May 10, 1961.

Ha-7. Strip-mine sample, Darco no. 3 mine, 12 miles southwest of Marshall; U. S. B. M. Coal Lab. no. C-67352; no. 45876, Selvig and others, 1950, pp. 24, 59.

Ha-7a. Strip-mine sample, as Ha-7; air-dried.

Ha-7b. Strip-mine sample, as Ha-7; moisture- and ash-free.

Ha-8. Strip-mine sample, Darco no. 3 mine, 12 miles southwest of Marshall; upper bench of upper bed; U. S. B. M. Coal Lab. no. C-84699; no. 46114, Selvig and others, 1950, pp. 24, 59.

Ha-8a. Strip-mine sample, as Ha-8; air-dried.

Ha-8b. Strip-mine sample, as Ha-8; moisture- and ash-free.

Ha-9. Strip-mine sample, Darco no. 3 mine, 12 miles southwest of Marshall; lower bench of upper bed; U. S. B. M. Coal Lab. no. C-84700; no. 46115, Selvig and others, 1950, pp. 24, 59.

Ha-9a. Strip-mine sample, as Ha-9; air-dried.

Ha-9b. Strip-mine sample, as Ha-9; moisture- and ash-free.

Ha-10. Strip-mine sample, Darco no. 3 mine, 12 miles southwest of Marshall; upper bench of lower bed; U. S. B. M. Coal Lab. no. C-84701; no. 46116, Selvig and others, 1950, pp. 24, 59.

Ha-10a. Strip-mine sample, as Ha-10; air-dried.

Ha-10b. Strip-mine sample, as Ha-10; moisture- and ash-free.

Ha-11. Strip-mine sample, Darco no. 3 mine, 12 miles southwest of Marshall; lower bench of lower bed; U. S. B. M. Coal Lab. no. C-84702; no. 46117, Selvig and others, 1950, pp. 24, 59.

Ha-11a. Strip-mine sample, as Ha-11; air-dried.

Ha-11b. Strip-mine sample, as Ha-11; moisture- and ash-free.

Henderson County

He-1. Mine sample, Dallas Lignite Company, mine at Tredlow, 1¼ miles east of Malakoff; analysis by Ledoux & Company, New York; Phillips and Worrell, 1913, pp. 98–99; no. 1278, Schoch, 1918, pp. 79, 190.

He-2. Mine sample, as He-1, analysis by Babcock & Wilcox Company, New York; Phillips and Worrell, 1913, p. 99; no. 1279, Schoch, 1918, pp. 79, 190.

He-3. Well sample, submitted by McKay Lignite Mining Company, Dallas; 8 miles west of Athens; seam, 6 feet thick; B. E. G. no. 1596; no. 1280, Schoch, 1918, pp. 79, 190.

He-4. Outcrop sample, submitted by McKay Lignite Mining Company, Dallas; 1/2 mile from test drill hole of He-3; B. E. G. no. 1597; no. 1281, Schoch, 1918, pp. 79, 190.

He-5. Probably outcrop sample, submitted by W. Reid, Dallas; north of Malakoff, about 2.5 miles from Stockard; seam, 12 feet thick; no. 1282, Schoch, 1918, pp. 80, 190.

He-6. Unspecified sample (probably mine sample), submitted by W. C. Dodd; Malakoff; B. I. C. no. 102; no. 1282a, Schoch, 1918, pp. 80, 190.

He-7. Mine sample, submitted by W. Reid, Dallas Lignite Company; 2.5 miles from Stockard; B. E. G. no. 216, Phillips and Worrell, 1913, p. 98.

He-8. Mine screenings, Malakoff mines of Alba-Malakoff Lignite Company; B. E. G. no. 751, Phillips and Worrell, 1913, p. 99.

He-9. Mine sample, Texas Fire Brick and Tile Company, C. M. Walters Headright; apparently air-dried; seam, 6 feet thick; no. 1, Dumble, 1892, pp. 166, 167.

He-10. Mine sample, as He-9; air-dried; no. 2, Dumble, 1892, pp. 166, 167.

He-11. Outcrop sample, 30-inch lignite bed on the York farm, W. W. Stirman Survey. Taken by F. C. Adams and analyzed in The Texas Company's laboratory at Port Arthur, Texas. Adams and others, 1927, p. 15.

Hopkins County

Hop-1. Mine sample, Como Coal Company, Como; T. M. S. A. no. 1549, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; in part, no. 1283, Schoch, 1918, pp. 80, 179.

Hop-2. Mine sample, Como Coal Company, Como; B. E. G. no. 75, Phillips and others, 1911, p. 47; no. 1288, Schoch, 1918, pp. 80, 179.

Hop-3. Mine sample, Como Coal Company, Como; B. E. G. no. 41, Phillips and others, 1911, pp. 45, 46; no. 1287, Schoch, 1918, pp. 80, 179.

Hop-4. Mine sample, Como Lignite Company, Como; no. 668, Phillips and Worrell, 1913, pp. 202, 203.

Hop-5. Mine sample, Lone Star Lignite Company, Como; no. 22, Phillips and others, 1911, pp. 45, 46.

Hop-6. Mine sample, Lone Star Lignite Company, Como; no. 517, Phillips and Worrell, 1913, pp. 202, 203.

Hop-7. Mine sample; shaft of W. H. King, 10 to 12 miles from Sulphur Springs; Dumble, 1892, p. 161; no. 1284, Schoch, 1918, pp. 80, 189.

Hop-8. Mine sample, as Hop-7; analysis by Everhart of Univ. Texas; apparently air-dried; Dumble, 1892, p. 161; no. 1285, Schoch, 1918, pp. 80, 189.

Hop-9. Unspecified sample, submitted by Crystal Ice Company, Sulphur Springs; B. E. G. no. 2384; no. 1286, Schoch, 1918, pp. 80, 189.

Hop-10. Test hole sample, submitted by McKay Lignite Mining Company, Dallas; Fry land, near Como; seam, 7 to 8 feet thick; B. E. G. no. 1209; no. 1289, Schoch, 1918, pp. 80, 189.

Hop-11. Mine sample, Industrial Lignite Company's mine #3, 1 mile west of Crush, Texas. From 6-foot seam in Room #6 from first west cross-entry off the main tunnel south on the south side of the railroad. Taken by F. C. Adams and analyzed in The Texas Company's laboratory at Port Arthur, Texas. Adams and others, 1927, p. 16.

Hop-12. Outcrop sample, Willie (Lang) Williams farm, John Fixer Survey, 5 miles northeast of Como, Texas. From a 34-inch lignite bed. Taken by F. C. Adams and analyzed in The Texas Company's laboratory at Port Arthur, Texas. Adams and others, 1927, p. 16.

Houston County

Hou-1. Mine sample, Houston County Coal & Manufacturing Company, Crockett; Wooters mine, 3 miles north of Lovelady; no. 1195, Lord and others, 1913, p. 189.

Hou-1a. Mine sample, as Hou-1; no. 1195, air-dried, Parker and others, 1905, pp. 28, 52.

Hou-2. Mine sample, as Hou-1; no. 1196, Lord and others, 1913, p. 189.

Hou-2a. Mine sample, as Hou-2; no. 1196, air-dried, Parker and others, 1905, pp. 28, 52.

Hou-3. Car sample, Houston County Coal & Manufacturing Company, Crockett; Wooters mine, 3 miles north of Lovelady; no. 1456, Lord and others, 1913, p. 189.

Hou-3a. Car sample, as Hou-3; no. 1456, air-dried, Parker and others, 1905, pp. 28, 52.

Hou-4. Mine sample, as Hou-1; dry basis; no. 1195-2, Lord and others, 1913, p. 189.

Hou-5. Mine sample, as Hou-2; no. 1196-2, Lord and others, 1913, p. 189.

Hou-6. Car sample, as Hou-3; no. 1456-2, Lord and others, 1913, p. 189.

Hou-7. Gas-producer test sample, Houston County Coal & Manufacturing Company; Wooters mine, 3 miles north of Lovelady; no. 1460, Lord and others, 1913, p. 246.

Hou-8. Mine sample, Houston County Coal & Manufacturing Company; Wooters mine, 3 miles north of Lovelady; no. 22, Phillips and others, 1911, pp. 45, 46.

Hou-9. Mine sample, Houston County Coal & Manufacturing Company, Wooters mine, 3 miles north of Lovelady; no. 430, Phillips and Worrell, 1913, pp. 202, 203.

Hou-10. Car sample, Houston County Coal & Manufacturing Company, 3 miles north of Lovelady; no. 3, Phillips and others, 1911, p. 105.

Hou-11. Screened sample, as Hou-10; no. 1, Phillips and others, 1911, p. 105.

Hou-12. Plant sample, as Hou-10; apparently air-dried; no. 2, Phillips and others, 1911, p. 105.

Hou-13. Screened sample, Houston County Coal & Manufacturing Company, 3 miles north of Lovelady; no. 648, Phillips and Worrell, 1913, p. 99.

Hou-14. Mine sample, Houston County Coal & Manufacturing Company, 3 miles north of Lovelady; T. M. S. A. no. 1545, Phillips, 1902, pp. 51, 58, and Phillips and Worrell, 1913, pp. 87, 88; in part, no. 1290, Schoch, 1918, pp. 80, 190 (Phillips, 1902, reported sulfur at 0.40% on dry basis; Schoch, 1918, listed 0.64).

Hou-15. Mine sample, submitted by Houston County Coal & Manufacturing Company; 3 miles north of Lovelady; B. E. G. no. 662; no. 1291, Schoch, 1918, pp. 80, 190.

Hou-16. Outcrop sample; Hyde's Bluff, Trinity River; Dumble, 1892, p. 201.

Hou-17. Outcrop sample; Bethed Headright; Dumble, 1892, pp. 201, 202.

Hou-18. Outcrop sample; Hyde's Bluff, Trinity River; no. 1, Dumble, 1892, p. 212.

Hou-19. Outcrop sample; Bethed Headright; no. 2, Dumble, 1892, p. 202.

Hou-20. Outcrop sample; Wallace Headright, near Calthorp; no. 3, Dumble, 1892, p. 202.

Hou-21. Sample of lignite shipped to Univ. Texas power house by Houston County Coal & Manufacturing Company; B. E. G. no. 2129; no. 1292, Schoch, 1918, pp. 80, 190.

Lee County

Lee-1. Mine sample, Rockdale Coal Company, Hicks; apparently air-dried; no. 55, Phillips and others, 1911, pp. 45, 46; in part, no. 670, Phillips and Worrell, 1913, pp. 202, 203; in part, no. 1297, Schoch, 1918, pp. 80, 190 (also listed as no. 1344 under Milam County by Schoch, 1918).

Lee-2. Outcrop sample; Blue Branch, western part of county; seam, 6 feet thick; Dumble, 1892, p. 182; Phillips, 1914, p. 164; no. 1298, Schoch, 1918, pp. 80, 190.

Lee-3. Unspecified sample, probably from outcrop; vicinity of Giddings; B. E. G. no. 1445; no. 1299, Schoch, 1918, pp. 81, 190.

Leon County

Leo-1. Mine sample, Bear Grass Coal Company, Jewett; no. 13, Phillips and others, 1911, pp. 45, 46; in part, no. 328, Phillips and Worrell, 1913, pp. 202, 203.

Leo-2. Car sample, Bear Grass Coal Company, Jewett; no. 4, Phillips and others, 1911, pp. 105, 106.

Leo-3. Mine sample, Bear Grass Coal Company, Jewett; air-dried; B. E. G. no. 234; no. 1300, Schoch, 1918, pp. 81, 191.

Leo-4. Mine sample, as Leo-3; air-dried; B. E. G. no. 235; no. 1301, Schoch, 1918, pp. 81, 191.

Leo-5. Mine sample, as Leo-3; air-dried; B. E. G. no. 236; no. 1302, Schoch, 1918, pp. 81, 191.

Leo-6. Mine sample, as Leo-3; B. E. G. no. 256; no. 1303, Schoch, 1918, pp. 81, 191.

Leo-7. Mine sample, Bear Grass Coal Company, representing shipment to E. J. Babcock, Mining Substation, Hebron, North Dakota; in part, no. 307, Phillips and Worrell, 1913, p. 100; no. 1304, Schoch, 1918, pp. 81, 191.

Leo-8. Mine sample, Bear Grass Coal Company, used for briquetting tests; air-dried; B. E. G. no. 373; no. 1306, Schoch, 1918, pp. 81, 191.

Leo-9. Mine sample, Bear Grass Coal Company, Jewett; in part, no. 551, Phillips and Worrell, 1913, p. 100; in part, no. 1307, Schoch, 1918, pp. 81, 191.

Leo-10. Mine sample, Bear Grass Coal Company, mine at Newby; upper part of seam; B. E. G. no. 2377; no. 1308, Schoch, 1918, pp. 81, 191.

Leo-11. Mine sample, as Leo-10; middle part of seam; B. E. G. no. 2338; no. 1309, Schoch, 1918, pp. 81, 191.

Leo-12. Mine sample, as Leo-10; lower part of seam; B. E. G. no. 2339; no. 1310, Schoch, 1918, pp. 81, 191.

Leo-13. Screened sample, Bear Grass Coal Company; screened through 3/8-inch grate, 20% of mine run; no. 933, Phillips and Worrell, 1913, p. 100; no. 1304, Schoch, 1918, pp. 81, 191.

Leo-14. Mine sample, submitted by F. V. Crosby, Bear Grass Coal Company, Jewett; B. E. G. no. 1888; Schoch, 1918, pp. 81, 191.

Leo-15. Mine sample, Bear Grass Coal Company, Newby; B. E. G. no. 2111; no. 1316, Schoch, 1918, pp. 81, 191.

Leo-16. Mine sample, submitted by Bear Grass Coal Company, Jewett; B. I. C. no. 435; no. 1319a, Schoch, 1918, pp. 81, 191.

Leo-17. Mine sample, Houston Coal & Manufacturing Company, Evansville; submitted to Hebron, North Dakota for briquetting; in part no. 342, Phillips and Worrell, 1913, p. 100; in part, no. 342, Phillips and Worrell, 1913, pp. 202, 203; in part no. 1305, Schoch, 1918, pp. 81, 191.

Leo-18. Mine sample (partly dried), Houston Coal & Manufacturing Company, Evansville; in part, no. 927, Phillips and Worrell, 1913, p. 100; in part, no. 1311, Schoch, 1918, pp. 81, 191.

Leo-19. Mine sample, Houston County Coal & Manufacturing Company, Evansville; in part, no. 928, Phillips and Worrell, 1913, p. 100; in part, no. 1312, Schoch, 1918, pp. 81, 191.

Leo-20. Car sample, lignite furnished Univ. Texas by Houston County Coal & Manufacturing Company, Evansville; B. E. G. no. 1987; no. 1315, Schoch, 1918, pp. 81, 191.

Leo-21. Car sample, lignite furnished Univ. Texas by Houston County Coal & Manufacturing Company, Evansville; B. E. G. no. 2203; no. 1317, Schoch, 1918, pp. 81, 191.

Leo-22. Car sample, as Leo-21; B. E. G. no. 2299; no. 1318, Schoch, 1918, pp. 81, 191.

Leo-23. Car sample, as Leo-21; B. E. G. no. 2363; no. 1319, Schoch, 1918, pp. 81, 191.

Limestone County

Li-1. Outcrop sample, submitted by H. L. Kniffin; vicinity of Teague; B.E.G. no. 1669; no. 1320, Schoch, 1918, pp. 81, 191.

Li-2. Outcrop sample; Heads Prairie, southeastern part of county; Dumble, 1892, p. 173; no. 1321, Schoch, 1918, pp. 81, 191.

McMullen County

McM-1. Outcrop sample; San Miguel Creek, south bank, about 300 yards west of State Highway 173, 9 miles north of Tilden; no. 60189, Maxwell, 1962, p. 80.

McM-2. Outcrop sample, as McM-1; no. 60097, Maxwell, 1962, p. 80.

McM-3. Outcrop sample, as McM-1; no. 60096, Maxwell, 1962, p. 80.

McM-4. Outcrop sample, as McM-1; no. 60095, Maxwell, 1962, p. 80.

McM-5. Outcrop sample, as McM-1; no. 60109, Maxwell, 1962, p. 81.

McM-6. Outcrop sample, as McM-1; no. 60186, Maxwell, 1962, p. 81.

McM-7. Outcrop sample, as McM-1; no. 60187, Maxwell, 1962, p. 81.

McM-8. Outcrop sample, as McM-1; no. 60188, Maxwell, 1962, p. 81.

McM-9. Outcrop sample, as McM-1; no. 60110, Maxwell, 1962, p. 81.

McM-10. Core sample; vicinity of San Miguel Creek, north-central part of county; as received, samples apparently air-dried; U.S.B.M. test no. 845, Maxwell, 1962, p. 85.

McM-11. Core sample, as McM-10; U.S.B.M. test no. 839, Maxwell, 1962, p. 85.

McM-12. Core sample, as McM-10; U.S.B.M. test no. 840, Maxwell, 1962, p. 85.

McM-13. Core sample, as McM-10; U.S.B.M. test no. 841, Maxwell, 1962, p. 85.

McM-14. Core sample, as McM-10; U.S.B.M. test no. 842, Maxwell, 1962, p. 85.

McM-15. Core sample, as McM-10; U.S.B.M. test no. 845, Maxwell, 1962, p. 85.

McM-16. Core sample, as McM-10; U.S.B.M. test no. 844, Maxwell, 1962, p. 85.

McM-17. Core sample, as McM-10; U.S.B.M. test no. 846, Maxwell, 1962, p. 85.

Medina County

Me-1. Mine sample, Carr mine, near Lytle; no. 1535, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; in part, no. 1322, Schoch, 1918, pp. 82, 191.

Me-2. Mine sample, Carr mine, Lytle, mine no. 3, 350 feet northeast entry no. 6; Phillips and Worrell, 1913, p. 105; no. 1324, Schoch, 1918, pp. 82,191.

Me-3. Mine sample, as Me-2, 600 feet northwest room at middle of northeast entry no. 5; Phillips and Worrell, 1913, p. 105; no. 1325, Schoch, 1918, pp. 82, 191.

Me-4.. Mine sample, Carr mine, near Lytle; Phillips, 1914, p. 180; no. 1326, Schoch, 1918, pp. 82, 191.

Me-5. Mine sample, Carr Wood & Coal Company, Carr mine, Lytle; no. 16, Phillips and others, 1911, pp. 45, 46; in part, no. 329, Phillips and Worrell, 1913, pp. 202, 203.

Me-6. Mine sample, Carr Wood & Coal Company, Carr mine, Lytle; no. 7330, Wright, 1912, p. 25, and Lord and others, 1913, p. 189.

Me-7. Mine sample, Carr Wood & Coal Company, Carr mine, Lytle; no. 7461, Wright, 1912, p. 25.

Me-8. Mine sample, Carr Wood & Coal Company, Lytle; no. 7584, Wright, 1912, p. 25.

Me-9. Mine sample, Carr Wood & Coal Company, Carr mine, Lytle; no. 1731, Lord and others, 1913, p. 189.

Me-10. Mine sample, Bertelli mine, Lytle; no. 1536, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; in part, no. 1323, Schoch, 1918, pp. 82, 191.

Me-11. Mine sample, Bertelli mine, Lytle; Phillips, 1914, p. 180; no. 1327, Schoch, 1918, pp. 82, 191.

Me-12. Mine sample, Bertelli mine, Lytle; no. 14, Phillips and others, 1911, pp. 45, 46; in part, no. 368, Phillips and Worrell, 1913, pp. 202, 203.

Milam County

Mi-1. Mine sample, American Lignite Briquette Company, Rockdale; no. 12, Phillips and others, 1911, pp. 45, 46; no. 361, Phillips and Worrell, 1913, pp. 202, 203.

Mi-2. Mine sample, American Lignite Briquette Company, Rockdale; probably air-dried on as-received basis; no. 57, Phillips and others, 1911, pp. 45, 46.

Mi-3. Mine sample, deep seam, American Lignite Briquette Company, Rockdale; no. 420, Phillips and Worrell, 1913, p. 101; no. 1336, Schoch, 1918, pp. 82, 191.

Mi-4. Boiler room sample, American Lignite Briquette Company; Phillips and Worrell, 1913, p. 101; no. 1329, Schoch, 1918, pp. 82, 191.

Mi-5. Mine sample, Aransas Pass Lignite Company, Rockdale; no. 1543, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; no. 1335, Schoch, 1918, pp. 82, 191.

Mi-6. Mine sample, Big Lump mine, Rockdale; no. 1542, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; no. 1334, Schoch, 1918, pp. 82, 191.

Mi-7. Mine sample, Big Lump mine, Rockdale; no. 7271, Lord and others, 1913, p. 189.

Mi-8. Mine sample, Big Lump mine, Rockdale; Phillips and Worrell, 1913, p. 106.

Mi-9. Mine sample, Black Diamond Coal Company, Rockdale; no. 1539, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; no. 1331, Schoch, 1918, pp. 82, 191.

Mi-10. Mine sample, Burnett Fuel Company, Milano; B. E. G. no. 46; no. 1328, Schoch, 1918, pp. 82, 191.

Mi-11. Mine sample, Eggette Coal Company, Vogel Switch, Rockdale; no. 1540, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; no. 1332, Schoch, 1918, pp. 82, 191.

Mi-12. Mine sample, J. J. Olsen & Son, Rockdale; no. 1541, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; no. 1333, Schoch, 1918, pp. 82, 191.

Mi-13. Mine sample, J. J. Olsen & Son, Rockdale; no. 2562, Lord and others, 1913, p. 189; Phillips and Worrell, 1913, p. 106; no. 1345, Schoch, 1918, pp. 83, 191.

Mi-14. Mine sample, J. J. Olsen & Son, Rockdale; no. 2734, Lord and others, 1913, p. 189; Phillips and Worrell, 1913, p. 106; no. 1347, Schoch, 1918, pp. 83, 191.

Mi-15. Mine sample, J. J. Olsen & Son, Rockdale; no. 2563, Lord and others, 1913, p. 189; Phillips and Worrell, 1913, p. 106; no. 1346, Schoch, 1918, pp. 83, 191.

Mi-16. Producer-gas test sample, J. J. Olsen & Son, Rockdale; Holmes, 1908, p. 259.

Mi-17. Car sample, Rockdale Consolidated Coal Company, Rockdale; apparently air-dried on as-received basis; no. 44, Phillips and others, 1911, pp. 45, 46; Phillips and Worrell, 1913, pp. 202, 203.

Mi-18. Mine sample, Rockdale Lignite Company, Rockdale; no. 28, Phillips and others, 1911, pp. 45, 46; no. 597, Phillips and Worrell, 1913, pp. 202, 203; no. 1341, Schoch, 1918, pp. 83, 191.

Mi-19. Mine sample, Rowlett & Wells, Rockdale; no. 25, Phillips and others, 1911, pp. 45, 46; no. 576, Phillips and Worrell, 1913, pp. 202, 203; no. 1340, Schoch, 1918, pp. 83, 191.

Mi-20. Strip-mine sample, submitted by McAlester Fuel Company, McAlester, Oklahoma; Sandow mine, southwest of Rockdale; U.S.B.M. Coal Lab. no. C-38297; unnamed bed; no. 46257, Selvig and others, 1950, pp. 24, 60.

Mi-20a. Strip-mine sample, as Mi-20; air-dried.

Mi-20b. Strip-mine sample, as Mi-20; moisture- and ash-free.

Mi-21. Strip-mine sample, McAlester Fuel Company; Sandow mine, southwest of Rockdale; middle bench; U.S.B.M. Coal Lab. no. C-84232; no. 46112, Selvig and others, 1950, pp. 24, 60.

Mi-21a. Strip-mine sample, as Mi-22; air-dried.

Mi-21b. Strip-mine sample, as Mi-22; moisture- and ash-free.

Mi-22. Strip-mine sample, McAlester Fuel Company; Sandow mine, southwest of Rockdale; lower bench; U.S.B.M. Coal Lab. no. C-84233; no. 46113, Selvig and others, 1950, pp. 24, 60.

Mi-22a. Strip-mine sample, as Mi-23; air-dried.

Mi-22b. Strip-mine sample, as Mi-23; moisture- and ash-free.

Mi-23. Strip-mine sample, McAlester Fuel Company; Sandow mine, southwest of Rockdale; upper bench; U.S.B.M. Coal Lab. no. C-84231; no. 46111, Selvig and others, 1950, pp. 24, 60.

Mi-23a. Strip-mine sample, as Mi-21; air-dried.

Mi-23b. Strip-mine sample, as Mi-21; moisture- and ash-free.

Mi-24. Mine sample, Texas Coal Company, Rockdale; no. 39, Phillips and others, 1911, pp. 45, 46; no. 630, Phillips and Worrell, 1913, pp. 202, 203; no. 1343, Schoch, 1918, pp. 83, 191.

Mi-25. Car sample, Texas Coal Company, Rockdale; no. 745, Phillips and Worrell, 1913, p. 101; no. 1338, Schoch, 1918, pp. 82, 191.

Mi-26. Car sample, Texas Coal Company, Rockdale; air-dried; no. 1339, Schoch, 1918, pp. 82, 191.

Mi-27. Car sample, Texas Coal Company, Rockdale; apparently air-dried; B. E. G. no. 661; no. 1337, Schoch, 1918, pp. 82, 191.

Mi-28. Mine sample, Texas Coal Company, Rockdale; Phillips and Worrell, 1913, p. 192.

Mi-29. Mine sample, Vogel & Lorenz (subsequently Vogel Coal & Manufacturing Company), Vogel Switch, Rockdale; no. 29, Phillips and others, 1911, pp. 45, 46; no. 601, Phillips and Worrell, 1913, pp. 202, 203; no. 1342, Schoch, 1918, pp. 83, 191.

Mi-30. Mine sample, Worley mine, Rockdale; no. 1538, Phillips, 1902, pp. 51, 53; no. 1330, Schoch, 1918, pp. 82, 191.

Mi-31. Mine sample, submitted by W. A. Butler, Hillsboro; southeast of Rockdale; B. I. C. no. 714; no. 1347a, Schoch, 1918, pp. 83, 192.

Panola County

Pa-1. Mine sample, from end of tunnel on Mineral Spring Ridge, 4.0 miles northwest of Beckville; seam, 4.5 feet thick; Dumble, 1892, p. 192.

Pa-2. Unspecified sample, from farm of D. R. Todd, near Gary; B. I. C. no. 520; no. 1349a, Schoch, 1918, pp. 82, 192.

Pa-3. Core sample; Martin Lake, Texas Utilities Company; Spl. 1169, 24′2″ to 35′0″.

Rains County

Ra-1. Outcrop sample; vicinity of Emory; Dumble, 1892, p. 171.

Ra-2. Outcrop sample; 7 miles east of Emory; Dumble, 1892, p. 171.

Robertson County

Ro-1. Mine sample, Central Texas Mining, Manufacturing, and Land Company; Calvert Bluff on Brazos River; T. M. S. no. 1544; no. 1544, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; no. 1350, Schoch, 1918, pp. 83, 192.

Ro-2. Mine sample, Southwestern Fuel & Manufacturing Company (subsequently Southwestern Fuel Company); no. 26, Phillips and others, 1911, pp. 45, 46; no. 590, Phillips and Worrell, 1913, pp. 202, 203.

Ro-3. Mine sample, Southwestern Fuel & Manufacturing Company; no. 6, Phillips and others, 1911, pp. 105, 106.

Ro-4. Mine sample, Southwestern Fuel & Manufacturing Company; no. 7403, Wright, 1912, p. 29, and Lord and others, 1913, p. 190; Phillips and Worrell, 1913, p. 106; no. 1351, Schoch, 1918, pp. 83, 192.

Ro-5. Mine sample, Southwestern Fuel & Manufacturing Company, Calvert Bluff on Brazos River; no. 7513, Wright, 1912, p. 29.

Ro-6. Mine sample, Southwestern Fuel & Manufacturing Company, Calvert Bluff; no. 7950, Wright, 1912, p. 29.

Ro-7. Average of mine samples, Southwestern Fuel & Manufacturing Company, Calvert Bluff; Wright, 1912, p. 29.

Ro-8. Mine sample, Southwestern Fuel & Manufacturing Company, Calvert Bluff; no. 7404, Lord and others, 1913, p. 190; no. 1352, Schoch, 1918, pp. 83, 192.

Ro-9. Mine sample, new shaft mine, 60 feet deep; Southwestern Fuel Company, Calvert Bluff; seam, 6.5 feet thick; no. 957, Phillips and Worrell, 1913, p. 102; no. 1358, Schoch, 1918, pp. 84, 192.

Ro-10. Car sample, Southwestern Fuel Company, Calvert; shipped to Univ. Texas; screened sample used in test on Belvet Rocking grates; screened through 1 inch, 8%; B. E. G. no. 1750; no. 1360, Schoch, 1918, pp. 84, 192.

Ro-10a. Car sample, as Ro-10; screened through 1 inch on 1/2-inch grate, 32%; B. E. G. no. 1751; no. 1361, Schoch, 1918, pp. 84, 192.

Ro-10b. Car sample, as Ro-10; screened through 1/2-inch and on 1/4-inch grate, 20%; B. E. G. no. 1752; no. 1362, Schoch, 1918, pp. 84, 192.

Ro-10c. Car sample, as Ro-10; screened through 1/4-inch and on 1/8-inch grate, 20%; B. E. G. no. 1753; no. 1363, Schoch, 1918, pp. 84, 192.

Ro-10d. Car sample, as Ro-10; screened through 1/8-inch grate, 10%; B. E. G. no. 1754; no. 1364, Schoch, 1918, pp. 84, 192.

Ro-11. Car sample, Southwestern Fuel Company, Calvert; shipped to Univ. Texas; screened samples used in test on Belvet Rocking grates; screened through 1-inch grate, 10%; B. E. G. no. 1755; no. 1365, Schoch, 1918, pp. 84, 192.

Ro-11a. Car sample, as Ro-11; screened through 1-inch and on 1/2-inch grate, 34%; B. E. G. no. 1756; no. 1366, Schoch, 1918, pp. 4, 192.

Ro-11b. Car sample, as Ro-11; screened through 1/2-inch and on 1/4-inch grate, 20%; B. E. G. no. 1757; no. 1367, Schoch, 1918, pp. 84, 192.

Ro-11c. Car sample, as Ro-11; screened through 1/4-inch and on 1/8-inch grate, 20%; B. E. G. no. 1758; no. 1368, Schoch, 1918, pp. 84, 192.

Ro-11d. Car sample, as Ro-11; screened through 1/8-inch grate, 15%; B. E. G. no. 1759; no. 1369, Schoch, 1918, pp. 84, 192.

Ro-12. Car sample, Southwestern Fuel Company, Calvert; shipped to Univ. Texas; screened samples used in test on Belvet Rocking grates; screened through 1-inch grate, 12%; B. E. G. no. 1760; no. 1370, Schoch, 1918, pp. 84, 192.

Ro-12a. Car sample, as Ro-12; screened through 1-inch and on 1/2-inch grate, 26%; B. E. G. no. 1761; no. 1371, Schoch, 1918, pp. 84, 192.

Ro-12b. Car sample, as Ro-12; screened through 1/2-inch and on 1/4-inch grate, 24%; B. E. G. no. 1762; no. 1372, Schoch, 1918, pp. 84, 192.

Ro-12c. Car sample, as Ro-12; screened through 1/4-inch and on 1/8-inch grate, 18%; B. E. G. no. 1763; no. 1373, Schoch, 1918, pp. 84, 192.

Ro-12d. Car sample, as Ro-12; screened through 1/8-inch grate, 20%; B. E. G. no. 1764; no. 1374, Schoch, 1918, pp. 84, 192.

Ro-13. Mine sample, Southwestern Fuel Company, submitted by C. M. Beard, Austin; B. E. G. no. 974; no. 1359, Schoch, 1918, pp. 84, 192.

Ro-14. Unspecified sample (probably mine sample), submitted by D. E. Matthews; vicinity of Bremond; B. E. G. no. 823; no. 1353, Schoch, 1918, pp. 84, 192.

Ro-15. Well sample, depth of 72 feet; from farm of Strumensky & Son, 2.5 miles northeast of Wootan; seam, 6.5 feet thick; no. 953, Phillips and Worrell, 1913, p. 102; no. 1354, Schoch, 1918, pp. 83, 192.

Ro-15a. Well sample, as Ro-15, depth of 73 feet; no. 954, Phillips and Worrell, 1913, p. 102; no. 1355, Schoch, 1918, pp. 83, 192.

Ro-16. Well sample; 0.5 mile northwest of locality in Ro-15; depth of 53 feet; no. 1356, Schoch, 1918, pp. 83, 192.

Ro-17. Well sample; 1/4 mile from locality in Ro-15; depth of 33.5 feet; seam, 8.5 feet thick; no. 956, Phillips and Worrell, 1913, p. 102; no. 1357, Schoch, 1918, pp. 84, 192.

Rusk County

Ru-1. Outcrop sample, submitted by E. T. Bartick; locality not specified; Dumble, 1892, p. 195.

Ru-2. Outcrop sample, as Ru-1; air-dried; Dumble, 1892, p. 195.

Ru-3. Outcrop sample; Grahams Lake, 12 miles west of Henderson; Dumble, 1892, p. 195.

Ru-4. Outcrop sample; Grahams Lake, 12 miles west of Henderson; seam, 3 to 6 feet thick; Phillips, 1914, p. 209; no. 1376, Schoch, 1918, pp. 84, 192.

Ru-5. Outcrop sample; vicinity of Iron Mountain; Dumble, 1892, p. 194, citing J. L. Riddell; no. 1377, Schoch, 1918, pp. 84, 192.

Ru-6. Unspecified sample, probably from outcrop; 5 miles southeast of Henderson; two seams, 38 inches thick; B. E. G. no. 2632; no. 1375, Schoch, 1918, pp. 84, 192.

Shelby County

Sh-1. Mine sample, Timpson Coal Company; 1 mile south of Timpson at Tandy Switch; no. 1546, Phillips, 1902, pp. 51, 53, and Phillips and Worrell, 1913, pp. 87, 88; no. 1378, Schoch, 1918, pp. 84, 193.

Sh-2. Outcrop sample; northeastern part of W. J. Crump Headright, about 7 miles south of Timpson; seam, 4 to 5 feet thick; Dumble, 1892, p. 193.

Titus County

Ti-1. Mine sample; Cookville Coal & Lumber Company, Mt. Pleasant; no. 18, Phillips and others, 1911, pp. 45, 46; no. 429, Phillips and Worrell, 1913, pp. 202, 203; no. 1383, Schoch, 1918, pp. 85, 193.

Ti-2. Mine sample, Libby Coal Company, Cookville; submitted by Texas Public Service Company, Mt. Pleasant; seam, 8 feet thick at depth of 50 feet; B. E. G. no. 1725; no. 1384, Schoch, 1918, pp. 85, 193.

Ti-3. Mine sample, East Texas Lignite Company's mine #1, two miles east of Winfield. Taken from 6-foot vein at heading of the main entry, 500 feet east of the shaft opening. Obtained by F. C. Adams and analyzed in The Texas Company's laboratory at Port Arthur, Texas. Adams and others, 1927, p. 17.

Ti-4. Mine sample, Winfield Lignite Company's mine #1, two miles east of Winfield. Taken from 6-foot vein at the first right off the fourth left, described in accordance with the mine plan. Obtained by F. C. Adams and analyzed in The Texas Company's laboratory at Port Arthur, Texas. Adams and others, 1927, p. 17.

Ti-5. Mine sample, Winfield Lignite Fuel Company's mine #1, two miles east of Winfield. Taken from the first right off the main entry. Obtained by F. C. Adams and analyzed in The Texas Company's laboratory at Port Arthur, Texas. Adams and others, 1927, p. 17.

Ti-6. Core sample, Winfield, Texas Utilities Company; Spl. 416, 51′7″ to 55′4″ and 56′9″ to 63′3″.

Van Zandt County

Va-1. Mine sample, Edgewood Coal & Fuel Company, Wills Point; locality not known; no. 36, Phillips and others, 1911, pp. 45, 56; no. 616, Phillips and Worrell, 1913, pp. 202, 203; no. 1388, Schoch, 1918, pp. 85, 193.

Va-2. Average of mine samples; localities not specified; G. H. Scheffler, letter dated May 10, 1961.

Va-3. Mine sample, East Texas Lignite Company's mine, 1 mile west of Canton, northeast part of Stockwell Survey. Five-foot-eleven-inch face of bed of lignite, representing lower one-half of a 12-foot vein. Obtained by F. C. Adams and analyzed in The Texas Company's laboratory at Port Arthur, Texas. Adams and others, 1927, p. 17.

Va-4. Mine sample from same mine as above, but taken on a different face. Obtained and analyzed as was previous sample. Adams and others, 1927, p. 17.

Va-5. Outcrop sample, stream on the Baker farm (just south of Mrs. S. E. Mixon farm, P. Young Survey), in the southern part of the county. Obtained by F. C. Adams and analyzed in The Texas Company's laboratory at Port Arthur, Texas. Adams and others, 1927, p. 17.

Wood County

Wo-1. Mine sample, Alba Lignite Company (succeeded by Alba-Malakoff Lignite Company); Alba; no. 40, Phillips and others, 1911, p. 45, 46; no. 667, Phillips and Worrell, 1913, pp. 202, 203.

Wo-2. Mine sample, Alba-Malakoff Lignite Company; apparently air-dried; Alba; no. 59, Phillips and others, 1911, pp. 45, 46; no. 1398, Schoch, 1918, pp. 86, 193.

Wo-3. Mine sample (screenings), Alba-Malakoff Lignite Company; Alba; no. 744, Phillips and Worrell, 1913, p. 103.

Wo-4. Mine sample, Consumers' Lignite Company, mine no. 1; Hoyt; no. 1241, Lord and others, 1913, p. 190; no. 1403, Schoch, 1918, pp. 86, 193.

Wo-5. Mine sample, Consumers' Lignite Company, mine no. 3; Hoyt; no. 1243, Lord and others, 1913, p. 190; no. 1404, Schoch, 1918, pp. 86, 193.

Wo-6. Mine sample, Consumers' Lignite Company; Hoyt; no. 1597, Lord and others, 1913, p. 190; no. 1405, Schoch, 1918, pp. 86, 193.

Wo-7. Mine sample, Consumers' Lignite Company; Hoyt; no. 1610, Lord and others, 1913, p. 190; no. 1406, Schoch, 1918, pp. 86, 193.

Wo-8. Mine sample, Consumers' Lignite Company; Hoyt; no. 2635, Lord and others, 1913, p. 190; no. 1407, Schoch, 1918, pp. 86, 193.

Wo-9. Mine sample, Consumers' Lignite Company; Hoyt; no. 2636, Lord and others, 1913, p. 190; no. 1408, Schoch, 1918, pp. 86, 193.

Wo-10. Mine sample, Consumers' Lignite Company; Hoyt; no. 2717, Lord and others, 1913, p. 190; no. 1409, Schoch, 1918, pp. 86, 193.

Wo-11. Mine sample, Consumers' Lignite Company; Hoyt; no. 291, Holmes, 1908, p. 260.

Wo-12. Mine sample, Consumers' Lignite Company; Hoyt; no. 298, Holmes, 1908, p. 260.

Wo-13. Mine sample, Consumers' Lignite Company; Hoyt; no. 303, Holmes, 1908, p. 260.

Wo-14. Mine sample, Consumers' Lignite Company; Hoyt; Holmes, 1908, p. 261.

Wo-15. Car sample, Consumers' Lignite Company; Hoyt; no. 7, Phillips and others, 1911, p. 105.

Wo-16. Mine sample, Consumers' Lignite Company; Hoyt; no. 17, Phillips and others, 1911, pp. 45, 46; no. 327, Phillips and Worrell, 1913, pp. 202, 203; no. 1396, Schoch, 1918, pp. 85, 193.

Wo-17. Mine sample, Consumers' Lignite Company; Hoyt; apparently air-dried; no. 56, Phillips and others, 1911, pp. 45, 46; Phillips and Worrell, 1913, p. 91.

Wo-18. Mine sample (lump), Consumers' Lignite Company; Hoyt; no. 282, Phillips and Worrell, 1913, p. 104.

Wo-19. Mine sample (screenings), Consumers' Lignite Company; Hoyt; no. 952, Phillips and Worrell, 1913, p. 104.

Wo-20. Mine sample (dust), Consumers' Lignite Company; Hoyt; no. 593, Phillips and Worrell, 1913, p. 104.

Wo-21. Mine sample (screenings), Consumers' Lignite Company; Hoyt; Phillips and Worrell, 1913, p. 104.

Wo-22. Mine sample (dust), Consumers' Lignite Company; Hoyt; no. 915, Phillips and Worrell, 1913, pp. 104, 141; no. 1401, Schoch, 1918, pp. 85, 193.

Wo-23. Mine sample (dust), Consumers' Lignite Company; Hoyt; no. 916, Phillips and Worrell, 1913, pp. 104, 141; no. 1402, Schoch, 1918, pp. 86, 193.

Wo-24. Mine sample (lump), Consumers' Lignite Company; Hoyt; no. 913, Phillips and Worrell, 1913, pp. 104, 141; no. 1399, Schoch, 1918, pp. 86, 193.

Wo-25. Mine sample (nut size), Consumers' Lignite Company; Hoyt; no. 914; Phillips and Worrell, 1913, pp. 104, 141; no. 1400, Schoch, 1918, pp. 86, 193.

Wo-26. Mine sample, Consumers' Lignite Company, mine no. 5; Hoyt; no. 6, Phillips and Worrell, 1913, p. 111.

Wo-27. Mine sample, Consumers' Lignite Company, mine no. 5; Hoyt; no. 7, Phillips and Worrell, 1913, p. 111.

Wo-28. Mine sample, Consumers' Lignite Company, mine no. 6; Hoyt; no. 1, Phillips and Worrell, 1913, p. 111.

Wo-29. Mine sample, Consumers' Lignite Company, mine no. 6; Hoyt; no. 2, Phillips and Worrell, 1913, p. 111.

Wo-30. Mine sample, Consumers' Lignite Company, mine no. 6; Hoyt; no. 3, Phillips and Worrell, 1913, p. 111.

Wo-31. Mine sample, Consumers' Lignite Company, mine no. 6; Hoyt; Phillips and Worrell, 1913, p. 111.

Wo-32. Mine sample, Consumers' Lignite Company, mine no. 6; Hoyt; Phillips and Worrell, 1913, p. 111.

Wo-33. Mine sample, Consumers' Lignite Company; Hoyt; Phillips and Worrell, 1913, p. 104; no. 1394, Schoch, 1918, pp. 86, 193.

Wo-34. Mine sample, Consumers' Lignite Company, mine no. 1; Hoyt; Phillips and Worrell, 1913, p. 107; no. 1403, Schoch, 1918, pp. 86, 193.

Wo-35. Mine sample, as Wo-34; Phillips and Worrell, 1913, p. 107; no. 1404, Schoch, 1918, pp. 86, 193.

Wo-36. Mine sample (run of mine), as Wo-34; Phillips and Worrell, 1913, p. 107; no. 1405, Schoch, 1918, pp. 86, 193.

Wo-37. Mine sample (screened), as Wo-34; Phillips and Worrell, 1913, p. 107; no. 1406, Schoch, 1918, pp. 86, 193.

Wo-38. Mine sample, as Wo-34; Phillips and Worrell, 1913, p. 107; no. 1407, Schoch, 1918, pp. 86, 193.

Wo-39. Mine sample, as Wo-34; Phillips and Worrell, 1913, p. 107; no. 1408, Schoch, 1918, pp. 86, 193.

Wo-40. Mine sample (run of mine), as Wo-34; Phillips and Worrell, 1913, p. 107; no. 1409, Schoch, 1918, pp. 86, 193.

Wo-41. Mine sample, Consumers' Lignite Company; Hoyt; B. E. G. no. 1716; no. 1410, Schoch, 1918, pp. 86, 193.

Wo-42. Mine sample, Consumers' Lignite Company; Hoyt; B. E. G. no. 1717; no. 1411, Schoch, 1918, pp. 86, 193.

Wo-43. Mine sample, Consumers' Lignite Company; Hoyt; apparently air-dried; B. E. G. no. 1718; no. 1412, Schoch, 1918, pp. 86, 193.

Wo-44. Mine sample, Consumers' Lignite Company; Hoyt; apparently air-dried; B. E. G. no. 1719; no. 1413, Schoch, 1918, pp. 86, 193.

Wo-45. Mine sample, Consumers' Lignite Company; apparently air-dried; Hoyt; B. E. G. no. 1720; no. 1414, Schoch, 1918, pp. 86, 193.

Wo-46. Car sample, shipped from Consumers' Lignite Company, Hoyt, to Univ. Texas power house (car no. 23510); upper part of car, screened; on 1-inch grate, 14%; B. E. G. no. 1728; no. 1415, Schoch, 1918, pp. 87, 193.

Wo-46a. Car sample, as Wo-46; through 1-inch and on 1/2-inch grate, 20%; B. E. G. no. 1729; no. 1416, Schoch, 1918, pp. 87, 193.

Wo-46b. Car sample, as Wo-46; through 1/2-inch and on 1/4-inch grate, 24%; B. E. G. no. 1730; no. 1417, Schoch, 1918, pp. 87, 193.

Wo-46c. Car sample, as Wo-46; through 1/4-inch and on 1/8-inch grate, 21%; B. E. G. no. 1731; no. 1418, Schoch, 1918, pp. 87, 193.

Wo-46d. Car sample, as Wo-46; through 1/8-inch grate, 21%; B. E. G. no. 1737; no. 1419, Schoch, 1918, pp. 87, 193.

Wo-47. Car sample, as Wo-46; middle part of car; on 1-inch grate, 22%; B. E. G. no. 1733; no. 1420, Schoch, 1918, pp. 87, 193.

Wo-47a. Car sample, as Wo-47; through 1-inch and on 1/2-inch grate, 32%; B. E. G. no. 1734; no. 1421, Schoch, 1918, pp. 87, 193.

Wo-47b. Car sample, as Wo-47; through 1/2-inch and on 1/4-inch grate, 10%; B. E. G. no. 1735; no. 1422, Schoch, 1918, pp. 87, 193.

Wo-47c. Car sample, as Wo-47; through 1/4-inch and on 1/8-inch grate, 14%; B. E. G. no. 1736; no. 1423, Schoch, 1918, pp. 87, 193.

Wo-47d. Car sample, as Wo-47; through 1/8-inch grate, 22%; B. E. G. no. 1737; no. 1424, Schoch, 1918, pp. 87, 194.

Wo-48. Car sample, as Wo-46; various sizes of lumps; B. E. G. no 1738; no. 1425, Schoch, 1918, pp. 87, 194.

Wo-49. Car sample, as Wo-46; on 1-inch grate, 20%; B. E. G. no. 1739; no. 1426, Schoch, 1918, pp. 87, 194.

Wo-49a. Car sample, as Wo-49, through 1-inch and on 1/2-inch grate, 38%; B. E. G. no. 1740; no. 1427, Schoch, 1918, pp. 87, 194.

Wo-49b. Car sample, as Wo-49; through 1/2-inch and on 1/4-inch grate, 20%; B. E. G. no. 1741; no. 1428, Schoch, 1918, pp. 87, 194.

Wo-49c. Car sample, as Wo-49; through 1/4-inch and on 1/8-inch grate, 16%; B. E. G. no. 1742; no. 1429, Schoch, 1918, pp. 87, 194.

Wo-49d. Car sample, as Wo-49; through 1/8-inch grate, 6%; B. E. G. no. 1743; no. 1430, Schoch, 1918, pp. 87, 194.

Wo-50. Car sample, as Wo-46; bottom part of car; on 1-inch grate, 32%; B. E. G. no. 1744; no. 1431, Schoch, 1918, pp. 87, 194.

Wo-50a. Car sample, as Wo-50; through 1-inch and on 1/2-inch grate, 40%; B. E. G. no. 1745; no. 1432, Schoch, 1918, pp. 87, 194.

Wo-50b. Car sample, as Wo-50; through 1/2-inch and on 1/4-inch grate, 16%; B. E. G. no 1746; no. 1433, Schoch, 1918, pp. 87, 194.

Wo-50c. Car sample, as Wo-50; through 1/4-inch and on 1/8-inch grate, 8%; B. E. G. no. 1747; no. 1434, Schoch, 1918, pp. 87, 194.

Wo-50d. Car sample, as Wo-50; through 1/8-inch grate, 4%; B. E. G. no. 1748; no. 1435, Schoch, 1918, pp. 87, 194.

Wo-51. Mine sample, North Texas Coal Company; Alba; T. M. S. no. 1547; no. 1547, Phillips, 1902, pp. 15, 53, and Phillips and Worrell, 1913, p. 88; no. 1392, Schoch, 1918, pp. 85, 193.

Wo-52. Mine sample, North Texas Coal Company; Alba; T. M. S. no. 1548; no. 1548, Phillips, 1902, pp. 15, 53, and Phillips and Worrell, 1913, p. 88; no. 1393, Schoch, 1918, pp. 85, 193.

Wo-53. Mine sample, Lone Star Lignite Company, Dallas; Alba; B. E. G. no. 17; no. 1397, Schoch, 1918, pp. 86, 193.

Wo-54. Unspecified sample, submitted by B. Snyder, Marshall; locality not specified, eastern part of county; B. E. G. no. 2272; no. 1392, Schoch, 1918, pp. 85, 193.

Wo-55. Mine sample, Morton Salt Company's mine no. 1, two miles south of Alba. Taken from 5-foot vein on the face of a new opening in the first east entry. Obtained by F. C. Adams and analyzed by The Texas Company's laboratory at Port Arthur, Texas. Adams and others, 1927, p. 19.

Zavala County

Za-1. Well sample, 12 miles west of La Pryor, at depth of 118 feet; submitted by W. J. Armstrong; apparently air-dried; B. E. G. no. 926; no. 1436, Schoch, 1918, pp. 87, 194.

Za-2. Well cuttings, I. T. Pryor ranch; average of 13 samples (air-dried); Baker, 1934, p. 333.

Za-3. Well sample, I. T. Pryor ranch; air-dried; Baker, 1934, p. 333.

Za-4. Outcrop sample, banks of Nueces River, about 1 mile downstream from crossing of U. S. Highway 83; no. 60085, Maxwell, 1962, p. 89.

Za-5. Outcrop sample, as Za-4; no. 60086, Maxwell, 1962, p. 89.

Za-6. Well cuttings, 281-86′, Pryor Ranch. Jeffreys, 1920, p. 19.

Za-7. Well cuttings, 281-84′, Pryor Ranch. Jeffreys, 1920, p. 19.

Za-8. Well cuttings, 231-35′, Pryor Ranch. Jeffreys, 1920, p. 19.