Report of Investigations No. 129

Environmental Geology of the Yegua-Jackson Lignite Belt, Southeast Texas

Mary L. W. Jackson
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Bureau of Economic Geology • W. L. Fisher, Director
The University of Texas at Austin • Austin, Texas 78712 • 1982

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assisted by
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CONTENTS

Figures

Tables

Maps

ABSTRACT

Environmental geologic maps of the Texas lignite belt were prepared in response to renewed production of lignite in Texas and enactment of Federal and State laws governing coal and lignite surface mining. The map area of this report encompasses the outcrop of the Yegua Formation and Jackson Group from south-central Texas to the Texas-Louisiana border. Yegua sediments are fluvial in outcrop and deltaic in the deeper subsurface. Jackson deposits are predominantly of deltaic origin.

Mapping involved interpretation of black-and-white, large-scale aerial photographs and extensive field work. Each of the 32 map units is defined in terms of substrate, soil, geomorphology, geologic process, vegetation, and land use. Additional information presented on the maps includes active and abandoned lignite mines and lignite resource blocks mapped by Kaiser and others (1980).

Floodprone areas, vegetation assemblages, and soil types presented on the maps provide basic data useful in mine planning. Correlation of sand outcrops with subsurface sand maps helps locate hydrologically sensitive areas that need careful consideration during lignite development. Environmental geologic maps can also aid public and private agencies in land use planning and land resource management.

INTRODUCTION

Since the mid-1970's, the rising cost of energy has stimulated renewed production of lignite in Texas. Current State and Federal legislation regulates coal and lignite surface mining. Consequently, the Bureau of Economic Geology prepared environmental geologic maps for use in lignite mine planning; the maps identify land resources and land capability. The maps also can be useful to researchers, construction engineers, and many others in planning projects ranging from road building to biological studies.

The Yegua-Jackson trend, which includes the Yegua Formation, the Jackson Group, and parts of over- and underlying formations, extends across Texas from the southwest to the east. The environmental geologic maps of this report cover this long and narrow trend over an area of approximately 13,000 km^2 (5,000 mi^2) (fig. 1). The northern limit of the map area is the northern edge of the Yegua outcrop. The southern edge of the map area is bounded by the surface position that lies 61 m (200 ft) above the stratigraphic top of the southeastward-dipping Jackson Group. This southern limit was chosen because 61 m (200 ft) is the depth below which lignite surface mining was not economical at the time of this study. The Colorado-Lavaca drainage basin divide in Fayette County is the southwestern map boundary and the Texas-Louisiana border is the eastern boundary.

Texas near-surface (6.1 to 61 m, 20 to 200 ft, deep) lignite resources are in the Eocene Wilcox and Jackson Groups and in the Yegua Formation in South and East Texas (Kaiser and others, 1980). East Texas contains approximately 92 percent of Texas' near-surface lignite; in Texas, Wilcox lignite is the most abundant and the highest in quality. However, 26 percent of the estimated 21,217 million metric tons (referred to in following text as "t") (23,377 million short tons [referred to in following text as "tons"]) of near-surface Texas lignite resources is in the Yegua-Jackson trend of this report (Kaiser and others, 1980). Of this 26 percent, most is poor-quality Jackson lignite; Kaiser and others (1980) estimated 458 million t (505 million tons) in the Yegua Formation and 2,186 million t (2,410 million tons) in the Jackson Group.

The first part of this report reviews previous studies, on which Yegua-Jackson maps were based, and describes the regional setting, geology, geomorphology, climate, soils, vegetation, hydrology, structure, and lignite potential of the map area. The second part of this report describes mapping procedures, expands definitions of the environmental units used in the map explanations, and describes applications of the environmental geologic maps.

PREVIOUS WORK

Previous environmental geologic mapping in Texas produced the Environmental Geologic Atlas of the Texas Coastal Zone (fig. 1) (Brown, 1972-1980). The atlas consists of seven basic data maps, each with eight accompanying special interest maps. The purpose of the Coastal Zone maps is to provide information on the interaction of coastal processes and to help delineate areas that are in delicate natural balance.

Another environmental geologic mapping project initiated in the early 1970's encompassed four river basins in south-central and South Texas, including the area overlying the Edwards and Carrizo-Wilcox aquifers (Gustavson and others, in preparation). Funded by the Texas Department of Water Resources and the U. S. Geological Survey, the project studied most of the southern Wilcox and Yegua-Jackson lignite belts and the South Texas uranium province. Environmental map units were established for Upper Coastal Plain sediments, such as the sands and muds of the Yegua Formation and Jackson Group. This study provided a basis for map units used later in East Texas environmental studies.

In response to the growing importance of lignite surface mining and the establishment of surface-mining laws, environmental geologic mapping was extended to the eastern and northern parts of the Texas lignite belt. Henry and Basciano (1979) mapped the Wilcox Group and used methods and units similar to those applied in the South Texas basin study (Gustavson and others, in preparation). This report continues mapping of the Texas lignite belt and follows the designation system used by Henry and Basciano.

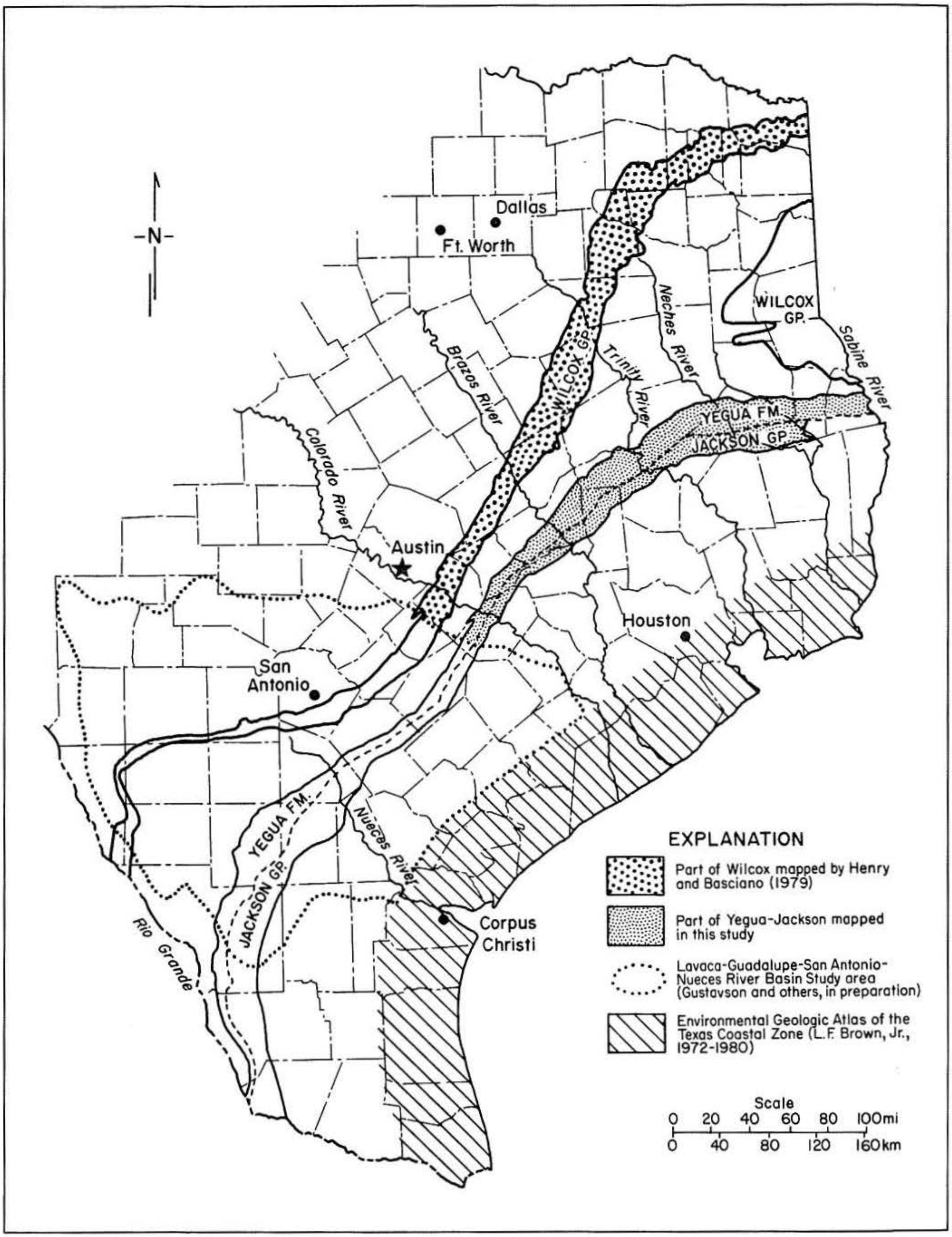

Figure 1. Environmental geologic maps by the Bureau of Economic Geology.

PHYSICAL SETTING

Physiography

The Yegua-Jackson map area crosses the Upper Coastal Plain and the Eastern Timbers regions of East Texas (fig. 2). On the drier Upper Coastal Plain, topography is gently rolling with small changes in relief (31 to 61 m, 100 to 200 ft). Small plains, or prairies, make up most of the land surface, and low rolling hills lie between the level areas. East of the Trinity River the topography is similar to that of the Upper Coastal Plain; however, because of higher precipitation, steep slopes formed by dissection are more common in the east.

Geology

The upper Eocene fluvial and deltaic sediments of the Yegua Formation and the Jackson Group (fig. 3) strike generally parallel to the present-day Texas coast (fig. 1). Dip is 0.25 to 4 degrees to the southeast (4 to 68 m/km, 20 to 360 ft/mi); dip values increase downdip because of basinal subsidence. Values above 4 degrees reflect the influence of local salt domes. In outcrop, Yegua and Jackson sediments are unconsolidated sands and muds. They are overlain in river valleys by Quaternary alluvium and on uplands south of the Navasota River by Pleistocene gravels (fig. 4). Differences between formations in the Yegua-Jackson trend are subtle. These units exhibit similar surface expressions because they are composed of fluvial and deltaic facies containing low percentages of sand.

Fisher and others (1970) and Kaiser and others (1980) interpret the Yegua Formation, the youngest formation in the Claiborne Group, as a fluvial system in the near-surface. Kaiser and others (1980) interpret the deep-basin part of the Yegua as a wave-dominated delta system. Fine-grained light-brown quartz sands interbedded with brown muds compose the Yegua; sand is more abundant near the base of the section. In many places these basal sands are iron stained, and in a few locations they are iron-oxide cemented. In San

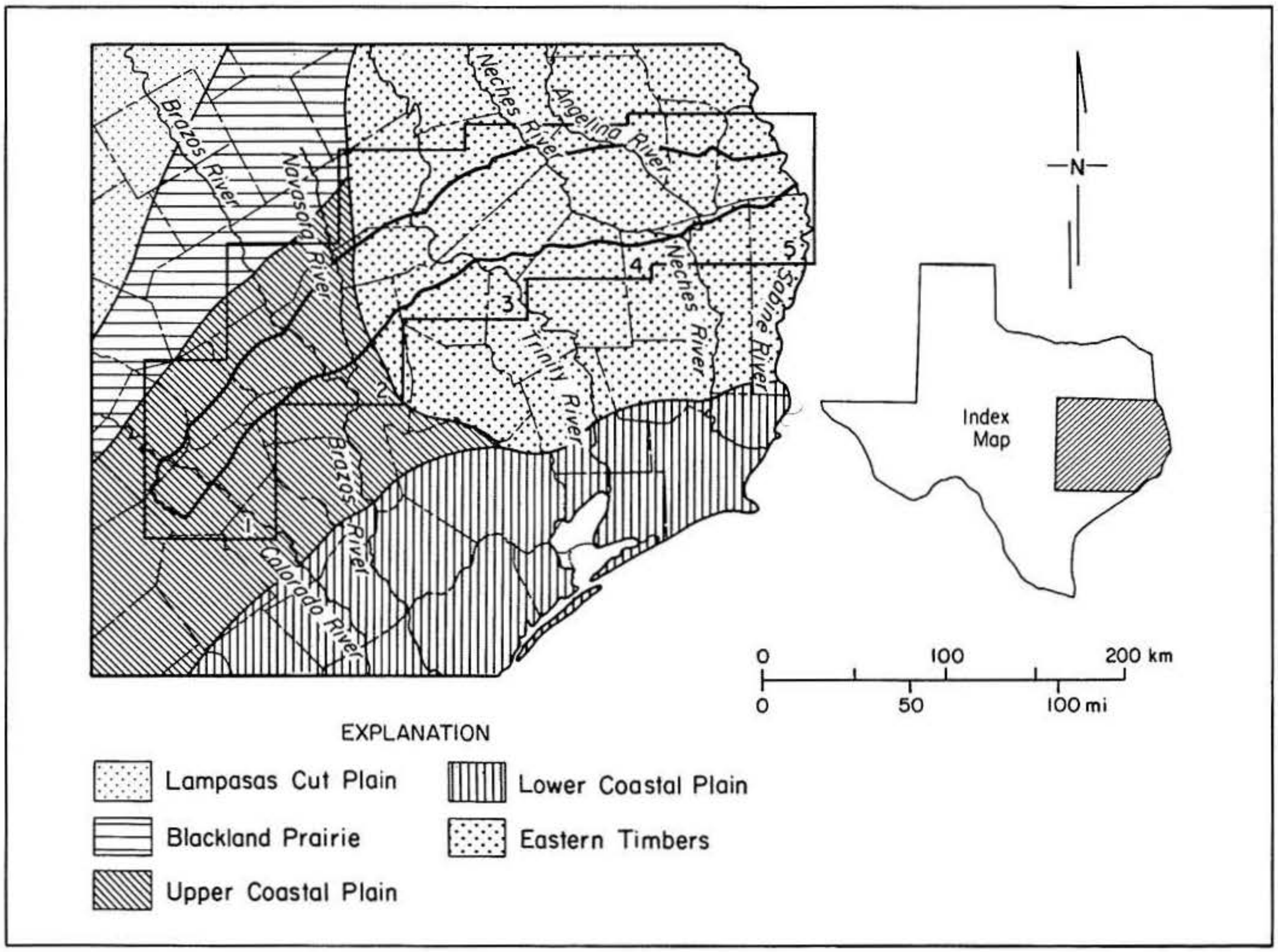

Figure 2. Physiographic regions of Central and East Texas (modified from Raisz, 1957). Bold outline and numbered rectangles indicate Yegua-Jackson map area.

Augustine and Sabine Counties, Yegua sands become silty; they are predominantly marine in origin. The Yegua ranges from 200 to 300 m (600 to 1,000 ft) in thickness (Barnes, 1967); it is thickest in outcrop at the middle part of the map area (Houston County) and thins where the Yegua changes from fluvial sand to marine mud at the east and southwest ends of the area.

The Caddell, Wellborn, Manning, and Whitsett Formations, which compose the Jackson Group in Central and East Texas, represent a period of relative sea-level drop (Fisher and others, 1970). Prodelta sediments at the base of the cycle are exposed in the Caddell Formation, which is 30 to 46 m (100 to 150 ft) thick southwest of the Trinity River and thins to less than 14 m (45 ft) to the east (Barnes, 1967, 1974a). The Caddell contains interbedded light-brown mud and a few fine- to medium-grained quartz sand lenses. The sands locally exhibit iron-oxide stains; iron content in the Caddell increases to the east.

The overlying Wellborn Formation contains interlayered medium-grained quartz sand and dark-brown mud, interpreted as delta-front sediments (Fisher and others, 1970). Wellborn strata are 46 m (150 ft) thick or more, and many of the sands are silica cemented in the upper few decimeters. East of the Trinity River the Wellborn Formation crops out as very fine grained glauconitic sand (Sellards and others, 1932); it pinches out at the Sam Rayburn Reservoir in Angelina County (Barnes, 1967).

The Manning Formation is interpreted as a delta-plain sequence (Fisher and others, 1970). Average thickness is 76 m (250 ft). Chocolate-brown mud, lignite, and channel sands compose the Manning section. The sands are fine to medium grained, gray, and tuffaceous (Barnes, 1974a). Eastward, stratigraphically equivalent sediments are represented by the marine clays, glauconitic sands, and thin limestones of the Yazoo Formation (Barnes, 1967).

Fisher and others (1970) interpret the Whitsett Formation as the fluvial counterpart of the deltaic Manning and Wellborn sequences. Whitsett sands are lighter colored than the rest of the Jackson sands. These cross-bedded quartz sands are fine to medium grained and tuffaceous, and they are in sequences up to 9 m (30 ft) thick. Thickness of the Whitsett Formation ranges from 18 to 40 m (60 to 130 ft) (Barnes, 1967, 1974a); in outcrop, major fluvial facies are limited to the region between Washington and Polk Counties. East of Angelina County, Whitsett strata interfinger with the marine Nash Creek Formation, which contains widely scattered fine-grained sands within a mud matrix.

Two additional Eocene stratigraphic units that lie within the map area are the Cook Mountain Formation, which is exposed north of the Yegua outcrop, and the Catahoula Formation, which crops out south of the Whitsett Formation. The upper part of the marine Cook Mountain Formation is a gray clay in outcrop. At a few locations the medium-grained brown sands of the Spiller Sand Member of the Cook Mountain Formation also crop out within the map area.

The Catahoula Formation exposed within the map area is a thick, light-gray, fine- to medium-grained quartz sand and interbedded light-olive-gray mud. The sand is locally indurated and tuffaceous. To the east, Catahoula sand becomes coarse grained, and in Polk County it is conglomeratic.

The major river valleys that traverse the map area—the Colorado, Brazos, Navasota, Trinity, Neches, Angelina, and Sabine—contain Quaternary alluvium. The Angelina and Sabine Rivers are dammed at the Catahoula outcrop, and therefore most of the floodplain deposits associated with these two rivers are submerged within the map area. Clay, sand, and gravel deposits and associated clay and sand terraces compose the alluvium. Alluvium reaches 25 m

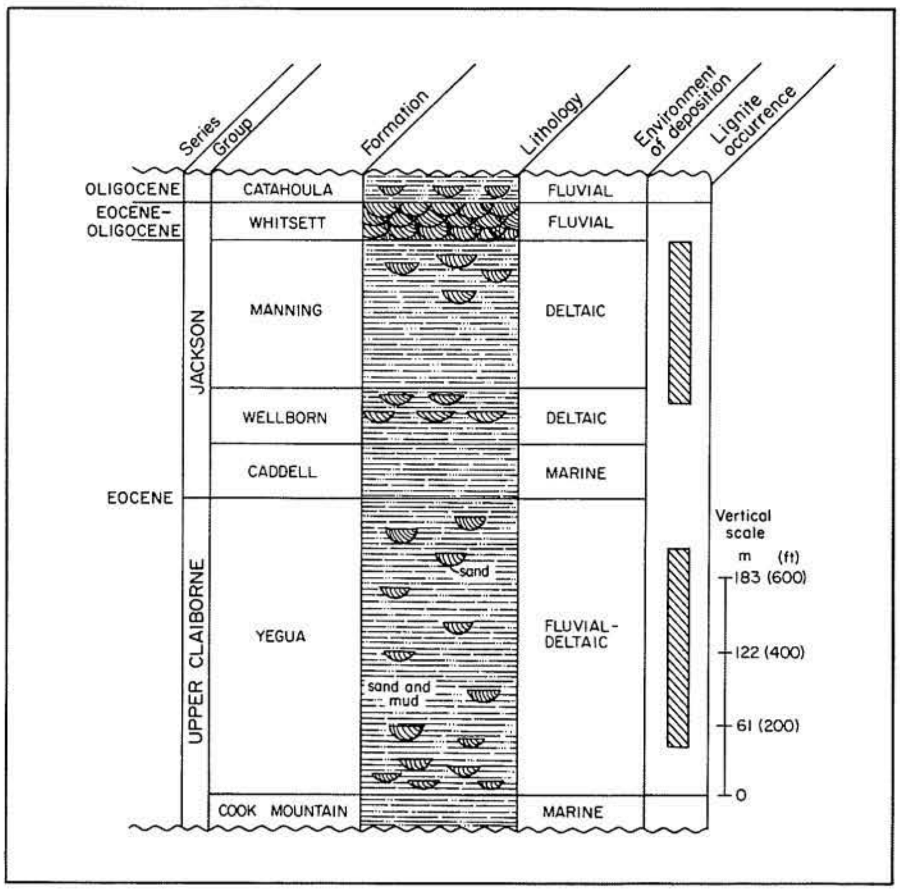

Figure 3. Generalized geologic section, Yegua-Jackson interval. Lignite occurrence from Kaiser and others (1980).

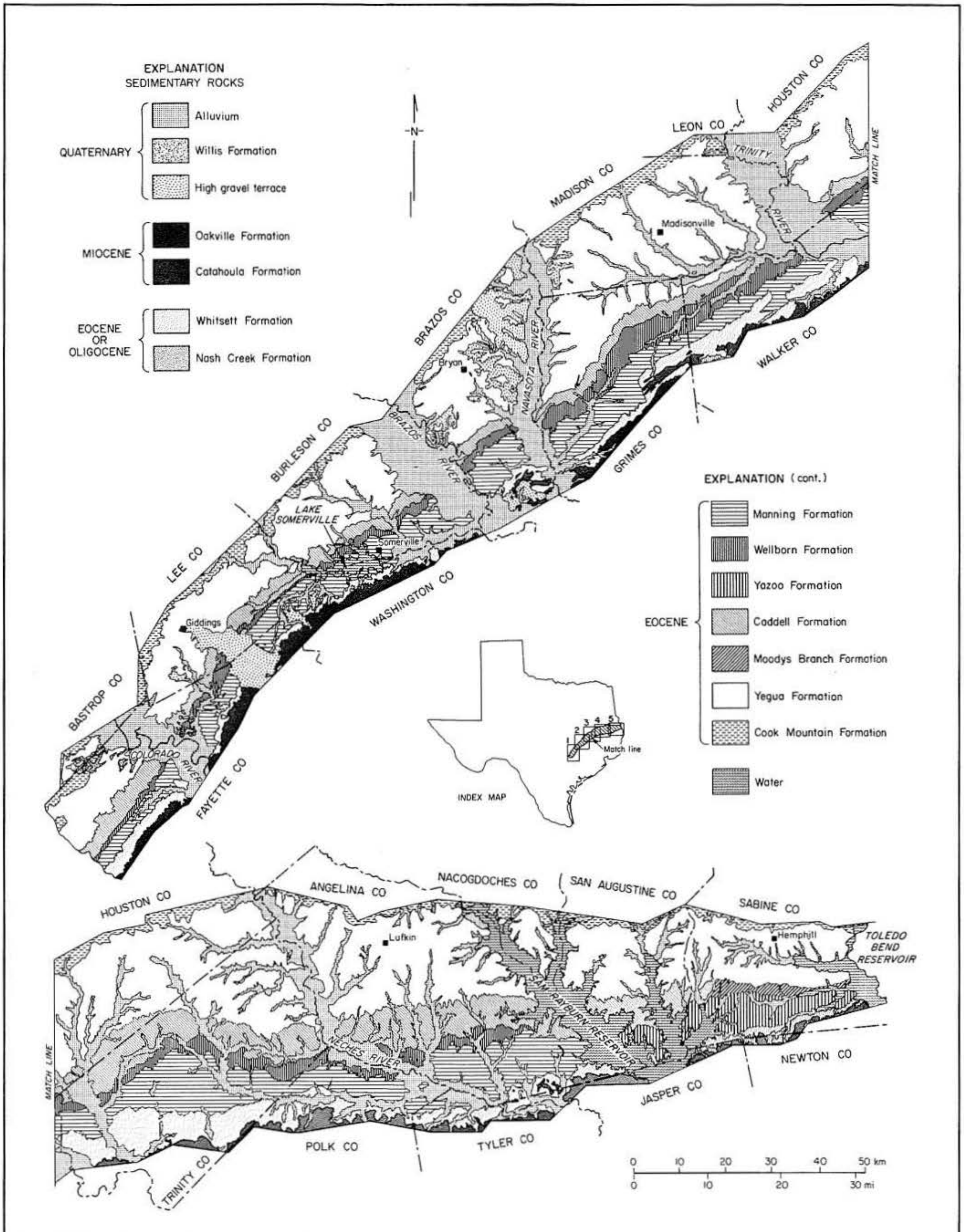

Figure 4. Geologic map of the Yegua-Jackson trend (Barnes, 1967, 1968, 1970, 1974a, b).

(80 ft) in thickness in the Brazos River valley (Follett, 1974), but averages 15 m (50 ft) thick. Other Quaternary deposits in the map area include Late Pliocene and Pleistocene high gravel terraces and alluvial fans that blanket much of the upland area between the Colorado and Navasota Rivers. The largest of these deposits, in southern Lee and northern Fayette Counties, averages 5 to 6 m (15 to 20 ft) thick.

Topography and Geomorphology

Topography of the Yegua-Jackson trend reflects the geology of the substrate (fig. 5). Southwest of the Trinity River, muds of the Cook Mountain Formation are expressed as prairies on the northern boundary of the map area and are punctuated by widely scattered low hills supported by the Spiller Sand Member. The basal sands of the Yegua Formation support prominent, individual hills, and these constitute the highest elevations in the Yegua-Jackson trend. The middle and upper sections of the Yegua contain only thin, discontinuous sands in outcrop, so this region and the sand-poor Caddell outcrop to the south are characterized by relatively featureless plains.

Topography of the Wellborn Formation is distinct; indurated and continuous sands form low cuestas. Where thinner and less indurated, the sands are also expressed as low rolling hills.

Like the Caddell and the Yegua, the Manning Formation intersects the surface as a gently undulating plain. A few notable sand ridges do occur, however, such as the one along Gibbons Creek in Grimes County (map sheet 2, in folder).

Whitsett sand bodies exhibit a different topography than the other Jackson sands. Because they are thicker and dip oriented, they form conspicuous groups of sand hills.

The escarpment supported by the Catahoula Formation is the most outstanding feature in the map area. It is best developed east of the Trinity River, where the Catahoula exhibits a fairly continuous and commonly steep-sided sand ridge.

Although drainage patterns are predominantly dendritic in the mapped area, sand-supported ridges of the Jackson Group impose quasi-trellis drainage patterns. The Wellborn cuesta in Lee County inhibits the migration of Nails Creek (map sheet 1), and the indurated sand ridge south of Carlos in Grimes County prevents lateral migration of Gibbons Creek (map sheet

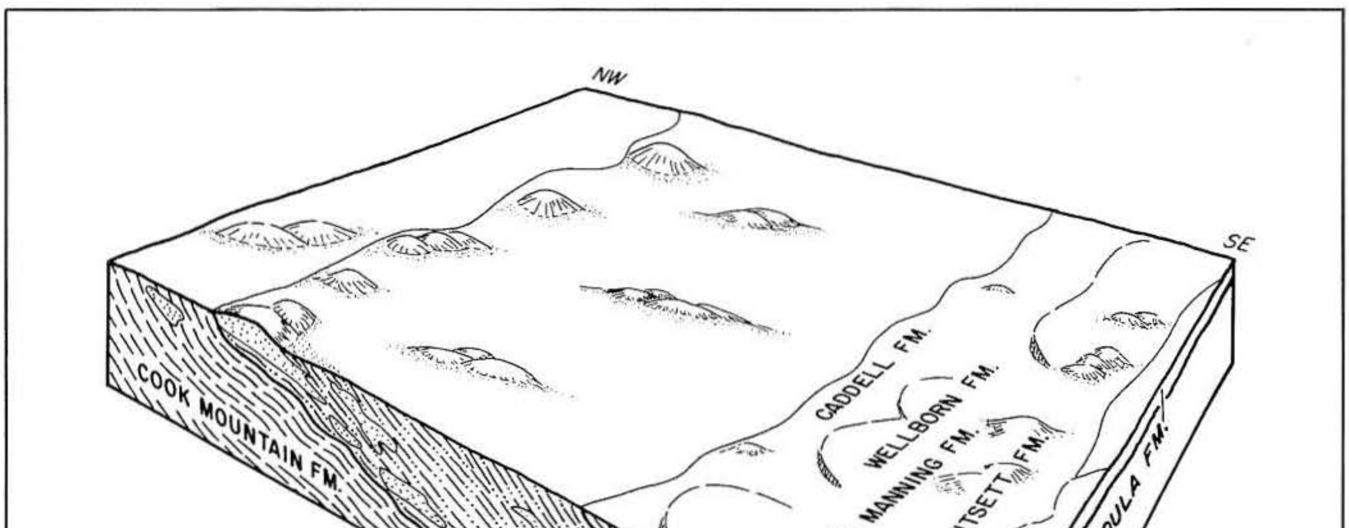

Figure 5. Relation between topography and geology along the Yegua-Jackson outcrop (vertical scale exaggerated).

2). Uncemented sands are more easily eroded than muds in the drier southern part of the map area, but in the eastern part, both sand and mud are dissected because abundant rainfall inhibits differential erosion.

Climate

Climate, soils, vegetation, and substrate interact to form a specific environment. Climate and substrate are primary variables on which soil and vegetation are dependent.

Climate in the mapped area is influenced by warm humid air from the Gulf of Mexico in the summer; cool humid maritime air and less common cold dry polar air control winter climate. The interaction of Gulf air and cooler air from the north is responsible for much of the precipitation in Central and East Texas (Orton, 1974). Convection cells that form locally cause thunderstorms; hurricanes and associated tornadoes may occur in summer and fall. Mean annual values for temperature, precipitation, frost-free days, and lake evaporation are shown for Central and East Texas in figure 6. The East Texas climate is considerably wetter than that of Central Texas, but the change from humid to semi-humid climate is gradational.

In East Texas the climate is humid subtropical; summers are hot and winters mild. Annual rainfall averages from 1,120 to 1,320 mm (44 to 52 inches) and is distributed relatively evenly throughout the year. Average rainfall exceeds the amount of lake evaporation by 760 to 1,150 mm (30 to 45 inches); net annual lake evaporation is from 130 to 380 mm (5 to 15 inches). Mean date of the first frost is November 16, and the last frost usually falls near March 16. Growing season is therefore 230 to 260 days long.

In the subtropical part of Central Texas summers are humid and winters are dry and mild. Precipitation, 910 to 1,120 mm (36 to 44 inches) annually, often comes in thunderstorms that are most severe and numerous in May. In comparison with those in East Texas, average rainfall values and lake evaporation rates are closer; rainfall exceeds evaporation by 380 to 760 mm (15 to 30 inches). December 1 is the average date of the first frost, and March 1 is the average date of the last frost; thus, growing season is 260 to 280 days long.

Summer and winter humidity values in the Yegua-Jackson trend differ by about 10 percent. Yearly averages are 85 percent at 6 a.m. and 60 percent at 6 p.m. Average number of sunny days is 220 to 235. Temperatures in the map area vary most in the spring when cold fronts descend from the north. Summer temperatures fluctuate little. Average summer temperature is in the 30's °C (90's °F); August is the hottest month (Orton, 1974). Mean annual temperature for the Yegua-Jackson trend is 20°C (68°F).

Soils

Soil type results from variations in substrate and climate. Because there are two different climates in the Yegua-Jackson trend, there are two major upland soil types. Organisms, topography, and depth of the water table also influence soil type. The reddish-brown, podzolic soils that lie south of the Trinity River contain medium to high amounts of calcium and magnesium, which percolate slowly down to the water table. Aluminum and iron also migrate down from the top layer, or A horizon, of these soils and reprecipitate in the B horizon (lower layer). Silica remains behind and is concentrated in the upper soil layers (Strahler, 1963).

In contrast, lateritic soils, which are common in East Texas, are acidic. Calcium and magnesium percolate down to the water table and are carried away in solution. Aluminum and iron remain in the A horizon of lateritic soil, but silica is also carried away in the ground water (Strahler, 1963). Most soils developed on Yegua and Jackson sediments display B horizons of dense clays; this plus a low humus content results in relatively impermeable and infertile soils. Exceptions are soils that support deep-rooted grasses on the Catahoula Formation. Such grasses help produce deep black A horizons and more fertile soils.

Soil associations for the Yegua-Jackson trend are shown on U.S. Department of Agriculture (USDA) Soil Conservation Service county soil maps and in detailed county soil surveys. In the map area, only surveys for Bastrop, Brazos, Nacogdoches, and Walker Counties were available. The information in the following paragraphs is taken largely from Baker (1979), McClintock and others (1979), Mowery and others (1958), and the USDA Soil Conservation Service (1971a, b, c, 1974a, 1977a, 1978, 1979a, b).

Principal soil associations southwest of the Trinity River are the Lufkin, Axtell-Tabor, Wilson-Crockett, and Falba upland soils, the Burleson terrace soils, and the Miller-Norwood, Kaufman-Gowen, and Kaufman-Tuscumbia floodplain, or bottomland, soils. The four upland soil associations have gray and brown fine sandy loam A horizons and mottled red, yellow, and gray clay B horizons. Occasionally loamy fine sand A horizons also develop. Depth of the upland soils is from 100 to 130 cm (40 to 50 inches), except for the Falba series soils that form on sandier and more tuffaceous substrates and are normally only 50 to 100 cm (20 to 40 inches) thick. On the Catahoula Formation, the fertile, clayey Houston Black - Heiden association develops in many locations.

Burleson soils lie on large terraces adjacent to the Brazos River. Burleson A and B horizons are composed of gray clay.

The Miller-Norwood association occurs on the Colorado and Brazos River floodplains. Both A and B horizons are brown fine sandy loams, and depth averages 150 cm (60 inches). Soils in the Miller-Norwood association are calcareous. The Kaufman-Gowen and Kaufman-Tuscumbia associations occur on the Yegua Creek, Navasota River, and Trinity River floodplains and exhibit A and B horizons of black clay.

Montmorillonite is the most abundant clay in the southeast Texas soils, which are acidic in the upper layers and alkaline below. All these soils have high shrink-swell potential and high corrosion potential for uncoated steel.

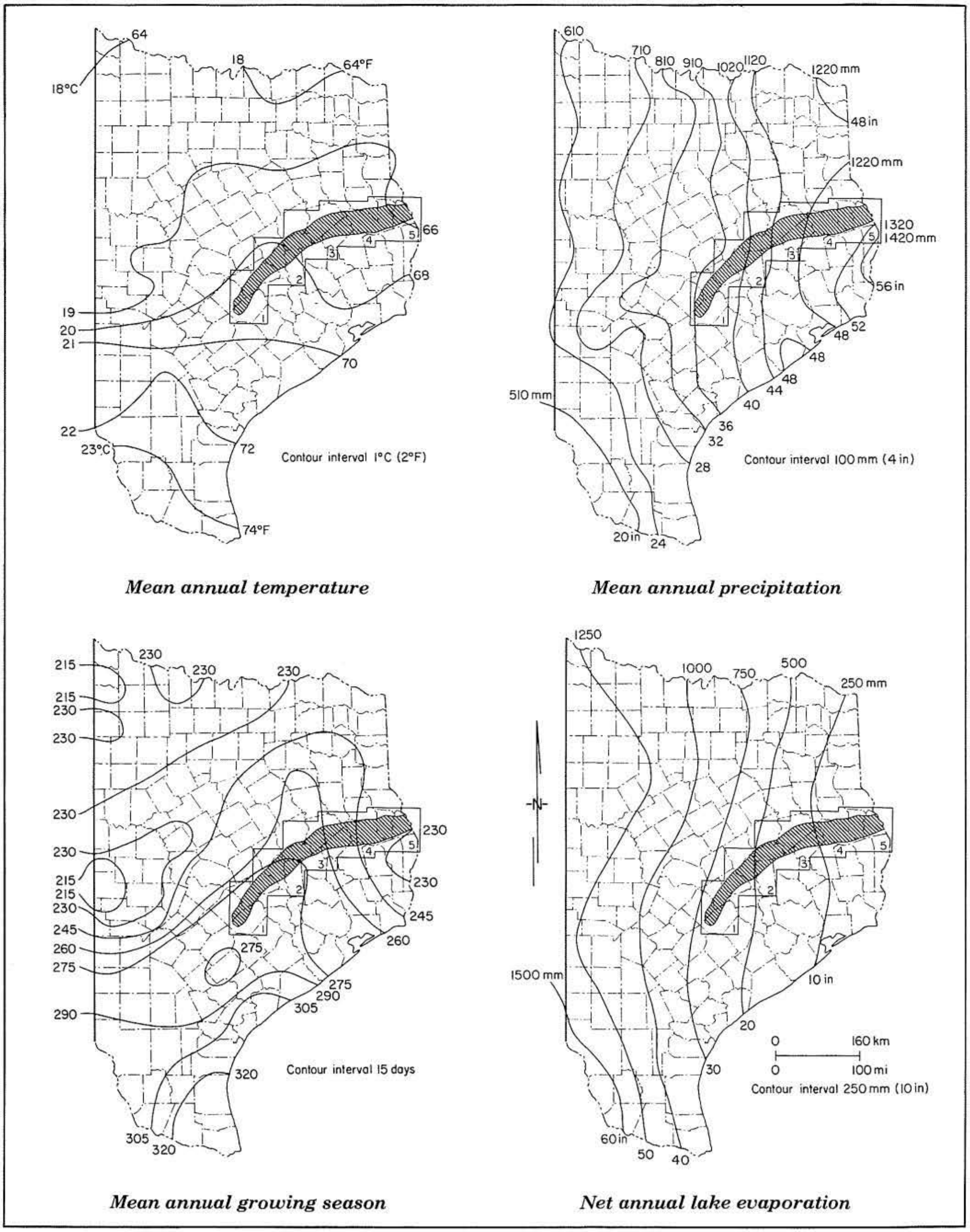

Figure 6. Climatic data for Central and East Texas (adapted from Arbingast and others, 1976). Shaded region and numbered rectangles indicate Yegua-Jackson map area.

East of the Trinity River, Sacul-Fuquay, Corrigan-Rayburn, and Woodtell soil associations lie on the uplands, Bernaldo soils on the terraces, and Mantachie soils on the floodplains. The information in this and the following paragraphs is taken from Dolezel (1980) and the USDA Soil Conservation Service (1971d, 1974b, c, 1975a, b, 1976a, b, c, and 1977b).

Upland soils are iron-rich, brown fine sandy loams with mottled clay B horizons, except for the Fuquay series soils, which are brown loamy fine sands overlying mottled sandy clay loams. Fuquay soils overlie substrates that have higher sand content. Sacul-Fuquay soils range from 150 to 250 cm (60 to 100 inches) deep, and Corrigan-Rayburn and Woodtell soils range from 75 to 150 cm (30 to 60 inches) deep. Sacul-Fuquay soils are mixed to montmorillonitic in clay composition, and Corrigan-Rayburn and Woodtell soils are montmorillonitic.

Bernaldo terrace soils are brown and have fine sandy loam A horizons and sandy clay loam B horizons. Depth rarely exceeds 200 cm (80 inches), and these soils are siliceous in composition. Mantachie soils are black clays overlying mottled clays. They have depths up to 150 cm (60 inches) and are also siliceous.

Nearly all soils east of the Trinity River are acid to strongly acid. Upland soils have high shrink-swell potential. Bernaldo and Mantachie soils cause fewer foundation problems because they are siliceous, but flooding is frequent on these soils.

Vegetation

Factors that control type of vegetation are climate, soil, topography, other plants in the area, and human modification. The interdependency of the first four factors results in two distinct major vegetation populations in the Yegua-Jackson trend: the Post Oak Savanna in the southwest, and the Pineywoods in the east (fig. 7). The map area also includes the Blackland Prairie, which borders the Post Oak Savanna. The oak-hickory-oak-pine forest in the Trinity River region represents a transition zone, or ecotone, between the oak forest and the eastern pines. Floodplain woody vegetation consists of water-tolerant hardwoods on all floodplains west and south of the Sam Rayburn Reservoir (map sheet 5). East Texas floodplains are forested with pines.

The Post Oak Savanna is also termed the Post Oak Belt, and it is thought that oak is the climax vegetation. However, the ages of trees and the presence of abundant climax prairie grasses support the theory that this region was once a grassland, or savanna, with few post oaks (Holm, 1975).

Woody species in the Post Oak Savanna are dominated by post oak and blackjack oak. Individuals are scrubby and gnarled, and they grow scattered between prairies of tall bunchgrass. The dominant species of prairie grass are little bluestem, Indian grass, switchgrass, purple top, silver bluestem, and Texas wintergrass. Yaupon, the dominant scrub understory vegetation in the Post Oak Savanna, is an invader, a subclimax plant (Gould, 1962). South of the Brazos River, slightly alkaline sandy areas support juniper trees.

Clayey soils on the Cook Mountain and Catahoula Formations support Blackland Prairie vegetation. Prairie vegetation is also in Fayette County on the outcrop of the Jackson Group, where sands are fewer. Mesquite grows abundantly among the prairie grasses, which include most of the same species that grow on the Post Oak Savanna. Post oak, blackjack oak, elm, and hackberry are scattered on less clayey soils in these areas.

Northeast of the Navasota River, hardwoods other than oaks, such as black hickory, winged elm, southern red oak, black gum, and Texas sugarberry, grow more abundantly, although the last three species are not as numerous as the others. Hickory becomes codominant with post and blackjack oak. Huckleberry, green hawthorn, and American beautyberry replace yaupon as the dominant shrubs (Gould, 1962).

The oak-hickory-oak-pine ecotone begins in Walker County; pines increase in number eastward, and in eastern Trinity and Houston Counties the ecotone changes to true Pineywoods. Post and blackjack oaks, black hickory, loblolly pine, and shortleaf pine are common in this region. Bluejack oak grows on high sandy ridges. Hickory grows in a limited area east of the Trinity River; thus in the ecotone of Trinity and Houston Counties, oak and pine are codominants (Gould, 1962). The oak-hickory-oak-pine transition zone is designated "pine-hardwood forest" on the environmental map (sheet 3) for simplification.

In the Pineywoods of East Texas, loblolly and shortleaf pine compose the dominant woody population. Virgin timber in this region was once almost completely longleaf pine (Tharp, 1926), but extensive timbering has all but eliminated this species in the Yegua-Jackson trend.

Beyond the southwestern edge of the pine forest are two outliers of the pine community, one on the north bank of the Colorado River in Fayette County (map sheet 1) and one near Carlos in Grimes County (map sheet 2). The southwesternmost outlier grows on a bluff on the north bank of the Colorado near the southern edge of the map area. Substrate of the bluff is dissected Pleistocene terrace sediment. The pines growing there are probably part of a larger forest that grew during a wetter climate, and they persist in this location because of suitable soil (Holm, 1975). The pine community near Carlos in Grimes County may still be living in our drier modern climate because of the sandier, more acidic soils on the hills near Carlos.

Water-tolerant hardwoods, primarily ash, pecan, water elm, hackberry, water oak, willow oak, and hickory, compose the floodplain vegetation southwest of the Trinity River. The understory consists of shrubs and vines. Within reach of yearly floodwaters, bermudagrass, cottonwood, and willow are established (Mowery and others, 1958). Floodplain vegetation persists along major tributaries and upstream along smaller creeks until the soils become too dry. Terrace vegetation, especially along the Brazos River, is primarily tall bunchgrass; scattered elm and mesquite are on clayier areas.

Dominant tree species that grow along the Trinity River floodplain are American sycamore, eastern cottonwood, green ash, sweet gum, water oak, southern red oak, and white oak. The same vegetation, plus cherrybark oak and loblolly pine, grows along the Neches River and along the Sam Rayburn and Toledo Bend Reservoirs (Gould, 1962). Terrace vegetation in this region is similar to floodplain vegetation.

Although vegetation in the Yegua-Jackson trend falls into two major zones, the Post Oak Savanna and the Pineywoods, the transition from one zone to the other is gradational. Line boundaries between vegetation units on the environmental geologic maps are not meant to indicate abrupt changes in vegetation type (map sheets 1-4).

Hydrology

In the Yegua-Jackson trend, the major aquifers, or water-bearing units, are sediments within the lower Tertiary Wilcox Group and Carrizo, Queen City, and Sparta Formations, which dip south and southeastward

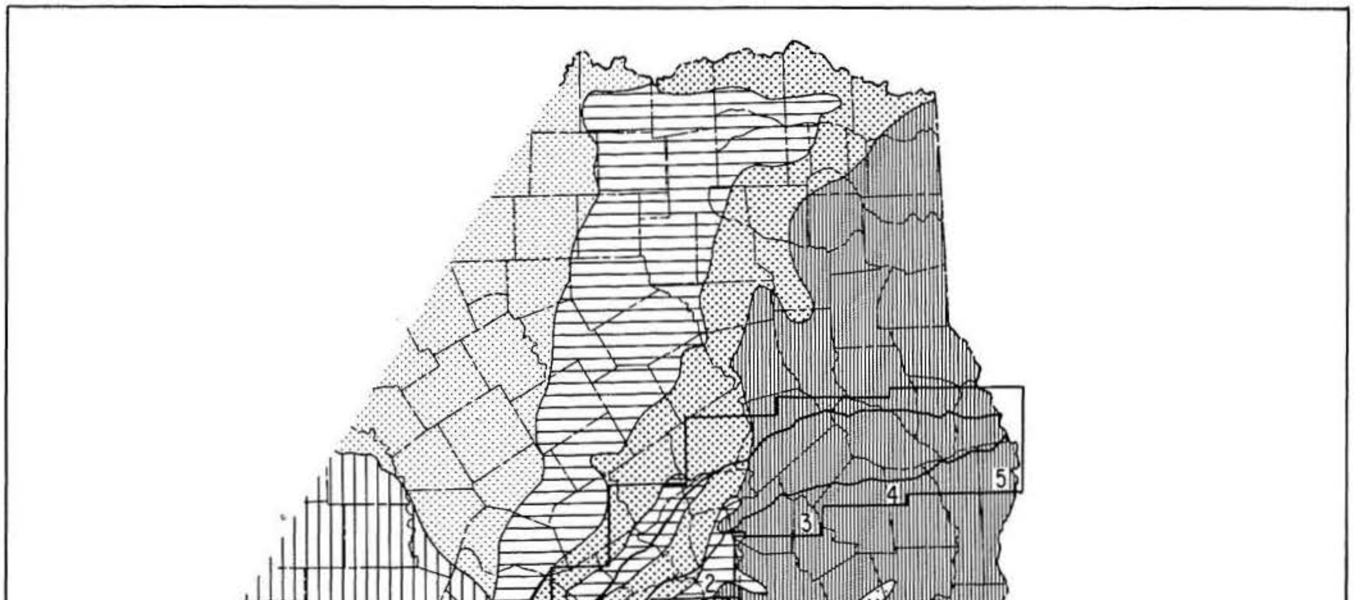

Figure 7. Vegetation assemblages of southeast Texas (from Gould, 1962). Bold outline and numbered rectangles indicate Yegua-Jackson map area.

under Yegua sediments. Along the southern edge of the map area, ground water is pumped primarily from upper Tertiary formations that constitute the Jasper and Evangeline aquifers (fig. 8). The Cook Mountain, Yegua, Jackson, and Catahoula Formations and Quaternary alluvium all yield some potable water, however. For example, in Brazos and Grimes Counties and east of Trinity County, the Yegua is tapped by several municipal wells, is used for irrigation, and is considered a minor aquifer. Water from Yegua and Jackson sediments mainly serves rural, domestic, and livestock purposes. The information in this and the following paragraphs is based on Baker and others (1974), Follett (1970, 1974), Rogers (1967), Sandeen (1972), Thompson (1960), and Winslow (1950) for the region southwest of the Trinity River; and on Anders (1967), William F. Guyton and Associates (1970), Tarver (1966), Tarver (1968), and Wesselman (1967) for the region east of the Trinity River.

The Yegua Formation produces small to moderate amounts (less than 32 L/s, 500 gal/min) of fresh to moderately saline water (from less than 1,000 to 10,000 ppm dissolved solids), but the quality is highly variable. Jackson sediments yield small amounts (less than 3.2 L/s, 50 gal/min) of fresh to moderately saline water. In the region south of the Trinity River, production increases where sands are more numerous, as in Yegua strata in Brazos, Burleson, and Fayette Counties and in Jackson strata in Washington and Fayette Counties. A significant decrease in the amount of Jackson sand to the east of the Trinity River lessens the water-bearing potential of this unit compared with the region southwest of the Trinity. Approximate depth to base of fresh to slightly saline water for the Yegua-Jackson trend is 310 m (1,000 ft).

The Mount Tabor Clay Member of the Cook Mountain Formation crops out along the northern edge of the map area; it is considered an aquitard, owing to its

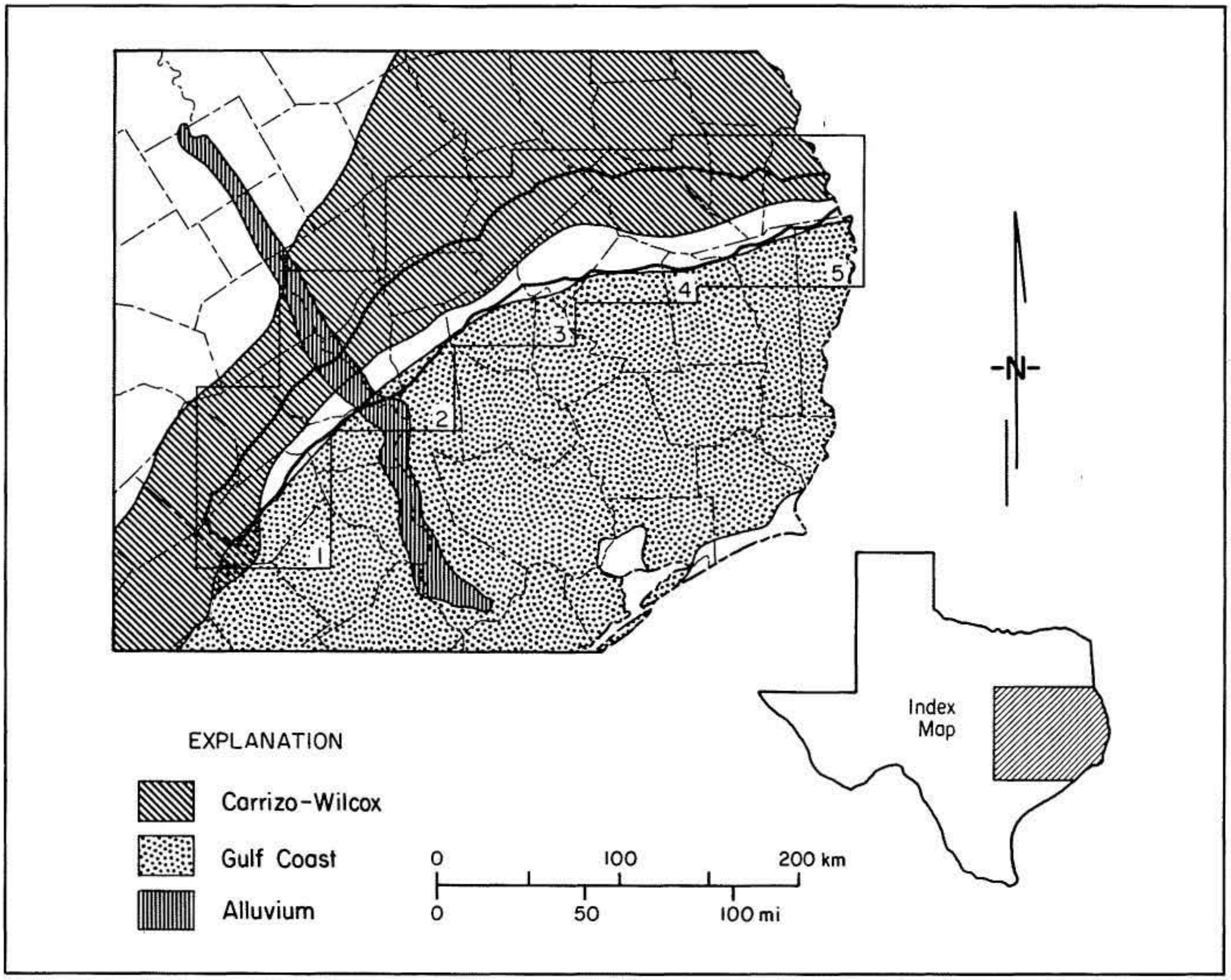

Figure 8. Major aquifer zones in southeast Texas (from Texas Water Development Board, 1968). The Gulf Coast aquifer zone includes the Jasper and Evangeline aquifers. Blank areas indicate absence of significant aquifer. Bold outline and numbered rectangles indicate Yegua-Jackson map area.

relatively high mud content. Stratigraphically below and cropping out north of the Mount Tabor Clay is the Spiller Sand Member, which yields small amounts of fresh to moderately saline water. The Spiller Sand crops out in Madison County.

The Oligocene Catahoula Formation is considered a major aquifer in Grimes, Polk, and Tyler Counties. It produces small to moderate quantities of fresh to slightly saline water for public, industrial, domestic, rural, and livestock use.

Alluvial deposits of major rivers contain shallow, fresh ground water but are prone to pollution from industrial or other sources. Colorado and Brazos River alluvium averages 15 m (50 ft) thick but locally reaches a thickness of 25 m (80 ft). Brazos River alluvial aquifers supply enough water for irrigation. On the Trinity and Neches River floodplains, the alluvium is thinner by 6 m (20 ft) or more and thus is not as productive as the Colorado and Brazos River alluvium.

The Catahoula and Yegua Formations and the Brazos River alluvium are the only strata in the mapped area that provide significant amounts of water. Water-bearing potential is greatest in high-sand-percent areas.

Land Use

Land in the Yegua-Jackson trend is employed primarily for agricultural purposes, which differ according to vegetative assemblage and soil association. Southwest of the Trinity River, livestock, poultry, and cotton are major agricultural products. In East Texas, timber is the dominant product; livestock and poultry are secondary (Bonnen, 1960).

The Post Oak Savanna in the southwestern part of the map area supports abundant pastureland and rangeland. Pastureland, in this report, is considered to be land that is either naturally fertile or land that has been planted with grass, root-plowed, or fertilized (improved pasture). Rangeland has not been fertilized or otherwise affected by human activity. Grass on rangeland only partly covers the ground, and trees and brush are more common than on pastureland. Rangeland is more common on sand hills where the soils are thinner.

Soils of the Blackland Prairie support pasture and crops, especially on the Catahoula Formation. Fertile floodplain soils of the Colorado and Brazos Rivers are farmed almost exclusively for cotton, corn, and sorghum.

Local deposits of iron-oxide-cemented sand or indurated sand occur in the basal Yegua at outcrop; these are quarried for road material. Sand, gravel, and clay pits are abundant in Recent alluvium, and gravel is quarried on upland gravel terraces.

The East Texas Pineywoods are used as a source of large amounts of timber and pulpwood. Outliers of the pine forest near La Grange and Carlos are also cut for timber. Recreation is an additional land use in Davy Crockett, Angelina, and Sabine National Forests.

Lignite Resources

Kaiser and others (1980) have described lignite quality and occurrence in the Yegua Formation and Jackson Group. Stratigraphically, lignite occurs in the middle two-thirds of the Yegua Formation, throughout the Manning Formation, and in the upper part of the Wellborn Formation (fig. 3).

Near-surface Yegua lignites are thought to have formed from swamps in interchannel fluvial environments (fig. 9) and thus are associated with low-sand areas. Yegua lignites average 1.2 m (4 ft) in thickness and 5 to 7 km (3 to 4 mi) in lateral extent. These lignites are of intermediate quality among Texas lignites, and actual resources are estimated to be relatively small (Kaiser and others, 1980).

In contrast, Jackson lignites are believed to have formed from extensive marsh deposits covering abandoned delta lobes (fig. 10); thus these lignites are above and below high-sand areas. Tabular to lenticular Jackson lignite deposits can extend up to 48 km (30 mi) along strike, and they average about 1.5 m (5 ft) thick. High ash content and many partings are locally characteristic of Jackson lignites.

Texas lignites are low in heating value and moderate in sulfur content compared with other coals. Yegua lignites average 1.9 weight percent sulfur on a dry basis, and Jackson lignites average 2.5 weight percent sulfur (Kaiser and others, 1980). Although Yegua lignite is of better grade than Jackson lignite, its smaller volume and discontinuous seams make it commercially less attractive. Resource blocks (areas) from Kaiser and others (1980) are shown on the environmental geologic maps (map sheets 1-5).

Structural Geology

The outcrop width of Yegua and Jackson sediments is affected by two major structures: the San Marcos Arch and the Houston Embayment (fig. 11). In Fayette County, Yegua-Jackson sediments thin over the San Marcos Arch, resulting in a narrow outcrop pattern. In contrast, sediments deposited in the Houston Embayment are thicker and exhibit a wider outcrop pattern. Although the Sabine Uplift is adjacent to the marine Yegua outcrop, it was not active during Yegua-Jackson deposition; the influence of the Uplift on Yegua and Jackson deposits has not been determined. Likewise, the influence of the Mexia-Talco Fault Zone, active during Eocene deposition, is unknown.

Yegua and Jackson sediments exhibit little structural deformation. A few faults, located primarily southwest of the Trinity River, have been mapped by Barnes (1967, 1968, 1970, 1974a, b). In Fayette County, a section of the Cook Mountain Formation was uplifted at Cistern, and the Yegua-Cook Mountain contact is faulted north of the same town (map sheet 1). Near Muldoon, down-to-the-coast faults cut the Wellborn Formation, and in Lee County the same kind of displacement, again cutting the Wellborn Formation

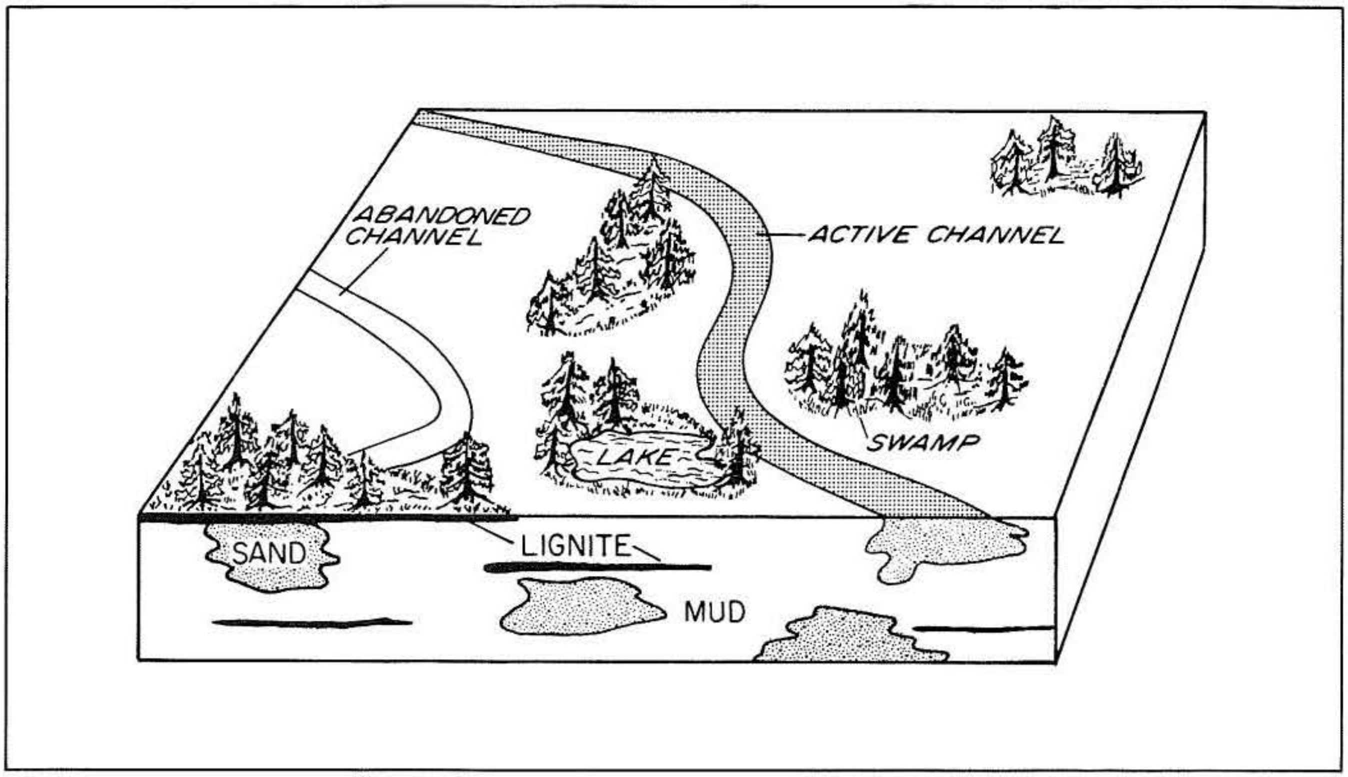

Figure 9. Schematic diagram showing the interchannel swamps from which Yegua lignite formed.

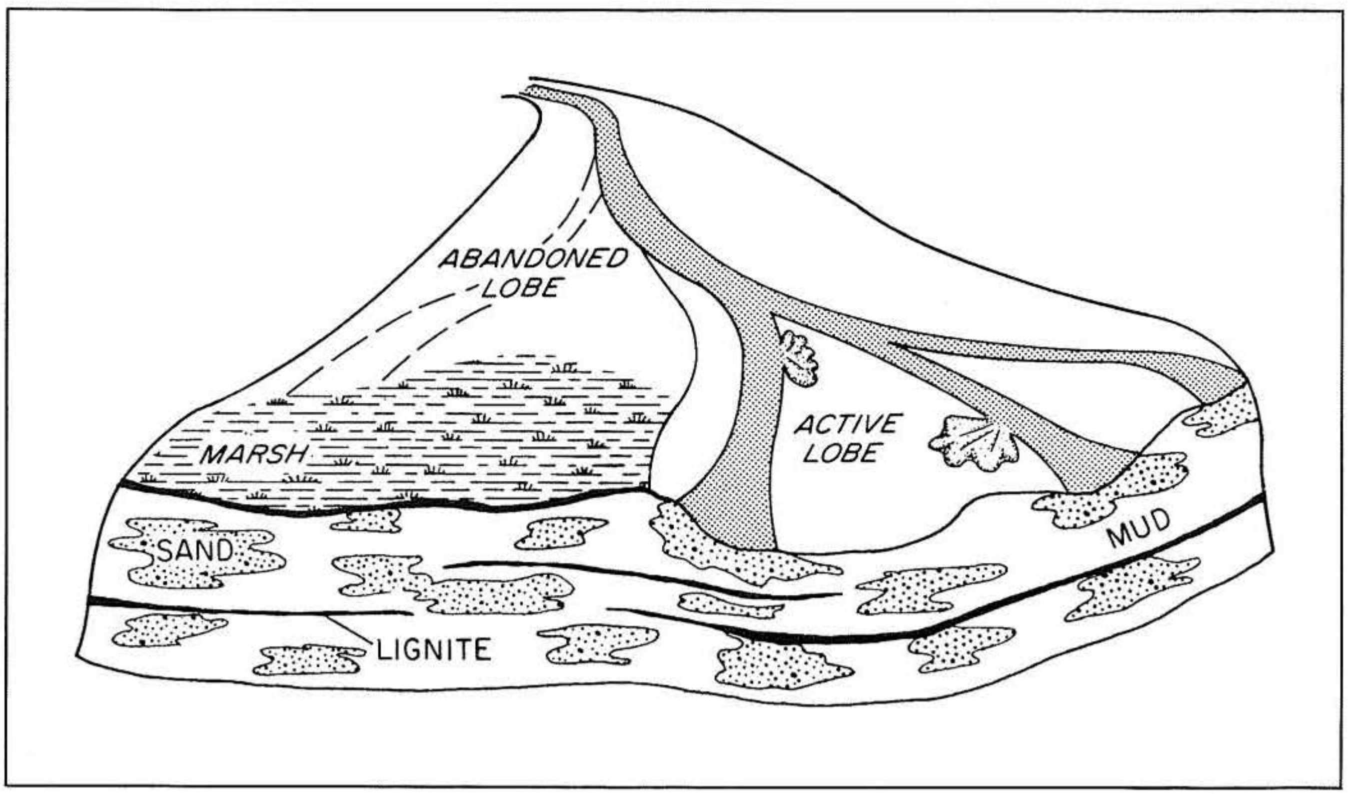

Figure 10. Schematic diagram showing a marsh, from which Jackson lignite formed, overlying an abandoned deltaic lobe.

(map sheet 1), has been mapped (Barnes, 1974b). Relatively abundant faults in southern Brazos County are associated with the Millican salt dome (map sheet 2). The most significant group of faults in the Yegua-Jackson trend cuts the Whitsett Formation several times along strike in the area north of Singleton in Grimes County (map sheets 2 and 3). To the east, up-to-the-coast faults are at Pineland and east of Hemphill in Sabine County (map sheet 5). Most of the faults in the map area have relatively small displacement (less than 122 m, 400 ft) and are difficult to detect on aerial photographs or topographic maps.

Salt domes intrude Yegua and Jackson sediments in five counties (Drake, 1960; Fisher and others, 1965; Sellards, 1936). Kittrell (Houston County), Day and Madisonville (Madison County), and Ferguson Crossing (Grimes County) salt domes have minor surface expression, but the formation of Clay Creek salt dome in Washington County has resulted in isolated exposures of both older Whitsett and younger Oakville sediments within the Catahoula outcrop belt. One small fault lies near the southern boundary of Clay Creek salt dome. Millican salt dome in Brazos County has uplifted the Catahoula and Whitsett Formations significantly; two gas fields are associated with this dome and adjacent faults. On the whole, however, structural deformation by faults and salt domes has been relatively minor in the map area.

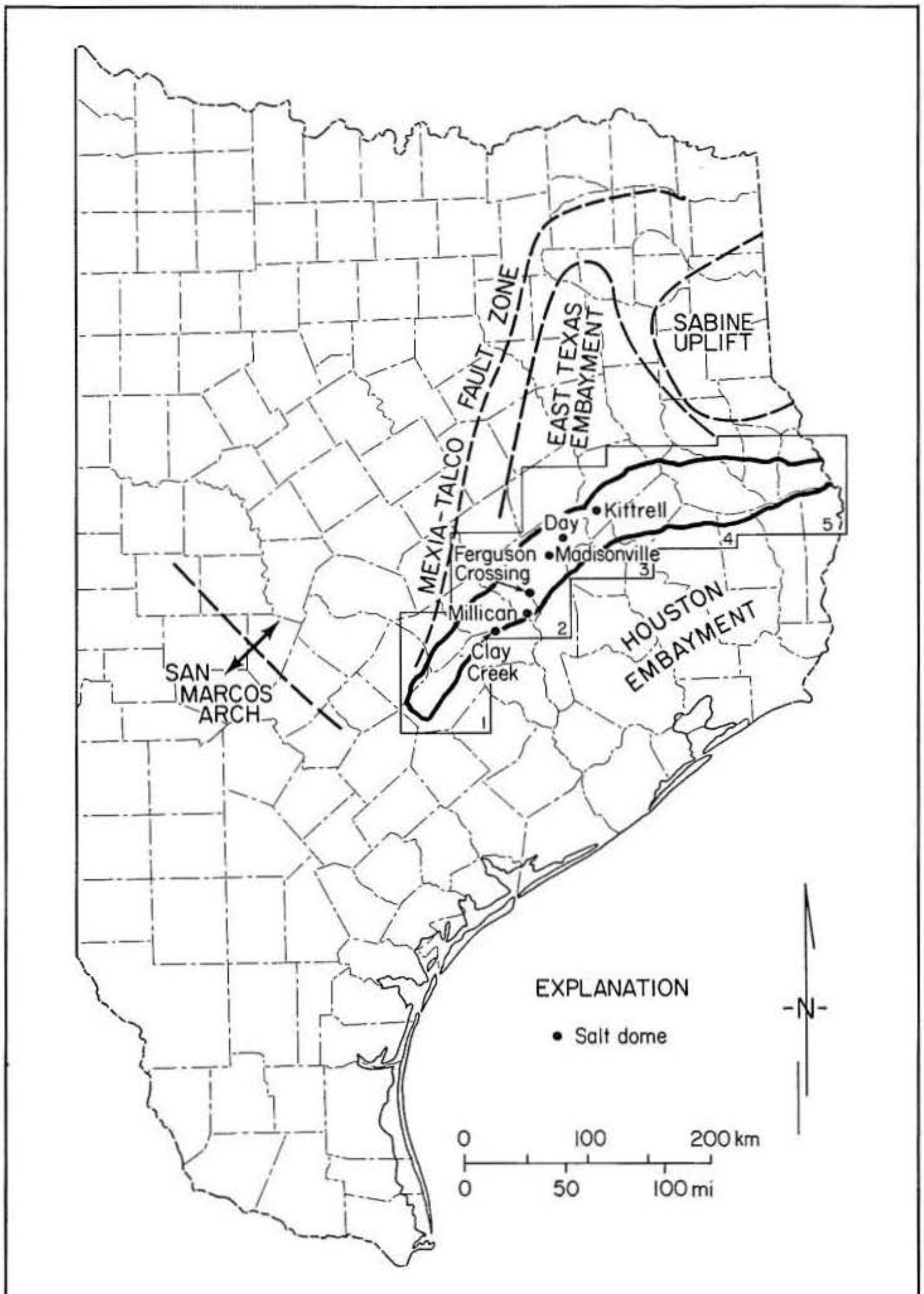

Figure 11. Regional structural features in East Texas. Bold outline and numbered rectangles indicate Yegua-Jackson map area.

MAPPING PROCEDURES

Mapping procedures for the Yegua-Jackson trend involved the use of aerial photographs, U. S. Geological Survey topographic maps, and extensive field verification. Map units used by Henry and Basciano (1979) in the Wilcox environmental map project were applied in the Yegua-Jackson where possible; new units were developed as required.

Preliminary mapping involved the examination of topographic maps (scales: 1:24,000 and 1:62,500) and of black-and-white aerial photographs at a scale of 1:20,000. Tone and patterns of tonal variation were the principal criteria used to map units on aerial photographs. In the Yegua-Jackson trend, dark soil tone indicates high moisture or high organic matter content. Bright white soil tone indicates high volcanic ash content or sandy soil; however, the difference between white mud and white sand substrates cannot be distinguished on the photographs, especially in the southwest part of the map area. Sand units were not mapped unless they were verified in the field, except in southern Walker County where many sand hills were inaccessible by public road. In this region a detailed soils map (McClintock and others, 1979) was available and was used in identification of sand hills.

Tonal differences exist between different types of vegetation; however, most of the aerial photographs were taken during the summer, so it was difficult to differentiate pine and oak communities. Forest types were spot-checked in the field, and false-color imagery at a scale of 1:300,000 was used to delineate hardwoods, pines, and floodplain vegetation. On the environmental geologic maps, to indicate the type of natural vegetation that an area can support, forest was mapped even in locations that have been clearcut or thinned for pasture.

Tonal patterns were helpful in distinguishing (1) sand and mud units where differential drainage creates mottled areas, (2) clay units where gilgai (microrelief structures) can be identified as near-parallel streaks (Gustavson, 1975), and (3) floodplain and terrace units where dark-gray tones indicate clayier soils and soil saturation in more frequently flooded areas. Aerial photographs were also used to update gravel pit locations, to locate gullied lands, and to determine land use.

Slope as a characteristic of the environmental geologic units was determined directly from topographic maps. Slope is divided into three classes: (1) 0 to 3 percent (30 m/km, 158 ft/mi) for prairies, (2) 3 to 10 percent (100 m/km, 528 ft/mi) for uplands, and (3) 10 to 25 percent (250 m/km, 1,322 ft/mi) for gullied areas. Error may have been introduced by determining slope from topographic maps instead of from field measurements, especially in East Texas where some topographic contours may have been determined from tree-top elevations.

The 3-percent lower slope limit is employed in this study to provide consistency with the environmental Wilcox maps of Henry and Basciano (1979) and was originally derived from tonal breaks observed on aerial photographs (T. C. Gustavson, personal communication, 1981). The 10-percent upper slope limit coincides with the upper limit of the slope of prime farmland as determined by the USDA Soil Conservation Service (Railroad Commission of Texas, 1981a). Only a few gullied lands slope more than 25 percent (map sheet 5). Slope of the floodplain does not exceed 2 percent, and the slope of undifferentiated alluvium and colluvium is not greater than 5 percent.

Floodplain boundaries were mapped using geomorphic criteria instead of empirical or measured boundaries. This method of mapping ensures that soil type is relatively uniform within a unit, since both the soil and the environmental geologic unit change at the break in slope. Floodplain and terrace boundaries on the environmental geologic maps are not intended for engineering use, but floodplain boundaries are within 1.5 m (5 ft) of recorded levels for 100-year floods on the Colorado, Brazos, Trinity, and Neches Rivers. The margin of error is 1.5 m (5 ft) on most of the topographic maps used in this study. Geomorphic floodplains thus include land that was flooded in the past and is likely to flood in the future. The writers ignored the effects of levees, dams, and other flood control devices in geomorphic floodplain mapping. Maps of floodprone areas, which are delineated from mathematical equations and flood records, are available from the U. S. Department of Housing and Urban Development for most of the counties in the Yegua-Jackson trend.

In the table of unit descriptions (table 1), "recharge" is grouped under geologic ("common") processes for simplification, although it is a hydrologic process. Recharge occurs intermittently and often simultaneously with discharge and is not uniform within any one environmental unit. The term "recharge" is used in this report to indicate high recharge potential in the environmental units. Thus, recharge is listed as a process occurring on high-sand units, such as floodplain, sand and sandy mud terraces, sand and mud, sand, and blacksoil units. The term "minor recharge" is used for the clay terrace, ironstone, and mud with sand-prairie units. These substrates have a lower recharge potential because of their higher mud content. Recharge is not listed for the remaining units because they are sufficiently impervious to inhibit infiltration and ground-water movement, and consequently other processes are more important. Recharge and minor recharge, used in table 1 and in the map explanations (map sheets 1-5), are meant in a regional sense and should not be used to determine whether a mine should be given a permit. Discharge and recharge occur to some extent in all the environmental geologic units.

Mapping on aerial photographs was followed by field verification. Map contacts were then transferred to U. S. Geological Survey 7½- and 15-minute topographic quadrangles. These environmental geologic maps are on open file at the Bureau of Economic Geology.

The information recorded on the maps was transcribed, and five color maps were completed at a

Table 1. Characteristics of the environmental

	Composition of Substrate	Soil Characteristics	Common Soil Series	Topography (Slope)	Common Processes
P1 FLOODPLAIN	clay mud with sand and minor gravel	clay and clay loam	Miller, Norwood, Kaufman	<2%	high- to moderate-frequency flooding, recharge,* ponding
P2 UNDIFFERENTIATED ALLUVIUM AND COLLUVIUM	clay mud and sand with minor gravel	fine sandy loam and clay loam	Tuscumbia, Gowen, Mantachie	<5%	low- to high-frequency flooding
A1 CLAY MUD TERRACE	clay mud with sand and minor gravel	fine sandy loam	Axtell, Burleson, Bernaldo	<2%	minor recharge, ponding, rare flooding, sheet-wash
A2 SAND TERRACE	sand with minor clay and gravel	fine sandy loam	Axtell, Burleson, Bernaldo	<2%	rare flooding, recharge
A3 SANDY MUD TERRACE	clay mud and sand with minor gravel	fine sandy loam	Axtell, Burleson, Bernaldo	<2%	rare flooding, recharge
A4 TERRACE MARGIN	same as that of adjoining terrace	fine sandy loam or very gravelly sand	Lufkin, Tabor	3 to 10%	gullying, low-frequency flooding where adjacent to floodplain, recharge
LOW TERRACE OVERLAY	----	----	----	----	low-frequency flooding
G1 DENSELY DISSECTED TERRAIN	variable, usually sandy	soil absent	----	10 to 25%	erosion, gullying
G2 DISSECTED SAND AND MUD	interbedded sand, mud, and sandy mud	fine sandy loam and clay loam	Rayburn, Woodtell	10 to 25%	recharge, erosion, gullying
G3 ALLUVIAL FAN	gravel, sand, and clay mud	fine sandy loam	Gowen, Tuscumbia, Mantachie	<2%	low-frequency flooding, recharge
J1 LOW-RELIEF SAND AND MUD-OAK FOREST	interbedded sand, mud, and sandy mud	fine sandy loam	Lufkin, Axtell, Tabor, Wilson, Crockett	<3%	gullying, recharge
J2 MODERATE-RELIEF SAND AND MUD-OAK FOREST	interbedded sand, mud, and sandy mud	fine sandy loam	Lufkin, Axtell, Tabor, Wilson, Crockett	3 to 10%	gullying, recharge
J3 LOW-RELIEF SAND AND MUD-PINE FOREST	interbedded sand, mud, and sandy mud	fine sandy loam	Rayburn, Leefield, Corrigan	<3%	recharge
J4 MODERATE-RELIEF SAND AND MUD-PINE FOREST	interbedded sand, mud, and sandy mud	fine sandy loam	Rayburn, Leefield, Corrigan	3 to 10%	recharge
J5 LOW-RELIEF MUD WITH SAND-PRAIRIE	mud with locally interbedded sand	fine sandy loam and clay loam	Wilson, Crockett	<3%	minor recharge
J6 MODERATE-RELIEF MUD WITH SAND-PRAIRIE	mud with locally interbedded sand	fine sandy loam and clay loam	Wilson, Crockett	3 to 10%	minor recharge

geologic units, Yegua-Jackson trend, southeast Texas.

Vegetation	Current Land Use	Geologic Formation/ Sedimentary Origin of Substrate	Resources and Economic Potential (Material Resources)	Distribution	
				Map Sheets	Counties
water-tolerant hardwoods or pine-hardwood	aquifer, cropland, pastureland	alluvium/fluvial	local sand, gravel, and clay (below floodplain level)	1, 2, 3, 4, 5	all counties
water-tolerant hardwoods or pine-hardwood	greenbelts, pastureland	alluvium/fluvial	-----	1, 2, 3, 4, 5	all counties
oak-hardwood or pine-hardwood	minor aquifer, cropland, pastureland	fluviatile terrace deposits/fluvial	clay	2, 5	Brazos, Burleson, Sabine, San Augustine
oak-hardwood or pine-hardwood	gravel pits, minor aquifer, pastureland	fluviatile terrace deposits/fluvial	sand and gravel	1, 2, 3, 4	Angelina, Bastrop, Brazos, Burleson, Fayette, Grimes, Lee, Madison, Trinity, Walker
oak-hardwood or pine-hardwood	gravel pits, minor aquifer, pastureland	fluviatile terrace deposits/fluvial	nonceramic clay, sand and gravel	1, 2, 3, 4, 5	all counties except Leon and Tyler
oak-hardwood or pine-hardwood	gravel pits, minor aquifer, rangeland, pastureland eastward	fluviatile terrace deposits/fluvial	same as that of adjoining terrace	1, 2, 3, 4	Angelina, and all counties on sheets 1, 2, and 3
-----	-----	-----	-----	1, 2, 3, 4	Angelina, Brazos, Fayette, Grimes, Houston, Madison, Polk, Trinity, Walker
sparse oak	rangeland	Yegua, Jackson/ fluvial, deltaic	-----	1, 2, 3	Bastrop, Brazos, Burleson, Fayette, Grimes, Lee, Leon, Madison
pine	commercial timberland, pastureland	Cook Mountain, Yegua, Jackson, Catahoula/fluvial, deltaic, marine	-----	1, 2, 3, 4, 5	Fayette, and all counties on sheets 3, 4, and 5
oak or pine	aquifer, rangeland, commercial timberland in East Texas	alluvium/fluvial	sand and gravel, timber in East Texas	1, 2, 3, 4, 5	Angelina, Brazos, Fayette, Houston, Jasper, Newton, Polk, Trinity, Walker
oak	minor aquifer, pastureland	Cook Mountain, Yegua, Jackson/ fluvial, deltaic, marine	lignite	1, 2, 3	Leon, Walker, and all counties on sheets 1 and 2
oak	minor aquifer, pastureland	Cook Mountain, Yegua, Jackson/ fluvial, deltaic, marine	lignite	1, 2, 3	Leon, Walker, and all counties on sheets 1 and 2
pine	pastureland, minor aquifer, commercial timberland	Cook Mountain, Yegua, Jackson/ fluvial, deltaic, marine	timber, lignite, industrial clay, swelling bentonite	1, 3, 4, 5	Fayette, Grimes, Walker, and all counties on sheets 4 and 5
pine	pastureland, minor aquifer, commercial timberland	Cook Mountain, Yegua, Jackson/ fluvial, deltaic, marine	timber, lignite, industrial clay, swelling bentonite	1, 2, 3, 4, 5	Fayette, Grimes, Lee, Walker, and all counties on sheets 4 and 5
prairie grasses	cropland, pastureland, rangeland	Cook Mountain/ marine	-----	1, 2, 3	Brazos, Burleson, Lee, Leon, Madison
prairie grasses	cropland, pastureland, rangeland	Cook Mountain/ marine	-----	1, 2, 3	Brazos, Burleson, Lee, Madison

(Continued on page 18.)

Table 1. Characteristics of the environmental geologic

	Composition of Substrate	Soil Characteristics	Common Soil Series	Topography (Slope)	Common Processes
J7 LOW-RELIEF MUD WITH SAND-PINE FOREST	mud with locally interbedded fine sand	fine sandy loam and clay loam	Sacul, Woodtell	<3%	runoff
J8 MODERATE-RELIEF MUD WITH SAND-PINE FOREST	mud with locally interbedded fine sand	fine sandy loam and clay loam	Sacul, Woodtell	3 to 10%	gullying, runoff
K1 CLAY MUD	clayey mud	loamy and clay loam	Wilson	<5%	sheetwash, shrink-swell
H1 SAND HILLS	friable to loose sand, finer and locally more compact eastward	fine sandy loam	Falba, Fuquay	3 to 10%	gullying, recharge
H2 LOW ROLLING SANDS	friable to loose sand and silty sand, locally more compact eastward	fine sandy loam	Falba, Fuquay	<3%	gullying, recharge
H3 FINE SAND	friable to loose fine sand and silty sand	fine sandy loam	Falba, Fuquay	<10%	gullying, recharge
H4 INDURATED SANDSTONE	silica-cemented sandstone	thin sand	Kittrell	<3%	sheetwash
B1 LOW-RELIEF BLACKSOIL	tuffaceous quartz sand, mud, and sandy mud, locally silica-cemented	fine sandy loam, loam, and clay	Heiden, Houston Black	<3%	gullying, recharge
B2 MODERATE-RELIEF BLACKSOIL	tuffaceous quartz sand, mud, and sandy mud, locally silica-cemented	fine sandy loam, loam, and clay	Heiden, Houston Black	3 to 10%	gullying, recharge
L1 HIGH-RELIEF IRON-CEMENTED UPLANDS	interbedded, iron-cemented sand with mud	fine sandy loam	Crockett, Wilson	10 to 25%, forms prominent hills	minor recharge
L2 ROLLING IRON-STONE AND SAND	interbedded, iron-cemented sand with mud	fine sandy loam	Crockett, Wilson	<10%	minor recharge
L3 GRAVEL CAP	siliceous gravel with minor sand and mud	very gravelly sand	Tabor	<5%	recharge
L4 ASH	consolidated, vitric ash	fine sandy loam	Corrigan, Rayburn	<5%	sheetwash
M1 LIGNITE SURFACE MINE	variable	soil dependent on extent of reclamation	----	slope dependent on extent of reclamation	processes dependent on extent of reclamation
M2 SURFACE-MINED LAND	variable	soil absent	-----	variable	erosion
M3 CONTROLLED INUNDATION	variable	variable	variable	<3%	variable

units, Yegua-Jackson trend, southeast Texas (continued).

Vegetation	Current Land Use	Geologic Formation/ Sedimentary Origin of Substrate	Resources and Economic Potential (Material Resources)	Distribution	
				Map Sheets	Counties
pine	commercial timber-land, pastureland, recreation	Yegua, Moodys Branch, Yazoo, Nash Creek/marine	timber, local lignite	5	Jasper, Newton, Sabine, San Augus-tine
pine	commercial timber-land, pastureland, recreation	Yegua, Moodys Branch, Yazoo, Nash Creek/marine	timber, local lignite	5	Jasper, Newton, Sabine, San Augus-tine
scattered oaks, prairie grasses, mesquite	cropland, pasture-land, rangeland	Yegua, Cook Moun-tain/marine	clay	1	Bastrop, Fayette, Lee
oak or pine	aquifer, pasture-land, rangeland	predominantly Whit-sett, Catahoula in East Texas/fluvial, deltaic	industrial sand in East Texas	2, 3, 4, 5	Angelina, Grimes, Houston, Jasper, Nacogdoches, Sabine, Trinity, Tyler, Walker
oak or pine	aquifer, pasture-land, rangeland	Yegua, Jackson, Catahoula in East Texas/fluvial, deltaic	industrial sand in East Texas	1, 2, 3, 4, 5	all counties except Nacogdoches and Newton
oak or pine	aquifer, pasture-land, commercial timberland in East Texas	predominantly Whit-sett/fluvial	sand	2, 3, 4, 5	Angelina, Burleson, Jasper, Polk, San Augustine, Trinity, Tyler
sparse, oak or pine	rangeland, pastureland in East Texas	predominantly Well-born/deltaic	building stone, road material	1, 2, 3, 4	Angelina, Fayette, Grimes, Houston, Lee, Polk, Trinity, Walker
oak-hardwood	pastureland, prime farmland, quarries	Catahoula/fluvial	prime farmland, in-dustrial sand in East Texas	1, 2, 3	Brazos, Fayette, Grimes, Walker, Washington
oak-hardwood	pastureland, prime farmland, quarries	Catahoula/fluvial	prime farmland, in-dustrial sand in East Texas	1, 2, 3	Brazos, Fayette, Grimes, Walker, Washington
oak-juniper or pine	quarries, range-land	Yegua, Cook Mountain/fluvial	road material, sand and gravel	1, 2, 5	Burleson, Lee, San Augustine
oak or pine	quarries, range-land	Yegua, Cook Mountain/fluvial	road material, sand and gravel	1, 2, 3	Brazos, Burleson, Lee, Leon, Madison
oak-hardwood	pastureland, rangeland	alluvium, Willis in southwest/fluvial	gravel and sand	1, 2	Brazos, Burleson, Fayette, Lee, Madison, Washington
pine	commercial timberland	Manning/deltaic	ash	4	Polk
vegetation de-pendent on extent of reclamation	land use dependent on extent of rec-lamation	Manning/deltaic	lignite	2	Grimes
sparse, oak or pine	minimal	Yegua, Wellborn, Manning, Whitsett, Catahoula/fluvial, deltaic	building stone, gravel, sand, and clay	1, 2, 3, 4, 5	Angelina, Jasper, Polk, Sabine, and all counties on sheets 1, 2, and 3
variable	variable	alluvium/fluvial	gravel, sand, clay, and lignite	1, 2, 3, 4, 5	all counties except Bastrop, Brazos, Grimes, Newton, Polk, and Tyler

*Recharge occurs intermittently and often simultaneously with discharge, and is not uniform within any one environmental unit. The terms "recharge" and "minor recharge," used in this table and in the environmental geologic map explanations (sheets 1-5), are meant in a regional sense and should not be used to determine whether a mine should be given a permit.

scale of 1:125,000 (map sheets 1-5). Federal, State, and farm to market roads, railroads, pipelines, transmission lines, streams, major bodies of water, cities, towns, counties, and Federal and State lands are included on the maps, as well as topographic contours at 6.1-m (20-ft) intervals. Current information not shown on U.S. Geological Survey maps was compiled from county road maps from the Texas Department of Highways and Public Transportation.

ENVIRONMENTAL GEOLOGIC UNITS

Definition

An environmental geologic unit is a mappable surface entity defined according to its natural resources. The unit is modeled after the "resource capability unit," described by Brown and others (1971) as "an environmental entity—land, water, area of active process, or biota—defined in terms of the nature, degree of activity, or use it can sustain without losing an acceptable level of environmental quality." In this report, little emphasis is placed on delineating acceptable levels for environmental quality because these levels are outlined in *Coal Mining Regulations,* published by the Railroad Commission of Texas in accordance with State and Federal law (Railroad Commission of Texas, 1981a). Instead, the maps describe environmental geologic units in terms of natural resources and processes, and delineate units that have applicability in mining and reclamation.

Environmental geologic units are defined using six major criteria:

(1) substrate—material beneath the soil zone; for example, Eocene sand and mud and Quaternary alluvium

(2) soil—surface material; A and B horizons

(3) geomorphology—land form and relief; for example, individual hills, low cuestas, prairies, and floodplains

(4) geologic processes—physical processes that occur at the earth's surface, such as flooding and gullying

(5) vegetation—such as forest, prairie, or floodplain growth

(6) land use—the effect that humans have on the land.

In addition, the environmental geologic units are grouped into geomorphic, substrate, and man-made categories (table 2). These three groups and the preceding six criteria were used in the environmental Wilcox study (Henry and Basciano, 1979) and are based on work done by Henry and Kastning (1975) and on the South Texas river basin study (Gustavson and others, in preparation). Alphanumeric unit designations used in the Wilcox study are used where possible in this report. The 32 environmental geologic units established for the Yegua-Jackson trend are defined as follows.

Geomorphic Units

Geomorphic units include bottomland, river terrace, and miscellaneous geomorphic units. These units are grouped together because they have similar landforms or geologic processes.

Bottomland Units

Floodplain (P1) and undifferentiated (mixed) alluvium and colluvium (P2) compose the bottomland

Table 2. Environmental geologic units and alphanumeric symbols used in the Yegua-Jackson trend, southeast Texas.

GEOMORPHIC UNITS
- Bottomland units
  - *P1 Floodplain*
  - *P2 Undifferentiated alluvium and colluvium*
- River terrace units
  - *A1 Clay mud terrace*
  - *A2 Sand terrace*
  - *A3 Sandy mud terrace*
  - *A4 Terrace margin*
  - *Low terrace overlay*
- Miscellaneous geomorphic units
  - *G1 Densely dissected terrain*
  - *G2 Dissected sand and mud*
  - *G3 Alluvial fan*

SUBSTRATE UNITS
- Sand and mud units
  - *J1 Low-relief sand and mud-oak forest*
  - *J2 Moderate-relief sand and mud-oak forest*
  - *J3 Low-relief sand and mud-pine forest*
  - *J4 Moderate-relief sand and mud-pine forest*
  - *J5 Low-relief mud with sand-prairie*
  - *J6 Moderate-relief mud with sand-prairie*
  - *J7 Low-relief mud with sand-pine forest*
  - *J8 Moderate-relief mud with sand-pine forest*
- Mud unit
  - *K1 Clay mud*
- Sand units
  - *H1 Sand hills*
  - *H2 Low rolling sands*
  - *H3 Fine sand*
  - *H4 Indurated sandstone*
- Blacksoil units
  - *B1 Low-relief blacksoil*
  - *B2 Moderate-relief blacksoil*
- Miscellaneous substrate units
  - *L1 High-relief iron-cemented uplands*
  - *L2 Rolling ironstone and sand*
  - *L3 Gravel cap*
  - *L4 Ash*

MAN-MADE UNITS
- *M1 Lignite surface mine*
- *M2 Surface-mined land*
- *M3 Controlled inundation*

units. Floodplains are located on the Colorado, Brazos, Navasota, Trinity, and Neches Rivers and on Yegua, Bedias, Rock, and Piney Creeks. Floodplains of the Angelina and Sabine Rivers are inundated by reservoirs. Included in the floodplain unit are marshes, ponds, abandoned channels, chutes, point bars, levees, and other associated features. Floodplain soils are clays and clay loams; slopes are less than 2 percent. Flood frequency ranges from annual flooding to low-frequency floods of 100-year magnitude or more. Both recharge and discharge occur in large amounts in this unit. Water-tolerant hardwoods are the dominant floodplain vegetation southwest of the Trinity River; mixed pines and hardwoods vegetate East Texas floodplains.

Flood frequency on undifferentiated alluvium and colluvium is low to moderate, but high enough to establish a small, flat or slightly concave valley. The upper limit of this unit has been placed at the point where the flat stream valley can no longer be recognized on topographic maps. At this position, alluvium becomes a minor component compared with colluvium. The accuracy and method of mapping this unit depend to some degree on the contour interval and on the precision of the topographic map used, but an effort was made to be consistent.

Soils on the P2 unit are intermediate between bottomland clays and upland fine sandy loams. Vegetation represents a transition from hardwoods to upland oaks or pines. Southwest of the Navasota River, undifferentiated alluvium and colluvium is left largely uncleared and used as greenbelts for livestock. Slopes are from 0 to 5 percent.

River Terrace Units

The four river terrace units are clay mud terrace (A1), sand terrace (A2), sandy mud terrace (A3), and terrace margin (A4). These units represent former floodplain surfaces. Terrace content was determined by surface examination and by observation of man-made or natural substrate exposures where possible. All the terraces are composed of a mixture of sand and mud, but those with higher sand content are designated sand *with* mud instead of sand *and* mud, which is used for terraces with a higher mud content. Contiguous terraces at different levels are of different ages, but no specific ages have been designated. Age of the terraces ranges from mid-Pleistocene through Holocene along the Trinity River; terraces are late Pleistocene to Holocene along all other rivers. Clay mud terraces are rare. Sand terraces occur primarily along the Colorado and Navasota Rivers, where they are common. Low terraces, those 3 m (10 ft) above the bankfull level of the river, are designated by a blue-colored line overlay. Terraces less than 1.5 m (5 ft) above bankfull stage are included in the floodplain unit.

Terrace soils are fine sandy loams with clay B horizons; slopes are less than 2 percent. Terrace vegetation is gradational between floodplain and upland and is progressively more mature and more abundant on older terraces. Flooding on terraces is rare except on low terraces, which undergo infrequent flooding.

Sheetwash, erosion, and rare gully erosion occur on terrace margins, which are the relatively steep edges of the terrace (A4). Terrace margins are on terrace-floodplain, terrace-terrace, or terrace-upland interfaces and are not floodprone in most locations.

Miscellaneous Geomorphic Units

Densely dissected terrain (G1) and dissected sands and muds (G2) are included in the geomorphic category because the geomorphic characteristics of these units are more important in proper land use than are their substrate compositions. They exhibit high relief, 10 to 25 percent slopes, and high erosion rates. G1 and G2 units are commonly adjacent to floodplains where the gradient changes abruptly.

G1 units develop on all substrates; G2 units form predominantly on interbedded sand and mud substrate. Densely dissected terrain (G1) has no soil, few oaks, and almost no profitable land use; it is found only southwest of the Trinity River, where rainfall is seasonal. In contrast, steep slopes exist east of the Trinity River but are vegetated and soil covered because of high precipitation rates. These areas, mapped as G2 units, support pine forests and are harvested for timber and pulp. The G2 unit does appear in two locations southwest of the Trinity River floodplain, however. One is on the north bank of the Colorado River, where pines grow on a dissected Pleistocene terrace. The pines have stabilized the soil, so the unit is mapped as G2 instead of G1. The second G2 unit is located on the dissected part of a cuesta supported by indurated sandstone southeast of Carlos in Grimes County. Sands are thicker and typically indurated in that area, forming resistant ledges below which soft sand and mud are easily eroded to produce steep slopes. The sandy soils support pines and improved pasture.

Alluvial fans (G3) are placed in the geomorphic category because their fan shape and distributary processes are distinctive. Although of small extent and not numerous, alluvial fans are distributed on all map sheet areas. The fans form at the junctions of gullies or streams and major floodplains; their gentle slopes are occasionally flooded. Southwest of the Navasota River, the fans are gravelly with thin soils and are vegetated with sparse oaks and grasses that provide range forage. On the fine-grained fans east of the Trinity River, pines are numerous. Fans on the Navasota River are sandy, and most support water-tolerant deciduous trees.

Substrate Units

Sand and mud, mud with sand, mud, sand, and blacksoil units are included in the substrate category. Miscellaneous substrate units are high-relief iron-cemented uplands, low rolling ironstone and sand, gravel cap, and ash.

Sand and Mud Units

Sand *and* mud units (J1, J2, J3, and J4) and mud *with* sand units (J5, J6, J7, and J8) constitute more than 50 percent of the land area on the environmental geologic maps. The units are divided according to sand content (sand and mud or mud with sand), relief (low or moderate), and vegetation type (oak forest, pine forest, or prairie).

Interbedded Yegua and Jackson sands and muds vary in thickness, and individual beds are difficult to distinguish in the field. Only distinctive sand hills and mud prairies are mapped separately. Boundaries between sand and mud units and mud with sand units were determined from known sand and mud content (Barnes, 1967, 1968, 1974a, b) as well as from field observations.

Yegua and Jackson sediments are mapped as sand and mud units (J1, J2, J3, and J4). In the marine Caddell Formation, sand content is somewhat less than that in the other Jackson formations. In the Cook Mountain Formation and east of the Angelina River in the Yegua, Moodys Branch, Yazoo, and Nash Creek Formations, sands are rare. These sediments are delineated as mud with sand units (J5, J6 [Cook Mountain only], J7, and J8). The Catahoula Formation in this area is also relatively low in sand content, and is designated as sand and mud instead of as sand hills.

Sand and mud and mud with sand units are divided into low- and moderate-relief areas. Low-relief units slope from 0 to 3 percent, characterizing gently rolling prairies. Moderate-relief units slope from 3 to 10 percent and form the upper ends of drainages and the few low hills and hillsides between the prairies. Although all geologic formations in the Yegua-Jackson trend exhibit both slope types, moderate-relief units (J2, J4, J6, and J8) are much smaller in area and fewer in number than low-relief units. Moderate relief is rarely found on outcrops of the Caddell and upper Yegua units, perhaps because these areas have low sand content. Both low and moderate slopes can support oaks, pines, or prairie vegetation.

The three vegetation divisions characterizing the sand and mud and mud with sand units are the three main forest types in the Yegua-Jackson trend. For example, the Cook Mountain Formation is mapped as low- or moderate-relief mud with sand-prairie (J5 and J6) where it lies within the Blackland Prairie zone southwest of the Trinity River. In Madison County the Yegua Formation is designated as low- or moderate-relief sand and mud-oak forest (J1 and J2), and in Houston County as low- or moderate-relief sand and mud-pine forest (J3 and J4).

Soils on units composed of sand and mud are fine sandy loams and loamy fine sands with clay B horizons. Mud with sand units have fine sandy loam and clay loam soils with clay B horizons. Soils in the east are deeper and more acidic than those to the southwest.

Aquifer recharge occurs on sand and mud units. Mud with sand units contain less sand, and thus infiltration and ground-water migration is slower in these units. Recharge into them is less than that on units composed of sand and mud.

Southwest of the Trinity River, sand and mud and mud with sand units are used for pasture and range; in the national forests of East Texas they are used primarily for timberland and recreation land.

Mud Unit

The single mud unit, clay mud (mud with more clay than silt) (K1), covers several small areas in the southwesternmost part of the study area, where the Yegua Formation becomes more marine in outcrop. Gilgai, microrelief structures that develop on clayey, high-shrink-swell soils, are easily detected on aerial photographs. Scattered oaks and mesquites grow on the fine sandy loam and clay loam soils. The single slope division, 0 to 5 percent, was used by Henry and Basciano (1979) for clay mud and is retained here because the Yegua clay mud has comparable slopes. Clay mud land is used for crops and pasture.

Sand Units

The four sand units mapped in the Yegua-Jackson trend are sand hills (H1), low rolling sands (H2), fine sand (H3), and indurated sandstone (H4). Sand hills (H1) are composed of medium-grained, siliceous, and unconsolidated sand, and are expressed as individual hills or, east of Grimes County, as groups of hills. In many locations these sands are channel deposits. Locally, thin sand beds are indurated, or the sand is iron-oxide stained. Sand hills form much of the outcrop of the Whitsett Formation in Grimes and Walker Counties and parts of the Catahoula and basal Yegua outcrop east of the Trinity River. Slopes are from 3 to 10 percent, and fine sandy loam soils support dominant pine vegetation, except on hills near Lake Somerville, where oaks predominate.

Low rolling sands (H2), or low-relief sand hills (slopes 0 to 3 percent), are more abundant than are sand hills units on the Yegua-Jackson outcrop. Most H2 units are mapped on the delta-front sands of the Wellborn Formation, but H2 occurs on all formations in the Yegua-Jackson trend. The thinner, surface sands in this unit are locally indurated.

The fine sand unit (H3), which has slopes of less than 10 percent, occurs primarily east of the Trinity River on the Whitsett outcrop. Here the sediments become finer in the transition from deltaic to marine facies. A fine sand unit is also located on the upper Yegua outcrop in Burleson County. Slopes on H3 units are greater than 3 percent at most locations; near the Trinity River and Lake Somerville, H3 slopes are less.

Soils on sand hills, rolling sand, and fine sand are thin fine sandy loams. B horizons, where developed, are composed of clay. Sandstone bedrock increases in iron content with the increase in marine influence toward the east. Oaks and junipers grow on Wellborn sand southwest of Bedias, and on rolling sand and fine sand units southwest of the Navasota River; pines grow to the east. These sand units have high potential for aquifer recharge. They are used for rangeland, as local aquifers, and for timber.

The thin indurated sandstone units (H4) are interbedded with sand units and with sand and mud units in East Texas, but they have been mapped separately where possible. Silica cementation is the source of induration in most of these Jackson sands. Indurated sand units, with two or three exceptions, occur southwest of the Colorado River in the Wellborn Formation near Muldoon, and in Grimes, Walker, and Trinity Counties. These sands can be 2 m (6 ft) thick in outcrop. Soils and vegetation on indurated sands are thin and sparse; therefore resistant cuestas and knolls formed by the hard sand are used mainly for rangeland.

Blacksoil Units

The low- and moderate-relief blacksoil units (B1 and B2) are mapped only on the Catahoula outcrop southwest of the Trinity River. The Houston Black-Heiden association and other deep, rich soils that develop on the Catahoula Formation are classified as prime farmland by the USDA Soil Conservation Service. Natural vegetation on blacksoil units consists of prairie grasses and scattered oaks, but most of the land has been cleared. The resultant vegetation break shows clearly on large-scale, false-color imagery. Moderate-relief areas of the blacksoil unit exist locally in sandier areas. Recharge into the Catahoula Formation is an important process because this formation is part of the Gulf Coast aquifer zone.

Miscellaneous Substrate Units

Miscellaneous substrate units include high-relief iron-cemented uplands (L1), rolling ironstone and sand (L2), gravel cap (L3), and ash (L4). Iron-cemented and ironstone units are on outcrops of basal fluvial sands of the Yegua Formation. These units contain iron-oxide-cemented sand, iron-stained sand, and interbedded mud. Most of the iron-rich regions are moderate in relief and outcrop southwest of the Trinity River, especially in Burleson County. In a few locations, relief is as high as 30 m (100 ft); these hills are mapped as L1.

High-relief iron-cemented uplands (L1) and rolling ironstone and sand (L2) have thin gravelly soils, which support junipers and oaks. The dark red-brown color of the iron-stained soils is striking on the ground, but cannot be dependably distinguished on black-and-white aerial photographs. Aquifer recharge is minor because of cementation; however, it may be locally high if fractures are present. L1 and L2 areas are used for rangeland and quarried for road material.

Gravel cap units (L3) vary in thickness, and commonly the margins of these remnant fluvial terraces and alluvial fans are difficult to see in the field. They are Pleistocene or late Pliocene in age, and composition is mainly siliceous sand and gravel that may have originated from the Balcones Escarpment region to the northwest. Fine white sandy loams, covering much of the Yegua Formation southwest of the Trinity River, are not present on the gravel cap unit, where the soils are darker gravelly sands. The medium-gray tone of the terraces can therefore be used to recognize this unit on aerial photographs. This method of mapping was used extensively in Brazos County.

Vegetation on the L3 unit is Post Oak Savanna. Fewer plants grow on the gravel cap than on surrounding units because the terrace substrate is well drained at the surface. The terraces are shallow aquifers and are used for rangeland and for sand and gravel production.

The pyroclastic material that composes the ash unit (L4) may be airfall or water transported. Both types of volcanically derived material are grouped together as L4 in this study. Ash units were mapped only in the Manning Formation in Polk County, although other ash deposits exist in the map area. For example, ash deposits occur on the Trinity River floodplain but are included in the floodplain unit because physical (fluvial) process is the more important characteristic of that region. Ash is common near Groveton in Trinity County, and a tuff (consolidated ash) quarry is nearby, but the deposits are too small to be mapped. Ash beds up to 6 m (20 ft) thick have been reported in the Manning Formation in Grimes County (Baker, 1931), but they were not located by these writers. Fisher (1965) and King and Rodda (1962) describe Jackson pyroclastic sediment in more detail. Soils, processes, vegetation, and land use on ash deposits are not significantly different from those on sand and mud substrate units, which locally have high ash content.

Man-Made Units

Human influence is of primary importance in the definition of the three man-made units in the Yegua-Jackson trend: lignite surface mine (M1), surface-mined land (M2), and controlled inundation (M3). The Gibbons Creek lignite mine, developed by the Texas Municipal Power Agency, is the only lignite surface mine (M1) active within the map area. Soils, processes, vegetation, and land use after mining are dependent on reclamation methods. Mining companies will often be required to approximate original land conditions.

Surface-mined land (M2) is land excavated mostly for road material, although ironstone, building stone, sand and gravel, clay, and ash pits are also shown on the maps. Many borrow pits exist along highways but are too small to show at the scale of the environmental geologic maps. None of the abandoned pits and quarries observed by the authors have been reclaimed; most have no soil, vegetation, or economic use, and some are extensively gullied.

Controlled inundation land (M3) is adjacent to Lake Somerville, Lake Livingston, and Sam Rayburn and Toledo Bend Reservoirs. Most of the M3 units would have been designated as floodplain if humans had not intervened. The M3 unit is subject to flooding when reservoir levels are raised. Trees are absent at most locations; grasses and shrubs may be sparse if the area has been flooded recently. Soils are the same as on the adjacent floodplain. The land is used for recreation.

Modifications of Environmental Geologic Units

All the environmental geologic units used by Henry and Basciano (1979) on the maps of the Wilcox Group lignite belt are used in this report, and six new units were added: G3, J7, J8, H4, B1, and B2. Because of slight substrate and climate differences between the Wilcox and Yegua-Jackson outcrop belts, minor changes were made in Wilcox unit descriptions when they were applied to the Yegua-Jackson maps. In a few instances, changes were made solely for clarification, such as changes from sandy mud units to sand and mud or mud with sand units. Floodprone land adjacent to reservoirs was delineated by a stippled overlay in the Wilcox; it is unit M3 on Yegua-Jackson maps. G2 was used to designate natural ponds in the Wilcox study, but it is used for dissected sand and mud in this report.

Additional Information Presented on Environmental Geologic Maps

Mines

Abandoned lignite mines, a lignite-fueled power plant, and areas overlying lignite resources are also designated on the environmental geologic maps. Most abandoned lignite mines were operated during the first decades of this century, when production reached as much as 1.1 million t (1.2 million tons) a year. Lignite production declined after 1939 because of competition from more economic petroleum resources.

In the Yegua Formation, only one group of abandoned lignite mines is recorded in the literature (table 3). This group, called the Lovelady mining district, located at Wooters Station, about 2.8 km (1.75

Table 3. Abandoned, active, and proposed lignite mines and lignite-fired power plants in the Yegua-Jackson trend, southeast Texas (from Broman, 1914; Bullock, 1928; Gentry, 1921; Phillips and Worrell, 1913; Taylor, 1911).

MINE TYPE	MINE NAME	LOCATION	DATES OF OPERATION
ABANDONED LIGNITE SHAFT MINES			
Yegua Formation	Houston County Coal and Manufacturing Co. (Lovelady Mining District)	Wooters Station, Houston County (map sheet 3)	1900-1906, 1909-1910, 1912-1914, 1916, 1920-1921, 1925-1926, 1928, 1930-1933
Jackson Group	Lower Strata Lignite Mining Co. formerly Black Diamond Mines formerly Big Four Mines	Ledbetter, Fayette County (map sheet 1)	1905-1911, 1913-1914, 1918
	Ledbetter Coal Co.	Ledbetter, Fayette County (map sheet 1)	?
	Melcher Coal and Clay Co.	O'Quinn, Fayette County	1911, 1914, 1928
	Grimes County Coal Co.	south of Bedias, Grimes County (map sheet 2)	1919-1921
	----	near Clay, Burleson County (map sheet 2)	?
ACTIVE LIGNITE MINE AND POWER PLANT			
Jackson Group	Gibbons Creek owned by Texas Municipal Power Agency	Carlos, Grimes County (map sheet 2)	1982-2005 (est.)
PROPOSED POWER PLANT			
Yegua Formation	Lovelady may be proposed by Gulf States Utilities	Lovelady, Houston County	-----
PROPOSED LIGNITE MINE			
Jackson Group	Jordan Creek - Cummins Creek may be proposed by Lower Colorado River Authority	south of Ledbetter, Fayette County (fig. 11)	-----

mi) north of Lovelady in Houston County, was mined intermittently from 1900 to 1933 (map sheet 3). There may have been as many as nine separate mines, each with one or two shafts. Mining was by the Houston County Coal and Manufacturing Company of Crockett, Texas (Broman, 1914; Bullock, 1928; Gentry, 1921; Phillips and Worrell, 1913; Stenzel and Twining; Taylor, 1911). Locating abandoned mines is important for prevention of ground-water contamination.

In the outcrop of the Jackson Group, underground mines existed near Clay in Burleson County (Kaiser and others, 1978), south of Bedias in Grimes County, and near Ledbetter in Fayette County. A steam plant that burned lignite operated for some time in nearby Giddings, Lee County (Phillips and Worrell, 1913). Lignite mining also took place in Fayette County near O'Quinn, 11.3 km (7 mi) south of Highway 71 near La Grange, but no shafts or structures were found (Bullock, 1928).

The only active lignite mine in the map area is the Gibbons Creek surface mine, permitted by the Railroad Commission of Texas in 1980. The first 5-year pit area (M1), located on map sheet 2, is subject to change as mining proceeds. Future pits will be located northeast along strike, toward Singleton. The power plant adjacent to the Gibbons Creek mine has been constructed and should be operational in 1983.

A lignite mine near Ledbetter (map sheet 1) may be proposed by the Lower Colorado River Authority, and a 600 MW lignite-fired power plant may be proposed near Lovelady for completion in 1994 or 1995 by Gulf States Utilities of Beaumont. The tentative tract location for the Jordan Creek - Cummins Creek mine near Ledbetter runs from Highway 290 south to Highway 77 (fig. 12). The exact location of the Lovelady plant and mine has not been determined.

At this time no lignite gasification plants are planned for the Yegua-Jackson trend.

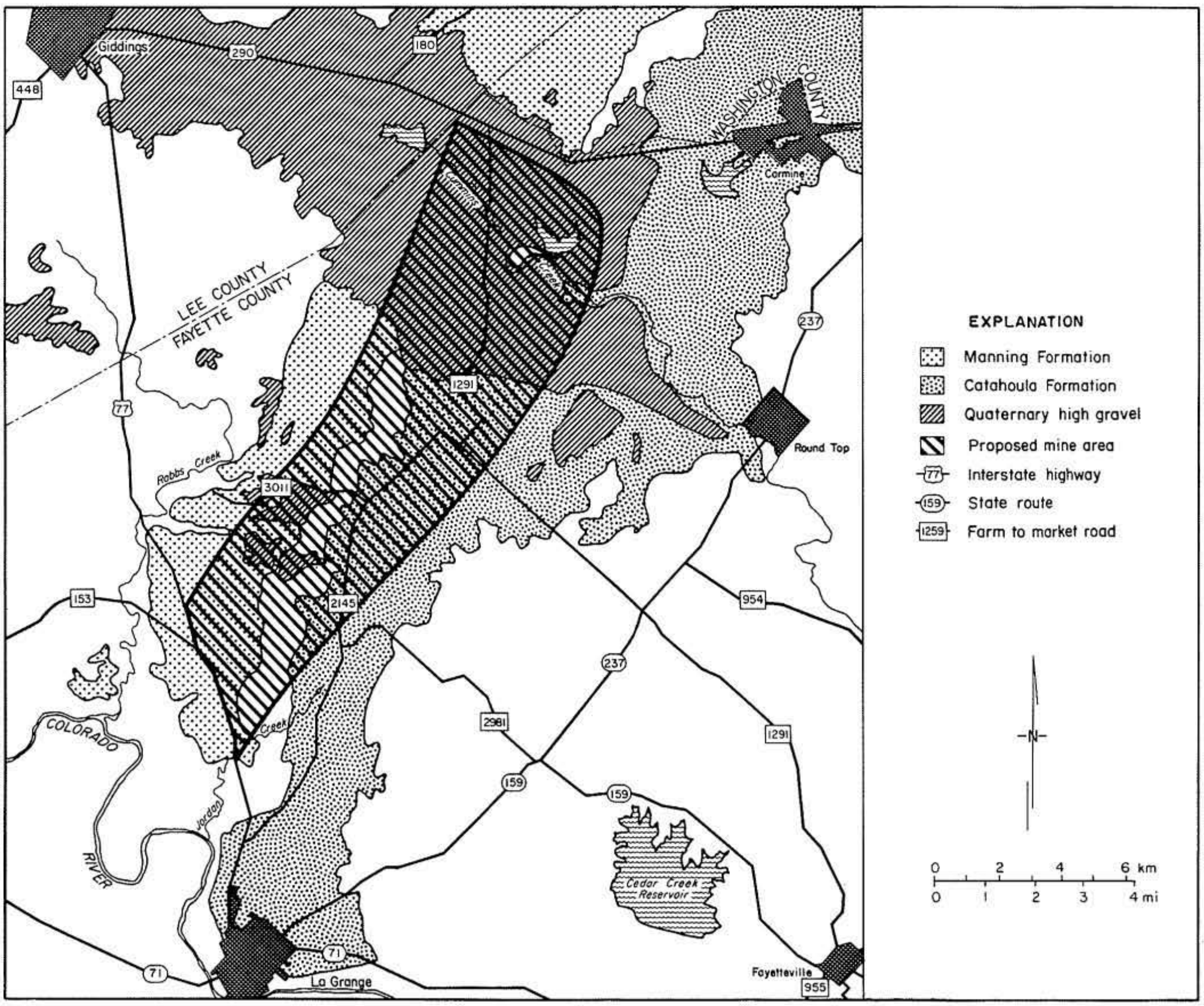

Figure 12. Jordan Creek - Cummins Creek lignite surface mine area, proposed by the Lower Colorado River Authority (LCRA) (from LCRA drilling permit, available at the Railroad Commission of Texas).

Lignite Resource Blocks

Measured, indicated, and inferred lignite resources are designated on the environmental geologic maps with a black-line overlay. This information was taken directly from Kaiser and others (1980). Kaiser calculated lignite resources using proprietary data for nine Jackson and four Yegua deposits and areas.

Lignite resources were calculated by Kaiser and others (1980) according to degrees of certainty. Measured resources are known to the highest degree of certainty and were computed from data points spaced at distances that allowed the deposits to be outlined. These resource blocks are shown on the environmental geologic maps as lines slanting up to the left. Indicated resources, shown as lines slanting up to the right, are known to an intermediate degree of certainty and were computed from widely spaced boreholes and geologic evidence and projection. Inferred resources, shown as horizontal lines, are known with the least degree of certainty and were computed only from geologic evidence and projection. Lignite resource information provides a guideline for assessing prospective mine areas.

APPLICATIONS OF IMPORTANT ENVIRONMENTAL GEOLOGIC UNITS

The Yegua-Jackson environmental geologic maps were designed primarily for use in lignite mining and reclamation planning. Floodplains, oak and pine forest designations, soil descriptions, and sand hill units relate directly to State coal mining laws and potential mine problems. In addition, environmental geologic units provide land criteria that may aid in land resource planning and in land use management.

Laws Governing Surface Mining of Lignite

Two surface-mining laws govern lignite surface mining in Texas. The Federal Surface Mining Control and Reclamation Act, passed in 1977, provides comprehensive guidelines for lignite mining and reclamation, but the primary responsibility for issuing and enforcing surface-mining regulations is entrusted to the states. The Texas State Surface Coal Mining and Reclamation Act, passed in 1979, restates Federal law and expands on certain regulations, such as mandatory soil recovery. All specific regulatory authority, however, is delegated to the Railroad Commission of Texas, which published *Coal Mining Regulations* in 1981.

Both State and Federal laws require that mined land be restored to a condition the same as or better than its original condition. If the land is gullied or otherwise unusable before mining, the permittee is required to restore the land to a useful condition. *Coal Mining Regulations* states that lands are unsuitable for mining if reclamation is not technologically and economically feasible and that mining may be prohibited on frequently flooded areas. More specifically, the rules require that

(1) natural riparian vegetation (floodplain, pond, and marsh) be restored and varied species of native vegetation be permanently replaced,

(2) topsoil (prime farmland) or a mixture of topsoil and overburden be removed and then replaced after mining,

(3) sediment introduced into surface water both in and outside the mine area be minimized, and

(4) the effect on the hydrologic balance, that is, ground- and surface-water quality and quantity, be minimized.

Examples of how environmental geologic maps are helpful in mine planning and reclamation follow.

Recognition of Floodprone Land

The floodplain unit is one of the most important units designated on the environmental geologic maps. Potential problems or additional costs involved in mining floodplains include surface flooding, ground-water seepage, and reclamation of prime farmland.

Although mining is prohibited on frequently flooded areas (those nearest the river), mines located in the geomorphic floodplain may still be subject to occasional flooding. Detriment to mine equipment and operations may result unless properly engineered structures are constructed and maintained, often at considerable cost.

The volume and frequency of flooding vary across the map area. In the southwestern part of the area, flood peaks are sharp and flash floods are frequent in the sparsely vegetated, relatively steep channels. In major East Texas channels, floodwaters rise and fall slowly, influenced by broad, gently sloping floodplains (Orton, 1974). Characterization of potential flood peaks is important in planning diversion structures needed in floodplain mining.

Floodprone areas are commonly underlain by permeable, water-filled sediments. The intersection of a mine face with these units may lead to collapse of the mine walls, slumping of spoil banks, flooding of the pit, or heaving of the pit floor. To avoid this, a dewatering program and appropriate water storage locations may be needed. Development of a surface mine that requires excessive dewatering may prove to be uneconomical and inefficient.

Another expense that may be encountered during mining on a floodplain is reclamation of prime farmland. Although prime farmland is not abundant in the Yegua-Jackson trend, it is common on fertile river sediments, especially along the Colorado and Brazos Rivers. Stockpiling and replacement of high-quality topsoil may triple the price of reclamation. The details of reclamation of prime farmland are explained later in this section.

Floodplains (P1) and smaller streams that may also flood (P2) are located on all the environmental geologic maps. The chance of flooding increases as the proximity to a major river increases. Flash floods are more likely southwest of the Trinity River; they are rare on and east of the Trinity. Fifty-year floods on the Colorado River and on streams between the Navasota and Trinity Rivers are seven times as large as the average annual flood. All other drainages in the map area undergo 50-year floods that are only about five times as large as the average annual flood (Patterson, 1963).

Native Vegetation and Reclamation

Delineation of plant associations is important in mine planning because developers are required to document natural land capability, which includes pre-mine vegetative cover. Representative species (with certain exceptions) of both native upland and riparian vegetation should be restored during reclamation unless the landowner requests otherwise. In areas where average rainfall exceeds 660 mm (26 inches) a year, such as the Yegua-Jackson trend, vegetation must be established and maintained for 5 years after mining is completed. A regional approximation of the type of reclamation necessary can be made using the environmental geologic maps.

To this end, forests, grasslands, and sparsely vegetated sand ridges are presented on the environmental geologic maps. The three major vegetation assemblages are represented in the substrate unit divisions: oak forest, pine forest, and prairie. Small pine forest outliers that are absent on many vegetation maps are designated on the environmental maps. Dominant species composing the overstory vegetation and grasses are also listed for each map unit. Thus basic guidelines are available for detailed studies of species once a prospect area has been delineated.

Aside from aiding in complying with permit requirements, identification of vegetative types is important early in mine planning to estimate reclamation costs and assess potential reclamation problems. For example, revegetating pine forest on acidic soil in rainy East Texas is less costly than replanting oak forest or reclaiming nonvegetated land (G1) in the drier areas southwest of the Trinity River.

According to the mining rules, riparian vegetation should be replaced, as well as native upland forests. Environmental geologic maps identify significant riparian areas; both major river valleys (P1) and smaller tributaries (P2) are mapped. These areas include not only land within the 100-year-flood limit but also regions where a relatively plentiful water supply results in water-tolerant vegetation and coexisting wildlife habitats. Riparian vegetation may be costly to reestablish because water-tolerant species are not readily available as seedlings. The environmental geologic maps provide basic data that can be used in reclamation planning as well as for documentation of land capability.

Distribution of Topsoil and Prime Farmland

Delineation of soil type, especially in areas containing prime farmland, is important in mine planning. The required method of topsoil reclamation is determined individually for each lignite surface mine. The Railroad Commission of Texas can require that various depths of topsoil be removed, stored if not used immediately, and mixed with the overburden in varying amounts when replaced. Equipment use and storage area plans are thus required. Environmental geologic maps are useful in planning this process because dominant soil compositions are included in the description of each environmental geologic unit, and association names are listed in the text.

Some soils are so productive that they are called prime farmland soils. The characteristics of these soils are defined precisely by the USDA Soil Conservation Service, and the soils require special reclamation procedures if they have been farmed. To avoid these costly procedures, mining companies must prove that land in the permit regions is *not* prime farmland according to one or more of the following criteria in *Coal Mining Regulations,* which state that land is not prime farmland if it

(1) has not been used for crops in 5 out of the last 20 years,
(2) has a slope greater than 10 percent,
(3) has no dependable or economic water supply,
(4) has an abundance of rocks,
(5) is flooded more than once in every 2 years, and
(6) has not been designated as having prime farmland soil by the USDA Soil Conservation Service.

USDA Soil Conservation Service criteria designate soil as prime farmland soil if

(1) ground water exists either at the base of the root zone or at a depth of 1 m (40 inches), whichever is less,
(2) at a depth of 50 cm (20 inches), the mean annual temperature is greater than 0°C (32°F),
(3) the pH is from 4.5 to 8.4 in the root zone or at a depth of 1 m (40 inches), whichever is less,
(4) the exchangeable sodium percentage is less than 15,
(5) the erodibility factor times the percent slope is less than 2, and
(6) less than 10 percent of the upper 15 cm (6 inches) contains rocks greater than 7.6 cm (3 inches) in diameter (*Federal Register,* 1978).

If land is designated as prime farmland by the Railroad Commission of Texas, the topsoil may not be mixed with overburden for reclamation but should be carefully removed and preserved during mining and then replaced. The A, B, and, if necessary, the C horizons should be stripped and stockpiled individually. These stockpiles should be vegetated or otherwise prevented from being washed or blown away. After mining is completed, the soil horizons should be replaced in their original order. This is an expensive process, which can double or triple the cost of reclamation.

Prime farmland in the Yegua-Jackson trend exists primarily on two geologic units: on terraces and occasionally flooded lands, and on that part of the Catahoula Formation that is mapped as blacksoil, southwest of the Trinity River. The computerized list of prime farmland soils for the State of Texas, printed by the USDA Soil Conservation Service (1977), includes those listed in table 4 for the Yegua-Jackson trend. Seven of the 22 soils listed are on floodplains (P1), and 10 others are on terraces along major river valleys (A1, A2, or A3).

Upland prime farmland soils are mainly in Houston, Walker, and Fayette Counties. The thick Lufkin soil series, although not abundant, overlies Yegua sediments in Houston County (USDA Soil Conservation Service, 1974b). The Huntsburg-Depcor association in Walker County overlies the Whitsett Formation in a relatively small area that crosses Interstate 45 south of Mossy Grove (USDA Soil Conservation Service, 1978). In Fayette County the Houston Black - Heiden association, mapped as blacksoil, overlies the Catahoula Formation (USDA Soil Conservation Service, 1974a). Prime farmland also exists in smaller regions on the Catahoula Formation northeast through Walker County (McClintock and others, 1979).

The area of prime farmland soils on Yegua-Jackson sediments is relatively small. Only companies proposing mines on the outcrop of the upper part of the Jackson Group southwest of the Trinity River, on terraces, or in major river valleys will need to be concerned with the reclamation of small areas of prime farmland.

Hydrology and Environmental Sensitivity

Sand units on the environmental geologic maps indicate the presence of surface sand bodies. These high-sand areas are hydrologically sensitive sediment sources and have high recharge potential; they need careful consideration in mine planning.

State Law and Applications to Hydrology

Texas State law contains regulations directly concerned with the effects of mining on surface- and ground-water systems. The main purpose of these regulations is to ensure that mining causes minimum disturbance of the hydrologic balance. Specific rules in *Coal Mining Regulations* (Railroad Commission of Texas, 1981a) state the following:

(1) Mining may be prohibited on renewable resource land, including aquifers and aquifer recharge areas, if the mining would result in "a substantial loss or reduction of long-range productivity of water supply or of food or fiber products" (Railroad Commission of Texas, 1981b).

(2) All surface drainage through a mine shall be passed through sedimentation ponds to prevent excess sediment from being released into surface waters.

(3) Wells having water supplies that are decreased in quantity as a result of mining must be replaced.

(4) Mined land shall be restored in such a way that discharge of harmful drainage waters into the ground-water system will be controlled or prevented.

In reference to the first regulation in this list, it is important to note that mining of Yegua and Jackson lignite will probably not interfere with the Carrizo-Wilcox or the Gulf Coast aquifers, the major aquifers of the region, because they are stratigraphically several hundred meters above or below the lignite zones (fig. 8).

The most important aquifer recharge zone in the Yegua-Jackson trend is the Catahoula Formation, which is stratigraphically below the Gulf Coast aquifer system. The underlying sand-rich Whitsett Formation may be hydrologically connected to the Catahoula, especially southwest of the Trinity River. Extra precautions may be needed to ensure protection of the quality and recharge potential of the Catahoula and Whitsett recharge zones. On the environmental geologic maps, the Catahoula outcrop is designated as low- or moderate-relief blacksoil in the region southwest of the Trinity River, as sand hills or low rolling sand from the Trinity River to the Sam Rayburn Reservoir, and as sand and mud from the Sam Rayburn Reservoir to the Texas-Louisiana border. Whitsett sand outcrops are designated as low rolling sands and sand hills southwest of the Trinity River, and as fine sand to the east.

Yegua, Wellborn, and Manning sand outcrops are also recharge zones, although the sands are not as thick as those in the Catahoula and Whitsett Formations. Mining in the Yegua Formation and in the lower part of the Manning Formation should be planned carefully to avoid adverse impact on these aquifers.

Excess sediment in surface waters, mentioned in rule 2, is a significant potential problem in high-sand areas, which erode easily and therefore can contribute abundantly to the sediment load of streams. Approximation of the amount and distribution of sand that will be intersected during mining can be useful in planning the size and location of sedimentation ponds. Sand units delineated on the environmental geologic maps are potential high-sediment sources. Sand hills, low rolling sands, and fine sand units are underlain by unconsolidated sediments; sand hills and fine sand are the more erodible of these units because of their relief. Low rolling sands will also erode easily if excavated. In contrast, indurated sand is not as significant a sediment source. Recognition of sand units H1, H2, and H3 will alert mining companies to the location of high-sand areas on the surface.

Sand outcrops indicate high-sand regions that have aquifer potential and regions where alternate sources of water may be available in downdip areas. This information can be used to minimize the depletion of or to permit replacement of local water supplies, mentioned in rule 3. If drawdown can be estimated during mine planning, both adequate quality and quantity of alternate water supplies can be assured by a drilling program before the mining process begins. In addition, mining can be planned to prevent significant drawdown if high-sand areas can be avoided or sealed off from the mine pit.

To date, acid mine drainage (rule 4) has not been a significant mine problem in Texas mines. Only two of the six lignite mines currently operating in Texas are producing acid water, and this water is being treated in retaining ponds before it is released downstream. The acid drainage that does exist has resulted from the exposure of overburden to runoff; in no case has water been contaminated after coming in contact with lignite, possibly because of the low-sulfur (1 to 3 percent) content of Texas lignites (Kaiser and others, 1980).

Surface Geometry of Water-Bearing Units

Sand outcrops shown on the environmental geologic maps (fig. 13) provide information helpful in the identification of water-bearing units in the Yegua-Jackson trend. Identification of these units is critical in minimizing hydrologic disturbances during surface mining.

The Bryan Sand, described by Stenzel (1940), crops out at the base of the Yegua Formation. Surface sand distribution is irregular and discontinuous, and sand thickness varies considerably. Sand rarely crops out in the middle of the Yegua Formation. It is found only near Lovelady in Houston County and in a few small areas in Angelina County (map sheet 4). The two sand deposits that crop out in the upper Yegua Formation in Burleson and Grimes Counties are finer grained than other Yegua sands.

In the Jackson Group, the Caddell is the only formation that does not contain more than 25 percent sand. Caddell sand outcrops have been observed only in Trinity County. The thin, commonly silica-cemented sands of the Wellborn Formation are continuous along strike for up to 16 km (10 mi) southwest of the Trinity River. Wellborn sand outcrops exhibit a more podlike areal surface geometry and diminish significantly in number east of the Trinity River.

In the Manning Formation the major sand outcrops are in Grimes County and at the Trinity-Polk county line. Outcropping sand beds in Grimes County can exceed 3 m (10 ft) in thickness. Thin, indurated sandstones overlie thick, unconsolidated sands along Gibbons Creek. Sand hills at the Trinity-Polk county line are mostly vegetated, but indurated blocks and flags of sand locally cover the hillsides.

Sands of the Whitsett Formation are relatively continuous in outcrop from the Colorado River to Piney Creek in Trinity County. They are unconsolidated and form relatively large individual hills. Whitsett sands are thicker than sands in other Jackson formations.

The environmental geologic maps indicate the probable absence of thick, extensive sands at the surface. Knowledge of the geometry and abundance of the sand bodies that do exist is important in locating local water conduits to ensure correct ground-water-

Table 4. Prime farmland soils in the Yegua-Jackson trend, southeast Texas (from USDA Soil Conservation Service, 1977c).

COUNTY	LOCATION	SERIES
Angelina	Angelina and Neches River terraces	Bernaldo
Bastrop	Colorado River floodplain	Bosque, Norwood, Smithville
Brazos	Brazos River terraces Brazos River floodplain	Burleson Norwood
Burleson	Brazos River terraces Brazos River floodplain	Burleson Norwood
Fayette	Colorado River floodplain Catahoula Formation upland	Ships, Norwood Heiden, Houston Black
Grimes	-----	-----
Houston	Trinity River terraces Trinity River floodplain Yegua Formation upland	Burleson Kaufman, if leveed Lufkin, if thick
Jasper	-----	-----
Lee	-----	-----
Madison	-----	-----
Nacogdoches	Angelina River terraces	Attoyac, Bernaldo, Besner
Newton	-----	-----
Polk	-----	-----
Sabine	Sabine River terraces	Bernaldo
San Augustine	Angelina River terraces	Bernaldo
Trinity	Trinity River terraces	Garner
Tyler	Neches River terraces Neches River floodplain	Elysian Iuka
Walker	Trinity River terraces Trinity River floodplain Whitsett Formation upland	Elysian Variant, Gomery, Kaman, Moten Kaufman Depcor, Huntsburg
Washington	-----	-----

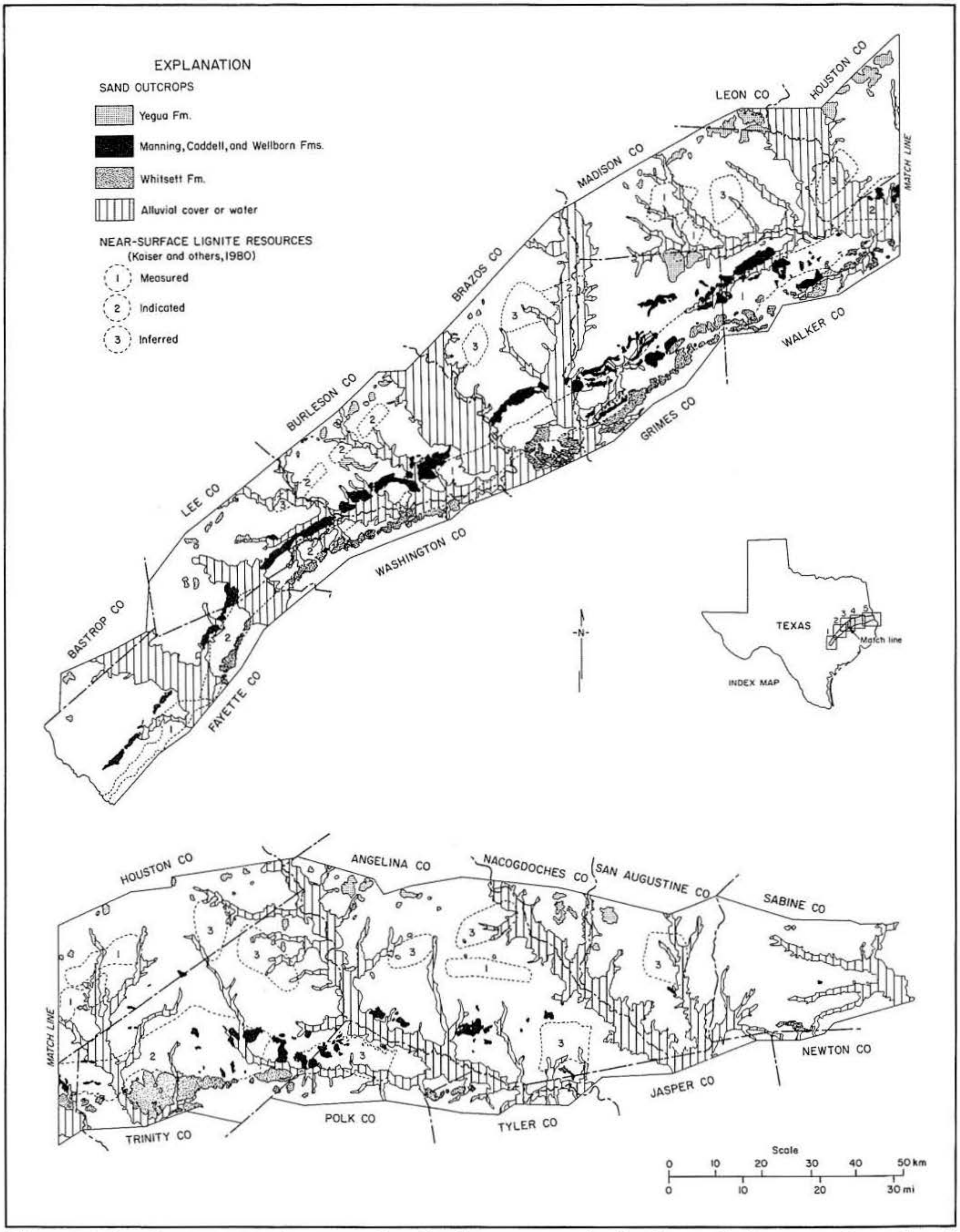

Figure 13. Sand outcrops and near-surface lignite resources in the Yegua-Jackson trend, southeast Texas.

monitoring procedures and to forecast the need for pumping in the mine pit.

Correlation of Sand Outcrops with Subsurface Sand Trends

Correlation of surface and subsurface sands improves understanding of surface and near-surface sand geometry. Awareness of this geometry is useful in predicting the potential ground-water problems discussed in previous paragraphs. Sand correlation also helps determine lithofacies configurations, which can aid in regional lignite exploration.

In figures 14 and 15, sand outcrop patterns (sand hills and low rolling sands units) of the Yegua and Jackson are correlated with subsurface sand-percent and maximum sand-body thickness maps of Kaiser and others (1980). Although erosion has changed their original shape, the distribution of surface sand outcrops may reflect, somewhat, the original geometry of Yegua and Jackson sand bodies. Because of gentle dips, the Yegua-Jackson outcrop provides a nearly plan view of the sedimentary facies along depositional strike. Three-dimensional geometry of these facies is shown on Kaiser and others' (1980) subsurface maps.

Yegua sand outcrops and adjacent subsurface sand trends are shown in figure 14. Individual sand bodies or small patches of sand outcrops, which lie updip from high sand-percent areas delineated on Kaiser's map, were areas of fluvial input during deposition. Surface sand bodies reflect subsurface sand distribution in these areas and allow prediction of sand distribution downdip from the outcrop and updip from the area of subsurface control. On a larger scale, two groups of sand outcrops, in Burleson County and on either side of the Trinity River, lie updip from two delta systems in the subsurface (A and B, fig. 14). Note that the larger surface sands lie updip from the larger delta system.

The location of Yegua lignites is difficult to predict; however, four of the five measured resource areas in the Yegua flank the major sediment input region located along the present-day Trinity River valley (fig. 13). Higher percentages of sand can be expected along channel trends than in adjacent interchannel areas.

Sand-percent maps of the Jackson show delta lobes, much like those shown in the deep-basin part of the Yegua Formation (Kaiser and others, 1980). However, the maximum sand-body-thickness map of the Jackson Group reveals linear sand bodies (fig. 15). Outcrops of the Jackson Group and subsurface areas are strike-oriented delta-plain and delta-front sands. Therefore, near-surface Jackson sand bodies may be thin and laterally extensive. East of the Trinity River, the structural strike of the Jackson is not parallel to depositional strike; consequently, Jackson sands are podlike and significantly fewer in number, representing the outcrop intersection with strike-elongate Jackson sand bodies.

Lignite in the Jackson Group appears in muddy sediments, but seams can lie above channel-fill or crevasse-splay sands. Thus, the correlation of sand outcrops with high-sand areas in the subsurface may aid in the identification of lignite deposits, especially in the lower delta-plain environment of the Manning Formation.

Additional Applications

Location of floodplain areas, designation of soil type, delineation of slope percent, distribution of sand outcrops, presence of lignite resources, and designation of substrates are important in short-term construction, in long-term land use planning, and in other land-resource-related programs.

Floodplains are areas that may be hazardous locations for permanent structures. Perhaps not as accurate as the 100-year-flood limits designated on maps of floodprone areas, the boundaries of the floodplain unit serve as supplemental information when floodprone area maps are available, and as a reasonably accurate guide when they are not available. Floodplain boundaries also outline areas likely to have potable water. The shallow water table of a floodplain precludes construction of septic tanks and sanitary landfills.

Soil type is important in determining profitable land use and necessary constraints for construction. Sandy soils are unsuitable for certain vegetables and grains but may be profitable for timber crops. Loamy and clayey soils will support crops and pastures but are not as suitable for buildings, septic tanks, or waste disposal sites because of the corrosive nature and low permeability of these soils. Prime farmland is indicated by the blacksoil unit designation. Geomorphic floodplain and terrace units also contain profitable cropland. Thus, soil designations, mapped in combination with substrate and vegetation type, can aid long-term land use planning.

If one is not familiar with topographic maps, slope divisions of the environmental geologic units may be useful in making decisions concerning construction of private dwellings, businesses, or roads. Construction of business structures and roads is more expensive on steeper slopes. Septic systems may be unfeasible in these steep areas. Slope divisions on land that may be developed for public use outline areas with favorable characteristics for building campgrounds and parking lots (0 to 3 percent slope) or for trail construction in national forests (3 to 10 percent slope). Slopes steeper than 10 percent are the least suitable for farming or timbering.

Locations of sand outcrops indicate high-sand areas containing ground-water resources downdip that may be large enough to supply domestic and rural needs. Material from sand hills and low rolling sands can also be used for construction purposes.

Potential areas of lignite mining are shown on the environmental geologic maps. These lignite resource blocks have a high potential for future mining; a person or company desiring to construct a reservoir, industrial facility, or other major operation, or simply to purchase, sell, or trade land, might benefit from this information. Lignite resource areas are shown on the maps of Kaiser

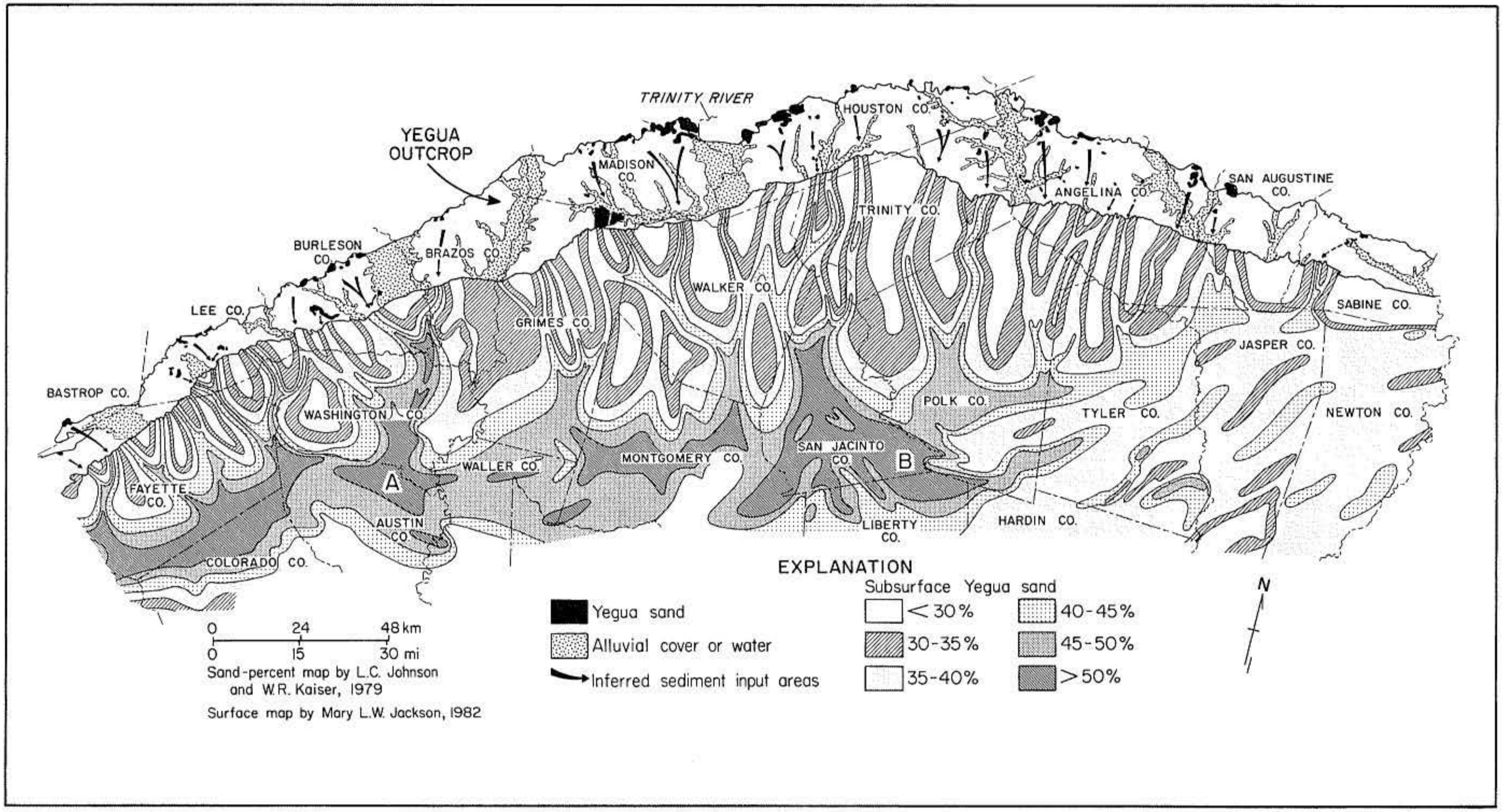

Figure 14. Sand outcrops and subsurface sand percent of the Yegua Formation, southeast Texas.

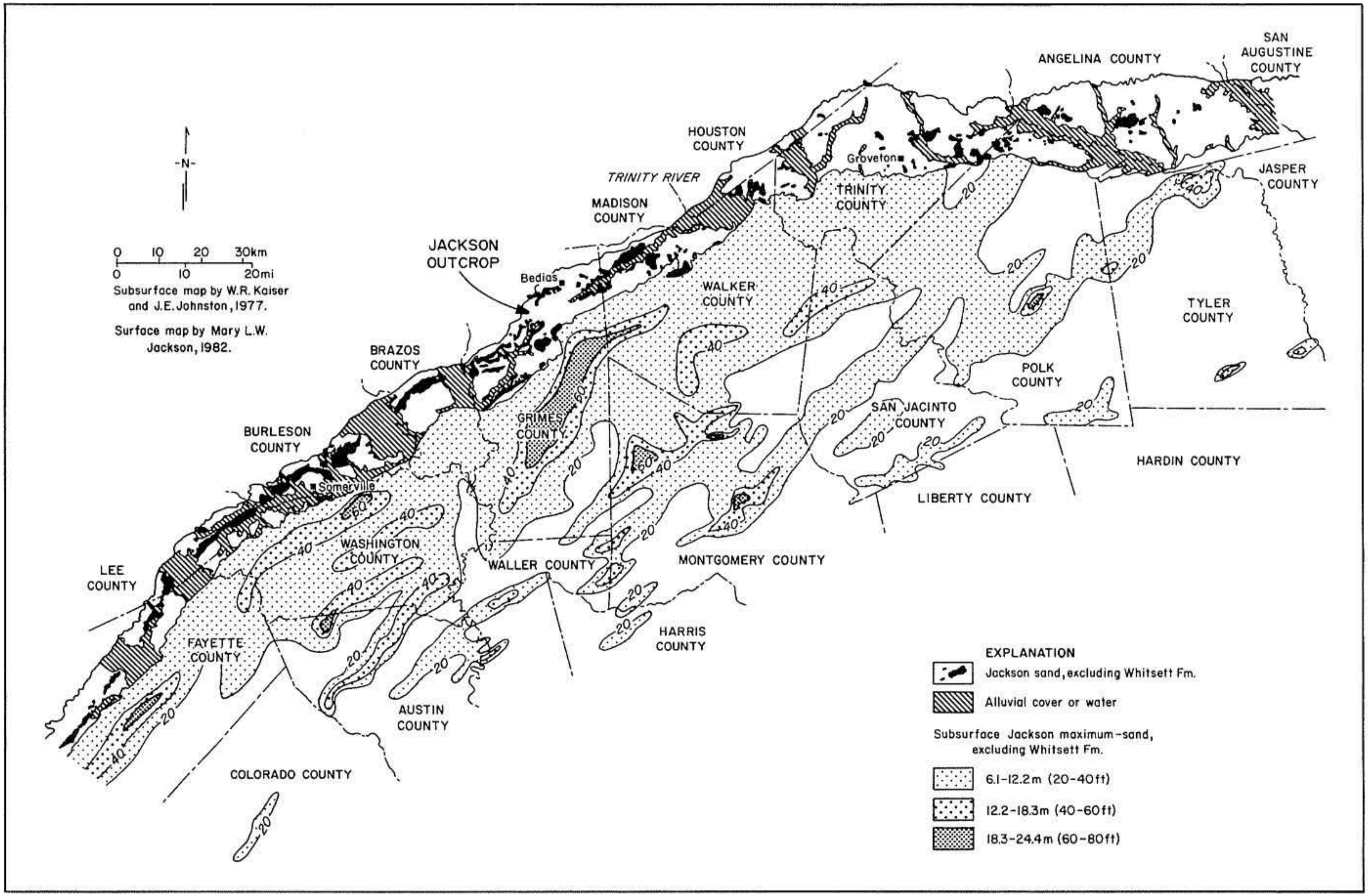

Figure 15. Sand outcrops and subsurface maximum sand-body thickness of the Jackson Group in southeast Texas, excluding the Whitsett Formation.

and others (1980), but the environmental geologic maps provide topography and additional landmarks to aid the user in relating lignite resource areas to geographic landmarks.

Substrate information can also be valuable. For instance, an area designated as indurated sandstone may require more time and expense to excavate for a foundation or a road and will not be a particularly productive agricultural area. However, the sandstone may provide needed road material. Ironstone and gravel cap units are also areas of economic potential in road building and construction.

SUMMARY

Renewed interest in Texas lignite resources began in the 1970's, and the enactment of Federal and State laws governing surface mining of lignite soon followed. In response to these events, environmental geologic maps of the Wilcox lignite belt were prepared (Henry and Basciano, 1979). Environmental geologic maps provide basic data useful in land capability assessment required by mining regulations. Mapping of the Yegua-Jackson lignite trend in southeast Texas further assesses Texas lignite belts.

The Yegua-Jackson map area extends from south-central Texas east to the Texas-Louisiana border and includes 13,000 km² (5,000 mi²). The southwestern part of the map area has moderate rainfall and develops poor, clayey soils and scattered post oak and grassland vegetation. In East Texas, where precipitation is high (up to 1,320 mm, 52 inches annually), lateritic soils and pine forests are typical. Low-relief topography characterizes the entire map area; dissection increases eastward.

Yegua and Jackson sands and muds are of fluvial and deltaic origin. Sand facies are most common in the basal Yegua section and in the Whitsett Formation of the Jackson Group. Most Yegua and Jackson sediments are not major aquifers; only the lower Yegua, Whitsett, and overlying Catahoula Formations contain significant water-bearing sands.

Mapping involved interpretation of black-and-white, large-scale aerial photographs and extensive field work. The environmental geologic units of this report include those used in an earlier Wilcox Group study (Henry and Basciano, 1979); several new units were added. Each of the 32 environmental geologic units is defined according to substrate, soil, geomorphology, geologic process, vegetation, and land use. The units are grouped into geomorphic, substrate, and man-made categories according to their most important characteristics. Additional information shown on the environmental geologic maps includes abandoned underground mines, an active surface mine, and lignite resource blocks mapped by Kaiser and others (1980).

Environmental geologic maps have many applications in lignite mining and reclamation planning. The maps delineate floodprone areas, vegetation assemblages, and soil types, all of which provide information necessary for land capability assessment. Floodprone areas call attention to land that may be hazardous because of flood potential and may be difficult to maintain during mining because of unstable, permeable river sediments. Vegetation assemblages provide basic data for detailed studies and indicate the type of revegetation required. Soil types outline prime farmland soils, which may need involved and expensive soil replacement procedures. Sand outcrops permit prediction of surface- and ground-water problems such as siltation and seepage. Correlation of sand outcrops with subsurface sand trends improves prediction of sand-body geometry at the surface; this can aid in planning for minimum hydrologic disturbance.

Environmental geologic maps may also be used in land use and land resource decisions not related to lignite mining. The maps provide the basis for a comprehensive approach to evaluating the natural characteristics of the land.

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REFERENCES

Anders, R. B., 1967, Ground-water resources of Sabine and San Augustine Counties, Texas: Texas Water Development Board Report 37, 115 p.

Arbingast, S. A., Kennamer, L. G., Ryan, R. H., Buchanan, J. R., Hezlep, W. L., Ellis, L. T., Jordan, T. G., Granger, C. T., and Zlatkovich, C. P., 1976, Atlas of Texas: The University of Texas at Austin, Bureau of Business Research, 179 p.

Baker, C. L., 1931, Volcanic ash in Texas: University of Texas, Austin, Bureau of Economic Geology Mineral Resource Circular 2, 4 p.

Baker, E. T., Follett, C. R., McAdoo, G. D., and Bonnet, C. W., 1974, Ground-water resources of Grimes County, Texas: Texas Water Development Board Report 186, 109 p.

Baker, F. E., 1979, Soil survey of Bastrop County, Texas: USDA Soil Conservation Service, 73 p.

Barnes, V. E., project director, 1967, Palestine sheet: The University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas, scale 1:250,000.

____ 1968, Beaumont sheet: The University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas, scale 1:250,000.

____ 1970, Waco sheet: The University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas, scale 1:250,000.

____ 1974a, Austin sheet: The University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas, scale 1:250,000.

____ 1974b, Seguin sheet: The University of Texas at Austin, Bureau of Economic Geology, Geologic Atlas of Texas, scale 1:250,000.

Berg, R. R., 1979, Koppe bridge, *in* Kersey, D. G., ed., Lower Tertiary of the Brazos River valley: Houston Geological Society Guidebook, p. 67-69.

Bonnen, C. A., 1960, Types of farming in Texas: Texas Agricultural Experiment Station Bulletin 964, 52 p.

Boone, P. A., 1979, Turkey Creek, *in* Kersey, D. G., ed., Lower Tertiary of the Brazos River valley: Houston Geological Society Guidebook, p. 70-72.

Broman, I. J., 1914, Fourth annual report of the state mine inspector of Texas, Texas State Mining Department: Texas State Library, archives section, 25 p.

Brown, L. F., Jr., project coordinator, 1972-1980, Environmental geologic atlas of the Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology, scale 1:125,000.

Brown, L. F., Jr., Fisher, W. L., Erxleben, A. W., and McGowen, J. H., 1971, Resource capability units— their utility in land- and water-use management with examples from the Texas Coastal Zone: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 71-1, 22 p.

Bullock, N. M., 1928, Annual report of the state mining industry of Texas, Texas State Mining Board: Texas State Library, archives section, 70 p.

Deussen, Alexander, 1930, Geology of the Coastal Plain of Texas west of the Brazos River: U.S. Geological Survey Professional Paper 126, p. 66-104.

Dolezel, Raymond, 1980, Soil survey of Nacogdoches County, Texas: USDA Soil Conservation Service and Forest Service, 146 p.

Drake, D. A., 1960, Millican and Millican East gas fields, Brazos County, Texas, *in* Russell, W. L., ed.: Houston Geological Society and Gulf Coast Section of the Society of Economic Paleontologists and Mineralogists guidebook for annual field trip, p. 11-13.

Dumble, E. T., 1918, The geology of East Texas: University of Texas, Austin, Bureau of Economic Geology Bulletin 1869, 338 p.

Federal Register, 1978: Office of the Federal Register, Washington, D. C., v. 43, no. 21, p. 4032.

Fisher, W. L., 1963, Lignites of the Texas Gulf Coastal Plain: University of Texas, Austin, Bureau of Economic Geology Report of Investigations No. 50, 164 p.

Fisher, W. L., with contributions by Chelf, C. R., Shelby, C. A., Garner, L. E., Owen, D. E., and Schofield, D. A., 1965, Rock and mineral resources of East Texas: University of Texas, Austin, Bureau of Economic Geology Report of Investigations No. 54, 439 p.

Fisher, W. L., Proctor, C. V., Jr., Galloway, W. E., and Nagle, J. S., 1970, Depositional systems in the Jackson Group of Texas—their relationship to oil, gas, and uranium: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 70-4, 28 p.

Folk, R. L., 1960, Tertiary field geology: University of Texas Geological Society, Austin, 31 p.

Follett, C. R., 1970, Ground-water resources of Bastrop County, Texas: Texas Water Development Board Report 109, 138 p.

____ 1974, Ground-water resources of Brazos and Burleson Counties, Texas: Texas Water Development Board Report 185, 194 p.

Gentry, Bruce, 1921, Annual report of coal mining, State of Texas, Texas State Mining Board: Texas State Library, archives section, 28 p.

Gould, F. W., 1962, Texas plants—a checklist and ecological summary: Agricultural and Mechanical College of Texas, College Station, Texas Agricultural Experiment Station, 111 p.

Gustavson, T. C., 1975, Microrelief (gilgai) structures on expansive clays of the Texas Coastal Plain—their recognition and significance in engineering construction: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 75-7, 18 p.

Gustavson, T. C., and others, in preparation, Lavaca, Guadalupe, San Antonio, Nueces River basin study: The University of Texas at Austin, Bureau of Economic Geology.

Guyton—see William F. Guyton and Associates.

Harris, G. D., 1941, Report on the geology of Lee County, Texas: University of Texas, Austin, Bureau of Economic Geology Mineral Resource Survey Circular 33, 30 p.

Henry, C. D., and Basciano, J. M., 1979, Environmental geology of the Wilcox Group lignite belt, East Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 98, 28 p.

Henry, C. D., and Kastning, E. H., 1975, Toward evaluating the potential environmental impact of lignite strip mining in East Texas (abs.): Geological Society of America, Abstracts with Programs, v. 7, no. 7, p. 1110.

Holm, Melody, 1975, A preliminary study of biologic assemblages of East Texas lignite belt: The University of Texas at Austin, Bureau of Economic Geology Research Note 1, 23 p.

Johnson, L. C., and Kaiser, W. R., 1979, Sand-percent map of the Yegua Formation: unpublished map on file with The University of Texas at Austin, Bureau of Economic Geology.

Kaiser, W. R., Ayers, W. B., Jr., and LaBrie, L. W., 1980, Lignite resources in Texas: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 104, 52 p.

Kaiser, W. R., and Johnston, J. E., 1977, Maximum-sand map of the Jackson Formation: unpublished map on file with The University of Texas at Austin, Bureau of Economic Geology.

Kaiser, W. R., Johnston, J. E., and Bach, W. N., 1978, Sand-body geometry and the occurrence of lignite in the Eocene of

Texas: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 78-4, 19 p.

King, E. A., and Rodda, P. U., 1962, Fused rocks in the Jackson Group (Eocene), Texas: Gulf Coast Association of Geological Societies Transactions, v. 12, p. 265-270.

LeBlanc, R. J., Jr., 1970, Environments of deposition of the Yegua Formation (Eocene), Brazos County, Texas: Texas A&M University, College Station, Master's thesis, 47 p.

McClintock, W. R., Jr., Castille, J. J., Stewart, Michael, and Andrew, L. E., 1979, Soil survey of Walker County, Texas: USDA Soil Conservation Service and Forest Service, 124 p.

Mowery, I. C., Oakes, Harvey, Rourke, J. D., Matzano, F., Hill, H. L., McKee, G. S., and Crozier, B. B., 1958, Soil survey of Brazos County, Texas: USDA Soil Conservation Series 1951, no. 1, 65 p.

Orton, R. B., 1974, The climate of Texas, *in* Officials of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Climates of the states: New York, Water Information Center, Inc., v. 2, p. 887-895.

Patterson, J. L., 1963, Floods in Texas: Texas Water Commission Bulletin 6311, 31 p.

Pedrotti, D. A., 1958, Geology of Roans Prairie-West, Grimes County, Texas: Agricultural and Mechanical College of Texas, College Station, Master's thesis, 95 p.

Phillips, W. B., and Worrell, S. H., 1913, The fuels used in Texas: University of Texas, Austin, Bureau of Economic Geology Bulletin 307, 287 p.

Railroad Commission of Texas, 1981a, Coal mining regulations: Railroad Commission of Texas, Office of Surface Mining, 332 p.

——— 1981b, Surface coal mining and reclamation act: Railroad Commission of Texas, Office of Surface Mining, 57 p.

Raisz, Erwin, 1957, Landforms of the United States: Boston, Ginn and Co., scale 1:4,800,000.

Renick, B. C., 1936, The Jackson Group and the Catahoula and Oakville Formations in a part of the Texas Gulf Coastal Plain: University of Texas, Austin, Bureau of Economic Geology Bulletin 3619, 104 p.

Rogers, L. T., 1967, Availability and quality of ground-water in Fayette County, Texas: Texas Water Development Board Report 56, 117 p.

Russell, W. L., 1955, Stratigraphy of the Wellborn and Manning Formations in east-central Texas: Gulf Coast Association of Geological Societies Transactions, v. 5, p. 165-172.

——— 1957, Faulting and superficial structures in east-central Texas: Gulf Coast Association of Geological Societies Transactions, v. 7, p. 65-72.

Sandeen, W. M., 1972, Ground-water resources of Washington County, Texas: Texas Water Development Board Report 162, 105 p.

Sellards, E. H., 1936, Structural map of Texas: University of Texas, Austin, Bureau of Economic Geology, scale 1:1,000,000.

Sellards, E. H., Adkins, W. S., and Plummer, F. B., 1932, The geology of Texas: University of Texas, Austin, Bureau of Economic Geology Bulletin 3232, v. 1, 818 p.

Smith, L. L., 1979, Historic coal mines in Texas: an annotated bibliography: Railroad Commission of Texas, Surface Mining and Reclamation Division, 46 p.

Stenzel, H. B., 1940, The Yegua problem, *in* Stenzel, H. B., and others, Contributions to geology, 1939: University of Texas, Austin, Bureau of Economic Geology Publication 3945, p. 847-910.

Stenzel, H. B., and Twining, J. T., Lignite data sheets: The University of Texas at Austin, Bureau of Economic Geology open-file report L-4a.

Strahler, A. N., 1963, The earth sciences: New York, Harper and Row, p. 576-578.

Tarver, G. E., 1966, Ground-water resources of Houston County, Texas: Texas Water Development Board Report 18, 86 p.

Tarver, G. R., 1968, Ground-water resources of Polk County, Texas: Texas Water Development Board Report 82, 109 p.

Taylor, S. J., 1911, First annual report of the State Mining Board of Texas, Texas State Mining Board: Texas State Library, archives section, 24 p.

Texas Water Development Board, 1968, The Texas water plan, Summary, 50 p.

Tharp, B. C., 1926, Structure of Texas vegetation east of the 98th meridian: The University of Texas, Austin, Bureau of Economic Geology Bulletin 2606, p. 22.

Thompson, G. L., 1960, Ground-water resources of Lee County, Texas: Texas Water Development Board Report 20, 131 p.

U.S. Department of Agriculture Soil Conservation Service, 1971a, General soils map, Burleson County, Texas: scale 1:126,720.

———1971b, General soils map, Grimes County, Texas: scale 1:126,720.

———1971c, General soils map, Lee County, Texas: scale 1:126,720.

———1971d, General soils map, Polk County, Texas: scale 1:126,720.

———1974a, General soils map, Fayette County, Texas: scale 1:126,720.

———1974b, General soils map, Houston County, Texas: scale 1:169,000.

———1974c, General soils map, Trinity County, Texas: scale 1:253,440.

———1975a, General soils map, Angelina County, Texas: scale 1:169,000.

———1975b, General soils map, Sabine and San Augustine Counties, Texas: scale 1:169,000.

———1976a, General soils map, Jasper County, Texas: scale 1:169,000.

———1976b, General soils map, Newton County, Texas: scale 1:190,000.

———1976c, General soils map, Tyler County, Texas: scale 1:190,000.

———1977a, General soils map, Bastrop County, Texas: scale 1:253,440.

———1977b, General soils map, Nacogdoches County, Texas: scale 1:169,000.

———1977c, Computer list of prime farmland soils.

———1978, General soils map, Walker County, Texas: scale 1:253,440.

———1979a, General soils map, Leon County, Texas: scale 1:190,000.

———1979b, General soils map, Washington County, Texas: scale 1:190,000.

Veatch, A. C., 1902, The geography and geology of the Sabine River, *in* Harris, G. D., Veatch, A. C., and Pacheco, J. A. A., The geology of Louisiana, part 4: Louisiana Geological Survey, p. 107-150.

Walton, W. L., 1959, Geology of the Carlos-East area, Grimes County, Texas: Agricultural and Mechanical College of Texas, College Station, Master's thesis, 104 p.

Wesselman, J. B., 1967, Ground-water resources of Jasper and Newton Counties, Texas: Texas Water Development Board Report 59, 167 p.

William F. Guyton and Associates, 1970, Ground-water conditions in Angelina and Nacogdoches Counties, Texas: Texas Water Development Board Report 110, 125 p.

Winslow, A. G., 1950, Geology and ground-water resources of Walker County, Texas: Texas Board of Water Engineers Bulletin 5003, 48 p.