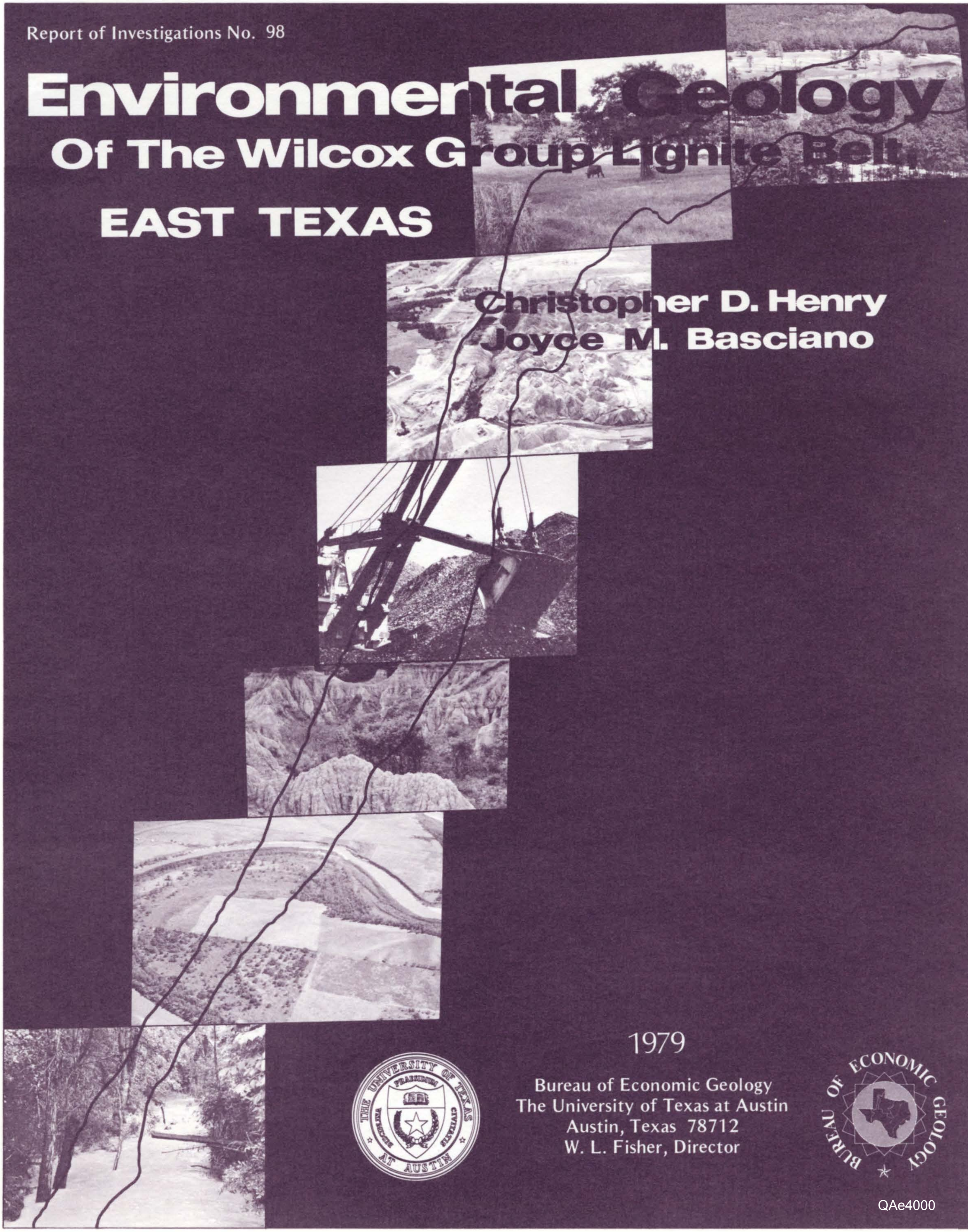
Report of Investigations No. 98

Environmental Geology Of The Wilcox Group Lignite Belt, EAST TEXAS



Christopher D. Henry
Joyce M. Basciano

1979

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

QAe4000

Report of Investigations No. 98

Environmental Geology Of The Wilcox Group Lignite Belt, EAST TEXAS

Christopher D. Henry
Joyce M. Basciano

1979

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

Cover photographs courtesy of
Christopher D. Henry, Joyce M. Basciano, and L. E. Garner

CONTENTS

FIGURES

TABLES

MAPS

INTRODUCTION

This report provides a data base for decisions about lignite mining and reclamation in the Wilcox Group of East Texas. Kaiser (1974; 1978) estimates that about 12.2 billion short tons of potentially strip-minable lignite resources occur in East and South Texas. About 8 billion tons of the lignite are within the Wilcox Group in the area of this study (Kaiser, 1978). Lignite production has grown from an estimated 2 million short tons in 1970 to 17 million tons in 1977 (Hawkins and Garner, 1978). Estimates of lignite demand indicate that all strippable reserves that can be economically recovered will be committed to use by 2000 (White, 1979).

A set of environmental geologic maps, which accompanies this report, depicts the character of the land that will be affected by mining. The environmental geologic maps of the East Texas lignite belt provide an accurate inventory of land resources. The maps identify areas where mining is most likely to occur, areas of critical natural resources that could be affected by mining, such as aquifer recharge areas, and areas of natural hazards, such as floodplains. Principal areas of both active and planned surface mining are also located. Although interest in lignite mining prompted the preparation of these maps, their use is not limited to planning mining or to evaluating the effects of mining.

Lignite mining will require the dedication of large amounts of land and water to mining and related activities, and in turn, mining can have considerable impact on land and water resources. Areas that are sensitive to lignite mining are also sensitive to other man-made alterations of the land surface. The environmental geologic maps provide information that can be useful for projects ranging from building a town or highway to setting aside an area for recreational use. The maps also provide an inventory of mineral resources such as sand and gravel, ironstone, and other aggregate materials.

The seven environmental geologic maps cover the outcrop area of the Wilcox Group, the major lignite host, and adjacent geologic units from Bastrop County to Texarkana (fig. 1). Total area mapped is about 18,000 km² (7,000 mi²). The environmental geology of additional areas of potentially minable lignite in South Texas has been described in the Guadalupe-San Antonio-Nueces River Basins Regional Study (Bureau of Economic Geology open-file report) (fig. 1).

This report begins with a discussion of various physical aspects of the lignite belt, including geology, hydrology, soils, climate, and land use, to aid in understanding the maps. The criteria and methodology used to delineate the environmental geologic units are discussed. The environmental geologic units are thoroughly described in both the text and the accompanying tables. Varied applications of the environmental geologic maps are considered.

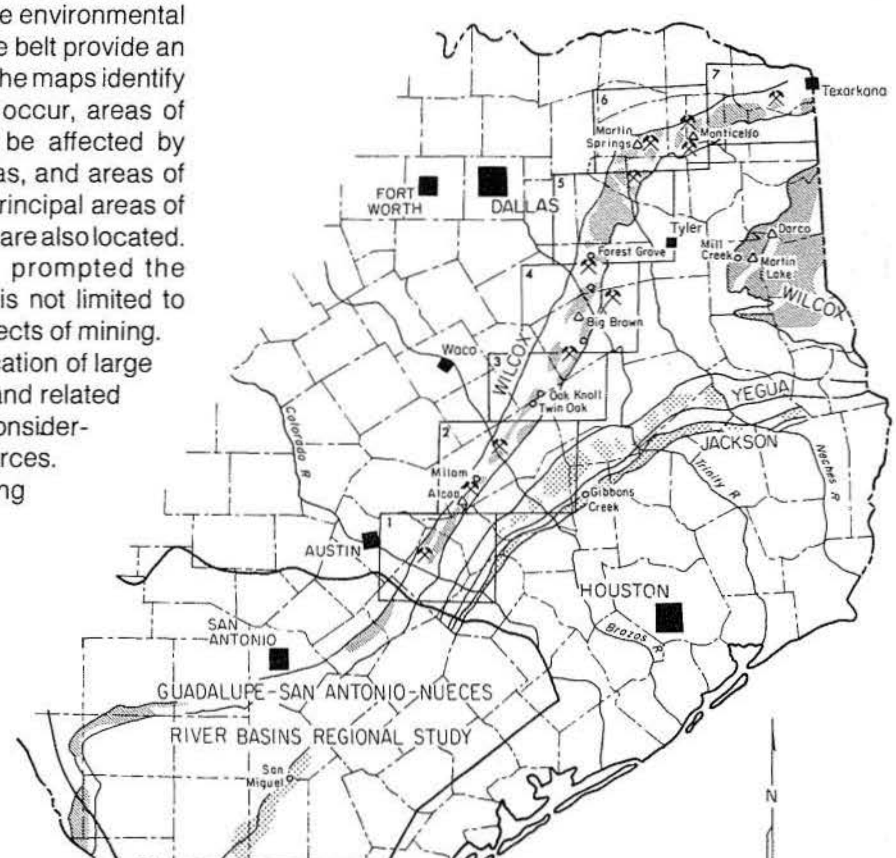


Figure 1. General location of near-surface lignite (adapted from Kaiser, 1974). Map areas of this report are indicated by the numbered rectangles.

PHYSICAL SETTING OF THE LIGNITE BELT

Land use is largely determined by the land's physical and biological setting. Physical setting includes innate characteristics, mostly composition of the geological substrate (geology), and characteristics that result from modification of the innate characteristics by natural processes. These derived characteristics include composition of soils, shape of the land's surface (geomorphology), and native vegetation. Climate, which influences both soils and vegetation, is a major factor influencing the processes that modify the land's surface. All these characteristics are used as criteria to define units of the environmental geologic maps. Thus, understanding the nature and origin of the criteria aids in understanding the maps.

Geology—Substrate Composition

Two fundamentally different geologic groups compose the substrates of the environmental geologic units. One is a thin surficial deposit of recent alluvium within stream valleys; the other group, composed of Tertiary units, extends as interbedded lenses and strata to greater depth.

A map shows only the surface distribution of material that continues into the subsurface. One of the criteria for defining environmental geologic units is the substrate material, and understanding the three-dimensional aspect of the substrate facilitates the efficient use of the environmental geologic maps. The relationship between the environmental geologic units and their subsurface extensions is illustrated in figure 2.

The geologic units of Tertiary age are distinct layers extending deep into the subsurface. The layers dip relatively uniformly between 0.25 and 2 degrees to the southeast (about 4 to 34 m/km; 20 to 180 ft/mi). Thus, they can be envisioned as a tilted stack of cards. The substrate of the environmental geologic unit mapped at the surface continues as a layer into the subsurface beneath other layered environmental geologic units.

Modern river deposits (alluvium) form a veneer on top of the Tertiary deposits. Rivers erode valleys into the Tertiary deposits while simultaneously depositing sediment in the valleys. Alluvial deposits in the Brazos River Valley are as much as 21 m (70 ft) thick but are commonly much thinner elsewhere and do not extend far into the subsurface. The fundamental difference in the three-dimensional aspects of the substrates of the environmental geologic units has important implications for exploration for lignite or ground water and for potential migration of mine drainage through the subsurface away from a lignite mine.

The major lignite deposits of Texas occur in three geologic units. From oldest to youngest they are the Wilcox Group, the Yegua Formation, and the Jackson Group (fig. 1). All the units are part of the Gulf Coast Tertiary province and are composed of clastic sediments—various mixtures of sand, silt, and clay. All lignite presently mined comes from the Wilcox Group; however, plans are underway for mining in both the Yegua and Jackson units and in additional areas in the Wilcox Group. Some lignite deposits in the Wilcox, Yegua, or Jackson units occur beneath alluvial deposits of major rivers. There, mining to obtain the lignite will first intersect the alluvium. The environmental geologic maps include all of the outcrop area of the Wilcox Group and the overlying Carrizo Sand, and parts of the overlying Reklaw Formation and Queen City Sand and the underlying Midway Group. Figure 3 is a geologic map of the area covered by the environmental geologic maps.

The Wilcox Group is composed of sand and mud deposited by ancient river systems in East and northeast Texas and in ancient barrier-bar and lagoon-bar systems in South Texas (Fisher and McGowen, 1967, Kaiser and others, 1978). The Wilcox Group between the Colorado and Trinity Rivers has been subdivided into three formations (Barnes, 1970, 1974).

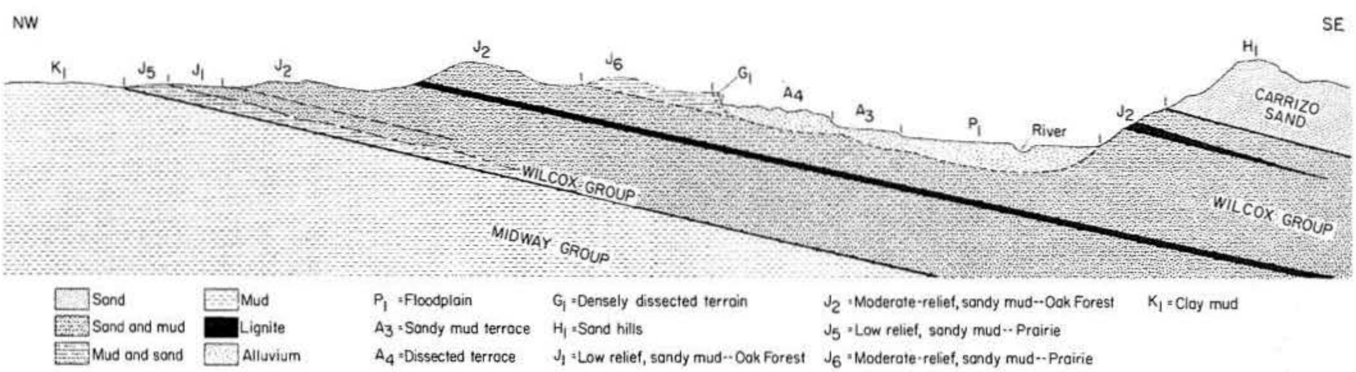


Figure 2. Schematic cross section showing relation between environmental geologic units at the surface and those in the subsurface.

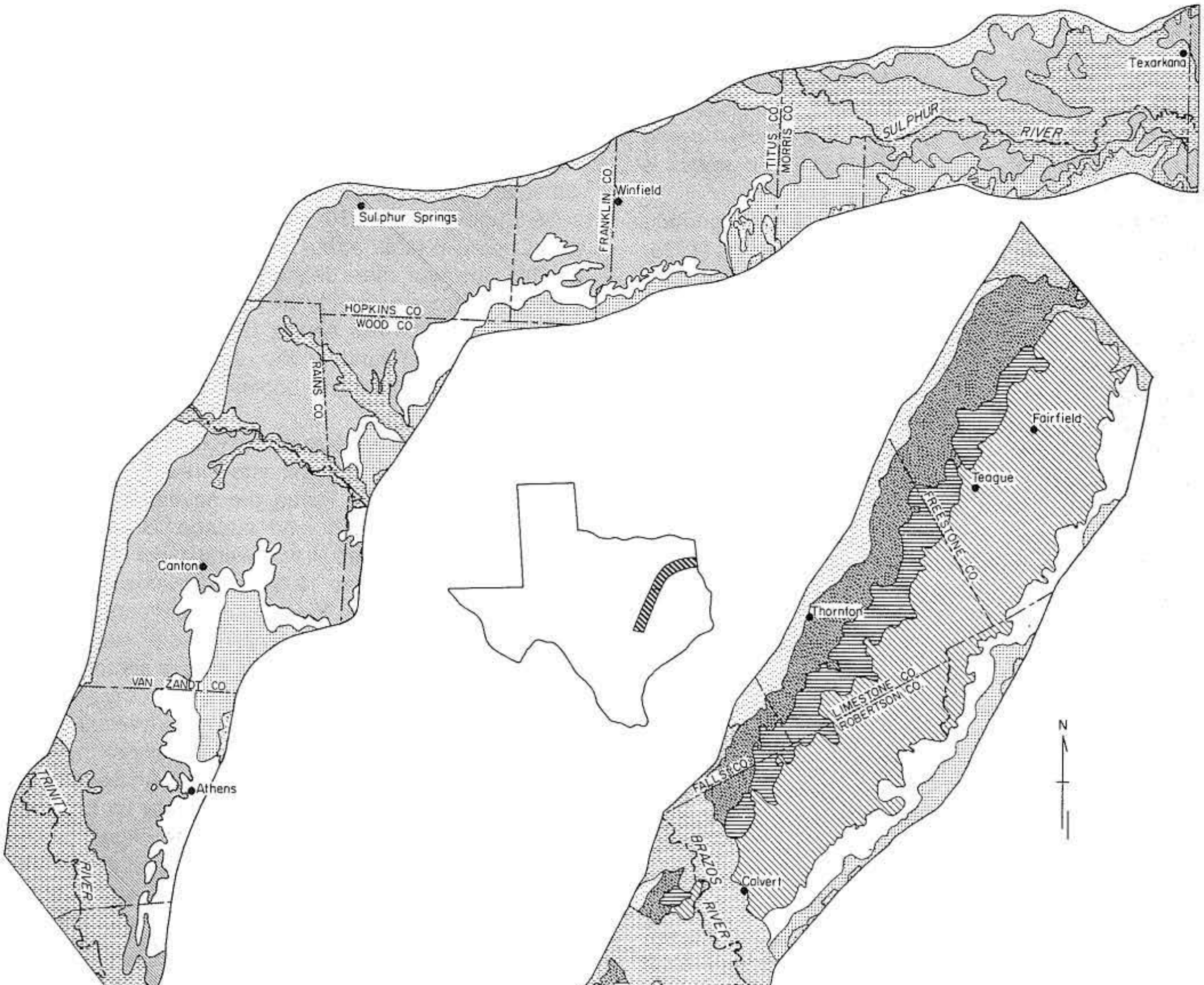


Figure 3. Geology of Wilcox Group lignite belt, East Texas.

From oldest to youngest, they are the Hooper Formation composed of mud and minor amounts of sand, the Simsboro Formation composed of sand, and the Calvert Bluff Formation composed of sand and mud. The Calvert Bluff Formation is the major lignite-bearing formation; however, lignite in the Hooper Formation is also receiving exploration attention.

The environmental geologic map and subsurface study of the Wilcox Group by Kaiser and others (1978) show that the Simsboro Formation pinches out as a continuous sheet sand southwest of the Trinity River in Freestone County. Even farther to the southwest, the Simsboro Formation forms a discontinuous outcrop, pinching out in several locations.

Detailed study of the Calvert Bluff Formation (Kaiser and others, 1978) indicates that it was deposited in a fluvial (riverine) environment. Major channel deposits (thick sands) are surrounded by extensive interchannel floodbasin deposits of sandy or silty clays and laminated sands and clays. Lignite seams occur mostly in the interchannel deposits.

The Wilcox Group northeast of the Trinity River is similar to the Calvert Bluff Formation. Sands deposited by ancient river systems are surrounded by deposits of fine-grained interchannel muds (Kaiser and others, 1978). As in the Calvert Bluff Formation, lignite occurs in the interchannel deposits. The Wilcox Group in the Sabine Uplift, which is located southeast of the study area, was not mapped in this study but is geologically similar to the Wilcox Group northeast of the Trinity River.

In the study area, environmental geologic mapping was completed over four Tertiary stratigraphic units that contain no lignite: Midway Group, Carrizo Sand, Reklaw Formation, and Queen City Sand. Only the uppermost part of the Midway Group is included in the environmental geologic maps. It is composed of silty clay of shallow marine origin. The Carrizo Sand is a thick, continuous sheet sand that extends from South Texas into northeast Texas near Mt. Pleasant. It is composed primarily of coarse-grained meanderbelt and braided-stream deposits (J. H. McGowen, personal communication, 1976) and contains no lignite.

The Reklaw Formation is composed of both sands and clays. In many places the lower part consists of fine sand and glauconite (an iron-rich mineral) and is commonly cemented with hematite; the upper part is mostly clay. The Queen City Sand consists of interbedded fine sand and clay.

Modern river deposits of sand, gravel, and clay occur within valleys of major streams, blanketing the older Tertiary material. These deposits are commonly coarsest at their base and become progressively finer upward. Areas of river deposits include floodplains where deposition still occurs during floods and terraces where deposition no longer occurs. River deposits contain no lignite.

General Hydrology

The Wilcox, Carrizo, and Queen City units are important sources of ground water. Though the Carrizo Sand and Wilcox Group are separate geologic units, sands within the two units are hydraulically connected either laterally or vertically, both at the surface and in the subsurface (Follet, 1970; Peckham, 1965). In general, the Carrizo-Wilcox strata are considered a single aquifer. However, three different sands characterize the Carrizo-Wilcox aquifer: (1) the thick, laterally extensive Simsboro and Carrizo sands, (2) the isolated (at the surface) channel sands in the undifferentiated Wilcox Group, and (3) the sand bodies in the Calvert Bluff Formation.

Much potential recharge is rejected by the Carrizo-Wilcox aquifer and runs off into streams. Like most aquifers in moist East Texas, the aquifer is saturated with water to near the land surface. Ground-water movement determined from water-table elevations (Guyton and Associates, 1972) is mostly downdip to the southeast. In addition, there is a significant shallow component of movement towards the major river valleys (Colorado, Brazos, Trinity) where some ground water discharges at seeps and springs. Many streams within the outcrop area are perennial as a result of the ground-water discharge. The natural rate of ground-water movement generally ranges between 3 and 30 m (10 and 100 ft) per year and occasionally up to about 100 m (300 ft) per year (Guyton and Associates, 1972). Recharge and rate of flow are controlled by the saturation of the aquifer; only as much water as is discharged from the aquifer can enter the aquifer and move downdip. Natural removal of ground water is by leakage through confining beds into stratigraphically higher aquifers and eventually to the surface.

Results of the environmental geologic mapping, along with correlation with subsurface analysis, provide a detailed picture of the sand geometry of the Wilcox and Carrizo. These results and applications to hydrology and ground-water availability are discussed in a later section of the report (see p. 21).

Geomorphology

The lignite belt is part of the Gulf Coastal Plain characterized by gently rolling to hilly countryside. The geomorphology closely follows the geology. Sands are generally more resistant to erosion and form topographic highs; mud deposits are more easily eroded and are expressed as valleys. The three major sand formations, the Simsboro, Carrizo, and Queen City units, form low irregular escarpments or cuestas of rounded, steep-sided hills that rise as much as 30 m (100 ft) above adjacent areas. The substrate of the Reklaw Formation is similar to muddy parts of the Wilcox Group and develops a low linear terrain parallel to and between the Carrizo and Queen City sands south of the Trinity River. North of the Trinity River, iron-cemented sands and muds in the Reklaw Formation form linear ridges or isolated hills. Areas of the clay-rich Midway Group are gently rolling and have generally more subdued topography than most areas in the Wilcox. Major rivers have cut broad, flat valleys that trend generally southeast across the area (fig. 3).

Soils, Vegetation, Climate, and Land Use

The environmental geologic maps encompass parts of three vegetational regions: Post Oak Savannah, Blackland Prairie, and East Texas Pineywoods (fig. 4). Each region is defined by a characteristic assemblage of vegetation and by characteristic soils. Different soil types result from the action of soil-forming processes on different substrates; climate, particularly rainfall, is a major factor in soil formation. Together, soils and climate determine vegetation. Thus substrate, soil, vegetation, and climate are highly interrelated. Substrate materials range from mostly sands to predominantly clay with both local and regional variations. The modifying influence of climate causes both local and regional variations in soil and vegetation.

General climatic characteristics are summarized in figure 5. Notable features are the increase in precipitation and the decrease in evaporation from west to east. Thus, lignite areas in East Texas are relatively water-rich, whereas lignite areas in South Texas are water-poor. Prevalence of water influences not only the natural characteristics of the land but also the ease and effectiveness of different reclamation methods in the mining areas.

The Wilcox strata are mostly intermediate in texture, that is, composed of subequal amounts of sand, silt, and clay. However, sandy beds occur throughout all seven map areas. Most of the area of the environmental geologic maps is within the Post Oak Savannah. Soils of the Post Oak Savannah are characteristically thin sandy loams over dense clay B horizons. Claypan soil derives its name from the characteristic clay B horizon. Areas of sandy substrates within the Wilcox Group and the adjacent Carrizo Sand have sandy soils with little clay accumulation in either the A or B horizon. The Post Oak Savannah is a region of transition from the deciduous forests of the east to the grassy prairies of the west. Vegetation consists of post oaks, blackjack oaks, and elms. A more detailed description of vegetation of the East Texas lignite belt is given by Holm (1975). Cattle raising is the dominant land use, although until the 1930's cotton farming was a major use. Much of the land is now cleared for improved pasture, and what land is not cleared is used as rangeland. At present only minor amounts of land are cropland.

Southwest of the Colorado River is a distinct transition from sandy Wilcox strata to more clayey substrates and soils. The transition follows the change in depositional environment of the Wilcox Group from fluvial in East Texas to lagoonal and deltaic in South Texas. Portions of the outcrop south of the Colorado River are Blackland Prairie. The Blackland Prairie also borders the Post Oak Savannah to the north and west

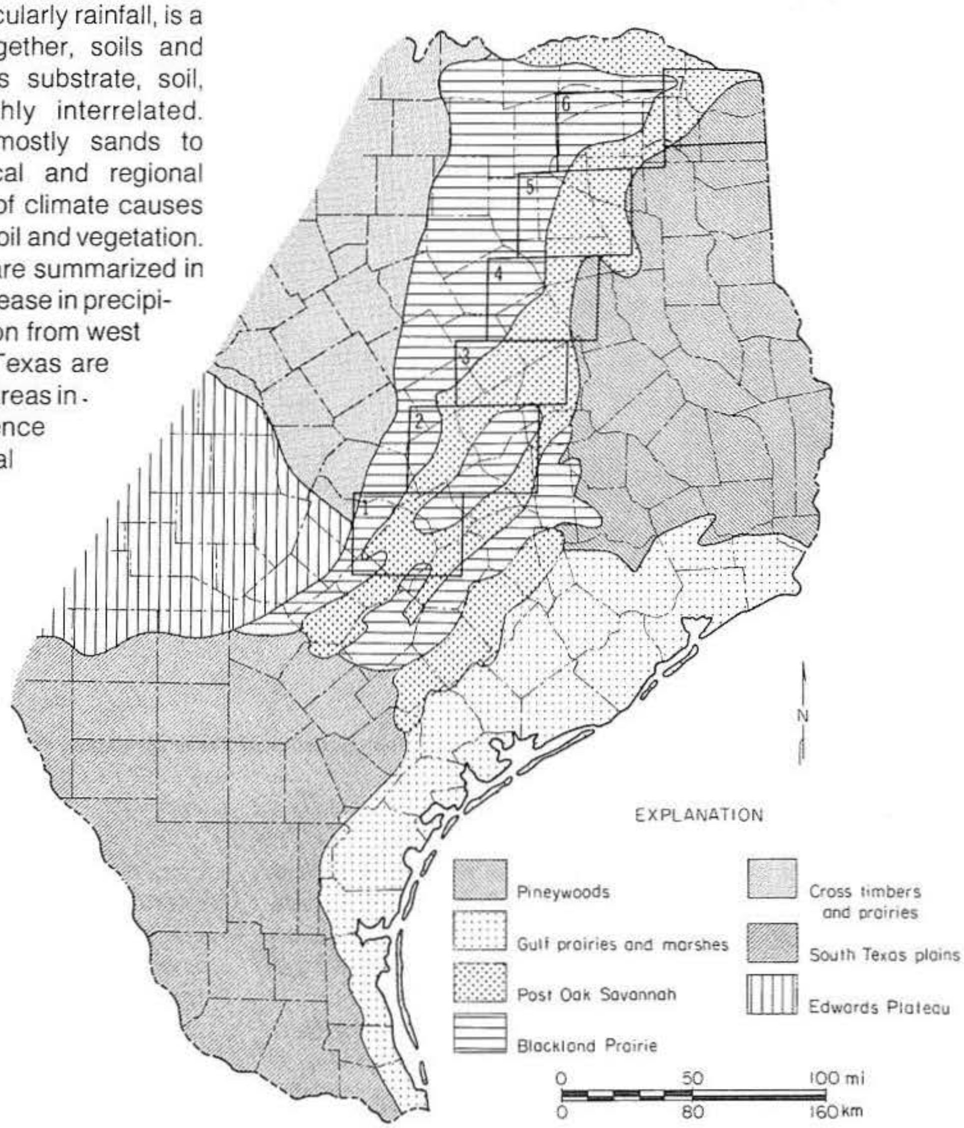


Figure 4. Vegetation areas of Texas (adapted from F. W. Gould, 1969). Map areas of this report are indicated by the numbered rectangles.

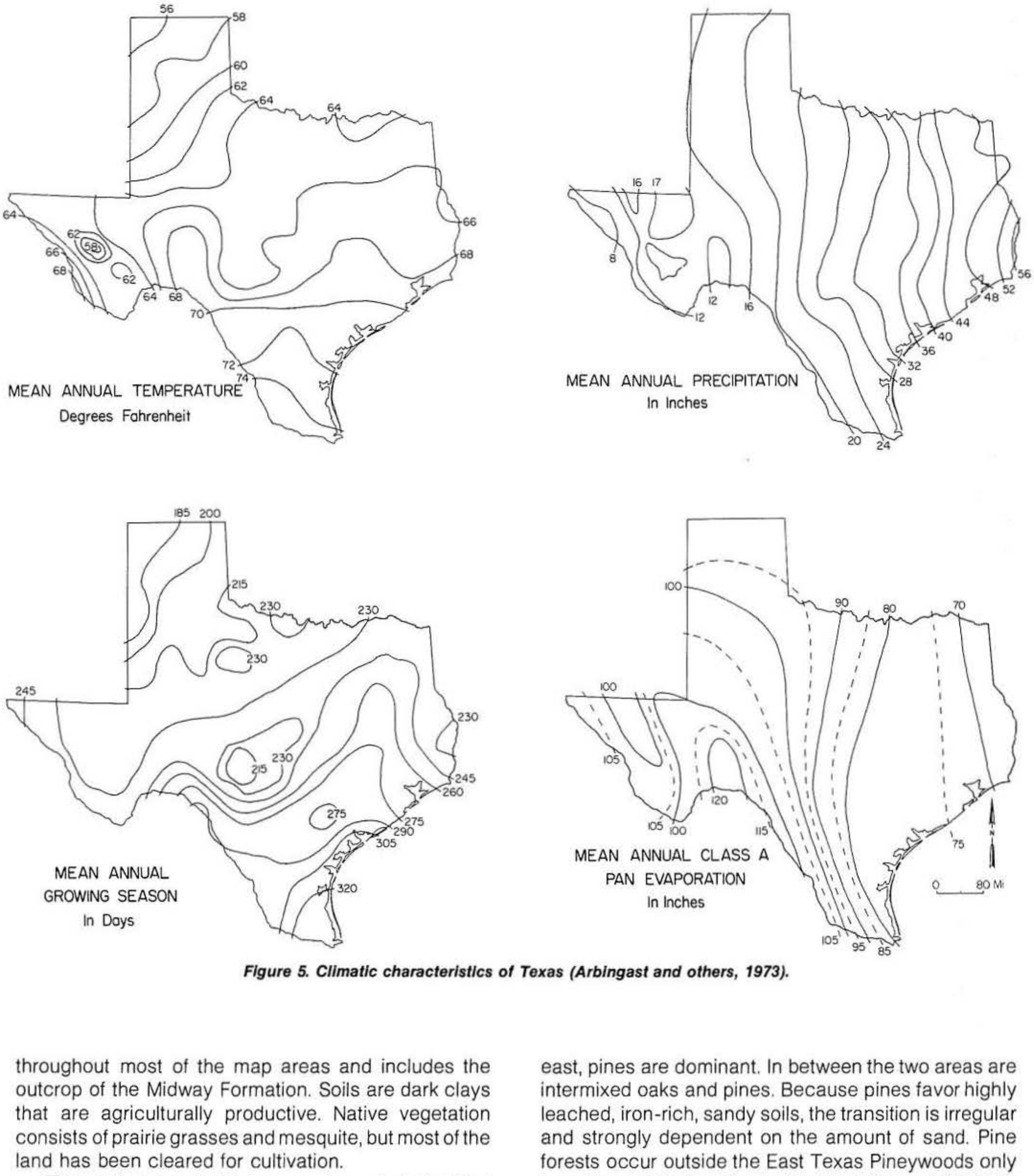


Figure 5. Climatic characteristics of Texas (Arbingast and others, 1973).

throughout most of the map areas and includes the outcrop of the Midway Formation. Soils are dark clays that are agriculturally productive. Native vegetation consists of prairie grasses and mesquite, but most of the land has been cleared for cultivation.

The northeast part of the mapped area is in the East Texas Pineywoods. There, substrates are similar to those of the Post Oak Savannah, but the greater precipitation of East Texas has produced slightly sandier and more leached soils on which a different vegetation assemblage develops. The change in vegetation is depicted on map sheets 6 and 7. To the west and southwest, post oaks are dominant; to the east, pines are dominant. In between the two areas are intermixed oaks and pines. Because pines favor highly leached, iron-rich, sandy soils, the transition is irregular and strongly dependent on the amount of sand. Pine forests occur outside the East Texas Pineywoods only in a few outliers such as the Lost Pines of Bastrop County. The Lost Pines occur on well-drained, sandy soils and are a remnant of a once more extensive pine forest. Land use in the Pineywoods is somewhat similar to that of the Post Oak Savannah. Cattle raising, a major industry, includes the cultivation of grain and forage crops and the use of forests for grazing land. However, lumbering is also important; both pines and hardwoods are produced on the uplands, and principally hardwoods on the floodplains. Pines have been introduced extensively as a cash crop outside their natural range. The construction of numerous reservoirs for water resources development has made the Pineywoods region well suited for recreational and industrial use.

Soils on alluvium of the major rivers throughout the Post Oak Savannah are deep clays and clay loams. Suspended, fine sediment derived partly from the Blackland Prairie and deposited by floods is the parent material. Like soils of the Blackland Prairie, the alluvial soils are more productive than are claypan soils. Where protected from too frequent flooding, the bottomlands are heavily cultivated, primarily for cotton or grain sorghum. Some parts of bottomlands that flood frequently or for long periods are not cultivated and are covered with thick forests of water-tolerant hardwoods. Characteristics of floodplain soils along small streams that drain only Wilcox outcrop are strongly determined by their parent materials. However, these areas are more productive than the claypan areas because the soils are more evenly textured and water is readily available. Soils of major rivers throughout the Pineywoods are similar to soils of the major rivers of the Post Oak Savannah, but most of these floodplain areas are left in their natural vegetative cover of water-tolerant hardwoods.

ENVIRONMENTAL GEOLOGIC MAPPING

The approach to environmental geologic mapping used in this study was developed during previous environmental studies conducted by the Bureau of Economic Geology (Wermund, 1974). Earlier work on the lignite belt (Henry and Kastning, 1975; Henry, 1976) and adjacent areas (Gustavson and Cannon, 1974) established much of the the methodology used here and also delineated many of the environmental geologic map units. Environmental geologic units are delineated by the various properties of the land that define the basic capabilities and types of productive use that the land can sustain. All environmental units of this report are defined with emphasis on their usefulness in planning mining and reclamation. The criteria used to define each environmental unit are as follows:

(1) Substrate—materials of the geologic formation.
(2) Soil—derived from substrate materials.
(3) Geomorphology—land form and relief.
(4) Geologic process—physical processes active on or near the earth's surface.
(5) Biological assemblage—mostly natural vegetation.
(6) Land use—human influence on natural cover.

In preparing the environmental geologic maps we had to determine what could and should be mapped. Field examination of the lignite belt was initiated to determine what environmental geologic units were mappable and to evaluate those units within the above six criteria. As distinctive units were identified, their characteristics in relationship to other units were determined. Once the field investigation had identified a group of potential environmental geologic units, areas were examined on 1:20,000 and 1:40,000 black-and-white stereographic aerial photographs to see if the units had distinctive characteristics that could be recognized from the photographs.

Photographic interpretation involved (1) tone, which varies with soil type, substrate material, vegetation, and moisture content, (2) patterns of tonal variation, which indicate changes in soil type, substrate, vegetation, or human modification, (3) morphology, which indicates substrate structure and composition, topographic conditions, and erosional or depositional processes, and (4) vegetation, for which various biologic assemblages can be identified. Summertime, high-altitude color-infrared negatives—scale 1:120,000—were used in the northernmost part of the study area to supplement the identification of vegetation species not readily interpreted on black-and-white aerial photographs.

Units were also subdivided on the basis of relief, determined by visual inspection of topographic maps. Eventually, a mappable set of environmental geologic units was established from the correlation of field, photographic, and topographic map investigation. Preliminary units, which were determined from field investigations but could not be distinguished on aerial photographs, were consolidated in mapping.

Most mapping consisted of examination of aerial photographs for preliminary delineation of environmental geologic units. The mapped areas were then checked extensively in the field to confirm the photographic identification and to ensure consistent usage as mapping progressed to new areas. As new areas were encountered the environmental geologic units were constantly reevaluated to determine whether or not they were appropriate in these areas. Additional environmental geologic units were added as necessary. Personnel from various agencies such as the U. S. Soil Conservation Service were consulted to ensure both that the environmental geologic units were properly identified and that those units would be useful to people conducting research in technical areas including soils.

After field checking, the environmental geologic units were transferred to U. S. Geological Survey 7.5-minute quadrangle maps (1:24,000) which are now on open file at the Bureau of Economic Geology. The final compilation of the units is published on a set of seven 1:125,000 base maps, with a topographic contour interval of 50 ft, which includes the following cultural features: major State and Federal highways, railroads, cities and towns, county boundaries, and Federal lands.

The cultural information was compiled from recent county highway maps published by the Texas Department of Highways and Public Transportation. Locations, names, and normal and maximum pool elevations for reservoirs in the study area were obtained from the Texas Department of Water Resources.

DESCRIPTIONS OF ENVIRONMENTAL GEOLOGIC UNITS

Subdivision of Units

On the basis of the 6 criteria described in the preceding section, 22 environmental geologic units have been recognized. Most characteristics of these units are presented in table 1. The units are discussed only briefly here to illustrate some applications and characteristics that could not easily be summarized in the table. The units were subdivided into three categories for classification. Two major categories are separated on the basis of their distinctive land forms (geomorphic units), or by the nature of their substrate material (substrate units). A third category of man-made units has only two units, surface-mined and surface-mined/reclaimed land, distinguished entirely by the effect of human activities. Nevertheless, they are distinctive units, uniquely different from other units defined by natural characteristics.

Units were further subdivided within the two major classes. Geomorphic units were subdivided into bottomland, terrace, and miscellaneous units; substrate units were subdivided into sand, sand and mud, mud, and miscellaneous substrates.

Although units were divided for classification in this manner, each unit is defined in terms of all six criteria. That is, each unit has characteristic substrate, soil, geomorphology, process, vegetation, and land use properties. The units could have been subdivided in several other ways. For example, they could have been grouped by process, such as flooding or recharge, or they could have been grouped as hydrologic units or resource units. Any such classification scheme is useful in emphasizing important characteristics. The classification scheme used here is logical, simple, and convenient.

A letter-number system is used to identify different units on the environmental geologic maps. The system is derived from but not identical to previous systems used in earlier environmental studies by the Bureau of Economic Geology (Gustavson and Cannon, 1974; Kier and others, 1977).

Geomorphic Units

Geomorphic units include two bottomland units, floodplain (P1), and undifferentiated alluvium-colluvium (P2), both of which are subject to flooding. Four different terrace units are distinguished by the composition of surficial material and by dissection as clay terrace (A1), sand terrace (A2), sandy mud terrace (A3), and dissected terrace (A4). Two miscellaneous geomorphic units, densely dissected terrain (G1) and natural ponds (G2), complete the geomorphic category. In addition, an overlay identifies those terraces that are subject to low-frequency flooding. The letter-number symbols in parentheses refer to designations on the colored environmental geologic maps.

Bottomland Units.—The overriding criterion for the classification of floodplains is the flooding process. Although other characteristics are also distinctive, flooding is such a major constraint on use of floodplains that it is the overriding basis for classification. Flood-prone areas were identified from historical records, including water stage records and personal recollection of local residents, and from geomorphic evidence of floodwater erosion or deposition.

On the environmental geologic maps, natural floodplains are identified without regard to flood control structures. Many of the floodplains of East Texas are protected from flooding to a variable degree. For example, dams have been constructed on the Colorado, Brazos, Trinity, and Sulphur River systems, and an extensive dike system protects the Trinity River floodplain (see map sheet 4). However, heavy rains falling downstream from a dam could still produce flooding. The probability of flooding is reduced but not eliminated by the dam. The precise frequency or extent of flooding cannot be determined. A flood covering most of a floodplain could occur several times in one year or not at all in several years. Clearly, higher parts of floodplains will flood less frequently than lower elevations.

Soils on floodplains are relatively clayey and highly fertile. Where not flooded frequently or for prolonged periods, such floodplains are extensively cultivated. Many floodplains are frequently flooded or stay wet for long periods, however, and are used solely for rangeland (or wildlife habitat). Flooding and agricultural productivity of floodplains are discussed more thoroughly below.

Undifferentiated alluvium-colluvium occurs as narrow belts in the headwaters of drainages along small streams throughout all map areas. The substrate along the streams is composed of alluvium deposited by the stream and colluvium washed down from slopes above the stream. The contact between the two types of material is gradational and indistinct. The two materials commonly interfinger to produce a land surface that is gently sloping, concave upward. Some areas of undifferentiated alluvium-colluvium are cleared for pasture along with adjacent non-alluvial areas. However, many areas are left as a narrow greenbelt providing a source of shade and surface water for livestock.

Areas of undifferentiated alluvium-colluvium are subject to flooding; in fact, many such areas have small floodplains that could not be identified at the scale of the environmental geologic map. Flooding can be as frequent as for larger floodplains, but because drainage areas to these streams are small, the volume of flood water and the areas flooded are relatively small.

Terrace Units.—Terraces are simply abandoned floodplains that were dissected by a downcutting river. Several levels of terraces can be recognized along major rivers. Many characteristics of terraces, including substrate and soil composition and relief are inherited from floodplains and are similar to those of floodplains except that terraces are no longer subject to flooding. Vegetation is more like that of upland areas of similar substrate than like the water-tolerant species of floodplains, partly because most terraces have been cleared.

Three kinds of terraces are distinguished by their surficial material. Sandy mud terraces with sandy loam and fine sandy loam soils are most abundant, but clay terraces with clay and clay loam soils are nearly as abundant. Both occur as large areas along major throughgoing rivers such as the Brazos, Trinity, or Sulphur Rivers. Sand terraces with sandy soils are rare and occur only as small patches within larger terraces and along small streams draining dominantly sand substrates. Many terraces have fertile, productive soils and are extensively cultivated especially because, unlike floodplains, they are not as subject to flooding.

Many terraces are partly dissected, either along their edges or along headwardly eroding streams. Terraces are considered dissected where dissection is sufficiently extensive to create a rolling topography rather than the flat surfaces characteristic of terraces. Dissected terraces commonly have gravel lag with clayey to sandy soils dependent upon original substrate and amount of dissection.

Miscellaneous Geomorphic Units.—Densely dissected terrain with slopes up to 25 percent occurs along several major rivers where lateral cutting of the river has created steep embankments adjacent to the floodplain. Subsequent erosion of the embankment has created almost a badlands topography. Soils are generally thin to absent because they are eroded away as quickly as they develop. The steep slopes and lack of soil severely limit use; even natural vegetation is depleted.

Natural ponds occur throughout the lignite belt in two settings: (1) on terraces composed of impermeable substrates, and (2) within sand (sand hills or low rolling sands). Ponds on terraces are unfilled depressions of former floodplains. Water collects in the ponds because they are low areas in impermeable substrates. Such ponds dry out during dry seasons.

Ponds within sand hills or low rolling sands are natural closed depressions that may have developed by wind erosion during the former drier climatic period. The ponds contain water year round, and the water elevation does not fluctuate significantly, suggesting that the ponds are at the water table within the sands.

Both densely dissected terrain and natural ponds are defined by surface features only. Unlike most other units, they have no characteristic substrate, nor do they extend into the subsurface. Alteration of the surface characteristics of either could totally eliminate them.

Substrate Units

Substrate units include (1) three sands: sand hills (H1), low rolling sands (H2), and fine sands (H3); (2) six sand and mud units with similar substrate but distinguished by soil composition, natural vegetation, and relief: low- and moderate-relief sandy mud—prairie (J5 and J6), low- and moderate-relief sandy mud—oak forest (J1 and J2), and low- and moderate-relief sandy mud—pine forests (J3 and J4); (3) one clay mud unit (K1); and (4) two miscellaneous substrate units, both of which contain abundant ironstone: high-relief iron-cemented uplands (L1), and rolling ironstone and sand (L2). The mapping code is given in parentheses here.

Sand Units.—Three different sand units have been distinguished on the basis of differences in relief, substrate, and soil. Sand hills and low rolling sands are found on all seven map sheets, whereas the fine sand unit occurs only on sheet 7 where it occurs within the outcrop of the Queen City Sand. The substrate of each unit consists of friable, fine to coarse sand. However, the fine sand unit is composed dominantly of fine, silty sand, whereas sand hills are composed of coarser, cleaner sand. The substrate of low rolling sands ranges from fine to coarse sand. All three are recharge areas for important aquifers, and the difference in grain size of the substrate material is significant in determining the hydrologic properties of each.

Soils on the various sand units are sandy and highly leached.The soils depicted on map sheets 1 through 5 support dense oak forests. Northeastward (map sheets 6 and 7), pines become the dominant tree species. Historically, these sands have not been cultivated. However, in recent years many areas have been cleared for pastures, which generally require heavy fertilization and sprig planting.

Sand and Mud Units.—Sand and mud units compose most of the area of the environmental geologic maps. The substrate consists of sandy mud and interbedded sand and mud for all units. Three broad subdivisions have been identified on the basis of differences in soils and vegetation and slight differences in substrate composition. Additionally, each subdivision has a category for low and moderate relief.

The sandy mud—oak forest units have sandy loam and loamy sand A horizons over dense clay B horizons (claypans). Natural vegetation consists of oaks and elms throughout map sheets 1 through 5. Map sheets 6 and 7 show a transition in vegetation to a mixture of oaks

Table 1. Properties of the environmental geologic

	Composition of substrate	Soil Characteristics, A and B horizon (Solum)	Topography, slope	Process	Vegetation	Current land use
Floodplain P1	Clay, sand, and gravel	Clay and clay loam (A and B)	Flat to gently sloping 2%	High to moderate flood frequency	Water-tolerant hardwoods	Cropland, pastureland, aquifer, rangeland
Undifferentiated alluvium-colluvium P2	Alluvium, colluvium; sand, silt, clay	Silt and silt loam (A and B)	Flat to gently sloping concave upward	Flooding	Oak-elm-hickory-box elder association	Pastureland (or uncleared "greenbelt")
Clay terrace A1	Clay, sand, and gravel (clay at surface)	Clay and clay loam (A); clay and silty clay (B)	Flat to gently sloping 2%	Minor recharge	Prairie grasses and mesquite (map sheets 1, 2, 4); oak-elm association (map sheet 7)	Cropland, pastureland, minor aquifer, gravel pits
Sand terrace A2	Clay, sand, and gravel (sand at surface)	Loamy sand (A); sandy clay loam (B)	"	Recharge	Oak forest	Minor aquifer, gravel pits, pastureland
Sandy mud terrace A3	Clay, sand, and gravel (sandy mud at surface)	Sandy and fine sandy loam (A); sandy clay loam (B)	"	"	"	Pastureland, cropland, minor aquifer, gravel pits
Dissected terrace A4	Minor clay, sand and gravel	Sandy clay and gravelly loam (A); sandy clay loam (B)	Rolling slopes 2-5%	Erosion and sheetwash	Oak and pine forest	Rangeland, pastureland, gravel pits
Densely dissected terrain G1	Intermixed sands and muds	Variable	Steep with local scarps	"	Oak to pine forest	Forest, range
Natural ponds G2	Variable (sand hill or terrace)	Determined by local substrate	Flat-bottomed depression	Ponded water	Water-tolerant grasses	Rangeland
Sand hills H1	Friable to loose sands, locally iron-cemented	Sand and fine sand (A); sand to sandy clay loam (B)	Rolling to steep hills 3-8%	Recharge	Pine-oak forest; post-oak to blackjack oak to oak-pine	Aquifer, rangeland, pastureland, commercial timberland in northeast
Low-rolling sands H2	Friable to loose sands	"	Flat to gently rolling hills 0-3%	"	"	"
Fine sand H3	Friable to loose fine sands	Fine sandy loam and loamy sand (A); sandy clay loam and sandy loam (B)	Rolling to steep hills 3-10%	"	Pine forest	Aquifer, commercial timberland, rangeland, pastureland
Low-relief, sandy mud—oak forest J1	Interbedded sand and mud and sandy mud	Sandy loam and loamy sand (A); clay loam and clay (B)	Flat to gently rolling hills 0-3%	"	Oak-elm association (map sheets 1-5); oak-elm-hickory association transitional to pine (map sheets 6, 7)	Pastureland, rangeland, aquifer
Moderate-relief, sandy mud—oak forest J2	"	"	Rolling to steep hills 3-8%	"	"	"

units of the Wilcox Group Lignite Belt, East Texas.

Physical properties (Shrink-swell potential)	**Infiltration capacity**	**Hydraulic conductivity,** $m^3/m^2/d$ (gpd/ft^2)	**Aquifer potential**	**Hydrologic characteristics**	**Resources, economic potential** (material resources)	**Distribution** (map sheet)
Variable—depending on surface material (mostly high because mostly clay)	Low to moderate	Variable	Good—large rivers with coarse, thick alluvium; low—small floodplains with thin alluvium	Very good aquifer in major rivers with thick, coarse alluvium; poor to fair aquifer in small rivers with thin alluvium	Sand and gravel (below floodplain)	1, 2, 3, 4, 5, 6,7—along moderate to large rivers
Variable, but mostly low—little clay	Moderate (to underlying bedrock)	"	Poor—thin deposit	Poor aquifers—deposit too thin	———	1, 2, 3, 4, 5, 6, 7—along headwater streams
High	Low—poorly drained versus permeable	Clay soil relatively impermeable; substrate variable	Good permeable substrate but relatively thin deposit, perched water table	All terraces have good permeable substrate, but perched water tables make them of local significance only	Commercial (industrial) clays; also sand and gravel	1, 2, 4, 7—along major rivers
Low	High	Variable, generally 6-20 (147-490)	Moderate	"	Sand and gravel	1, 2, 3, 4, 7—small areas along major rivers and small streams
Low to moderate	Moderate to low	Variable	Poor to moderate	"	"	1, 2, 3, 4, 5, 6, 7—along major rivers
Low	Moderate to high	"	"	"	Sand and gravel deposits	1, 2, 3, 4, 7
"	Variable—dependent on surface material and substrate	"	Poor or none	———	———	1, 2, 4, 6, 7
Not applicable (?); low on H1, H2 moderate to high on terraces	Low—terraces; high—H1, H2;	Variable, generally 1-2 (25-50)	Poor—but part of sand aquifer	———	———	1, 2, 3, 4, 5, 6
Low	High	6-20 (147-490)	Good	All sands are very good major aquifers, but fine sand has lower permeability	Sand deposits; commercial timberland	1, 2, 3, 4, 5, 6, 7
"	"	"	"	"	"	1, 2, 3, 4, 5, 6, 7
"	"	"	Moderate to good	"	"	7
Low to moderate	High to moderate	Variable—range 1-2 (25-50) of mud to 6-20 (147-490) of sands	Variable—good to poor	Good aquifers, with pine forest units having slightly higher permeability; interbedded thin sands are irregularly distributed; water quality is variable	Lignite	1, 2, 3, 4, 5, 6,7
"	"	"	Good	"	"	1, 2, 3, 4, 5, 6, 7

Table 1. Properties of the environmental geologic units

	Composition of substrate	Soil Characteristics, A and B horizon (Solum)	Topography, slope	Process	Vegetation	Current land use
Low-relief, sandy mud—pine forest J3	Interbedded sand and sandy mud	Sandy loam and loamy sand (A); sandy clay loam (B)	Flat to gently rolling hills 0-3%	Recharge	Dominantly pine forest	Rangeland, pastureland, commercial timberland
Moderate-relief, sandy mud—pine forest J4	"	"	Rolling to steep hills 3-8%	"	"	Rangeland, pastureland, commercial timberland, recreational area
Low-relief, sandy mud—prairie J5	Interbedded sand and mud and sandy mud	Fine sandy loam and clay loam (A); clay and silty clay (B)	Flat to gently rolling hills 0-3%	Major recharge	Prairie grasses and mesquite (map sheets 1-6); oak forest (map sheet 7)	Cropland, minor aquifer
Moderate-relief, sandy mud—prairie J6	"	"	Rolling to steep hills 3-6%	Minor recharge	"	Cropland, pastureland, minor aquifer
Clay mud K1	Clayey mud	Clay and clay loam (A); clay (B)	Flat to gently rolling hills 0-5%	Gulleying	Prairie grasses and mesquite	Cropland, pastureland
High-relief, iron-cemented uplands L1	Iron-cemented sand and mud	Gravel lithosols; ironstone material	Steep with local scarps 8-25%	Sheetwash	Mixed oak-juniper forest; pine-oak forest	Rangeland—quarried for road metal
Rolling ironstone and sand L2	Interbedded sand and iron-cemented sand and mud	Gravel and sand	Gently to moderately rolling hills 3-8%	Recharge	Oak-mesquite forest; pine-oak forest	"
Gravel cap L3	Siliceous gravel (chert), probably highly dissected terrace remnant gravel lag	Gravelly sandy loam	Flat to gently rolling hills 0-5%	"	Oak forest	Gravel pits
Surface-mined/ reclaimed land M1 or M2	Variable—mostly sand and mud and sandy mud now disturbed by mining (M1)	Unreclaimed—no soil; reclaimed—homogenized substrate	Reclaimed flat to gently rolling; unreclaimed—pits, etc.	———	Dependent on reclamation use—pasture, oak, pines	Relcaimed—pastureland, unreclaimed—some stock ponds, generally unused
Low terrace Overlay	Same as modified terrace	Same as modified terrace	Same as modified terrace	Low-frequency flooding	Same as modified terrace	Same as modified terrace
Flood-prone land Overlay	Same as modified unit	Same as modified unit	Same as modified unit	"	Same as modified unit	Variable—but influenced by flooding potential

of the Wilcox Group Lignite Belt, East Texas *(con.).*

Physical properties (Shrink-swell potential)	**Infiltration capacity**	**Hydraulic conductivity,** $m^3/m^2/d$ (gpd/ft^2)	**Aquifer potential**	**Hydrologic characteristics**	**Resources,economic potential** (material resources)	**Distribution** (map sheet)
Low	High to moderate	Variable—range 1-2 (25-50) of mud to 6-20 (147-490) of sands	Good	Good aquifers, with pine forest units having slightly higher permeability; interbedded thin sands are irregularly distributed; water quality is variable	Lignite	7
"	"	"	"	"	"	7
Moderate to high	Moderate to low	Variable—mud characteristics dominant	Fair	Poor aquifers, some thin sands (fewer than oak and pine forest sandy muds) interbedded with relatively impermeable deposits	"	1, 2, 3, 4, 5, 6, 7
"	"	"	Fair to low	"	"	1, 2, 3, 4, 5, 6, 7
High	Low	Extremely low	None	Not an aquifer	Ceramic clays	1, 2, 3, 4
Low	Low to moderate	Variable	Fair	Variable due to decrease in permeability by iron-cementing, also high iron ion concentration of water, with L2 slightly higher in permeability because of the presence of clean sands	Sand and gravel deposits	1, 2, 3, 4, 5, 6, 7
"	Moderate	"	Moderate (to good)	"	"	1, 2, 3, 4, 5, 6, 7
"	High	6-20 (147-490)	Good—but thin deposits (permeable substrate)	———	Gravel	2
"	Moderate to high	Variable	Reclaimed—variable; unreclaimed—not applicable	Reclaimed material is disturbed (homogenized) sand and mud; overall high permeability, which decreases slightly as material compacts with time	Additional sands, gravel, clays	1, 2, 3, 4, 5, 6, 7
Same as modified terrace	Same as modified terrace	Same as modified terrace	Same as modified terrace	Same as modified terrace	Same as modified terrace	2, 3, 4, 5, 6, 7
Same as modified unit	Same as modified unit	Same as modified unit	Same as modified unit	Same as modified unit	Same as modified unit, possibly influenced by flooding potential	2, 3, 5, 6, 7

and pines, but the transition area has not been mapped as a separate unit. On map sheet 7 two separate sand and mud units, those with dominantly pine trees as natural vegetation, are recognized. The two sandy mud—pine forests units have overall slightly sandier soils, which, along with the difference in vegetation, distinguish them from the sandy mud—oak forest units. Otherwise, substrate composition is similar. The transition in soil and vegetation probably results from the progressive increase in rainfall in East Texas.

The sandy mud—prairie units have fine sandy loam and clay loam A horizons and clay B horizons. These units are common in areas of Wilcox outcrop only on map sheets 1 and 2, are rare in the Wilcox outcrop on sheets 3 and 4, and occur only in the Midway Group on sheets 5 through 7. The fine-grained soils probably reflect both finer grained substrates and lesser rainfall in the southwestern parts of the environmental geologic maps. Natural vegetation consists of prairie grass and mesquite throughout map sheets 1 through 6 but changes to oaks on sheet 7. Today, areas of sandy mud—prairie units are commonly cleared for cropland or pastureland. When settlers first came to East Texas, and to some extent even now, the sandy mud—prairies were areas of prairie among thick oak forests.

The substrate of the sandy mud units was deposited in interchannel areas by Tertiary river systems. Peats were also deposited in the interchannel areas and were eventually transformed to lignite; all present lignite mining is in the sandy mud units, and undoubtedly almost all future mining will also be there. Lignite mining may, however, intersect other units where the sandy mud substrate dips underneath them.

The sand and mud units are the most variable of any of the environmental geologic units in substrate composition and in proportion of sand and mud. The variation is on a local scale, however, and is difficult to recognize, especially because of the homogenizing influence of soil development. Nevertheless, each of the sand and mud units contains thin, but permeable, interbedded sand layers. The sands give the sand and mud units important potential as aquifers, and the proportion of sand to mud in the different units determines their hydrologic characteristics.

Runoff and erosion are major processes acting on the sand and mud units. In many places erosion has cut through the protective cover of vegetation and soil to produce deep, steep-walled gullies. Clearing of the vegetative cover for agriculture has aggravated erosion and produced such extensive gully systems that large tracts of land were made unusable. Because much mining and reclamation will occur in this substrate, its erodability is an important characteristic.

Clay Mud Units.—The clay mud unit has a clay substrate and develops clay and clay loam soils of high shrink-swell capacity. The clay mud unit is rare in the Wilcox Group except south of the Colorado River. In the mapped region its major occurrence is in the adjacent, underlying Midway Group, but even in the Midway strata it does not occur north of the area depicted on sheet 4. Clay soils developed on the clay substrate are highly fertile and extensively cultivated.

Miscellaneous Substrate Units.—Iron-cemented sands and muds compose the substrate of two units. In areas of the most extensive iron-cementing the substrate material is highly indurated and resistant to erosion. The resistant material forms high-relief iron-cemented uplands with slopes commonly greater than 10 percent. Most of the few rock outcrops of East Texas consist of ironstone. The steep slopes and rocky soil limit use to rangeland. The high-relief iron-cemented upland unit grades into rolling ironstone and sand with a decrease in amount of iron-cementing and an increase in the proportion of uncemented sands. Slopes are less than 8 percent, and there are no indurated outcrops; soils are commonly red and have abundant ironstone concretions. Vegetation on both units grades from oaks and rarely mesquite (sheet 1) to oaks and pines (sheet 6) and oaks, pines, and hickory (sheet 7).

Man-Made Units

Surface-mined and surface-mined/reclaimed land are two related man-made units. The units are subdivided as to whether mining was for lignite (M1) or for clay, sand, gravel, or ironstone (M2). Some areas mined for lignite have been or are being reclaimed as shown by an overlay pattern on the accompanying maps. No areas mined for other materials have been reclaimed; most such unreclaimed areas are barren ground with little or no productive use or borrow pits or quarries partly filled with water.

Overlays

Two additional overlay patterns were used to modify mapped units. One is for flood-prone land, land upstream from reservoirs and below spillway elevation. These lands could be flooded during periods of high water in the reservoir. The flood-prone land description can modify all other units, and all other characteristics are simply those of the modified unit.

The other overlay pattern indicates low terraces. Historical evidence indicates that certain low terraces along major rivers have been inundated during low-frequency, high-magnitude floods. These terraces do not show geomorphic evidence of flooding, however, and cannot be mapped as floodplains. The low-terrace designation is restricted to terraces no more than 3 m (10 ft) above the identified floodplain.

Additional Information Presented on the Environmental Geologic Maps

Additional information provided on the maps includes the location of existing and proposed lignite surface mines, existing and proposed lignite-fired power plants, abandoned underground mines, and areas of potentially minable lignite.

Existing and proposed lignite surface mines are indicated both in figure 1 and on map sheets 1 through 7. As of July 1978, there were five active mines in the Wilcox Group: three are located within the area presently mapped, and two others are over the Sabine Uplift. Numerous additional mines are planned, not only in the Wilcox lignite belt but also in outcrops of the Yegua and Jackson Formations. Identified planned mines are shown in figure 1. They are also shown on map sheets 1 through 7, but only where the location is precisely known. Many additional areas have been leased and will undoubtedly be mined. However, areas and plans are so uncertain at this time that they cannot be shown either in figure 1 or on the environmental geologic maps. Existing and proposed lignite-fired power plants are similarly shown on map sheets 1 through 7 and listed in table 2.

From the late 1800's to 1944, lignite was mined underground by the room-and-pillar method in many parts of East Texas. All underground mines are now abandoned. With the advent of large-scale surface mining and experimentation with in situ gasification of lignite, there is almost no possibility that underground mining for lignite will again be used. The sites of all underground mines where their locations are precisely known are shown on the various maps. Location was based on onsite examination or recognition on aerial photographs of old shafts, railroad right-of-ways, and sinkholes formed by collapsed tunnels. Additional abandoned underground mining areas reported by Fisher (1963) and Fisher and others (1965) that cannot be precisely located are listed in table 3 but are not shown on the environmental geologic maps.

Areas of potentially minable lignite to a depth of 60 m (200 ft) are shown on the environmental geologic maps and are from Kaiser (1974, 1978, and unpublished data). Location of these areas was determined largely from the distribution of channel sand and interchannel muds derived from examination of electrical logs. Lignites were deposited in interchannel areas composed primarily of sandy muds and interbedded sand and mud rather than in channels. In table 1 lignite is shown as a potential resource in the several sandy mud units because the lignite occurs in the substrate of these units. As shown by the distribution of potentially minable lignite, lignite can also occur below the surface area of other environmental geologic units, for example floodplains, although it does not occur in the substrate material of those units.

Location of old underground mining areas and of outcrops of lignite, and results of recent lignite exploration were used to define the distribution of lignite more precisely. Additionally, the results of environmental geologic mapping, which shows the surface distribution of channel sands and interchannel muds, have further defined the lignite distribution. The distribution of potentially minable lignite shown on the environmental geologic maps is derived from the best available information. However, without extensive drill core data the precise location of lignite and the exact number and thickness of seams in any one area cannot be determined.

A depth of 60 m (200 ft) has been used as a practical limit for extraction of lignite by surface mining. Below that depth a combination of technical and economic restraints will probably restrict most surface mining. For example, slumping of the high wall may make it impossible to mine at greater depths. Lignite does occur below 60 m (200 ft), and there is considerable interest in methods to extract either the lignite or the energy contained within lignite. In situ gasification, a process by which lignite is converted in place to low-Btu gas, is the most promising method. Presently, several companies are experimenting with gasification; one test plant is operating near Tennessee Colony near the Trinity River southeast of the area depicted on map sheet 4, and one is planned near Alcoa Lake (sheet 2).

APPLICATIONS OF THE ENVIRONMENTAL GEOLOGIC MAPS

State and Federal Mining Laws

The environmental geologic maps of the Wilcox lignite belt were prepared because of the extensive interest in mining lignite and the recognition that mining could have a considerable impact on land and water resources. Although the maps' uses are decidedly not limited to planning of mining, illustration of the application by comparison with requirements of recent State and Federal mining laws is useful. As such, this discussion updates and expands the discussion in Henry (1976).

Regulation of lignite mining in Texas has had a complex history. In 1975, the Texas Legislature passed the Texas Surface Mining and Reclamation Act, which regulated surface mining for coal, lignite, and uranium in Texas. In 1977, Congress passed the Federal Surface Mining Control and Reclamation Act, which regulates surface mining nationwide but only for coal and lignite. The Federal law takes precedence over the State law. However, a provision of the Federal law allows each state to administer its regulatory program if the state's program meets the requirements of the Federal law. The 1975 law was based partly on an early draft of the

Table 2. Active and planned surface mines.*

Name	Map sheet	Location: County	Location: Vicinity	Owner	Date started (scheduled)	Power plant (MW)	Comments
Sandow	2	Milam	SW of Rockdale	Aluminum Company of America Aluminum Company of America and Texas Power and Light Company	1954 (1981)	3-120 575	Power plant and mine area on map
Milam	2	Milam	E of Rockdale	Shell Oil Company	(1981)	?	Mine area on map
Twin Oak	3	Robertson	E of Bremond	Texas Power and Light Company and Aluminum Company of America	(1984-1985)	2-750	Power plant on map
Oak Knoll	-----	Limestone	E of Kosse	Texas Utilities Generating Company	(1985?)	2-750	-----
-----	4	Freestone	E of Fairfield	Dow Chemical Company	(1981?)	?	-----
Big Brown	4	Freestone	NE of Fairfield	Texas Utilities Generating Company	1971	2-575	Power plant and mine area on map
-----	4	Henderson	SW of Athens	North American Coal Company	(1982?)	?	Mine area on map
Forest Grove	4	Henderson	W of Athens	Texas Utilities Generating Company	(1982)	750	Power plant on map
Monticello	6	Titus	W of Mt. Pleasant	Texas Utilities Generating Company	1974	2-575 1-750	Power plant and mine area on map
-----	6	Hopkins	SE of Sulphur Springs	Texas Utilities Generating Company	1978	To supply Monticello Power Plant	Mine area on map

*Information from Texas Railroad Commission and W. R. Kaiser (1978).

Federal law and thus in many respects already met Federal requirements. However, to fullfill the total requirements the Texas Legislature passed the Surface Coal Mining and Reclamation Act in 1979. Uranium mining is still regulated by the 1975 law.

Sections of the Texas law require that applicants for a surface mining permit (1) identify the natural capability of the land prior to mining, (2) control erosion and sedimentation into surface water, (3) avoid chemical pollution of ground and surface water, (4) provide adequate top soil of sufficient quality for revegetation, and (5) minimize disturbance to the prevailing hydrological balance. In addition, the law states that certain areas may be deemed unsuitable for surface mining, including (1) areas in which reclamation is unfeasible, (2) areas of frequent flooding or unstable geology, (3) areas that contain aquifers and aquifer recharge, or (4) areas of important natural systems that will be damaged significantly by mining operations. The Texas law is administered by the Railroad Commission.

Permanent regulations of the Federal law are set forth in the Federal Register of March 13, 1979. Several provisions of the Federal law are significant in Texas. They are provisions for (1) restoration of mined land capability, (2) designation and treatment of prime farmlands during mining, (3) protection of the hydrologic balance of both ground and surface water, including quality and quantity of water, and (4) protection of the hydrologic functions of alluvial valleys. Court challenges to the regulations may result in some modifications but are not likely to alter the major thrust of the regulations.

The environmental geologic maps may facilitate meeting the requirements of both State and Federal surface mining laws. However, the maps may also be used to plan any project that requires land with specific characteristics or that needs to avoid areas with other characteristics. For example, land for disposal of solid wastes should have an impermeable substrate. The clay mud environmental geologic unit fits this requirement, whereas none of the sand units do. Muddier, less permeable parts of any of the sand and mud units could have appropriate substrates, but because the units also contain interbedded sands, sites in areas of sand and muds would have to be selected carefully. Floodplains might have impermeable near-surface material, but excavation of a disposal pit could intersect coarser, more permeable alluvium below the

Table 3. Abandoned underground mines.

Map sheet	Location County	Location Town	Placement on environmental geologic maps	Surface evidence	Comments
1	Bastrop	8 km (5 mi) N of Bastrop	Precise	Shaft, abandoned railroad right-of-way	*
1	Bastrop	13 km (8 mi) N of Bastrop	Near Sayersville	None known	*
1	Bastrop	Near McDade	Not known	None known	*
2	Lee	13 km (8 mi) S of Rockdale	Precise	Shafts	Hicks mining area *
2	Milam	11 km (7 mi) SW of Rockdale	Not shown	None known	In area of present surface mining *
2	Milam	3-6.5 km (2-4 mi) E of Rockdale	Precise	Shafts; extensive, collapsed underground workings	One of largest mining areas *
2	Milam	16 km (10 mi) W of Calvert	Not shown	None known	Jones Prairie *
2	Milam	Near Milano	Not shown	None known	*
2	Robertson	8 km (5 mi) W of Calvert	Precise	Collapsed underground workings	In floodplain of Brazos River * †
2	Robertson	N of Calvert	Not shown	None known	* †
3	Leon	8 km (5 mi) S of Donie	Approximate	None known	Bear Grass and Evansville mining areas* †
3	Freestone	Near Donie	Approximate	None known	* †
4	Henderson	1.5-3 km (1-2 mi) N of Malakoff	Precise	Collapsed underground workings; abandoned surface mines	Malakoff mining area * †
4	Henderson	6.5 km (4 mi) ENE of Malakoff	Precise	Shafts	Malakoff mining area * †
4	Henderson	Athens	Not shown	None known	*
5	Van Zandt	Near Canton	Not shown	None known	* †
5	Van Zandt	Near Edgewood?	Not shown	None known	*
5	Van Zandt	Near Grand Saline	Not shown	None known	†
5	Wood-Rains	1.5-5 km (1-3 mi) S and E of Alba	Precise	Numerous shafts; collapsed underground workings	Alba mining area †

Table 3. (*con.*)

Map sheet	Location County	Location Town	Placement on environmental geologic maps	Surface evidence	Comments
5	Rains	6.5 km (4 mi) SE of Emory	Approximate	None known	* †
6	Hopkins	Near Sulphur Springs	Not shown	None known	*
6	Hopkins	E of Como	Precise	Collapsed underground workings	Como mining area * †
6	Hopkins	5 km (3 mi) N of Como	Precise	Collapsed underground workings	Como mining area * †
6	Camp	5 km (3 mi) WSW of Leesburg	Precise	Collapsed underground workings	Newsome mining area * †
6	Titus	Winfield	Precise	None known	Near site of present surface mine* †
6	Titus	S of Mt. Pleasant	Not shown	None known	* †
7	Titus	1 km (0.5 mi) N of Cookville	Not shown	None known	* †
7	Cass	N of Cass	Not shown	None known	* †
7	Bowie	8 km (5 mi) N of Maud	Precise	Collapsed underground workings	* †
7	Bowie	5 km (3 mi) N of Maud	Not shown	None known	Carbondale mining area * †

*Reported by Fisher (1963)
†Reported by Fisher and others (1965)

surface. This possibility along with the potential for flooding makes floodplains poor disposal sites. The environmental geologic maps are intended for applications such as these.

Land Capability

Both the State and Federal laws require identification of land capability, not simply present land use, of any proposed mining area. The distinction between land capability and land use is essential. An area of land may not presently be used for a purpose of which it is capable. For example, potentially productive agricultural land may not now be cultivated, yet could be put into production as demands for food increase. Restoration of such "unused" land simply to present use may significantly alter its capability. Alternatively, an area such as an aquifer recharge area may have a natural capability that is independent of human use. People may be dependent on the recharge area for water supply but are not consciously using it as such. Proper restoration of land capability would recognize this natural capability.

Identification of land capability is precisely the intent of the environmental geologic maps. By considering all natural characteristics of the land and distinguishing different types of land on the basis of those characteristics, the maps provide an accurate inventory of land resources. Applications of the environmental geologic maps which follow are actually specific illustrations of identifying land capability.

Prime Farmland

Recognizing the need to preserve productive agricultural land, both the State and Federal laws have provisions for reclaiming mined land to a condition equal to or better than that before mining. Specifically, the Federal law requires the designation, on the basis of soil and land use characteristics, of areas of prime farmland and mandates methods of topsoil preservation and reclamation. Prime farmland is generally defined as having characteristics to "economically produce sustained high yields of crops when treated and managed according to modern farming methods." Prime farmland must also have been used for the production of cultivated crops for at least 5 of the last 20 years. Specific criteria for designation of prime farmlands are based on U. S. Department of Agriculture classification of soils. The criteria describe required moisture, temperature, chemical, textural, and permeability characteristics of the soils.

Many soils and most of the land area within the lignite belt presently mapped probably met the original requirement to be designated prime farmland. However, some ambiguity exists in the exact interpretation of the regulations. For example, there was initially some uncertainty as to whether or not improved pasture constituted a cultivated crop.

One critical criterion of the initial regulations requires that soils have minimum permeability of 0.06 inches per hour in the upper 20 inches to be designated prime farmland. However, if the mean annual soil temperature is 59°F or higher, permeability is not a limiting factor. This criterion makes the extensive East Texas claypan soils prime farmland. Claypan soils have sandy loam and fine sandy loam A horizons and clay B horizons. The clay B horizons generally have lower permeability than required, but they also have mean annual soil temperatures greater than 59°F. The claypan soils also meet other specific requirements.

Designation of claypan soils as prime farmlands and disregard of the permeability factor is considered inappropriate by many soil scientists (L. R. Hossner, personal communication, 1978). Although the claypan soils do not make poor farmland, they are considerably less productive than soils of Texas generally considered the best farmland. The low permeability is in fact one of the critical features in the low productivity of claypan soils. The impermeable clay B horizon prevents proper drainage of the soil during wet seasons and makes the soils droughty during dry seasons. The dense clay also makes rooting of row crops and even pasture grasses difficult. Finally, the soils are low in nutrients, particularly organic matter, potassium, and phosphorus, as are most of the highly leached soils of East Texas.

Most of the claypan areas are used as improved pasture. It was initially uncertain whether pasture constituted cultivated land because discing is necessary for establishment of pasture. A recent interpretation concludes that pasture grass is not a cultivated crop.

Studies of reclamation at the lignite mine that supplies the Big Brown Steam Electric Station near Fairfield show that reclamation using unsegregated overburden to develop a new soil is in most respects equal to or superior to reclamation by segregation of top soils (Hons and others, 1978). The unsegregated overburden is low in nutrients but has nutrient concentrations equal to those of original top soils. More important is the fact that disruption of the dense clay B horizon and mixing of overburden create a more evenly textured soil having better permeability and drainage that allows vegetation to establish roots more easily. Segregation and restoration of the various soil horizons would in fact retain the worst characteristics of the claypan soil. Thus, segregation of soil, commonly regarded as necessary for reclamation, would retard revegetation.

On the basis of such studies, State and Federal authorities agreed that (1) segregation and restoration of top soil would not be required and mixing with overburden would be allowed where adequate evidence existed that the technique would result in land as productive as or more productive than the land before mining; (2) permeability is a limiting factor in the designation of prime farmland regardless of mean annual soil temperature; (3) rangeland, woodland, and pastureland where the only cultivation consisted of discing to establish forage cover are not considered cultivated land (Heine, 1978).

Procedures for handling soils in designated prime farmland are delineated in the regulations. Generally, the soils must be stripped off and stockpiled separately from overburden and restored after overburden is restored and regraded.

The claypan soils are a special case. In many mining areas in Texas and other states, soils will need to be segregated and restored because they are superior to the mixed overburden. An example is found at the proposed San Miguel lignite mine in South Texas (fig. 1) where top soils will be segregated. A study by the applicant shows that although the original soils are not of the highest quality they are superior to mixed overburden. Although top soil segregation is not required in every case, restoration of the land to equal or better productivity is required.

The environmental geologic maps can be used as a regional inventory of agricultural land, especially as an inventory of land most likely to be mined. By law, final responsibility for designation of prime farmland rests with the U. S. Soil Conservation Service. Because of the uncertainty in designation at this time, it is appropriate to talk only about regional aspects.

Lignite occurs in the substrate of the various sand and mud environmental geologic units. With a few exceptions, mining will intersect one of the sand and mud units. Exceptions exist where one of the geomorphic units (for example, floodplains or terraces) blankets the sand and mud substrate or where lignite extends under another substrate unit. In either situation, mining will have to cut through the other units to reach lignite. Even with these exceptions, most mining will be in the sand and mud units.

Claypan soils are characteristic of the low- and moderate-relief sandy mud—oak forest units. Thus soils of these units will generally not be designated prime farmland. Some areas of prime farmland soils are included in these units, but the areas are only a small part of the total. They will need to be identified by site-specific studies.

Clay soils that are typical of the clay mud environmental geologic unit will probably be designated prime farmland. The clay soils have high nutrient contents and are extensively farmed. However, areas of clay soils on clay mud units are rare within the Wilcox lignite belt north of the Colorado River; they do not occur at all north of the area on map sheet 2 except in the outcrop area of the Midway Group which contains no lignite. The environmental geologic maps show that there is little overlap between areas of minable lignite and areas of clay mud. Thus, it is unlikely that these areas of probable prime farmland will be mined.

Soils of the low- and moderate-relief sandy mud—prairie environmental geologic units are transitional between those of the clay mud and those of sandy mud—oak forest units, but many are claypans. According to Soil Conservation Service figures, most soils of the sandy mud—prairies are more productive than soils of the sandy mud—oak forest units and are more commonly cultivated. There is some overlap between areas of minable lignite and areas of sandy mud—prairie. Site-specific evaluation of the soils will be needed if mining occurs in these areas.

The greatest overlap between prime farmland and minable lignite is most likely to occur on floodplains and terraces. Soils of these units are highly productive and will probably be designated prime farmland. The further impact of mining on floodplains and terraces is discussed more fully below.

Ground-Water Resources

Impact of Lignite Development.—Possibly one of the most critical impacts of lignite mining will be its effect on both quantity and quality of ground and surface water. Like lignite, water is a resource, but human dependence upon water is far more absolute than our dependence on lignite.

Consumption of lignite will place great demands upon water, primarily for cooling of power plants, and use of water for lignite development will reduce its availability for other uses. In Central and East Texas, surface water will be the major source of water for lignite development, but much surface water is already appropriated for other uses. Thus, increase in ground-water consumption will result from displacement of surface-water uses. In South Texas, which has little available surface water, ground water will have to be used almost exclusively. All cooling water for the proposed San Miguel lignite operation (fig. 1) will come from the Carrizo aquifer.

Lignite mining and associated activities can alter both the quantity and the quality of water. Water quantity can be affected by alteration of recharge characteristics of substrates involved in mining and by consumption of water for lignite development. Water quality can be altered by drainage of water from a mine into either ground or surface water. Problems of mine drainage are reviewed by Henry (1976). Additionally, increase in population accompanying lignite development could also contribute to water pollution.

It is therefore necessary to have an accurate inventory of ground and surface water, including knowledge of both quantity and quality, and of how they will be affected by lignite development. Ground water is probably of more critical concern because more is known about surface water and because identifying and avoiding impact on surface water is easier than identifying and avoiding impact on ground water. To evaluate the quantity and quality of ground water, it is necessary to know the geometry and hydrologic characteristics of an aquifer, the area where recharge occurs, and the relationship of lignite (and therefore of lignite mining) to the aquifer.

Geometry of the Carrizo-Wilcox Aquifer.—Three distinct parts of the Carrizo-Wilcox aquifer have already been mentioned; the thick sheet-like Carrizo and Simsboro sands, the channel sands of the undifferentiated Wilcox Group, and those of the Calvert Bluff Formation. Interchannel areas of the Wilcox Group and Calvert Bluff Formation are composed of interbedded sand and mud and sandy mud and are the host for lignite seams. Understanding the geometry of the various sands and their occurrence relative to lignite deposits will show how mining can impact ground water.

The Simsboro and Carrizo sands are the dominant water-bearing formations of the Carrizo-Wilcox aquifer. On the environmental geologic maps, the outcrop of the two units is mapped as sand hills and low rolling sands as are the Wilcox and Calvert Bluff channel sands. The environmental geologic maps do not specifically identify the Simsboro and Carrizo stratigraphic units, but their location can be determined by correlation with figure 3. Although the outcrops have been mapped previously, the environmental geologic maps provide an updated and more precise delineation of the area. Substrates of both the sand hills and low rolling sands are friable to loose sands with sandy soils. These units exhibit low drainage density, which suggests little runoff and high permeability. Most of the recharge to the sands probably occurs in these outcrop areas. Thus the environmental geologic maps provide an inventory of recharge areas.

The environmental geologic maps show that the Simsboro Formation between the Colorado and Trinity Rivers is not a continuous sand body as previously considered, but a complex of large but discontinuous sands. On the other hand, the Carrizo Sand is more continuous and extensive in outcrop.

The Simsboro and Carrizo sands are thick coarse-grained sand units that dip 0.25 to 2 degrees to the southeast. Ground-water flow is generally downdip at a rate as high as 30 m/year (100 ft/year). Both sand formations are highly permeable—6 to 20 $m^3/m^2/d$ (150 to 490 gpd/ft^2)—and are usually saturated to or near the land surface because of the high rainfall of East Texas. The Simsboro and Carrizo aquifers extend far into the subsurface and have extensive recharge areas. Thus, there is abundant ground water available for use. The overall quality of available water is very good; that is, total dissolved solids (TDS) are no more than several hundred mg/l. Because these sands are highly permeable, they have been extensively flushed with meteoric water and contain little syngenetic soluble material that would contribute to the total dissolved solids.

The surficial outcrops of both the channel sands and the interchannel sands and muds of the Calvert Bluff Formation and the undifferentiated Wilcox Group had not previously been mapped. However, they are delineated on the environmental geologic maps. Outcrops of the channel sands are mapped as sand hills or low rolling sand units. These sands are recharge areas that appear as scattered sand bodies of various sizes in the Calvert Bluff Formation between the Colorado and Trinity Rivers and as isolated groups of small sand bodies or individual sand bodies of moderate size in the Wilcox Group north of the Trinity River.

Interchannel sand and mud in which lignite deposits are found are mapped as low- and moderate-relief, sandy mud—oak forest,—pine forest, or—prairie environmental geologic units. The substrate of all these units is interbedded mud and sand or thinly laminated sand and clay on which a sandy loam soil develops. These units form gently rolling landscapes, with slopes less than 8 percent. The drainage density is greater over the sandy mud units than over the sands, showing evidence of more runoff and less infiltration. Sandy mud substrates are far less permeable than cleaner sands and have been treated here as being relatively impermeable.

Correlating data from environmental geologic map units with subsurface mapping by Kaiser and others (1978) provides a good understanding of the geometry of the Wilcox aquifer (Basciano and Henry, 1978; Henry and Basciano, 1978). Kaiser and others used electrical logs to determine the total thickness and percentage of sand in the Wilcox Group. High-percentage sand areas in the Calvert Bluff Formation in the subsurface are stream channel complexes that project updip to sand outcrops. Low-percentage sand areas are interchannel areas that project updip to mud outcrops. This correlation is especially good in the vicinity of Fairfield in Freestone County (fig. 6). Here the major subsurface channel complexes greater than 30 m (100 ft) thick have relatively large outcrop areas (10 to 40 km^2 or 4 to

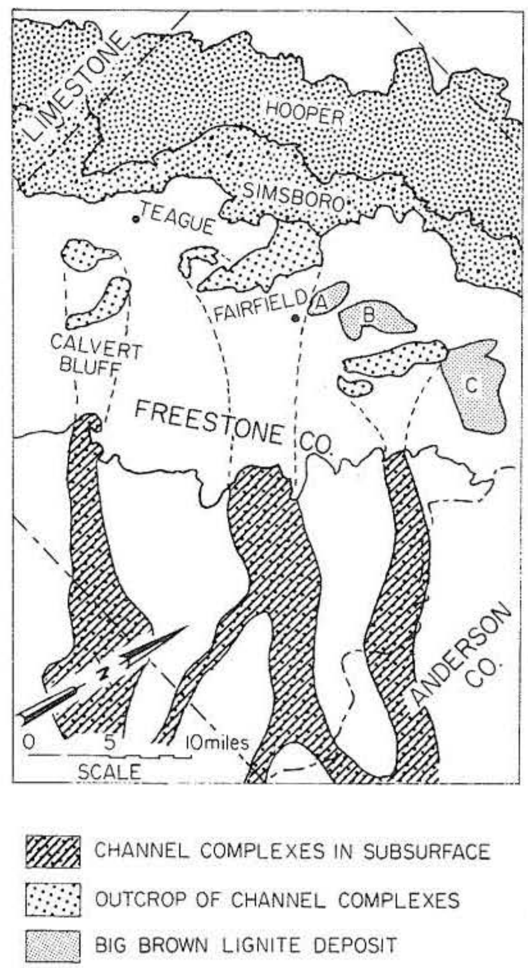


Figure 6. Lithofacies map of Calvert Bluff Formation, Freestone County, Texas (Henry and others, 1976).

16 mi²). Lignite deposits at one active mine occur adjacent to these sands in the outcrop area of the interchannel muds. A channel divides two major lignite deposits, A and B, from a third deposit, C. A major channel complex west of Fairfield marks the southwest limit of commercial lignite.

A cross section of the Fairfield deposit (fig. 7) shows that lignites are associated with interchannel muds that include thin, fine-grained tributary sands. Lignite beds are separated laterally by the thicker, coarse-grained sand channel complexes.

The environmental geologic maps indicate only the outcrop position of major sands. Sands less than about 6 m (20 ft) thick do not have sufficient surface expression to be mapped but can be identified on electrical logs. The fact that the outcrops of channel sand in the Fairfield area (fig. 8) are large and continuous suggests that the sands are few and thick rather than numerous and thin.

In the vicinity of Rockdale (fig. 8) the correlation of individual subsurface and surface units is not as good as it is near Fairfield. High sand percentages in the subsurface near Rockdale may be caused by several sands less than 6 m (20 ft) thick alternating with the mud in the Calvert Bluff Formation.

South of the Colorado River in Bastrop County (fig. 8) the subsurface data indicate a high mud content. In the same area the environmental geologic maps indicate very few sands. The southern region is the high-mud part of the deltaic system of the Wilcox Group, and the surface and subsurface mapping confirms that it is a low-sand area.

North of the Trinity River (fig. 9) the Wilcox Group is undifferentiated because the Simsboro Formation is no longer present as a continuous mappable unit. Therefore, sand percent maps are derived from the thickness of the entire Wilcox Group rather than from only the Calvert Bluff Formation. The region north of the Trinity River is within the fluvial-deltaic system of the Wilcox Group. Here sand channel complexes alternate with interchannel areas as in the subsurface south of the Trinity River. Environmental geologic mapping shows scattered sand outcrops concentrated in a few areas, for example, in the vicinity of Sulphur Springs in Hopkins County.

In the vicinities of both Texarkana and the Trinity River, our studies show that high-percent sand areas in the subsurface do not project updip to the surface. In these areas the environmental geologic maps indicate extensive alluvial cover, including floodplains and terraces, which obscures the Wilcox substrate and prohibits the direct correlation of subsurface and surface mapping.

Application to Hydrology.—Surface/subsurface correlations illustrate the complexity of the sand versus mud geometry of the Wilcox Group. Previously the Wilcox aquifer was treated as homogeneous because the information on geometry necessary to do otherwise was not available. Hydrology of the aquifer is controlled largely by the distribution of sands and muds. Sands are more permeable than muds; the degree of permeability depends on the grain size and sorting of the sands. Both the Simsboro and Carrizo sands are coarse grained and highly permeable; available hydraulic conductivity values range from 6 to 20 $m^3/m^2/d$ (W. F. Guyton, personal communication, 1978).

Hydraulic conductivities of channel sands in the Calvert Bluff Formation or undifferentiated Wilcox Group shown on the environmental geologic maps have not been determined directly. Hydraulic conductivity of the channel sands in these units is probably similar to that of the Carrizo and Simsboro sands for two reasons: (1) The channel sands are similar in grain size and sorting (Fisher, 1965) and in thickness to the coarse, permeable sands of the Carrizo and Simsboro units. (2) Hydraulic conductivity values determined in undifferentiated Wilcox Group fall into two categories: one at 1 to 2 $m^3/m^2/d$, which is associated with interchannel areas, and another at 6 to 20 $m^3/m^2/d$, associated with sands. The higher values are similar to those of the Carrizo and Simsboro sands and are apparently from channel sands in the Wilcox strata. These sands are both recharge areas in outcrop and permeable conduits carrying ground water in the subsurface. The relatively high hydraulic conductivity of the interchannel areas probably results from the presence of very fine grained to fine-grained distributary sands.

Water quality in the Wilcox Group is variable. Available Texas Department of Water Resources analyses (Texas Natural Resources Information System, 1977) generally range from several hundred mg/l to several thousand mg/l TDS. The Simsboro Formation and channel sands in the Calvert Bluff Formation contain water that has low total dissolved solids and similar composition (Henry and others, in press). Ground water in interchannel parts of the Calvert Bluff has higher dissolved solids resulting largely from higher chloride and sulfate concentrations. Water quality in channel sands and interchannel deposits of the undifferentiated Wilcox Group is probably similar to that in the Calvert Bluff Formation.

Conclusions and Application.—The comparison of environmental geologic mapping with subsurface mapping and hydrologic data shows the following correlations:

(1) High percent sands in subsurface with surface sand outcrops.

(2) Lignite deposits with interchannel muds.

(3) High permeability values with channel sands.

(4) Low total dissolved solids with channel sands.

Knowledge of variations in ground-water hydrology and water quality as reflected by sandy environmental geologic units can be used in planning strip mining.

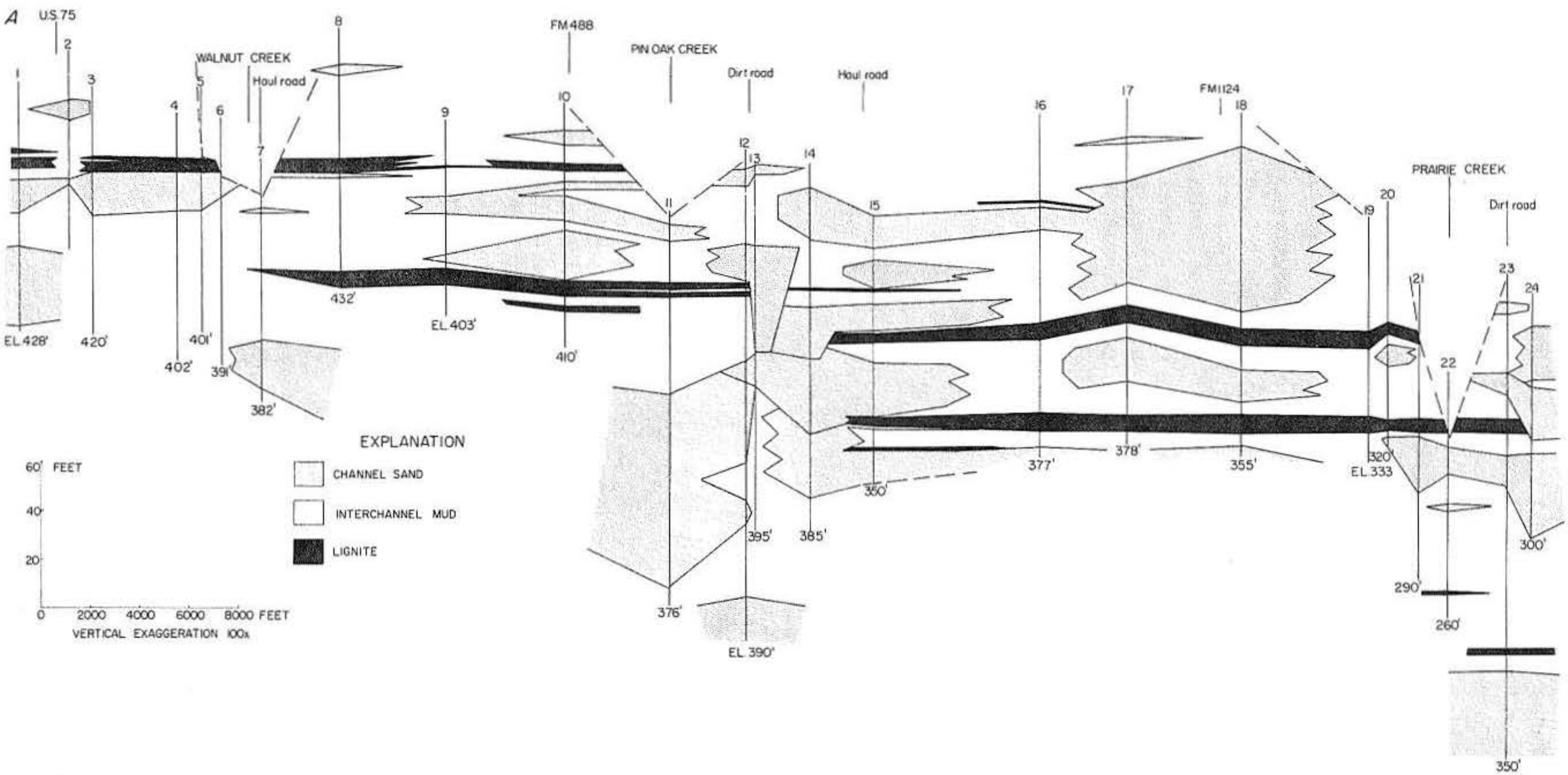


Figure 7. Strike section across the Big Brown lignite deposit (Henry and others, 1976). Most sands are thin, fine-grained tributary sands. The thicker sand complex in center of section is medium-grained channel fill.

Figure 8. Environmental geology of the Wilcox Group and subsurface geology of the Calvert Bluff Formation from Bastrop County to Trinity River (subsurface percent sand from Kaiser and others, 1978).

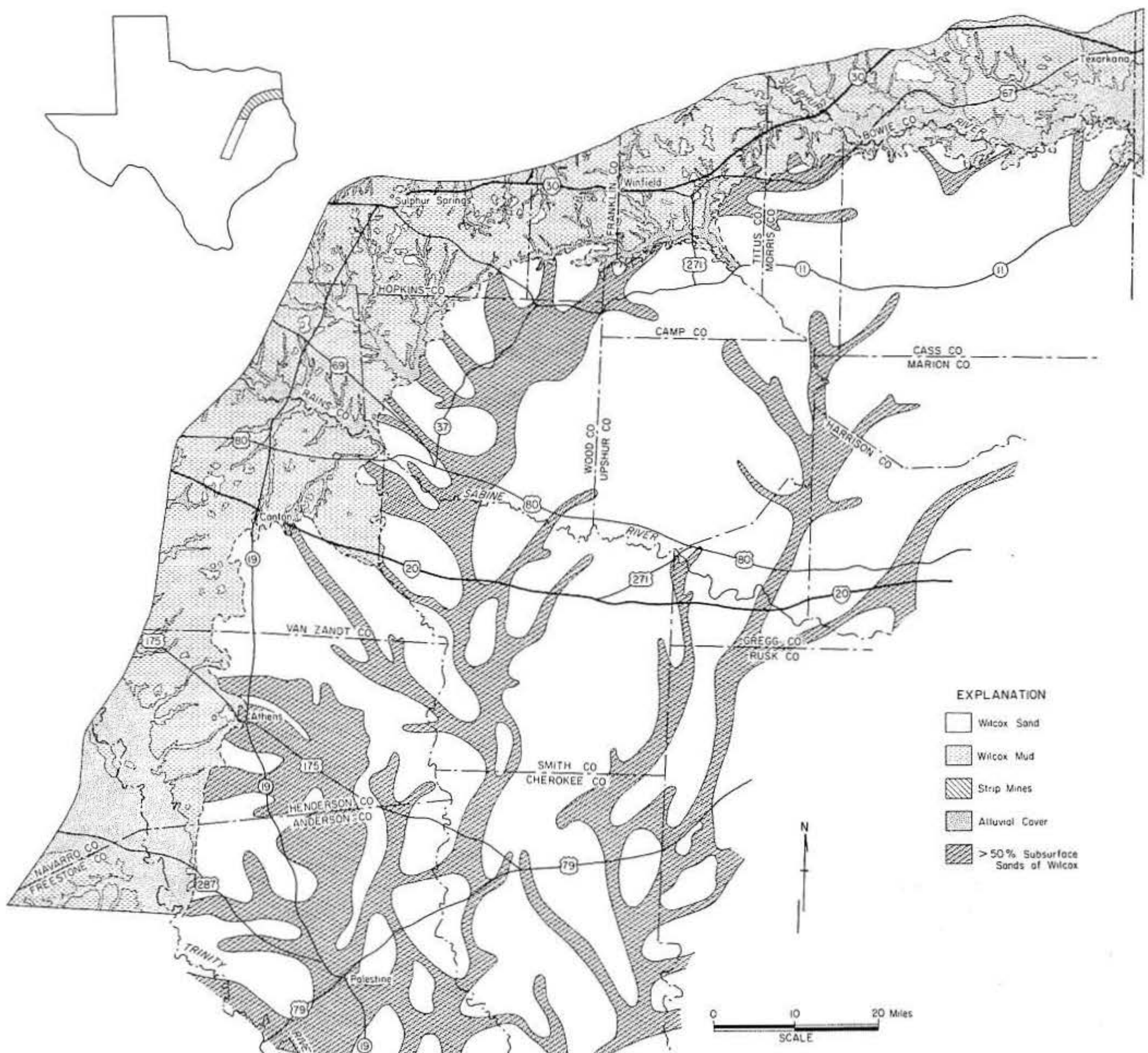


Figure 9. Environmental geology and subsurface geology of the Wilcox Group from Trinity River to Texarkana, Texas (subsurface percent sand from Kaiser and others, 1978).

Mining that cuts through the major channel sands could result in both significant water discharge into the mines, and, after reclamation, drainage from disturbed overburden into the aquifer. Because lignite is generally associated with interchannel mud deposits, strip mining should not intersect the major channel sands, but there are exceptions. For instance, at Fairfield (fig. 6), mining area "C" cuts the edge of a major sand body. This has resulted in some ground-water discharge into the mine area. After mining ceases and the spoil material is placed in the pit, ground water percolating through the spoil could discharge into the channel sand. Although there is no indication that this is happening at Fairfield, it could occur in a similar setting. One must know the hydrologic characteristics of the sands as well as their location relative to mining to predict accurately the quantity of discharge and to plan for the alleviation of any problems that might result.

Mining through channel sands of the Wilcox Group may be less common than mining through the Carrizo Sand. Matching the environmental geologic maps and the distribution of shallow lignite shows that minable lignite extends under large areas of permeable sands. For example, on map sheets 3, 4, and 5, lignite is known to occur at the top of Wilcox strata just below the Carrizo Sand. In this area the Carrizo varies from less than 30 to about 60 m (100 to 200 ft) thick. Thus, mining for lignite could potentially extend through the entire outcrop area of the Carrizo Sand. The fact that lignite occurs there does not necessarily mean that it will be mined. Ground-water discharge into a mine pit from the highly permeable Carrizo Sand will require extensive pumping, and maintenance of high walls composed of water-saturated, unconsolidated sands will be difficult. Because the sands are major present or potential sources of ground water, any mining that intersects major sands must be carefully planned, carried out, and monitored.

Floodplains and Alluvial Valley Floors

Floodplains and other flood-prone areas identified by the environmental geologic maps are important for two reasons. First, distinguishing areas of flooding is important in itself. Second, many floodplains of East Texas have highly fertile soils and abundant surface and ground water and are cultivated and productive. The Texas surface mining law designates areas of frequent flooding as one of several categories of land that may be "deemed unsuitable for surface mining." As of July 1978, no major areas subject to flooding have been proposed to be mined, so the question of how the law will be applied has not arisen.

Flooding is a natural part of any river, and floods create characteristic deposits that can be recognized and accurately mapped. Major floods in Texas have resulted in considerable loss of life and property because of failure to recognize and respect flood-prone areas. Flood magnitudes are usually classified in terms of recurrence, that is, the 50-year flood is of greater magnitude than the 10-year flood. Floods large enough to cover most of a floodplain may occur several times in a single year or not at all for several years. Flooding has obvious implications for mining and all other land use. Until now, the use of floodplains in East Texas has largely been restricted to agriculture either as cropland or pastureland, which can withstand occasional flooding, or as rangeland. Few permanent structures have been built on floodplains except where they are protected by flood control structures or where flooding is infrequent for natural reasons.

Mining on an unprotected floodplain would be impossible if the river flooded even once every several years. If mining is to occur on floodplains it will require some method to avoid floods. Small streams whose floodplain represents only a minor part of the total mining area could conceivably be diverted around the mining operation. Mines totally within floodplains, for example, along large rivers, would have to be protected either by reservoirs or by extensive dike systems. Either would add considerably to the cost of mining.

The Federal mining law has no specific provisions regarding mining on floodplains, but does recognize the importance of alluvial valley floors. The alluvial valley floor provision applies only to the Western United States, west of the 100° meridian, but a few characteristics of the alluvial valleys may be similar to those of floodplains of East Texas. For example, (1) alluvial valley floors have higher quality soils than adjacent uplands; (2) water for agriculture is readily available from surface water or ground water in valley alluvium; and (3) the alluvial valleys are a major source of forage for livestock. The Federal law requires that mining in or near alluvial valley floors be "conducted so as to preserve the essential hydrologic functions."

Floodplains of East Texas also produce abundant crops, have both highly fertile soils and available water. Compared with the claypan soils of the uplands, soils in floodplains and terraces are far more productive. The U. S. Department of Agriculture Soil Conservation Service estimates of agricultural yields are much higher for floodplain soils than for claypan soils. Many of the floodplains are heavily farmed, for example, the floodplain of the Brazos River, which is protected from most flooding by Whitney Dam near Waco, and the floodplain of the Trinity River, which has an extensive dike system (map sheet 4). Some areas are farmed as long as they do not flood either too frequently or for prolonged periods. The Trinity River outside the dike system is not so extensively cultivated because of frequent, prolonged flooding.

One criterion of prime farmland is that the soil not be flooded frequently. Many floodplain and terrace soils could be designated prime farmland on the basis of their high productivity. However, the same soils in areas of frequent flooding must be excluded from prime farmlands. A preliminary list of prime farmland soils of Freestone County compiled by the Soil Conservation Service includes Trinity and Kaufman Clays, characteristic soils of the floodplain environmental geologic unit in the area. Where frequently flooded, the same soils are not designated prime farmland.

Floodplain alluvium is a major source or potential source of ground water. Many of the largest rivers of the lignite belt (Colorado, Brazos, and Sulphur Rivers) have thick deposits of alluvium. The alluvium commonly grades from clay and silt at the surface to sand and gravel at the contact with underlying Wilcox deposits. The water table is shallow, and the coarse material is highly permeable. Ground water from alluvium along the Brazos River is used heavily for irrigation; other major rivers having similar hydrologic charcteristics could be significant sources of ground water for irrigation or other uses in the future.

Floodplains of some of the larger rivers of East Texas are several miles wide and overlie major lignite deposits, for example, the floodplains of the Brazos and Trinity Rivers. If mining is to occur in floodplains, the special problems of mining through substrates bearing ground water and the agricultural productivity of floodplain and terrace soils will have to be recognized.

Although there are similarities, floodplains are not yet legal equivalents of the Western alluvial valley floor.

SUMMARY

Preparation of a suite of environmental geologic maps of part of the East Texas lignite belt has been prompted by the tremendous increase in surface mining of lignite in the last decade and by projections of continued increase. The maps are intended to aid in mine planning and reclamation and to provide an inventory of land resources for many other purposes. The maps cover the outcrop belt of the Wilcox Group, the major lignite-bearing unit of Texas, and adjacent formations between Bastrop County and Texarkana. This area is important because it contains an estimated 8 billion tons of strip-minable lignite and because the Wilcox Group and overlying Carrizo Sand make up the major aquifer in East Texas.

The Wilcox Group and other geologic units are composed of mixtures of sand, silt, and clay. Lignite occurs primarily in the Calvert Bluff Formation (Upper Wilcox) between the Colorado and Trinity Rivers and in the undifferentiated Wilcox Group between the Trinity River and Texarkana. Both lignite-bearing units are composed of mixed sands and muds that were deposited by ancient river systems, probably on a deltaic plain. Lignite is associated with the muds deposited in interchannel areas.

Soil composition is strongly controlled by substrate composition. Claypan soils, consisting of sandy loam A horizons and dense clay B horizons, are characteristic of muddy parts of the Wilcox Group.

Most of the Wilcox lignite belt is within the Post Oak Savannah vegetation area. Native vegetation consists of post oak, blackjack oak, and elm. Much of the land has been cleared for improved pasture. A small part of the lignite belt near Texarkana is in the East Texas Pineywoods.

Criteria used to define environmental geologic units are (1) substrate, (2) soil, (3) geomorphology, (4) geologic process, (5) biologic assemblage, and (6) land use. Mapping was done from 1:20,000 scale, black-and-white aerial photographs and extensive field checking. The published maps are at a scale of 1:125,000.

From the above criteria, a total of 22 environmental geologic units have been recognized. The units and their characteristics are presented in table 1.

Additional information shown on the environmental geologic maps includes the location of existing and proposed lignite surface mines, existing and proposed lignite-fired power plants, abandoned underground mines, and areas of potentially minable lignite to a depth of 60 m (200 ft).

Application of the environmental geologic maps can be illustrated by comparison with requirements of the Texas and Federal surface mining laws. Significant requirements are (1) to identify natural capability of the land prior to mining, (2) to reclaim land to similar or "substantially beneficial use," and (3) to avoid disruption or pollution of aquifers. Aquifers and aquifer recharge areas and areas of frequent flooding may be deemed unsuitable for surface mining.

The Federal law requires the identification, on the basis of a set of soils criteria, of areas of prime farmland. Areas of prime farmland can be mined but must be reclaimed under more stringent practices than required for other lands. Initial Federal regulations would have made almost all of the Wilcox lignite belt prime farmland. However, revision of the regulations to remove areas of claypan soils from prime farmland status excludes most of the lignite belt. Environmental geologic units within the lignite belt of which significant parts will probably be designated prime farmland include floodplain, some terrace, and clay-mud units. Small parts of the sand and mud—prairie units may also be designated prime farmland. Because of the irregular distribution of lignite, the greatest overlap between prime farmland and minable lignite is most likely to occur on floodplains and terraces.

The Wilcox Group and overlying Carrizo Sand compose the major aquifer of East Texas. Lignite development will place considerable demand on surface and ground water, and mining could adversely affect recharge and water quality.

The environmental geologic maps have been combined with subsurface mapping of the Wilcox Group constructed from electrical logs to provide an accurate portrayal of aquifer geometry. The combined maps show that the Wilcox Group consists of a complex interfingering of sands and muds dipping gently toward the Gulf Coast, and that high-sand-percent parts of the subsurface extrapolated to the surface correlate with major sand outcrops. Sand-outcrop areas on the order of several tens of km^2 separate much larger interchannel areas with few and minor sands. Correlation between the surface and subsurface information is good except (1) in areas of extensive surficial alluvial cover, (2) in high-sand-percent parts of the subsurface consisting of numerous thin sands, and (3) in areas of few wells having insufficient control for subsurface mapping.

Comparison of aquifer geometry with available hydrologic and water chemistry data suggests that the channel sands have high hydraulic conductivity (6 to 20 $m^3/m^2/d$) and low total dissolved solids (several hundred mg/l). Interchannel muds have low hydraulic conductivity (1 to 2 $m^3/m^2/d$) and higher dissolved solids (up to several thousand mg/l). Because lignite was deposited primarily in interchannel areas, most lignite mining will not intersect the thick, permeable sands. Ground-water discharge from the impermeable interchannel muds into mine pits should be minor, as will be mine-water discharge into the muds after mining. By knowing where mining will intersect the major sands, miners can avoid ground-water problems.

Areas of floodplain and terrace environmental geologic units along major rivers of East Texas share some characteristics with alluvial valley floors of the Western United States. The floodplains and terraces (1) have higher quality soils than adjacent uplands, (2) have abundant available surface and ground water, and (3) are a major source of forage for livestock. The alluvial valley flood designation is restricted to areas west of 100° longitude, however.

The environmental geology maps, which delineate geologic units on the basis of all the natural characteristics of the land, are an inventory of land resources. They may be used in engineering decisions on land capability as well as in mining and reclamation decisions.

ACKNOWLEDGMENTS

Numerous people contributed to the success of this project. Ernst H. Kastning assisted with the environmental geologic mapping and Melody Holm studied the native vegetation of East Texas lignite lands. Timothy W. Duex, Janet Nilsson, Sarah Ulerick, and Margaret Sanders assisted with data collection and map compilation. G. E. Fogg, R. S. Kier, T. C. Gustavson, E. G. Wermund, and J. O. Maberry reviewed drafts of the report. The entire project was supported by the Energy Lands Program of the U. S. Geological Survey, grant numbers 14-08-0001 and G 158/316/412.

REFERENCES

Arbingast, S. A., Kennamer, L., Ryan, R. H., Lo, A., Karney, D. L., Zlatkovich, C. P., Bonine, M. E., and Steele, R. G., 1973, Atlas of Texas: The University of Texas at Austin, Bureau of Business Research, 125 p.

Barnes, V. E., Project Director, 1970, Waco sheet: The University of Texas at Austin, Bureau of Economic Geology Geologic Atlas of Texas, scale 1:250,000.

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

Basciano, J. M., and Henry, C. D., 1978, Application of environmental geology to ground-water hydrology of the Wilcox lignite belt: Gulf Coast Lignite Conference, The Woodlands, Texas, Proceedings.

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., Chelf, C. R., Shelby, C. A., Garner, L. E., Owens, 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., and McGowen, J. H., 1967, Depositional systems in the Wilcox Group of Texas and their relationship to occurrence of oil and gas: Gulf Coast Association of Geological Societies Transactions, v. 17, p. 105-125.

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

Gould, F. W., 1969, Texas plants—a checklist and ecological summary: Texas A&M University, Texas Agricultural Experiment Station, MP-585/Revised, 121 p.

Gustavson, T. C., and Cannon, P. J., 1974, Preliminary environmental geologic mapping on the inner Coastal Plain, southwest Texas, *in* Wermund, E. G., ed., Approaches to environmental geology: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 81, p. 79-100.

W. F. Guyton Associates, 1972, Ground-water conditions in Anderson, Cherokee, Freestone, and Henderson Counties, Texas: Texas Water Development Board Report 50, 250 p.

Hawkins, M. E., and Garner, L. E., 1978, Minerals in the economy of Texas: U. S. Bureau of Mines State Mineral Profiles, 33 p.

Heine, W. N., 1978, Letter to the commissioners of the Railroad Commission of Texas: U. S. Department of the Interior, Office of Surface Mining, Washington, D. C., June, 1978.

Henry, C. D., 1976, Land resources inventory of lignite strip-mining areas, East Texas—an application of environmental geology: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 76-2, 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.

Henry, C. D., Kaiser, W. R., and Groat, C. G., 1976, Reclamation at Big Brown steam electric station near Fairfield, Texas: geologic and hydrologic setting: The University of Texas at Austin, Bureau of Economic Geology Research Note 3, 10 p.

Henry, C. D., and Basciano, J. M., 1978, Application of environmental geology to ground-water hydrology of the Wilcox lignite belt in Texas (abs.): Geological Society of America, Abstracts with Programs, v. 10, no. 7, p. 419.

Henry, C. D., Basciano, J. M., and Duex, T. W., in press, Hydrology and water quality of the Eocene Wilcox Group: significance for lignite development in East Texas: Gulf Coast Association of Geological Societies Transactions, v. 29.

Holm, M., 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.

Hons, F. M., Askenasy, P. E., Hossner, L. R., and Whiteley, E. L., 1978, Physical and chemical properties of lignite spoil material as it influences successful vegetation, *in* Kaiser, W. R., ed., Gulf Coast Lignite Conference: Geology, Utilization, and Environmental Aspects, 1976, Proceedings: The University of Texas at Austin, Bureau of Economic Geology, Report of Investigations No. 90, p. 209-217.

Kaiser, W. R., 1974, Texas lignite: near-surface and deep-basin resources: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 79, 70 p.

_____ 1978, Electric power generation from Texas lignite: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 78-3, 18 p.

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.

Kier, R. S., Garner, L. E., and Brown, L. F.,Jr., 1977, Land resources of Texas: The University of Texas at Austin, Bureau of Economic Geology special report, 42 p., 4 map sheets, scale 1:500,000.

Peckham, R. C., 1965, Availability and quality of ground water in Leon County, Texas: Texas Water Rights Commission Bulletin 6513, 102 p.

Texas Natural Resources Information System, 1977, Ground-water quality data, *in* File description report: Publication NR-01210-01, revision no. 01, file no. 04020200, p. 4.2. 0200.1.

Wermund, E. G., ed., 1974, Approaches to environmental geology: a colloquium and workshop: The University of Texas at Austin, Bureau of Economic Geology Report of Investigations No. 81, 268 p.

White, D. M., 1979, Texas lignite development priorities over the next 25 years: Texas Energy Advisory Council, 10 p.