GEOLOGICAL CIRCULAR 75-7

MICRORELIEF (GILGAI) STRUCTURES ON EXPANSIVE CLAYS OF THE TEXAS COASTAL PLAIN – THEIR RECOGNITION AND SIGNIFICANCE IN ENGINEERING CONSTRUCTION

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MICRORELIEF (GILGAI) STRUCTURES ON EXPANSIVE CLAYS OF THE TEXAS COASTAL PLAIN—THEIR RECOGNITION AND SIGNIFICANCE IN ENGINEERING CONSTRUCTION

Thomas C. Gustavson

ABSTRACT

Cracked pavements, undulating road surfaces, broken curbs, stairstep fractures of brick and stone building walls, and tilted power poles are common occurrences in areas underlain by cracking, expansive clay soils of the Vertisol order. These soils, which underlie 15 to 20 percent of the Coastal Plain of Texas, are composed predominately of montmorillonite and develop distinctive microtopographic features known as gilgaies. Relief between adjacent microknolls or ridges and microdepressions ranges up to 18 inches (45.7 cm). Cracks develop in these soils to depths of 60 inches (152.4 cm) and to widths of 4 inches (10.2 cm).

Gilgai microtopography forms as montmorillonitic clay soils expand with the adsorption of water introduced via deep cracks, root holes, animal burrows, and normal gravity infiltration. Subsoil clay and dry clay soil which has fallen into cracks from the surface expand, causing subsoil material to move both laterally and upward. Areas of marked vertical movement produce diapirlike ridges of light-colored clay subsoil extending upward into dark surface soils. The subsoil diapirs underlie surface microknolls and microridges.

Areas of gilgai microrelief are easily recognized from aerial photographs on which the scale is greater than 1:80,000. On slopes of less than 1 percent, the pattern is an irregular network of microridges. As slope increases, microridges and microdepressions become elongated downslope, resulting in a pattern of alternating linear ridges and troughs that are approximately parallel to slope direction. Towards the bases of slopes, gilgai microtopography becomes obscured by colluvium.

As a consequence of large hydration pressures, vertical soil movements in areas of gilgai microrelief may place severe limitations on the construction of roads, buildings, power lines, buried transmission lines, and pipelines.

Current engineering techniques for the mitigation of damage to highways and buildings include lime stabilization, ponding, and subgrading of highways and use of steel reinforcing bars or post-tension cables in concrete-foundation slabs of buildings.

INTRODUCTION

Many large areas of the Texas Coastal Plain are underlain by deposits that are in large part composed of montmorillonitic clay. These areas characteristically have high shrink-swell potential and are overlain by cracking, expansive black waxy soils belonging to the Vertisol order. (See Soil Survey Staff, 1966, for a discussion of soil classification terminology and characteristics.)

The expansive soils develop a group of distinctive microtopographic features which collectively have come to be known as gilgaies. The term gilgai comes from the language of the Australian aborigine and means small water hole. Other equally colorful terms have been used to describe these features—hog-wallow, melon hole, crab hole, and devil-devil. These features have been extensively studied in Australia (Costin, 1955; Hallsworth and others, 1955; Crook, 1958; Collins, 1972; Paton, 1974), but have been largely overlooked by geologists in the United States. Soil scientists are well aquainted with this phenomenon (Oakes and Thorp, 1967), but soil processes of this type and the materials on which they occur are incompletely known for the Texas Coastal Plain.

Recognizing map units of first-order environmental significance for adequate land management requires an understanding of the biological, chemical, and physical elements which affect man's environment. Resource capability units, as defined by Brown and others (1971), include (1) physical units, such as geologic substrate and soils, (2) process units, such as floodplains and beaches where active physical processes are dominant, (3) biologic units, such as marshes and swamps, and (4) man-made units, such as spoil heaps and dredged areas. Gustavson and Cannon (1974) have defined environmental geologic units which are based on one or more of the following elements: (1) geologic substrate and soil, (2) topography and landform morphology, (3) geologic process, (4) biota, and (5) human activity. The identification of certain environmental geologic units or areas of similar resource potential requires a knowledge of the processes that act on the earth's surface, including the processes which form gilgai.

The shrink-swell capacity and heaving aspect of some Texas soils has been observed in many areas (Al-Layla, 1970; Collins, 1972; Gustavson, 1975). Recognizing the characteristic microtopography and understanding the processes by which gilgai form in areas of high shrink-swell potential will facilitate rapid and accurate identification of clay facies where severe limitations may be expected in the construction of buildings, roads, bridges, sewers, pipelines, electrical transmission lines, and buried telephone cables.

This report is an outgrowth of a regional environmental geologic mapping project of the Bureau of Economic Geology. The larger project covers the drainage basins of the Lavaca, Guadalupe, San Antonio, and Nueces Rivers and was supported in part by the Texas Water Development Board.

Field work for this report took place primarily in Gonzales County on the inner Coastal Plain of the Texas Gulf Coast and within the drainage basin of the lower Guadalupe River (fig. 1).

ACKNOWLEDGMENTS

Appreciation is expressed to William L. Fisher, Charles W. Kreitler, and E. G. Wermund, Bureau of Economic Geology, The University of Texas at Austin, who offered helpful criticisms of the manuscript. Laboratory tests were made under the direction of D. A. Schofield, Mineral Studies Laboratory, Bureau of Economic Geology. L. E. Garner, Bureau of Economic Geology, performed the X-ray analysis.

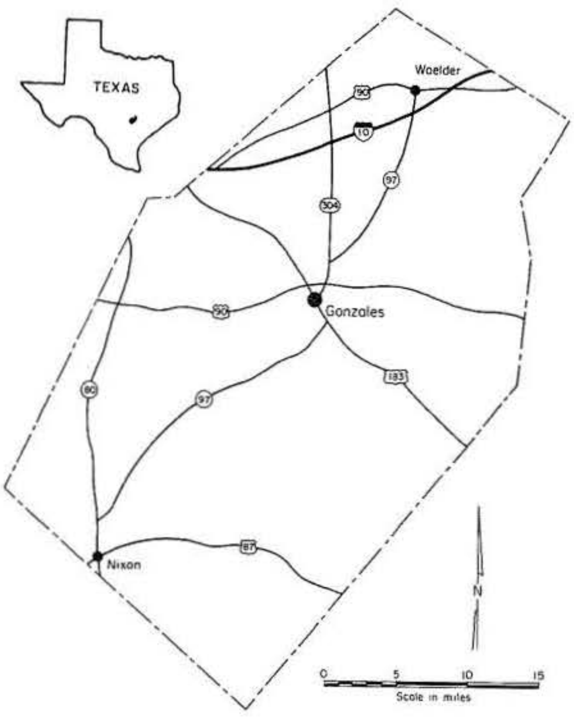


Figure 1. Gonzales County, Texas

GILGAI MORPHOLOGY

Gilgai soil structures are recognizable on aerial photographs or mosaics of aerial photographs where scale is larger than 1:80,000. The gilgai pattern consists of an alternation of soil types; dark organic-rich soils (Elmendorf series) line depressions and lie adjacent to relatively lighter, less organic-rich soils (Denhawken series) which are developed on diapirs or ridges of subsoil material (fig. 2) (U. S. Department of Agriculture, Soil Conservation Service, 1972). On hillcrests or essentially undissected areas where slopes are generally less than 1 percent, light soils form an irregular network of microridges. Irregularly shaped microdepressions lie approximately 1 foot (30.5 cm) below ridges and contain relatively dark soil (figs. 3A, B). Troughs range from 15 to 20 feet (4.6 to 6.1 m) in width. When the surface slope exceeds 1 percent, microridges and microdepressions become elongated, subparallel and oriented downslope (fig. 3C). Gilgai patterns on slopes of less than 1 percent are sharply defined, suggesting abrupt changes between the soils of the microridges and the soils of the microdepressions. On hillslopes, the boundary between soils of ridges

Figure 2. Topographic map and aerial photograph of the Denhawken and Elmendorf soil series. Open triangle (contour interval 10 feet) marks the type area for descriptions of the Denhawken (microridge, light toned) and Elmendorf (microdepression, dark toned) soil series. This site is located in Wilson County, Texas, approximately 24 miles southwest of Nixon.

and depressions becomes increasingly diffuse downslope, suggesting a mixing of soil series. The mixing of soils is probably due to slopewash and creep. If colluvial or alluvial material collects at the base of the hillslope, the gilgai structures become obscured. On gullied slopes where the dark Elmendorf series soils have been removed, gilgaies are not recognizable.

Complex terminologies describing the variations in gilgai patterns over a range of slopes have been suggested by Hallsworth and others (1955) and Paton (1974). Hallsworth and others recognized six morphologic types: (1) normal gilgaies occur where mounds (microridges) and shelves (microdepressions) show no preferred orientation; (2) lattice gilgaies occur on low slopes, are intermediate between normal gilgai and linear gilgai, and consist of discontinuous ridges aligned in a downslope direction; (3) linear gilgaies occur on sloping land and are relatively continuous and subparallel in a downslope direction; (4) melonhole gilgaies occur in tropical areas of high rainfall and consist of large mounds and broad depressions which abruptly deepen 15 to 25 cm (the melon hole) near the center; commonly, one or more sinkholes underlie the melon hole; (5) stony gilgaies occur in arid areas and consist of normal, lattice, and linear gilgai forms developed on stony soils; and (6) tank gilgaies consist of microridges and microdepressions in a roughly rectangular form.

Paton (1974) recognized eight types of gilgaies on the basis of soil microrelief: (1) α-type—ridges and depressions are equally developed; (2) β-type—ridges are wider than depressions; (3) γ-type—depressions are wider than ridges; and

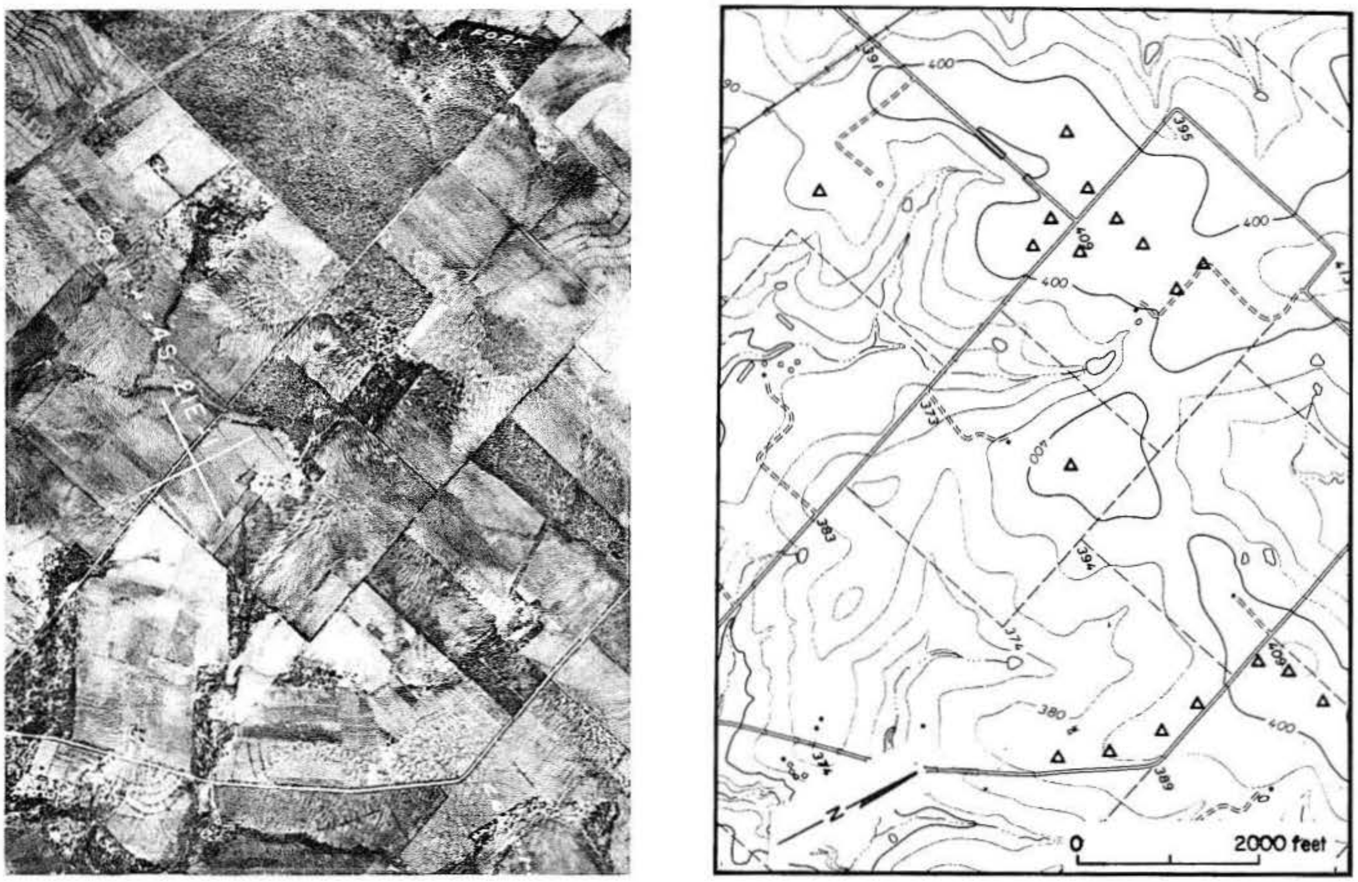


Figure 3A. Open triangles on the topographic map locate areas of anastomosing networks of microridges and depressions. They may be seen on the accompanying aerial photograph of the same area. Map area is approximately 5 miles north of Gonzales, Texas

(4) δ-type—ridges and depressions are separated by a flat shelf. All four types of cross sectional morphology are found in linear gilgaies and in gilgaies with no preferred orientation.

The gilgaies discussed in this report occur in two classes, the regular and the linear gilgai morphological types of Hallsworth and others (1955).

SOILS

The United States Soil Conservation Service has defined the Elmendorf and Denhawken soil series in northeastern Wilson County, near the Gonzales County boundary. These series comprise gilgaies developed on the Cook Mountain Formation. The Elmendorf series is a member of the fine, montmorillonitic, hyperthermic family of Vertic Argiustolls; it occurs as a dark to very dark gray-brown clay loam in microdepressions of gilgaied areas. These soils are typified by thick clayey Bt horizons that grade from very dark gray in the upper part to yellow or brownish yellow in the lower part. The Denhawken series is a member of the fine, montmorillonitic, hyperthermic family of Vertic Ustochrepts; it underlies the microridges. Denhawken soils are calcareous and lack a Bt horizon. The A horizon is a thin grayish-brown clay loam and the B horizon is a brown clay or clay loam. Both soils are developed on sandy muds or mudstone and both contain obvious pressure faces or slickensides.

Most Vertisols that occur on the Gulf Coastal Plain exhibit gilgai microrelief (table 1). All of the Coastal Plain soil series that develop gilgaies, with the exception of the Denhawken series, are defined from microdepressions. Microrelief ranges from 3 to 18 inches (7.6 to 45.7 cm), and distance between adjacent microridges is 15 to 20 feet (4.6 to 6.1 m). With the exception of the Coy, Elmendorf, and Denhawken series, Vertisols lack B horizons. All series are characterized by intersecting slickensides in the lower A and C horizons suggesting that vertical movement is common and ongoing. These soils are further characterized by surface cracks which occur to widths of 4 inches (10.2 cm) and to depths of 60 inches (152.4 cm) in response to dehydration of clay minerals between periods of precipitation.

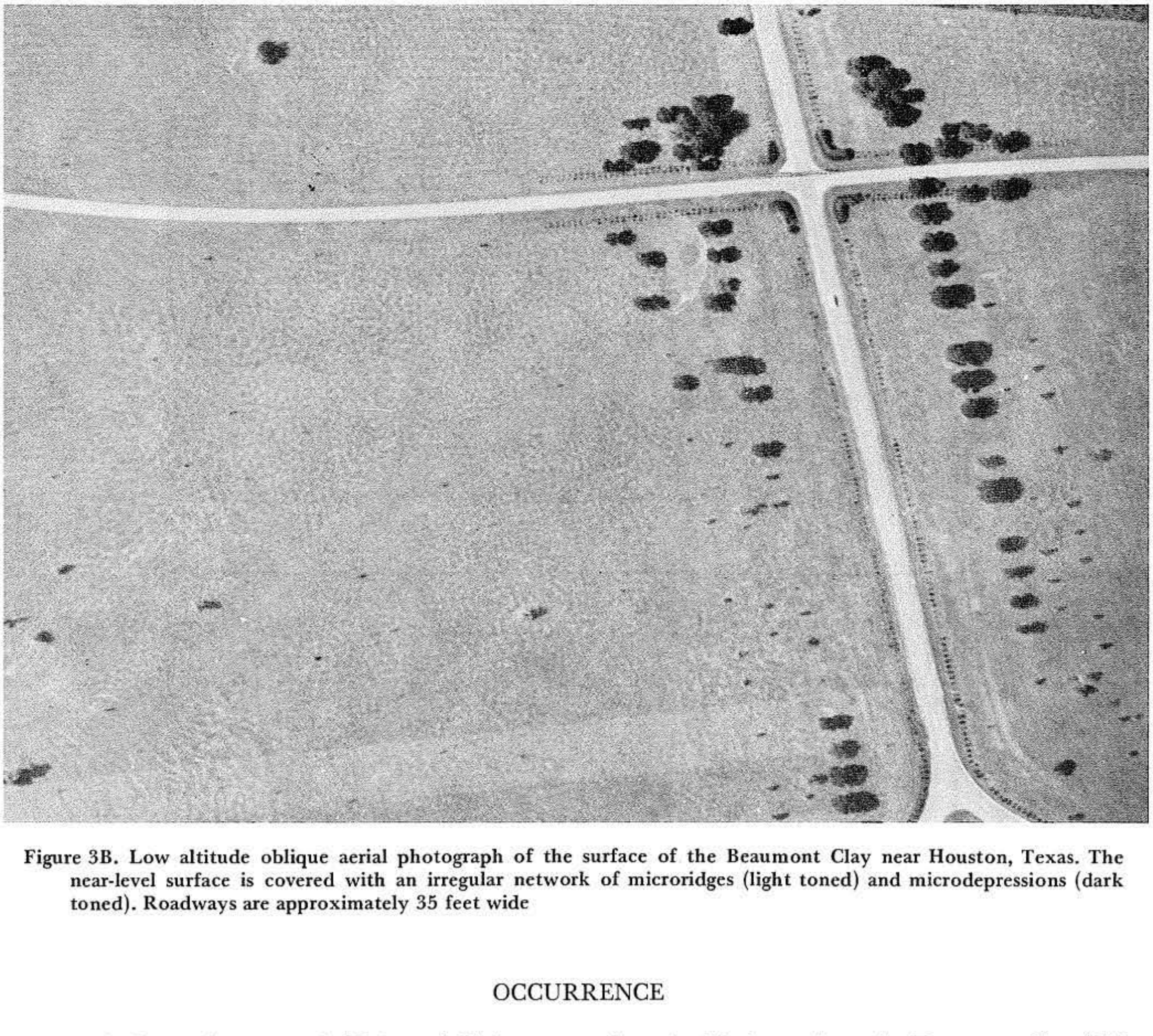


Figure 3B. Low altitude oblique aerial photograph of the surface of the Beaumont Clay near Houston, Texas. The near-level surface is covered with an irregular network of microridges (light toned) and microdepressions (dark toned). Roadways are approximately 35 feet wide

OCCURRENCE

Vertisols on the Texas Gulf Coastal Plain are confined to sediments in which montmorillonite is the chief clay-mineral constituent. Vertisols are generally known to occur over approximately 17,500,000 acres in the Texas Coastal Plain (Godfrey and others, 1973). Muds and mudstones containing more than 50 percent montmorillonite occur in all stratigraphic units from Upper Cretaceous rocks to sediments presently being deposited in bays along the Texas coastline (Fisher and Garner, 1965; Morton, 1972; and J. H. McGowen, personal communication). Furthermore, Sorenson (1975) has shown that montmorillonite clay is the dominant constituent of suspended sediment being transported by the Guadalupe River where it crosses the Coastal Plain. Thus, montmorillonite clays are found in sediments laid down throughout the full range of

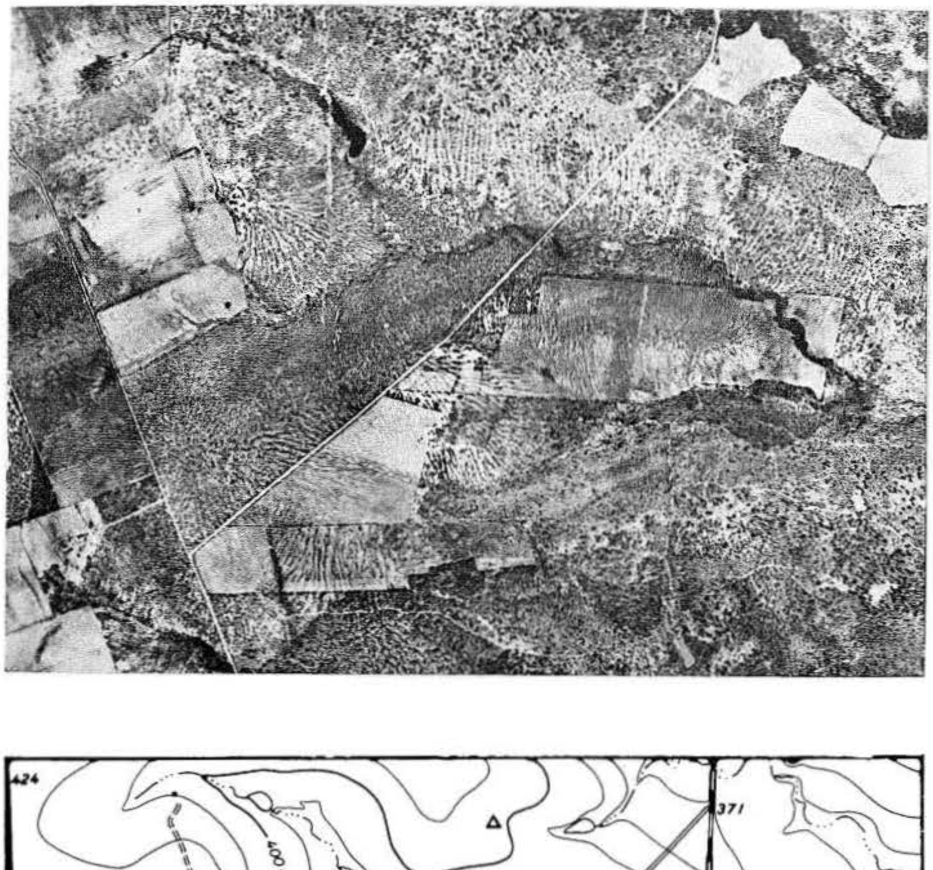


Figure 3C. Open triangles on the topographic map locate areas of linear microridges and depressions (slope >1 percent). They may be seen on the accompanying aerial photograph of the same area. Map area is approximately 7 miles north of Gonzales, Texas.

Table 1. Soil series characteristics and limitations to use

Series	Family	Montmorillonitic	Thermic	Hyperthermic	Crack width		Crack depth		Slickensides	Gilgai relief		Slope (percent)	Shrink-swell potential	Roads	Buried pipes	Building	C zone contains
					in	cm	in	cm		in	cm						
Denhawken	Vertic Ustochrept	yes		yes	2	5.1	50	128	0	2-8	5.1-20.5	0-5	High	S	S	S	dark streaks from above
Elmendorf	Vertic Argiustoll	yes		yes	2	5.1	50+	128	0	0	0	0-5	High	S	S	S	
Coy	Vertic Argiustoll	yes		yes	2	5.1	40	103	0	0	0	0-6	High	S	S	S	vertical dark streaks to 65 inches
Heiden	Udic Chromustert	yes	yes		0	0	0	0	yes	3-12	7.7-30.77	.5-20	High	S	S	S	
Houston Black	Udic Pellustert	yes	yes		4	10.3	<20	51.3	yes	10-18	25.6-46.15	0-8	High	S	S	S	streaks of gray from above
Burleson	Udic Pellustert	yes	yes		3	7.7	60+	154	yes	3-10	7.7-25.6	5	High	S	S	S	
Lake Charles	Typic Pelludert	yes	yes		2	5.1	50	128	yes	6-15	15.4-38.5	0-8	High	S	S	S	gray streaks from above
Victoria	Typic Pellustert	yes	yes		3	7.7	60	154	yes	18	46.15	near level	High	S	S	S	
Montell	Entic Pellustert	yes	yes		4	10.3	<20	51.3	yes	3-12	7.7-30.77	<.5	High	S	S	S	
Catarina	Paleustollic Torrert	yes	yes		0	0	0	0	yes	3-12	7.7-30.77	0-5	High	S	S	S	vertical cracks
Monteola	Typic Pellustert	yes	yes		0	0	0	0	yes	0	0	0-8	High	S	S	S	vertical and horizontal fractures
Harlingen	Entic Chromustert	yes	yes		0	0	0	0	yes	2-5	5.1-12.8	0-3	High	S	S	S	
Luling	Udic Chromustert	yes	yes		0	0	54	138	yes	6-14	15.4-35.9	0-8	High	S	S	S	dark crack fillings
Leemont	Udorthentic Pellustert	yes	yes		0	0	0	0	yes	0	0	3-8	High	S	S	S	vertical and horizontal fractures
Beaumont	Entic Pelludert	yes	yes		0	0	0	0	yes	6-15	15.4-38.5	0-1	High	S	S	S	
Marcelinas	Vertic Argiustoll	no		yes	2	5.1	0	0	yes	0	0	0-3	High	S	S	S	
Lomalta	Udorthentic Pellustert	yes		yes	4	10.3	<30	77	yes	0	0	0	High	S	S	S	root channels, animal burrows

0 no information
S severe limitation to construction: high shrink-swell capacity

depositional environments for clay-size material—floodplains, oxbow lakes, abandoned channels, coastal bays, lagoons, prodelta slopes, and shelf areas. Recognition of gilgaies from aerial photographs allows mapping not only of areas of high shrink-swell potential but also of depositional facies where sediments are predominately clay. This is especially useful on the Coastal Plain where outcrops are extremely rare.

In Tertiary and Cretaceous sediments, montmorillonite clays are commonly associated with or derived from bentonites and volcanic ash deposits. Quaternary montmorillonite clays were derived from older montmorillonitic soils, ash beds, and bentonites.

All of the gilgai terrane illustrated in this report is developed on the Cook Mountain Formation (Eocene) with the exception of a portion of the Beaumont Clay terrane near Houston, Texas, illustrated in figure 3A. The Cook Mountain Formation consists of up to 750 feet (229 m) of fossiliferous marine muds and poorly indurated mudstones with minor interbeds of sand and limestone. The Beaumont Clay in the Houston area consists primarily of interdistributary muds including some bay and floodplain deposits.

CLIMATE

Climatic conditions play an important role in determining the development of gilgai microtopography on montmorillonitic clay terranes. In an arid climate, the frequency of hydration-induced swell-shrink cycles is reduced simply because of the infrequency of precipitation events. Strongly humid climates, on the other hand, also tend to retard the development of microrelief because soils remain wet for long periods. This in turn diminishes the frequency of shrink-swell cycles and also inhibits gilgai formation.

The climate of the central and northern portion of the Texas Coastal Plain is humid to subhumid. Gonzales County is subhumid with soil temperatures remaining above freezing throughout most of the year. Climatic parameters are illustrated in figure 4. Frosts occur, but freezing penetrates no more than an inch or so into the soil. Precipitation is approximately 36 inches (91.4 cm) per year coming from convective storms, from the passage of frontal systems, and from tropical storms generated in the Gulf of Mexico. Although the average annual relative humidity approaches 70 percent, mean annual pan evaporation is moderately high at 75 to 80 inches (190.5 to 203.2 cm) per year. The mean annual evaporation from standing bodies of water is approximately 30 inches (76.2 cm) per year. Soils dry rapidly in this climate and form deep cracks. Furthermore, the numerous wet-dry cycles that occur throughout the year in response to episodic rainfall result in numerous swell-shrink cycles and facilitate the formation of microtopography.

COMPOSITION AND GRAIN SIZE OF COOK MOUNTAIN SEDIMENTS

During June and July of 1974, soils developed on the Cook Mountain Formation were exposed by construction on U. S. Highway 87 for approximately 6 miles west of Nixon, Texas. Exposures along the highway clearly showed the cross-sectional structure of gilgaies (figs. 5, 6).

Samples were collected for X-ray and grain-size analysis from the soil and subsoil zones of both a microridge and a microdepression. All samples for X-ray analysis were prepared as powder packs of dried and crushed but otherwise untreated material. CUKα X-ray diffraction pattern was obtained for each sample (figs. 7A, B). The clay minerals from each sample predominantly consist of montmorillonite with lesser amounts of illite and kaolinite. These results are similar to the findings of Morton (1972) who reported clay-mineral percentages of smectite (81 percent), illite (12 percent), and kaolin (7 percent) from the Guadalupe River delta, and of Sorenson (1975) who reported Ca montmorillonite percentages of 70 to 85 percent with lesser amounts of illite and kaolinite from suspended clays of the Guadalupe River.

The samples examined for clay composition were also examined for grain-size distribution. Each sample was disaggregated mechanically and dispersed using sodium hexametaphosphate (Calgon). Grain-size distribution was determined by the hydrometer method (ASTM Designation 422-61T). Graphic plots of the size distribution are

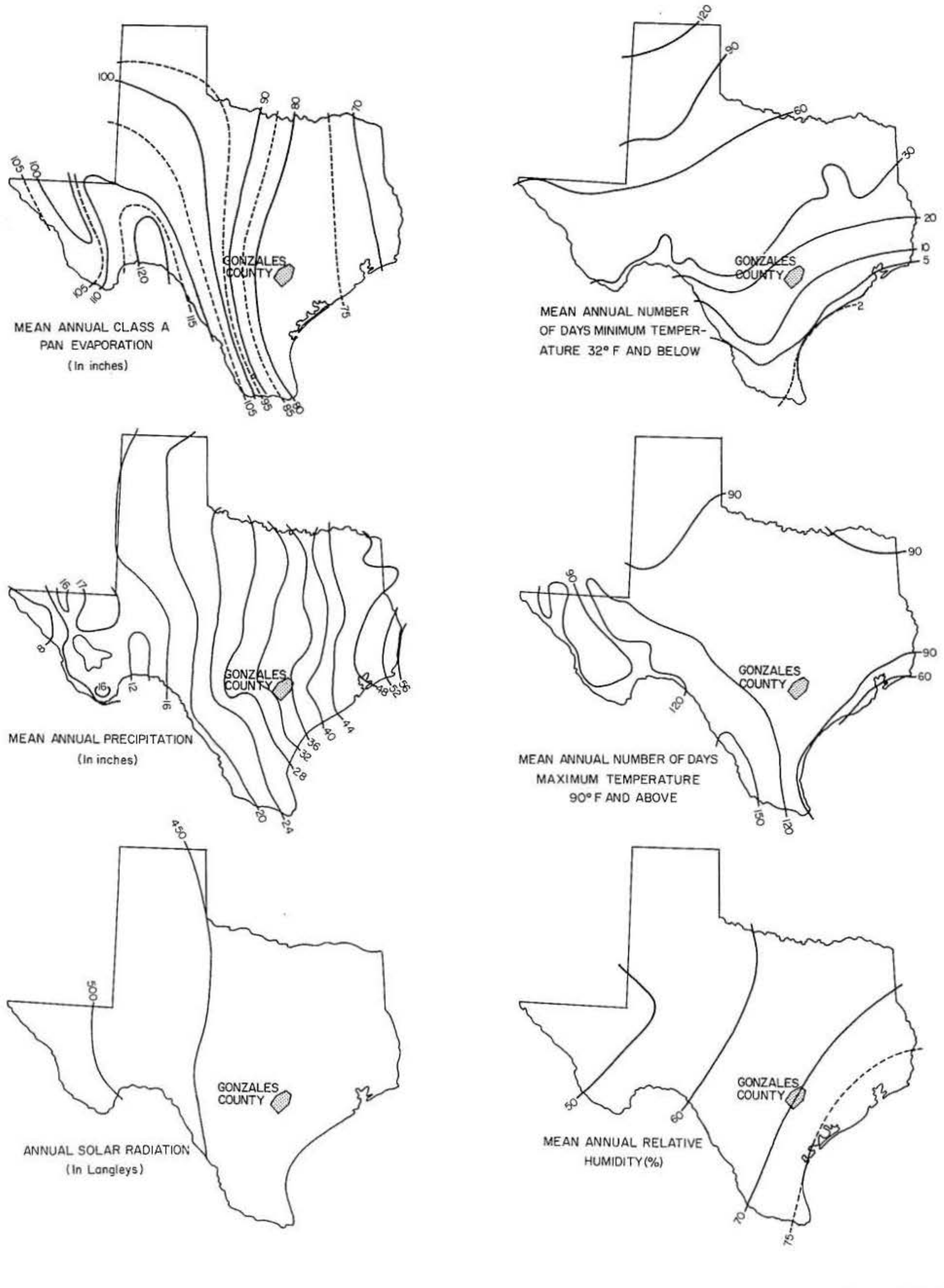


Figure 4. Texas climatic factors. From the U. S. Department of Commerce, Climatic Atlas of the United States (1968).

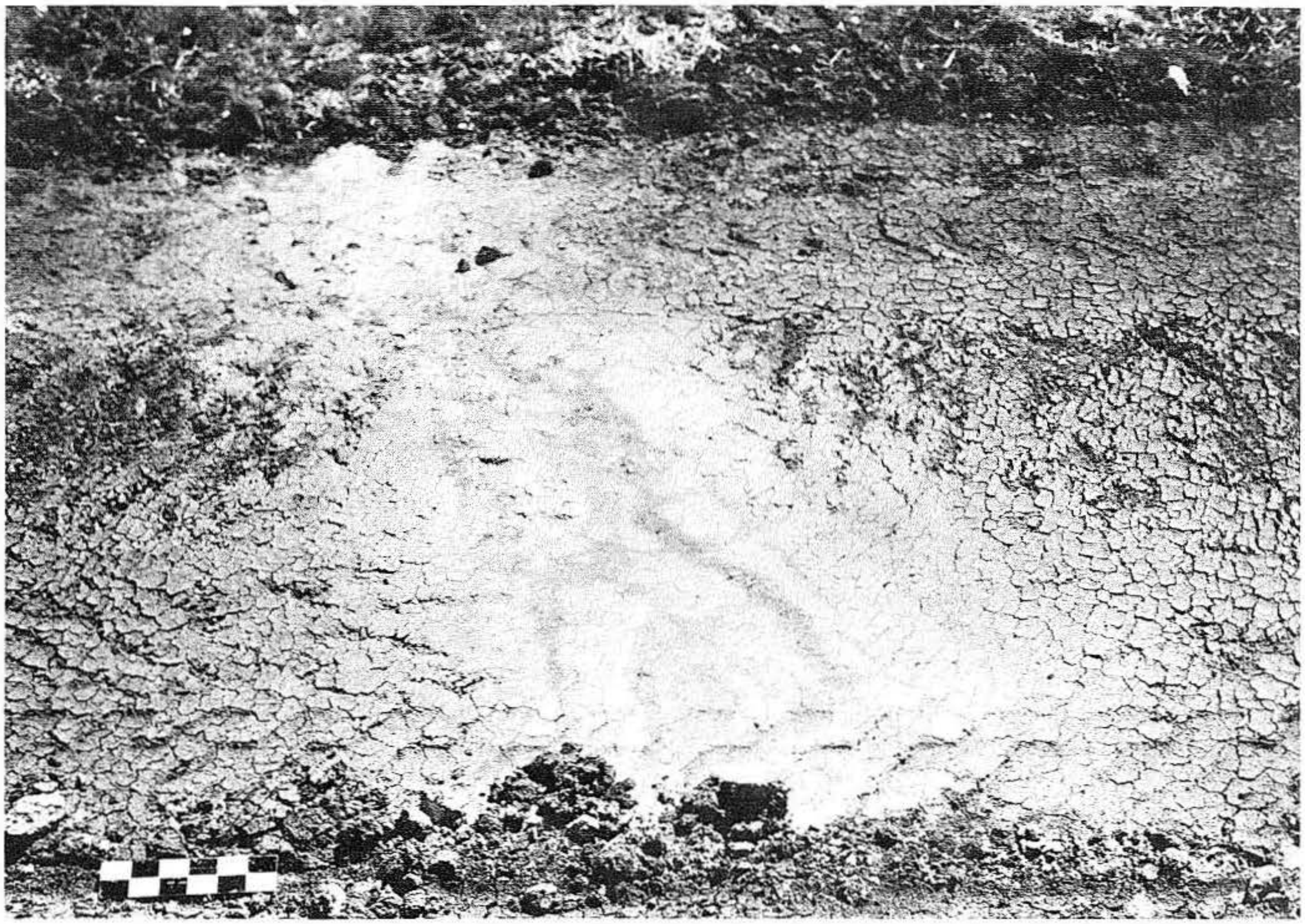


Figure 5. Light-toned diapir (Denhawken series) exposed east of Nixon, Texas, on U. S. Highway 87. Note soil surface cracks. Scale 30 cm. Tonal variations in thrust zone may indicate original bedding, but more likely illustrate differential iron staining from waters percolating through the soil

given in figure 8. Using the terminology of Folk (1954), most of the samples are sandy muds while one each is a sandy clay and a sandy silt. When the same clast-size distribution data is plotted on a triangular diagram of the textural classification used by the U. S. Department of Agriculture Soil Conservation Service (silt is 0.5 to 0.002 mm), most samples plot as clay loams with one each as a silt loam and a clayey soil (fig. 9).

Soils of the Cook Mountain Formation, then, are largely clay loams developed on sandy marine muds whose clay composition is predominately montmorillonite with lesser amounts of illite and kaolinite.

SHRINK-SWELL CHARACTERISTICS OF MONTMORILLONITE

Mielenz and King (1955) have shown that free-swelling Ca montmorillonite can expand 45 to 145 percent. The percentage of free swelling is decreased for synthetic mixtures of montmorillonite, kaolinite, and sand. Furthermore, the original density of the material affects expansion. Expansion increases as original density increases. Experimental work by Mielenz and King (1955) has shown that hydration pressures of as much as 15 tons per square foot (142 metric tons/m^2) occur in undisturbed montmorillonitic clays or shales and bentonitic clays. However, the usual range is from 1 to 6 tons per square foot (9.5 to 56.8 metric tons/m^2).

Accordingly, Mielenz and King (1955) suggest that two mechanisms are responsible for the

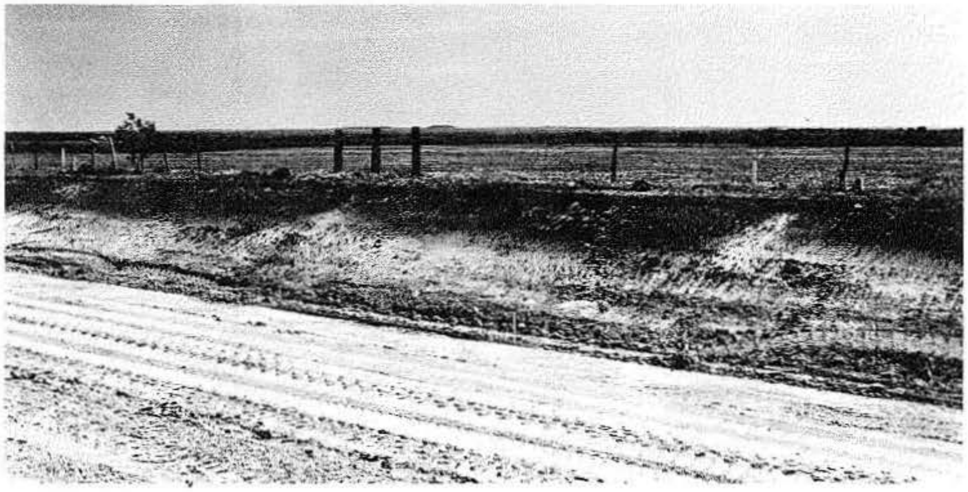


Figure 6. Three light-toned (Denhawken series) diapirs underlying microridges and separating four wide microdepressions filled with very dark-brown soil (Elmendorf series). U. S. Highway 87, east of Nixon, Texas

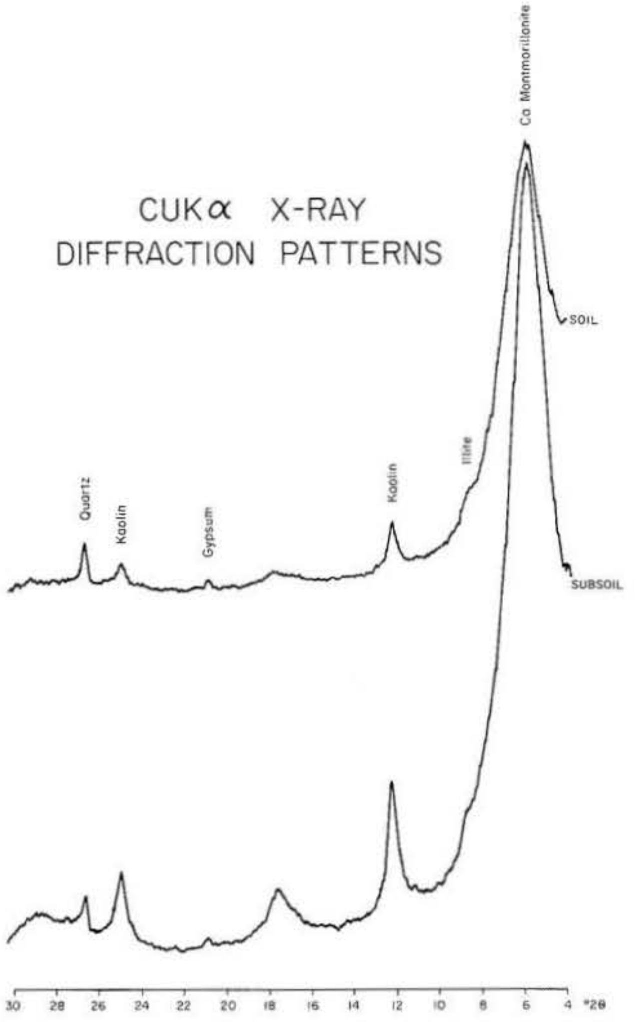


Figure 7A. X-ray defraction patterns from soil and subsoil material underlying a gilgai microridge

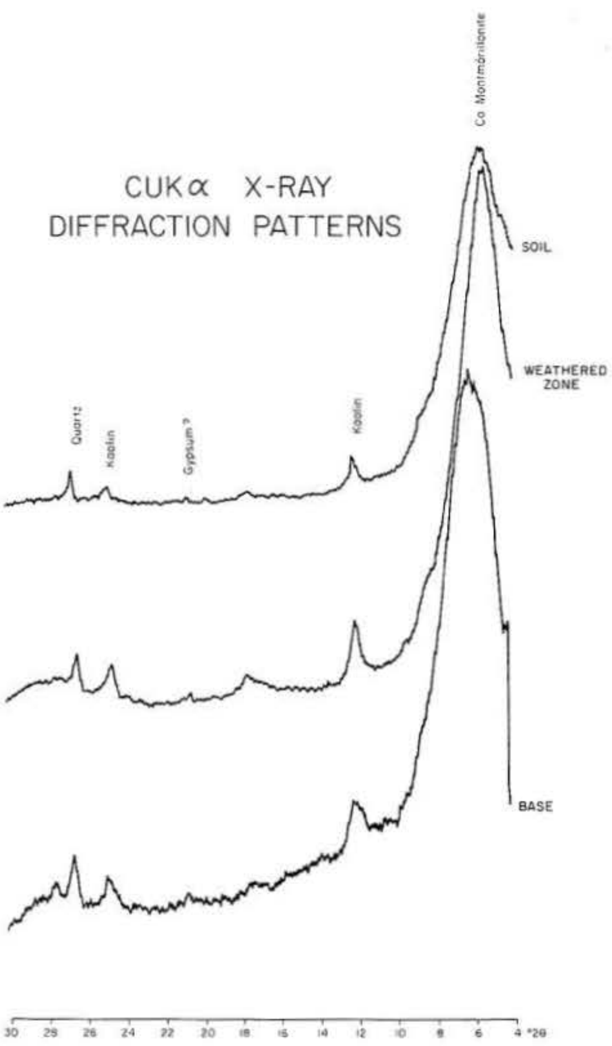


Figure 7B. X-ray defraction patterns from soil, weathered zone, and subsoil material underlying a gilgai microdepression

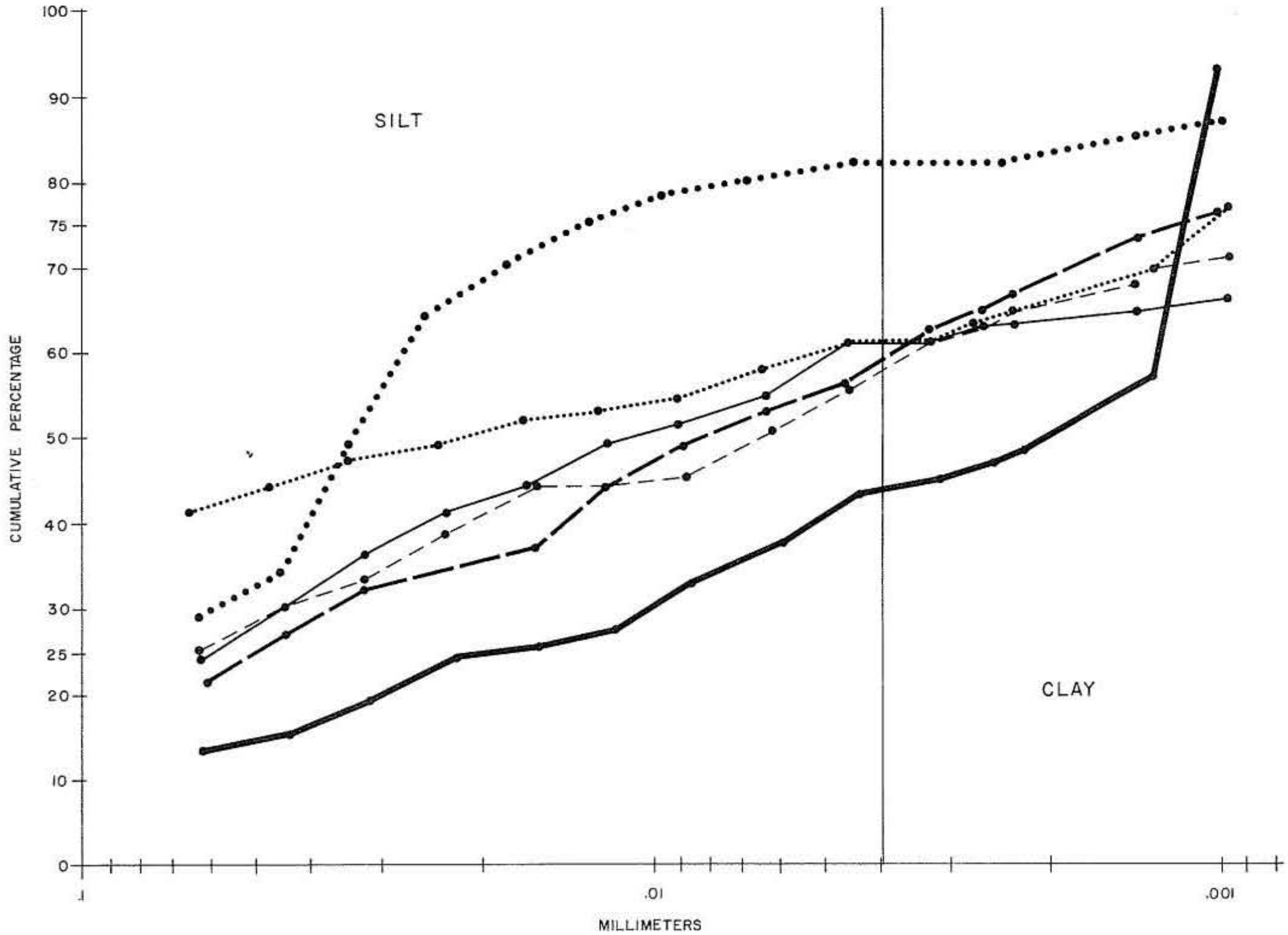


Figure 8. Cumulative grain-size distribution from soils and subsoils in gilgai terrane

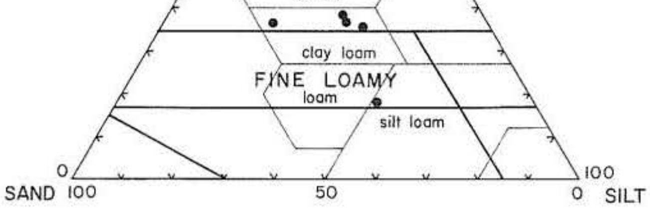


Figure 9. Modified soil textural classification

swelling of soils: (1) relaxation of effective compressive strength related to enlargement of capillary films, and (2) adsorption of water by clay minerals with an expanding lattice.

Vijayvergiya and Sullivan (1974) analyzed 184 samples from the Beaumont Clay of the Texas Coastal Plain and observed that the percentage of swell under pressure of 0.1 ton per square foot ranged from 0.5 to 13.6. Swell pressures ranged from 0.21 to 6 tons per square foot (2.19 to 56.8 metric ton/m^3). Liquid limits ranged from 33 to 76 and plastic limits ranged from 12 to 34. Beaumont soils, typical of the clay-rich facies of the Beaumont Formation, develop gilgai with relief of 6 to 15 inches (15.2 to 38.1 cm) (fig. 3B).

Percent swell of Cook Mountain Formation material under atmospheric pressure varies from 50 to 200. The liquid limit varies from 63 to 119 and the plastic limit from 23 to 38.

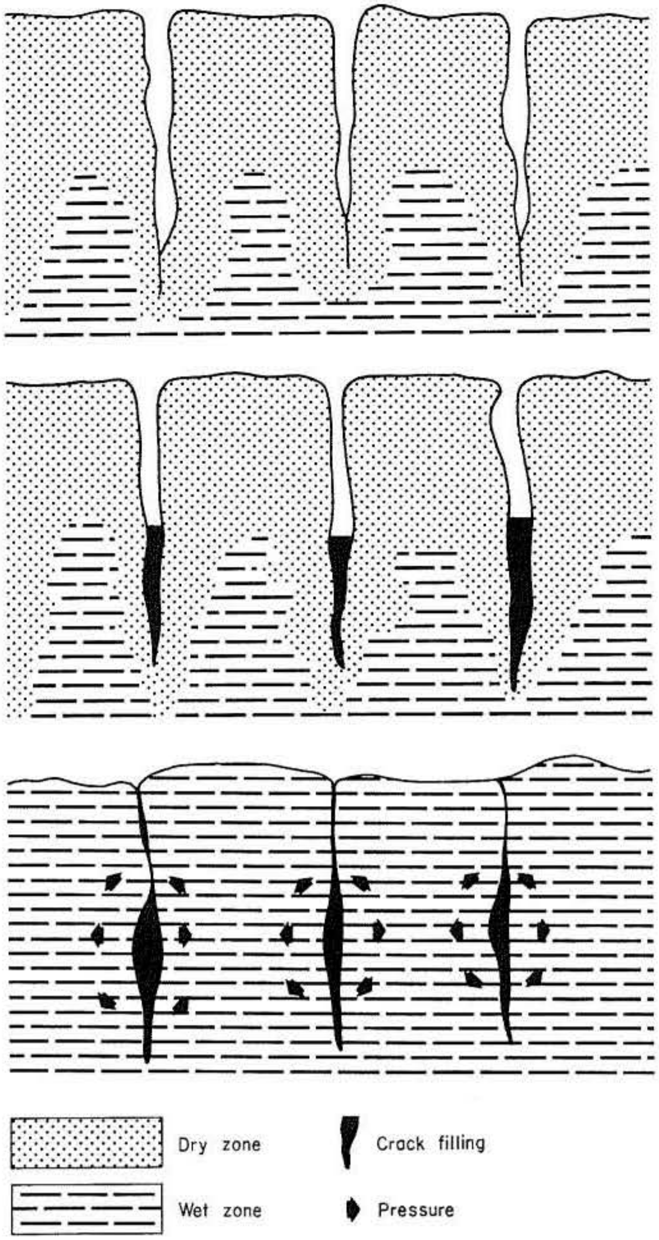
GENESIS OF GILGAI

There are several processes which have been proposed as the mechanism by which gilgaies form. The earliest of these was the suggestion by Hilgard (1906) that deep cracks in soils where "hog-wallows" (gilgai) were present became partly filled by material falling in from the surface; when the soils were completely wet and expanded, the cracks could not close because of the surplus of material in them. This resulted in the forcing upward of material near the cracks (fig. 10).

Later, Howard (1932) rejected Hilgard's theory and postulated that expansion occurred as the clay subsoil was wetted adjacent to major cracks. Expansion of the clay subsoil was considered to be the force which caused the expansion of material beneath microridges. Where observed on the Coastal Plain, desiccation cracks were developed without a preferred orientation.

Paton (1974) implied that the two previously considered theories were not sufficient to explain the process by which gilgai form. He suggested that gilgaies were formed by a process of differential loading where clays moved from areas of high confining pressure to low confining pressure. Paton drew analogies between gilgaies and sedimentary load structures and mudlump islands from the Mississippi delta (see Morgan and others, 1968).

Paton's application of the process by which sedimentary load structures and mudlump islands occur to the formation of gilgaies is questionable. In the case of both sedimentary load structures and mudlump islands, densely packed, water-saturated sands and silts in grain to grain contact overlie highly fluid muds which may be as much as 80 percent water by volume. Under these conditions, the overlying relatively more dense sands and silts tend to founder in the less dense watery muds. The muds tend to move laterally and upwards towards areas of low confining pressure resulting in mud diapirs. In each case, the driving mechanism results from the large disparities in densities of the mud and overlying sand or silt. This marked density difference has not been observed in soils, and consequently, it is unlikely that gilgaies form in this manner. Furthermore, when sedimentary load structures have formed on depositional slopes, the structures tend to be elongated transverse to slope direction. Gilgaies, when they occur on slopes greater than 1 percent, are elongated ridges and troughs parallel to the slope direction. Although it is possible under some circumstances that cross-sectional views of gilgaies and sedimentary load structures may exhibit some degree of similarity, gilgaies are not formed by the same processes that create sedimentary load structures.



After Verger 1964

Figure 10. Formation of gilgai by cycles of drying, crack filling, and expansion

ADDITIONAL COMMENTS ON THE FORMATION OF GILGAI STRUCTURES IN SOUTH TEXAS

The soils series along the Gulf Coast of Texas that have developed gilgai structures are mostly montmorillonitic clay loams in which the clay fraction may contain as much as 80 percent montmorillonite (table 1). These soils readily expand or contract as montmorillonite adsorbs or loses water from between its structural layers. This remarkable property of montmorillonite accounts for the deep cracks that are characteristic of montmorillonite clay soils. The clay soils of the Texas Coastal Plain form cracks as much as 4 inches (10.2 cm) wide that extend to depths of more than 5 feet (152.4 cm). In many cases, the cracks which occur at horizontal intervals of 1 or 2 feet (30.5 to 61 cm) penetrate the Ac or C zone of the soil profile. Roots and animal burrows also extend to the Ac or C zone. Soil cracks, root holes, and animal burrows in the Ac and C zones commonly are filled with dark material which has fallen in from the upper portion of the soil profile. Consequently, the observations and processes proposed by Hilgard (1906) are correct although possibly incomplete.

The presence of cracks, root holes, and animal burrows in the Ac and C zones of montmorillonitic clay soils facilitates the rapid movement of water to these depths. Water moves easily from these open conduits to the surface by capillary action along the minute spaces between soil peds. As water reaches montmorillonitic clays, whether allochthonous soil filling the cracks and burrows or autochthonous soil, the clays absorb water and expand.

Gilgaies occur on the substrates with the highest potential for expansion, montmorillonite clays or shales. Gilgai microrelief, because of the reduced expansion potential, does not form on interbedded sands and muds even though the clay fraction is still montmorillonitic. Terrigenous sand and silt grains occupy the space of potentially expansive clays and dilute the effect of the process.

On slopes greater than 1 percent, gravitational forces may act in conjunction with expansive forces. Here microridges and microdepressions are elongate downslope and are apparently the equilibrium morphology (fig. 11).

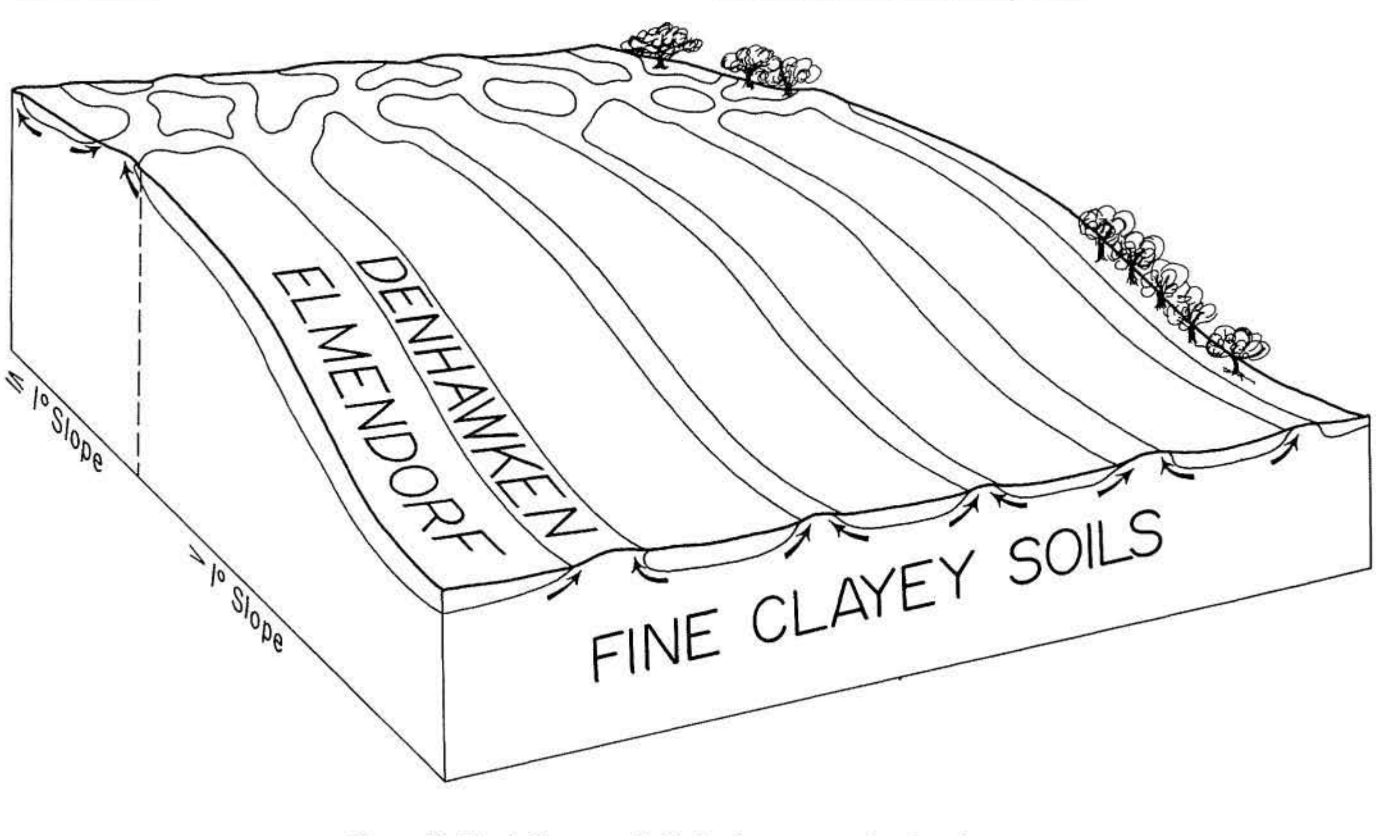


Figure 11. Block diagram of gilgai microtopography showing arrangement of morphology types and soils series types

Although the process by which gilgaies form is incompletely understood, it is suggested that the theories of both Hilgard (1906) and Howard (1932) apply at least in part. The movement of soil and subsoil material results from the hydration of: (1) previously expanded clays including crack in-fillings; (2) clays adjacent to deep cracks, root holes, and burrows; (3) clays which were previously unexpanded because of confining lithostatic pressures. Once movement is initiated, slickensides are developed as blocks of soil material slip by each other. Apparently paths of preferential movement are established along which soil continues to move during each period of expansion to form diapirs beneath microridges.

CONSTRUCTION HAZARDS

Six categories of natural hazards have been identified on the Texas Coastal Zone—shoreline erosion, subsidence, faulting, stream flooding, hurricane flooding, and hurricane winds (Brown and others, 1974). Man-made structures in areas where these hazards occur are subject to potentially severe damage. Differential expansion within soils with a high shrink-swell capacity often results in extensive damage to buildings and roads over widespread areas and should also be considered as a natural hazard of the Gulf Coastal Plain.

The two most common problems associated with expanding or heaving clay soils are damages to roads and buildings. Damage to transmission lines and in-the-ground pipelines occurs to a lesser extent. Damage to buildings with shallow foundations is common on the soils of the Cook Mountain Formation where microrelief ranges from 2 to 8 inches (5.1 to 20.3 cm). A gilgai microridge underlies the motel illustrated in figure 12 and vertical offset of approximately 6 inches (15.2 cm) has resulted in severe structural damage to the stone facing and interior walls of the motel.

Where gilgai microridges underlie roadways, undulating, cracked road surfaces and broken or offset curbs are common (fig. 13). Construction and maintainence of roads in these areas is expensive. Furthermore, the comfort and safety of vehicle passengers is markedly reduced when differential movements of more than 0.4 inch (1 cm) occur over highway distances of 20 feet (6.1 m) or less (Williams, 1965).

The differential tilting of electrical transmission lines by soil movement can increase the stress on wires between towers and damage the tower structure (fig. 14).

Pipelines are also subject to damage from soil movement. This is especially true of water and sewage lines where even minor damage can create leaks. The water or effluent leaks in turn saturate the material adjacent to the leak causing continued expansion or movement and in essence compounding the effect of the original damage.

Figure 12. Microridge development (in the area of the soft drink machine) resulting in extensive damage to concrete walks, drives, stone facing, and interior walls of this motel

Figure 13. Rippled road surface and cracks on U. S. Highway 183 north of Gonzales, Texas

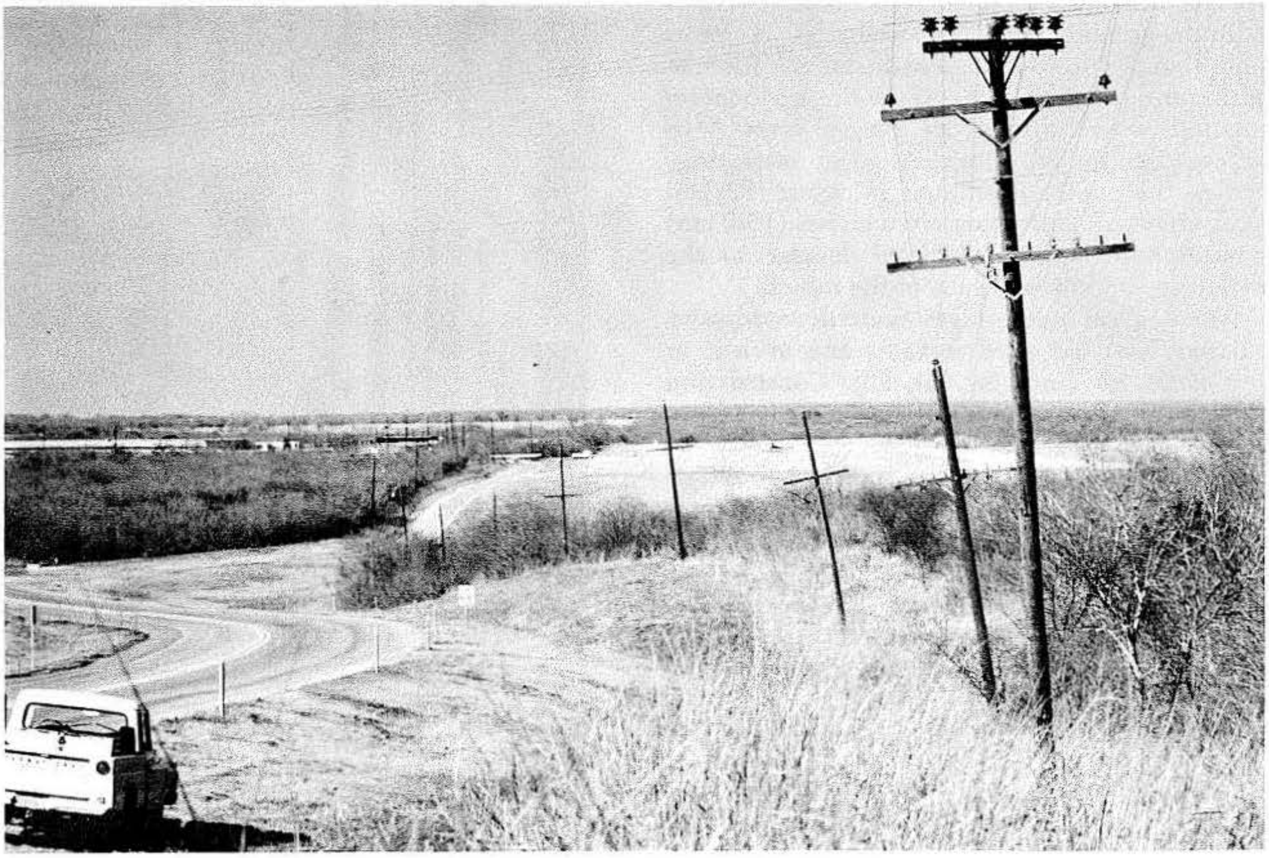


Figure 14. Power poles tilted over expansive clays along U. S. Highway 183 north of Gonzales, Texas

CURRENT MEASURES FOR CONTROL OF EXPANSIVE CLAYS

Most of the current engineering methods for control of expansive clays have been developed by highway engineers as attempts to reduce road roughness and to extend highway life. The most common techniques are lime stabilization, ponding, and subgrading. For lime stabilization of expansive clays underlying roads that will be paved with either concrete or flexible material, hydrated lime is added to pulverized subgrade material. The lime is thoroughly mixed into the subgrade, compacted, and allowed to cure before paving. In subgrading, the materials underlying the planned road are cut, scarified, and recompacted to provide uniform moisture and density. Additional stable materials are then added to the subgrade to provide a base of uniform moisture content and density prior to paving. Wide shoulders and adequate drainage are used to insure a stable moisture content.

Cracks in the expansive soils of the Gulf Coastal Plain (table 1) extend below 60 inches (152.4 cm). This indicates that montmorillonitic clays are actively expanding and contracting at these depths and probably at greater depths. Consequently, the thin surfaces caps of stabilized subgrade material may not completely eliminate ground swell in areas of montmorillonitic clay soils.

Ponding is a technique in which water is added to the soil to induce swelling prior to construction (Teng and others, 1974). The moisture content of the road base is then stabilized to reduce further swelling or contraction.

Most homes and small buildings on the Texas Coastal Plain are constructed on concrete slabs. Prevention of damage to the foundation slab is facilitated by placing a pad of stable material between the foundation slab and the expansive clays below. The concrete slabs are reinforced by steel bars or by plastic-coated steel cables to which tension is applied after the slab has set.

CONCLUSIONS

The development of gilgaies is a significant natural hazard both because of the potential of damage to man-made structures and because of their widespread occurrence on the Texas Coastal Plain—17,500,000 acres.

Gilgais are indicators of sandy muds or mudstones that produce clay loam soils irrespective of original depositional environment.

Microrelief which may reach 18 inches (45.7 cm) between adjacent microridges and microdepressions results from the implacement of diapirlike intrusions of subsoil material at regular intervals in the soil profile. Diapir movements result from the hydration of clays within the soil or subsoil. Movement is generated from excess material in the soil profile derived from soil crack filling and as newly available clays became hydrated and expand at depth.

Gilgai microrelief is easily recognized from aerial photographs on which the scale is greater than 1:80,000. Recognition of the correlation of gilgai structures and patterns with expansive soils permits rapid mapping and delineation of lands which can cause problems to any sort of rigid structures. These hazards may be partially mitigated by techniques that attempt to stabilize the swelling property of clays or that provide a stable foundation for buildings.

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