CALVERT MINE FIELD TRIP

GUIDEBOOK

For the Southern Regional Soil Survey Conference

July 14, 2010

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Southern Regional Soil Survey Conference

hosted by

Texas AgriLife Research
College Station, TX
and
Natural Resources Conservation Service
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ACKNOWLEDGEMENTS

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Faculties of state experiment stations and extension services are commonly indebted to soil scientists of the Natural Resources Conservation Service for their cooperation and support in research and extension endeavors. For the work of putting together this field trip, thanks and appreciation are extended to Dennis Williamson and James Gordon of the State Staff for support and planning, and to the following individuals stationed locally who contributed time and effort in writing sections, describing pedons, opening and preparing pits, and for advice and collaboration: Dennis Brezina, Julia McCormick, Richard Reid, and Chance Robinson. By the time we actually run the field trip, I am sure the list will be extended.

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OVERVIEW OF
CLIMATE, SOILS AND GEOLOGY OF TEXAS

This section presents an overview of the climate and soils of Texas which will aid the participant in understanding the variety and range of conditions in the state and to place the soil-climate conditions of the tour area in perspective. An overview of soil and climate in a state the size of Texas (approximately 68 million hectares) can, at best, be only a generalization. However, it is hoped that a vision of diversity and complexity will emerge that gives an appreciation of the unique combinations of natural resources available in the state.

The climate of Texas ranges from humid in the east to arid in the west and temperate to subtropical from north to south. Sudden change in weather is common, and events such as hail, torrential rains with flooding, tornadoes, freezes, hurricanes and drought occur periodically. Sunshine is abundant, ranging from 60 to 80% possible sunshine across the state from east to west (Godfrey et al., 1973).

Mean annual precipitation is lowest (about 200 mm) in far West Texas near El Paso and progressively increases to the east, reaching the highest level of precipitation in Southeast Texas at the Louisiana border (about 1400 mm). Annual precipitation commonly varies markedly from long-term means. Rainfall is greatest over much of the state during the spring months, especially May. However, in the Trans-Pecos area (far West Texas), July, August, and September are the months of most precipitation. Drought is common over much of the state during the summer. For many crops grown in Texas, rain during the summer months, especially July, is critical. Precipitation during this period generally occurs as short duration-high intensity rainfall events, commonly referred to as thunderstorms often accompanied by lightening, hail and flash flooding.

Mean annual temperatures range from about 13°C in the northwest corner of the state to about 23°C at the southern tip. Associated with temperature is the average frost-free period which ranges north to south from about 189 days to over 320 days.

The soil resource of Texas is both vast and varied. Three soil moisture regimes (Soil Survey Staff, 1999) are regionally represented in the state. The aridic moisture regime which occurs in West and Southwest Texas corresponds to that portion of the state which cannot be dryland farmed, even under fallow management schemes. In contrast, the udic moisture regime in East Texas coincides approximately to a humid climate where water deficiency may occur during the growing season but is seldom severe or prolonged. Intermediate between the extremes of aridic and udic soil moisture regimes is the ustic moisture regime which corresponds approximately to the semi-arid and sub-humid portions of the state. The concept of an ustic regime is one of limited moisture; sufficient moisture is present most years for dryland crop production but periods of water stress during the growing season are common and expected most years. Interspersed within the "regional" soil moisture regimes is the aquic soil moisture regime that occurs when the soil is both saturated with water and virtually free of dissolved oxygen for significant periods of time as to invoke reduction of iron at shallow depths.

Three soil temperature regimes are recognized in Texas, mesic, thermic, and hyperthermic. Soil temperature regimes represent the mean annual temperature at a depth of 50 cm below the soil surface (Soil Survey Staff, 1999). The mesic temperature regime (mean annual soil temperature between 8 and 15°C) in the north part of the Panhandle generally coincides to that section of the state which is too cool to grow cotton feasibly. The hyperthermic regime (mean annual temperature greater than 22°C) of South Texas is the zone in which most of the winter vegetables are produced. At the southern tip of the state, production of citrus is possible, but freezes during the winter constitute a risk. Intermediate between the mesic and hyperthermic zones is the thermic soil temperature regime (between 15 and 22°C).

The soils of Texas are shown in Fig. 1, generalized at the broadest level of Soil Taxonomy, the soil order (Soil Survey Staff, 1999). A brief description of the soil orders is given in Table 1. Of the twelve recognized soil orders, nine are found in Texas; Histosols and Spodosols occur only in limited acreage in Texas and are not represented in Fig. 1. The generalized soil order map depicts the dominant soil within each delineation. The degree of generalization is perhaps best expressed to the reader by indicating that, at the most detailed level of soil classification, there are approximately 1300 series or different soils in Texas.

Most agronomic production in Texas utilizes Alfisols, Mollisols and Vertisols. Mollisols and most of the Texas Vertisols formed under grassland vegetation and have a relatively high content (>1%) of organic matter in the surface soil (Fig. 2). However, about half of the Mollisols are shallow (<50 cm) to bedrock (Fig. 2), and not commonly cultivated. Bedrock is generally deep in the Vertisols and Alfisols. Due to the relatively warm temperatures and length of growing season, management of crop residue to maintain soil organic matter levels is continually needed throughout the state. Additionally, about half the state has soils that are calcareous to the surface. Shallow soils and/or incomplete leaching of carbonates are common in all regions except for the more humid sections of the state.

Texas is divided into some 20 Major Land Resource Areas(MLRAs)(USDA, 2006) based on similarity of soils, topography, climate, vegetation and land use. Figure 3 presents the MLRAs and Table 2 summarizes soils, land use and native vegetation. The sites covered on the tour are within the Texas Claypan Area. A discussion of the Claypan Area is presented later. Table 3 gives selected soil series common within the Claypan Area along with their family classification. Most are Alfisols with loamy sand or sandy loam surfaces over clayey argillic horizons that represent abrupt texture changes, hence the common term "clay pan". Clays in many of the soils are dominated by smectite, a layer silicate the shrinks and swells on drying and wetting.

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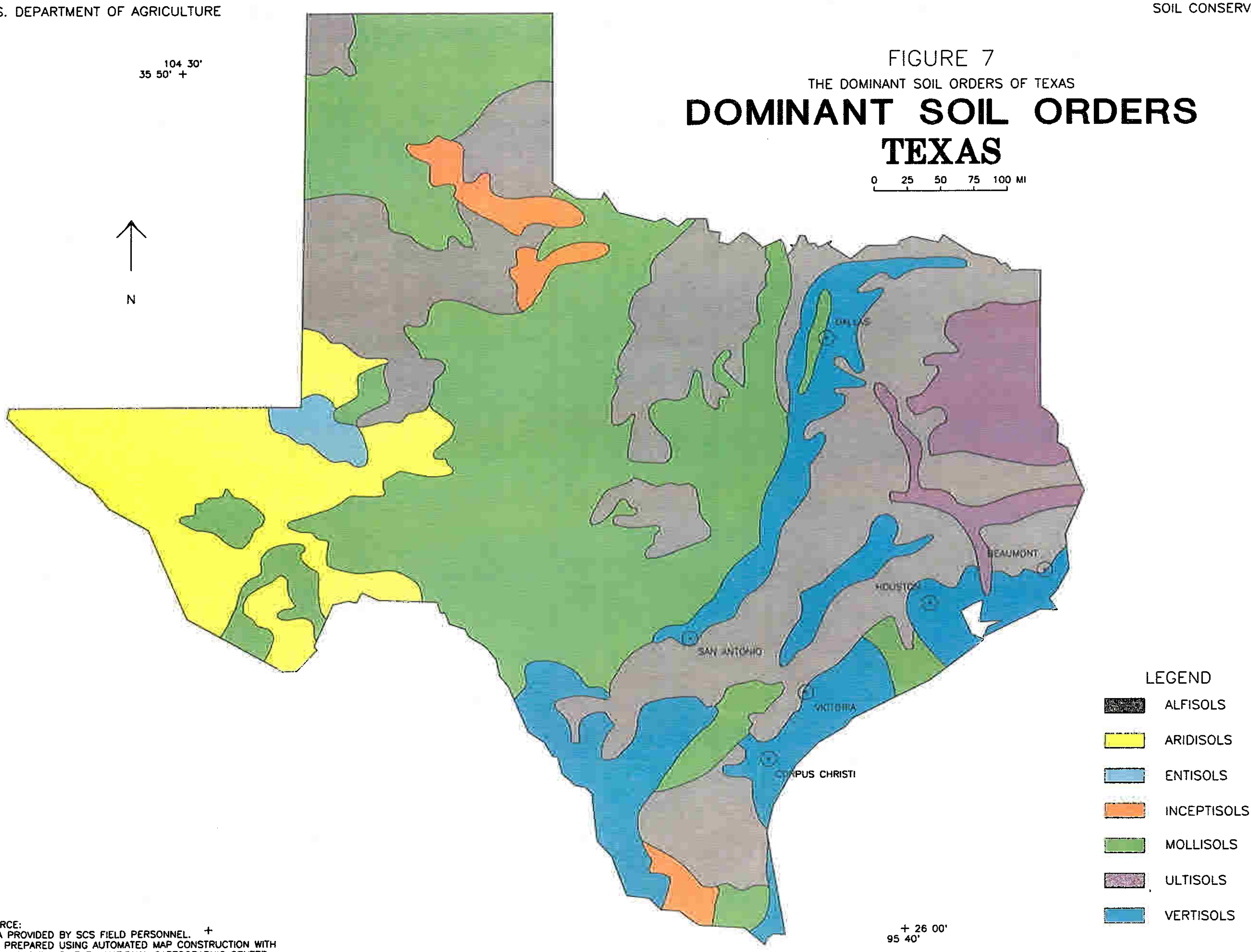
FIGURE 7

THE DOMINANT SOIL ORDERS OF TEXAS

DOMINANT SOIL ORDERS
TEXAS



SOURCE:
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MAP PREPARED USING AUTOMATED MAP CONSTRUCTION WITH
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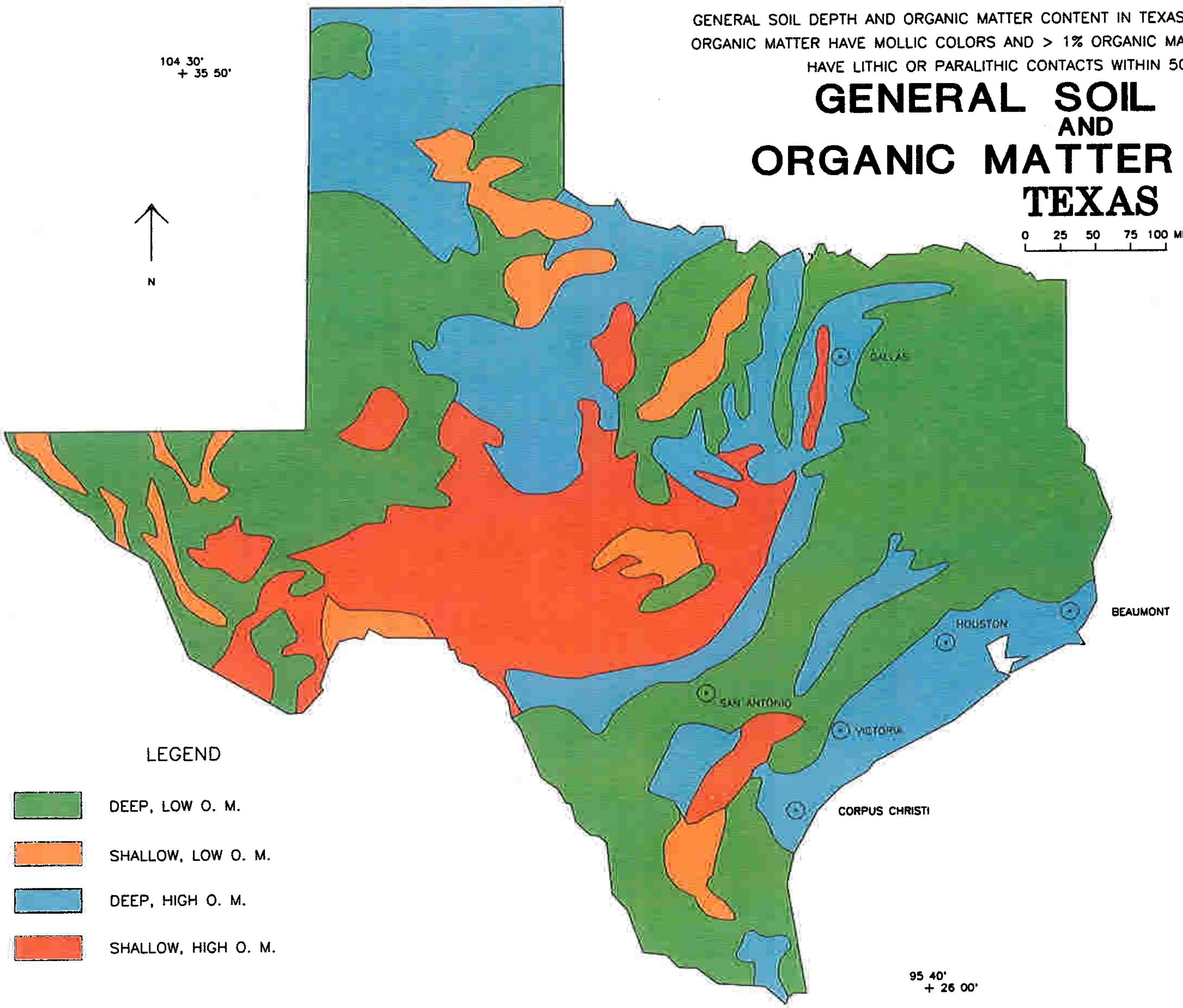
FIGURE 8

GENERAL SOIL DEPTH AND ORGANIC MATTER CONTENT IN TEXAS SOILS. SOILS DESIGNATED AS HIGH ORGANIC MATTER HAVE MOLLIC COLORS AND > 1% ORGANIC MATTER. SOILS DESIGNATED AS SHALLOW HAVE LITHIC OR PARALITHIC CONTACTS WITHIN 50 CM OF THE SURFACE.

GENERAL SOIL DEPTH AND ORGANIC MATTER CONTENT TEXAS



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DATA PROVIDED BY SCS FIELD PERSONNEL.
MAP PREPARED USING AUTOMATED MAP CONSTRUCTION WITH THE *FOCAS* EQUIPMENT. NATIONAL CARTOGRAPHIC CENTER FORT WORTH, TEXAS

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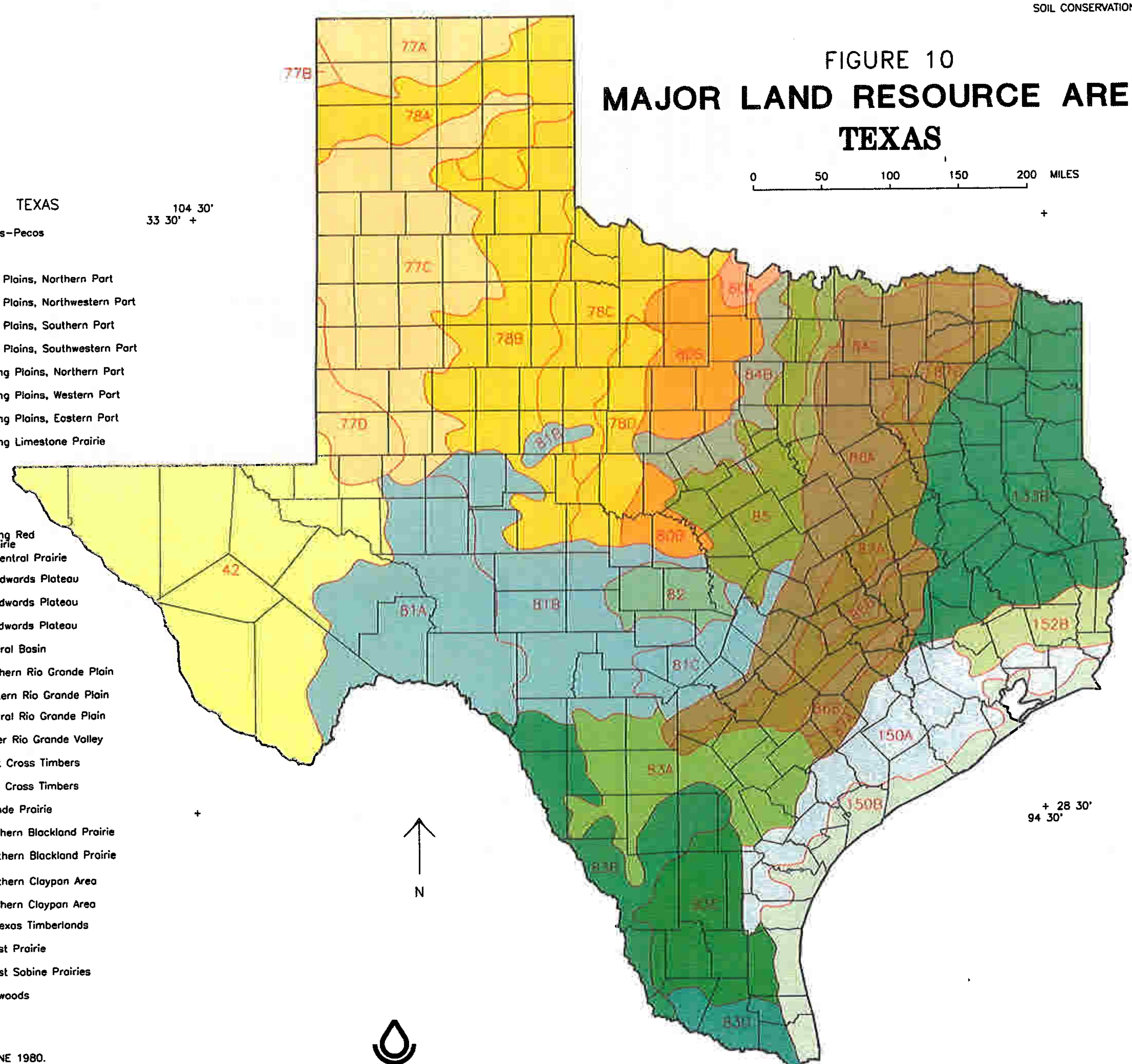
FIGURE 10

MAJOR LAND RESOURCE AREAS
TEXAS



LEGEND

NATIONAL	TEXAS
42 Southern Desertic Basin, Plains and Mountains	42 Trans-Pecos
77 Southern High Plains	77A High Plains, Northern Part
	77B High Plains, Northwestern Part
	77C High Plains, Southern Part
	77D High Plains, Southwestern Part
78 Central Rolling Red Plains	78A Rolling Plains, Northern Part
	78B Rolling Plains, Western Part
	78C Rolling Plains, Eastern Part
	78D Rolling Limestone Prairie
80A Central Red Rolling Prairies	80A Rolling Red Prairie
80B Texas N. Central Prairies	80B N. Central Prairie
81 Edwards Plateau	81A W. Edwards Plateau
	81B C. Edwards Plateau
	81C E. Edwards Plateau
82 Texas Central Basin	82 Central Basin
83A Northern Rio Grande Plain	83A Northern Rio Grande Plain
83B Western Rio Grande Plain	83B Western Rio Grande Plain
83C Central Rio Grande Plain	83C Central Rio Grande Plain
83D Lower Rio Grande Valley	83D Lower Rio Grande Valley
84B West Cross Timbers	84B West Cross Timbers
84C East Cross Timbers	84C East Cross Timbers
85 Grande Prairie	85 Grande Prairie
86 Texas Blackland Prairie	86A Northern Blackland Prairie
	86B Southern Blackland Prairie
87 Texas Claypan Areas	87A Southern Claypan Area
	87B Northern Claypan Area
133B Western Coastal Plain	133B E. Texas Timberlands
150A Gulf Coast Prairie	150A Coast Prairie
150B Gulf Coast Sobine Prairie	150B Coast Sabine Prairies
152B Western Gulf Coast Flatwoods	152B Flatwoods

SOURCE:
DIGITIZED FROM SCS THEMATIC 1003272 DATED JUNE 1980.
MAP COMPILED USING AUTOMATED MAP CONSTRUCTION WITH THE *FOCAS* EQUIPMENT.
NATIONAL CARTOGRAPHIC CENTER, FORT WORTH, TEXAS 1990.

REVISED AUGUST 1990 1004588-47

USDA-SCS-NATIONAL CARTOGRAPHIC CENTER, FT. WORTH, TX.-1990

Table 1. Soil Orders, Generalization of their Diagnostic Properties, and Approximate Equivalence in the FAO System of Soil Classification.

Order	General Diagnostic Property	Approximate FAO Equivalent[c]
Alfisols	Soils with an argillic horizon and high base saturation.	Luvisols
Andisols[b]	Soils dominated by allophone or volcanic glass.	Andosols
Aridisols	Most soils with diagnostic subsurface horizons and an aridic moisture regime.	Xerosols, Yermosols
Entisols	Soils with little or no evidence of subsoil development.	Arenosols, Fluvisols, Regosols
Gelisols	Soils with permafrost	Cryosols
Histosols[a]	Organic soils.	Histosols
Inceptisols	Soils with moderate but insufficient pedogenesis to meet other orders.	Cambisols
Mollisols	Soils with base-rich, thick, dark-colored surface horizons.	Chernozems, Greyzems, Rendzinas, Krastanozems, Phaeozems
Oxisols[b]	Soils with an oxic horizon (highly weathered subsurface horizon).	Ferralsols
Spodosols[a]	Soils with spodic horizons (subsurface horizon enriched in illuviated organic matter and Fe, Al oxi-hydroxides).	Podzols
Ultisols	Soils with an argillic horizon and low base saturation.	Acrisols
Vertisols	High clay content with shrink-swell properties.	Vertisols

[a] Found in Texas but in small, isolated acreages.
[b] Not found in Texas.
[c] Soils with aquic moisture regimes and without diagnostic illuvial horizons would be Gleysols; soils with lithic contacts would be Lithosols; those with natric horizons and highly saline horizons would be Solonetz and Solonchaks, respectively.

Table 2. Summary of major soils and land use in Texas by Major Land Resource Areas (MLRAs).

No.	MLRA Name	Major Soils	Major Land Use	Dominant Native Vegetation
42	Trans-Pecos	Haplocalcids Haplocambids	Range, limited irrigated farming	Desert grass-shrub
77	Southern High Plains	Paleustalfs Paleustolls	Dryland & irrigated farming; range	Short, mid, and tall grasses
78	Rolling Plains	Argiustolls Paleustalfs Haplustepts	Range; dryland farming	Mid and tall grasses
80A	Central Rolling Red Prairies	Argiustolls Paleustolls	Range; dryland farming	Tall grasses
80B	Texas North-Central Prairies	Calciustolls Paleustalfs	Range; dryland farming	Savanna (Oak-tall grasses)
81	Edwards Plateau	Calciustolls Argiustolls Haplustolls	Range	Desert shrub (west) to Savanna (Oak-mid and tall grasses)
82	Texas Central Basin	Paleustalfs Haplustepts	Range	Savanna (Oak-mid and tall grasses)
83A	Northern Rio Grande Plain	Paleustalfs Calciustolls	Range; dryland & irrigated farming	Open grassland and mixed shrubs
83B	Western Rio Grande Plain	Haplustalfs Natrustalfs Haplusterts	Range	Open grassland and mixed shrubs
83C	Central Rio Grande Plain	Paleustalfs Ustipsamments	Range	Mid and tall grass with few trees
83D	Lower Rio Grande Plain	Calciustolls Paleustalfs	Irrigated & dryland farming; range	Mid grasses with scattered shrubs
84B	West Cross Timbers	Paleustalfs	Range, improved pasture	Savanna (Oak and tall grasses)

84C	East Cross Timbers	Paleustalfs	Improved pasture	Savanna (Oak and tall grasses)
85	Grand Prairie	Calciustolls Haplusterts	Range; dryland farming	Tall grasses
86	Blackland Prairies	Haplustolls Haplusterts	Improved pasture; dryland farming	Tall grasses
87	Claypan Area	Paleustalfs	Improved pasture; range	Savanna (Oak and tall grasses)
133B	East Texas Timberlands	Paleudults Paleudalfs	Forest/woodland; improved pasture	Pine-hardwood forest
150A	Gulf Coast Prairies	Paleudalfs Hapluderts Argiustolls	Dryland and irrigated farming	Tall grasses
150B	Gulf Coast Saline Prairies	Natraqualfs Quartzipsamments Haplaquolls	Range	Salt tolerant grasses
152B	Western Gulf Coast Flatwoods	Glossaqualfs Vermaqualfs Paleudults	Forest	Pine-hardwood forest

Modified from U.S.D.A. (2006).

Table 3. Common Soils of the Claypan Region, and their Classification.

Soil Series	USDA Classification
Axtell	Fine, smectitic, thermic Udertic Paleustalfs
Boonville	Fine, smectitic, thermic Chromic Vertic Albaqualfs
Crockett	Fine, smectitic, thermic Udertic Paleustalfs
Edge	Fine, mixed, active, thermic Udic Paleustalfs
Hammond	Fine-loamy, mixed, superactive, nonacid, thermic Udic Ustorthents
Mabank	Fine, smectitic, thermic Oyaquic Vertic Paleustalfs
Rader	Fine-loamy, mixed, semiactive, thermic Aquic Paleustalfs
Ships	Very-fine, mixed, active, thermic Chromic Hapluderts
Tabor	Fine, smectitic, thermic Oxyaquic Vertic Paleustalfs
Weswood	Fine-silty, mixed, superactive, thermic Udifluventic Haplustepts
Wilson	Fine, smectitic, thermic Oxyaquic Vertic Haplustalfs
Zack	Fine, smectitic, thermic Udertic Paleustalfs
Zulch	Fine, smectitic, thermic Udertic Paleustalfs

The 1992 publication by the Bureau of Economic Geology giving a general map and discussion (back side of map) of the "Geology of Texas" is presented as a broad overview. Our field trip will be in the Coastal Plains Sediments (CPS) represented by the Claiborne and Wilcox Groups. Bryan and College Station are mostly on the Yegua formation, so driving to the Calvert Mine site will be going across progressively older CPS.

A schematic giving the "Geology and Soils of the Texas Gulf Coast" (Fig. 4) shows the major formations of the CPS in Texas. Coastal Plains Sediments are a mixture of continental and marine materials where rivers were constantly building seaward, and sea level was fluctuating. All formations/groups shown in the schematic have facies that are both terrestrial and marine in origin, and commonly the terrestrial facies grade to marine facies towards the Gulf of Mexico. Some of the formations are composed of chiefly terrestrial sediments, notably Wilcox, Carrizo, Queen City, Sparta, Yegua, and all formations more recent than the Jackson Group. As with all terrestrial CPS, poorly consolidated sandstones, siltstones and shales may be found. Reklaw, Weches, Cook Mountain, and the Jackson Group have significant marine components representing periods when the ocean transgressed landward leaving marine deposits above older terrestrial deposits. The marine facies commonly contain glauconite, phosphate nodules, shark's teeth, and marine fossils and casts. Intermediate between clearly terrestrial and marine materials are transitional littoral and lagoonal sediments.

Near the beginning of the Eocene period in Texas, the ocean shoreline was just northwest of Calvert (see Fig. 4) marked by the contact of the Midway and Wilcox groups. The Wilcox marked the beginning of a drop in sea level, allowing the accumulation of mostly littoral and terrestrial sediments, to include numerous seams of organic rich sediments that form the present day lignite deposits. Sedimentation continued throughout the Eocene with a general extension of terrestrial materials and a regression of the sea, marked with occasional sea transgression represented by Reklaw, Weches, Cook Mountain, and Jackson formations. By the beginning of the Miocene period, land extension into the sea dominated into the Holocene (recent).

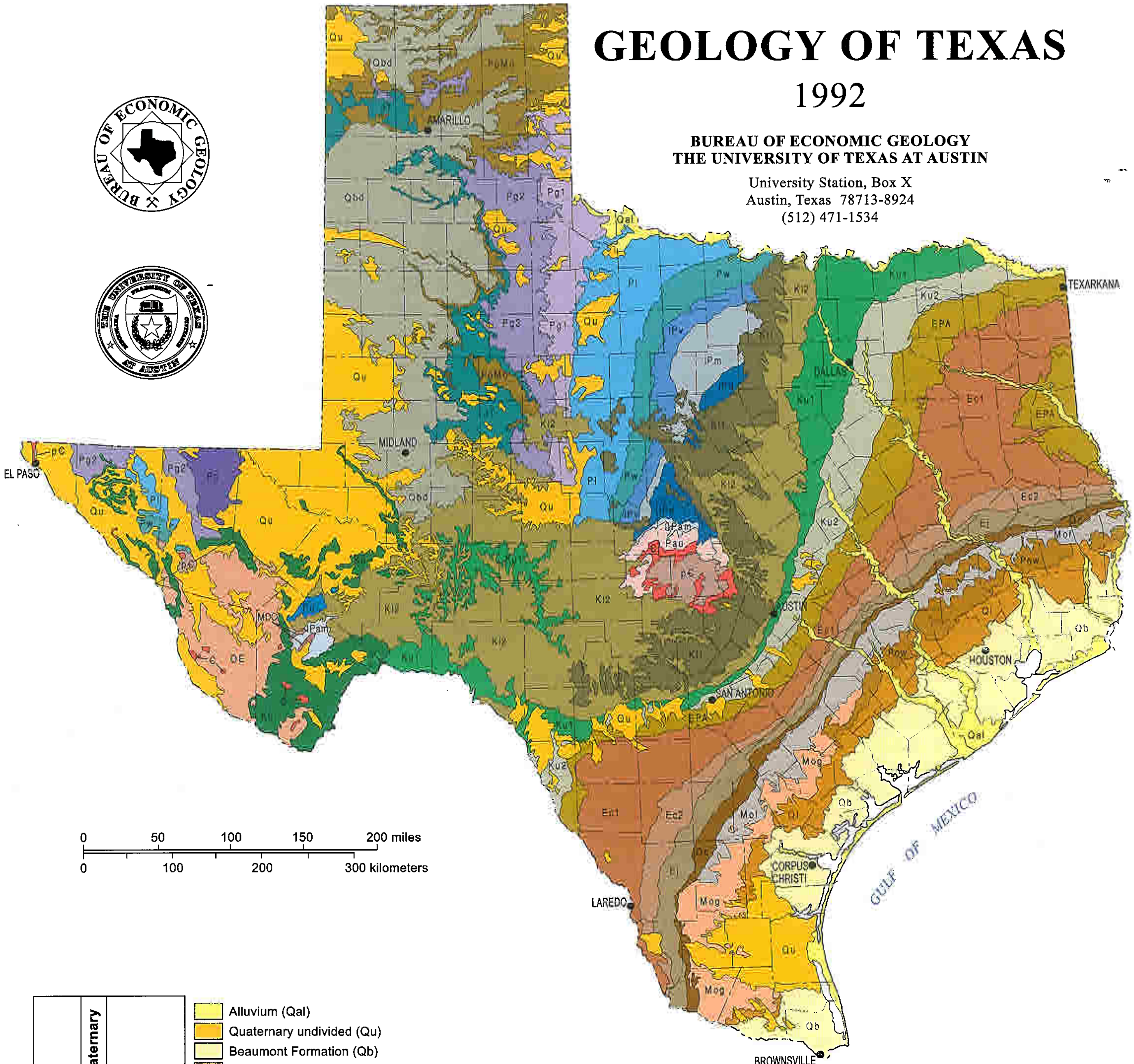
As is shown in Fig. 4, CPS formations dip gulfward at a greater rate than the change in elevation, so as one travels southeast across the CPS, progressively younger sediments are encountered. Dominant soils found on each formation are also indicated.

Another event significant to the Texas Blackland Prairies and the CPS is the formation of the Balcones Fault, actually a series of faults that was last active in the Miocene. During the Miocene, the sediment loading by the younger CPS upon the underlying Cretaceous limestones, chalks, marls, and shales resulted in a series of normal faults and grabens. The fault zone is just west of Interstate 35 and the cities of San Antonio, Austin, and Waco, and resulted in displacement of several hundred feet. It is these Cretaceous deposits which are the source of oil and gas operations in the Bryan, Giddings, Franklin, and Caldwell area where wells are commonly drilled to 20,000 feet or more.

GEOLOGY OF TEXAS

1992

BUREAU OF ECONOMIC GEOLOGY
THE UNIVERSITY OF TEXAS AT AUSTIN
University Station, Box X
Austin, Texas 78713-8924
(512) 471-1534



Era	Period	Epoch / Age	Unit
CENOZOIC	Quaternary	2 m.y.	Alluvium (Qal)
			Quaternary undivided (Qu)
			Beaumont Formation (Qb)
			Lissie Formation (Ql)
			Blackwater Draw Formation (Qbd)
	Tertiary	Pliocene 5 m.y.	Willis Formation (Pow)
		Miocene	Ogallala Formation (PoMo)
			Goliad Formation (Mog)
		24 m.y.	Fleming and Oakville Formations (Mof)
		Oligocene 38 m.y.	Catahoula Formation (Oc)
			Oligocene and Eocene undivided (OE) (volcanic rocks and conglomerates in Trans-Pecos Texas)
		Eocene	Jackson Group (Whitsett, Manning, Wellborn, Caddell, Yazoo, and Moodys Branch Fms.) (Ej)
			Claiborne Group (Yegua Formation) (Ec2)
		58 m.y.	Claiborne Group (Cook Mountain, Sparta, Weches, Queen City, and Reklaw Fms.) (Ec1)
		Paleocene	Wilcox and Midway Groups (EPA)
MESOZOIC	Cretaceous	66 m.y.	Navarro and Taylor Groups (Ku2)
			Austin, Eagle Ford, Woodbine, and U. Washita Groups (Ku1)
			Fredericksburg and L. Washita Groups (Kl2)
			Trinity Group (Kl1)
		144 m.y.	Cretaceous undivided (Ku)
	Jurassic Triassic	245 m.y.	Jurassic Triassic undivided (JT)

Era	Age	Unit
PALEOZOIC	245 m.y.	Ochoan Series (Po)
		Guadalupian Series (Whitehorse and Quartermaster Formations) (Pg2)
		Guadalupian Series (Blaine and San Angelo Formations (Pg1)
		Leonardian Series (Pl)
		Wolfcampian Series (Pw)
	286 m.y.	Permian undivided (Pu)
		Virgilian Series (IPv)
		Missourian Series (IPm)
		Desmoinesian Series (IPd)
	320 m.y.	Atokan and Morrowan Series (IPam)
	505 m.y.	Mississippian, Devonian, and Ordovician undivided (MDO)
	570 m.y.	Cambrian (-Є)
		Paleozoic undivided (Pau)
Pre-cambrian	1200 m.y 2000 m.y.	Precambrian undivided (p-Є)

Geology of Texas

The geologic history of Texas is recorded in the rock strata that fill the many subsurface sedimentary basins and crop out across the state. The origin of these strata documents a changing geography that began several billion years ago in the Precambrian Era. Mountains, seas, rivers, volcanoes, and earthquakes are part of the geologic story of Texas, and the resources produced by geologic phenomena (petroleum, coal, lignite, metals, groundwater, salt, limestone, ceramic clays, and various soils) are the legacy of the state's changing face.

Texas is underlain by Precambrian rocks more than 600 million years old. The deformed ancient volcanic and intrusive igneous rocks and sedimentary rocks were formed early in the Earth's history. They are now exposed in the Llano Uplift and in a few small areas in Trans-Pecos Texas.

During the early Paleozoic, broad inland seas inundated the stable West Texas region (Texas Craton), depositing widespread limestones and shales. Lower Paleozoic rocks are now exposed around the Llano Uplift and in the mountains of Trans-Pecos Texas. The Texas Craton was bordered on the east and south by the Ouachita Trough, a deep-marine basin extending along the Paleozoic continental margin from Arkansas and Oklahoma to Mexico. Sediments accumulated in the Ouachita Trough until late in the Paleozoic Era when the European and African continental plates collided with the North American plate. Convergence of the North and South American plates in this area produced fault-bounded mountainous uplifts (Ouachita Mountains) and small basins filled by shallow inland seas that constituted the West Texas Basin.

Broad limestone shelves and barrier reefs surrounded the deeper parts of the marine subbasins. Rivers flowed to the landward edges of the basins, forming deltas, and coastlines shifted repeatedly as nearshore sediments were deposited and then eroded by marine processes. Pennsylvanian strata that are products of these processes are exposed today in North-Central Texas. Near the end of the Paleozoic Era, the inland seas retreated southwestward, and West Texas became the site of broad evaporite basins where salt, gypsum, and red muds were deposited in a hot, arid climate. The strata originally deposited in the Permian Basin are exposed in the Rolling Plains of West and Northwest Texas and in Trans-Pecos Texas.

The Mesozoic Era in Texas began about 245 million years ago when the European and African plates began to break away from the North American plate, producing a belt of elongate rift (fault-bounded) basins that extended from Mexico to Nova Scotia. Sediment from adjacent uplifts was deposited in these basins by streams. While Europe and Africa drifted farther away, the basins were buried beneath marine salt as the East Texas and Gulf Coast Basins were created. During the rest of the Mesozoic Era, broad limestone shelves were periodically buried by coastal plains and deltaic deposits as the Texas continental margin gradually shifted southeastward into the Gulf of Mexico. In the East Texas Basin, deeply buried salt deposits moved upward forming salt ridges and domes, providing a variety of folded structures and traps for oil and gas.

In West Texas, during the early Mesozoic Era, a large shallow lake occupied the abandoned site of the Permian Basin, but eventually waters from the Gulf of Mexico encroached and flooded West Texas beneath a shallow sea. Dinosaurs roamed the land and shallow waters, and marine reptiles dominated the Mesozoic seas until the waters withdrew from West Texas, near the end of the era. Mesozoic strata are exposed along the western and northern margin of the Gulf Coast and East Texas Basins and extensively across West Texas.

When the Cenozoic Era dawned in Texas, about 66 million years ago, the East Texas Basin was filling with lignite-bearing deposits of river and delta origin. The early Cenozoic Mississippi River flowed across East Texas, and a large delta occupied the region north of Houston. Smaller deltas and barrier islands extended southwestward into Mexico, very much like the present Texas coast. Delta and river sands were transported southeastward into progressively deeper waters of the Gulf of Mexico. In the Gulf Coast Basin, deeply buried lower Mesozoic salt moved upward to form domes and anticlinal structures. Now, Cenozoic strata are exposed throughout East Texas and in broad belts in the coastal plain that become younger toward the Gulf of Mexico.

In Trans-Pecos Texas, extensive Cenozoic volcanoes erupted, thick lava flows were deposited over older Mesozoic and Paleozoic strata, and rift basins were formed. Cenozoic volcanic rocks are now well exposed in the arid region of Trans-Pecos Texas.

In northwestern Texas, late Cenozoic streams deposited gravel and sand transported from the Rocky Mountains of southern Colorado and northern New Mexico. During the Ice Age (Pleistocene Epoch, beginning about 2 million years ago) the Pecos River eroded northward into eastern New Mexico and isolated the alluvial eolian deposits of the Texas High Plains from their Rocky Mountain source. The isolated High Plains were eroded by several Texas rivers during and since the Ice Age, causing the eastern margin (caprock) to retreat westward to its present position.

While the northern part of the continent was covered by thick Pleistocene ice caps, streams meandered southeastward across a cool, humid Texas carrying great volumes of water to the Gulf of Mexico. Those rivers, the Colorado, Brazos, Red, and Canadian, slowly entrenched their meanders as gradual uplift occurred across Texas during the last 1 million years. Sea-level changes during the Ice Age alternately exposed and inundated the continental shelf. River, delta, and coastal sediments deposited during interglacial (high-sea-level) stages are exposed along the outer 80 kilometers of the coastal plain. Since sea level reached its approximate present position about 3,000 years ago, thin coastal-barrier, lagoon, and delta sediments have been deposited along the Gulf Coast.

Texas is a composite of nature's processes. Texas today is but one frame in a dynamic geological kaleidoscope of changing rivers, subsiding basins, shifting beaches, uplifting mountains, and eroding plateaus. The face of modern Texas is the link that connects its geologic past to its inevitable future.

Bureau of Economic Geology

The **Bureau of Economic Geology,** established in 1909, was the first research unit at The University of Texas at Austin; it also functions as the State Geological Survey. The Bureau curates the largest volume of subsurface core and cuttings in the U.S. and provides extensive outreach services. As part of the Jackson School of Geosciences, the Bureau conducts basic and applied research related to oil, natural gas and coal, mineral resources, coastal processes, Earth and environmental systems, hydrogeology, carbon sequestration, nanotechnology, energy economics, and geologic mapping. Bureau reports and maps are available for a nominal price.

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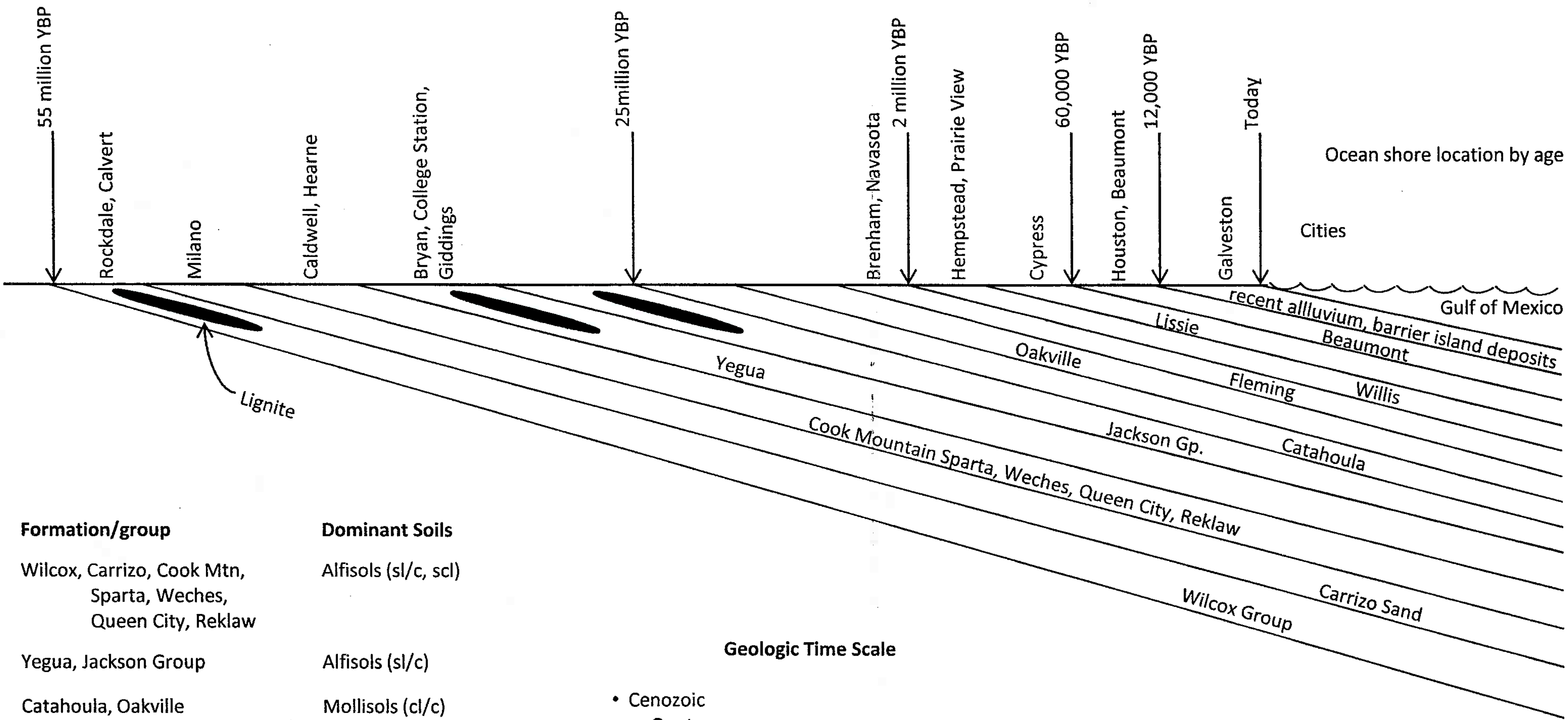
Geology and Soils of the Texas Gulf Coast

(transect from NW to SE, about 175mi.)



Formation/group	Dominant Soils
Wilcox, Carrizo, Cook Mtn, Sparta, Weches, Queen City, Reklaw	Alfisols (sl/c, scl)
Yegua, Jackson Group	Alfisols (sl/c)
Catahoula, Oakville	Mollisols (cl/c) Alfisols (sl/c)
Fleming	Vertisols (c/c)
Willis	Alfisols (sl/c, scl)
Lissie	Alfisols (l/cl, c) Mollisols (l/l)
Beaumont	Vertisols (c/c) Mollisols (cl/c)
Recent	Entisols (s/s or c/c)

Geologic Time Scale

- Cenozoic
  - Quaternary
    - Recent (last 12,000 yrs)
      Pleistocene (began 2 million years BP)
  - Tertiary
    - Pliocene (began 5 million years BP)
    - Miocene (began 25 million years BP)
    - Oligocene (began 35 million years BP)
    - Eocene (began 55 million years BP)

Land surface slope (average) = 2.5 ft/mi

Formation slope (average dip) = 60 ft/mi

Figure 4. Geology and Soils of the Texas Gulf Coast.

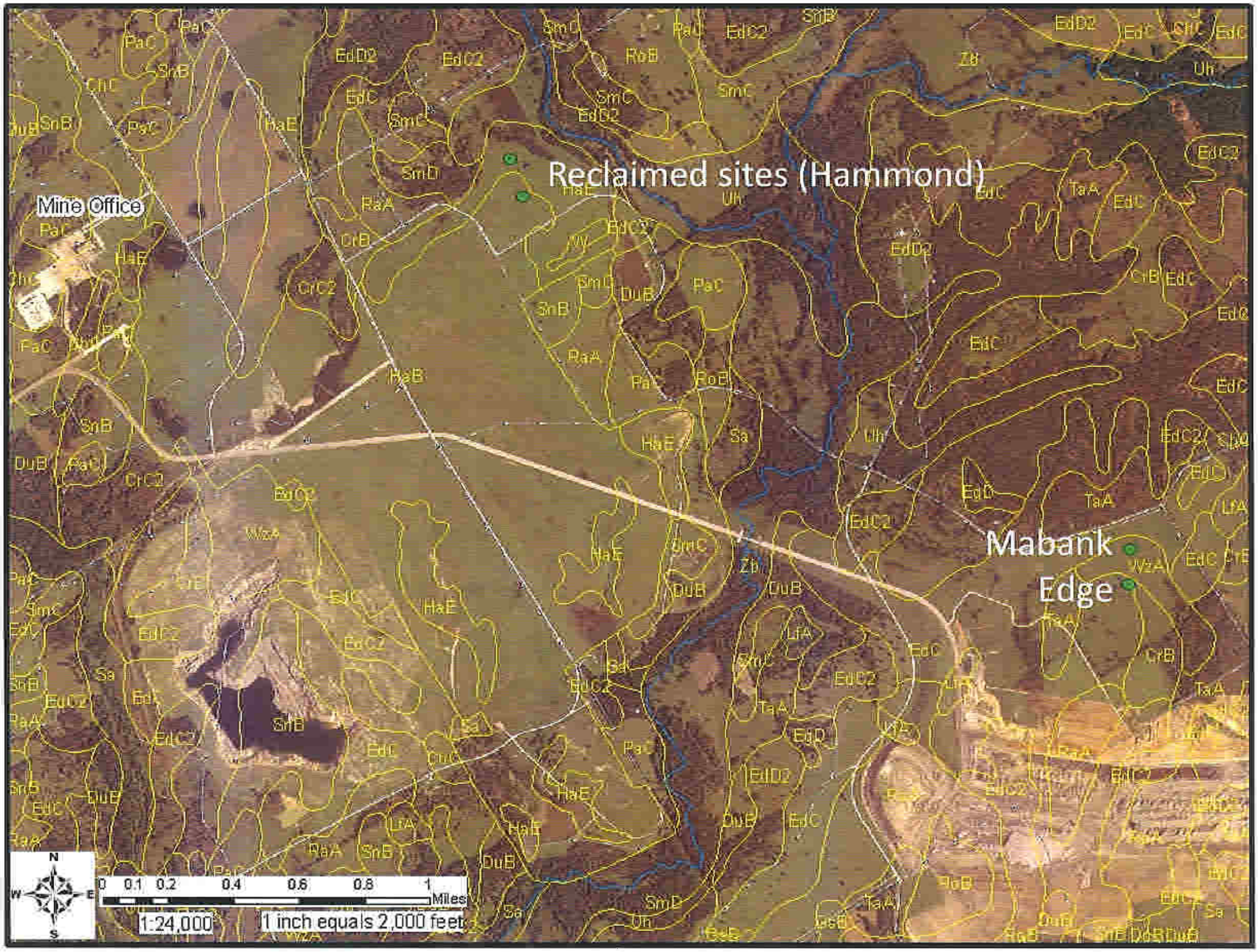
The Calvert Mine
Walnut Creek Mining Company
Prepared by Dan Kowalski

Located in northwest Robertson County, Texas, Walnut Creek Mining Company produces approximately 2,000,000 tons of lignite per year from its Calvert Mine. The mining permit area covers about 11,000 acres. The lignite is mined from up to six individual seams that range in thickness from 2 to 8 feet, and generally dip to the east. Depths of the seams vary from 20 feet to over 180 feet from the surface. The process of removing overburden and uncovering each lignite seam is done by using either a Bucyrus-Erie 1570 Dragline with an 80 cubic yard bucket and/or a Caterpillar 5230 Shovel and 150 cubic yard End Dumps. An average of 5,500 tons of lignite is mined daily and transported by End Dumps six miles to the Twin Oaks Power Plant.

The Calvert Mine is the only surface lignite mine in the State of Texas that employs 100% topsoiling of reclamation. Topsoil depths range from 7 to 12 inches over mixed overburden. To assure quality reclamation, six composite soil samples are taken to a depth of four feet within 500 x 500 foot grids and analyzed for the Texas Suite of Parameters including, but not limited to, texture, pH, acid/base accounting, sulfur forms, electrical conductivity (EC) and sodium adsorption ratio (SAR). Most reclaimed areas are planted with coastal bermudagrass and returned to pastureland and water resources (ponds). The entire mining process from topsoil stripping, overburden removal, lignite removal, regrading, topsoiling, revegetation, monitoring to final bond release, takes from 8 to 10 years. To date, we have reclaimed over 3,000 acres and returned over 500 acres to the original landowners.

The Calvert Mine, September, 2008.

Walnut Creek Mine



MABANK FINE SANDY LOAM

Print Date: 07/07/2010
Description Date: 06/30/2010
Describer: C. T. Hallmark, Julia A. McCormick, Chance M. Robinson, Dennis N. Brezina
Site ID: P10TX-395-901
Site Notes: Vegetation consists of bahiagrass (Paspalum notatum, PANO2), wooly croton (Croton capitatus, CRCA6), bitter sneezeweed (Helenium drummondii, HEDR2) and mesquite (Prosopis glandulosa, PRGL2)
Pedon ID: P10TX-395-901
Soil Name as Described/Sampled: Mabank
Soil Name as Correlated: Wilson
Classification: Fine, smectitic, thermic Oxyaquic Vertic Haplustalfs
Pedon Type: map unit inclusion
Pedon Purpose: full pedon description
Taxon Kind: series
Associated Soils: Crockett, Edge, Tabor, Wilson
<u>Location Information</u>
Country: United States
State: Texas
County: ROBERTSON
MLRA: 87A -- Texas Claypan Area, Southern Part (proposed)
Quad Name: Owensville, Texas
Location Description: Walnut Creek Mine pre-mine area, Stop #4 for the EM meter, stop 3 for the day
Latitude: 31 degrees 5 minutes 3.60 seconds north
Longitude: 96 degrees 36 minutes 56.70 seconds west
Datum: NAD83
UTM Zone: 14
UTM Easting: 727447 meters
UTM Northing: 3441389 meters
Physiographic Province: Coastal Plain
Physiographic Section: West Gulf Coastal plain
Geomorphic Setting:
backslope of interfluve of
Upslope Shape: concave
Cross Slope Shape: linear
Primary Earth Cover: grass/herbaceous cover
Secondary Earth Cover: rangeland, grassland
Plant Association Name: Claypan Prairie Range Ecological Site
Parent Material: Calvert Bluff (Eocene, Wilcox Group)
Particle Size Control Section: 10.6 to 30.3 in.
Diagnostic Features:

Slope (%)	Elevation (feet)	Aspect (deg)	MAAT (F)	MSAT (F)	MWAT (F)	MAP (in)	Frost Free Days	Drainage Class	Slope Length (feet)	Upslope Length (feet)
0.5	402	10	67	82	51	38.7	254	somewhat poorly		

Ap--0 to 18 centimeters (0.0 to 7.1 inches); brown (10YR 5/3), fine sandy loam, brown (10YR 4/3), moist; weak fine and medium subangular blocky structure; friable, very hard; many fine and medium roots throughout; very strongly acid, pH 4.5, Hellige-Truog; Cracks at the surface that are 5 to 10mm wide.; clear wavy boundary.

E--18 to 27 centimeters (7.1 to 10.6 inches); light brownish gray (10YR 6/2), fine sandy loam, very dark grayish brown (10YR 3/2), moist; weak medium subangular blocky structure; friable, very hard; many fine and medium roots throughout; very strongly acid, pH 4.5, Hellige-Truog; abrupt wavy boundary.

Bt1--27 to 57 centimeters (10.6 to 22.4 inches); dark grayish brown (10YR 4/2), clay, very dark grayish brown (10YR 3/2), moist; weak medium and coarse angular blocky structure; very firm, extremely hard, very sticky, very plastic; common fine roots between peds; 10 percent discontinuous faint pressure faces on faces of peds and 10 percent patchy faint clay films on faces of peds; 1 percent fine and medium spherical weakly cemented iron-manganese concretions; very strongly acid, pH 5, Hellige-Truog; gradual wavy boundary.

Bt2--57 to 76 centimeters (22.4 to 29.9 inches); dark gray (10YR 4/1), clay loam, very dark gray (10YR 3/1), moist; weak medium and coarse angular blocky structure; very firm, extremely hard, very sticky, very plastic; common very fine and fine roots between peds; 10 percent discontinuous faint pressure faces on faces of peds and 10 percent patchy faint clay films on faces of peds; 1 percent fine faint spherical moderately cemented iron-manganese concretions; noneffervescent, by HCl, 1 normal; neutral, pH 7, Hellige-Truog; gradual wavy boundary.

Bt3--76 to 130 centimeters (29.9 to 51.2 inches); gray (10YR 5/1), clay loam, dark gray (10YR 4/1), moist; moderate medium subangular blocky structure; very firm, extremely hard, very sticky, very plastic; common very fine and fine roots between peds; 2 percent patchy faint clay films on faces of peds; 1 percent fine faint spherical moderately cemented iron-manganese concretions; 1 percent fine barite crystals; noneffervescent, by HCl, 1 normal; moderately alkaline, pH 8, Hellige-Truog; clear wavy boundary.

BCk1--130 to 157 centimeters (51.2 to 61.8 inches); light brownish gray (2.5Y 6/2), silty clay loam, grayish brown (2.5Y 5/2), moist; massive; firm, very hard; 20 percent medium distinct dark grayish brown (10YR 4/2) iron depletions on faces of peds and 2 percent fine distinct brownish yellow (10YR 6/6) iron concretions on faces of peds and 1 percent fine distinct cylindrical iron-manganese masses; 2 percent fine barite crystals and 1 percent fine cylindrical carbonate masses; 2 percent nonflat rounded indurated 5- to 10-millimeter ironstone nodules; noneffervescent, by HCl, 1 normal; moderately alkaline, pH 8, Hellige-Truog; clear wavy boundary.

BCk2--157 to 196 centimeters (61.8 to 77.2 inches); light gray (2.5Y 7/2), silt loam, light brownish gray (2.5Y 6/2), moist; massive; firm, very hard; 25 percent fine and medium prominent yellowish brown (10YR 5/6) masses of oxidized iron on horizontal faces of peds and 1 percent fine iron-manganese masses; 1 percent fine cylindrical carbonate masses; noneffervescent, by HCl, 1 normal; moderately alkaline, pH 8, Hellige-Truog.

EDGE FINE SANDY LOAM

Print Date: 07/07/2010
Description Date: 06/30/2010
Describer: C. T. Hallmark, Julia A. McCormick, Chance M. Robinson, Dennis N. Brezina
Site ID: P10TX-395-902
Site Notes: Vegetation consists of bahiagrass (Paspalum notatum, PANO2), wooly croton (Croton capitatus, CRCA6), and post oak (Quercus stellata, QUST)
Pedon ID: P10TX-395-902
Soil Name as Described/Sampled: Edge
Soil Name as Correlated: Edge
Classification: Fine, mixed, active, thermic Udic Haplustalfs
Pedon Type: within range of series
Pedon Purpose: full pedon description
Taxon Kind: series
Associated Soils: Crockett, Gasil, Tabor, Wilson

Location Information

Country: United States
State: Texas
County: ROBERTSON
MLRA: 87A -- Texas Claypan Area, Southern Part (proposed)
Quad Name: Owensville, Texas
Location Walnut Creek Mine pre-mine area, Stop #8C for the EM meter, stop 4 for the day.
Latitude: 31 degrees 4 minutes 58.10 seconds north
Longitude: 96 degrees 36 minutes 57.10 seconds west
Datum: NAD83
UTM Zone: 14
UTM Easting: 727439 meters
UTM Northing: 3441223 meters
Physiographic Province: Coastal Plain
Physiographic Section: West Gulf Coastal plain
Geomorphic Setting:
shoulder of interfluve of
Upslope Shape: linear
Cross Slope Shape: convex
Primary Earth Cover: grass/herbaceous cover
Secondary Earth Cover: rangeland, grassland
Plant Association Name: Claypan Savannah Range Ecological Site
Parent Material: Calvert Bluff (Eocene, Wilcox Group)
Particle Size Control Section: 7.5 to 27.2 in.
Diagnostic Features:

Slope (%)	Elevation (feet)	Aspect (deg)	MAAT (F)	MSAT (F)	MWAT (F)	MAP (in)	Frost Free Days	Drainage Class	Slope Length (feet)	Upslope Length (feet)
2	407	10	67	82	51	38.7	254	well		

Ap--0 to 19 centimeters (0.0 to 7.5 inches); brown (10YR 5/3), fine sandy loam, brown (10YR 4/3), moist; weak fine and medium subangular blocky structure; friable, soft; many very fine and fine roots throughout; 5 percent fine and medium distinct reddish brown (5YR 4/4) iron concentrations on surfaces along root channels; slightly acid, pH 6.5, Hellige-Truog; abrupt smooth boundary.

Bt1--19 to 56 centimeters (7.5 to 22.0 inches); reddish brown (2.5YR 4/4), clay, reddish brown (2.5YR 4/3), moist; moderate medium angular blocky structure; very firm, extremely hard, moderately sticky, moderately plastic; common very fine and fine roots between peds; 1 percent patchy distinct reddish brown (2.5YR 4/3) clay films; 12 percent fine and medium prominent brown (7.5YR 5/4) iron concentrations on faces of peds; neutral, pH 7, Hellige-Truog; clear smooth boundary.

Bt2--56 to 85 centimeters (22.0 to 33.5 inches); brown (7.5YR 5/3), clay, brown (7.5YR 4/3), moist; weak coarse prismatic structure parting to moderate medium angular blocky structure; very firm, extremely hard, moderately sticky, moderately plastic; common very fine and fine roots between peds; 1 percent continuous distinct clay films on faces of peds; 25 percent fine and medium prominent red (2.5YR 5/6) iron concentrations throughout; neutral, pH 7, Hellige-Truog; clear smooth boundary.

Bt3--85 to 132 centimeters (33.5 to 52.0 inches); brown (7.5YR 5/4), clay loam, brown (7.5YR 4/4), moist; 30 percent medium and coarse distinct pink (7.5YR 7/4) mottles; weak coarse prismatic structure parting to moderate medium subangular blocky structure; very firm, extremely hard, moderately sticky, moderately plastic; common very fine roots between peds; 1 percent continuous faint brown (7.5YR 4/4) clay films on faces of peds; 1 percent fine barite masses; neutral, pH 7, Hellige-Truog; clear smooth boundary.

BCt--132 to 169 centimeters (52.0 to 66.5 inches); very pale brown (10YR 7/4), sandy clay loam, pale brown (10YR 6/3), moist; 3 percent medium distinct strong brown (7.5YR 5/6) and 2 percent fine and medium prominent light gray (10YR 7/2) mottles; weak coarse prismatic structure; friable, very hard, slightly sticky, slightly plastic; common very fine roots between peds; 1 percent continuous faint clay films on vertical faces of peds; moderately alkaline, pH 8, Hellige-Truog; horizontal bedding planes throughout; gradual smooth boundary.

CB--169 to 193 centimeters (66.5 to 76.0 inches); very pale brown (10YR 7/4), clay loam, pale brown (10YR 6/3), moist; 1 percent medium prominent gray (2.5Y 6/1) mottles; weak coarse prismatic structure; firm, very hard, slightly sticky, slightly plastic; 1 percent discontinuous faint clay films on vertical faces of peds; moderately alkaline, pH 8, Hellige-Truog; horizontal bedding planes throughout; clear smooth boundary.

C--193 to 210 centimeters (76.0 to 82.7 inches); silty clay loam, 45 percent gray (2.5Y 6/1) and 50 percent pale yellow (2.5Y 7/3), moist; 5 percent fine and medium distinct brownish yellow (10YR 6/6) mottles; massive; firm, very hard, slightly sticky, slightly plastic; 1 percent fine iron-manganese masses; moderately alkaline, pH 8, Hellige-Truog; strong horizontal bedding planes throughout.

HAMMOND SANDY CLAY LOAM

Print Date: 07/07/2010
Description Date: 06/30/2010
Describer: C. T. Hallmark, Julia A. McCormick, Chance M. Robinson, Dennis N. Brezina
Site ID: P10TX395-903
Site Notes: Vegetation consists of Bermuda grass (Cynodon dactylon, CYDA)
Pedon ID: P10TX395-903
Pedon Notes: Site was reclaimed 1998-1999.
Soil Name as Described/Sampled: Hammond
Soil Name as Correlated: Hammond
Classification: Fine-loamy, mixed, superactive, nonacid, thermic Udic Ustorthents
Pedon Type: within range of series
Pedon Purpose: full pedon description
Taxon Kind: series

<u>Location Information</u>

Country: United States
State: Texas
County: Robertson
MLRA: 87A -- Texas Claypan Area, Southern Part
Quad Name: Hammond, Texas
Location Description: Walnut Creek Mine. Stop #8 for the EM meter, stop 1 for the day.
Latitude: 31 degrees 6 minutes 1.70 seconds north
Longitude: 96 degrees 38 minutes 47.70 seconds west
Datum: NAD83
UTM Zone: 14
UTM Easting: 724470 meters
UTM Northing: 3443122 meters
Physiographic Province: Coastal Plain
Physiographic Section: West Gulf Coastal plain
Primary Earth Cover: grass/herbaceous cover
Secondary Earth Cover: pastureland, tame
Plant Association Name: None assigned
Parent Material: Loamy surface mine reclamation material
Particle Size Control Section: 9.8 to 39.4 in.
Diagnostic Features: ochric epipedon 0.0 to 5.5 in

Slope (%)	Elevation (feet)	Aspect (deg)	MAAT (F)	MSAT (F)	MWAT (F)	MAP (in)	Frost Free Days	Drainage Class	Slope Length (feet)	Upslope Length (feet)
3	390	80	67	82	51	38.7	254	well		

Ap--0 to 14 centimeters (0.0 to 5.5 inches); brown (10YR 4/3), sandy clay loam, brown (10YR 5/3), dry; 22 percent clay; 2 percent fine prominent reddish yellow (7.5YR 6/6) mottles; moderate fine subangular blocky structure parting to moderate medium subangular blocky structure; friable, slightly hard; common fine roots throughout and common very fine roots throughout; moderately alkaline, pH 8; abrupt smooth boundary.

C1--14 to 69 centimeters (5.5 to 27.2 inches); light olive brown (2.5Y 5/4), sandy clay loam, light yellowish brown (2.5Y 6/4), dry; 30 percent clay; 4 percent medium prominent yellowish red (5YR 5/6) and 5 percent fine and medium distinct gray (2.5Y 5/1) and 2 percent fine distinct brownish yellow (10YR 6/6) mottles; massive; very firm, very hard; common very fine and fine roots throughout; 3 percent 2- to 20-millimeter coal fragments; neutral, pH 6.8; clear smooth boundary.

C2--69 to 114 centimeters (27.2 to 44.9 inches); yellowish brown (10YR 5/6), clay loam, brownish yellow (10YR 6/6), dry; 38 percent clay; 5 percent medium distinct olive yellow (2.5Y 6/6) and 2 percent medium prominent light brownish gray (2.5Y 6/2) mottles; massive; firm, hard; common very fine roots between peds; 1 percent 2- to 5-millimeter coal fragments; neutral, pH 6.8; abrupt smooth boundary.

C3--114 to 138 centimeters (44.9 to 54.3 inches); dark yellowish brown (10YR 4/4), clay, yellowish brown (10YR 5/4), dry; 15 percent medium distinct gray (10YR 5/1) and 10 percent medium prominent red (2.5YR 4/8) and 5 percent fine and medium distinct brownish yellow (10YR 6/8) mottles; massive; very firm, extremely hard; common very fine roots between peds; 2 percent 2- to 20-millimeter coal fragments; neutral, pH 6.8; clear smooth boundary.

C4--138 to 170 centimeters (54.3 to 66.9 inches); yellowish brown (10YR 5/4), clay loam, light yellowish brown (10YR 6/4), dry; 38 percent clay; 10 percent medium prominent light brownish gray (2.5Y 6/2) and 7 percent fine and medium faint brownish yellow (10YR 6/8) and 3 percent medium prominent light gray (10YR 7/1) mottles; massive; firm, very hard; 5 percent 2- to 20-millimeter coal fragments; strongly acid, pH 5.5; clear smooth boundary.

C5--170 to 203 centimeters (66.9 to 79.9 inches); yellowish brown (10YR 5/4), sandy clay loam, light yellowish brown (10YR 6/4), dry; 25 percent clay; 7 percent medium distinct brownish yellow (10YR 6/6) and 5 percent fine and medium prominent light gray (2.5Y 7/1) mottles; massive; firm, very hard; 7 percent 2- to 20-millimeter coal fragments; neutral, pH 6.8.

HAMMOND (VARIANT) SANDY CLAY LOAM

Print Date: 07/07/2010
Description Date: 06/30/2010
Describer: C. T. Hallmark, Julia A. McCormick, Chance M. Robinson, Dennis N. Brezina
Site ID: P10TX395-904
Site Notes: Soil was reclaimed in 1998-1999
Pedon ID: P10TX395-904
Pedon Notes: Vegetation consists of Bermuda grass (Cynodon dactylon, CYDA) and black willow (Salix nigra, SANI)
Soil Name as Described/Sampled: Hammond
Soil Name as Correlated: Hammond
Classification: Coarse-loamy, mixed, superactive, thermic Udic Ustorthents
Pedon Type: map unit inclusion
Pedon Purpose: full pedon description
Associated Soils: Crockett, Edge, Padina, Rader, Tabor, Wilson

Location Information

Country: United States
State: Texas
County: Robertson
MLRA: 87A -- Texas Claypan Area, Southern Part
Soil Survey Area: TX395 -- Robertson County, Texas
Quad Name: Hammond, Texas
Location Description: Walnut Creek Mine. Stop #2 for the EM meter, stop 2 for the day.
Latitude: 31 degrees 6 minutes 7.70 seconds north
Longitude: 96 degrees 38 minutes 49.90 seconds west
Datum: NAD83
UTM Zone: 14
UTM Easting: 724401 meters
UTM Northing: 3443304 meters
Physiographic Province: Coastal Plain
Physiographic Section: West Gulf Coastal plain
Primary Earth Cover: grass/herbaceous cover
Secondary Earth Cover: pastureland, tame
Plant Association Name: None assigned
Parent Material: Loamy surface mine reclamation material
Particle Size Control Section: 9.8 to 39.4 in.
Diagnostic Features: ochric epipedon 0.0 to 7.9 in.

Slope (%)	Elevation (feet)	Aspect (deg)	MAAT (F)	MSAT (F)	MWAT (F)	MAP (in)	Frost Free Days	Drainage Class	Slope Length (feet)	Upslope Length (feet)
2	400	180	67	82		38.7	254	moderately well		

Ap--0 to 20 centimeters (0.0 to 7.9 inches); brown (7.5YR 4/4), sandy clay loam, brown (7.5YR 5/4), dry; 4 percent fine and medium distinct yellowish red (5YR 4/6) mottles; weak fine and medium subangular blocky structure; very friable, soft; common very fine roots throughout and common fine roots throughout; strongly acid, pH 5.5; clear smooth boundary.

C1--20 to 42 centimeters (7.9 to 16.5 inches); brown (7.5YR 5/4), fine sandy loam, light brown (7.5YR 6/4), dry; 2 percent fine prominent grayish brown (10YR 5/2) and 4 percent fine and medium distinct strong brown (7.5YR 5/6) mottles; massive; very friable, soft; common very fine roots between peds; very strongly acid, pH 5; 10% (10YR 5/3) sandy clay loam material; gradual smooth boundary.

C2--42 to 66 centimeters (16.5 to 26.0 inches); brown (7.5YR 4/4), loamy fine sand, brown (7.5YR 5/4), dry; 2 percent medium faint pale brown (10YR 6/3) and 2 percent fine distinct yellowish red (5YR 4/6) mottles; massive; very friable, soft; common very fine roots between peds; strongly acid, pH 5.5; clear smooth boundary.

C3--66 to 120 centimeters (26.0 to 47.2 inches); brown (7.5YR 4/4), loamy fine sand, brown (7.5YR 5/4), dry; 5 percent medium distinct yellowish red (5YR 4/6) and 5 percent medium faint brown (7.5YR 5/4) and 2 percent medium faint pale brown (10YR 6/3) mottles; massive; very friable, soft; common very fine roots between peds; moderately alkaline, pH 8; gradual smooth boundary.

C4--120 to 193 centimeters (47.2 to 76.0 inches); dark grayish brown (10YR 4/2), sandy loam, grayish brown (10YR 5/2), dry; massive; very friable, soft; 1 percent 2- to 5-millimeter coal fragments; moderately alkaline, pH 8.

TECHNOLOGY DEMONSTRATION: SOIL ECa AND VNIR SPECTROSCOPY

Cristine Morgan[1], James Vandyke[1], and Katrina Wilke[2]

[1] Texas Agrilife Research, College Station, Texas; [2] USDA NRCS, Bismarck, North Dakota

INTRODUCTION

Information on soil properties at fine (meter) resolutions is beneficial to applications such as precision agriculture, watershed modeling, and other precision resource management applications. Unfortunately, soil sampling at fine resolutions is cost and labor prohibitive. Some techniques can rapidly measure soil characteristics at finer spatial scales, but tools that provide fine resolution information on soils provide lower quality data. For example, sensors that measure soil electrical conductivity (EC_a) are soil survey tools that can provide non-invasive, real-time measurements of large areas at a meter-scale, but the information collected only shows relative differences across the field. Mapping soil EC_a can show where an important soil property varies, but does not provide absolute information. On the other hand, soil coring combined with lab analysis yields high quality information about the soil profile, but at a coarser spatial resolution. For mapping purposes, soil cores are not collected at a fine resolution; therefore, soil data must be interpolated and extrapolated for the areas not sampled. Proximal soil sensing using visible and near infrared diffuse reflectance spectroscopy (VNIR-DRS) has the potential to fill the need for providing soil profile characterization faster than traditional soil coring and lab analysis, and complements the high-resolution information provided by EC_a.

Recently using VNIR-DRS has become a popular method for non-destructively and rapidly quantifying soil properties. The formation of a global library by Brown et al., (2005) sparked interest in developing a larger global library and now VisNIR-DRS is one of the cornerstone methods for the GlobalSoilMap.net project (Sanchez et al., 2009). VNIR-DRS can provide soil property data on a soil profile faster than traditional soil coring methods and compliments both laboratory analysis and high resolution information provided by EC_a. Using VNIR-DRS has been proven to predict soil properties on air-dried, ground samples and intact cores taken into the lab; however, few studies have evaluated spectroscopy's predictability in the field. The optical fiber of a VNIR spectrometer can now be mounted into a soil penetrometer, which can take spectral measurements of soil profiles (cm vertical increments) at individual locations in a field. A multi-sensor platform that combines high-resolution areal data collected horizontally using an EC_a sensor and high-resolution profile data using the VNIR-DRS would be advantageous for soil mapping.

Bulk Soil Electrical Conductivity

Soil EC_a is a measurement which provides high resolution meter-scale information and is currently used to map the spatial variability of soils across large areas (Corwin and Plant, 2005). Soil EC_a can be collected with a variety of commercially available instruments. The EM38DD (Geonics Ltd., Mississauga, Ontario, CA) is a conductivity meter that provides measurements of soil EC_a, from the surface to approximately 1.5-m deep, but the actual depth of response for a given soil varies with the soil resistivity (Callegary et al., 2007). Soil EC_a is a measure of the ability of the bulk soil to conduct an electrical current. Soil is generally a poor conductor of electrical current; therefore, the EC_a of soil is primarily a function of the conductivity of the moisture-filled pores within the soil (McNeill, 1980). Soil EC_a is influenced by soil moisture content, the amount and composition of clay, soil porosity, salinity, and temperature (McNeill, 1980; Rhoades et al., 1976). In areas where the soils are well drained, and therefore not saline, soil EC_a properties are primarily influenced by the amount of water, amount of clay, and type of clay minerals.

Because soil EC_a can be used in mapping soil water and clay content, it has been used in precision agriculture applications that need maps of soil spatial variability. The depth to the soil substratum (Doolittle et. al., 1994), depth to clay pan (Vitharana et al., 2008), as well as thickness of the loess layer (Mertens et. al., 2008) have also been mapped using EC_a. Because soil EC_a values are correlated to soil water , soil clay, and soil solum thicknesses, along with many associated soil properties, an EC_a map can be used to employ stratified random sampling to select soil or crop sampling locations (Corwin and Lesch, 2005; Johnson et al., 2005).

VNIR Spectroscopy

Spectroscopy is the study of light as a function of wavelength that has been emitted, reflected, or scattered from a solid, liquid, or gas (Clark, 1999). When light strikes a material, the light is absorbed, reflected, or transmitted, and spectral measurements can be made by measuring the amount of light reflected or transmitted (Fig. 1) (Workman and Shenk, 2004). Diffuse reflectance spectroscopy (DRS) measures the scattering of light reflected at all angles from a surface. When the diffuse reflectance of a material is measured, the absorbance bands provide information about the material's molecular composition. Absorbance peaks are viewed as valleys of the spectral signature when presented as reflectance (Fig. 1). The three key parameters in a spectra that are important are the following: 1) The wavelength at which peaks occur, 2) the amplitude of the peak compared with a 100% reflected or transmitted standard, and 3) the bandwidth, which refers to the broadness of the peak (Workman and Shenk, 2004).

VNIR-DRS scans of air-dried, ground soil have been used to directly measure soil properties such as mineralogy, clay content, organic carbon (C), inorganic C, and water content. These soil properties are considered direct measurements because each has absorption bands in the VNIR region. Figure 2 shows the reflectance of four clay minerals commonly found in soil. Other soil properties like cation exchange capacity, potassium, phosphorus, pH, sodium (salt), electrical conductivity, and extractable bases have also been predicted using VNIR, but are considered indirect measurement, sometimes leading to lower prediction accuracies. These measurements are considered indirect because the soil properties do not have direct absorbance bands in the VNIR region, but are related to soil properties with absorptions in the VNIR region.

Though VNIR-DRS on air-dried, ground soils is moving from research labs to practitioner labs, such as the USDA-NRCS National Lab, much more knowledge is needed regarding how well spectroscopy works on intact cores, how VNIR-DRS will perform when mounted on a penetrometer, and how to best use spectroscopy to map soils in the field (e.g. Morgan et al., 2009; Waiser et al, 2007). Field application of VNIR-DRS requires development in scanning protocol and in the use of statistical techniques to create a desirable end result.

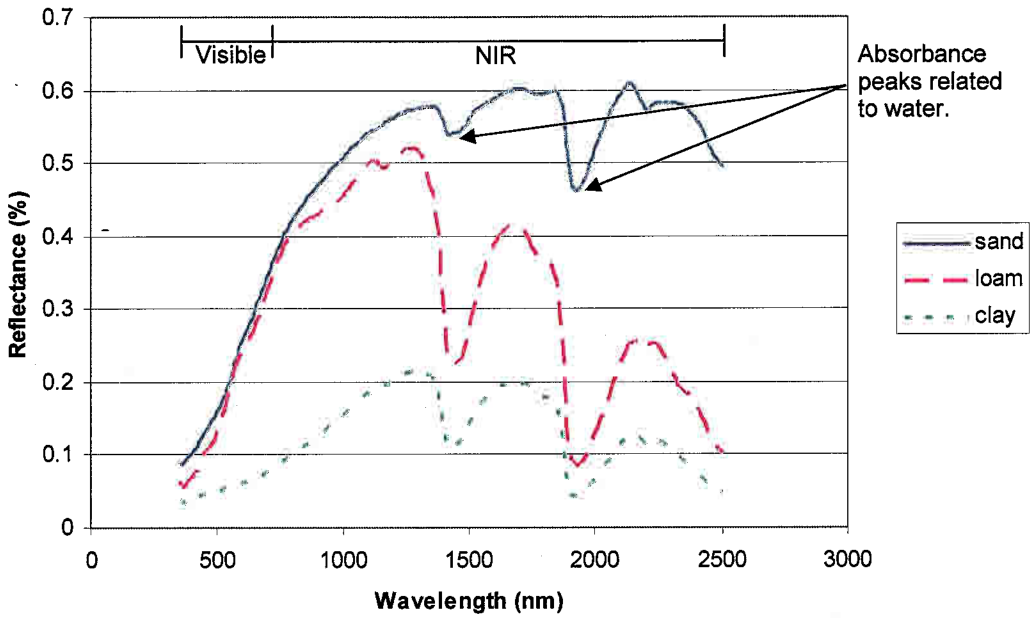


Fig.1. Soil reflectance of three soils from Erath County, Texas: sand, loam, and clay.

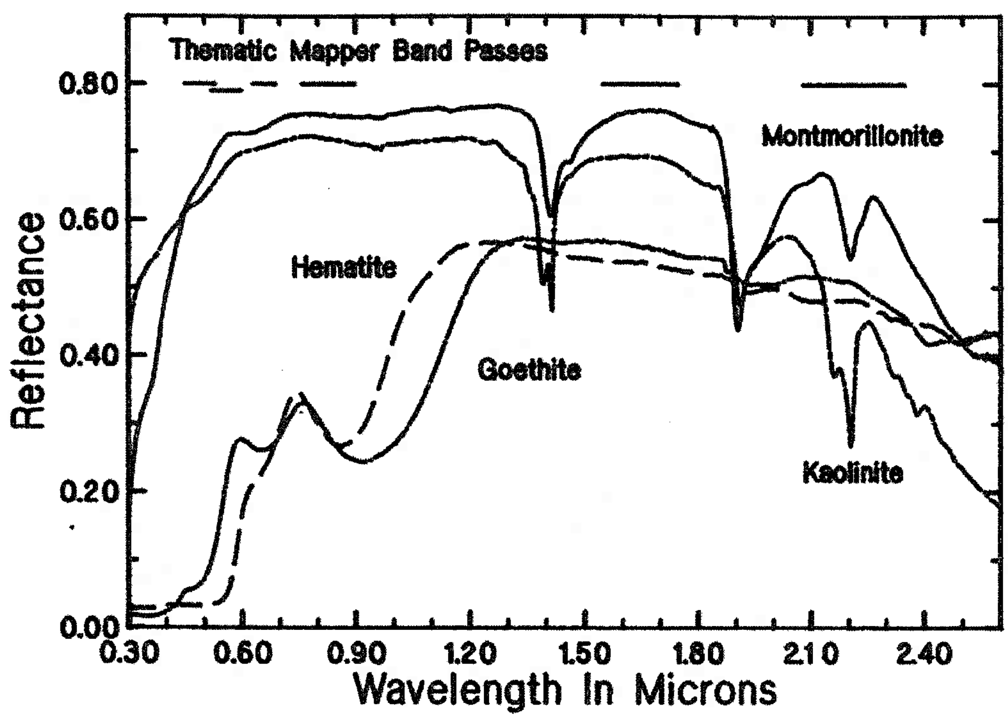


Fig. 2. Comparison of visible near-infrared reflectance between four common soil minerals. (Figure from Mustard and Sunshine, 1999)

METHODS

1. Two fields were selected for this demonstration. One field was reclaimed from the lignite mining operation (Reclaimed) and one field has yet to be disturbed by mining (Unmined Perry).

2. A 20-m resolution map of EC_a was created for each field. Bulk soil electrical conductivity was measured using an EM38DD (Geonics Ltd., Mississauga, Ontario, CA) landscape survey sensor. The EM38DD was mounted to a wooden sled and pulled behind an ATV while the GPS antenna was attached to the top sled. Twenty-meter wide transects were driven while logging all data at 1-s intervals, at a 20 to 30 km hr^{-1} traveling speed.

3. The EC_a map was used to select locations for soil cores, and subsequent VisNIR-DRS analysis. Each field was partitioned into three EC_a zones using fuzzy k-means (Fig. 3). Three sampling locations were randomly located in each EC_a zone. A total of 10 sampling sites in each field were chosen (Fig. 3).

4. Soil cores were cut in half, lengthwise, using a utility knife to cut the plastic sleeve and a piano wire to cut the soil cores. One-half of each core was used for scanning. A wire grid was used to identify two columns and multiple rows (each row was 2.5-cm thick) on the intact soil core. A schematic of the scanning methodology can be seen in Fig. 4.
An ASD AgriSpec VisNIR diffuse reflectance spectrometer (Analytical Spectral Devices, Boulder, CO), with a spectral range of 350-2500 nm was used to scan the soil cores using a contact probe containing a halogen white light source within. A white reference Spectralon panel was used prior to scanning each core to set reflectance to 100%. Each row within a column was scanned twice, with a 90° rotation of the contact probe between scans.

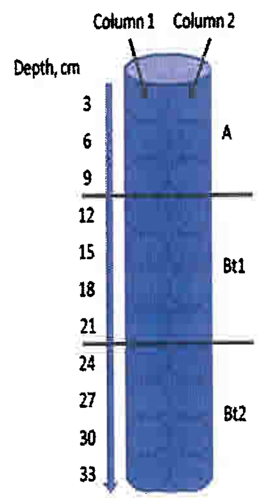


Fig. 4. Schematic of scanning soil cores.

5. The 1st derivatives of the spectra were used for making calibration models. Two models were created; one to predict clay in the Unmined field and one to predict total carbon in the Reclaimed field. Each model was made using the VNIR and lab data from all but 2 cores per field. Those two cores were held out to assess of model performance.

6. Five, 2.5-cm thick soil samples were collected from each core. The soil samples were ground and passed through a 2-mm sieve for particle size distribution (pipet method) analysis and fine ground for total carbon analysis (dry combustion method; Soil Survey Staff, 1996).

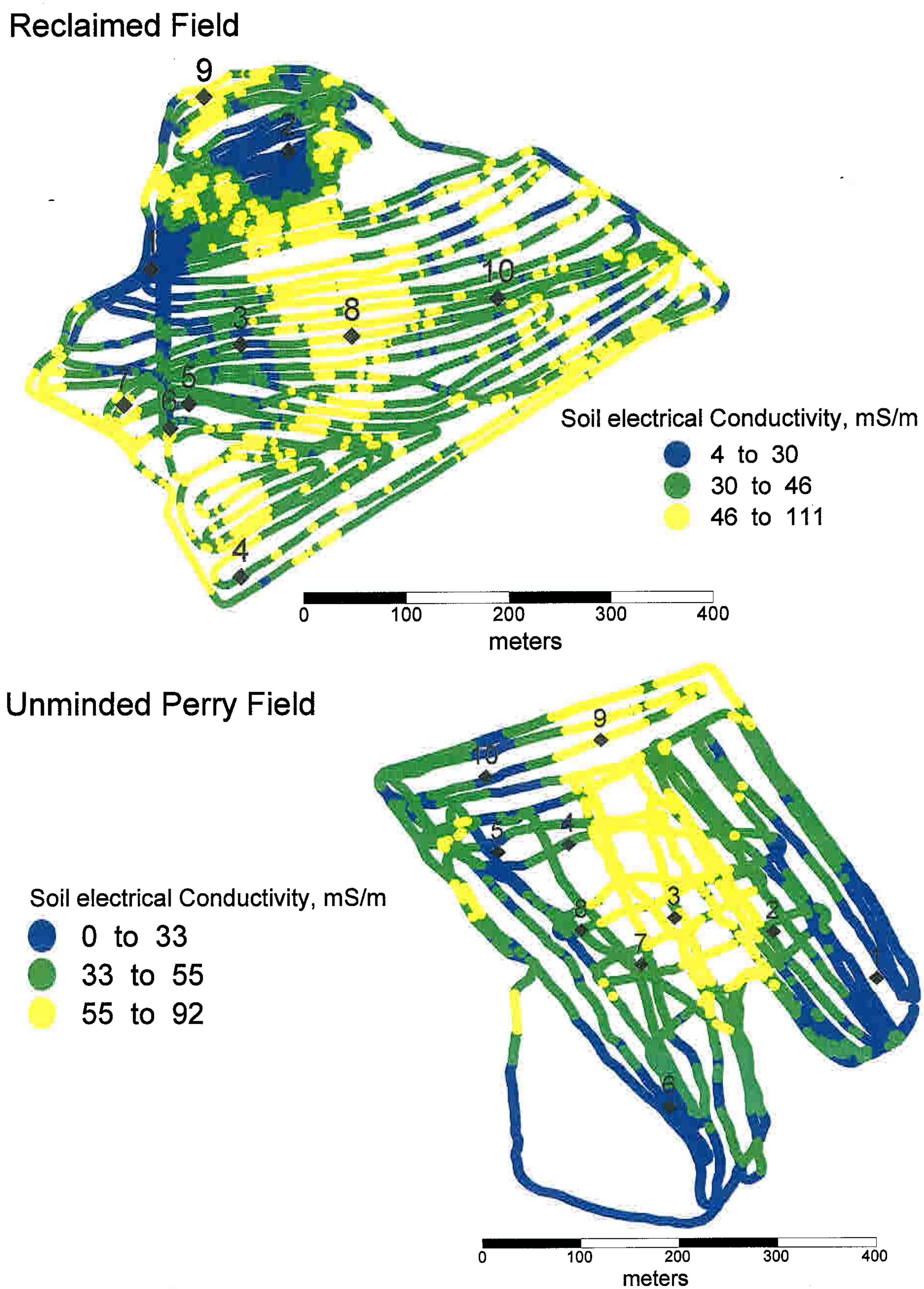


Fig. 3. Electrical conductivity map of the Reclaimed and Unminded (Perry) fields.

RESULTS

Unminded (Perry) Field

The soil ECa (EM38) measurements appear to have responded to soil moisture and somewhat to clay content. Figure 4 shows soil clay content of each site with depth. The only clear difference between the sites in this plot is the shallower depth at which the argillic appears in the cores found in higher-valued ECa zones (yellow). The two dominate soil series in the unmined (Perry) field are Maybank and Edge. Edge is found on higher landscape positions. The pit of Maybank was dug at Site 4 and the pit of Edge was dug at Site 8.

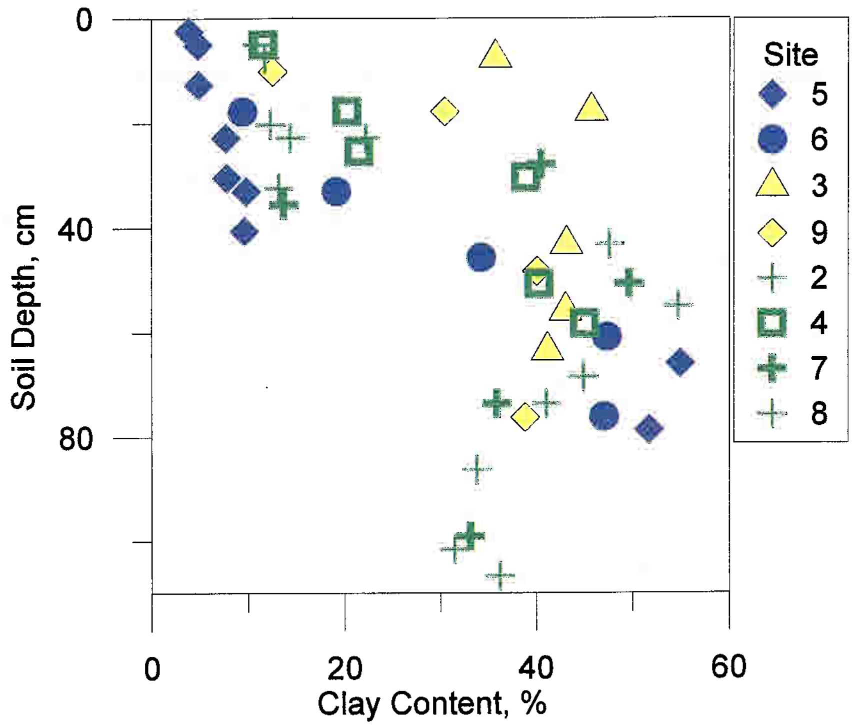


Fig. 4. Clay content profiles for the Unmined Perry field.

At the time of the EM38 survey, much of the area colored yellow in Fig. 3 had puddles of standing water. In Fig. 5, five soil cores from the unmined Perry field (200) are shown; for example core 210 corresponds to Site 10 on Fig. 3. Core 210 was located in the low-value ECa zone and the morphology indicated that it was one of the better drained sites ine this field, given the red-colored Argillic horizon. Though it is not clearly consistent, The ECa values appear to be responding to soil water, which was not measured. However, variation in soil morphology, particularly color of the Argillic, formation of E horizons, and presence of Maybank or Edge soils, indicate the hydrology of the field. Hence the ECa was useful in mapping this variability and providing a guide for soil coring.

The VNIR results show a very good match to clay content in the unmined field (Fig. 6). The added advantage of the VNIR data is a contimuous plot of clay conetnt with depth. The E horizons and horizon boundaries are clear to see with the conimuous VNIR data.

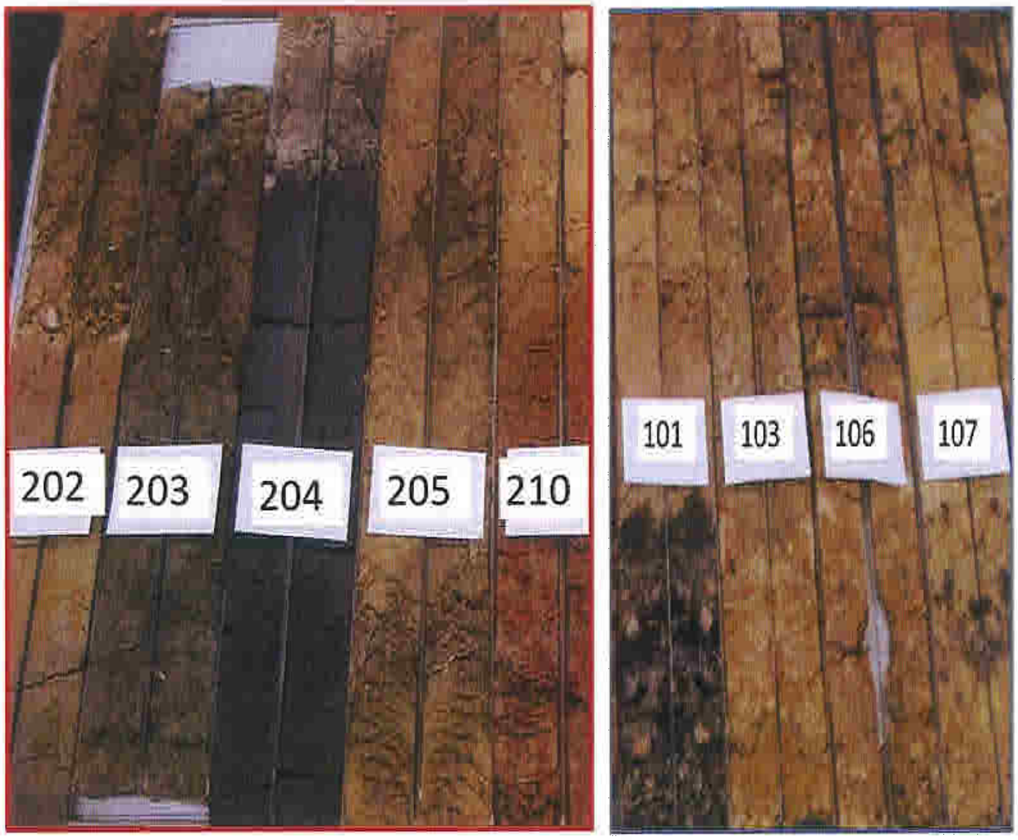


Fig. 5. Soil cores from the Unmined Perry (200) and Reclaimed Field (100).

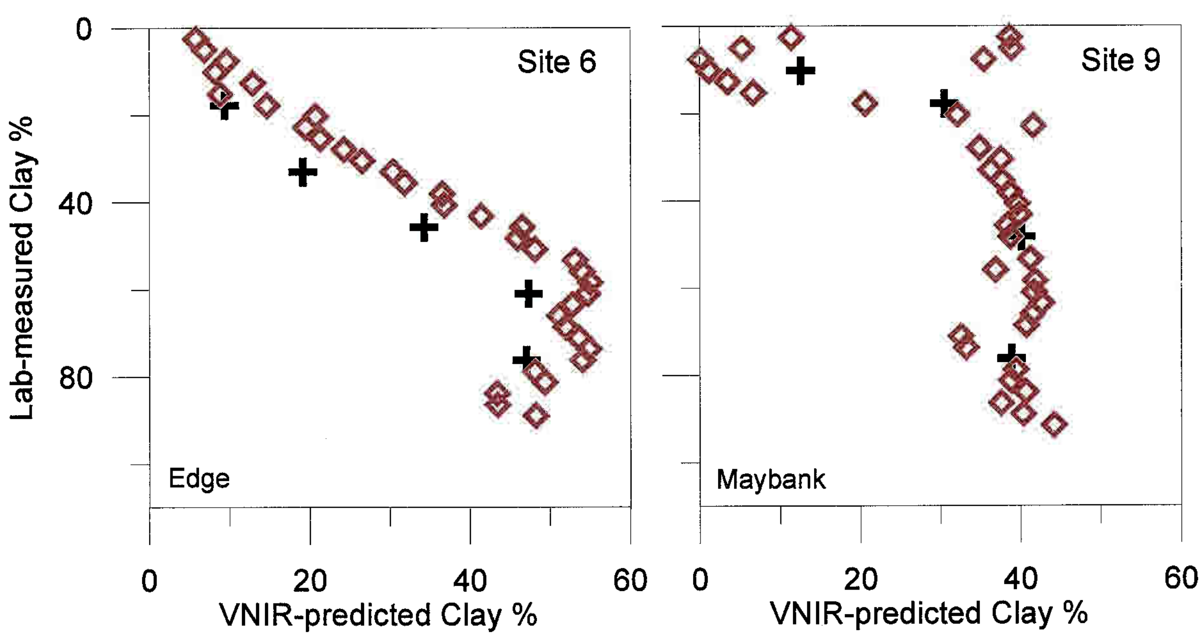


Fig. 6. VNIR predicted (◇) and lab measured (+) clay contents.

Reclaimed Field

The soil ECa (EM38) measurements appear to responded to soil moisture in the Reclaimed field. The realtionship between soil and ECa in the reclaimed site was much clearer. Soil cores located in the lowest ECa zone had much thicker sandy surfaces than the higher-valued ECa zones. For example, Site 1 in Fig. 3 corresponds with core number 101 in Fig. 5. The sandy surface is 65 cm deep and the clayey C material has lignite (black colors). On the other hand, soil core #107, in Fig. 5, has a sandy surface that is 24 cm deep. The core pulled at site 8 (Fig. 3) only had 5 cm of sandy surface.

As expected, the VNIR spectra are difficult to determine in the Reclaimed field (Fig. 7). Because of the visible lignite in the reclaimed material, we though it would be interesting to see how VNIR picked up carbon in the lignite. The predictions did not do so well. The hypothesised reasons for a poor prediction include, 1) the large particle size of the lignite, and 2) very few calibration points. Further VNIR and laboratory analysis of carbon on the ground soil samples are planned.

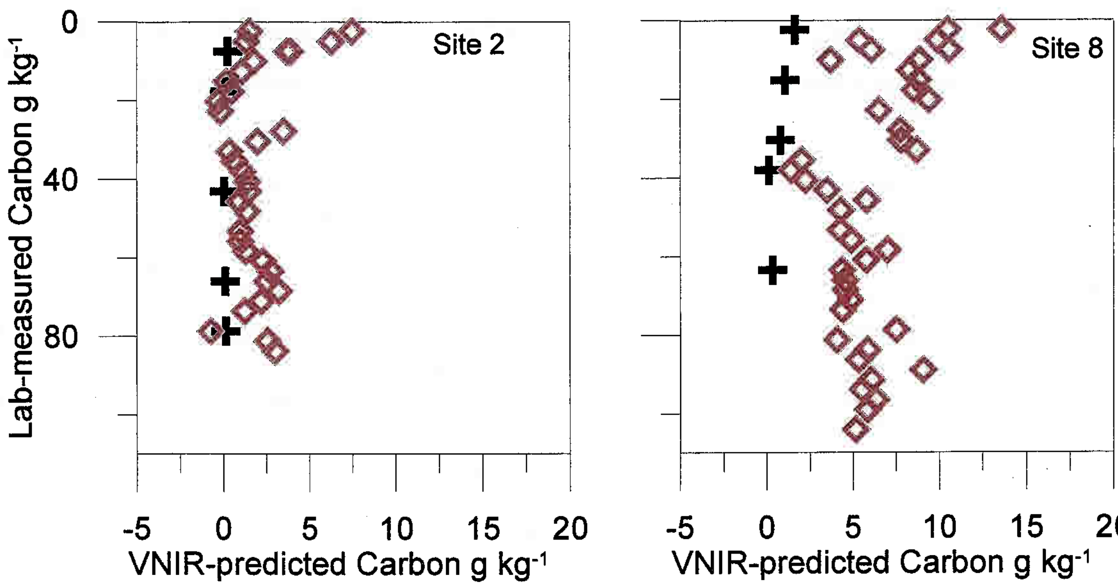


Fig. 7. VNIR predicted (◇) and lab measured (+) total carbon.

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Appendix A

"Soils of Land Resource Region J, MLRA 87, and Robertson County, Texas"

By Richard Reid, Soil Survey Project Leader, Bryan, Texas

Table of Contents

J - Southwestern Prairies Cotton and Forage Region
LRR J Overview

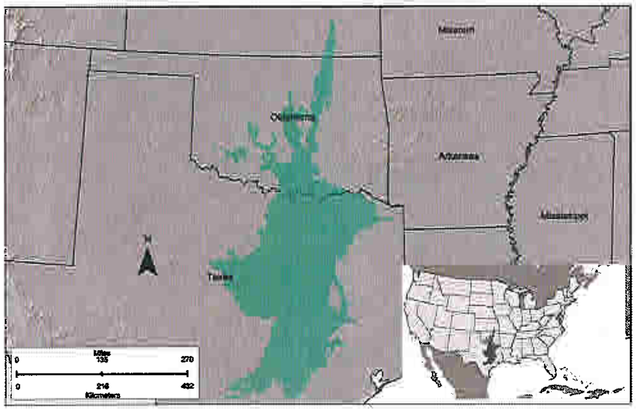

Figure 1- Land Resource Region J – Southwestern Prairies Cotton and Forage Region

The majority of this region (shown in fig.1) is located within Texas (78 percent). The Southwestern Prairies Cotton and Forage Region makes up 59,700 square miles (154,695 square kilometers) which occurs in Texas, Oklahoma, and Kansas. It is in the southern Great Plains Province. Most of the population in Texas, away from the coast, lives in this region. This region consists of gently rolling to hilly uplands dissected by numerous streams. Moderate precipitation is accompanied by moderately high temperatures. The average annual precipitation ranges from 31 to 44 inches (785 to 1,120 millimeters). Most of the precipitation falls in spring, early summer and fall. The average annual temperature ranges from 62 to 67 degrees F (17 to 19 degrees C). The freeze-free period ranges from 245 to 290 days, increasing in length from north to south. Within Texas, Land Resource Region J is divided up into four Major Land Resource Areas (MLRA's) in Texas which include: MLRA 86A, 86B, 87A, and 87B (shown in Figure 2). MLRA 86A and 86B are referred to as the "Texas Blackland Prairies, Southern and Northern parts" and MLRA 87A and 87B are referred to as the "Texas Claypan Areas, Southern and Northern parts".

Major Land Resource Area 87A and 87B – Texas Claypan Areas, Southern and Northern Parts

MLRA 87A and 87B Overview

The region known as MLRA 87A and 87B, also commonly called the "Texas Claypan Prairies" (**fig. 2**) consists of approximately 15,015 square miles in Central Texas. This region includes the following cities: Ennis, Fairfield, Groesbeck, Franklin, Centerville, Madisonville, Rockdale, Bryan, College Station, Bastrop, Giddings, Luling, and Gonzales located in MLRA 87A and Greenville, Sulphur Springs, Paris, Mount Vernon, Canton, and Athens located in MLRA 87B.

This region's landscape is a nearly level to gently sloping inland coastal plain that is dissected by broad river systems. Slopes generally range from 1 to 8 percent. The elevation in this region ranges from 200 to 750 feet (60 to 230 meters) increasing gradually from south to north. The following major rivers are located in MLRA 87: Trinity, Navasota, Brazos, Colorado, Lavaca, Guadalupe, Red River, Sulphur, and Sabine rivers. The climate in MLRA 87 generally receives an average annual precipitation of 27 to 45 in (685 to 1,145 mm), mostly in the spring to early summer and fall months. The average annual temperature ranges from 62 to 70 degrees F (17 to 21 degrees C) and the freeze-free period ranges from 245 to 310 days.

Water sources throughout MLRA 87 are comprised mainly of shallow ground water from the Carrizo-Wilcox, Trinity Group, and Oakville Sandstone aquifers. These aquifers provide approximately 58 percent of the ground water supplies for municipalities and homesteads. Where groundwater is shallow the water is generally hard and where groundwater is found deeper the water is generally soft due to the high amounts of sodium.

Land use throughout MLRA 87 varies from improved pasture and rangeland for beef production, to timber production, as well some crop production along major rivers. MLRA 87 is referred to as an "oak savannah" where typical vegetation consists mainly of woody species such as post oak and blackjack oak along with a variety of forbs and native grasses. In areas of the MLRA that border an udic moisture regime stands of native pines and areas of hardwood forest communities can be found. Some of the major wildlife species in this area are white-tailed deer, javelina, coyote, fox, bobcat, raccoon, skunk, opossum, jackrabbit, cottontail, turkey, bobwhite quail, scaled quail, white-winged dove, and mourning dove.

The major soil resource concerns are water erosion, maintenance of the content of organic matter and productivity of the soils, and management of soil moisture. Conservation practices on cropland generally include reduced till or no-till systems, crop residue management, and nutrient management. Conservation practices on pasture and hayland include grazing management, applications of the proper kinds and amounts of fertilizer and lime, and control of brush and weeds. The most important conservation practice on rangeland is prescribed grazing.

The soils located in MLRA 87 are underlain predominantly by interbedded sandstone, siltstone, and shales, as well as unconsolidated to weakly coherent marine sands, silts, and clays. Some common geologic formations include the Tertiary aged Wilcox Group, Carrizo Sand, Reklaw Formation, Queen City Sand, Weches Formation, Sparta Sand, and Yegua Formation, the Eocene and Oligocene aged Jackson Group, and the Catahoula Formation of Miocene age. These geologic groups generally occur parallel to the Texas Gulf Coast and are incised by several major stream systems. Quaternary stream terraces and alluvium are associated with the meander belts of the major rivers.

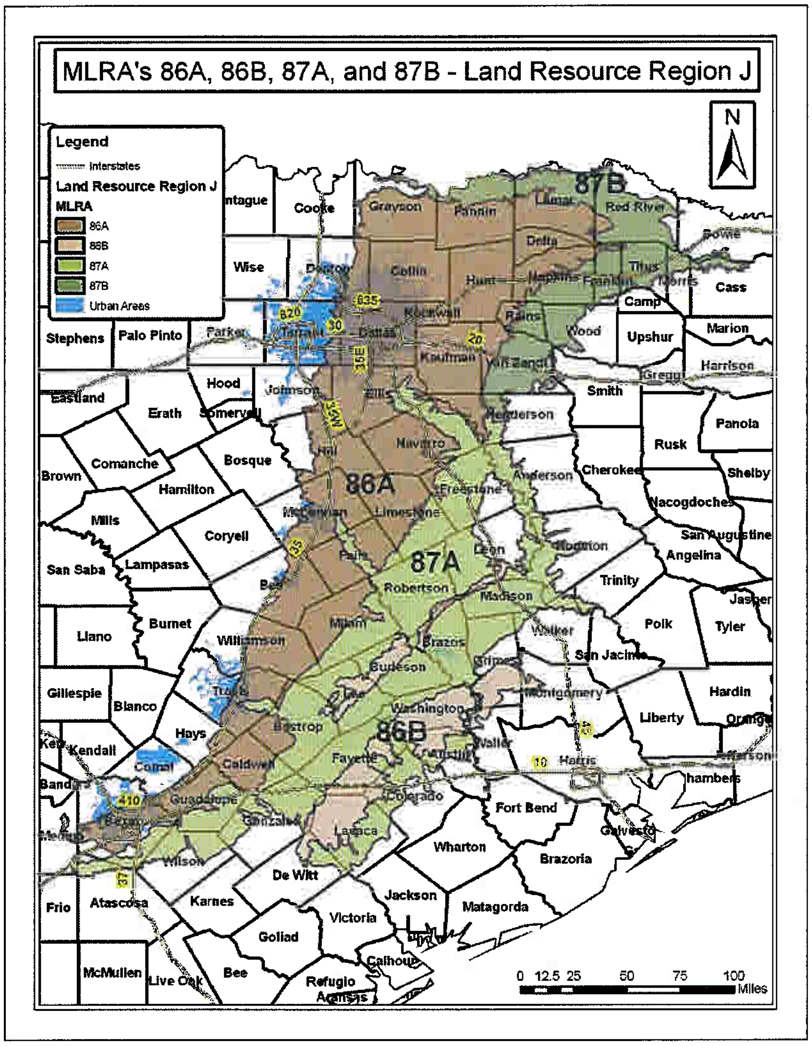

Figure 2- Land Resource Region J – MLRA 86A, 86B, 87A, and 87B

The dominant soil orders that occur throughout MLRA 87 include Alfisols, Vertisols, Mollisols, Ultisols, Inceptisols, and Entisols. These soils are moderately deep to very deep, somewhat excessively drained to somewhat poorly drained, coarse textured to fine textured and have smectitic, siliceous, and mixed mineralogy.

The soils of Robertson County, Texas

Robertson County, Texas Overview

Robertson County is in the eastern part of central Texas (**fig. 3**). The total area of the county, including water areas, is 553,747 acres, or about 865 square miles. The southern boundary of the county is the Old San Antonio Road. The western boundary is the Brazos River, and the eastern boundary is the Navasota River. The northern boundary joins Falls and Limestone Counties. Franklin, located in the central part of the county, has been the county seat since 1880. Other towns and communities include Benchley, Bremond, Calvert, Easterly, Hammond, Hearne, Mumford, New Baden, Owensville, Ridge, and Wheelock.

The topography in Robertson County is undulating to gently rolling and generally slopes from the central part of the county to the flood plains of the Brazos and Navasota Rivers. Elevations here range from 590 feet at the highest point to about 240 feet in the southwestern part of the county. The MLRA 87A portion of Robertson County has light-colored, mostly loamy soils that formed under vegetation of a post oak savannah.

The average annual total precipitation is 38.70 inches. Of this, about 49 percent usually falls in April through September. The average annual temperature is approximately 67.1 degrees F (19.5 degrees C) and the freeze-free period averages 275 days. The average relative humidity in mid-afternoon is about 56 percent. Humidity is higher at night, and the average at dawn is about 86 percent. The prevailing wind is from the south. Average windspeed is highest, 12.6 miles per hour, in April.

Rangeland is the major land use in Robertson County although roughly 15 percent of the county is used for cropland. Some of the rangeland or unimproved pasture is densely covered with post oak and is used as rangeland or as wildlife habitat. Improved pasture and hayland make up significant areas of the county.

The most important natural resources in Robertson County are soil, water, wildlife, petroleum, natural gas, and lignite coal. Soil is critical for the production of livestock, hay, forage, crops, and orchards, which are the main sources of income in the county. Some ironstone and gravel are mined in the county along the Brazos River which is used for the construction of roads and buildings. The largest areas of water are Lake Limestone, Twin Oaks Reservoir, and Camp Creek Lake, all of which are in the eastern part of the county. Land leased or sold for mining lignite coal has become increasingly important to the county. The lignite is mainly in the Wilcox geologic material in the northern part of the county and is currently being mined in open pits and burned to generate electricity. The major mining project is between Calvert and Bremond. Most of the oil and natural gas wells are in the northern, north-central, and southern parts of the county and are mainly related to the Wilcox and Cook Mountain geological formations.

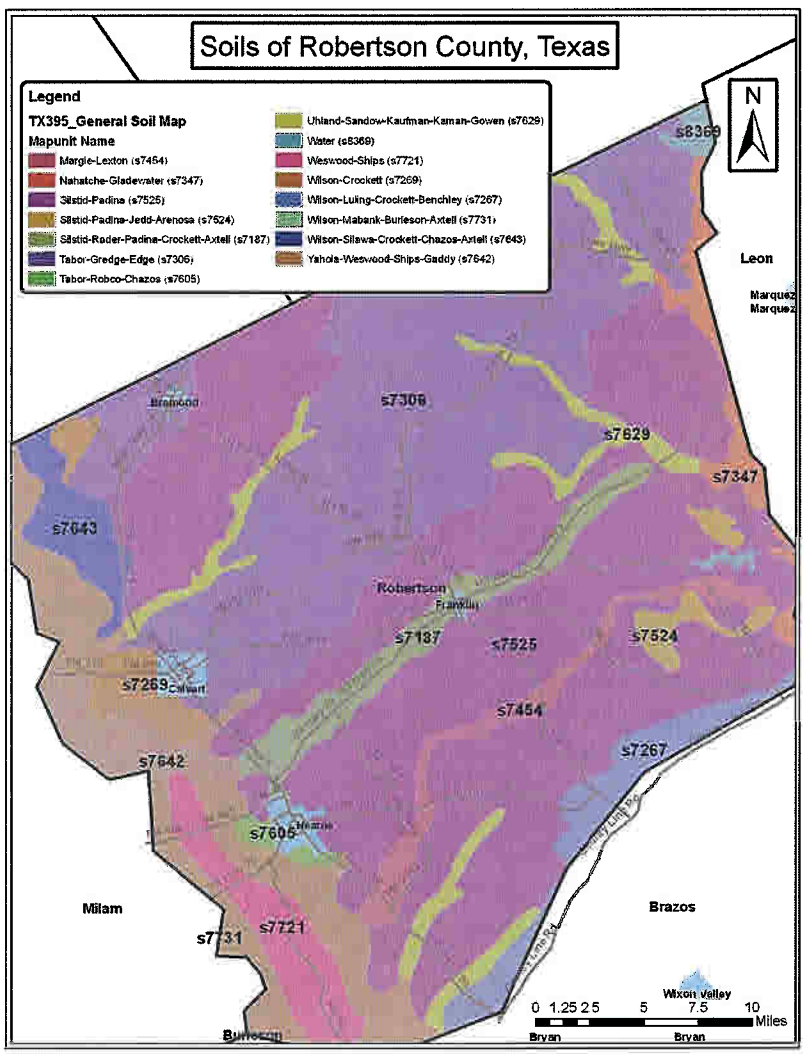

Figure 3- The Soils of Robertson County, Texas

About 52 percent of the soils in Robertson County are dominantly Sandy and Loamy soils on uplands. These soil series are Crockett, Edge, Gasil, Hearne, Padina, Robco, Rosanky, and Silstid. These soils developed in sandy and loamy sediments, shale, sandstone, and mudstone. The landscape is very gently sloping to strongly sloping. The soils are moderately well drained or well drained. Permeability ranges from very slow to moderate. These soils are used mainly as pasture, hayland, or rangeland. Vegetation ranges from native grasses to native trees and shrubs. Native grasses include bluestems, indiangrass, paspalums, and panicums. Trees include post oak and blackjack oak with an understory of yaupon. Improved grasses include coastal bermudagrass and bahiagrass. A few areas are planted in watermelons and small grains. The main limitations of these soils affecting urban use are a high potential for shrinking and swelling, a very slow permeability, low soil strength, and seepage.

About 5 percent of the soils in Robertson County are Loamy and Clayey prairie soils on uplands. The major soil series are Benchley, Crockett, Luling, and Margie soils. Most of these soils have a loamy surface layer and a clayey subsoil layer however, Luling soils are clayey throughout. The soils developed mostly in shale and weathered glauconitic material of the Cook Mountain and Weches formations. They are very gently sloping or gently sloping. These soils are moderately well drained or well drained. Permeability is moderately slow to very slow. The soils in this group are used mainly for pasture, hayland, or rangeland. Some areas are used as cropland. Vegetation on these soils ranges from native grasses, improved grasses, to native trees. Native grasses include: bluestem, indiangrass, paspalum, sideoats grama, and Texas wintergrass. Improved grasses include: bermudagrass, bahiagrass, and kleingrass. Trees are dominantly scattered elm, oak, and hackberry. The main crops are small grains. When used for crops, these soils need proper conservation practices, such as contour farming, terraces, or minimum tillage, in order to reduce the hazard of water erosion. These soils have some limitations for most urban uses which are mainly a high or very high potential for shrinking and swelling, very slow permeability, and low soil strength. The limitations can be overcome by properly designing and installing building foundations, septic tank absorption fields, and roads and streets.

About 25 percent of the soils in Robertson County are Sandy, Loamy, and Clayey soils on terraces. The major soils soil series in this group are Bastrop, Bremond, Burleson, Chazos, Dutek, Eufaula, Gasil, Rader, Robco, Silawa, Tabor, and Wilson. These soils developed in sandy, loamy, and clayey alluvium of Holocene or Pleistocene age. These soils are in broad, nearly level to moderately sloping areas on various levels of stream terraces near the Brazos, Little Brazos, and Navasota Rivers. They are also on terraces along many large creeks and adjacent tributaries. Some areas are remnants of terraces in the uplands and are not associated with present-day streams in the county. These soils are moderately well drained to excessively well drained and are slowly permeable to rapidly permeable. The soils in this group are used mainly for pasture and hayland. Improved bermudagrass and bahiagrass are the main improved pasture types used throughout the county. Some areas are in native rangeland which includes bluestems, indiangrass, paspalums, and panicums along with areas of scattered post oak and yaupon. A few areas are used as cropland and planted mainly in small grains. These soils have some limitations that affect most urban uses. These limitations include a very high or high potential for shrinking and swelling, very slow permeability, and low soil strength. The limitations can be overcome by properly designing and installing building foundations, septic tank absorption fields, and roads and streets.

Approximately 18 percent of the soils in Robertson County are primarily Loamy and Clayey soils that occur on flood plains. The major soil series in this group are Coarsewood, Highbank, Navasota, Oletha, Sandow, Ships, Uhland, Weswood, Whitesboro, Yahola, and Zilaboy. These soils developed in clayey and loamy sediments of Holocene age or Pleistocene age. These nearly level to very gently sloping soils are on flood plains. They are somewhat poorly drained to well drained and are moderately permeable to very slowly permeable. In this group, the soils on the Brazos River flood plain are used mainly as cropland. Soils on other flood plains in the county are used mainly as rangeland. A few areas are in pasture and hayland. Cotton, corn, and grain sorghum are the main crops grown in rarely flooded areas along the Brazos River. Among native plants, Bluestems, Virginia wildrye, broadleaf uniola, panicums, and sedges are the most dominantly ccurring. Water oak, elm, cottonwood, and pecan are the dominant trees. Improved bermudagrass, common bermudagrass, and dallisgrass are the main pasture and hayland plants. Some limitations of these soils for urban uses include flooding and a very high potential for shrinking and swelling.

Taxonomic Classification of the Soils in Robertson County, Texas

The table below illustrates the taxonomic classification of the soils that occur in Robertson County, Texas (**Table 1**).

Table 1 – Classification of the soils of Robertson County, Texas

Soil name	Family or higher taxonomic class
Arenosa	Thermic, uncoated Ustic Quartzipsamments
Bastrop	Fine-loamy, mixed, active, thermic Udic Paleustalfs
Benchley	Fine, smectitic, thermic Udertic Argiustolls
Bremond	Fine, smectitic, thermic Udertic Paleustalfs
Burleson	Fine, smectitic, thermic Udic Haplusterts
Cadelake	Sandy, siliceous, thermic Typic Humaquepts
Chazos	Fine, smectitic, thermic Udic Paleustalfs
Coarsewood	Coarse-silty, mixed, superactive, calcareous, thermic Udic Ustifluvents
Crockett	Fine, smectitic, thermic Udertic Paleustalfs
Desan	Loamy, siliceous, active, thermic Grossarenic Paleustalfs
Dimebox	Fine, smectitic, thermic Udic Haplusterts
Dutek	Loamy, siliceous, active, thermic Arenic Haplustalfs
Edge	Fine, mixed, active, thermic Udic Paleustalfs
Eufaula	Siliceous, thermic Psammentic Paleustalfs
Gaddy	Sandy, mixed, thermic Udic Ustifluvents
Gasil	Fine-loamy, siliceous, semiactive, thermic Ultic Paleustalfs
Hammond	Fine-loamy, mixed, superactive, nonacid, thermic Udic Ustorthents
Hearne	Fine, mixed, semiactive, thermic Typic Haplustults
Highbank	Fine, mixed, active, thermic Udertic Haplustepts
Lexton	Fine, mixed, active, thermic Udic Haplustalfs
Lufkin	Fine, smectitic, active, thermic Oxyaquic Vertic Paleustalfs
Luling	Fine, smectitic, thermic Udic Haplusterts
Margie	Fine, mixed, semiactive, thermic Udic Haplustalfs
Navasota	Fine, smectitic, thermic Aeric Endoaquerts
Oletha	Fine-loamy, siliceous, superactive, thermic Aquic Haplustepts
Padina	Loamy, siliceous, active, thermic Grossarenic Paleustalfs
Rader	Fine-loamy, mixed, semiactive, thermic Aquic Paleustalfs
Robco	Loamy, siliceous, active, thermic Aquic Arenic Paleustalfs
Roetex	Very fine, mixed, active, thermic Aquic Hapluderts
Rosanky	Fine, mixed, semiactive, thermic Ultic Paleustalfs
Sandow	Fine-loamy, siliceous, superactive, thermic Udifluventic Haplustepts
Ships	Very fine, mixed, active, thermic Chromic Hapluderts
Silawa	Fine-loamy, siliceous, semiactive, thermic Ultic Haplustalfs
Silstid	Loamy, siliceous, semiactive, thermic Arenic Paleustalfs
Spiller	Fine, mixed, semiactive, thermic Ultic Paleustalfs
Tabor	Fine, smectitic, thermic Oxyaquic Vertic Paleustalfs
Uhland	Coarse-loamy, siliceous, superactive, thermic Aquic Haplustepts
Weswood	Fine-silty, mixed, superactive, thermic Udifluventic Haplustepts
Whitesboro	Fine-loamy, mixed, superactive, thermic Cumulic Haplustolls
Wilson	Fine, smectitic, thermic Oxyaquic Vertic Haplustalfs
Yahola	Coarse-loamy, mixed, superactive, calcareous, thermic Udic Ustifluvents
Zilaboy	Fine, smectitic, thermic Oxyaquic Hapluderts

Works Cited

- "Soil Survey of Robertson County, Texas", USDA-NRCS (2007)

- "Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin", USDA Agriculture Handbook 296 (2006)

LOCATION SHIPS TX+OK

Established Series
Rev. GLL-SEB-ACT
10/97

SHIPS SERIES

The Ships series consists of very deep, moderately well drained, very slowly permeable soils that formed in clayey alluvial sediments. These soils are on nearly level to gently sloping flood plains. Slopes range from 0 to 5 percent.

TAXONOMIC CLASS: Very-fine, mixed, active, thermic Chromic Hapluderts

TYPICAL PEDON: Ships clay--cultivated. (Colors are for moist soil unless otherwise stated.)

Ap--0 to 6 inches; dark reddish brown (5YR 4/3) clay, reddish brown (5YR 4/3) dry; weak fine angular blocky structure; very hard, firm, very sticky and very plastic; common fine roots; very slight effervescence; moderately alkaline; clear smooth boundary.

A--6 to 14 inches; dark reddish brown (5YR 3/3) clay, reddish brown (5YR 4/3) dry; moderate fine angular blocky structure; very hard, very firm, very sticky and very plastic; common fine roots; few pressure faces; very slight effervescence; moderately alkaline; gradual wavy boundary. (the combined A subhorizons are 6 to 22 inches thick)

Bss1--14 to 34 inches; dark reddish brown (5YR 3/3) clay reddish brown (5YR 4/3) dry; moderate fine angular blocky structure; very hard, very firm, very sticky and very plastic; common fine roots; common large slickensides; common pressure faces; very slight effervescence; moderately alkaline; gradual wavy boundary.

Bss2--34 to 54 inches; dark red (2.5YR 3/6) clay, red (2.5YR 4/6) dry; moderate fine angular blocky structure; very hard, very firm, very sticky and very plastic; few fine roots; many large grooved slickensides; common pressure faces; vertical cracks filled with darker soil from above; few fine calcium carbonate concretions; moderately alkaline; diffuse wavy boundary. (combined Bss subhorizons are 30 to 68 inches thick).

Bkss--54 to 80 inches; dark reddish brown (2.5YR 3/4) clay, reddish brown (2.5YR 4/4) dry; weak coarse angular blocky structure; very hard, very firm, very sticky and very plastic; few fine roots; common slickensides; common pressure faces; few threads and masses of calcium carbonate; few calcium carbonate concretions; slight effervescence; moderately alkaline.

TYPE LOCATION: Falls County, Texas; from the intersection of Texas Highway 7 and Texas Highway 6 in Marlin; 0.8 mile west on Texas Highway 7; 315 feet north in cultivated field.

RANGE IN CHARACTERISTICS: Solum thickness is more than 80 inches. The weighted average clay content of the particle size control section ranges from 60 to 70 percent. Depth to threads, masses or concretions of calcium carbonate ranges from 28 to 60 inches. Cracks at least a centimeter wide extend from the surface to a depth of more than 20 inches when the soil is dry. The cracks are open for 60 to 90 cumulative days during most years. The COLE ranges from 0.07 to 0.18. There are many large grooved slickensides in some part of the control section. Undisturbed areas have subdued gilgai with Microknolls 2 to 6 inches higher than microdepressions. Some pedons have buried A horizons within a depth of 60 inches of the soil surface.

The A horizon has colors with hue of 5YR or 7.5YR, value of 3 to 4, chroma of 2 or 4. Horizons with value of 3 and chroma of 2 are less than 12 inches thick in 50 percent or more of the pedon.

The Bss, Bkss, BCkss horizons have hue of 2.5YR to 7.5YR, value of 3 to 5 and chroma of 3 to 6. Some pedons have masses or spots with color value of 3 or 4 and chroma of 2. These dark colors are related to organic material. Texture is clayey throughout but some pedons have thin discontinuous strata of silt loam, loam, or silty clay loam. Calcium carbonate threads, masses, and concretions range from none visible to about 5 percent in some subhorizons.

COMPETING SERIES: There are no completing series. Similar soils are the Brazoria, Burkeville, Dylan, Miller, Moreland, Redco, Roetex, and Tahoula series. Brazoria and Dylan soils are in the hyperthermic family. Burkeville, Redco, and Tahoula soils have smectitic mineralogy. In addition Burkeville, Dylan, Redco, and Tahoula soils have hue yellower than 7.5YR. Miller and Moreland soils have a fine particle-size control section. Roetex soils have redox depletions due to wetness within a depth of 18 to 30 inches of the surface.

GEOGRAPHIC SETTING: Ships soils are on nearly level to gently sloping flood plains. Slopes are mainly less than 1 percent but range to 5 percent. The soil formed in reddish and brownish clayey alluvial sediments. Mean annual precipitation ranges from 30 to 40 inches, and mean annual temperature ranges from 64 to 69 degrees F. Frost free days range from 240 to 270 days, and elevation ranges from 200 to 1100 feet. Thornthwaite P-E indices range from 44 to 64.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the similar Roetex series, and the Highbank, Weswood, and Yahola series. Roetex soils have iron depletions within 30 inches of the surface layer and are in depressed, wetter positions. Highbank, Weswood and Yahola are in similar flood plain positions. Highbank soils have a loamy surface layer. Weswood soils have a coarse-silty control section. Yahola soils have a coarse-loamy control section.

DRAINAGE AND PERMEABILITY: Moderately well drained. Permeability is very slow. Runoff is low on 0 to 1 percent slopes; medium on 1 to 3 percent slopes; and high on 3 to 5 percent slopes. Flooding occurs at intervals of once in 1 to more than 20 years except where protected.

USE AND VEGETATION: Mainly used as cropland. Crops include cotton, corn, grain sorghum, small grain, and some improved pastures of bermudagrass, johnsongrass, or small grain. Native vegetation includes big bluestem, little bluestem, indiangrass, switchgrass, Virginia wildrye, and beaked panicum. Adjacent to stream channels ash, elm, and pecan are the dominant trees.

DISTRIBUTION AND EXTENT: Mainly along the Colorado and Brazos Rivers of Texas. The series is of moderate extent.

MLRA OFFICE RESPONSIBLE: Temple, Texas

SERIES ESTABLISHED: Bastrop County, Texas, 1973.

REMARKS: These soils were formerly included in the Miller series. NSSL data is available from the type location of this series (74L351-74L354). Other data in Washington County (NSSL 76P0733-76P0735), Falls County (NSSL 78P0057-78P0065), and Burleson County (TAMU S86TX-051-005).

Active cation exchange activity class. Diagnostic horizons and features recognized in this pedon are:

Mollic epipedon - 0 to 34 inches (Ap, A, and Bss1 horizons)

Cambic horizon - 34 to 80 inches. (Bss and Bkss horizons)

Vertic properties - slickensides from 14 to 80 inches. When dry, cracks at least a centimeter wide extend from the surface to a depth of more than 20 inches.

Soil Interpretation Record No.: TX0288

National Cooperative Soil Survey
U.S.A.