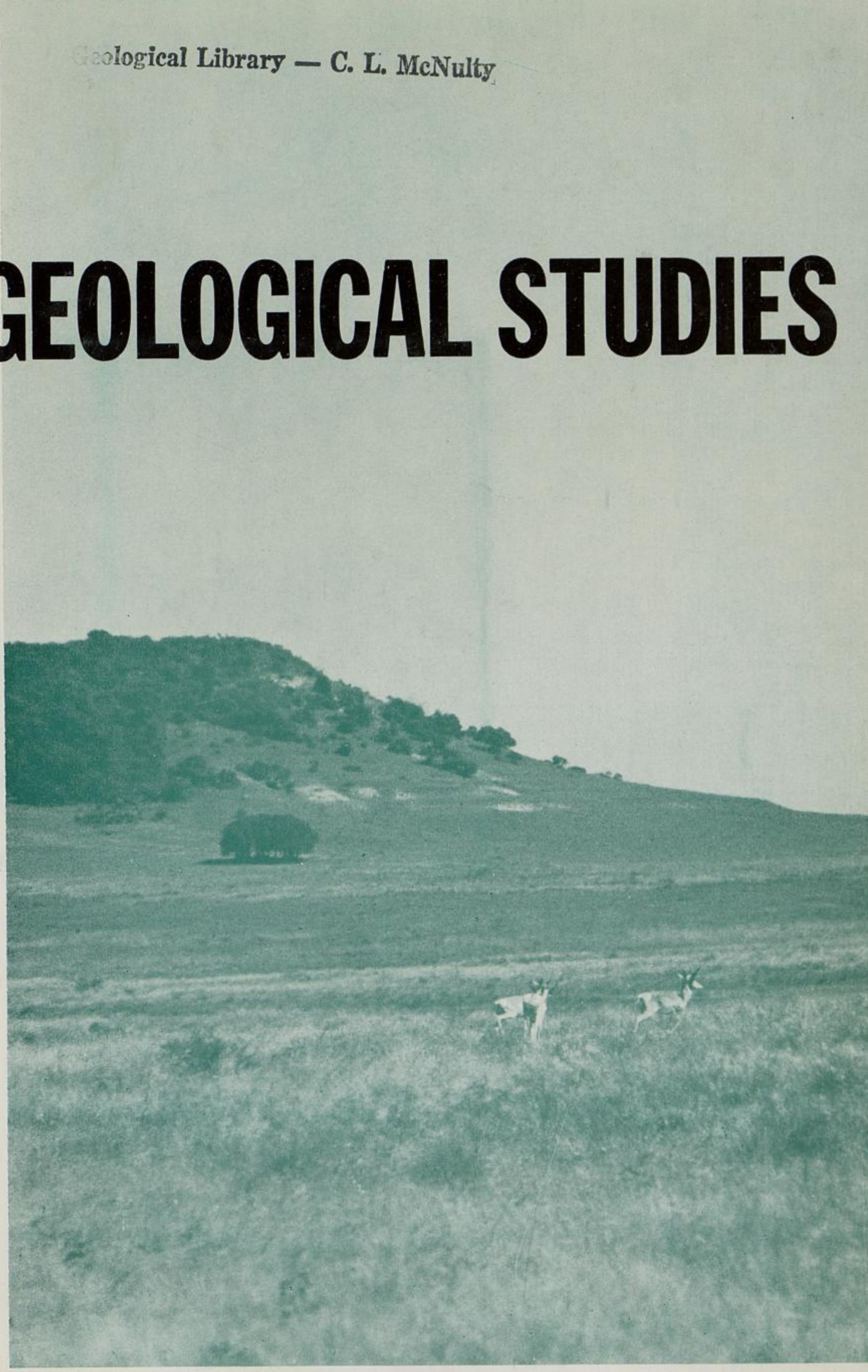
BAYLOR GEOLOGICAL STUDIES



FALL 1963

Bulletin No. 5

The Role of Geology in a Unified Conservation Program, Flat Top Ranch, Bosque County, Texas

JOHNNIE B. BROWN

"Creative thinking is more important than elaborate equipment--"

Frank Carney, Ph.D.
Professor of Geology
Baylor University
1929-1934

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The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

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BAYLOR GEOLOGICAL STUDIES

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The Role of Geology in a Unified Conservation Program, Flat Top Ranch, Bosque County, Texas

JOHNNIE B. BROWN

BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Fall, 1963

Baylor Geological Studies

The Baylor Geological Studies Bulletin is published semi-annually, Spring and Fall, by the Department of Geology at Baylor University. The Bulletin is specifically dedicated to the dissemination of geologic knowledge for the benefit of the people of Central Texas. The publication is designed to present the results of both pure and applied research which will ultimately be important in the economic and cultural growth of the Central Texas region.

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The Role of Geology in a Unified Conservation Program, Flat Top Ranch, Bosque County, Texas

JOHNNIE B. BROWN

ABSTRACT

Flat Top Ranch in Bosque County, Texas, is an ideal area for studying geological principles in conservation practices. The conservation program is ideally suited to the outcropping Lower Cretaceous Fredericksburg group which, in descending order, is composed of Edwards limestone, Comanche Peak limestone, Walnut clay, and Paluxy sand.

Soil development is controlled by 5 independent factors—parent material, topography, climate, organic factor, and time. In the Flat Top Ranch area, geology (parent material) is the most important soil forming factor. Outcropping formations are characterized by particular soils whose genesis is closely related to parent material.

Topographic configuration of the area is controlled by differential weathering characteristics of outcropping rock units. In turn, topography induces local climatic variations which differ considerably from regional climatic conditions.

Most of the surface reservoirs on Flat Top Ranch were constructed where stream channels flow over permeable Paluxy sand. This has greatly facilitated restoration of the ground-water table in the area by constant recharge of the Paluxy sand with subsequent increase in subirrigation adjacent to streams. The effectiveness of subirrigation is directly related to bank storage capacity of the outcropping formations, principally the Paluxy sand. The position of the aquifer relative to surface reservoirs, character of the aquifer, surface spreading of water, and control of runoff are factors which control the efficiency of bank storage.

Ground water is obtained from the Paluxy sand in limited quantities; larger quantities are obtained from basal sands of the Trinity group. No flowing wells occur in the area.

The most significant factor in the success of the Flat Top Ranch conservation program is that the entire surface water storage system was developed in the highly permeable Paluxy sand. Had the surface storage system been located on formations stratigraphically above or below the Paluxy sand, the success of the conservation program would probably have been less spectacular.

INTRODUCTION[1]

The nature of the conservation program practiced at Flat Top Ranch (fig. 1) makes it an ideal example of what can be done with proper use of underground water storage in regions of similar geology and climate.

In 1938, Mr. Charles Pettit purchased the original 7100-acre Flat Top Ranch in northern Bosque County. Around this initial purchase he bought small farms and ranches, all in poor soil-range condition, until the ranch included 17,000 acres. The philosophy behind the conservation program which has been carried on at Flat Top Ranch is that the land is the ultimate source of all wealth and that its condition will determine the welfare of the people who inhabit it (Webb, 1960, p. 5).

The influence that geology exerts on the success of any conservation program is often overlooked. The purpose of this investigation is to illustrate the inseparable relationship between the geology and the pedological and hydrological factors which determine the effectiveness of the conservation program at Flat Top Ranch.

LOCATION

Flat Top Ranch is located about 5 miles northwest of Walnut Springs, Bosque County, Texas. The ranch covers approximately 27 square miles in northern Bosque County with portions extending into southwestern Erath and southeastern Somervell counties (fig. 1). The area lies in the outcrop belt of the Lower Cre-

[1] A thesis submitted in partial fulfillment of the requirements for the M.S. degree in Geology, Baylor University, 1964.

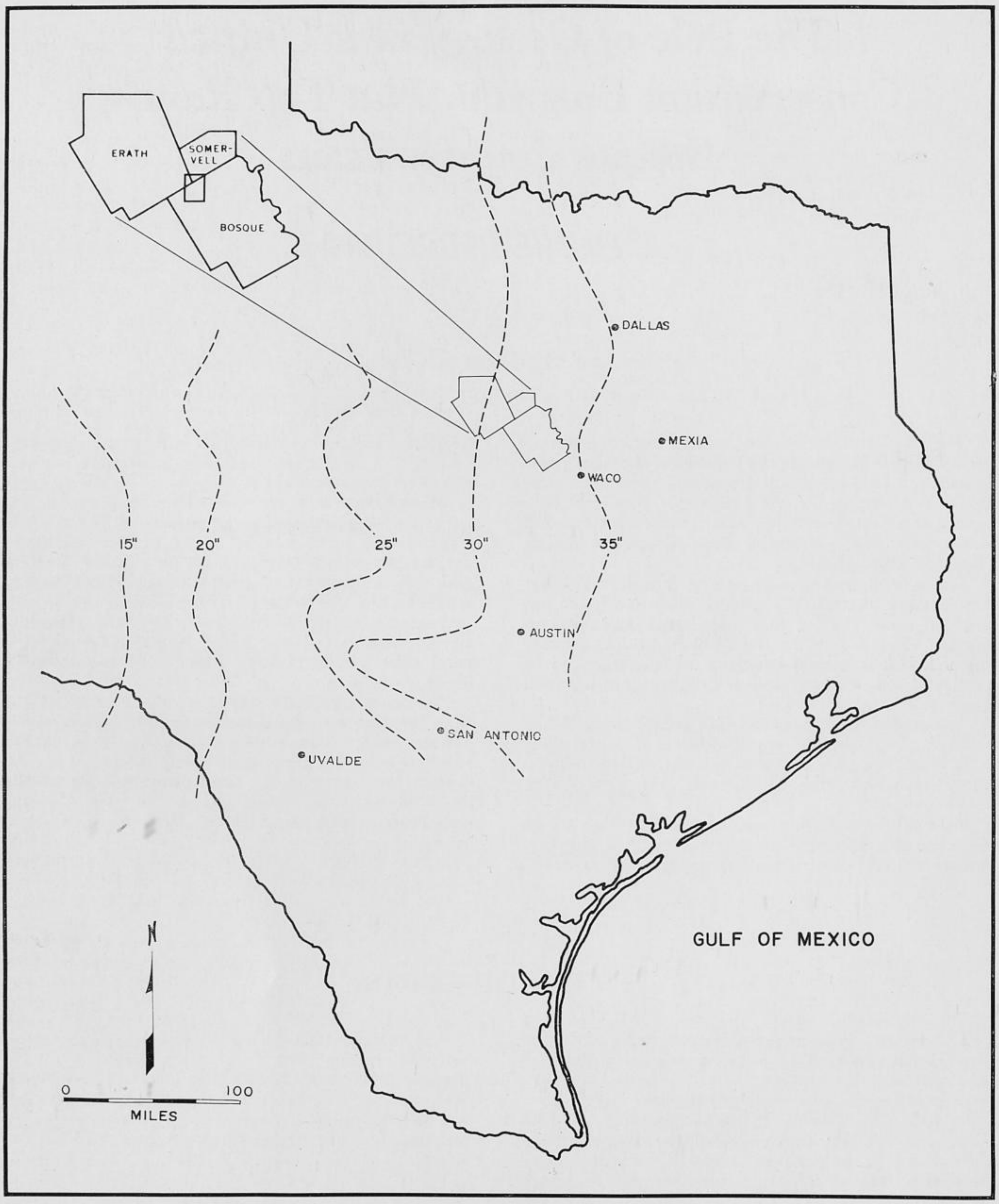

Fig. 1. Index and rainfall map.

taceous Fredericksburg group, Comanchean series. The map area includes, in addition to the ranch, the area adjacent to the ranch between longitude 97°46'W and 97°53'W and latitude 32°00'N and 32°07'30"N (Pls. I, II).

PROCEDURES

The study was completed during the spring of 1962. Because existing topographic maps are inadequate, the base map was constructed from controlled aerial mosaics kindly furnished by Edgar Tobin Aerial Surveys, San Antonio, Texas.

The outcropping geological formations and various soils were mapped in the field with the aid of aerial photographs. The soil map units (Pl. II) were *not* correlated with the Standard Soil Survey, Department of Agriculture, Soil Conservation Service. Subsurface data were available only from drillers' logs and were used with caution. Elevation data for structure control on top of the Paluxy sand (fig. 3) were obtained from altimeter surveys. A profile section illustrating the relationship of geology, physiography, and soil development (fig. 2) was surveyed with plane table and alidade.

PREVIOUS WORK

Ferdinand Roemer, a German geologist, made the first detailed observations of Texas Cretaceous rocks while visiting the state during 1845-47. In 1852 *Die Kreidebildungen von Texas* was published, in which the Cretaceous was divided into upper and lower units.

Jules Marcou (1856) confirmed the presence of lower Cretaceous strata in North America by identifying fossils collected by G. G. Shumard as Neocomian in age.

B. F. Shumard in 1860 (pp. 582-590) named, described, and assembled into stratigraphic units the Cretaceous rocks recognized in Texas. His formation names were based on geographic locations or faunal content. The paleontologic names have been replaced by geographic names.

In 1886 R. T. Hill began his investigation of lower Cretaceous rocks. Hill (1887, p. 303) divided the Comanchean strata into an upper Washita and a lower Fredericksburg division. His Fredericksburg division included B. F. Shumard's (1860) *Caprotina* limestone, now called the Glen Rose limestone. In 1888, Hill named the underlying Trinity division and transferred the *Caprotina* limestone from the basal Fredericksburg division to the Trinity division (Hill, 1901).

S. A. Thompson (1935, p. 1534) proposed the name Gatesville formation and included as members, the Walnut clay, Comanche Peak limestone, and Edwards limestone. In this classification the Fredericksburg division included the Kiamichi and Gatesville formations.

The results of surface and subsurface studies by F. E. Lozo (1949, 1959) are in agreement with Hill's (1937) conclusion that the Fredericksburg cycle of deposition in central Texas began with deposition of the Paluxy sand followed by deposition of the Walnut, Comanche Peak and Edwards formations.

Subsurface work by H. D. Holloway (1961) helped to clarify nomenclature of the Trinity rocks in central Texas by correlating Tyler basin and outcrop terminology.

W. A. Atlee (1962) studied the Paluxy sand in central Texas and recognized depositional environments ranging from shallow marine to non-marine. He also noted down-dip thinning of the Paluxy sand resulting from interfingering with the overlying Walnut formation.

Unpublished soil surveys conducted since 1957 by the U. S. Department of Agriculture, Soil Conservation Service, have been completed on a number of farms within and bordering the map area. Surveys prior to 1957 are considered inadequate by present U. S. Soil Survey standards. The soil map (Pl. II) included in this report is based on work by Goerdel (1962).

ACKNOWLEDGMENTS

The writer appreciates the guidance of Professors O. T. Hayward and L. F. Brown, Jr., Department of Geology, Baylor University. He is further indebted to Mr. Charles Pettit for permission to undertake the study on Flat Top Ranch. The following contributed significantly to the project: Messrs. W. B. Roberts, W. M. Preston, and Oland Hedrick, Flat Top Ranch, for information concerning ranch operations and conservation program; Mr. Lemund Goerdel, Department of Agriculture, Soil Conservation Service, for soil data, field supervision and aid in mapping soils; Mr. J. R. Thomas and staff, U. S. Department of Agriculture, Soil Conservation Service, Stephenville district, for unpublished soil surveys; Drs. Frank E. Lozo and David L. Amsbury, Shell Development Company, for critical reading of the manuscript and for information and suggestions concerning the Paluxy sand and associated formations; Mr. George Shafer, U. S. Geological Survey, Ground Water Branch, for providing subsurface records; Dr. B. C. Tharp, Professor Emeritus of Botany, The University of Texas, for information concerning geology and soil relationships; and various students of Baylor University, for aid in field work. Final illustrations and color cartography were prepared by Jerry L. Goodson, Department of Geology, Baylor University.

GEOLOGY

The geological formations which crop out on and around Flat Top Ranch are Lower Cretaceous (Comanchean series) strata and Recent alluvium which covers some of the valley floors (Pl. I).

The Cretaceous rocks are predominantly of the Fredericksburg group; a small outcrop of Glen Rose limestone of the underlying Trinity group occurs in the southwestern corner of the map area. The Fredericksburg group is composed of 4 formations which, in descending order, are the Edwards limestone, Comanche Peak limestone, Walnut clay, and Paluxy sand.

The Glen Rose limestone is underlain by basal sands of the Trinity group. Although these sands do not crop out in the area, they are important in this study because they comprise the principal deep aquifers in the region.

The Cretaceous strata strike north-northeast and dip gently southeastward at about 20 feet per mile. The structure of the area is relatively simple (fig. 3); however, some local structures were caused by biohermal reefs in the Edwards limestone and by channel sands of the Paluxy formation.

The map area includes two physiographic divisions—the Lampasas Cut Plain and the Paluxy Cross Timbers.

The Lampasas Cut Plain consists of flat-topped mesas and ridges capped by resistant Edwards limestone with less resistant Comanche Peak limestone exposed on the steep slopes. The Walnut clay crops out on the lower grass-covered slopes and valley floors (Pl. IV, fig. A).

The outcrop area of the Paluxy sand, which is called the Paluxy Cross Timbers, is characterized by dense post oak, blackjack oak, and other small hardwoods. Coarse bunch grasses and some short grasses are native to the area (Atlee, 1962, p. 12).

QUATERNARY SYSTEM

The Quaternary system in the map area (Pl. I) is represented by Recent alluvium in the major stream valleys. The alluvium is parent material for two soils (Pl. II), the Catalpa series and Lewisville series. The Catalpa soils develop on the flood plains of streams which drain calcareous prairie soils (Pl. IV, fig. B). The Lewisville soils develop on higher calcareous alluvial and terrace deposits (Goerdel, 1962). These soils, especially the Catalpa series, form the most fertile soils in the area and are intensively cultivated.

CRETACEOUS SYSTEM

EDWARDS LIMESTONE

Regional Geology

In 1899 Hill and Vaughn (pp. 193-321) applied the name Edwards limestone to cherty and rudistid-bearing strata between the Georgetown and Comanche Peak formations. This name was proposed to replace Shumard's earlier (1860) paleontologic term "*Caprina* limestone." The type locality of the Edwards limestone is Barton Creek near Austin, Texas (Adkins, 1932, p. 331).

The Edwards limestone is the uppermost formation of the Fredericksburg group (table 1).

The Edwards limestone crops out along a line trending approximately north-south beginning west of Fort Worth and passing west of Waco, Austin and San Antonio; the outcrop extends northwestward and westward from San Antonio across the Edwards Plateau.

In its outcrop area the Edwards limestone ranges from about 10-30 feet thick in the Brazos Valley to about 300 feet thick in the Colorado Valley. Southward thickening resulted from downdip addition of successively older Edwards facies at the expense of the underlying Fredericksburg rocks (Lozo, 1959, p. 5).

The Edwards limestone consists of several distinct facies: a reef facies of rudistid mollusks, an inter-reef facies consisting of small reefs and abundant reef clastics, and a lagoonal facies of dolomitic calcareous siltstones (Nelson, 1959). It conformably overlies the Comanche Peak limestone, and is unconformably overlain by the Duck Creek member of the Georgetown formation south of Waco and the Kiamichi member of the Georgetown formation in the north.

Flat Top Ranch Area

In the Flat Top Ranch area the Edwards limestone caps the steep, flat-topped divides of the Lampasas Cut Plain. The most notable outcrop is in the south-central part of the area where Edwards limestone caps Flat Top Mountain and Cedar Mountain, each standing about 250 feet above the surrounding prairie (Pl. I). The Edwards limestone crops out in the northeastern and northwestern parts of the area where it caps the steep-faced ridges of the cut plain topography (*idem*).

On Flat Top Mountain the Edwards limestone consists of 16 feet of gray to white massive reef limestone, composed primarily of the rudistid, *Eoradiolites*.

In the north-central part of the area at Flagpole Hill (Pl. I), the Edwards formation is represented by about 10 feet of bedded limestone with some alternating marl beds near the top. The Edwards limestone contains a variety of non-rudistid pelecypods and some gastropods. The lithology and fauna suggest a relatively quiet inter-reef environment.

Soils developed on the Edwards limestone (Pl. II) are normally of the Crawford series (table 1). The Edwards limestone commonly contains more than 99 percent calcium carbonate, while soils of the Crawford

Table 1. Outcropping geologic formations and dominant soil series, Flat Top Ranch.

System	Series	Group	Formation	Dominant Soil Series
Quaternary	Recent		Undifferentiated Alluvium	Catalpa Lewisville Krum
CRETACEOUS	COMANCHEAN	FREDERICKSBURG	Edwards Limestone	Crawford
			Comanche Peak Limestone	Brackett
			Walnut Clay	Denton-Tarrant San Saba Denton Tarrant
			Paluxy Sand	Windthorst Stephenville
		TRINITY	Glen Rose Limestone	Denton-Tarrant Denton

series are normally non-calcareous, neutral to slightly acidic (Goerdel, 1962). This suggests that Crawford soils are the products of accumulation of non-calcareous residual material derived from both the Kiamichi clay and the Edwards limestone.

Native vegetation commonly found on the Crawford soils are varieties of bluestem and gramas in addition to Texas wintergrass, buffalo grass and some mottes of live oak, post oak or shin oak trees. However, when the land is abused, which is common in this area, cedar (juniper), sumac, mesquite trees, and undesirable grasses and weeds dominate the pastures.

COMANCHE PEAK LIMESTONE

Regional Geology

The Comanche Peak limestone was first included in the "Comanche Peak group" by Shumard in 1860, who at that time correctly placed it below the Edwards limestone but incorrectly above the Austin chalk (Adkins, 1932, p. 334).

In 1889 R. T. Hill defined the Comanche Peak limestone as a persistent, fossiliferous, white, chalky limestone of the Fredericksburg group lying conformably beneath the Edwards limestone and above the Walnut clay (Wilmarth, 1938, p. 498).

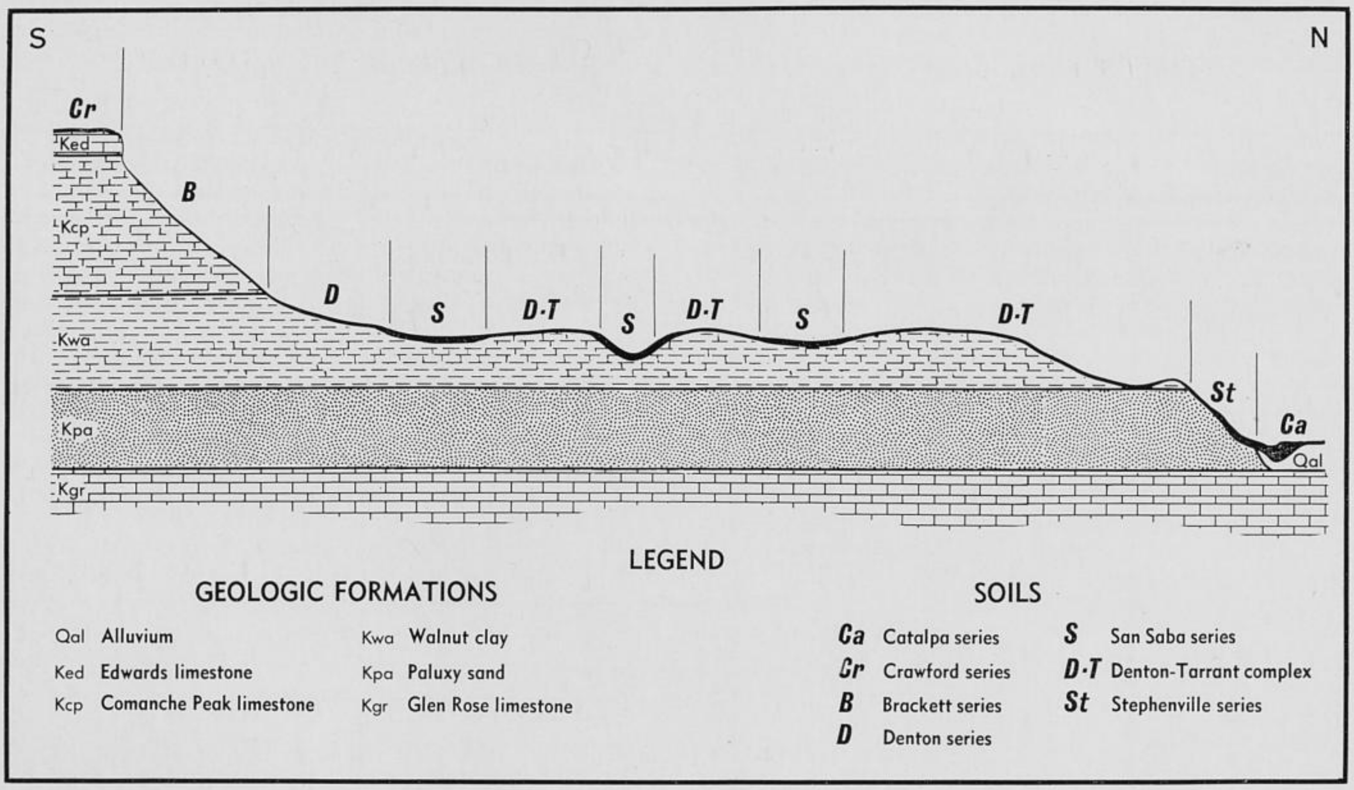

Fig. 2. Geology—soil relationship (cross section), Flat Top Ranch.

Hill (1901, p. 203) described 100 feet of Comanche Peak limestone at the type locality at Comanche Peak, Hood County. The Comanche Peak limestone thins southwestward and thickens southeastward. In the Waco area, 60 miles southeast of the type locality, electrical logs of wells indicate 120 feet of Comanche Peak limestone.

The northern equivalent of Comanche Peak and Edwards limestones is the Goodland formation which occurs northward from Tarrant and Parker counties.

Flat Top Ranch Area

In the Flat Top Ranch area the Comanche Peak limestone crops out on steep slopes of escarpments in the Lampasas Cut Plain. These escarpments are capped by more resistant Edwards limestone; the valleys are developed in the less resistant Walnut clay (Pl. I). At a few localities in the area the basal part of the Comanche Peak limestone caps the low rolling hills of the prairie topography (*idem*). The upper part of the Comanche Peak limestone is relatively hard, gray to white, fossiliferous, nodular limestone with abundant shale partings and filled animal borings. The Comanche Peak formation gradually grades downward to a softer, nodular limestone containing more argillaceous material intercalated with limestone beds. The chalky, nodular appearance of the Comanche Peak formation is the most diagnostic feature.

The conformable Comanche Peak-Edwards contact is easily mapped because the Comanche Peak limestone is much less resistant to weathering than is the Edwards limestone. The Comanche Peak-Walnut contact is more difficult to trace because of its gradational nature.

A clay zone about 12 feet thick containing a few thin limestone beds occurs about 30 feet above the base of the Comanche Peak limestone at Flat Top Mountain. These limestone beds are similar to beds in the underlying Walnut clay and they probably represent a major regression which allowed "intertonguing" of Walnut and Comanche Peak rock types. The regression was rapidly followed by a transgression which resulted in deposition of additional nodular chalky limestone.

The dominant soil type associated with the Comanche Peak limestone (Pl. II) is the poorly developed Brackett series (table 1) which develops on steep slopes where formation of deep soil can not occur. The most diagnostic vegetation on Comanche Peak soils is the Spanish or Texas oak tree. Grasses commonly associated with this formation are little bluestem, hairy dropseed, and a variety of gramas.

WALNUT CLAY

Regional Geology

The Walnut clay was named by R. T. Hill (1891, p. 512) for exposures near the town of Walnut Springs, Bosque County, Texas. The Walnut clay occurs below the Comanche Peak limestone and above the Paluxy sand, Fredericksburg group.

In the type area the Walnut formation consists of alternating clay, nodular marly limestone, crystalline limestone, and massive shell beds composed of *Exogyra texana* Roemer and *Gryphaea mucronata* Gabb (=*G. marcoui* Hill and Vaughn)[2]. The earliest formation names, such as "*texana* beds" and "*Gryphaea* rock" described these characteristic shell aggregates.

The Walnut formation thins westward and northward from the type area. The shell beds common in the lower part of the formation in the type area extend northward as far as Parker County. The Walnut for-

[2]Stanton, 1947, p. 28.

mation thickens downdip at the expense of the underlying Paluxy sand. South and west of the type locality, chalky limestone beds of the overlying Comanche Peak formation replace successively older marl and nodular limestone beds present in the Walnut clay at the type area (Lozo, 1959, p. 5).

Flat Top Ranch Area

Flat Top Ranch is located in the type area of the Walnut clay. The Walnut formation crops out extensively in the map area (Pl. I) where it supports the rolling prairie topography which is typical of this region.

In this report the Walnut formation is divided into two lithologic units. The upper part of the formation typically consists of thick beds of calcareous clay, chalky limestone, soft marly limestone, and a few hard crystalline limestone beds, which are fossiliferous and exhibit cream to buff color on weathered surfaces. The lower part of the formation is composed of alternating, thin-bedded limestone and gray marl beds, massive shell beds, and hard crystalline fossiliferous limestone beds separated by thin shale seams.

The Walnut-Comanche Peak contact is gradational. In the study area the contact has been placed at the top of the first hard fossiliferous limestone bed below the massive nodular Comanche Peak-type limestone beds. The contact approximately coincides with a topographic change from steep Comanche Peak limestone slopes to more gentle Walnut clay slopes.

The upper and lower parts of the Walnut formation are separated by a shell bed composed of *Gryphaea mucronata* in a clay matrix. This *Gryphaea* bed occurs throughout the area and is easily recognized in the field and on aerial photographs. It supports most low but prominent hills of the rolling prairie topography (Pl. I). The *Gryphaea* bed (Pl. III, fig. A) is about 10 feet thick and the base of the bed is about 40 feet above the Paluxy sand.

The basal part of the Walnut formation consists of very hard crystalline limestone beds separated by thin shale beds. These basal limestone beds contain abundant *Gryphaea* and *Exogyra*. The most distinct of these beds occurs about 1 foot above the Walnut-Paluxy contact and is mappable throughout the area (Pl. III, fig. B). The bed is hard crystalline limestone containing abundant shell fragments; it exhibits ripple marks about 8 inches high with a wave length of about 3 feet which indicate a turbulent environment during initial Walnut deposition.

The Walnut-Paluxy contact is commonly marked by a 1 foot zone of reworked sand, shell and limestone fragments. The contact is sharp throughout the area. The reworked zone is undoubtedly the product of wave action in the transgressing Walnut sea (Pl. III, fig. B).

The Walnut clay was deposited in a relatively stable, shallow transgressing sea. However, conditions must have been more turbulent during deposition of the lower part of the formation as evidenced by ripple-marked limestone and fragmented shell beds. The abundant *Exogyra texana* and *Gryphaea mucronata* in the lower part of the Walnut formation suggest widespread but unique ecologic-environmental controls. Local periodic extermination of these pelecypods may have resulted from increase in water depth, influx of clay, change in salinity, availability of food supply, and/or turbulence of the seas.

As the Walnut sea transgressed westward clay and marl beds of the upper Walnut formation were deposited. The transgressive nature of the Walnut clay is further substantiated by abundant littoral organisms, such as gastropods, pelecypods, serpulid worms, and oysters, which contrast with the characteristic land-derived plants in the underlying Paluxy sand.

Several different soils (Pl. II) are developed on the Walnut clay in this area. The most characteristic soils are the San Saba series, Denton series, Tarrant series, and the Denton-Tarrant complex (table 1). The San Saba and Denton soils are widespread mature soils which occur on gentle slopes developed predominantly on clays of this formation. Typical native vegetation on Denton and San Saba soils consists of a wide variety of grasses with scattered mottes of live oak trees. The most abundant grasses are little bluestem, several species of grama, Texas wintergrass, and Indiangrass. The Tarrant and Denton-Tarrant complex are normally developed on limestone sections on somewhat steeper slopes.

PALUXY SAND

Regional Geology

In 1891 R. T. Hill (p. 504) named the Paluxy sand for exposures along the Paluxy River in Erath County and on the highlands near the town of Paluxy, Hood County, Texas. These sands were first confused by Hill with older Trinity sands north of the type locality, but later studies in the vicinity of Comanche Peak, Hood County, revealed the Paluxy sand to be a mappable rock unit between the Glen Rose and Walnut formations (Hill, 1891, p. 511).

Most early workers considered the Paluxy sand to be the uppermost formation of the Trinity group. However, Lozo (1949) following Hill (1937) demonstrated that the Paluxy sand is genetically the lowermost formation of the Fredericksburg division in central Texas. Stratigraphically the Paluxy formation lies between the Walnut clay above and the Glen Rose limestone below.

The Paluxy sand crops out in the northern part of central Texas and is especially well developed in Parker, Hood, Somervell, Erath, Bosque, Hamilton, Coryell, and Comanche counties (Atlee, 1962, p. 12). The Paluxy sand thickens northward and merges with Trinity sands in Wise County to form a single rock unit, the Antlers sand. Paluxy sand occurs in the subsurface from Louisiana to Freestone and Limestone counties, Texas, where it grades to a shale and marl facies (Atlee, 1962, p. 12).

The Paluxy sand thins about 2 feet per mile southward from the type locality; however, the thickness may vary locally. The formation is thickest in central Texas at Twin Mountains, northwestern Erath County, where it is 190 feet thick. Southward the Paluxy sand thins by interfingering with the overlying Walnut formation until it passes into shales and marls assigned to the Walnut clay immediately south of Waco in McLennan County, Texas (Atlee, 1962, pp. 9, 13).

Flat Top Ranch Area

The Paluxy sand crops out in most stream valleys on Flat Top Ranch (Pl. I). The best exposures normally occur in valley walls; valley floors are commonly covered by alluvium.

The Paluxy sand is composed primarily of fine to very fine-grained, homogeneous, white to buff quartz sand with dark, impure clay lenses. The sands are commonly cross-bedded and/or laminated.

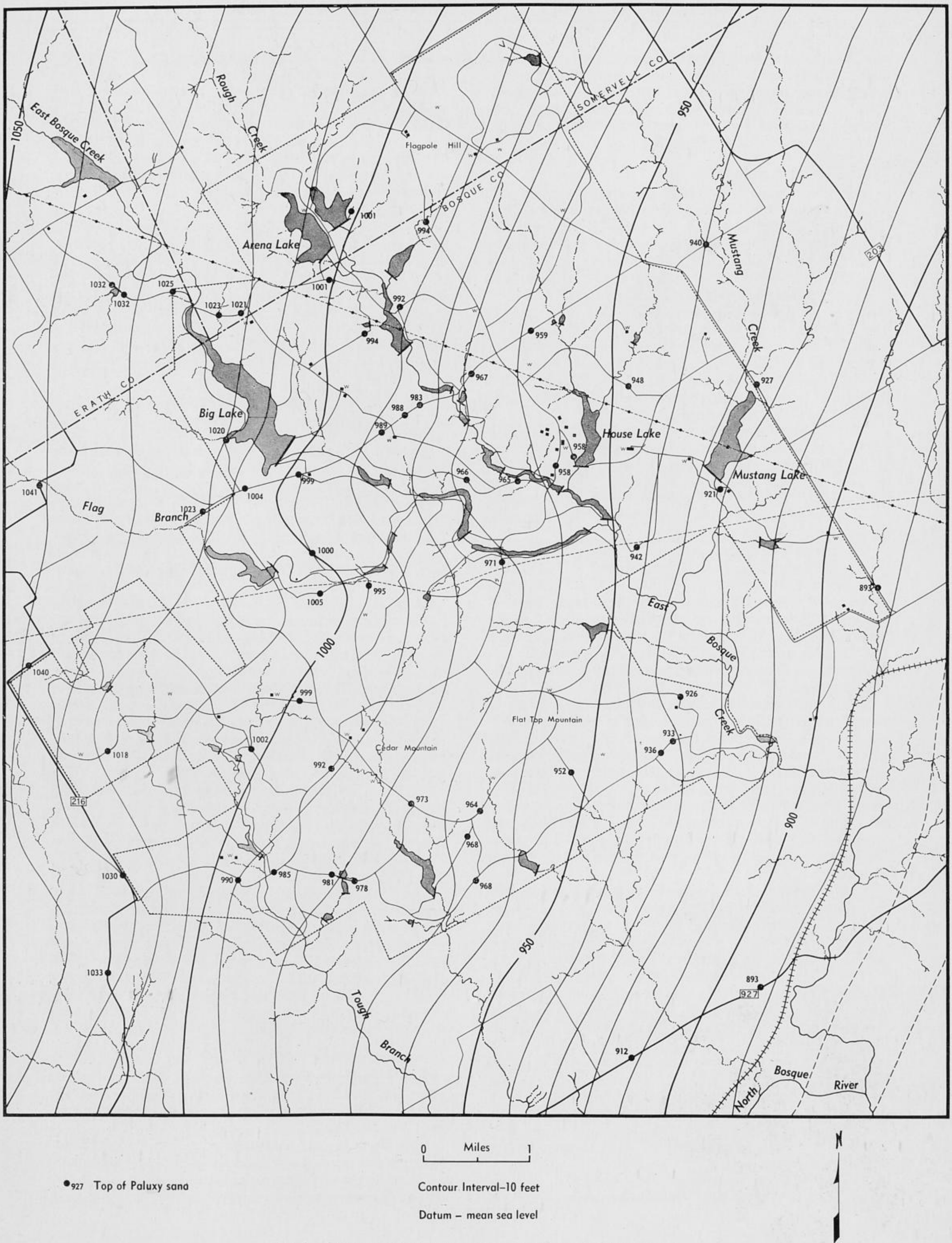

Fig 3. Structure map, top of Paluxy sand, Flat Top Ranch.

In the map area the Paluxy sand is approximately 80 feet thick and can be divided into two distinct sand units. The division is marked by an indurated limestone bed about 12 inches thick, containing shell fragments and quartz grains. The limestone is underlain by about 2 feet of dark shale.

The upper part of the Paluxy sand is commonly composed of uncemented cross-bedded or horizontally-bedded sand; horizontally-bedded sands contain some clay seams. At Arena Lake spillway the uppermost part of the Paluxy sand is composed of interstratified sand and clay beds exhibiting some well-developed slump structures, and is underlain by a lenticular oyster bed 3 feet thick (Pl. III, fig. C). More persistent thin seams of macerated shell fragments occur at the same level in this vicinity. Below the shell bed is a very fine, massive "packsand" with some lignite fragments.

Some cross-bedded sands exhibit very small-scale internal cross-laminae, which are apparently similar to micro-cross-laminae described by Hamblin (1961). Amsbury (1962, oral communication) referred to this Paluxy cross-lamination as rib and furrow structure (*after* Stokes, 1953) because as seen on bedding planes the laminae normally form parallel rows of ridges 1-3 inches apart (Hamblin, 1961, p. 395). A common type of large-scale cross-bedding consists of steeply-dipping, alternating thin beds of sand, silt, and clay (Pl. IV, fig. C). Ridges of the rib-and-furrow structure parallel the strike of the large cross-beds, or co-sets (McKee and Wier, 1953). The very small-scale internal cross-laminae apparently originated from ripple marks caused by a weak but relatively constant source of energy—possibly longshore currents which flowed parallel to the ridges (Hamblin, 1961, pp. 396, 400).

The lower part of the Paluxy sand is best exposed along East Bosque Creek near its junction with Rough Creek (Pl. I). At this locality the limestone bed which marks the contact between the upper and lower parts of the Paluxy sand is well exposed. Underlying the limestone bed is a dark shale bed about 2 feet thick which overlies a greenish, argillaceous sand which may represent an ancient soil profile (Amsbury, 1962, oral communication). Below this argillaceous sand are typical fine-grained sands of the Paluxy formation.

The Paluxy formation also contains numerous channel sand bodies in this area. The most prominent channel is about 40 feet thick and consists of thick cross-laminated beds of very fine sand (Pl. III, fig. D). Dips of cross-laminae indicate that currents normally flowed southeastward. This thick channel deposit, which trends northwest-southeast across the area, is possibly of fluvial origin. Linear structural highs on top of the Paluxy sand (fig. 3) define the approximate areal extent of this channel and outline other possible channels in the area.

The Paluxy formation was deposited in several environments which occurred near the ancient coast line. Dinosaur tracks (Booth, 1956) in Rough Creek, rare marine fossils, brackish water ostracodes (Atlee, 1962, p. 17), abundant lignite, and diagnostic sedimentary structures suggest that some of the sands were deposited in a fluvio-marine environment.

Some of the Paluxy sand may have been deposited by wind action (Atlee, 1962, p. 19). Midway between Walnut Springs and Iredell on Farm Road 927, about 2 miles southwest of the railroad crossing, cross-bedded sand dips northeastward at approximately 34 degrees (*idem*, fig. 10). This angle of repose reflects a non-marine environment. McKee (1952, p. 18) found experimentally that subaerial cross-beds dip 30 to 40 degrees, whereas subaqueous beds display dips from 20 to 35 degrees; this difference is especially pronounced in fine-grained sand. Most cross-bedded sands observed in the area dip southeastward.

Cross-stratified sands, commonly displaying internal micro-cross-laminae, were probably transported to the area by streams and deposited as bar sands or marine channel sands by tidal currents. Laminated sands, possibly deposited as deltaic sheet sands, apparently do not exhibit micro-cross-laminae.

The interstratified sand and clay may represent cyclic fluctuations in available sediments, and the presence of oyster beds suggests a brackish water environment.

A limestone bed that divides the upper and lower parts of the Paluxy formation may represent a minor marine transgression. This unit is traceable south and west of the map area (Atlee, 1962, p. 13, fig. 4).

Typical soils developed on the Paluxy formation (Pl. II), in order of importance, are the Windthorst, Stephenville, and Nimrod series (table 1). These are neutral to slightly acidic, red and yellow soils with acidity controlled by calcium bicarbonate in the runoff water from the overlying Walnut soils (Goerdel, 1962). Development of Paluxy soils occurs under a grass and scattered post oak cover characteristic of the Western Cross Timbers.

GLEN ROSE LIMESTONE

The Glen Rose limestone was named by R. T. Hill in 1891 (pp. 507-509) from outcrops along the Paluxy River at and near Glen Rose, Somervell County, Texas. The term Glen Rose replaced the name "*Caprotina* limestone" previously applied by B. F. Shumard (1860).

The Glen Rose limestone is characterized by a variety of prominent limestone beds alternating with shale; the outcrop is typified by a pronounced bench-terrace topography. The Glen Rose formation thickens along the outcrop from about 200 feet at the type area to about 600 feet in the Colorado River Valley (Lozo, 1959, p. 5). In the subsurface at Waco the Glen Rose limestone is about 800 feet thick.

The Glen Rose limestone, which is the uppermost formation of the Trinity group, crops out in the extreme southwestern corner of the map area (Pl. I), where the upper few feet of alternating limestone and marl beds are exposed. The Glen Rose formation is about 275 feet thick, as interpreted from well logs in the area.

Soils on the Glen Rose limestone are similar to soils on the Walnut clay in the map area (Pl. II). The Denton series (table 1) normally occurs on gently sloping areas underlain by marl and clay, while shallow-phase Denton and Denton-Tarrant complex soils commonly develop on the more resistant limestone beds. Native vegetation, consisting of a variety of grasses with some mottes of live oak trees, is also similar to that growing on the Walnut formation.

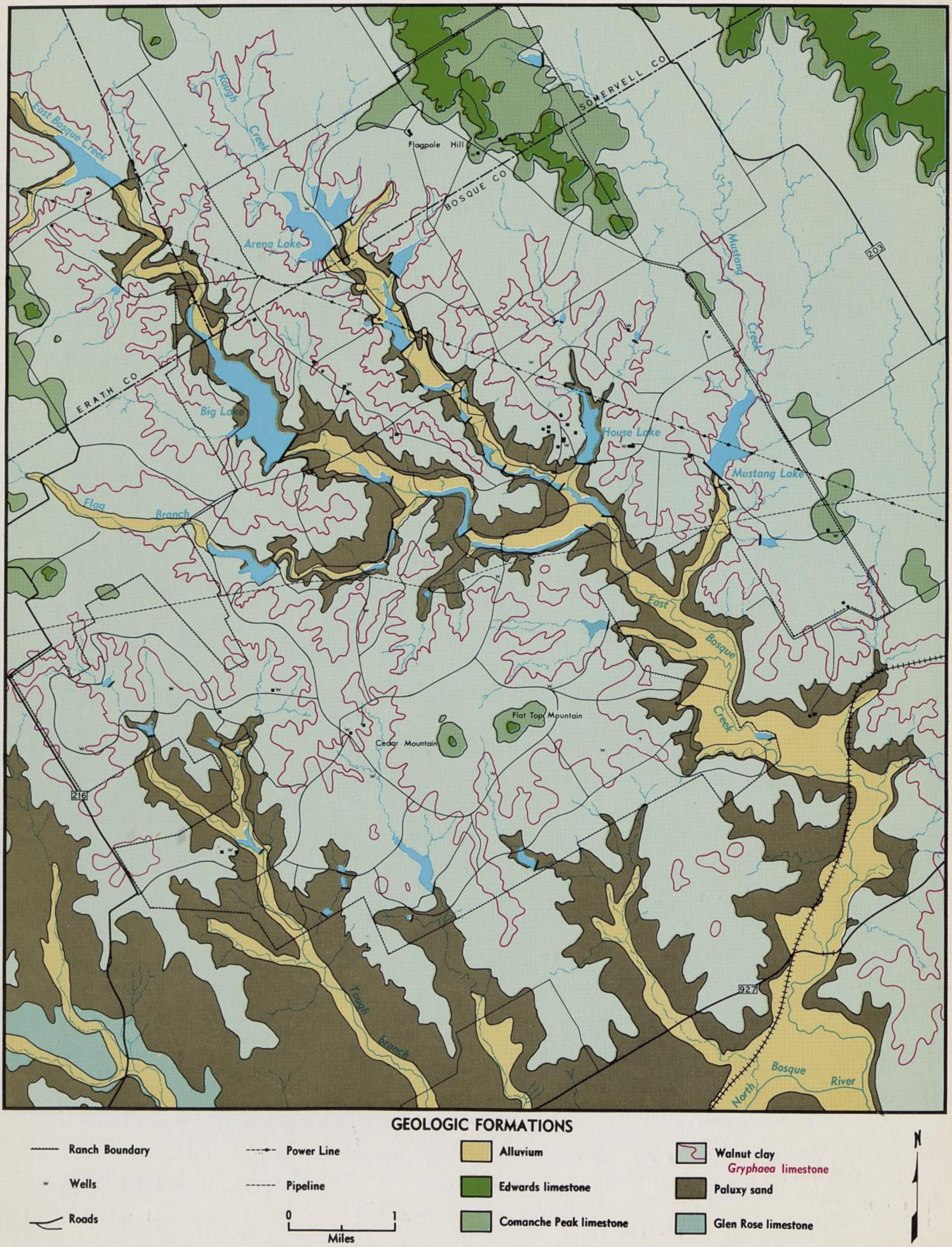

Plate I. Geologic map, Flat Top Ranch.

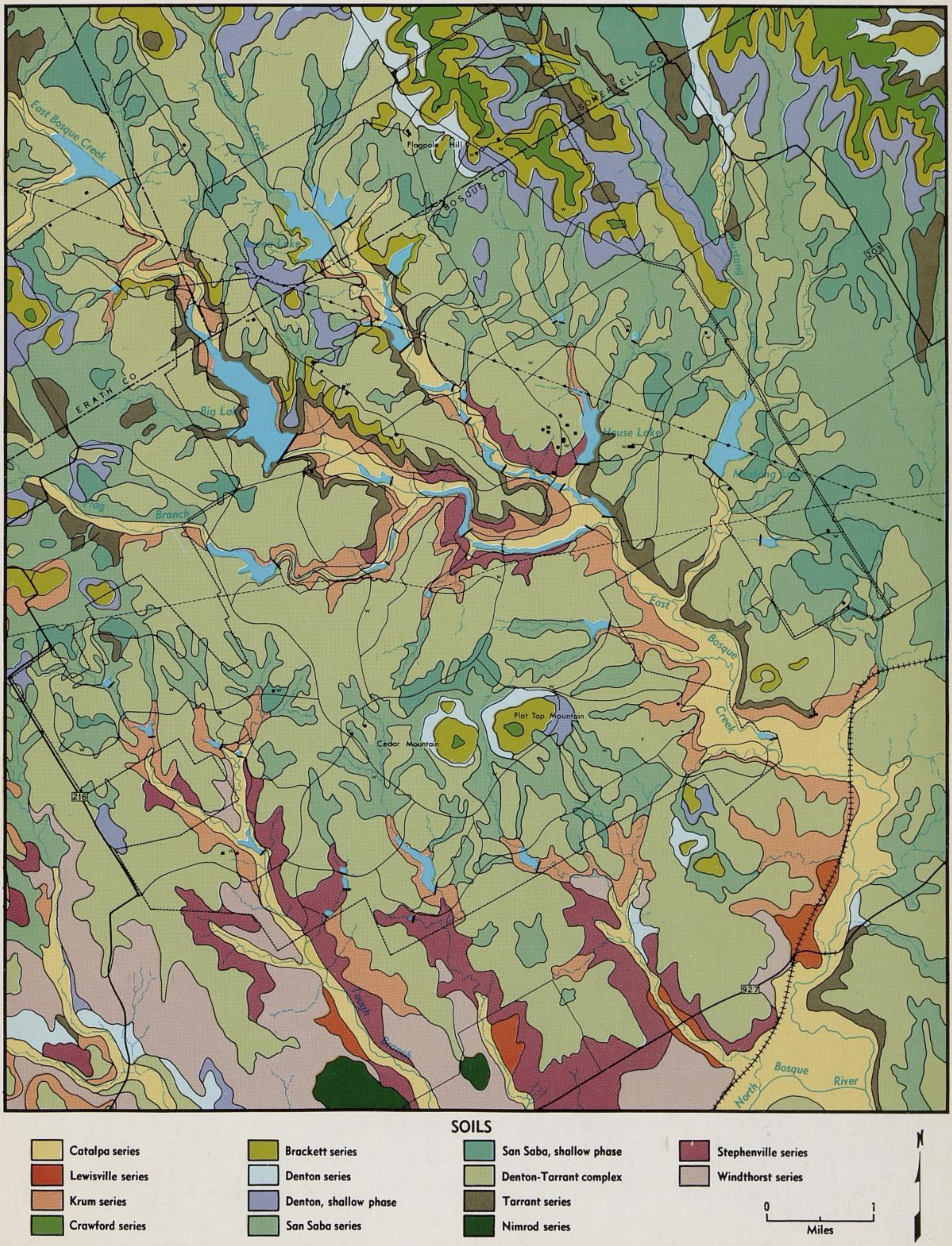

Plate II. Soil map, Flat Top Ranch.

Table. 2. Physical properties and characteristics of dominant soil series, Flat Top Ranch.

SOIL	HORIZON	DEPTH	TEXTURE	COLOR	REACTION pH	REACTION HCl Test	INSOLUBLE RESIDUE	REMARKS
Crawford shallow stony clay	A	0-6″	clay	dark reddish brown	7.0	—	100%	This soil contains limestone up to 8″ diameter.
	B	6-15″	clay	dark reddish brown	7.0	—	100%	
	—	15″+	hard limestone	white	—	violent	0.6%	Parent material.
San Saba clay	A	0-20″	clay	very dark gray	8.0	slight	97%	
	B	20-60″	clay	dark olive gray	8.0	weak	92%	
	C	60″+	marl	—	8.0	violent	19%	Accumulation of $CaCO_3$.
	—	—	marl	—	8.0	violent	30%	Partly weathered marl.
Denton clay	A	0-8″	clay	dark brown	8.0	violent	53%	
	B	8-36″	clay	brown	8.0	violent	48%	
	C	36″+	marl	—	8.0	violent	14%	Accumulation of $CaCO_3$.
	—	—	marl	—	8.0	violent	30%	Partly weathered marl.
Tarrant clay	A	0-8″	clay	dark grayish brown	8.0	strong	89%	Well developed lithosol.
	C	8-14″	clay & limestone	—	—	violent	Not tested	Clay and limestone fragments.
	—	—	coquinoid limestone	—	—	violent	4.5%	Parent material.
Brackett clay loam	A	0-8″	clay loam	gray	8.0	violent	22%	Lithosol.
	C	8-36″	clay loam?	light gray	8.0	violent	26%	Weathered parent material.
	—	36″+	soft limestone	white	—	violent	10%	Bedrock.
Catalpa clay loam	—	0-24″	clay loam	dark grayish brown	8.0	strong	86%	Alluvial soil.
	—	24-60″+	clay loam	grayish brown		(not tested)		
Windthorst fine sandy loam	A	0-8″	fine sandy loam	brown	7.0	—	—	
	B	8-24″	sandy clay	dark reddish brown	6.5	—	—	
	—	24-36″	sandy clay	dark red	6.5	—	—	
	C	36″+	sandy loam	yellowish	6.0	—	—	Material varies.
Stephenville fine sandy loam	A	0-8″	fine sandy loam	brown	7.0	—	—	
	B	8-22″	sandy clay	dark red	6.5	—	—	
	—	22-40″	sandy clay loam	red	6.5	—	—	
	C	40″+	sandy loam	yellowish red	6.0	—	—	Material varies.

(*after* Goerdel, 1962)

PEDOLOGY

Soil is a mixture of mineral and organic material at the land surface which is capable of sustaining plant life. Soil is the product of the interaction of five factors: (1) parent material, (2) topography, (3) climate, (4) organic influence and (5) time. Parent material is considered the dominating factor in soil formation in the Flat Top Ranch area.

A common characteristic of all mature soils is the presence of 3 distinct layers or *horizons*. A vertical section of the soil horizons is called a *profile*. The surface layer (*A* horizon) is normally dark and relatively high in organic matter. Below is another layer (*B* horizon) which commonly contains more clay than the topsoil and may differ in color. Material below the *B* horizon is normally the lighter colored *C* horizon which rests upon parent material (either bedrock or alluvium).

The development of mature soil results from the interaction of various combinations of the soil forming factors. The stage of development of a soil can be determined from the soil profile. Transported soils, eolian or alluvial, are "young soils" with little or no evidence of horizon development. Where development of *A* and *B* horizons has begun and can be easily recognized, the soils are considered immature. Mature soils have profiles which display full development of *A* and *B* horizons in equilibrium with the prevailing weathering forces. "Old soils" exhibit fully mature profiles which are undergoing modifications due to changes in environmental conditions (Thompson, 1952, p. 84).

Soils with poorly developed horizons are called *lithosols*. The Brackett series, which commonly develops on steep slopes of Comanche Peak limestone, represents a typical lithosol in the Flat Top Ranch area.

The *soil type* is the principal unit in soil classification. A soil type is a group of soils which are similar in all profile characteristics. Soil types are grouped into series. A *soil series* (Appendix I) is a group of soils which are similar in all profile characteristics, except the texture of the *A* horizon (Thompson, 1952, p. 86).

Soil complexes are used in mapping soil associations or parts of soil associations which are too small areally to be separated. The term *soil phase* is used as a subdivision of a soil type where bedrock occurs in place of the bottom horizon of the profile. Methods and standards of soil mapping and classification are discussed in the Soil Survey Manual (1951) published by the U. S. Department of Agriculture.

PARENT MATERIAL

In the Flat Top Ranch area the characteristic properties of the dominant soils (table 2) are primarily controlled by the outcropping rocks. The influence of parent material is readily illustrated by comparing geology and soils (Pls. I, II; fig. 2). Sandy soils develop from Paluxy sand; clay and clay loam soils occur on limestone, marl, and clay beds of the Glen Rose, Walnut, Comanche Peak, and Edwards formations. Soils overlying each of these outcropping geological formations are characterized by one or more distinctive series (fig. 2), whose genesis and economic importance (Appendix II) are closely controlled by the underlying parent material.

Edwards Limestone Soils

Soils of the Crawford series are most commonly developed on the Edwards limestone outcrop (fig. 2). These are non-calcareous, medium to shallow soils which develop on flat, well-drained areas of resistant limestone. The Crawford soils are mature soils representing a long period of development. Approximately 15 inches of neutral to slightly acidic clay soil have accumulated on a limestone that contains only 0.6 percent insoluble residue. Assuming that all of this material was derived from the Edwards limestone, calculations indicate that about 125 feet of limestone weathered to form the Crawford soil. However, the Edwards limestone in this area rarely exceeds 30 feet in thickness, which indicates that much of the Crawford soil material developed from the overlying Kiamichi clay of the Georgetown formation (Goerdel, 1962).

Comanche Peak Limestone Soils

The Comanche Peak limestone is parent material for the poorly developed Brackett series (fig. 2). The Brackett series includes light-colored, calcareous lithosols formed on soft chalky limestone and marl. This soil normally develops on slopes steeper than 5 percent.

The topographic position of the Comanche Peak limestone, which crops out on steep slopes of hills capped by more resistant Edwards limestone, causes accelerated erosion to remove much weathered rock debris. Also, excessive loss of moisture occurs through runoff. The moisture loss consequently decreases the effectiveness of soil formation by creating a more arid micro-climate. Therefore, primarily as a result of stratigraphic position and composition, the Comanche Peak limestone normally occupies a topographic position which is not conducive to the development of a thick soil cover (fig. 2).

Walnut Clay Soils

A variety of soils develop on the Walnut clay (fig. 2), which crops out over a large part of the map area. Lithologic variations within the Walnut formation dictate the development of each soil type. Soils which develop on the Walnut formation can be divided into clay-derived soils and limestone-derived soils.

Soils of the San Saba and Denton series are typical soils developed on clay beds of the Walnut formation. The Denton series includes calcareous granular soils of medium depth, which occur on gently to moderately sloping areas (fig. 2). The Denton soil series exhibits moderate horizon development because of limited runoff and greater effectiveness of moisture on gentle slopes. Denton soils, which are associated with San Saba soils, commonly occupy a slightly higher and steeper topographic position.

The most intensive soil development on the Walnut formation is the San Saba series. This series is best developed on relatively impervious clays, which occur on flat, poorly drained areas. Because of topographic position, San Saba soils receive additional moisture from run-off, resulting in a more humid micro-climate, which in turn accelerates soil development. San Saba soils normally develop to about 6 feet deep, possessing distinguishable *A, B,* and *C* horizons.

The Denton and San Saba series also have shallow phase soils, which are similar to the deeper soils previously discussed. Although shallow phase Denton or San Saba soils may develop at topographic positions similar to their deeper counterparts, the amount of limestone in underlying parent material normally regulates the degree and depth of soil development.

The outcrop of the lower part of the Walnut formation is characterized by limestone-derived soils. The most dominant are dark lithosols of the Tarrant series. In this study the Tarrant series includes the Tarrant stony clay and soils of the Denton-Tarrant complex. The Tarrant stony clay is a shallow, grayish-brown, granular, calcareous clay. It typically develops from the hard crystalline limestone beds of the basal Walnut formation.

The Denton-Tarrant complex includes Denton clay, shallow phase Denton, and Tarrant stony clay. These soils were grouped because of the small areal extent of individual units and their gradational relationships. This soil complex, as an undifferentiated unit, is the most extensively developed in the map area (Pl. II). Normally, the shallow stony soils of this complex develop on more calcareous basal units of the Walnut formation and the deeper soils form on more argillaceous units of the Walnut formation.

Poorly developed Brackett soils rarely occur on steep, marly limestone slopes capped by limestone beds in the Walnut formation. The most common occurrence of Brackett soil from Walnut parent material is on steep slopes capped by the thick *Gryphaea* bed, which is the boundary between the upper and lower parts of the Walnut formation in the map area.

Paluxy Sand Soils

Soils of Windthorst, Stephenville, and Nimrod series are typically developed on the outcrop of Paluxy sand (fig. 2). Zonation is pronounced in these soils and the contact between the sandy *A* horizon and the sandy clay *B* horizon is sharp. More pronounced zonation occurs in sandy soils than in limestone-derived soils because calcium ions tend to flocculate clay and humate colloids, preventing dispersion and removal from soil by leaching (Jenny, 1941, p. 72).

The Windthorst fine sandy loam is the most extensive Paluxy-derived soil in this area. The *A* horizon is brown fine sandy loam that changes abruptly into the underlying *B* horizon. The *B* horizon is neutral to slightly acidic, dark reddish-brown sandy clay with firm blocky structure. This horizon grades downward into a dark red sandy clay with similar properties. A diagnostic feature of the Windthorst series is a subsoil (*B* horizon) that is less permeable and friable than subsoils of the Stephenville series.

The Stephenville fine sandy loam includes neutral to slightly acidic brown fine sandy loam in the *A* horizon (topsoil), and a dark red sandy, slightly acidic clay with moderately blocky, friable structure in the *B* horizon. The *A* horizon-*B* horizon contact is sharp. The *B* horizon grades downward into red slightly acidic sandy clay loam which is gradational with the *C* horizon composed of slightly acidic, yellowish-red sandy loam containing red and yellow laminae.

The Nimrod series includes light-colored sands with mottled, slightly permeable subsoils. These soils are not important in this study since they occur only in two small areas in the southern part of the area (Pl. II).

Other soils that occur within the map area are included with previously described soils because of small areal extent. The Harbin and Milam series were included in the Stephenville series and the Travis series was included with the Windthorst soils.

Distribution of Paluxy-derived soils is controlled by topography in the area. Windthorst soils normally occur on gentle slopes, Stephenville soils on steeper slopes, and Nimrod soils on flat areas.

Glen Rose Limestone Soils

Soil development on the Glen Rose limestone is principally controlled by the outcrop of alternating beds of limestone and marl. However, Glen Rose-derived soils are of minor importance in this study because of their small areal extent in the map area. Calcareous lithosols of the Tarrant series develop on resistant limestone beds and soils of the Denton series form on marl beds. The complex soil distribution developed on the alternating limestone and marl beds of the Glen Rose formation has necessitated mapping some Glen Rose-derived soils as Denton-Tarrant complex soils.

Alluvial Soils

In the Flat Top Ranch area Catalpa series, Krum series, and Lewisville series soils develop on alluvial deposits. These soils are derived from parent material eroded from calcareous prairie soils in the area.

The Catalpa series includes grayish-brown calcareous soils developed on flood plains of streams (Pl. IV, fig. D). The Catalpa series is the most extensive alluvial soil series and is especially well developed along East Bosque Creek (Pl. II).

The Lewisville series includes well-drained, dark brown, granular soils which have developed on higher (older) calcareous alluvial and terrace deposits. These soils normally occur on upland sites adjacent to Catalpa covered bottomland sites (Pl. II).

Dark grayish-brown calcareous soils of the Krum series occur on slope alluvium from weathered calcareous Tarrant, Denton and other similar Walnut soils which were washed from higher slopes. Sandy alluvial slopes on Paluxy sand outcrops are commonly covered by Krum series soils (Pl. IV, fig. D).

TOPOGRAPHY

Topography results from development of a drainage system. Soils and parent materials which are less resistant to erosion are naturally removed first; consequently, soils and parent materials which are more resistant to erosion normally occur at higher elevations in the drainage basin. Other soil-forming factors being equal, a significant change in topography (fig. 2) is normally accompanied by a change in soil type (Thompson, 1952, p. 81).

The influence of topography on soil formation in the Flat Top Ranch area is only slightly less important than the influence of parent material, which also controls the topographic configuration. In this area the topography is almost exclusively the product of a uniform climate weathering and eroding widely varying rock types. High hills are capped by Edwards limestone. Steep slopes are normally developed on Comanche Peak limestone. Lowlands and rolling prairie topography are characteristic of Walnut clay outcrops (Pl. IV, fig. A).

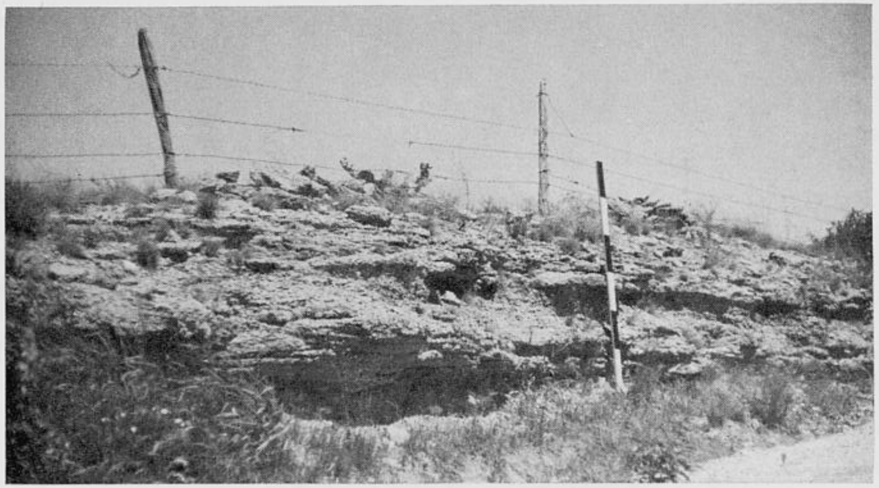

Fig. A. *Gryphaea mucronata* bed marking boundary between upper and lower units of the Walnut clay. Approximately 1 mile northwest of Walnut Springs, Texas. View looking southeast.

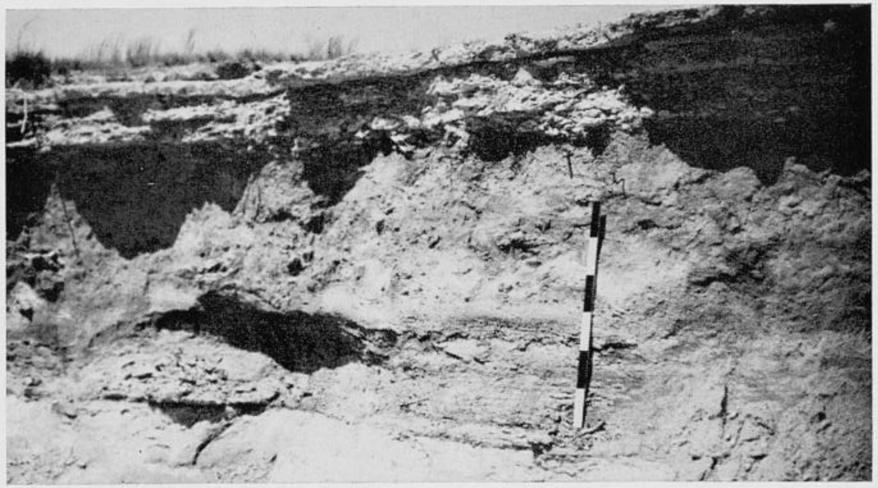

Fig. B. Walnut-Paluxy contact, Arena Lake spillway. View looking west.

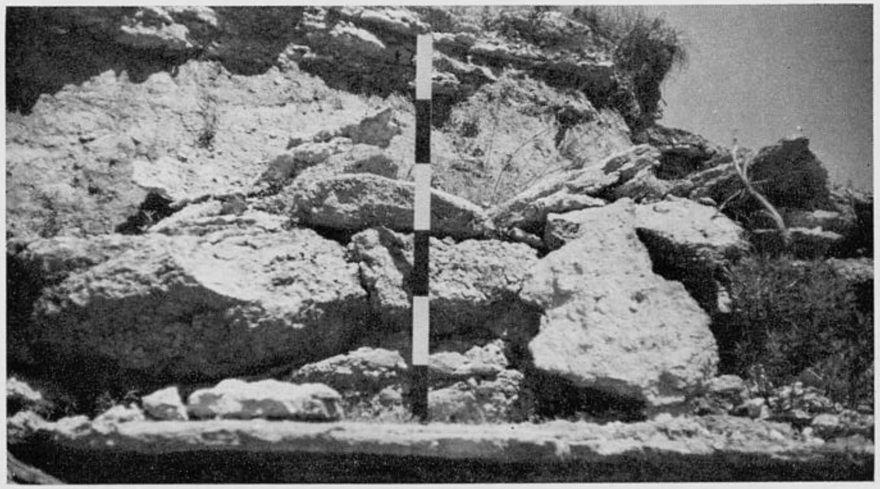

Fig. C. Oyster bed in upper Paluxy sand, Arena Lake spillway. View looking northwest.

Fig. D. Channel sand in Paluxy formation, Big Lake spillway. View looking north.

Plate III. Outcrop features, Fredericksburg group, Flat Top Ranch.

Because of the close relationship between topography and stratigraphy, geologic mapping in this area can be accomplished by charting topographic variations.

As a result of topography, local micro-climatic variations occur, which locally control the degree of soil development. For example, poorly developed Brackett soils form under arid conditions on the steep slopes of the outcropping Comanche Peak limestone, and well-developed San Saba soils form under humid conditions which exist on the gently sloping Walnut clay outcrop.

CLIMATE

Climate has been commonly considered the major factor in soil formation. However, climatic control, which is most important in the development of soil, is the climate at the soil surface and within the soil profile —the *micro-climate*.

Although climate may largely determine the maximum soil development in a given region, it is the micro-climate and other soil-forming factors which determine the wide variety of soils found in a single major climatic region.

Micro-climate, which is extremely significant in soil development, is primarily controlled by topography and vegetation, both of which are largely determined by parent material. Again, parent material exerts an important influence upon another soil-forming factor.

The primary climatic factors are rainfall, evaporation-transpiration, and temperature. In the Flat Top Ranch area, average annual rainfall is slightly over 30 inches and the temperature averages from 45°F in January to 83°F in July (fig. 1). Rate of soil formation is influenced by the effectiveness of the rainfall as indicated by the ratio of rainfall to evaporation (Jenny, 1941). The map area lies within the maximum soil construction belt (Keller, 1957, p. 90), which occurs in a band between the 60 and 100 ratio (rainfall/evaporation x 100).

The regional climatic influence on soil development is relatively uniform because of the small size of the map area. However, as previously mentioned, topography can change the effective local climate. High runoff on steep slopes creates an arid climate, or less runoff and increased seepage on flatter, low-lying areas create, in effect, more humid conditions.

ORGANIC FACTOR

Introduction of organic matter into the soil-forming process initiates the constructional phase of soil development. The organic factor greatly affects the differentiation of the *A* horizon from the underlying layers (Thompson, 1952, p. 77).

The organic factor, while controlled by the rate of soil formation and soil-moisture conditions, is also extremely dependent upon parent material.

The elements available for plant and animal growth are supplied by air, water and parent material. Air varies only slightly in composition from place to place, but parent material (and consequently, ground water) can vary widely over short distances. Topography and micro-climate, which also depend greatly upon parent material, largely determine rate of soil development and accumulation, and eventually the thickness and zonation of the soil. This combination of factors, therefore, controls the plant community.

Maximum root activity of plants, especially grasses, and maximum clay formation normally occur from 2 to 10 inches below the soil surface. This is probably due to the fact that this zone is subject to more constant environmental conditions and increased chemical activity due to decomposition of organic matter (Barshad, 1959, pp. 129-130). Clay formation in soil is reported to be more pronounced under grass-type vegetation than tree-type vegetation because of the fine fibrous root system of grasses (*idem*, p. 120).

Large amounts of metallic cations and silica are returned to the *A* horizon of the soil as plant residues. The roots of plants exchange hydrogen ions for other cations, which are adsorbed on the clay, resulting in a supply of hydrogen to decompose the parent material (Keller, 1957, p. 30).

Many lower forms of life such as algae, fungi, actinomyces, both aerobic and anaerobic bacteria, and protozoans are important in soil development. Agriculturally, the most important macro-organism in the soil is probably the earthworm, which provides improved conditions for plant growth (Goerdel, 1962).

The end-product of decomposed organic matter (humus) contains many elements and compounds originally present in the soil. In addition, many new organic compounds, formed during growth and decomposition, are also present. Some of these important substances in humus are carbohydrate, lignin, and proteins (Teuscher and Adler, 1960, p. 28).

The Flat Top Ranch is located in the tall grass prairie vegetation belt. Natural vegetation and conservation treatment of the various soils of the area are summarized in Appendix II and III. Tall grasses predominate on deep soils such as San Saba, Denton, Catalpa and Krum series; midgrasses and short grasses (grasses with shallow root development) are more important on shallow Denton, Tarrant, and Brackett series soils (Goerdel, 1962).

TIME

In development of soil, time is a relative factor which is often used in reference to soil maturity. However, in a given region soil develops most rapidly on relatively porous parent material, which is high in insoluble content and nutrients. In addition, soil development is more rapid on less resistent parent material which is exposed on gentle slopes. Parent material exhibiting these properties will display a mature soil in much less time than parent material possessing opposite characteristics.

Therefore, maturity of soil cannot be discussed entirely as a product of time, but must be considered a product of a specific parent material upon which soil-forming processes, largely parent material controlled, have acted for a given amount of time.

Parent material, by control over the topography and local micro-climatic variations, will have a profound influence on the degree of maturity of any soil in this area in a given amount of time. Thus, old soils and mature soils are not necessarily synonymous.

FLAT TOP RANCH SOILS

The variety of soils developed on Flat Top Ranch is almost exclusively the product of parent material acted upon by a uniform regional climatic factor. Soils of the area may be described by accepted soil classification terms, but the most significant feature of soil development is the relationship of a given soil series to a given bedrock composition.

The Edwards limestone is characterized by mature, non-calcareous, medium to shallow soils of the Crawford series. A considerable part of this soil series probably developed from the overlying Kiamichi shale.

Light-colored, poorly developed, calcareous lithosols of the Brackett series develop from Comanche Peak limestone parent material on slopes normally steeper than 5 percent.

The Walnut clay outcrop is characterized by a variety of soils, which develop on the varied rock types within the formation. Moderate to deep soils of the Denton and San Saba series develop on gently sloping areas underlain by clay beds. Shallow phase soils of the Tarrant series commonly develop on marly limestone and limestone beds of the Walnut formation.

The Windthorst, Stephenville, and Nimrod series typify soil development on the Paluxy sand. Distribution of these soils is controlled by topography; Windthorst soils commonly occur on gentle slopes, Stephenville soils on steeper slopes, and Nimrod soils on flat-lying areas.

Alluvial soils in this area are the Catalpa, Krum, and Lewisville series which are formed primarily from parent material eroded from calcareous prairie soils in the area.

The relationship between a given soil series and a given bedrock composition (parent material) can be translated into agricultural economics. The maximum grass yield to be expected from areas of Walnut clay outcrop (San Saba and Denton series soils) in the Flat Top Ranch climatic zone is 7,000 pounds of dry forage per acre per year, while soils developed on the adjacent Paluxy sand (Windthorst and Stephenville series soils) may be expected to yield a maximum of 5,000 pounds of dry forage per acre per year.

In terms of pounds of feeder cattle per section, Walnut clay soils are capable of yielding approximately 40 percent more beef per section than Paluxy sand soils.

The significance of this relationship between soils and bedrock is that estimates of potential yield of a region may perhaps be better determined by consideration of the geology when geology and soil relationships are understood.

WATER CONSERVATION

One of the most spectacular aspects of Flat Top Ranch is the success of the water conservation program. This success is directly attributed to the nature and sequence of outcropping geological formations. The stratigraphic position of the permeable Paluxy sand between the less permeable Walnut clay and Glen Rose limestone is the critical geological factor.

The water conservation program depends upon the interrelationship of surface and subsurface conservation practices.

SURFACE WATER

Flat Top Ranch lies within the North Bosque River drainage basin which joins the Brazos River system at Waco. The area is drained by East Bosque Creek, Rough Creek, Mustang Creek, Flag Branch, Tough Branch and many unnamed tributaries (Pl. I).

Within the map area the major streams have cut valleys into Paluxy sand. Periods of stream flow have been extended due to the bank storage capacity of the sand formation. Stream flow is also sustained by water-spreading practices along valleys by stream diversion, and by grassland development in divide areas. Maximum runoff prevention by thick grass cover facilitates bank storage, since the amount of moisture available for infiltration into the aquifer is much greater than in areas of sparse vegetation. Vegetation on Flat Top Ranch effectively prevents destructive runoff even after heavy rainfall.

Lakes and ponds, commonly in areas of Paluxy outcrop, are major factors in surface water conservation. Surface storage accelerates the rate of bank storage infiltration, thus increasing storage volume and consequently the period of discharge. This bank storage program has converted all major drainage from intermittent to perennial streams. Water spreading techniques, based upon elevating surface water by dams, is a significant irrigation method in alluvial bottomland.

GROUND WATER

In the Flat Top Ranch area the principal aquifers are the Paluxy sand (Fredericksburg group) and the basal sands (Trinity group) of Cretaceous age. The basal Trinity sands are the principal subsurface aquifers penetrated by deep wells. The Paluxy sand is a shallow aquifer subject to natural recharge and discharge where it crops out in this region.

The location of the Paluxy sand outcrop is the most significant factor in the success of the conservation program. The entire surface storage system is developed in the highly permeable Paluxy sand, so that maximum underground (bank) storage is possible. Had the surface storage system been located on geological formations stratigraphically above or below the Paluxy, the effectiveness of the conservation program would have been greatly reduced.

Water wells penetrate the basal sands in this area at a depth of 425 to 650 feet, depending upon well site elevation. Wells penetrating the basal sands have a greater production capacity than wells penetrating the Paluxy sand; however, the quality of water from basal sand wells is reported to be poorer than water from Paluxy wells. Henningsen (1962) discussed the regional chemical variations in the water from the basal sands of central Texas, including the area of this study.

The effectiveness of bank storage and subirrigation in areas adjacent to streams is directly related to bank storage capacity of the Paluxy sand. Geologic factors

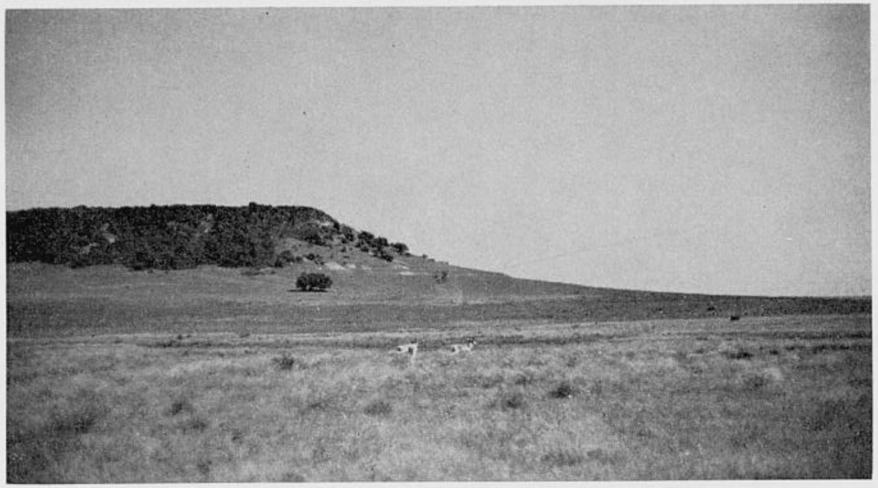

Fig. A. Typical Lampasas Cut Plain topography, Flat Top Mountain. View looking south.

Fig. B. Alluvial covered bottomland along East Bosque Creek, approximately 1.5 miles north of Flat Top Mountain. View looking east.

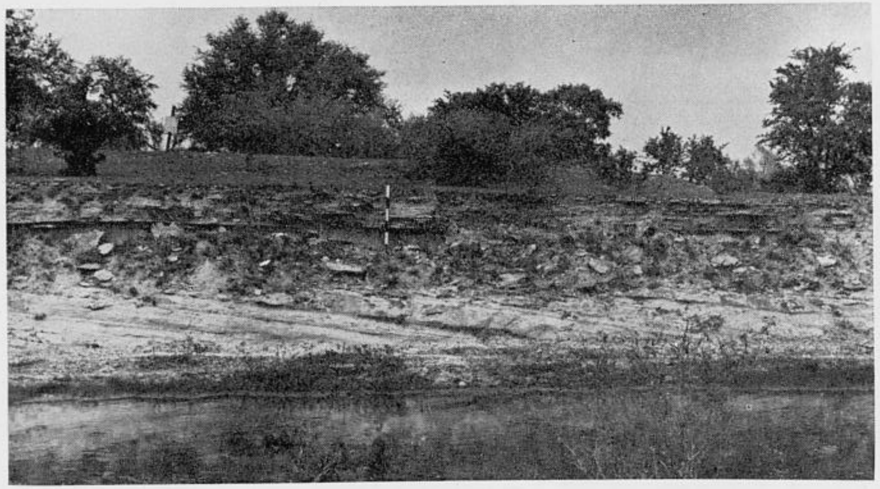

Fig. C. Cross-bedded Paluxy sand beneath Walnut clay, House Lake spillway. View looking north.

Fig. D. Catalpa series soil in East Bosque Creek valley with Krum series soil covering slope in foreground. View looking north.

Plate IV. Outcrop, physiographic and soil features, Fredericksburg group, Flat Top Ranch.

which control the bank storage capacity of this formation include permeability, effective porosity, thickness, areal extent and topographic position of the Paluxy formation.

Lithologic variations within the Paluxy formation produce local variations in the effective bank storage capacity. Friable "packsands" and well sorted, cross-laminated channel sands probably display maximum permeability. Although no quantitative data are available, the highly permeable nature of the Paluxy sand suggests that effective subirrigation through bank storage occurs appreciable distances from stream channels.

The low permeability of Walnut clay and alluvial deposits limits bank storage capacity in these geologic units.

The success of the Flat Top Ranch water conservation program may be best appraised during excessively dry years. In July, 1956, after 6 years of severe drought, East Bosque Creek entered the ranch dry (Pl. I) but flowed continuously where it passed out of the ranch. Construction of dams and control of runoff through intelligent grass management are primary factors responsible for changing the major drainage from intermittent to perennial streams. Areas of similar geology adjacent to the ranch, where such conservation practices have not been undertaken, are without perennial streams.

CONCLUSIONS

(1) The geology (parent material) is the most important factor in soil development in this area. The formations, which crop out in the Flat Top Ranch area, are each characterized by particular soils whose genesis is closely controlled by parent material. Sandy soils develop from Paluxy sand, and clay and clay loam soils develop from limestone, marl, and clay beds in the Edwards, Comanche Peak, Walnut and Glen Rose formations. Alluvial soils are developed on parent material derived from calcareous prairie soils in the area.

(2) Topography, which is controlled by geology, causes local micro-climatic variations which influence soil development. Steep, well-drained slopes of the Comanche Peak outcrop display arid conditions, while flat, poorly drained Walnut clay outcrops exhibit local humid conditions.

(3) Regional climatic conditions determine only in a general manner the weathering rate of various rock units. The dominant factor controlling the weathering rate is lithologic variation in the local stratigraphic sequence.

(4) The permeable Paluxy sand is cut by most streams on the ranch. Construction of surface reservoirs on Flat Top Ranch, therefore, allows constant recharge of the Paluxy sand, which results in subirrigation adjacent to streams. The effectiveness of subirrigation is directly related to bank storage capacity of the outcropping Paluxy formation.

(5) Bank storage efficiency or capacity depends upon the volume and rate of infiltration into the aquifer. Infiltration is controlled by character of the aquifer, position of the aquifer relative to surface reservoirs, surface spreading of water, and runoff control.

(6) Development of ground-water storage in the highly permeable Paluxy sand is perhaps the most significant factor in the success of the conservation program. If other formations of the upper Trinity or Fredericksburg groups cropped out along the stream system of the ranch, underground storage would be greatly reduced and success of the conservation program would be less spectacular.

(7) The conservation program at Flat Top Ranch is ideally suited to the geology of the area. The success of the program is principally related to the bedrock. The program would have to be modified to fit different geologic conditions.

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APPENDIX I

DESCRIPTION OF SOIL SERIES, FLAT TOP RANCH

SANDY PARENT MATERIALS

Windthorst Series

The Windthorst series include red and yellow sandy soils developed on sandy clay parent materials under grass and scattered post oak cover. Subsoil is less permeable and friable than subsoil of Stephenville series.

Windthorst fine sandy loam

A 0-8"	Brown fine sandy loam; neutral; changes abruptly into next horizon.
B 8-24"	Dark reddish brown sandy clay; neutral to slightly acidic; clay is blocky, firm, sticky and stiff; grades into next horizon.
24-36"	Dark red sandy clay with properties similar to above.
C 36"+	Parent materials variable.

Stephenville Series

The Stephenville series include soils with friable sandy clay loam and sandy clay subsoils.

Stephenville fine sandy loam

A 0-8"	Brown fine sandy loam; neutral to slightly acidic.
B 8-22"	Dark red sandy clay; medium blocky; friable; plastic wet and hard dry; slightly acidic; changes gradually into next horizon.
22-40"	Red sandy clay loam; friable; slightly acidic; grades into next horizon.
C 40"+	Yellowish-red sandy loam; laminated; slightly acidic.

Nimrod Series

The Nimrod series include light-colored sands with mottled slightly permeable subsoils.

Nimrod loamy fine sand

A 0-25"	Pale brown fine sand; slightly acidic; abrupt change into next horizon.
B 25-40"	Mottled yellow and light gray sandy clay; massive; stiff and slightly permeable; moderately acidic.
C 40"+	Non-calcareous sandy parent materials.

Other Soils

Other soils occur within map area but were included with the series described above because of small areal extent, difficulty in delineating correct soil boundary, and lack of soil survey information.

Soils of the Harbin series are calcareous equivalents of the Stephenville series and are included with the Stephenville soils. Milam series soils are mapped along southern edge of map area near the North Bosque River. These are terrace soils resulting from Paluxy sand overwash covering calcareous terrace deposits of the Bosque River. Because of difficulty in making proper delineations, these soils are included with the Stephenville soils.

Terrace soils of Travis series are developed under similar conditions to the Milam series and are included with Windthorst soils.

LIMESTONE, MARL, AND CLAY PARENT MATERIALS

Brackett Series

The Brackett series include light-colored calcareous lithosols formed on chalky limestone and marl. This soil commonly occurs on slopes steeper than 5 percent.

Brackett clay loam

A 0-8"	Gray clay loam; granular; calcareous; contains small fragments of limestone; grades into next horizon.
C 8-36"	Weathered clay loam material; light gray; contains large limestone fragments; rests on less weathered bedrock.
36"+	Partially weathered nodular limestone.

Catalpa Series

Include grayish brown calcareous alluvial soils of streams which drain calcareous prairie soils.

Catalpa clay loam

0-24"	Dark grayish brown clay loam; friable; crumbly; calcareous; grades into next horizon.
24-60"+	Grayish brown calcareous clay loam.

Crawford Series

Non-calcareous medium to shallow soils which have developed on flat, well-drained areas of hard limestone. Represents mature soils found on the Edwards limestone.

Crawford shallow stony clay

A 0-6"	Dark reddish brown clay; granular; sticky and plastic wet and hard dry; non-calcareous and neutral.
B 6-15"	Dark reddish brown clay; medium blocky; sticky and plastic wet; non-calcareous and neutral to slightly acidic. Both horizons contain limestone fragments up to 8 inches in diameter.
15"+	Hard crystalline limestone with clay filled fissures.

Denton Series

Calcareous granular soils of medium depth developed on gently to moderately sloping areas. Occur in association with San Saba soils.

Denton clay

A 0-8"	Dark brown clay; weakly granular; calcareous; grades into next horizon.
B 8-36"	Brown clay; moderately blocky; calcareous.
C 36"+	Partly weathered parent material.

Denton clay, shallow phase

Similar to regular Denton clay except for depth, which ranges from 15 to 24 inches over broken limestone.

Krum Series

The Krum series include dark grayish-brown calcareous soils developed from slope alluvium washed from higher slopes of Tarrant, Denton and other similar soils.

Krum clay

0-10"	Dark grayish brown clay; granular and friable; strongly calcareous.
10-24"	Grayish brown clay; granular, crumbly, and friable; strongly calcareous.
24-48"	Brown clay with similar properties.
48"+	Material varies commonly into sands of the Paluxy formation. Most of the Krum mapped in the study area has formed on the Paluxy valley slopes from materials washed down from overlying Walnut soils.

This map unit contains soil of the Stephenville series within the map area.

Lewisville Series

The Lewisville series include well-drained dark brown granular soils developed on higher (older) calcareous alluvial and terrace deposits.

0-10"	Dark brown clay; granular; crumbly and friable; strongly calcareous.
10-24"	Brown clay similar to above.
24-48"	Light brown clay or silty clay; granular and friable; contains soft calcium carbonate concretions.
48"	Light colored alluvial materials and gravels.

San Saba Series

Dark gray prairie soils developed from limestone and marl in flat, poorly-drained areas. Occur in association with Denton soils which are better drained.

San Saba clay

A 0-20"	Very dark gray clay; strong, very fine blocky; sticky and plastic wet, hard dry; weakly calcareous; grades into next horizon.
B 20-60"	Dark olive gray clay similar to above.
C 60"+	Partly weathered marl with some accumulation of calcium carbonate.

San Saba clay, shallow phase

Shallow soil 18 to 24 inches deep over hard limestone. Other properties are similar to **A** horizon above.

Tarrant Series

Dark colored lithosols developed generally on harder limestones than the Brackett soils.

Tarrant clay

A 0-8"	Dark grayish-brown clay; strongly calcareous; granular; friable.
C 8"+	Partly weathered limestone containing small amounts of brown clay in crevices.

Denton-Tarrant Complex

Grouping of stony Denton, small areas of Denton clay, Denton clay shallow phase, and Tarrant soils.

APPENDIX II

CONSERVATION TREATMENT OBJECTIVES BY CAPABILITY CLASSES FOR CROPLAND AND GRASSLAND.

LAND CAPABILITY CLASS	SOILS, SLOPE AND EROSION CONDITIONS	MINIMUM CONSERVATION TREATMENT FOR CROPLAND	CONSERVATION TREATMENT FOR GRASSLAND
I	Level San Saba and Catalpa soils.	Grow deep rooted legumes or perennial grasses one year out of every four years (25%).	Grassland is treated according to range sites as shown in Appendix III. Treatment Objectives 1. Manage grasses for better root development and plant vigor by: (a) Leaving at least one-half of the annual growth. (b) Timely rest periods to maintain vigor of desirable plants. 2. Work toward forage plants adapted to the soil, moisture, and seasonal use. These plants are shown as climax grasses in Appendix III. (*after* Goerdel, 1962)
II	San Saba and Denton soils on 1 to 3% slopes.	Grow deep rooted legumes or perennial grasses one year out of every three years (35%). Complete terrace system with contour cultivation.	
III	Denton and Krum soils on 3 to 5% slopes and the shallow San Saba and Denton soils.	Grow deep rooted legumes or perennial grasses one year out of every two years (50%). Complete terrace system with contour cultivation.	
	Stephenville and Windthorst soils on 3 to 5% slopes.	One-third of land in legumes or grasses. One-third of land in close growing high residue crops. Winter cover crops after peanuts. Complete terrace system with contour cultivation.	
IV	Includes soils with moderate past erosion and steeper than 5% slopes.	Grow deep rooted legumes or perennial grasses four years out of five years (80%). Complete terrace system. Without terrace system, use all of land for close growing crops and legumes or grasses.	
V	(None in map area)		
VI	Denton-Tarrant complex and Tarrant soils with up to 5% slopes.	Unsuitable for cultivation.	
VII	Brackett soils and Denton-Tarrant complex soils with greater than 5% slopes.	Unsuitable for cultivation.	

APPENDIX III

RANGE SITE (AND SOIL) DESCRIPTIONS AND VEGETATION UNDER CLIMAX CONDITIONS WITH VARIOUS DEGREES OF USE AND OVERUSE.*

RANGE SITE	DOMINANT SOILS	GENERAL DESCRIPTION	LAND USE	VEGETATION: GRASSES	VEGETATION: WOODY PLANTS	VEGETATION: FORBS	VEGETATION: WEEDS	ESTIMATED RATES OF PRODUCTION (Lbs. Air Dry Forage/Acre)
Bottomland Site	Catalpa series	Deep clay, clay loam, and fine sandy loam alluvial soils developed from calcareous alluvium.	Climax (Natural) Conditions: (1) Decreasers with use—	Big bluestem, Indiangrass, and switchgrass------65% Little bluestem and Canada wildrye---------------15%	Pecan, elm, and live oak may form a 10 to 15% canopy.			Excellent Condition: 8,000 to 10,000
			(2) Increasers with use—	Hairy and meadow dropseed, sideoats grama, Texas wintergrass, vine mesquite, and white tridens--20%				
			Invaders with overuse:	Threeawns, buffalograss, sand dropseed and tumble windmillgrass.	Mesquite, sumac, and persimmon.		Western ragweed and nightshades.	
Deep Upland Site	San Saba, Denton, Krum, and Lewisville series	Deep clay and clay loam soils of the upland areas with the residual soils predominating. Mostly soils of the Walnut formation.	Climax Conditions: (1) Decreasers with use—	Big bluestem and Indiangrass most important. Switchgrass, Texas bluegrass, little bluestem, and Canada wildrye are less important---------80%	Elm, pecan, and hackberry make up less than 5% canopy along small streams.	Maximillian sunflower, Illinois bundle flower, dotted gayfeather, prairie clovers, compassplant, wild alfalfa, and scurfpeas.		Excellent Condition: 5,000 to 7,000
			(2) Increasers with use—	Sideoats grama, silver bluestem, Texas wintergrass, meadow dropseed, Texas cupgrass, and vine mesquite ----------------------------------20%				
			Invaders with overuse:	Threeawns, buffalograss, and Texas grama.	Mesquite, some juniper and prickly pear.		Western ragweed and broomweed.	Poor Condition: 1,000
Rolling Prairie Site	Denton-Tarrant stony soils	Shallow to very shallow clay and clay loam soils over broken and fractured limestones and marl. Walnut formation.	Climax Conditions: (1) Decreasers with use—	Little bluestem-----------------------------------50% Indiangrass, some big bluestem, and switchgrass--20%	Treeless in eastern part of Grand Prairie, some liveoak in the western part.	Dotted gayfeather, Englemanndaisy, compassplant, wild alfalfa, black samson, prairie clover, and trailing ratany.		Excellent Condition: 4,000 to 5,000
			(2) Increasers with use—	Sideoats grama, tall and hairy grama, hairy dropseed, silver bluestem, rough tridens, buffalograss, and Texas wintergrass --------------------------30%				
			Invaders with overuse:	Hairy tridens, red and Texas grama, fall witchgrass, and threeawns.	Mesquite, prickly pear, and flameleaf sumac.		Gray goldaster, queensdelight, and western ragweed.	Poor Condition: 500
Redland Site	Crawford series	Moderately deep neutral to slightly acidic, stony soils on the Edwards limestone.	Climax Conditions: (1) Decreasers with use—	Little bluestem (55%) and Indiangrass and big bluestem (20%) ----------------------------------75%	Live oak, or post oak, or Bigelow oak (shinnery) may make up 10 to 15% canopy.	Black samson, bush sunflower, perennial legumes, and Mexican sagewort.		Excellent Condition: 4,500 to 6,000
			(2) Increasers with use—	Sideoats grama, hairy dropseed, silver bluestem, Texas wintergrass, buffalo grass, and curlymesquite--25%				
			Invaders with overuse:	Annual grasses, threeawn, Texas and red grama, and hairy tridens.	Agarita, mesquite, and catclaw.		Western ragweed and others.	Poor Condition: 1,000
Adobe Site	Brackett soils	Very shallow light colored calcareous clay loams over marls and soft limestone. The Comanche Peak formation.	Climax Conditions: (1) Decreasers with use—	Little bluestem (50%) and hairy dropseed, sideoats grama, and tall grama (15%)--------------65%	Scattered clumps of Texas oak (Spanish oak).	Wild alfalfa, big top dalea, white milkroot, and trailing ratany.		Excellent Condition: 1,500 to 2,500
			(2) Increasers with use—	Hairy grama, Wrights and purple threeawn, and silver bluestem ------------------------------------35%				
			Invaders with overuse:	Hairy tridens, Texas grama, and red grama.	Juniper may dominate this site.		Queensdelight	Poor Condition: 500
Sandy Loam Site	Windthorst, Stephenville, and other similar soils	Deep sandy loam soils with neutral to slightly acid red sandy clay subsoils developed on the Paluxy formation.	Climax Conditions: (1) Decreasers with use—	Little bluestem (50%) and big bluestem, Indiangrass, switchgrass, and sand lovegrass (25%)---------75%	Post oak and blackjack savannah.	Perennial lespedeza, scurfpea, and yellow neptunia.		Excellent Condition: 4,000 to 5,000
			(2) Increasers with use—	Hairy dropseed, sideoats grama, silver bluestem, hairy grama, and Scribner panicum-----------------25%				
			Invaders with overuse:	Threeawns, sand dropseed, red and gummy lovegrass, and hooded windmillgrass.	The oaks may increase and dominate the site.		Silverleaf nightshade and western ragweed.	

*Information for this appendix was developed from Range Site Descriptive Technical Guides for Area 9, USDA, Soil Conservation Service, Stephenville, Texas. (*after* Goerdel, 1962)

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5. Layman's guide to the geology of central Texas, 1959. Out of print.
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7. One hundred million years in McLennan County, 1960. Out of print.
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10. Popular geology of central Texas, Bosque County, 1961. $1.00 per copy.
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