Mineral Resources of University Lands,
Exclusive of Oil and Gas

BUREAU OF ECONOMIC GEOLOGY
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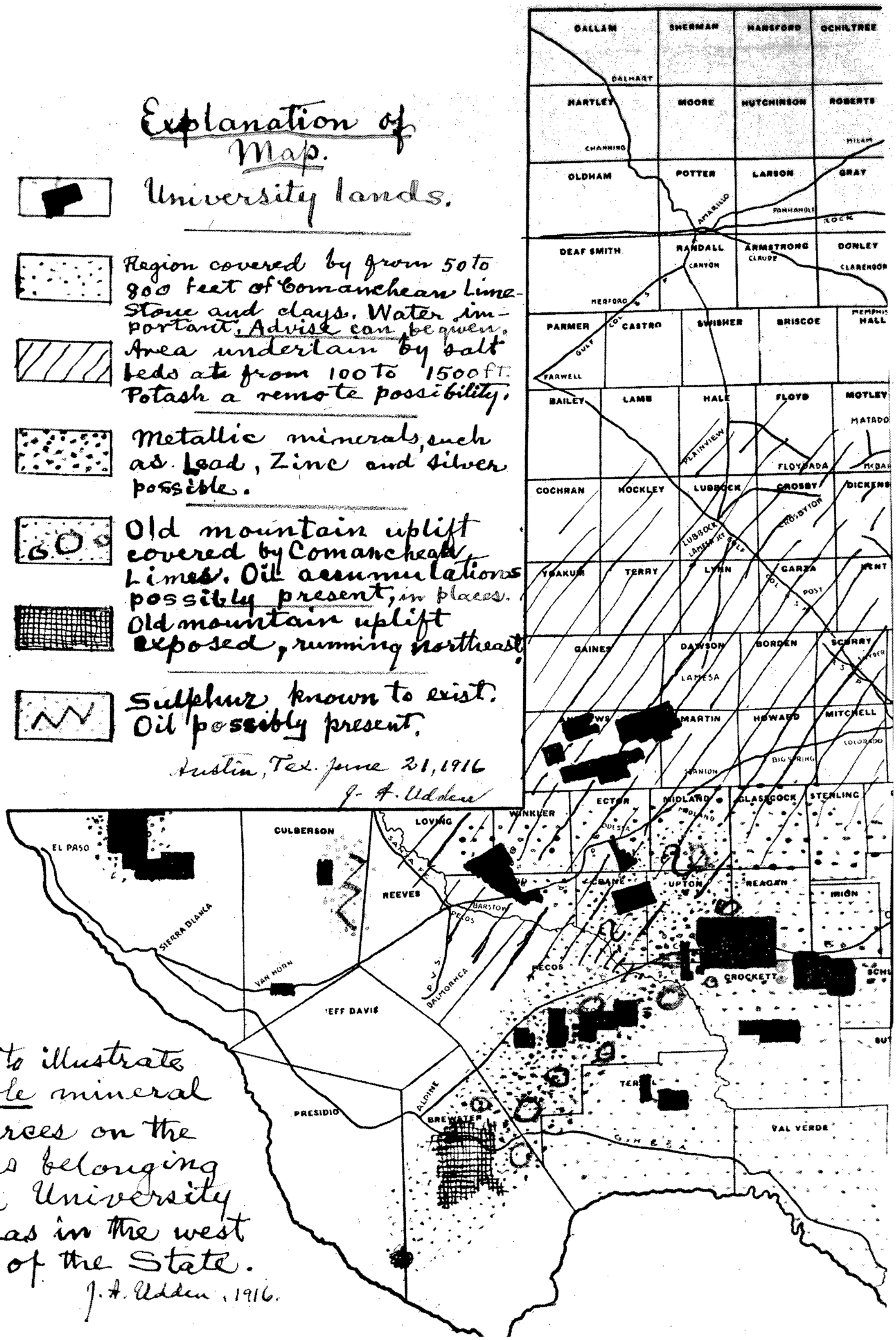


Map to illustrate *possible* mineral resources on the lands belonging to the University of Texas in the west part of the State.

J. A. Udden, 1916.

MINERAL RESOURCES OF UNIVERSITY LANDS, EXCLUSIVE OF OIL AND GAS

Prepared by the Staff of
the Bureau of Economic Geology
The University of Texas at Austin

INTRODUCTION

SCOPE AND METHODS OF INVESTIGATION

This report describes and evaluates mineral resources, other than oil and gas, occurring on or beneath lands belonging to The University of Texas. The data utilized were derived from geologic mapping, field examination and sampling, laboratory analysis of samples, and compilation of available pertinent literature on the geology and mineral resources of University Lands and adjacent areas. The results of this study are presented in maps, sections, tables, and descriptive text that stress characteristics important in determining industrial or other economic use of the mineral resources.

For convenience in mapping and description, the University Lands (fig. 1) were divided into six areas or map areas, each named for a nearby town, and geologic maps at a scale of 1:125,000 were prepared for each area (Pls. I-VI). The geology of each area is described separately in the first part of the report. In addition to these maps, one set of detailed geologic maps at a scale of 1:24,000, on Edgar Tobin Regional Survey Maps with land ownership boundaries, has been submitted to the Office of Investments, Trusts, and Lands of The University. All mapping was done on aerial photographs at scales of 1:24,000 and 1:70,000; the photographs are on file at the Bureau of Economic Geology and are available for examination.

Mineral resources are described by commodity

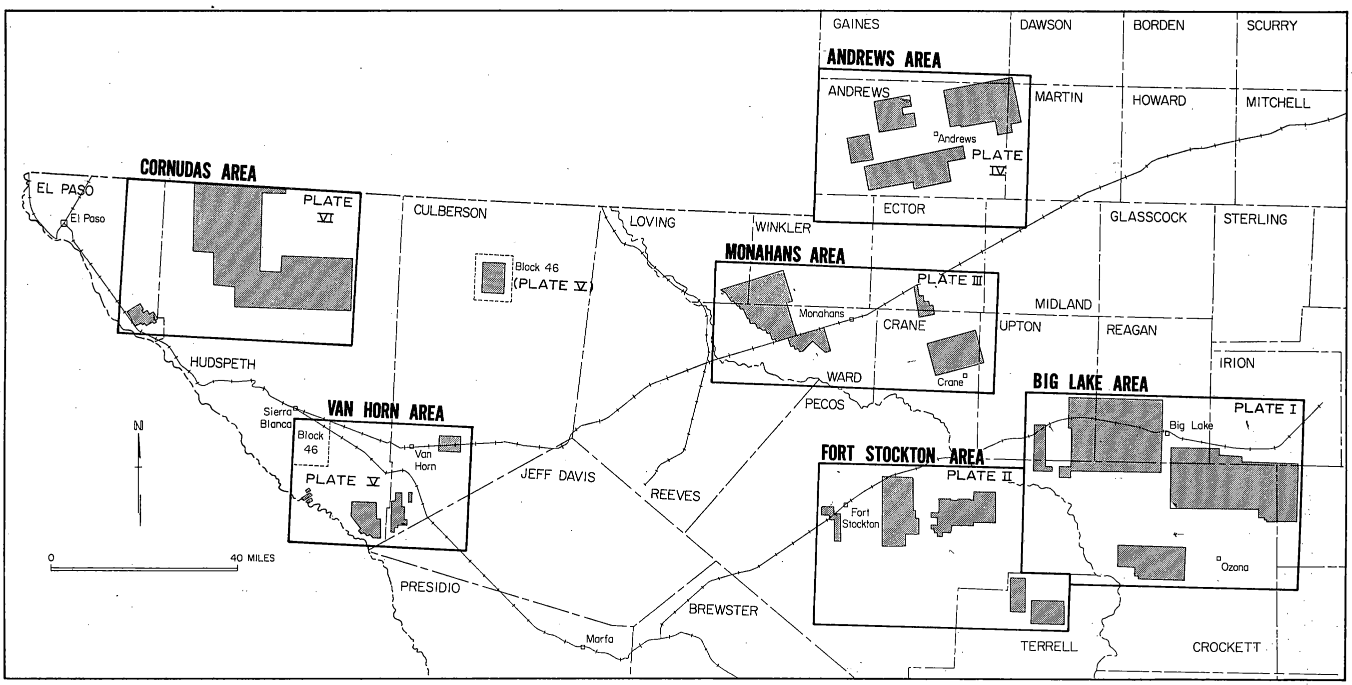


FIG. 1. Map showing location of University Lands.

and keyed to map units; sampling and testing data are presented in the Appendix and are discussed in appropriate resource sections. Special emphasis is placed on the location of these materials in relation to population centers and potential markets, a critical factor in determining the value of most industrial minerals. For this reason, an introductory section on the physical, cultural, and economic setting of the University Lands area is included in this report.

This project was carried out by several members of the Bureau staff; those involved and their responsibilities are listed below.

C. G. Groat--Project coordination and compilation of the report. Geologic mapping and sample collection in the Van Horn and Cornudas areas. Report sections: Introduction, Van Horn and Cornudas areas, ground water, sulfur, metals and miscellaneous nonmetals, and summary and conclusions.

P. U. Rodda--Report editing. Geologic mapping and sample collection in the Big Lake and Fort Stockton areas. Report sections: Big Lake and Fort Stockton areas and industrial carbonates.

L. E. Garner--Geologic mapping and sample collection in Monahans and Andrews areas. Report sections: Monahans and Andrews areas, crushed stone, and industrial sands.

W. R. Stearns--Report sections: salt and potash. Assisted by Carolyn Leach.

L. F. Brown, Jr.--Report sections: gypsum and clays.

Testing and analysis of rocks and minerals were performed in the Bureau of Economic Geology's Mineral Studies Laboratory, J. T. Etheredge, Chemist; D. A. Schofield, Chemist-in-Charge. Illustrations were prepared under the direction of J. W. Macon. Josephine Casey and Elizabeth Moore edited and typed the manuscript.

AREA INCLUDED

All major blocks of University Lands in the western part of the State are included in this report (fig. 1). Not considered are McDonald Observatory land and small parcels of land given or willed to The University for special purposes. Lands of the Cotton Trust, located in Culberson and Hudspeth counties, are included in this report, although they are not a part of the permanent University Lands. Although detailed geologic and economic considerations are limited to University Lands, the distribution of mineral industries in surrounding areas is discussed to provide a framework for resource evaluation of the Lands.

PHYSIOGRAPHY

Most of the University Lands area is characterized by moderate to high relief provided by canyons and basins bounded by steep slopes. Rock units are readily available for sampling and utilization, but areas of high relief pose transportation problems. The Big Lake, Cornudas, and Fort Stockton areas are characterized by broad uplands and mesas separated by canyons cut into thick sequences of limestone. Relief in the Van Horn area is provided by high mountain blocks adjacent to broad, alluvium-filled valleys and basins.

The Andrews and Monahans areas are relatively flat, featureless terranes characterized by sparse vegetation and low relief. Rock outcrops are few and alluvium mantles most of the region. Figure 2 shows the availability of topographic maps for the University Lands area.

Grazing and pasture development have altered the natural patterns of vegetation on University Lands. The plateaus of the Big Lake area (Pl. I) have oaks, cedar, and mesquite in the uplands in the eastern part grading to desert shrubs in the Fort Stockton region. Short grasses are also present but are much more abundant to the east. The Andrews and Monahans areas are characterized by sparse vegetation composed of short grasses, juniper, mesquite, dwarf oak, and yucca. Desert vegetation dominates the western University Lands area; creosote bush or greasewood is widespread, yucca and cactus are common, short grasses and bunch grasses are sparse.

Uplands throughout University Lands are stony and have thin soils over broad areas. Where upland areas support thicker soils, such are generally dark calcareous clays and clay loams with some sandy loams. Calcareous subsoils and thick caliche are common. Bottomlands have thicker soils that are generally dark brown to reddish-brown silt loams to clayey alluvial soils. Most soils are calcareous and some, especially in the basins in the far western areas, are saline. Figure 3 indicates the availability of soil maps for the University Lands area.

CLIMATE

University Lands are hot and dry most of the year. The average annual temperature ranges from 67°F in the Big Lake area to 60° near Cornudas (fig. 4). Summers are hot and marked by thunderstorms which produce intense rains over local areas. The first frost occurs in early November, the last in late March. The growing season or frost-free period is about 220 to 250 days.

University Lands average less than 20 inches of rain per year; amounts range from nearly 20 inches

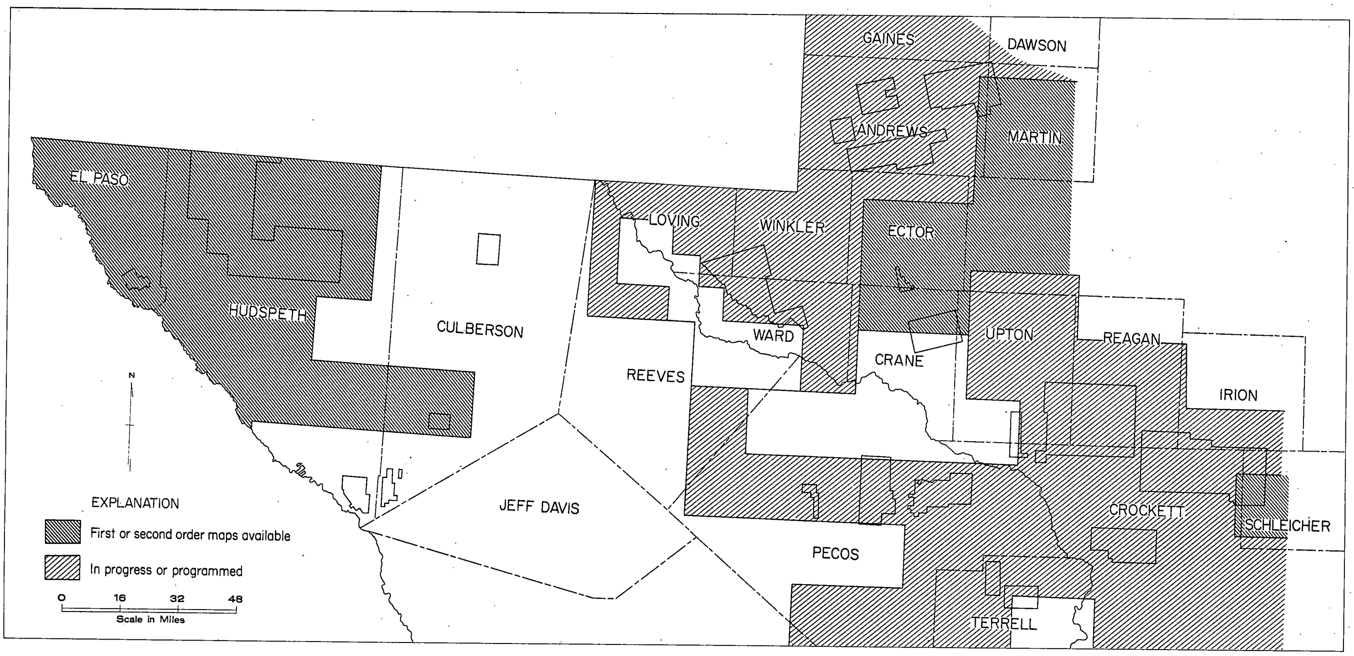


FIG. 2. Status of topographic mapping in University Lands area.

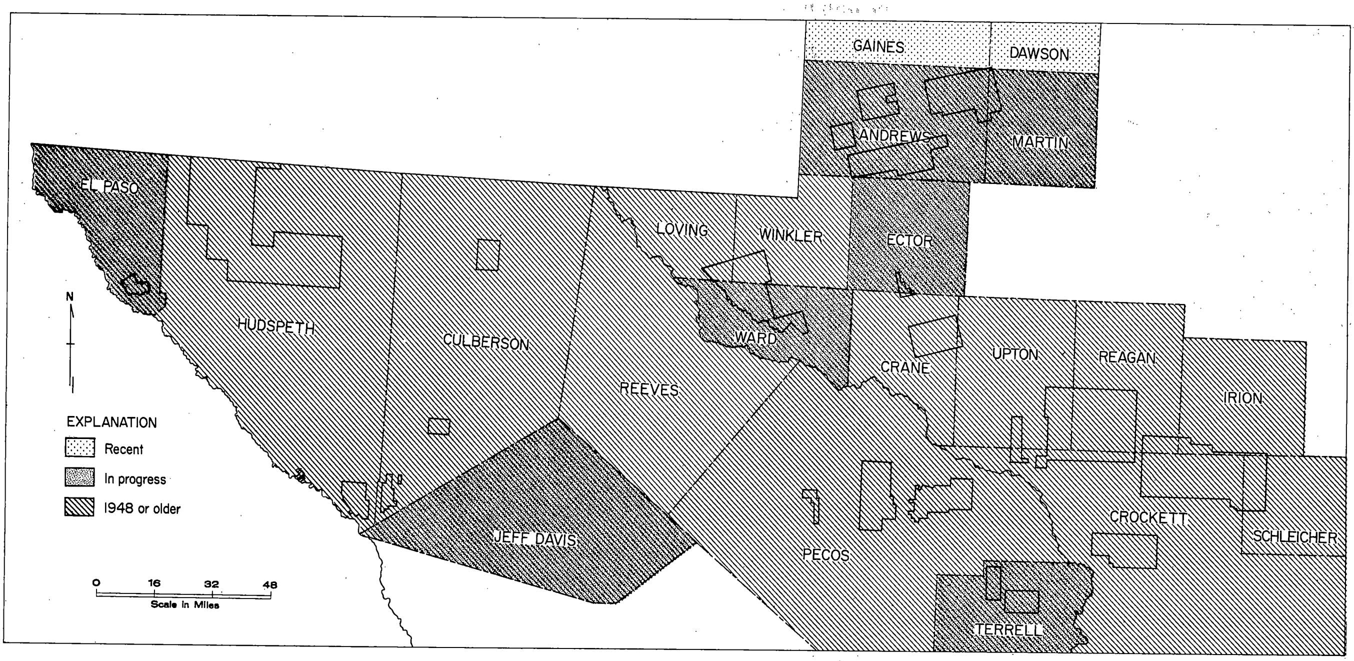


FIG. 3. Soil survey mapping in West Texas by U. S. Soil Conservation Service.

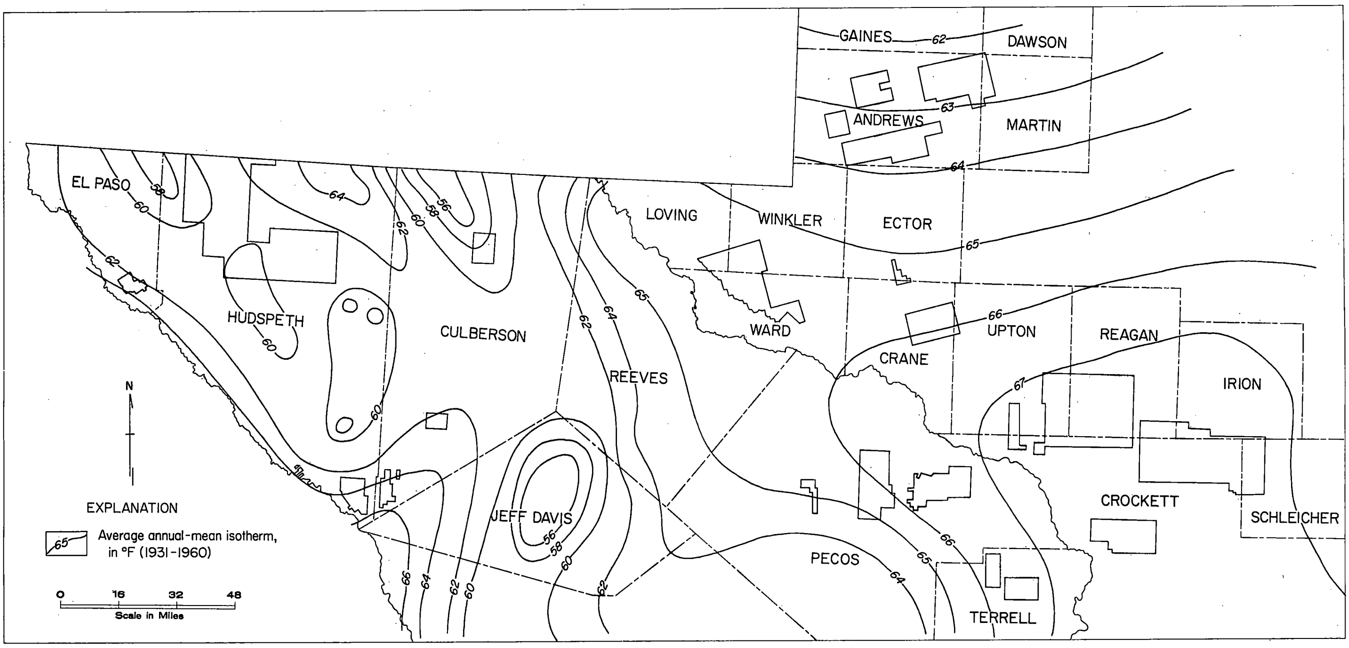


FIG. 4. Average annual mean free-air temperature, University Lands area.

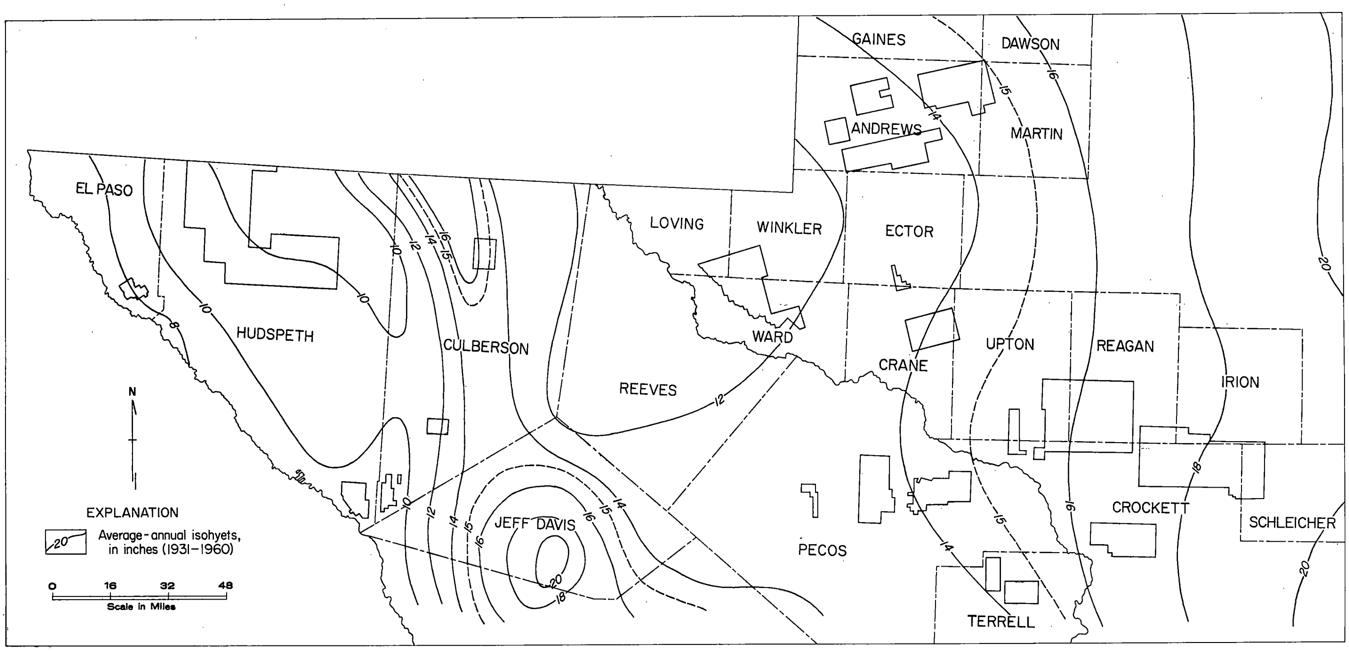


FIG. 5. Average annual precipitation, University Lands area.

in the eastern areas to less than 10 inches in the westernmost regions (fig. 5). This low precipitation, combined with evaporation rates that far exceed precipitation, makes irrigation a necessity for farming. The sparse vegetation and generally intense rainfall favor high runoffs; thus little of the precipitation replenishes diminishing ground-water supplies.

ECONOMIC SETTING AND RESOURCES

The economy of the vast area in West Texas that includes University Lands is dominated by oil and gas. The exploration for petroleum and its production are magnets that have drawn more people into the area than would be there if the other significant economic factor, agriculture, were the only industry. The dramatic shift in population patterns from rural to urban that has occurred during the past two decades has been counterbalanced in West Texas by an influx of people to supply the demands of an expanding oil and gas industry.

Table 1 summarizes present economic patterns in the counties in which University Lands are situated. With the exception of El Paso and Hudspeth counties, where there is no petroleum production, oil and gas account for nearly all of the income from mineral resources, and most of the manufacturing value is related in some way to petroleum products. Even with El Paso and Hudspeth counties included, oil and gas provide approximately 98 percent of the mineral value of counties having University Lands. The remainder is accounted for by cement, sand and gravel, crushed stone, gypsum, sulfur (Pecos County), and talc (Hudspeth County).

Farm income accounts for 6 percent of the total value of mineral, manufacturing, and agricultural recources. Livestock grazing utilizes most of the land in West Texas; crops are raised in more limited areas where ground water is available for irrigation. Income from crops is most significant in Pecos and El Paso counties. Manufacturing provides 15 percent of the total; much of this is the manufacture of petroleum liquids and other products. Mineral resources account for the remaining 79 percent of the total, 98 percent of which is attributable to oil and gas.

Human resources are as available as the opportunities to utilize them. The population of the area is well adjusted to the local economy and has increased as the demands for more manpower have been created by the petroleum industry and auxiliary businesses. Any demand for a larger labor force caused by the development of a new resource would be easily satisfied.

Transportation facilities have been well developed to satisfy the needs of the petroleum industry. Good roads and major rail facilities are available. Energy resources required by large-scale manufacturing are obvious; the great stores of oil and gas would be more than adequate to supply any needs imposed by industrial expansion.

TABLE 1. *Economic data for University Lands area* (from 1970-71 Texas Almanac).

County	1967 Mineral Value*	Manufacturing Value 3-year average 1965-1967	1968** Total Farm Income	Econ. Index 1969-70***	Population 1950	Population 1960	Population Change
COUNTIES WITH UNIVERSITY LANDS							
Andrews	$ 285,795,701	$ 516,000	$ 2,370,000	1.046	5,002	13,450	+
Crane	219,097,510	210,000	686,000	0.684	3,965	4,699	+
Crockett	32,026,047	66,000	5,579,000	0.164	3,981	4,209	+
Culberson	3,748,236	59,000	2,528,000	0.036	1,825	2,794	+
Ector	272,868,409	69,289,000	981,000	1.615	42,102	90,995	+
El Paso	5,589,947	155,724,000	26,662,000	1.653	194,968	314,070	+
Hudspeth	501,123	143,000	6,307,000	0.030	4,298	3,343	-
Irion	3,637,305	8,000	2,679,000	0.026	1,590	1,183	-
Loving	11,272,067	-0-	279,000	0.046	227	226	-
Martin	6,719,446	328,000	14,935,000	0.073	5,541	5,068	-
Pecos	81,960,595	616,000	14,432,000	0.390	9,939	11,957	+
Reagan	45,967,339	78,000	2,373,000	0.157	3,127	3,782	+
Schleicher	14,722,642	151,000	4,590,000	0.076	2,852	2,791	-
Terrell	5,425,048	6,000	2,940,000	0.037	3,189	2,600	+
Upton	69,778,193	346,000	1,249,000	0.298	5,307	6,239	+
Ward	87,318,493	2,945,000	1,562,000	0.379	13,346	14,917	+
Winkler	91,911,783	345,000	431,000	0.409	10,064	13,652	+
Totals	$1,238,339,884	$230,830,000	$90,553,000	7.119	311,323	495,975	+
ADJACENT COUNTIES WITH ECONOMIC TIES TO UNIVERSITY LANDS COUNTIES							
Midland	63,126,264	11,671,000	5,963,000	0.563	25,785	67,717	+
Reeves	12,795,820	1,887,000	21,826,000	0.172	58,929	64,630	+
Tom Green	8,088,094	22,378,000	16,559,000	0.373	11,745	17,644	+
TOTALS: University lands plus adjacent counties	$1,322,350,062	$266,766,000	$134,901,000	8.227	407,782	645,966	+
All counties above minus El Paso County	$1,316,760,115	$111,042,000	$108,239,000	6.574	212,814	331,896	+
University lands minus El Paso County	$1,232,749,937	$ 75,106,000	$ 63,891,000	5.466	116,355	181,905	+

*Includes oil and gas.
**Includes crops, livestock and products, and U. S. Government payments.
***Percent of total State economy.

GEOLOGY

INTRODUCTION

The geology section is organized by map area. A geologic map with columnar section and descriptive geology is presented for each of six map areas: Big Lake, Fort Stockton, Monahans, Andrews, Van Horn, and Cornudas (Pls. I-VI). These areas (fig. 1) were delineated on the basis of distinctiveness of the geology and convenience in presenting the data. Similar rock units may appear on more than one area map, but they are described separately for each map. Discussions of rock units stress characteristics and properties of interest to persons who might utilize the rocks and deposits for industrial or constructional purposes. Units are defined on the basis of their physical properties; formations of different geologic ages that have similar physical properties were mapped as the same unit. The columnar section accompanying each of the geologic maps (Pls. I-VI) includes conventional stratigraphic terminology.

Rock units from each map area were sampled and tested; results are keyed to the map unit and map area. Test results are discussed in the appropriate resource section, and the actual test results are presented in the Appendix.

BIG LAKE AREA

Introduction

University Lands in the Big Lake area (Pl. I) include blocks in Crockett, Irion, Reagan, Schleicher, and Upton counties, an area that encompasses the northwestern part of the Edwards Plateau. The region is slightly to extensively dissected, mostly by tributaries of the Pecos River; the northern part is within the Colorado River basin and is drained by tributaries of the Concho River. In the western part of the area the Pecos drainage has eroded deeply into the limestone bedrock, forming high steep slopes above Live Oak Draw (Block 29), Five Mile Draw (Blocks 14 and 15), and other streams. The more northern and eastern parts are less dissected; the valleys are shallower and slopes generally are less steep. In both areas the bedrock slopes are capped by hard granular limestones; softer limestones form most of the slopes below the cap rocks. Surficial deposits mantle much of the lower slopes, fill the lower parts of the valleys, and cover wide areas on top of the Plateau.

Geologic structure is simple. The strata dip to the southeast about 15 to 30 feet per mile; the oldest rocks exposed in Blocks 14 and 15 in Upton County in the northwest part of the area are below the surface in blocks to the east and south. Minor faults and small folds are present locally on the outcrop but are insignificant.

Stratigraphy

Ten separate rock types, four surficial units and six bedrock units, have been mapped on the 1:24,000-scale geologic maps of University Lands in Crockett, Irion, Reagan, Schleicher, and Upton counties. Each map unit consists predominantly of one rock type or a particular combination of rock types, but each may include small amounts of other rock types. A general summary of the characteristics, distribution, and value is given for each map unit.

On the 1:125,000-scale geologic map of the Big Lake area (Pl. I), map units include (1) surficial deposits, (2) bedrock sands, (3) hard granular limestone, (4) softer nodular limestone, marl, and dolomite, and (5) interbedded hard and soft limestone.

Bedrock units include Lower Cretaceous sands, silts, limestones, and marls. The basal sands and silts are commonly referred to as the Trinity Sands, or Trinity Group. The lower part of the limestone and marl sequence generally has been referred to as the Edwards, or Lower Edwards, Formation (Fredericksburg Group); the upper limestones have been called the Upper Edwards, or Georgetown, Formation and the Buda Formation (Washita Group).

The younger, surficial deposits were derived from the underlying Cretaceous bedrocks.

Rocks in the northern and southern parts of the Big Lake map area are similar, but in the southern blocks the granular cap-rock limestones generally are thicker and the slope-forming units harder and less marly. The rock section thickens to the south; total thickness of exposed bedrock is about 500 feet. The oldest rocks (sands, dolomite, and some limestones) are exposed in the deeply dissected areas in the Pecos River drainage (Blocks 14, 15, and 29); to the east these rocks are below the surface.

SURFICIAL DEPOSITS

The surficial deposits are included in four separate map units that are present in most of the six map areas. These deposits were derived by erosion of the local bedrocks; all surficial units are calcareous and extensively calichified. Surficial deposits have been quarried locally and used for subgrade and base material on secondary roads.

Colluvium.--This unit consists mostly of coarse, angular rubble eroded from the bedrock and moved downslope by slide and creep, forming a thin mantle at the foot of steep bedrock slopes. Thickness ranges from a few inches to several feet. This unit has not been quarried in the Big Lake map area.

Slope wash.--This unit consists mostly of soft (where not calichified), gray to tan, calcareous silt, marginal to upslope colluvial deposits. Fine-grained material was removed selectively by slope wash and deposited on low-angle slopes below the colluvium. Slope-wash deposits commonly have open growths of mesquite, indicating relatively high water content and contrasting with the predominantly greasewood vegetation on the colluvium. Vegetation on slope-wash deposits generally forms characteristic banded patterns on aerial photographs. Included in this map unit are the extensive, calichified, fine- to coarse-grained, surficial deposits developed in place on the sinkhole-dotted upper surface of the alternating limestone unit. Thickness of the slope-wash deposits is estimated to be from a few feet to as much as 20 feet. Calcium carbonate content of a sample of calichified slope-wash silt was 83 percent, and such material has been quarried locally for road material.

Alluvium.--This unit includes thick surficial deposits of calcareous silt, sand, and gravel in stream valleys downslope from colluvium and slope-wash deposits. Alluvium generally is characterized by thick growths of mesquite and other plants, indicating a relatively high water content. Alluvium includes loose unconsolidated material as well as deposits cemented by caliche. Thickness ranges from a few feet to as much as 200 feet in the larger valleys. Calcium carbonate content is similar to that of slope-wash deposits. Alluvium has been quarried locally for road material. Small to large quantities of water are produced from the thick alluvium of the larger valleys.

Lake deposits.--This unit includes generally soft, gray, calcareous sand, silt, and silty clay deposited in the numerous sinkholes that dot the upper surface of the Edwards Plateau. The sinkholes developed by solution of the interbedded limestone unit. Most of these deposits are small, thin, and to 30 feet or more at Big Lake. Calcium carbonate content of a sample of clayey silt from Big Lake was 49 percent. The lake deposits in this area have not been quarried.

BEDROCK UNITS

Sand and silt.--The oldest rocks exposed on University Lands in the Big Lake map area are gray to red-brown and purple sands and silts exposed on lower slopes in Blocks 14 and 15 in Upton County southwest of Rankin. Maroon silty clays occur locally in nearby areas but were not observed on University Lands. Fine- to medium-grained sand and sandstone are the most common rock types. The sands grade upward through impure limy sands and sandy limestones to the overlying limestone units. Maximum exposed thickness of this unit is about 30 feet. The base of this unit is not exposed in the Big Lake map area; total thickness of the unit as determined from wells varies but generally is between 100 and 150 feet. These sands and silts were deposited on an irregular surface eroded in older sands, clays, and limestones. Locally, the harder sands in this unit have been quarried for road material. Weakly cemented sands would be suitable for industrial uses where high iron content and fine grain size are not critical. The sands are a major source of ground water in this area.

Marly limestone and marl.--This unit consists of soft, gray to tan, nodular weathering, very fine-grained marly limestone and soft gray marl. These rocks crop out in many parts of the Big Lake map area, but they are best exposed in the northwest part (Blocks 14 and 15) where they form steep slopes below the resistant granular limestone cap rock. Nodular, marly limestone also is present in this area in the lower slopes immediately above the bedrock sands. The lower marly limestone is about 50 feet thick; the upper marly limestone and marl is about 150 feet thick. The only other outcrops of the lower unit on University Lands are small exposures in lower slopes at the west edge of Block 29 at the east edge of the Pecos Valley. Most of the upper marly limestone and marl section grades to the east and south to harder, more granular, less nodular limestone. At the west edge of the southern area (Block 29) the upper marly limestone section is only about 50 feet thick. In less dissected areas to the east, generally the lower part of the upper marly unit is not exposed. In the northwestern outcrops marl content of the upper unit is about 50 percent; marl generally is not present in University Lands south and east of Blocks 14 and 15. Calcium carbonate content of the marly limestone and marl unit ranges from 50 to 90 percent, depending on marl content; the marly limestones alone generally range from 80 to 90 percent. The nodular, marly limestone has been quarried locally for road material. The marly sections are good natural cement rock.

Nodular fine-grained limestone.--This unit consists mostly of gray to tan, slightly nodular weathering, moderately hard, fine-grained limestone. Compared to the marly limestone this unit is harder, more granular, less marly, and less nodular. Principal outcrops of this limestone unit are in steep slopes below the hard cap rocks in the southern part of the Big Lake map area. The unit is about 150 feet thick and grades northward into marly limestone and marl. Calcium carbonate content of these limestones is generally between 93 and 96 percent. The rock has been quarried locally for road material.

Granular limestone.--This unit consists mostly of hard, dense, fine- to coarse-grained limestones that form the prominent cap rocks of the Edwards Plateau and also less prominent scarps lower in the landscape. In the southern and eastern parts of the Big Lake map area these lower granular limestones contain abundant nodular chert; northwestern outcrops (Upton County) have little chert. The lower granular limestones are about 40 feet thick. The higher, cap-rock limestones are 60 to 120 feet thick, increasing southward. In the southern outcrops this unit consists of a nearly continuous series of granular limestone beds forming a high, sheer bluff. In the northern outcrops the unit consists of two smaller scarp-forming sequences separated by a thin interval of softer, nodular-weathering limestone. The granular limestones are the purest and most durable stone in the Big Lake area. Calcium carbonate content generally exceeds 95 percent; about 40 percent of the samples tested contained more than 97 percent calcium carbonate. This unit has been quarried locally for road material, but the rock is suitable for most industrial uses. In the southern and eastern parts of the area the lower granular limestones (together with the dolomites) are a major aquifer tapped by numerous wells. In the northeastern part of the area water is obtained locally from a perched water table in the upper granular limestones.

Interbedded hard and soft limestone.--This unit consists of interbedded hard, dense, fine- to coarse-grained limestone, and soft, yellowish, nodular-weathering, marly limestone. Individual hard or soft limestone intervals are as much as 15 feet thick but mostly are 2 to 10 feet thick. Maximum thickness of the entire unit ranges from 30 feet in the south to 100 feet in the north. Softer, marly limestones in the lower part of the unit in the north grade southward into hard granular limestones. The unit occupies the highest topographic position and forms the broad flat surface of the Plateau; in the northern part of the area, this surface is marked by numerous sinkholes. Calcium carbonate content of the hard limestones ranges from 94 to 97 percent; that of the soft marly limestone ranges from 86 to 91 percent. The unit has been quarried locally for road material.

Dolomite.--Gray-brown, soft to hard, mostly thin-bedded, fine-grained, porous dolomites and dolomitic limestones crop out in the lower slopes, beneath the lower hard granular limestones in Upton County (Blocks 14 and 15) and Crockett County (Block 29). Thickness of the dolomite unit ranges from 45 to 100 feet; thickness and dolomite content generally decrease northward. The dolomite unit generally contains abundant nodular chert. Magnesium carbonate content ($MgCO_3 + CaCO_3$) ranges from 90 to 97 percent. This unit has not been quarried commercially in the Big Lake map area but could be used for road material. In the southern and eastern parts of the area the dolomites (together with the lower granular limestones) are a major aquifer.

FORT STOCKTON AREA

Introduction

University Lands in the Fort Stockton map area (Pl. II) include blocks in Pecos and Terrell counties. These areas are part of the Stockton Plateau, a western, Trans-Pecos extension of the Edwards Plateau of Central Texas.

The Terrell County blocks (34, 35, 36) are in the heart of the Stockton Plateau, an area deeply dissected by tributaries of the Pecos River. Slopes rise steeply from deep, broad valleys and are capped by sheer bluffs of hard limestone. Softer limestones from the slopes below the cap rock and other hard limestones crop out near the base of the slopes. Surficial deposits mantle much of the lower slopes and fill the lower parts of the valleys.

The Stockton Plateau is bounded on the north by the alluvial valley of the Pecos River. Above Iraan the broad Pecos Valley is mainly in relatively soft sands and clays; long gentle slopes descend to the modern river channel. Below Iraan the Pecos River has cut a steep, relatively narrow canyon in hard limestones. Dissection of the northern margin of the Stockton Plateau has formed isolated mesas and buttes with hard limestone caps and slopes of softer limestone and marl. Other hard limestones, dolomites, and bedrock sands and silts crop out in the lowest part of the topography. Surficial deposits mask much of the lower slopes, cover most of the broad areas between mesas, and fill the stream valleys.

Geologic structure is simple. The strata dip to the southeast about 15 to 30 feet per mile; the oldest rocks exposed in the Pecos County blocks are below the surface in the Terrell County area. Minor faults and folds are present locally. In the Pecos County area (Blocks 16, 24, 25, 26) several large slump blocks of bedrock have moved downslope along fractures that parallel the edge of the Pecos Valley; vertical displacement along these slide blocks is a few feet to several tens of feet.

STRATIGRAPHY

Nine separate rock types, three surficial units and six bedrock units, have been mapped on the 1:24,000-scale geologic maps of University Lands in Pecos and Terrell counties. Each map unit consists predominantly of one rock type, or a particular combination of rock types, but may include small amounts of other rock types. A general summary of the characteristics, distribution, and value is given for each map unit.

On the 1:125,000-scale geologic map of the Fort Stockton area (Pl. II), the map units include (1) surficial deposits, (2) bedrock sands, (3) hard granular limestone, (4) softer nodular limestone, marl, and dolomite, and (5) interbedded hard and soft limestone.

Bedrock units include Lower Cretaceous sands, silts, limestones, and marls. The basal sands and silts are commonly referred to as the Trinity Sands, or Trinity Group. In Terrell County the limestone sequence has been referred to as the Upper Edwards, or Georgetown, Formation, and the Buda Formation (Washita Group). In Pecos County the limestones and marls have been referred to as the Fredericksburg and Washita Groups.

The younger, surficial deposits were derived from the underlying Cretaceous bedrocks.

The rocks in the Pecos and Terrell County blocks are similar, but in the Pecos area slope-forming units below the cap rocks are softer and more marly. Also, older rocks, sands, dolomites, and some limestones exposed in the Pecos area are not exposed in the Terrell County blocks because of the regional southeast dip. The rock section thickens to the southeast; the total thickness of exposed bedrock is about 400 feet in both counties.

SURFICIAL DEPOSITS

The surficial deposits are included in three separate map units that are present in all mapped areas. These deposits were derived by erosion of the local bedrocks; all three units are calcareous and extensively calichified. Surficial deposits have been quarried in the Fort Stockton area and used for subgrade and base material on secondary roads.

Colluvium.--This unit consists mostly of coarse, angular rubble eroded from the bedrock and moved downslope by slide and creep, forming a thin mantle at the foot of bedrock slopes. Thickness ranges from a few inches to several feet. This unit has not been quarried in the Fort Stockton map area.

Slope wash.--This unit consists mostly of soft (where not calichified), gray to tan, calcareous silt marginal to upslope colluvial deposits. Fine-grained material was removed selectively by slope wash and deposited on low-angle slopes below the colluvium. Slope-wash deposits commonly have open growths of mesquite which indicate relatively high water content and contrast with the predominantly greasewood vegetation on the colluvium. Vegetation on slope-wash deposits forms characteristic banded patterns on aerial photographs. Thickness of the slope-wash deposits is estimated to be from a few feet to as much as 20 feet. Calcium carbonate content of a sample of calichified slope-wash silt was 83 percent; such material has been quarried locally for road material.

Alluvium.--This unit includes thick surficial deposits of calcareous silt, sand, and gravel in stream valleys downslope from colluvium and slope-wash deposits. Alluvium generally is characterized by thick growths of mesquite and other plants, indicating a relatively high water content (or shallow water table). Alluvium includes loose unconsolidated material and deposits cemented by caliche. Thickness ranges from a few feet to as much as 200 feet in the larger valleys. Calcium carbonate content is similar to slope-wash deposits. Alluvium has been quarried locally for road material. Small to large quantities of water are produced from the thick alluvium of the larger valleys.

BEDROCK UNITS

Sand, silt, and clay.--The oldest rocks exposed on University Lands in the Fort Stockton map area are gray to red-brown and purple sands and silts exposed on the lower slopes north of University Mesa in Blocks 24, 25, and 26. Maroon silty clays occur locally in nearby areas but were not observed on University Lands. Fine- to medium-grained sand, locally cemented to sandstone, is the most common rock type. The sands grade upward through impure limy sands and sandy limestones to the overlying limestone units. The maximum outcrop thickness of about 60 feet of sand and silt beds is exposed in Block 26 on the north side of East Mesa (also called University Mesa); the base of the unit is not exposed in the Fort Stockton map area. Total thickness of this unit, as determined from wells, varies but is between 100 and 150 feet. These sands, silts, and clays were deposited on an irregular surface eroded in older sands, clays, and limestones. The harder sand units have been quarried locally for road material. Weakly cemented sands would be suitable for industrial uses where iron content and grain size are not critical. In the subsurface the sands are a major aquifer in this area.

Marly limestone and marl.--This unit consists of soft, gray to tan, nodular-weathering, very fine-grained, marly limestone and soft gray marl. These rocks crop out on University Lands in the northern part of the Fort Stockton map area (Blocks 16 to 26) and form shallow to steep slopes below harder cap-rock limestones. This unit is between 100 and 140 feet thick and thins to the south and east by grading to harder, more granular, less nodular limestone. Marl content of the map unit is between 25 and 40 percent, greater in the western blocks. Calcium carbonate content of the unit ranges from about 50 to 90 percent and averages about 70 to 75 percent; lower values are from the more marly sections. The marly limestone has been quarried locally for road material. This unit is a good natural cement rock.

Nodular fine-grained limestone.--This unit consists mostly of gray to tan, slightly nodular-weathering, moderately hard, fine-grained limestone. Compared to the marly limestone this unit is harder, more granular, less marly, and less nodular. Principal outcrops of this unit are in high, steep slopes below the hard cap rocks; minor outcrops occur on lower slopes in the University Mesa area. In the Pecos County blocks this unit is about 120 feet thick; in the Terrell County blocks, it is about 130 feet thick. Calcium carbonate content is generally between 93 and 96 percent. The rock has been quarried locally for road material.

Granular limestone.--This unit consists mostly of hard, dense, fine- to coarse-grained limestones that form the thick prominent cap rocks of the mesas and also less prominent scarps lower in the landscape. In the northeastern part of the Fort Stockton map area (University Blocks 16 to 20) these lower granular limestones contain abundant nodular chert; more westerly outcrops are chert free. The lower granular limestones have a total thickness of about 50 feet. The higher cap-rock limestones have a total thickness of 90 to 130 feet; the thickness increases southward. This unit contains the purest and most durable stone in the Fort Stockton area. Calcium carbonate content of the granular limestones generally exceeds 95 percent; about 40 percent of the samples tested contained more than 97 percent calcium carbonate. The rock is suitable for most industrial uses, and the unit has been quarried for road material. Water may be obtained locally from wells in these granular limestones.

Interbedded hard and soft limestone.--This unit consists of interbedded hard, dense, fine- to coarse-grained limestone and soft, yellowish, nodular-weathering, marly limestone. Individual soft or hard limestone intervals generally are 2 to 10 feet thick. Total thickness of the unit ranges from a few feet in the northern blocks in Pecos County to 60 feet in Terrell County. The interbedded unit forms relatively low-angle slopes on the tops of mesas above the prominent cap rocks. Calcium carbonate content of the hard limestones ranges from 94 to 97 percent; that of the soft marly limestones ranges from 86 to 91 percent. The unit has been quarried locally for road material.

Dolomite.--Gray-brown, soft to hard, mostly thin-bedded, fine-grained, porous dolomites and dolomitic limestones crop out in the lower slopes beneath the lower hard granular limestones in the Bakersfield area (Blocks 16 to 20). Dolomite is more common to the east; laterally equivalent beds in the University Mesa area are not dolomitic. The dolomitic unit does not crop out in the Terrell County blocks. About 20 feet of dolomite and dolomitic limestone crop out in the Bakersfield area (Blocks 16 to 20); the base of the dolomite unit is not exposed. East of the Pecos River, between Iraan and Lancaster Hill, the dolomite unit is 60 to 100 feet thick. The dolomite unit generally contains abundant nodular chert. Magnesium carbonate content ranges from 13 to 37 percent;

total carbonate content ($MgCO_3$ + $CaCO_3$) ranges from 90 to 97 percent. This unit has not been quarried in the Fort Stockton map area but probably could be used for road material.

MONAHANS AREA

Introduction

The Monahans area (Pl. III) is within the generally featureless region that comprises the east side of the broad Pecos Valley. The topography is flat to gently rolling with a gradual southwesterly slope towards the Pecos River. There are very few bedrock outcrops and the overall aspect is of a broad alluvial plain, with scattered mesquite, sage, and greasewood providing a sparse vegetative cover. Dunes and sheets of eolian sand are common features throughout the area.

Stratigraphy

SURFICIAL DEPOSITS

Loose and carbonate-cemented alluvial deposits are the only rocks exposed over large areas in the Monahans area. These sediments, of fluvial and eolian origin, mantle a calichified sandstone that locally contains granule and pebble conglomerate; this sandstone is the oldest rock unit in the region and is exposed locally, but not on University Lands. The sandstone and conglomerate were deposited by the Pecos River, probably during Pliocene or Pleistocene time. The four alluvial units mapped in the Monahans area, sheet sand, dune sand, cover sand, and alluvial-fan deposits, are of Pleistocene and Holocene (Recent) age.

Sheet sand.--Deposits of sheet sand are composed of windblown, tan, medium to very fine quartz sand that locally is weakly cemented by iron oxide. The sheet sand is derived from the underlying cover sand, from which the silt has been winnowed and the sand blown into broad blanket deposits stabilized in places by vegetation. Maximum thickness is approximately 15 feet.

Dune sand.--Dune sand is similar to sheet sand and includes the active dunes and dune fields that have only sparse vegetation. Maximum thickness is 15 feet. Possible industrial uses of these sand deposits are discussed in the section on industrial sands.

Cover sand.--This is the most widespread map unit and consists of silty, grayish-red, fine to medium quartz sand, locally containing caliche nodules and calcium carbonate cement. The silty sand is mainly windblown material with some alluvial deposits. Maximum thickness is approximately 25 feet.

Fan deposits.--This unit is limestone gravel and sand derived from bedrock limestones (Cretaceous) and deposited as coalescing fans from the west-facing scarp of Cretaceous limestone south of Penwell and northeast of Crane. The fan deposits generally are cemented with calcium carbonate and are moderately hard. Maximum thickness is approximately 15 feet.

Surface Mineral Deposits

Surficial deposits of the Monahans area have been quarried at many places and used primarily as aggregate and secondary road-surfacing material. Because outcrops of the surficial units are scarce, these quarry pits were important sampling localities for this study. Sampled excavations are indicated on Plate III, and results of testing are given in the Appendix.

Crushed stone, natural cement rock, cement raw materials, and industrial sands are surface materials of potential commercial interest within the Monahans map area. General specifications and requirements for crushed stone, cement raw materials, and industrial sand are given in the Mineral Resources section of this report.

ANDREWS AREA

Introduction

The Andrews area (Pl. IV) is in the southernmost part of the High Plains. Topography is level to rolling with scattered shallow draws and intermittent lakes. Vegetation consists principally of grasses and mesquite with local areas of shin oak on surficial sands.

Stratigraphy

Rock units exposed within and adjacent to the University Lands in the Andrews map area are bedrock sand, sandstone, and gravel and conglomerate (Dockum Formation and Paluxy Formation), calichified surficial sands, silts, clays, and gravels (Ogallala Formation), lake deposits (Tahoka Formation), and surficial sand (cover sand, sheet sand, and dune sand). Seven rock units, three bedrock and four surficial, are mapped (Pl. IV). Only small exposures of the bedrock units occur in the Andrews map area. The Ogallala Formation crops out in these exposures as well as in the banks of Monument Draw in northeastern Andrews County; it occurs in the shallow subsurface throughout the map area, generally blanketed by sheet sand, cover sand, or dune sand.

SURFICIAL DEPOSITS

Cover sand.--This unit is the oldest, most widespread map unit and consists of silty, grayish-red, fine to medium quartz sand, locally containing caliche nodules and calcium carbonate cement. The silty sand is mainly windblown material with some alluvial deposits overlying calichified sandstone. Maximum thickness is approximately 25 feet. This unit directly overlies the Ogallala Formation in most places.

Sheet sand.--Deposits of sheet sand are composed of windblown, tan to pink, medium to very fine quartz sand weakly cemented by iron oxide. This unit is derived from the underlying cover sand from which the silt has been winnowed and the sand blown into broad sheet deposits stabilized by vegetation. Maximum thickness is approximately 15 feet.

Dune sand.--Dune sand is similar to sheet sand and includes active dunes and dune fields with only sparse vegetation. Maximum thickness is approximately 10 feet. Possible industrial uses of these sands are discussed in the Mineral Resources section of this report.

Lake deposits (Tahoka Formation).--This unit is a light to dark gray, fine to coarse quartz sand containing local lenses of gravel and silty clay; gypsum crystals are locally abundant. Lake deposits are exposed only around Shafter and Whalen Lakes. Maximum thickness is approximately 25 feet.

Calichified sand, silt, clay, and gravel (Ogallala Formation).--This unit consists of gray to pink, fine to medium quartz sand with interbedded gravel and silty clay. At the surface the unit is extensively calichified, generally forming a sandy limestone. In the subsurface, the Ogallala generally is porous; it is the major aquifer for the Texas High Plains. Maximum exposed thickness in the Andrews map area is about 30 feet; total thickness as shown by wells is as much as 250 feet.

BEDROCK UNITS

Sand (Paluxy Formation).--This unit is composed of gray to tan, fine to coarse quartz sand with scattered gravel lenses. The sand and gravel locally are cemented by silica. The unit is exposed only near Shafter Lake. Maximum exposed thickness is about 10 feet.

Sandstone and conglomerate (Dockum Sandstone).--This unit consists of red-brown, fine- to coarse-grained quartz sandstone and conglomerate cemented with iron oxide. The unit is exposed only in a small area near Shafter Lake. Maximum exposed thickness is about 5 feet.

SURFACE MINERAL DEPOSITS

Surficial deposits of the Andrews area have been produced intermittently from many pits and used primarily as aggregate and secondary road-surfacing material. The pits were important sampling localities for this study since outcrops are scarce. Sampled excavations are indicated on Plate IV.

Crushed stone, natural cement rock, portland cement, raw materials, and industrial sands are surface materials of potential economic importance in the Andrews area. Specifications for crushed stone, cement, raw materials, and industrial sand are given in appropriate parts of the section on Mineral Resources. Test results are given in the Appendix.

VAN HORN AREA

INTRODUCTION

The Van Horn map area is a composite of three smaller areas of different geologic settings. For this reason a separate geologic column is presented for each (Pl. VI).

University Lands Block 46 is located in the Delaware Basin portion of the Permian Basin and platform complex. The rocks that crop out in Block 46 are also exposed in a large area outside that Block where they are more easily accessible and better exposed. The University Lands area is bisected in a north-south direction by a large ephemeral stream, Wild Horse Draw. Rocks exposed to the west are sandstone, siltstone, and thin limestone of the Bell Canyon Formation; those to the east are gypsum and calcium carbonate of the Castile Formation, part of the thick evaporite sequence that characterizes the Delaware Basin.

The University Lands block east of the town of Van Horn is on the north edge of the Wylie Mountains, which are developed of Permian rocks.

Most of the University Lands are underlain by alluvium shed from the Wylie Mountains.

The Van Horn, Indio, and Quitman Mountains section of the Van Horn map area is the most geologically complex terrane included in University holdings. The rocks exposed in these sections were deposited near the margins of the Chihuahua Trough, a Cretaceous depositional basin that was strongly deformed in late Cretaceous time and broken by extensive block faulting in middle Tertiary time. Faults are therefore a common feature in these mountain areas but are not presented on the maps accompanying this report. Details of structure and stratigraphy are shown on several geologic quadrangle maps (Twiss, 1959; Underwood, 1963; Jones and Reaser, 1970).

Tertiary volcanic and intrusive activity in the mountainous areas resulted in mineralization in some parts of the Cretaceous host rock. Fluorspar, copper, silver, lead, and a few other minerals of economic interest have been prospected for and mined in areas adjacent to University holdings. These minerals and the relations of their occurrences to University Lands are discussed in the Metals and Miscellaneous Nonmetals section of this report.

Stratigraphy

BLOCK 46 SECTION

Alluvium I.--This unit consists of the apron of detritus shed westward from the gypsum and thin limestone exposed in the eastern half of Block 46. Poorly sorted mud, sand, some gravel, and gypsite a few inches to 15 feet thick comprise the unit. Gypsite, an irregularly distributed alluvial aggregate of gypsum crystals derived from rocks outcropping to the east, occurs in irregular patches and lenses. Except for the presence of gypsite, this unit is similar to the Alluvium III on the Cornudas area map (Pl. VI).

Alluvium II.--The channels of the larger drainages are floored with sand and gravel a few to a few tens of feet thick. Sorting is generally poor, but lenses of relatively clean sand and gravel are present in some places. This alluvium supports some of the densest vegetation present in the Block 46 area.

Gypsum.--The eastern two-thirds of Block 46 is underlain by gypsum with thin interbeds of dark limestone. The gypsum is white or light gray and finely laminated; some of the laminae are calcite. Salt is present to the northeast of Block 46, but none crops out in the block; anhydrite is present in the subsurface. Native sulfur has been reported from outcrops immediately to the northeast and that area has been extensively prospected for sulfur. The area one-fourth to 1 mile east of Wild Horse Draw provides the best outcrops of this unit; otherwise outcrops are generally poor and the commonly collapsed and brecciated gypsum is mantled by an irregular sheet of gypsiferous alluvium. The most complete exposures of the gypsum occur in the vast area of outcrop east of University holdings.

Sandstone with some interbedded limestone.--The scarp bordering Wild Horse Draw on the east and all of the terrane to the west of the arroyo is developed on thin- to thick-bedded, very fine sandstone with interbeds of dark gray, fine-grained limestone. Some sandstone units are massive and as much as 50 feet thick. Total thickness exceeds 1,000 feet; 400 to 500 feet is exposed in Block 46.

WYLIE MOUNTAINS SECTION

Alluvium I.--Gravel and gravelly sand with interbedded silty sand occur near the bases of the hills and extend away from them as an irregular, narrow apron. The gravelly material becomes finer away from the mountains, where it is transitional into Alluvium IA. Gravelly alluvium also floors the larger washes originating within the Wylie Mountains.

Alluvium IA.--A low, broad, gently sloping alluvial plain extends from the transitional margins of Alluvium I basinward toward the Salt Basin to the north. The material is mostly sand and silt, but irregular patches of gravel are present in small washes. Xerophytic plant growth is dense on these slopes. Mounds of windblown sand are present among the greasewood and other shrubby plants; locally, eolian sand is a major component of the surficial alluvium. Irregular patches of this type of alluvium occur within the larger washes (Alluvium II). This unit is a few hundred to several hundred feet thick.

Alluvium II.--The channels of the larger washes and arroyos, notably Wild Horse Draw within University Lands, are floored by sand and gravel, patches of which are moderately well sorted and silt free. Sand is the most abundant constituent; silty areas within the channel area support patches of vegetation and commonly contain windblown sand. This unit is a few feet to more than 15 feet thick.

Dolomite.--Uniformly fine-textured and evenly bedded, light to medium gray, chert-free dolomite is the only bedrock unit in the Wylie Mountains section. Beds are 6 inches to 1½ feet thick. As much as 200 feet of this unit crops out along rubble-covered slopes of the hills in this area. An abandoned road material quarry cut into the dolomite is located a few hundred yards west of University holdings; 20 to 25 feet of rock is exposed in the quarry face.

VAN HORN-INDIO-QUITMAN MOUNTAINS SECTION

University holdings in these mountain areas are a grid of alternate sections and detached parcels of land. For the purposes of geologic mapping, an approximate boundary was drawn that includes all University and interspaced non-University land in each area and the entire included area was mapped.

Alluvium I.--Coarse gravel and interbedded sand occur along the flanks of the mountain blocks, in the channels of the larger arroyos, and as patches within the mountain areas. This material was deposited adjacent to its source at various stages in the tectonic history of the mountain areas. The alluvium is poorly stratified and texturally heterogeneous. Thickness varies from a few feet to several hundred feet. Caliche is well developed in some portions of the gravel and most is moderately indurated.

Volcanic and associated sedimentary rocks.--Interbedded lavas, tuffs, and sedimentary rocks are the youngest bedrock in the Van Horn map area. Volcanic rocks cap some of the higher mountains and occur in downthrown fault blocks. The lavas are hard and resistant; they form prominent scarps in many areas. The interbedded sedimentary rocks are mostly tuffaceous conglomerate and sandstone that are irregular in texture and distribution. The lavas are trachytes and rhyolites; where present, small intrusive dikes and sills are rhyolite. Individual lavas and interbedded tuff and sedimentary units are a few tens to a few hundreds of feet thick.

Interbedded hard and marly limestone.--Medium to dark gray, fine-grained, hard, fossiliferous limestone alternates with light to medium gray, marly, nodular, comparatively soft limestone in many of the cliff faces in the mountainous areas. The hard, ledge-forming units, 2 to 10 feet thick, are typically massive with indistinct bedding. Interbedded nodular, marly units are poorly exposed; they are from 1 to 8 feet thick.

The massive, resistant units are concentrated in the upper parts of each interbedded sequence; the lower parts contain more and thicker nodular limestone beds as well as some shale and sandstone.

Several analyses of material from this unit and from the hard, finely crystalline limestone described below are in the Appendix; their properties are considered in the section on industrial carbonates.

Hard, finely crystalline limestone.--This unit is similar to the massive, hard portions of the limestone described above but is significantly higher in calcium carbonate and is more granular in the area sampled. This rock contains high purity industrial-grade limestone, though compositional characteristics may vary laterally to those of the more common, lower purity limestones. The unit commonly forms steep cliffs with individual ledges as much as 25 feet thick separated by a few thin interbeds of more marly material; the unit is underlain by 2- to 4-foot-thick interbeds of resistant and marly limestone. Total thickness exceeds 100 feet.

Sandstone and shale with some interbedded limestone.--Sandstone is the most abundant lithology in this unit in most areas of occurrence; however, mudstone or shale and marly limestone comprise up to 60 percent of the section in some localities. The sandstone is fine-grained over most of the area but locally is medium to coarse grained and contains pebble-gravel lenses. Beds are a few inches to a few feet thick and are commonly cross-bedded and burrowed. Marly, locally hard, limestone is interbedded with the sandstone where it is transitional into overlying interbedded hard and marly limestone. Softer interbeds of siltstone and shale and limestone are less resistant to erosion and are poorly exposed. Most of the sandstones have a distinctive dark red-brown or orange-brown weathering color.

Some of the thicker shaly sections contain thin, discontinuous beds of bituminous coal.

This unit ranges in thickness from 50 to more than 1,000 feet.

Conglomerate and sandstone.--This unit is similar to the previously described sandstone and shale unit except that it contains significant amounts of conglomerate, especially in the lower part, and contains less limestone.

The conglomerate is composed of pebbles and cobbles of limestone, varicolored chert, vein quartz, and quartzite. The conglomerate units are interbedded with conglomeratic sandstone and sandstone. The conglomeratic lower part of this unit contains copper mineralization, described in a later section of the report.

The upper part of the unit contains conglomerate but is dominated by fine- to medium-grained sandstone, siltstone, shale, and limestone. Lithologies and mode of outcrop are similar to the sandstone and shale unit described above.

The rock has a distinctive red-brown weathering color. More than 2,000 feet of rock has been measured in the Indio Mountains where this unit is most extensively exposed.

CORNUDAS AREA

Introduction

Most of the Cornudas map area is located in the north-central part of the Diablo Plateau, the physiographic expression of the Diablo Platform (Pl. VI). Stratigraphic units are thin in this shelf region, thickening abruptly near the southwestern platform edge. The rocks of the Diablo Plateau are sandstone, shale, marl, and limestones.

The Diablo Plateau is a gently rolling plain broken by ridges of resistant sandstone and limestone and by hills developed on intrusive igneous rocks; Permian limestone and dolomite crop out at the surface in the northern part of the Plateau area, Cretaceous limestone and sandstone occur to the south.

The southwestern part of the Cornudas map area is within the boundaries of the Hueco bolson, a structural basin filled with Tertiary and Quaternary sediments shed from adjacent mountain blocks. University Lands in the Fabens area are underlain by the fine-grained portion of the bolson fill and by alluvium deposited by the Rio Grande and its tributaries; windblown sand mantles much of the area. The Fabens area is a sand-mantled alluvial plain sloping towards the Rio Grande. Several arroyos cut the bolson fill; San Felipe Arroyo is the largest of these.

Stratigraphy

SURFICIAL DEPOSITS

Alluvium I.--The uplands and gentle slopes in the Fabens area are mantled by fluvial sand and muddy sand that is interbedded with and overlain by loose, generally active, windblown sand. Both the fluvial and eolian sediments were derived from the underlying bolson deposits.

The windblown sand is the most conspicuous deposit over most of the broad upland north of Interstate Highway 10 where it forms a hummocky topography with low, irregular dunes and swales. Vegetation is sparse, but some of the windblown sand is partially stabilized by shrubs and grasses. The loose sand, a few inches to nearly 10 feet thick, is composed mostly of quartz grains, but heavy minerals and feldspar are minor to locally major components. Magnetite and ilmenite are the most abundant heavy minerals. Analyses of the eolian sand for possible industrial use are presented in the Appendix and discussed in the Industrial Sands section of this report.

Calcium carbonate cements the lower part of the fluvial and windblown sand and upper bolson deposits in some of the upland areas. This caliche is not as well developed on University Lands as it is on the higher basin surface to the north and northeast.

Alluvium II.--Sand, silt, and small amounts of gravel derived from the bolson fill and from the Alluvium I unit occupy the floors of the numerous small streams in the Fabens area. This material was mapped as a distinct unit along San Felipe Arroyo where the alluvium is spread across the 500- to 1,000-foot-wide valley floor, and at the arroyo mouth where it forms the broad, thin alluvial apron on which most of the city of Fabens is built. The thickness of this unit is not known, but at the arroyo mouth it is thin and is underlain by Rio Grande deposits.

Sand and gravel occupying the floors of the larger washes and draws throughout the Cornudas map area are also included in this map unit. Most of the gravel clasts are limestone and sandstone, but intrusive igneous-rock clasts are present near Sierra Prieta, Red Hills, and other intrusive bodies. The alluvium is sandy, poorly sorted, and varies in thickness from a few inches to a few tens of feet.

Alluvium III.--Coarse colluvium mantles the slopes at the bases of prominent outcrops of resistant sandstone and limestone; this material grades to finer gravel and becomes more sandy downslope toward the larger washes. It is generally a thin veneer over bedrock but in places is several feet thick. Thickness and texture are extremely variable. Caliche is common in the upland portions of this unit and may be suitable for road metal.

Rio Grande alluvium.--Silt, mud, and sand deposited as overbank or flood-plain materials by the Rio Grande are present at the southwestern edge of the Fabens area. The flood-plain deposits are a few to a few tens of feet thick and are underlain by gravel and sand channel deposits. The flood plain is extensively farmed; these soils are the most valuable earth materials presently developed in the Cornudas map area.

BEDROCK UNITS

Bolson deposits.--Claystone, mudstone, and sandstone of Tertiary and Quaternary age crop out in stream valleys and on the slopes of a poorly defined escarpment along the northeastern edge of the Rio Grande valley between Tornillo and Fabens. These deposits are the fine-grained portion of a widespread bolson fill that grades from conglomerate near the basin margins to claystone at the basin center. The sediments were deposited on alluvial fans and in lakes that varied from fresh to saline.

Exposures of the bolson fill on University Lands are poor, but in nearby areas the deposits are interbedded, buff, brown, and orange-brown mudstone and siltstone with minor amounts of sandstone. Texture and thickness are highly variable. Gypsum is present in some of the mudstone as disseminated crystals. The most abundant clay mineral is montmorillonite; kaolinite comprises less than 10 percent of the clay fraction. Clay samples were collected from the deposits; the analyses are presented in the Appendix and discussed in the section on Clays. The silt and sand-sized fractions of the sediments are chiefly quartz and feldspar with 1 to 3 percent heavy minerals.

The fine-grained part of bolson-fill deposits provides good sites for sanitary landfills; their low permeability insures a good seal from the surrounding environment. The city of Fabens maintains a dump in bolson deposits exposed along the northwest edge of San Felipe Arroyo, about 2½ miles northeast of the town. This is not a sanitary landfill operation, however, as the refuse is dumped on the surface and is not covered. Heavy rains could easily transport soluble and particulate matter from the dump into San Felipe Creek; however, flow from the creek is impounded behind an earth dam before the stream reaches Fabens or the Rio Grande, hence downstream contamination is limited to the uninhabited reach above the dam.

Igneous rocks.--Fine- to coarse-grained trachyte, phonolite, and nepheline syenite crop out in a line of widely spaced groups of hills trending across the Cornudas map area from the southeast corner toward the northwest. These alkalic or soda-rich igneous rocks are part of a chain of intrusions that parallel the regional structural grain across the Diablo Platform into New Mexico. All are similar in mode of outcrop, stratigraphic position, effects on the rocks they intrude, and chemical composition.

The medium to dark gray intrusive rock moved vertically through underlying Paleozoic limestone and sandstone and either entered the limestone as thin sills paralleling the thick bedding of these rocks or broke through the limestone into the overlying soft sandstone and marl, forming massive mushroom-shaped bodies. These are expressed in the modern landscape as hills standing 700 to 2,000 feet above the surrounding plain. The intrusions on University Lands are of the larger type intruded into sandstone and marl with little effect on the underlying limestone. Some fluorite was noted in the contact zone around Sierra Prieta, but other than slight baking and discoloration of adjacent rock, mineralization was insignificant.

Samples of all intrusive rocks were collected and analysed for the complete range of metals and rare earths; selected samples of adjacent country rock were also studied. The test results, presented in the Appendix, indicate nothing of economic interest.

Another type of intrusive rock, rhyolite, crops out in a cluster of low, rounded hills or mounds approximately 7 miles southeast of Cornudas. This quartz-bearing rock was not separated on the map from the other intrusive rocks because its economic or commercial import is no different from the alkalic intrusives. The rhyolite is much older than the syenite, however, and is highly fractured. Its exact mode of implacement is not clear, and the effects on the country rock it intruded are not known because the intrusive contact is not exposed. Spectrographic analysis indicated nothing of economic interest.

Interbedded hard and marly limestone.--Light to medium gray, hard, fine-grained limestone interbedded with less resistant, marly, nodular limestone caps several prominent mesas in the Cornudas map area. Both limestone types are fossiliferous. The units are commonly massive with indistinct bedding; where bedding is discernible it is 8 inches to 2 feet thick. Total exposed thickness of this map unit is generally 25 to 50 feet.

The hard, cliff-forming limestone units are 4 to 10 feet thick; the softer nodular limestone units form poorly exposed, recessive slopes and are 2 to 7 feet thick. A 3- to 4-foot-thick brown sandstone bed is present within this alternating limestone sequence at Molesworth Mesa. The lower part of the sequence becomes more marly and is transitional into the sandstone unit below. Analyses of samples from this unit are in the Appendix.

Sandstone with interbedded limestone.--Sandstone is the most abundant rock type in this unit, which also contains varying amounts of interbedded limestone, marl, mudstone, conglomerate, and limestone conglomerate. Quartz is the chief component of the sandstone with lesser amounts of chert, feldspar, and heavy minerals, the latter commonly altered to limonite. Texture is highly variable and several types of sedimentary structures occur; burrows are the most common structure. Bedding is thin to thick.

The limestone and marl associated with the sandstone is also highly variable in composition and texture; most is clayey or marly and contains abundant fossil oysters. Locally, carbonate rocks may be absent or may comprise as much as 50 percent of this unit.

Granule-and-pebble conglomerate is interbedded with the sandstone, especially near the northern margins of the Cornudas area. Limestone conglomerate is a significant component locally. Shale and siltstone are also present as interbeds within the sandstone.

The economic potential of this map unit is slight; the sandstone contains far too much iron for industrial use, and although some of the marls may qualify as natural cement rock, their distribution and composition are too variable for development.

Dolomite.--Fine-grained, light to medium gray, evenly bedded dolomite crops out at the eastern margin of the Cornudas map area. This unit grades to limestone in areas adjacent to University Lands, but all samples analysed for this report are dolomite. Bedding is 8 to 14 inches thick. Texture is generally uniformly finely crystalline, with pieces or ghosts of small fossils.

This unit is at least 50 feet thick in the Cornudas area. The surfaces of the beds have a distinctive weathering pattern that resembles mudcrack polygons with 1- to 10-inch-wide cracks separating polygonal plates that are 6 inches to 2 feet in diameter. This unit is discussed in the section on Carbonate Rocks and analyses are presented in the Appendix.

Dark gray hard limestone.--Most of the northern half of the Cornudas map area is underlain by dark gray to black, evenly bedded, uniformly microcrystalline limestone. Most beds are 8 inches to 1 foot thick; some are as thick as 2 feet. Small fossil fragments, 2 to 3 millimeters in diameter, are common. Ten to 20 feet of this unit are well exposed in several road cuts along U. S. Highways 62 and 180, and the unit is intermittently exposed along most slopes in the area.

Chert is common in some sections; amounts range from 1 or 2 percent to as high as 20 percent. The chert occurs as irregular masses and nodules 1 inch to 2 feet in diameter.

This limestone is very hard and is suitable for aggregate. Analyses are presented in the Appendix.

Rhyolite.--Precambrian rhyolite crops out as a series of low, rounded hills about 7 miles southeast of Cornudas. This rock is part of the basement complex that forms a local high near the center of the Diablo Platform. The rhyolite is a dark red-orange porphyry with large phenocrysts of feldspar and quartz. The rhyolite is highly fractured in places and contains veins of coarser grained igneous rocks.

Igneous rocks containing valuable rare earths and trace elements are, in some places, associated with igneous rocks of the type present in the University Lands area; however, the ore materials are generally associated with much deeper intrusive igneous rocks than those on University Lands. Because the Precambrian rhyolite is part of the underlying basement complex, the vein materials were sampled and analysed because of the possibility that the intrusive vein material in the rhyolite might be a part of a deep-seated intrusive mass containing valuable minerals. Spectrographic analyses of several samples revealed nothing that would indicate presence of minerals or elements of economic interest.

MINERAL RESOURCES

INDUSTRIAL CARBONATES

INTRODUCTION

Carbonate rocks are one of the most important nonfuel mineral resources in Texas. Annual value of limestone and dolomite produced for bulk constructional uses and as chemical and industrial process stone is slightly more than $50 million. Value of cement and lime produced from carbonate rocks is about $140 million. Annual value of limestone and dolomite produced in a 38-county area surrounding the University Lands (fig. 6) is approximately $2.4 million, or about 4 percent of the State total. Cement production in this area is about 6 percent of the State total.

General information on the occurrence and production of carbonate rocks is found in Gillson et al. (1960); principal industrial carbonates of Texas are described by Rodda et al. (1966).

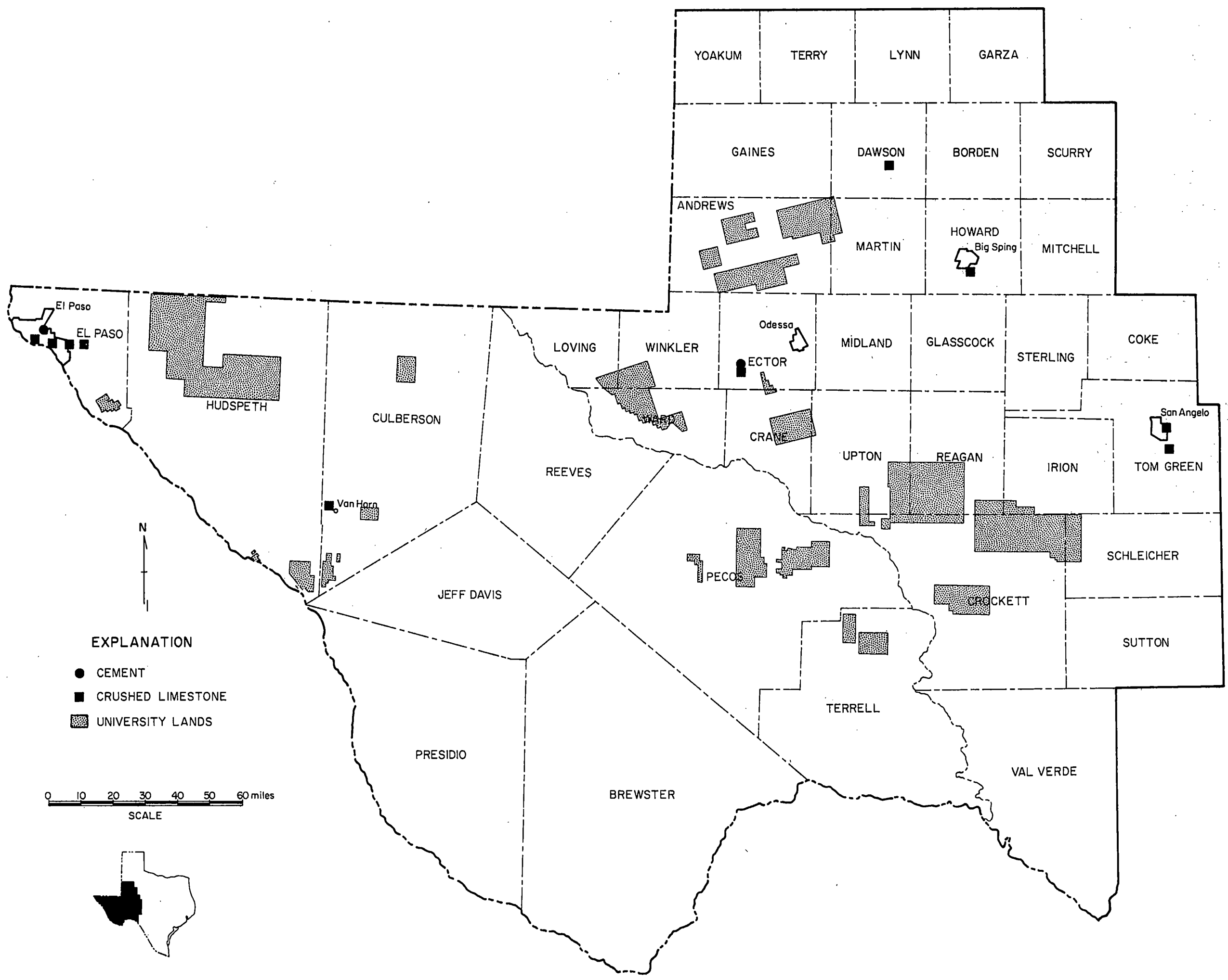


FIG. 6. Sites of limestone and cement production in West Texas.

DEFINITIONS

Rocks composed predominantly of the mineral calcite ($CaCO_3$) are called *limestone*; rocks consisting chiefly of the mineral dolomite ($CaCO_3 \cdot MgCO_3$) are called *dolomite* ($MgCO_3$ content greater than 23 percent). Rocks of intermediate composition are referred to as *dolomitic limestone*. *High-calcium limestone* contains more than 97 percent $CaCO_3$; *high-magnesium dolomite* contains more than 36 percent $MgCO_3$. *Marly limestone* is a softer rock high in clay or aluminum silicates; *marl* is soft calcareous clay (less than 50 percent $CaCO_3$). *Caliche* is an impure secondary limestone formed in surficial deposits.

SAMPLING AND TESTING PROCEDURES

About 200 samples of carbonate rocks were collected from readily accessible exposures in quarries and road cuts and from natural exposures. Samples collected are representative of major carbonate rock types on University Lands. Rock descriptions, thickness, sample intervals, chemical analyses, and locality descriptions are reported in the Appendix. Sample localities are designated by county name (or abbreviation) and listed numerically (e.g., PECOS-4). Individual samples were taken as chip samples from nonuniform intervals corresponding to significant changes of rock type; samples are designated by Mineral Studies Laboratory numbers (e.g., 70122).

Calcium and magnesium (expressed as oxides and carbonates) were determined for selected samples by titration methods and by flame photometry; silica, alumina, and iron (expressed as oxides) were determined by spectrophotometric methods (colorimetry).

Occurrence on University Lands

INTRODUCTION

Carbonate rock types on University Lands include bedrock and surficial units (fig. 7). Both types are widespread in the southern University Lands in the Edwards and Stockton Plateaus and in Trans-Pecos Texas. In these areas the bedrock units commonly form high steep topography; surficial deposits, extensively calichified, mantle the lower slopes, fill the valleys, and cover wide areas on the top of broad bedrock plateaus. In the northern University Lands, in the Southern High Plains, surficial carbonate deposits are widespread, but under-

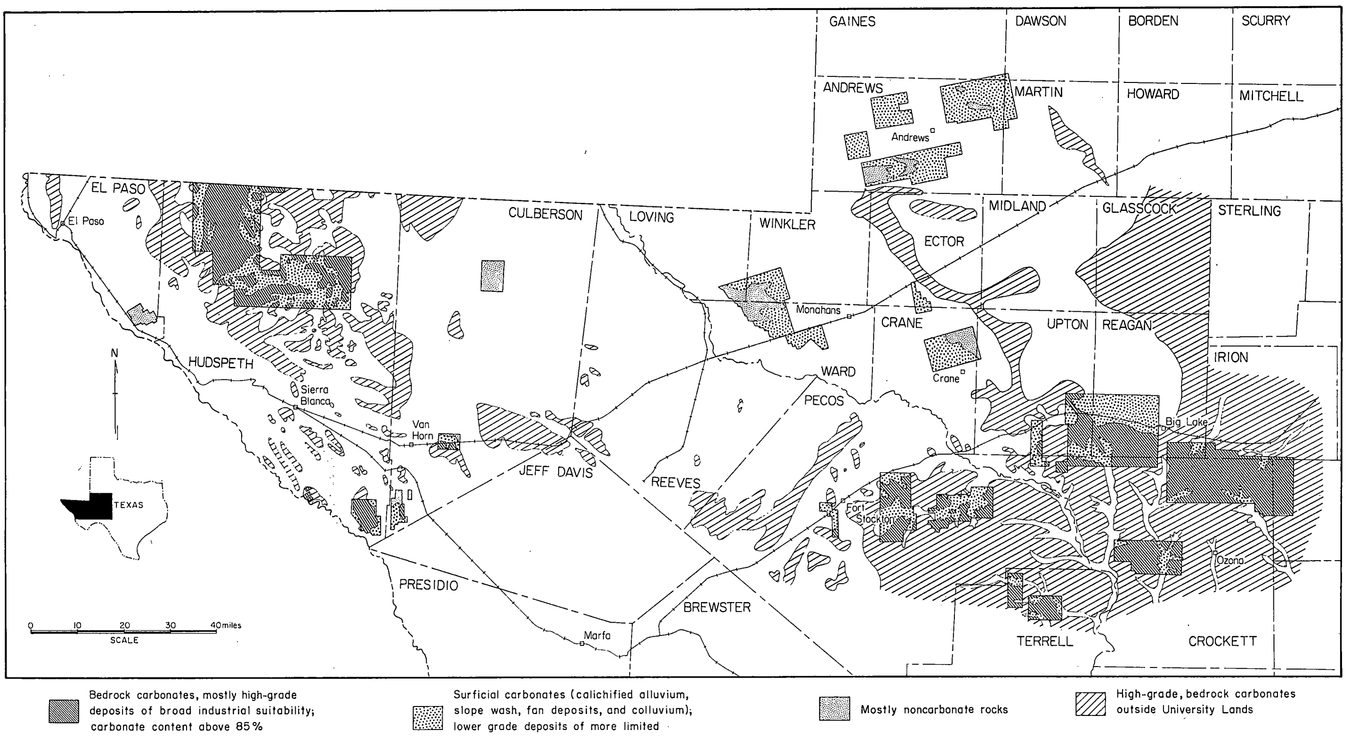


FIG. 7. Distribution of carbonate rocks on University Lands.

lying bedrock limestones are exposed only locally.

LIMESTONE

Limestones on University Lands include a variety of types ranging from soft, marly, nodular limestones relatively high in clay-size impurities to hard, massive, granular limestones generally high in calcium carbonate. Total carbonate content ($CaCO_3$ + $MgCO_3$) of sampled limestones ranges from 54 to 100 percent and averages about 93 percent (fig. 8). Calcium carbonate ($CaCO_3$) content alone ranges from 51 to 99 percent and averages about 90 percent (fig. 9). All analysed carbonate rocks contain magnesium carbonate, mostly in small amounts (fig. 10); 85 percent contain less than 3 percent $MgCO_3$. About 6 percent of the samples analysed contain sufficient magnesium carbonate (more than 23 percent) to be classed as dolomite.

Variations in physical properties generally correspond to variations in chemical quality. Only the hardest limestones have hardness, toughness, and durability sufficient for most aggregate and constructional uses. Softest limestones mostly are suitable only as highway base material and subgrade.

Based on chemical quality, grain size, hardness, and weathering characteristics, four kinds of bedrock carbonates and one surficial carbonate type have been recognized on University Lands. Purest, most durable stones are hard, massive, granular limestones that form extensive cap rocks, and also crop out in lower slopes, in the Big Lake and Fort Stockton areas, are thick and extensive in the

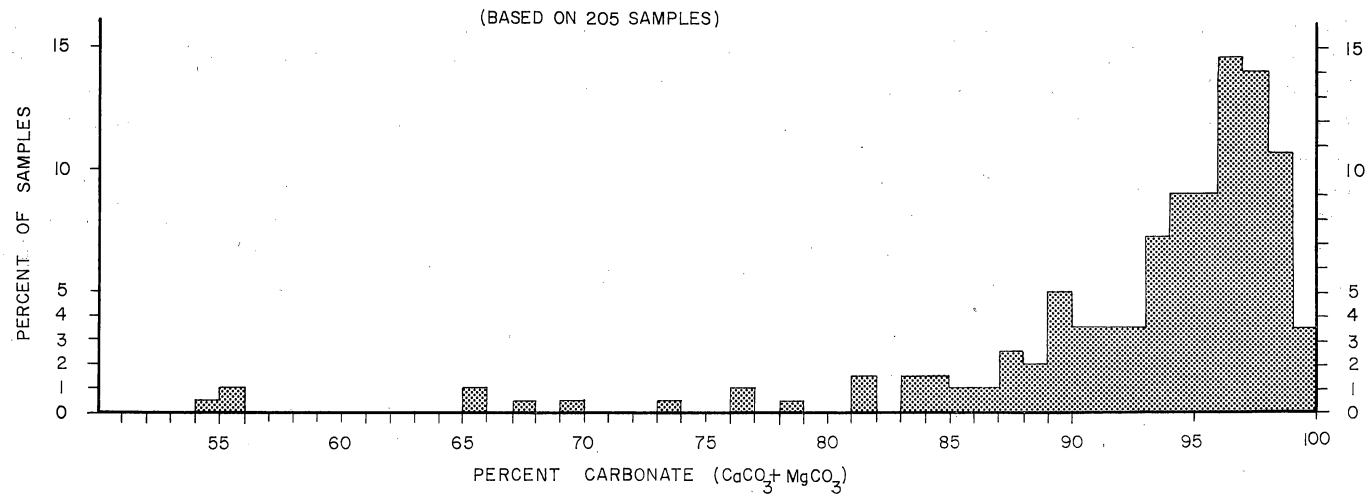


FIG. 8. Total carbonate content ($CaCO_3$ and $MgCO_3$) of limestones and dolomites, University Lands.

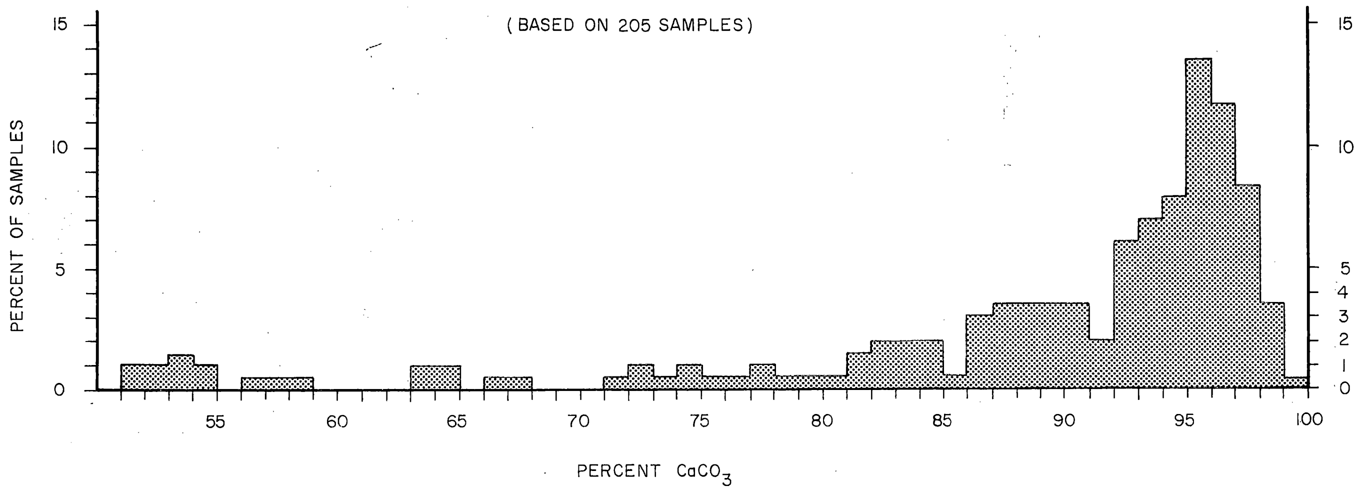


FIG. 9. Calcium carbonate content of limestones, University Lands.

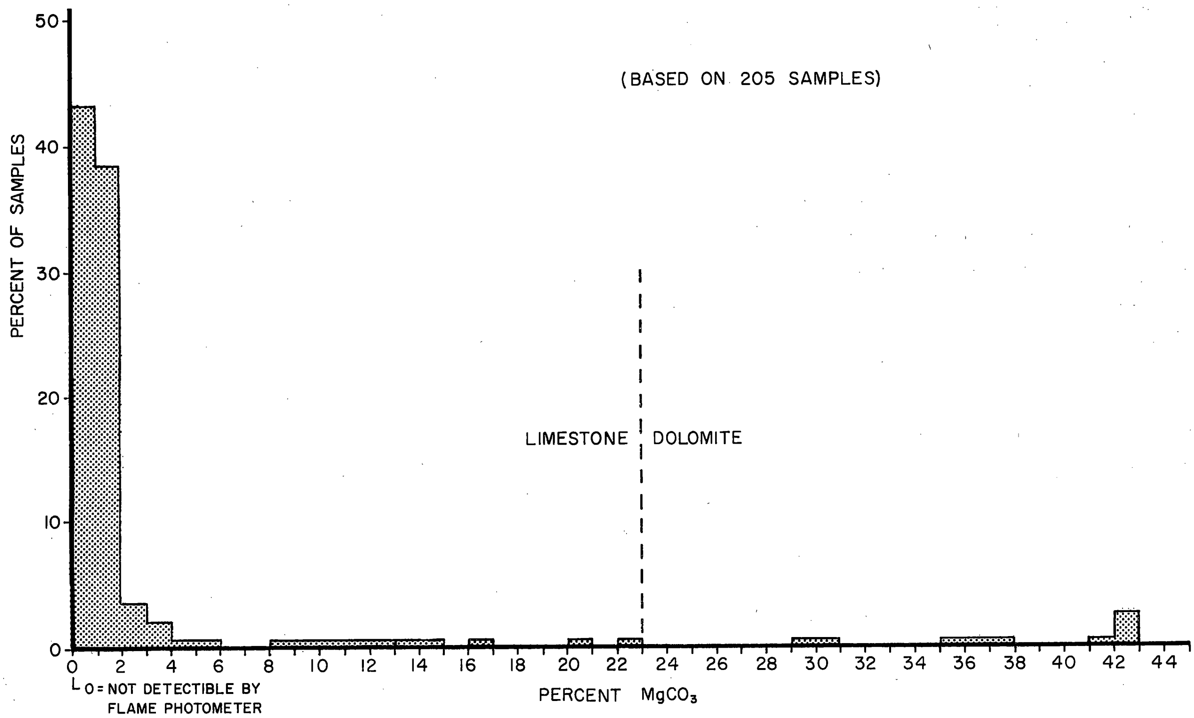


FIG. 10. Magnesium carbonate content of limestones and dolomites, University Lands.

Cornudas area, and are present in the Van Horn area. Calcium carbonate content of these rocks generally ranges from 95 to 98 percent; they are suitable for a wide variety of industrial uses. High-purity limestone ($CaCO_3$ content greater than 98 percent) occurs locally in the upper part of the section in the Big Lake area and in the Van Horn Mountains (Van Horn area). Nodular chert is common to abundant in the lower granular limestones in the southern and eastern parts of the Big Lake and Fort Stockton areas. All analyses in this report are exclusive of free chert (SiO_2); presence of chert is indicated in diagrammatic sections in the Appendix. Based on published analyses of similar limestones to the east (Rodda et al., 1966), noncarbonate impurities consist of silica (0.5 to 1.5 percent), alumina (0.1 to 0.5 percent), and iron oxide (0.05 to 0.2 percent).

The second limestone type is moderately hard, very fine grained, slightly nodular weathering, and has a calcium carbonate content generally between 93 and 96 percent. This unit commonly forms extensive steep slopes below the harder granular caprock limestone in the Fort Stockton and Big Lake areas. The stone is suitable for many industrial uses.

Soft, nodular-weathering, marly limestone is common on slopes below the harder limestones in the Big Lake and Fort Stockton areas. This limestone is commonly interbedded with thick units of marl. Calcium carbonate content generally is from 87 to 90 percent; more marly sections have values as low as 70 percent. Marl units contain about 40 percent $CaCO_3$. Noncarbonate impurities include silica (7 to 20 percent), alumina (2 to 7 percent), and iron oxide (1 to 2 percent). The rock is suitable for subgrade and some base material and (including the interbedded marl) is a good natural cement rock.

The fourth bedrock limestone unit consists of interbedded hard, very fine- to coarse-grained limestone and softer, nodular, marly limestone. This unit is on the tops of plateaus and mesas in the Big Lake and Fort Stockton areas and is widespread in the Cornudas and Van Horn areas. Thickness of individual interbeds ranges from 1 foot to 15 feet; the harder interbeds generally are thinner than the softer nodular beds. Calcium carbonate content of the hard beds is from 94 to 97 percent, and that of the soft beds is from 85 to 92 percent. This rock unit is suitable for base material.

Surficial limestones are widespread in all areas and make up virtually all the carbonate rocks in the northern University Lands in the Southern High Plains. In the southern areas these surficial deposits are composed variously of carbonate clay, silt, sand, and gravel derived from local carbonate bedrock; the deposits are extensively calichified. In the northern areas the surficial carbonates consist of extensively calichified carbonate and noncarbonate alluvial material, most of which was derived from distant sources. Calcium carbonate content of the surficial carbonates ranges from 53 to 85 percent; most contain less than 80 percent. Noncarbonate impurities and physical properties also vary widely. The surficial carbonates have been used for highway subgrade and base material, especially for secondary roads. Many surficial deposits contain sufficient silica, alumina, and iron to qualify as natural cement rock.

DOLOMITE

Thick deposits of hard, dense, fine-grained, high-magnesium dolomite occur in the Cornudas and Van Horn areas. Magnesium carbonate content of analysed samples exceeds 42 percent; total carbonate content ranges from 94 to 99 percent. High-grade refractory dolomite is present locally in the Van Horn area. These dolomites are chert free. The unit has been quarried for road material.

Relatively soft, porous, fine-grained dolomite occurs in lower slopes in the western part of the Big Lake area and the northeastern part of the Fort Stockton area. Exposed thickness of dolomite units ranges from 15 to 40 feet. Magnesium carbonate content ranges from 23 to 37 percent and averages 31 percent. High-magnesium dolomite is rare in these areas. Total carbonate content ($CaCO_3$ + $MgCO_3$) ranges from 90 to 95 percent. Noncarbonate impurities are similar to those in limestones from the same area. Nodular chert is commonly associated with this dolomite. The unit has not been quarried in this area.

Utilization and Specifications

Carbonate rocks are crushed for use as concrete aggregate, road material, railroad ballast, and other constructional uses; fluxing agent in the smelting and refining of metals; soil conditioner and fertilizer; source of lime, chemical and industrial process raw material; and mineral fillers and pigments. Limestone is the basic raw material for portland cement; dolomite is a source of high-grade refractories. Limestone also is cut for use as dimension building stone. For certain uses physical properties are most important; for other uses chemical properties or a combination of both physical and chemical properties are critical. Limestone and dolomite that will meet chemical specifications for most uses are less common than those that have suitable physical properties. Limestones and dolomites suitable for most uses are widespread and abundant on University Lands, though materials meeting highly exacting specifications are localized (table 2).

CEMENT

Cements produced from naturally occurring materials include hydraulic cement, portland, masonry, and other types. Portland cement is produced by calcining to incipient fusion a finely ground mixture of lime, silica, alumina, and iron oxides and grinding the resulting clinker; a small amount of gypsum is added to the finished product. Natural and hydraulic cements are produced by low-temperature calcination of naturally occurring materials containing approximately the required proportions of lime, silica, alumina, and iron oxides. Masonry cements are made by grinding portland cement clinker or finished portland cement with limestone and an air-entrained plasticizer to greater fineness than portland cement. These cements have strong hydraulic properties, high plasticity, and high water retention. Natural masonry cement utilizes natural cement rock ground with a small quantity of portland cement. Special cements include oil-well cement, white cement, and hydroplastic, plastic, and waterproofing cements.

Portland cement is the cement most manufactured and used; a more uniform and dependable product generally can be made from an artificial mixture of materials than from natural cement rock. In the production of cement from other than natural cement rock, alumina and silica are obtained by addition of clay or shale.

Limestones on University Lands include both natural cement rock and higher purity stone to which silica, alumina, and iron components must be added to make cement. The two cement producers in the West Texas area (at Penwell, Ector County, and El Paso, El Paso County) utilize limestone, marly limestone, and marl derived from a single quarry or from adjacent pits.

LIME

When limestone and dolomite are heated to 1000°C to 1100°C they yield carbon dioxide gas and an oxide--calcium oxide (calcium lime) from limestone and calcium oxide plus magnesium oxide (magnesium lime) from dolomite. Calcining or burning is accomplished in either vertical stationary

TABLE 2. *Specifications and availability of limestone and dolomite carbonate rocks for principal consuming industries.*

Use	Specifications: Chemical	Specifications: Physical	Availability from University Lands
Portland cement	MgO, maximum 3%, preferably <2%; total alkalies, maximum 0.5%; $CaCO_3$, minimum 75%, depending on availability of other raw materials	Should crush and pulverize easily	Abundant in all areas
Natural cement and hydraulic lime	Clayey materials, 13% to 35%, of which 10% to 22% should be SiO_2; Al_2O_3 and Fe_2O_3, 4% to 16%; remainder $CaCO_3$ and $MgCO_3$	Should crush and pulverize easily	Widespread in middle part of outcrop sections (marly limestones and marls) in northern parts of Fort Stockton and Big Lake areas
High-calcium lime	$CaCO_3$, minimum 96%, preferably >97%	In some processes rock should not decrepitate during calcining; 6" to 10" sizes for vertical kilns, ½" to 1½" for rotary kilns	Common in Cornudas, Van Horn, Fort Stockton, and Big Lake areas
Magnesium lime	MgO, 10% to 15%, preferably 11% to 12%	Same as high-calcium lime	Present in lower part of outcrop sections in eastern Fort Stockton and western Big Lake areas
Fluxstone (blast furnace)	$CaCO_3$ and $MgCO_3$, >90%; SiO_2, <5%; Al_2O_3, <2%; MgO, <4% to 15% (variable); P_2O_5, maximum trace	Particle size, ½" to 4"; rock should not decrepitate during calcining	Abundant in Cornudas, Van Horn, Fort Stockton, and Big Lake areas
Fluxstone (open hearth)	$CaCO_3$, >98%; SiO_2, <1%; Al_2O_3, <1.5%; P and S, no more than trace	Particle size, 2" to 12", generally 4" to 8"; some processes should hold lump form until consumed in melt	Locally hard granular limestones in Fort Stockton and Big Lake areas will meet specifications; also locally in Van Horn area
Refractory dolomite (deadburned)	MgO, minimum 18%; SiO_2, <1%; Fe_2O_3, <1%; Al_2O_3, <1% (lower grades locally accepted but in no case should SiO_2 exceed 2.5%)	Particle size, approximately 5/8"	Some dolomite in Cornudas area will meet specifications; dolomite in Van Horn area will approach them
Sugar beet refining	SiO_2, maximum 1%; MgO, maximum 4%; Fe_2O_3, <0.5%; no impurities that will give taste	Particle size, 2" to 8"; should not decrepitate during calcining	Common in Cornudas, Van Horn, Fort Stockton, and Big Lake areas
Agricultural limestone and dolomite	Maximum $CaCO_3$ and $MgCO_3$ desirable, at least >85%	Particle size, -4 mesh; soft and friable	Abundant in Cornudas, Van Horn, Fort Stockton, and Big Lake areas
Glass	$CaCO_3$ and $MgCO_3$, <98%; Fe_2O_3, <0.05%, preferably <0.02% (lower grades locally used)	Particle size, -16 mesh	Locally hard granular limestones in Fort Stockton and Big Lake areas will meet specifications; also locally in the Van Horn area

TABLE 2 (continued).

Use	Specifications: Chemical	Specifications: Physical	Availability from University Lands
Calcium carbide and calcium cyanamide	$CaCO_3$, >98%; MgO, <0.5%; Al_2O_3, Fe_2O_3, <0.5%; SiO_2, <1.2%; P, <1.2%; S, no more than trace	Rock must hold lump form during calcining	Locally hard granular limestones in Fort Stockton and Big Lake areas will meet specifications; also locally in the Van Horn area
Rock wool	Impure raw material, $CaCO_3$, 40% to 65%; remainder SiO_2 and Al_2O_3; iron sulfide should be low	Particle size, 2" to 5"	Locally present to abundant in all areas
Paper (sulfite process - tower system)	$CaCO_3$, <95%; MgO, <2.5%; SiO_2, Fe_2O_3, Al_2O_3, <2.5%	Particle size, 8" to 14"	Abundant in Cornudas, Van Horn, Fort Stockton,and Big Lake areas
Paint and whiting	$CaCO_3$, >96%; MgO, generally <1%; Fe_2O_3, <0.25%; SiO_2, <2%; SO_3, <0.1%	Degree of whiteness is main controlling characteristic	Locally granular limestones in Fort Stockton area will meet specifications
Miscellaneous ground fillers	$CaCO_3$, >96%; uniform distribution of impurities	Should crush and pulverize easily; particle size distribution specified, depending on use	Abundant in Cornudas, Van Horn, Fort Stockton, and Big Lake areas
Mineral foods	$CaCO_3$, <95%; fluorine compounds very low; $MgCO_3$, low	Particle size, -200 mesh, except poultry grit, -2 to +10 mesh	Abundant in Cornudas, Van Horn, Fort Stockton, and Big Lake areas
Crushed stone (aggregate, ballast, base materials, etc.)	Low alkalies, low surface organic matter, very low opaline silica for concrete aggregate	Clean, strong, durable, tough, low porosity; particle size, variable but specified	Abundant in all areas
Dimension stone	Low in mineral grains or impurities that result in stains and streaks on weathering	Free working (split with approximately equal ease in all directions); durable, tough, strong; color and texture variable	Widespread in Cornudas, Van Horn, Fort Stockton, and Big Lake areas
Stone sand	Same as aggregate where used in concrete	Clean, durable, free of flaky particles; uniform particle size distribution	Common in all areas
Stone chips (roofing granules, terrazzo, exposed aggregate, etc.)	Same as aggregate where used in concrete	Clean, free of dust and soft particles; pleasing appearance; particle size specified	Common in all areas
Filter stone	Generally none, depends on performance	Clean, free of dust; particle size range within 1" between minimum and maximum	Common in all areas
Alkalies	$CaCO_3$, >98%; SiO_2, <1%	Particle size, 1" to 6"	Hard granular limestones in Fort Stockton, Big Lake, and Van Horn areas will locally meet specifications

kilns or in inclined rotary kilns. Purity of the lime is controlled largely by the quality of the raw material. Generally, a raw material with less than 4 percent noncarbonate impurities is suitable; raw materials for magnesium or dolomitic lime should contain about 20 to 30 percent magnesium carbonate.

The calcined kiln product, known as quicklime, has a strong affinity for carbon dioxide and water and must be protected from moisture in storage and in transit. The addition of proper amounts of water to quicklime forms hydrated lime or calcium hydroxide, which is relatively stable under atmospheric conditions.

In Texas, lime is produced from high-purity limestone in Central Texas and from oyster shell dredged from Texas bays. Most of the production is used in the eastern part of the State for clay stabilization of highway subgrade and in the manufacture of many chemical products. Limestone and dolomite suitable for producing lime are abundant and widespread on University Lands.

CRUSHED STONE

For use as aggregate or for other physical purposes, limestone and dolomite should be durable, sound, nonporous, and free of such impurities as chert, organic matter, and pyrite. Relative ease in crushing and widespread occurrence account for the extensive use of limestone as a crushed stone. Marly, nodular limestones and some dolomites generally are too soft or porous for constructional uses, except locally as base materials.

Crushed stone is produced at ten commercial operations in the West Texas area; all but one are well outside the area of the University Lands.

Sound, durable stone suitable for most aggregate uses is abundant and widespread on University Lands. Much of this limestone will meet class 1 specifications (Texas Highway Department) for highway base material. Softer marly bedrock limestones and soft calichified surficial carbonates generally are suitable for subgrade or for base material for secondary roads.

CHEMICAL AND INDUSTRIAL PROCESS STONE

Limestone and dolomite are used directly and indirectly as lime in several important chemical and industrial processes that include processing of paper, pulp, and sugar and the manufacture of glass, caustics, alkalies, calcium carbide, and calcium cyanamide. Limestone for chemical and industrial uses must be high purity with calcium carbonate content commonly specified at 98 percent or greater. Lime used generally must contain calcium oxide in excess of 96 percent. Such impurities as alumina, iron oxides, silica, sulfur, and phosphorus must be very low and uniform in distribution.

Chemical- and industrial-grade limestone and dolomite are present locally in the Big Lake, Fort Stockton, Van Horn, and Cornudas areas.

FLUXSTONE

Limestone is used as a fluxing agent in the smelting of metals. Limestone supplies calcium oxide which combines with undesirable acid constituents in the ore and fuel to form a slag separable from the molten metal. The fluxstone should be fine grained, have uniform particle size distribution, have hardness sufficient to allow crushing to uniform size, be easily calcined, and be low in acid constituents, such as silica, alumina, sulfur, and phosphorus. Magnesium oxide is not critical in a blast furnace fluxstone but should be less than 5 percent for use in open hearths. Fluxstone should contain no more than a trace (0.005 to 0.006) of phosphorus pentoxide.

Except for possible restrictions imposed by phosphorus content, which was not determined, limestones suitable for fluxstone are widespread in the southern University Lands. Fluxstone has been produced in the El Paso area.

DIMENSION STONE

Dimension stone is quarried, cut, or broken in special shapes and sizes. Main controlling factor in selection of a dimension stone is physical appearance, chiefly color and texture. Specifications chiefly concern strength, soundness, durability, and freedom from cracks and other defects. Exact specifications depend on whether the stone is for interior or exterior use, and whether it is to be used structurally or as a facing stone.

Hard dense granular limestone or dolomite in the Big Lake, Fort Stockton, Van Horn, and Cornudas areas are sufficiently durable and sound for use as dimension stone. Currently, no dimension limestone is produced in West Texas, but in previous years it has been produced in the El Paso area.

TABLE 3. *Production and utilization of limestone and dolomite in Texas, 1969* (from U. S. Bureau of Mines mineral data sheets).

	Quantity (thousand short tons)	Value (thousand dollars)
Aggregate, ballast, base material, riprap, and allied crushed stone	26,217	36,407
Portland and masonry cement	6,758	7,200
Lime	1,547	2,709
Fluxstone	920	1,179
Agricultural limestone	270	298
Alkalies, paper, glass, paint, asphalt filler, stone sand, and other industrial use	1,093	1,973
Dimension stone	14	370
TOTAL	36,819	50,136

PRODUCTION AND VALUE

Production of carbonate rocks in Texas in 1969 was approximately 44 million tons valued at about $50 million (table 3). Sixty-seven percent of the total limestone produced in Texas was used as aggregate, railroad ballast, riprap, road material, and for other bulk constructional purposes; 21 percent of the total production was used to manufacture cement; an additional 5 percent was used for making lime. Production of cement in Texas in 1969 was 37 million barrels valued at about $122 million; production of lime was 1.6 million tons valued at $22 million (table 4).

Limestone and dolomite production in 1969 in the 38-county area surrounding the University Lands was approximately 2 million tons valued at about $2.4 million; production of cement in the two West Texas plants was about 2 million barrels valued at about $7.7 million (table 5). These figures represent about 4 percent of the total State production of carbonate rocks and about 6 percent of the total cement production. Current commercial producers of limestone, dolomite, and cement in the West Texas area are listed in table 6; geographic distribution of current production is indicated in figure 6.

TABLE 4. *Production of cement and lime in Texas, 1969* (from U. S. Bureau of Mines mineral data sheets).

	Quantity	Value (thousand dollars)
Portland and masonry cement (thousand barrels)	37,147	121,863
Lime (short tons)	1,633	22,107

TABLE 5. *Production and utilization of carbonate rocks and production of cement in West Texas area, 1969* (from U. S. Bureau of Mines mineral data sheets; see fig. 1 for area covered).

	Quantity	Value (thousand dollars)
Crushed limestone and dolomite (aggregate, ballast, base material, cement raw material, riprap, etc.) (thousand short tons)	1,958	2,394
Portland and masonry cement (thousand barrels)	2,171	7,701

Limestone and dolomite production in the West Texas area amounted to less than half a million tons in 1950 but climbed steadily to the 1969 high of about 2 million tons. This reflects increase of total State production from less than 5 million tons in 1950 to the 1969 high of nearly 37 million tons. Average value of limestone produced in Texas in 1969 was about $1.35 per ton f.o.b. plant.

Production of carbonate rocks from University Lands has been of crushed limestone or dolomite, quarried locally and intermittently and used for highway construction (subgrade and base material). Principal quarries that have been opened on University Lands are indicated on the geologic maps (Pls. I-VI). None of the quarries are active at present.

ECONOMIC CONSIDERATIONS

Limestone and dolomite suitable for most constructional, industrial, and chemical uses are abundant and readily available over much of Central, North, and West Texas. These materials are bulky, low-unit-value commodities, and location of de-

TABLE 6. *Current commercial producers of carbonate rocks, West Texas* (from Texas Mineral Producers, 1970, compiled by Roselle Girard).

	County	Crushed stone	Portland and masonry cement
Texas Architectural Aggregate, Inc.	Culberson	x	
T. M. Brawn and Sons, Inc.	Dawson	x	
Southwestern Portland Cement Co.	Ector	x	x
H. and H. Materials, Inc.	El Paso	x	
McMillan Quarry, Inc.	El Paso	x	
Southwestern Portland Cement Co.	El Paso	x	x
Vowell Material Company	El Paso	x	
Jagoe-Public Company	Howard	x	
The Jarbet Company	Tom Green	x	
Strain Brothers	Tom Green	x	

posits in relation to suitable transportation facilities and markets is critical.

Approximately one-third of the limestone marketed in Texas as crushed or broken stone is shipped from plants to points of consumption by rail; the rest is transported by truck. Truck hauls generally are limited to a radius of about 50 miles from the plant or quarry site; rail transport is utilized for longer hauls.

Most industrial carbonates are produced and consumed in the eastern half of the State. Principal market areas for crushed limestone and manufactured limestone products (cement and lime) are metropolitan and industrial areas in North and Central Texas and along the Texas Gulf Coast (figs. 11 and 12). Principal West Texas markets adjacent to University Lands are in the Midland-Odessa and El Paso areas.

Carbonate raw materials for most industrial uses are widespread on University Lands and reserves are vast (measured in trillions of tons). However, these low-unit-value commodities generally cannot be shipped economically to distant markets. Equally large reserves of comparable raw materials are available closer to all principal market areas and to virtually all local consumers. Under present patterns of population, industry, water supply, and transportation in West Texas, the demand for carbonate raw materials will remain low outside of metropolitan areas. The only industrial carbonate likely to be produced on University Lands for many years to come is crushed limestone for use as road material in highway construction. Potential production will depend on specific routes and relative scope of Federal, State, and local highway programs. If, in the future, new markets could develop in this part of the State, the effect on limestone production from University Lands would depend on exact market locations and relationship to transportation facilities, since comparable raw materials are available over most of the West Texas area.

GROUND WATER

INTRODUCTION

Ground water is available in nearly all parts of University Lands but is widely variable in quantity and quality and in dependability of the supplies. This section of the report deals with ground water on a regional basis and is keyed to maps giving an overall picture of water distribution and quality (Pls. VII and VIII). These maps incorporate data from several years and different aquifer systems, but they provide general information important for planning. More detailed information on the individual aquifers and specific areas is presented in the text; it can also be obtained from Texas Water Development Board and U. S. Geological Survey publications (fig. 13).

Much of the best water beneath University Lands occurs in and near areas underlain by limestone and characterized by large numbers of producing oil and gas wells. Limestone, because it is commonly jointed and has numerous solution channels, provides easy and, very commonly, direct connection between the ground surface and the ground-water-saturated zone below. For this reason it is critical that great care be taken in handling and disposing of oil-field brines; once they percolate into fresh-water aquifers the damage is severe and long lasting. The fresh water that underlies University

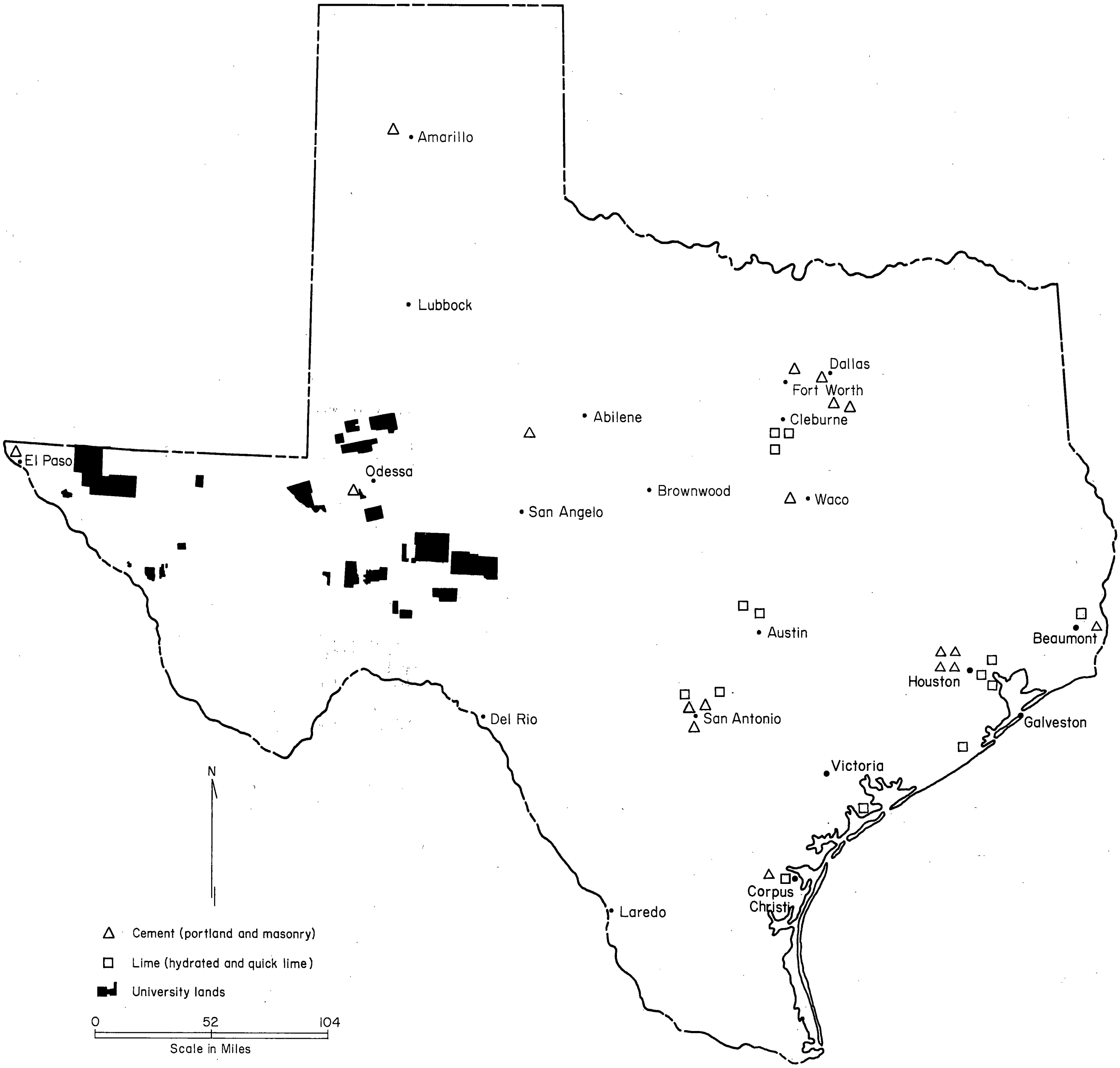


FIG. 11. Cement and lime plants in Texas.

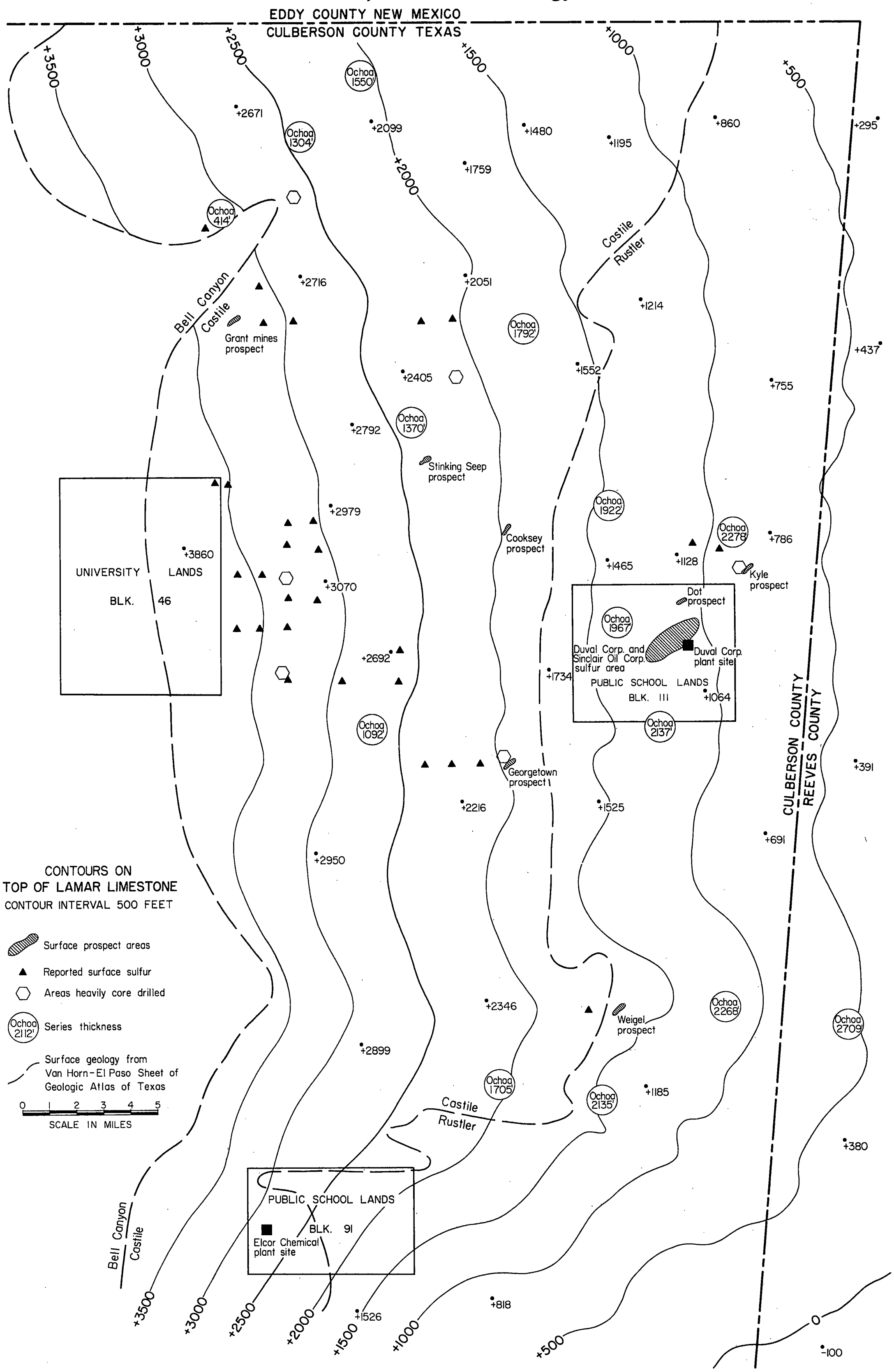


FIG. 12. Principal market areas in Texas for limestone and dolomite products.

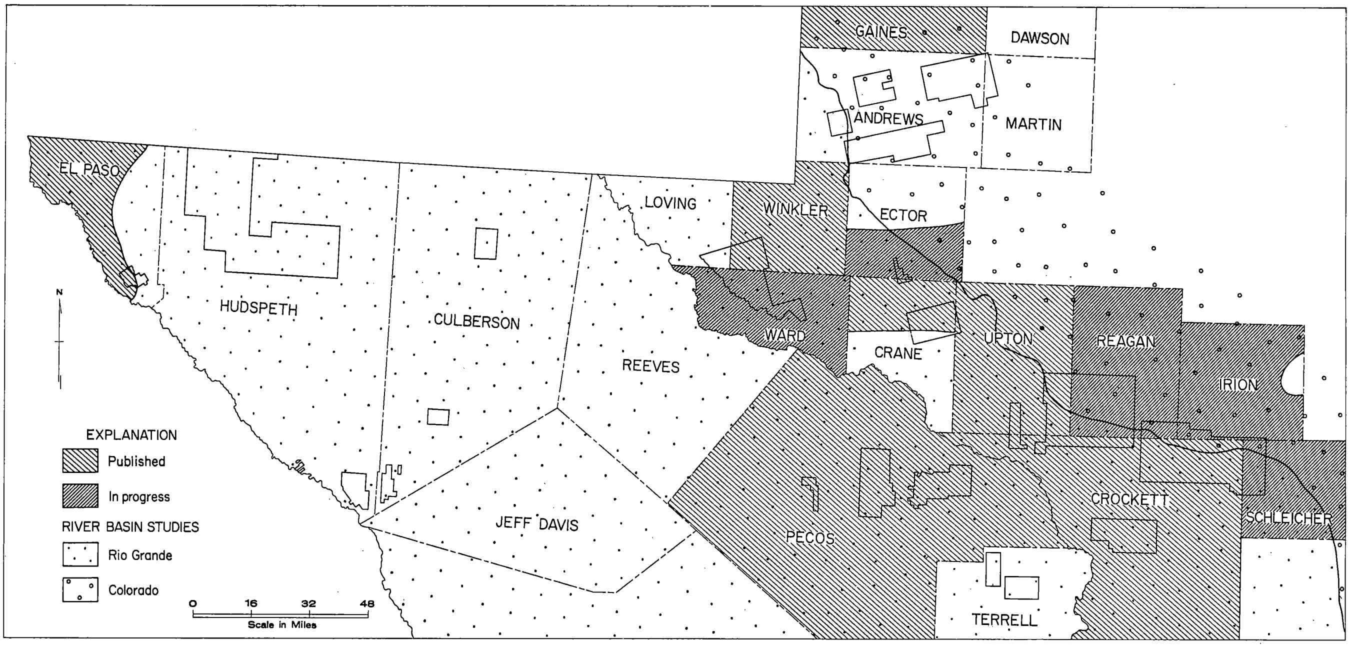


FIG. 13. Status of detailed ground-water reports made by Texas Water Development Board and U. S. Geological Survey.

Lands in these areas is a valuable resource, and careful surveillance is necessary to insure that it is not rendered valueless before it is developed. Strict enforcement of regulations now in effect should eliminate the most serious form of brine contamination, disposal in unlined pits. Contamination of ground-water supplies by oil-field brines is not limited to limestone terranes, however, and all regions in the University Lands map areas (Pls. I-VI) have been subjected to brine contamination.

The rapid and large-scale agricultural development that followed World War II severely depleted ground-water supplies in much of West Texas. Water levels have declined at rapid rates, especially in areas where alluvial aquifers supply large quantities of water for irrigation. As fresh-water supplies are depleted, water of poorer quality commonly encroaches into the fresh-water aquifers. This deterioration of quality can be as limiting a factor on regional development as decreases in the quantity of water available. Thus, while there is water of suitable quality for most uses beneath most areas of University Lands, a future that includes increased demands on water supplies necessarily includes a steady decrease in the quantity and quality of ground water available for use. This decrease in quantity is a particularly significant factor in West Texas because the area is dry; recharge to the ground-water supply is relatively small. For practical purposes, therefore, the use of large quantities of ground water is a mining operation since replenishment does not keep pace with use.

New uses for ground water will have to be weighed against present uses with which the new utilizations will be in direct competition. Frasch sulfur operations, for example, require large supplies of relatively fresh water. The best sources for this water were tapped long ago for agricultural use, and in many areas sulfur operations would have to tap these same supplies, further straining a short supply of water and in direct conflict with agricultural use. Also, the use of fresh water for waterflood operations in petroleum-producing areas needs to be carefully evaluated. Saline water is available at depth throughout University Lands; chemical compatibility problems that are the main reason for use of fresh water instead of saline waters perhaps can be solved by treatment of the saline water rather than by use of fresh water. The Texas Railroad Commission's present practice of requiring a permit for the use of fresh water for waterflooding and prohibiting disposal of brine in unlined pits is an encouraging sign of concern over fresh-water supplies.

Aquifer Systems

General Setting

The Texas Water Development Board has classified or grouped the principal ground-water-bearing rocks of Texas into major and minor aquifers on the basis of yield, geologic age, and rock type (figs. 14 and 15). A major aquifer is defined as one that yields large quantities of water in a comparatively large area of the State; much University Land is located in areas where major aquifers provide dependable water supplies. Parts of University Lands not supplied by major aquifers derive ground water from a variety of rocks; these are discussed as a group under Miscellaneous Aquifers.

The water-bearing characteristics of the major and minor aquifers are summarized in table 7; the rock types and outcrop characteristics are described in the section on Geology. Although these generalized water-bearing characteristics are a useful guide in ground-water exploration programs, the rock units are locally variable, resulting in unsuccessful wells.

The data used in construction of the piezometric surface and water quality maps (Pls. VII and VIII) were derived from publications and files of the Texas Water Development Board supplemented by field observations. Because of insufficient data, water-level and quality maps could not be constructed for the Van Horn and Cornudas map areas; the data for scattered localities presented on Plate VIII must serve as a very general guide to ground-water conditions in these data-deficient areas. Further discussion is provided in the map-area summaries below.

EDWARDS-TRINITY (PLATEAU) AQUIFER

A large part of University Land is in those counties on the Edwards Plateau that derive their water supplies from the Cretaceous sandstone and limestone aquifers that comprise the Edwards-Trinity aquifer. This includes University Lands in Crockett, Irion, Pecos, Reagan, Schleicher, Terrell, and Upton

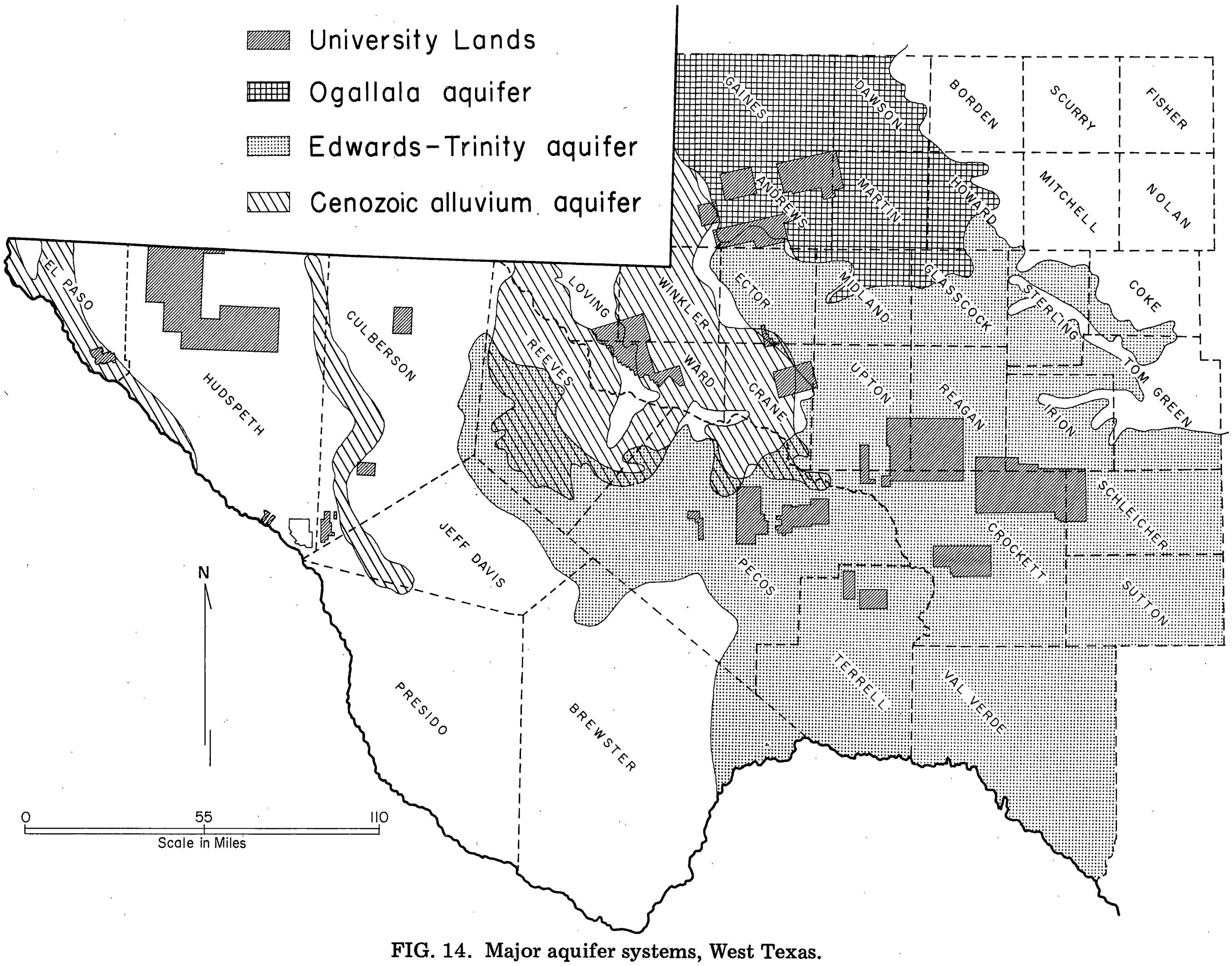


FIG. 14. Major aquifer systems, West Texas.

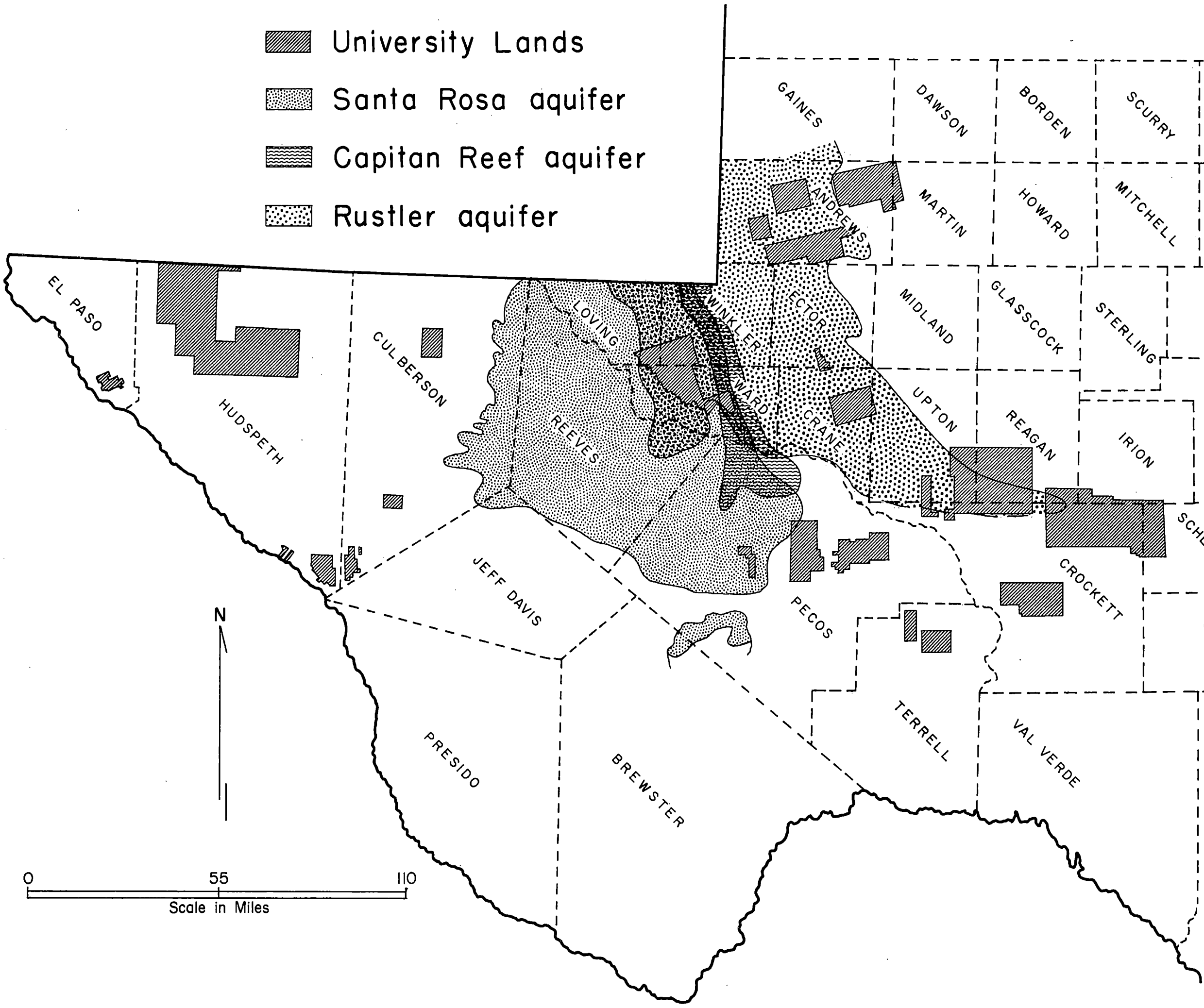


FIG. 15. Minor aquifer systems, West Texas.

counties (Pls. I, II).

The Edwards-Trinity aquifer includes all parts of the Lower Cretaceous rocks that are below the zone of saturation. In the southernmost University Lands in Crockett and Terrell counties, the basal sandstone sequence (Trinity aquifer) and the overlying limestones (Edwards aquifer) are water bearing; updip, to the north in Upton County, the Edwards is above the zone of saturation, leaving the saturated Trinity as the principal aquifer.

Yields in the Edwards limestone aquifer are most commonly 1 to 20 gpm (gallons per minute) with as much as 2,000 gpm in the most permeable sections of the limestone. Most of the water is pumped with windmills for livestock and domestic use, but electric submersible pumps are becoming more popular. The lower or Trinity sands produce more water, on the average, than does the limestone, but it is of poorer quality and is not utilized if water from the limestone is available.

Lithologic variations within the Edwards-Trinity aquifer have been a complicating factor in development of the aquifer system. Many of the sands are lenticular, and the permeability of the limestone is variable. This makes predictions of well success difficult and can make the cost of obtaining a successful well high.

The Edwards aquifer yields water of generally uniform, good quality over most of the University Land in the Big Lake map area. Total dissolved solids range from about 200 to 400 ppm (parts per million); the water is the calcium bicarbonate type with sulfate and chloride less than 50 ppm in most wells (Inglehart, 1967, p. 39). The water is hard but is suitable for most uses.

TABLE 7. *Water-bearing characteristics of geologic units, University Lands area.* (Data summarized from Texas Water Development Board publications. Stratigraphic terminology is generalized and may not coincide with accepted usage in all areas.)

Aquifer System	Ground-water Yield and Quality	Thickness (feet)	Lithology	Unit or Group*	Series or Group*	System
Alluvium	Small amounts of fresh to moderately saline water in some parts of all areas	0-300	Sand, gravel, and some mud along mountains	Alluvium		QUATERNARY
	Moderate to large amounts of fresh to moderately saline water in parts of Monahans, Fort Stockton, and Cornudas areas	0-1,500+	Conglomerate and sandstone near mountains, grading to sandstone and mudstone near basin center	Bolson fill		
Ogallala	Moderate to large amounts of fresh to moderately saline water in part of Andrews area	0-300	Sandstone with some conglomerate and mudstone	Ogallala Formation		TERTIARY
Miscellaneous	Small amounts of water in conjunction with Cretaceous rocks in mountain areas of Van Horn area	0-2,500+	Syenite, lava, tuffs, and associated sedimentary rocks	Volcanic and intrusive igneous rocks		
	Small amounts of water in some areas	0-3,700	Shale, sandstone, marl, and thin limestone beds		Gulf	CRETACEOUS
	Small amounts of water from fractures in Big Lake area	0-100	Light gray, dense, fine-grained limestone	Buda Limestone	Washita	
Edwards-Trinity	Moderate to large amounts of fresh water in Big Lake and Fort Stockton areas	0-400	White to gray, thin-bedded to massive, fossiliferous limestone	Georgetown Limestone		
	No known production	0-70	Clay and marl	Kiamichi Clay		
	Moderate to large amounts of fresh water in Big Lake and parts of Fort Stockton areas	0-800	Thin- to massive-bedded fossiliferous limestone with rudistid reefs and some dolomite	Edwards Limestone	Fredericksburg	
	Moderate to large amounts of water in Big Lake and parts of Fort Stockton areas	0-90	Thin-bedded argillaceous limestone with gypsiferous clay	Comanche Peak Limestone		
	Moderate to large amounts of fresh to moderately saline water in Big Lake and Fort Stockton areas	0-350	Quartz sand and conglomerate with thin limestone beds	"Trinity sand"	Trinity	
	Small amounts of water in conjunction with "Trinity sand"	0-900	Silty and marly limestone	Glen Rose Limestone		
Santa Rosa	Small amounts of saline water in parts of Monahans and Andrews areas	0-1,000	Purple, maroon, and red shale and sandstone	Chinle Formation equivalent	Dockum	TRIASSIC
	Small to large amounts of moderately to highly saline water in Andrews and Monahans areas	0-350	Reddish-brown to gray, medium to coarse-grained sandstone and conglomerate with interbedded shale	Santa Rosa Sandstone		
	No known production	0-270	Red shale, siltstone, and fine sandstone	Tecovas Formation		
Miscellaneous	Small amounts of highly saline water in parts of Monahans area	0-580	Thin-bedded siltstone with some shale	Dewey Lake red beds	Ochoa	PERMIAN
	Small to moderate amounts of moderately to highly saline water in Monahans and Fort Stockton areas	0-500	Anhydrite, gypsum, dolomite, and limestone with some interbedded sandstone and shale	Rustler Formation		
	Small to large amounts of highly saline water in Monahans, Fort Stockton, and Delaware Basin portion of Van Horn areas	0-4,000	Gypsum, anhydrite, and halite with thin limestone units	Salado and Castile Formations		
		700-3,000	Massive limestone flanked on platform and in Delaware Basin by sandstone, shale, and evaporites	Capitan reef complex, Bell Canyon Formation, and equivalent rock units	Guadalupe	
Miscellaneous	No known production	900-1,500	Light gray, fossiliferous limestone and dolomite	Victorio Peak Formation and equivalent rock units	Leonard	
	Small amounts of slightly to moderately saline water in Cornudas area	300-1,500	Dark gray, finely crystalline, thin-bedded limestone underlain by sandstone and conglomerate	Hueco Limestone	Wolfcamp	

Water from the Trinity sand contains 250 to 8,400 ppm total dissolved solids. Sulfate content is high, commonly greater than the limits recommended by the U. S. Public Health Service for drinking water. The water is also hard because of its high carbonate content. However, this water is the only supply available over much of Upton County and eastern Pecos County and is utilized for domestic and industrial supplies. Most University Land in the Big Lake map area is located where better quality water is available from the Edwards; water from the Trinity is extensively utilized only where better quality water from the Edwards is not available.

OGALLALA AQUIFER

Ground water from the Ogallala Formation is the economic base for much of the High Plains of Texas; dependable supplies of good quality water have prompted the development of a major agricultural industry in the Texas Panhandle. The Ogallala aquifer, consisting of sands, muds, and gravels, extends southward into Andrews County and underlies University Lands (fig. 14). Although the Ogallala is considerably thinner in the Andrews map area than it is to the north, wells in northeastern Andrews County produce from as much as 50 feet of water-saturated Ogallala deposits. The water table in this area is generally less than 100 feet below the surface.

The quality of water obtained from the Ogallala in Andrews County is poorer than that in areas to the north. Total dissolved solids are generally above 500 ppm and in places exceed 1,000 ppm. In some areas fluoride is in excess of the 1.5 ppm recommended by the U. S. Public Health Service. Total hardness ranges from 252 to 640 ppm; sulfate and chloride are each less than 250 ppm. The water is suitable for drinking in most areas and for irrigation in all areas (Cronin, 1964).

SANTA ROSA AQUIFER

The Triassic Santa Rosa Sandstone, a minor aquifer, is a source of ground water in some parts of University Lands (fig. 15). It is the principal source of fresh water in Winkler County and is utilized to a lesser extent in Andrews, Ward, Loving, Ector, Crane, and Upton counties. Water derived from the southern limits of the Santa Rosa aquifer in Upton County is very saline; most is used for livestock and little is suitable for human consumption.

In Winkler County the Santa Rosa Sandstone is separated from the overlying alluvium by the Chinle Formation equivalent (sand and shale) over much of the area, but locally it is missing, and the Santa Rosa and alluvium are hydrologically connected. The Santa Rosa yields small to large quantities of water to wells; near Kermit, wells yield more than 1,000 gpm where they tap fractured Santa Rosa Sandstone (Garza and Wesselman, 1959). The Santa Rosa ranges from 0 to nearly 350 feet in thickness and is from 1,100 to 1,800 feet below the land surface.

The quality of water from the Santa Rosa is generally fair to poor; most contains more than 1,000 ppm dissolved solids and some more than 3,000 ppm. Sulfate and chloride commonly exceed 250 ppm and in some wells are nearly 1,000 ppm each. Fluoride commonly exceeds the recommended 1.5 ppm and the water is hard. Better quality water is available from the Santa Rosa in the western area, and poor quality water occurs in the east and southeastern areas. Locally, the quality has been reduced further by contamination due to disposal of oil-field brines in unlined pits.

ALLUVIUM AQUIFERS

Alluvium filling structural basins and stream valleys is the primary source of water in several areas that include University Lands. These aquifers vary greatly in thickness and are hydrologically complex; the alluvium is a separate aquifer in some areas whereas in others it is hydrologically connected with one or several bedrock aquifers. In the upper part of the Pecos River basin in Texas, in Winkler, Crane, Ward, Loving, Pecos, and Reeves counties, alluvial basin fill as much as 2,500 feet thick yields large volumes of water. Alluvium is an important source of ground water on University Lands in the Monahans, Van Horn, and southwestern Cornudas map areas.

The alluvium in the structural basins grades from gravel and sand near the basin margins to sand, silt, and mud near the basin centers. The best quality water and the highest yields come from the zone of highest sand concentration that occurs near the edges of the relatively flat basin floors. Water quality is variable, but most is suitable for irrigation and much is potable. Shallower wells tend to yield higher quality water than do deeper ones, and wells near the Pecos River yield poorer quality water than those in other areas. Total dissolved solids range from 200 to more than 13,000 ppm. Sulfate and chloride are generally high in comparison to bicarbonate. Most water from the alluvium aquifer is used for irrigation, but several municipalities in Crane, Pecos, Ward, and Winkler counties obtain some or all of their water supplies from the alluvium aquifer.

Alluvium other than that in deep basins provides water for agricultural and domestic supplies. Ground water in the Rio Grande channel and flood-plain deposits supplies mineralized water in the Fabens area of the Cornudas map area. Alluvium along stream channels and in arroyos furnishes some water for stock and domestic use in all parts of University Lands areas, but these supplies are commonly seasonal and undependable on a long-term basis.

MISCELLANEOUS AQUIFERS

Several aquifers that are important in areas adjacent to University Lands or that are utilized in scattered areas supply water in limited sections of University Lands. These include various rocks of Permian age (Hueco Limestone, Capitan Reef complex, and Rustler Formation) and fractured rocks of various ages in the mountainous areas of the Van Horn map area. Permian rocks are secondary aquifers in Ward, Winkler, Loving, and Pecos counties and a primary aquifer of local importance on University Lands in northern Hudspeth County in the Cornudas map area.

Water from the Rustler Formation is generally unsuitable for human consumption and where developed is used for irrigation and stock watering. Total dissolved solids exceed 2,000 ppm in most places and commonly as much as 6,000 ppm. The water is high in sulfate and relatively low in chloride and bicarbonate; hydrogen sulfide is also present.

The Capitan Reef complex yields water that, like the Rustler water, is unfit for human consumption but is used to some degree for irrigation and to a larger extent for oil-field waterflooding. The aquifer is very deep--thus wells are expensive--but it is a good source for waterflooding in its limited area of occurrence.

The Hueco Limestone and associated conglomerate yield small amounts of water over much of the northern portion of the Cornudas map area. It, and locally underlying Paleozoic rocks, is the only reliable supply of water over much of this area. Yields are small and wells must be drilled 800 to more than 1,000 feet to obtain water; zones of suitable permeability are not continuous and unsuccessful wells are to be expected.

Fractured rocks of various types and ages supply limited quantities of ground water in the mountainous areas of the Van Horn map area. The water is used primarily for livestock. Yields are small and there are no reliable criteria to be offered for locating successful wells.

Summary of Ground-Water Occurrence by Map Area

BIG LAKE AREA

Dependable supplies of good-quality water are available in most parts of the Big Lake map area. The principal aquifer with the highest water quality is the Edwards Limestone; most wells are completed in this formation where it is below the zone of saturation. In the western and northern parts of the Big Lake map area, the Edwards is above the saturated zone, and the underlying Trinity sandstone is the principal water source. Yields from the Trinity are generally greater than from the Edwards, but the water quality is lower. Alluvium in the larger draws supplies ground water in many local areas.

Water quality in the Big Lake area is generally good; many wells, particularly in the Edwards, produce water with total dissolved solids less than 500 ppm (Pl. VIII) and nearly all water is suitable for human, agricultural, and industrial use. Ground water is very hard and tends to be high in fluoride. Contamination by oil-field brines has been a problem in some areas.

The Big Lake map area has a large potential supply of ground water. The chief limiting factor for development is the nature of the aquifer system; zones of suitable permeability are irregular and yields therefore variable. Yields are more consistent in the underlying Trinity aquifer.

FORT STOCKTON AREA

Trinity sandstones furnish most of the ground water in the eastern third of the Fort Stockton map area; yields of as much as 500 gpm are utilized as domestic, agricultural, and industrial supplies. The overlying limestones are above the zone of saturation in most of the area, but locally they yield small quantities of water.

Throughout most of the Fort Stockton map area the principal aquifer is interconnected alluvium and bedrock, chiefly the Trinity sandstone; this aquifer complex has been termed the Pecos aquifer by the Texas Water Development Board. It has been extensively developed for irrigation supplies and is also utilized for waterflooding operations. Fort Stockton, Imperial, and McCamey obtain municipal supplies from the Pecos aquifer. The extensive development of this aquifer since World War II has lowered the water table drastically in some areas, and most springs have declined in flow or dried up.

Deeper Permian formations, chiefly the Rustler and San Andres, yield water in a few wells; the water is highly mineralized and suitable only for irrigation and waterflooding operations. The great depth of these aquifers and the poor water quality currently restrict their use.

Most water derived from the Trinity sandstone and from the alluvium Trinity aquifers has more than 1,000 ppm total dissolved solids and commonly as high as 2,500 ppm. Sulfate and chloride are high. The water decreases in quality toward the Pecos River to the north.

MONAHANS AREA

Water supplies in the Monahans map area are derived from alluvium and from the Santa Rosa Sandstone. The alluvium yields large quantities of water having a total dissolved solids content of from 200 to 13,000 ppm; most is suitable for drinking, nearly all is suitable for irrigation. This water has also been used for waterflooding by itself and as a dilutant for more mineralized waters. The Santa Rosa aquifer is utilized chiefly for irrigation, waterflooding, and municipal supplies. The water is high in sulfate and fluoride; total dissolved solids range from 55 to 3,600 ppm.

Water from deeper Permian formations, chiefly the Rustler Formation, is available but is saline and unfit for human consumption. Potential use for this water is in oil-field waterflooding operations.

As in nearly all areas on University Lands, contamination of fresh-water supplies by oil-field brine is a fact and a potential danger. Deterioration in quality resulting from circulation of irrigation water high in dissolved solids has occurred in some areas.

ANDREWS AREA

Ground-water supplies in the Andrews map area are obtained from the Santa Rosa Sandstone, Ogallala Formation, and from alluvium. Alluvium is most important in the southwestern part of the area; the Ogallala and Santa Rosa furnish water over most of the rest of the area. Water from the Ogallala is shallow, 50 to 150 feet in most areas, and is suitable for most uses; total dissolved solids range from 300 ppm to 1,200 ppm in most areas. Water from the Santa Rosa is available over most of the map area. Dissolved solids range from about 300 ppm to several thousand ppm; the water is hard but is suitable for irrigation, waterflooding, and for domestic supplies where other sources of water are lacking. Cretaceous rocks are sources of ground water in the southern part of this map area.

VAN HORN AREA

No major fresh-water aquifers underlie University Lands in the Van Horn map area. Small supplies of water for domestic and livestock use are obtained locally from fractured rocks in the mountain areas and from alluvium along the mountain flanks. Because of insufficient data, water quality and piezometric maps could not be constructed for this area. Block 46, for example, has no recorded wells and ground-water conditions there are unknown. Because the area is underlain by evaporites, chances for large amounts of good quality water are not good.

CORNUDAS AREA

Alluvium supplies water to wells in the Fabens portion of the Cornudas map area. Moderately mineralized water from bolson deposits and Rio Grande alluvium is used for irrigation and domestic supplies. Alluvium along the larger draws in the University Lands area provides small, intermittent supplies for livestock use.

Lower Permian limestone and conglomerate yield small quantities of potable water at depths of 800 to 1,000 feet over parts of the Cornudas map area. Data are too sparse for regional evaluation. Lack of continuity of permeability makes ground-water exploration a speculative operation in this area.

SULFUR

Introduction

The following discussion of sulfur is taken chiefly from a comprehensive report on the geology and economics of sulfur in West Texas by J. B. Zimmerman and Eugene Thomas published by the Bureau of Economic Geology in 1969 as Geological Circular 69-2.

Sulfur is a basic raw material for the chemical industry; it has hundreds of uses, but most is used in the manufacture of fertilizers, fibers, papers, pigments, pharmaceuticals, and explosives. This important role ranks sulfur with coal, salt, and limestone as key materials in an industrial economy.

Surface occurrences of sulfur in West Texas were reported in the mid-19th century, and studies of these localities were undertaken in the early part of the 20th century. A few small shipments were made, but it was not until 1967 that large-scale sulfur exploration began in West Texas following the success of Duval Corporation's Frasch pilot operation near Fort Stockton. Exploration was also spurred by the short supply of sulfur and resulting high prices. Sulfur exploration activity in West Texas is related directly to market value; only when value is high are exploration and production in this area attractive to the larger corporations.

Occurrence

Surface shows of sulfur are fairly common in Permian rocks (Castile Formation) immediately east of University Lands Block 46 in the Van Horn map area (fig. 16). Subsurface shows have been reported from hundreds of oil wells drilled into Paleozoic formations. The most significant shows have been in Permian rocks along the western edge of the Delaware Basin and south of the Central Basin Platform (fig. 17).

The sulfur is associated with interbedded evaporites and limestone. The richest zones are in limestone and dolomite where the high porosity of these rocks has been an important factor in concentrating sulfur. As sulfur content increases gypsum decreases, and calcite, nearly always associated with sulfur, increases. In the Permian Basin complex the limestone host rocks generally grade laterally into gypsum and anhydrite. Figures 18 and 19 illustrate the stratigraphic relationships of Permian sulfur-bearing rocks in University Lands Block 26 near Fort Stockton.

Mining and Processing

West Texas sulfur is mined by the Frasch process which consists of melting the sulfur in place with heated water and forcing the molten sulfur to the surface with compressed air. This is accomplished through three nested strings of pipe in a well drilled into sulfur-bearing limestone. The process requires a dependable supply of relatively good-quality water or of poor-quality water that can be treated to make it suitable for injection. The nucleus of a Frasch plant is the water heaters, and the greatest expenditures are for their construction and fuel for their operation.

Dependable water supplies and abundant cheap fuel are necessary for a Frasch plant to be an economic success. Fuel, in the form of natural gas, is readily available throughout most of the West Texas area, and suitable water has been obtained for present operations. Water is the most tenuous resource in the operation because supplies are distant from plants that are located in the Delaware Basin area. Long pipelines increase plant costs considerably, and serious legal complications could result from heavy drafts on ground-water supplies normally used for agriculture. This is especially true for plants that now obtain their water supplies from alluvial gravels near the Davis Mountains; these gravels are an important aquifer for agricultural water, and heavy demands by Frasch operations could lower the water table considerably.

Because mining is accomplished by wells, development costs are generally low compared with underground or open-pit operations. However, if large numbers of wells are needed because of the geometry of the deposit or limited life of individual production wells, mining costs might be high.

Production

Sulfur is currently being produced at several localities near, but not on, University Lands. University Lands have been explored, sulfur is present, and production potential is good. In 1967 the University leased 10,000 acres on trend with Duval's Fort Stockton plant.

Sinclair Oil Company built a pilot plant in Pecos County near Fort Stockton in 1967 and announced expansion of the facility in 1968. Production in 1969 averaged about 300 long tons per day. The sulfur occurs at depths of about 160 to 750 feet; the water used to mine it is obtained locally from the Rustler Formation at a depth of about 150 feet.

Duval Corporation constructed a plant near Fort Stockton in 1967 with a capacity of 500 long tons of sulfur per day; later that year they announced plans for doubling the capacity of the plant. The rate of production in 1969 was about 800 long tons per day. The sulfur occurs at depths of 250 to 800 feet; the water for mining is obtained on site from the San Andres Formation at a depth of about 2,000 feet.

Duval also constructed a Frasch plant 18 miles southwest of Orla in Culberson County. Anticipated expansion of the facility will make it the largest sulfur mine in the United States and probably the largest in the world with a design capacity of 1.5 million long tons of sulfur per year and a capability for 2.5 million long tons. Sulfur occurs at depths of 240 to about 1,250 feet. Water is ob-

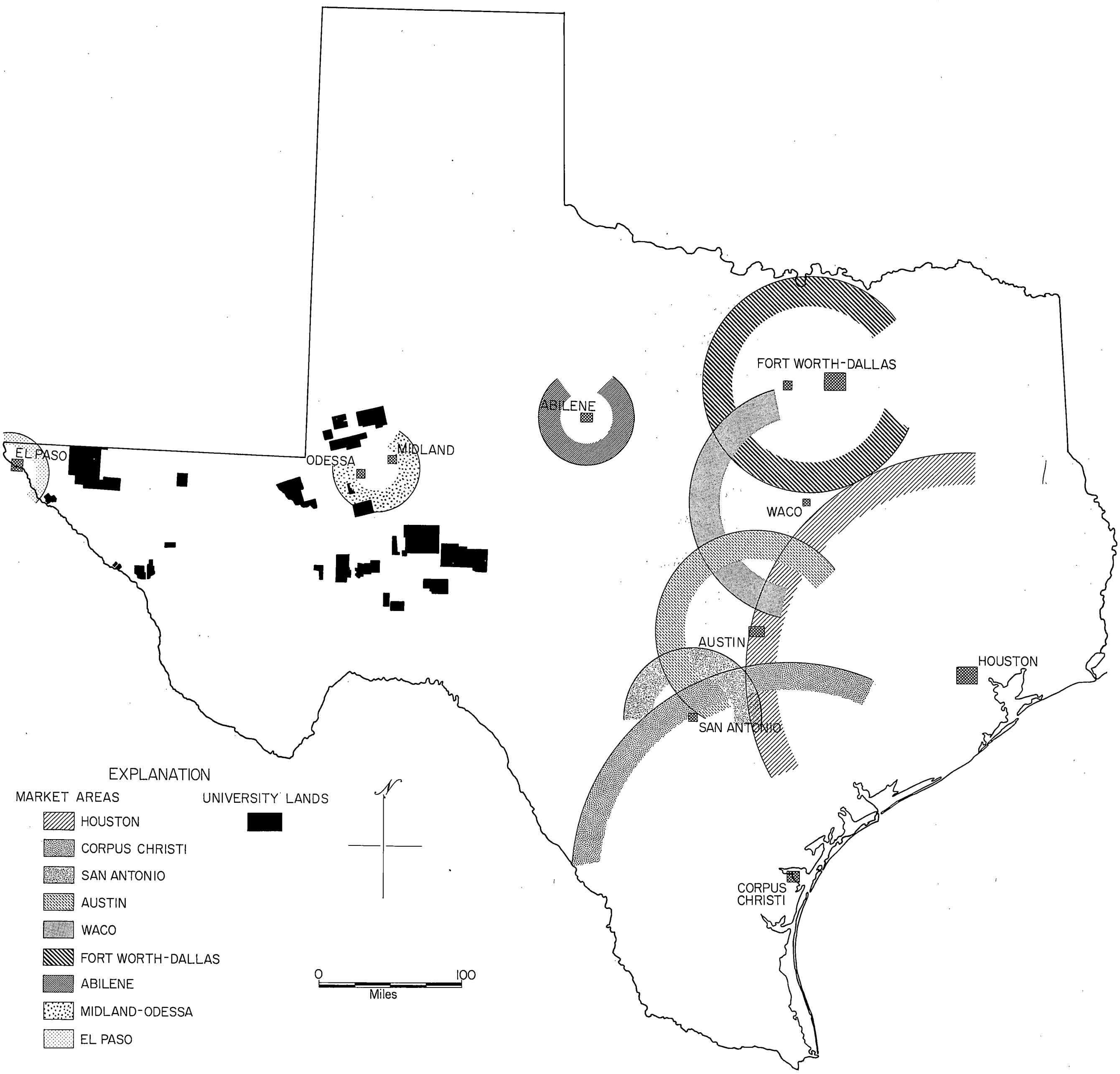


FIG. 16. Sulfur occurrences and mining operations, eastern Culberson County, Texas (from Zimmerman and Thomas, 1969).

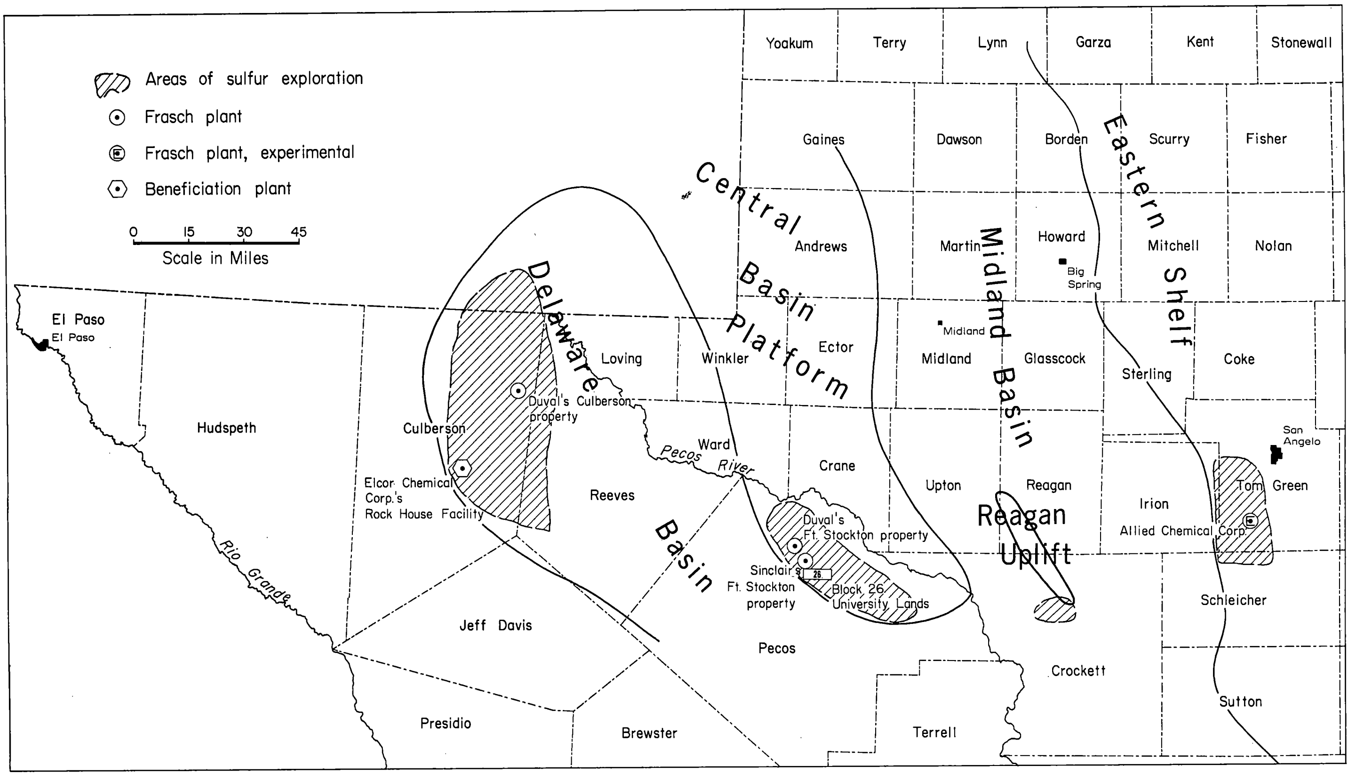


FIG. 17. Index to sulfur deposits and developments in West Texas (from Zimmerman and Thomas, 1969).

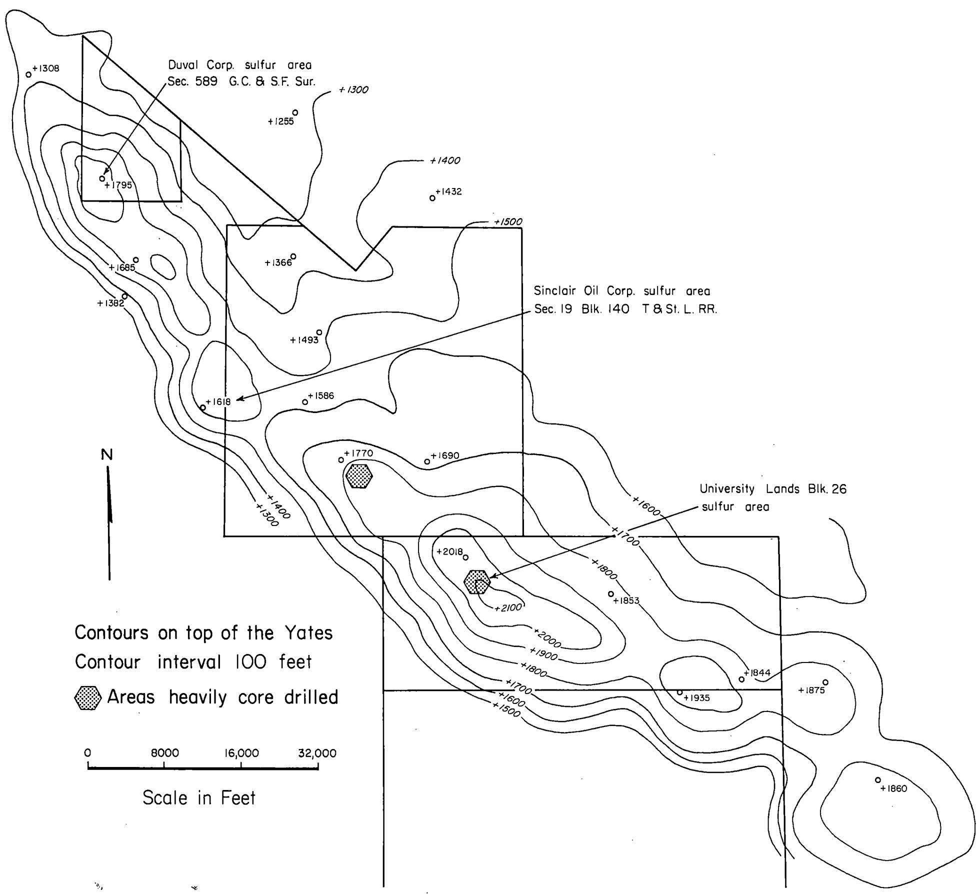


FIG. 18. Occurrence of sulfur in Fort Stockton area, Pecos County, Texas (from Zimmerman and Thomas, 1969).

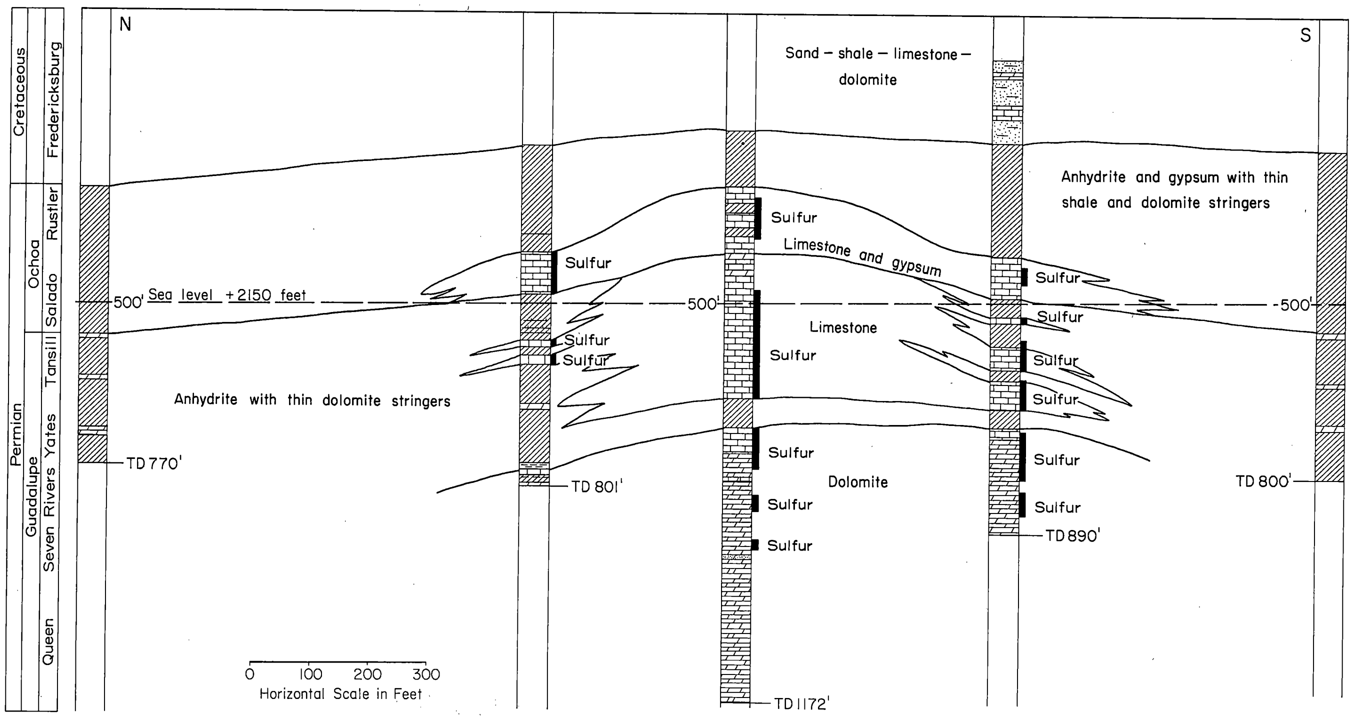


FIG. 19. Stratigraphic distribution of sulfur, University Lands Block 26, Fort Stockton area, Pecos County, Texas (from Zimmerman and Thomas, 1969).

tained from alluvial gravels near the Davis Mountains about 38 miles southeast of the plant.

Elcor Chemical Corporation has constructed a plant to extract sulfur from gypsum in Culberson County about 40 miles northeast of Van Horn. Announced costs of the facility were $24 million plus more than $2 million for land acquisitions. Gypsum is mined by open-pit methods; Elcor has estimated it will require between 9.5 and 11.7 short tons of gypsum to recover 1 long ton of sulfur. This process, if successful and economically competitive, holds great promise for the Delaware Basin area, including University Lands Block 46 in the Van Horn map area, because of the vast supplies of gypsum available. The plant has been plagued with design and operational difficulties along with current low prices for sulfur; production, originally scheduled for April 1969, has not yet occurred.

Sulfur is shipped in molten form by rail; spur lines to plants are necessary. Railroad facilities are available in the West Texas area and have been utilized by operating plants.

Economic Considerations

Sulfur has an irreplaceable role in the industrial economy and as the economy grows and industrialization increases, so will the demand for sulfur. It is not the demand for sulfur, then, that is the primary economic consideration in evaluating the future for West Texas Frasch sulfur; rather it is the ability of sulfur from this area to be competitive on the open market. Sulfur exploration has come to West Texas only during times of short supply and high prices, especially during periods of high prices. Most recently the price of sulfur has declined considerably in response to Canadian imports of low-cost sulfur recovered from sour gas and other imports; currently, exploration in West Texas has practically ceased and active producers have curtailed plant operations. Improvements in other methods for obtaining sulfur, notably sour-gas recovery, could likewise make Frasch production of sulfur uneconomic in West Texas.

Sulfur production has increased steadily over the past two decades and projections show similar or greater growth through 1986 (fig. 20). Frasch production of sulfur accounts for more than 70 percent of total sulfur in the United States since 1940 (fig. 21). Before Frasch production began in West Texas, all Frasch sulfur in Texas was produced from cap-rock deposits on Gulf Coast salt domes. Coastal domal deposits have the advantage of location in and near the Gulf Coast industrial complex; West Texas producers must bear high transportation costs. Although Gulf Coast sulfur will hold a

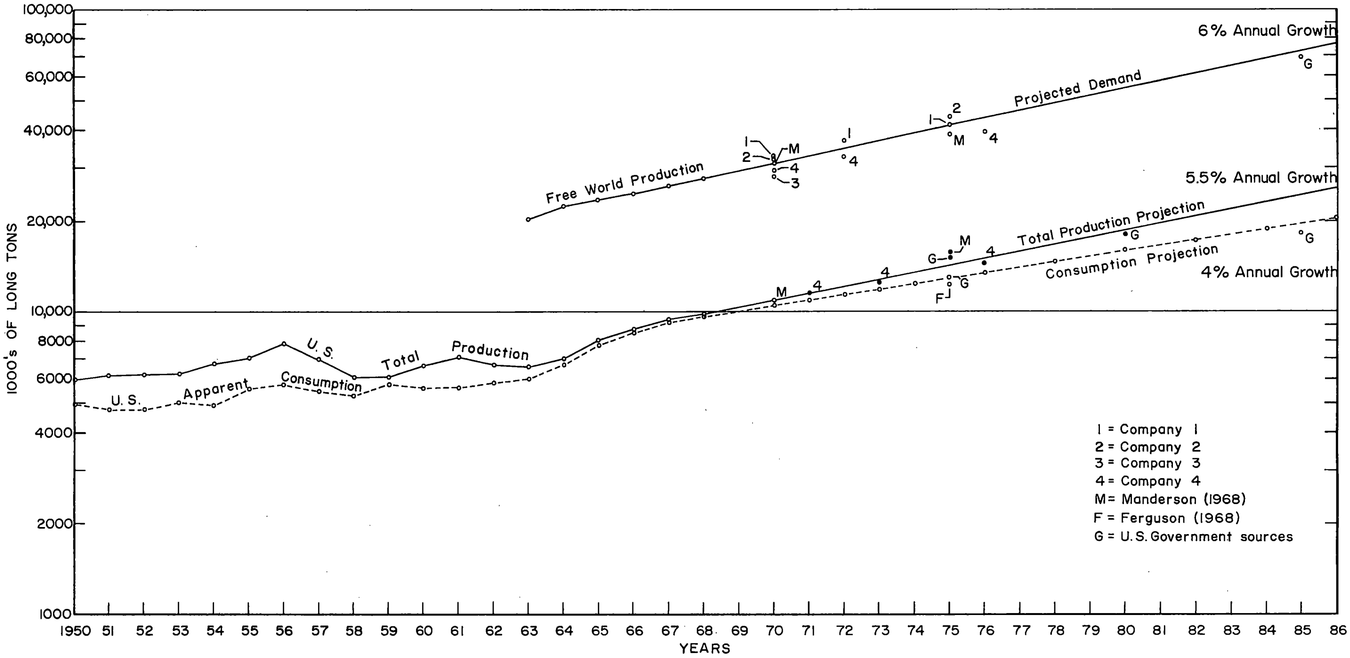


FIG. 20. United States and Free World sulfur production and consumption, with projected demands through 1986 (from Zimmerman and Thomas, 1969).

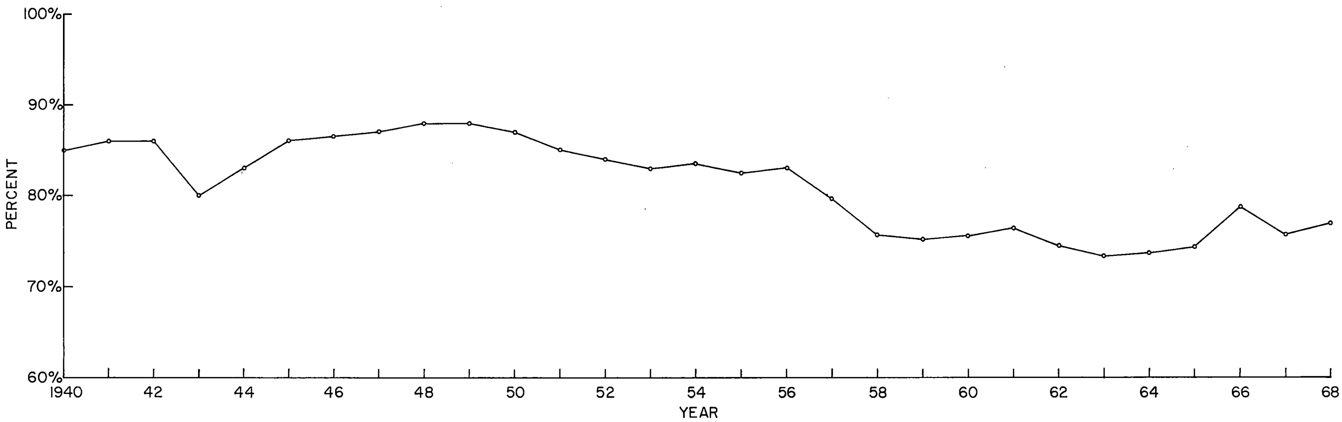


FIG. 21. Production of Frasch sulfur in the United States, 1940-1968 (from Zimmerman and Thomas, 1969).

commodity lead in the immediate future, a significant part of the total reserves of that area has been depleted.

Sulfur prices rose to $42 per long ton in 1968 as a result of short supply that was caused by several factors including accelerated increases in fertilizer demand and smaller than expected Mexican imports. By 1969 prices had declined to about $38 per long ton and in mid-1970 were below $15. Recently developed processes for removing sulfur from smokestack gases of petroleum-fueled industries and from sulfuric acid operations have also adversely affected the future for West Texas sulfur. If the demand for sulfur doubles by 1981, as projected (fig. 20), the long-range outlook for West Texas Frasch sulfur should be considerably enhanced.

Produced Frasch sulfur costs about $15 to $20 per long ton including royalties and depreciation; transportation to the Gulf Coast costs about $5.50 to $8.00 per ton. These costs are expected to increase as exploration costs increase. Plant construction costs about $900 to $1,500 per 1,000 gallons daily heating capacity, depending on total capacity. Given these costs under present conditions, exploration for sulfur in West Texas will probably continue as long as prices are above $30.

SALT

Introduction

The Permian Basin, which occupies an area in excess of 300,000 square miles in eastern New Mexico, western Texas, western Oklahoma, eastern Colorado, western Kansas, and south-central Nebraska, contains significant quantities of common salt. The Permian salt beds in western Texas and eastern New Mexico cover an area of approximately 90,000 square miles and contain about 25,000 cubic miles of salt (halite) (Adams, 1963). The Permian salt has been delineated almost entirely from wells drilled for oil and gas.

Occurrence

Salt underlies approximately one-half of all University Lands in the West Texas area (Pl. IX). There are no salt deposits underlying University Lands in Culberson, Hudspeth, and El Paso counties and portions of University Lands in Pecos, Crockett, Irion, and Schleicher counties. Approximately 1,470 square miles of University Lands are underlain by salt. The salt thickness map (Pl. IX) indicates that this area contains approximately 280 cubic miles of salt.

Salt deposits under University Lands are primarily Permian (McKee et al., 1967a, b).

Production and Utilization

At the present time no salt is being mined from the Permian salt beds of West Texas. Although vast quantities of salt are at depths and of thickness (Pl. IX) suitable for conventional shaft and pillar mining methods, lack of local markets has precluded development.

Salt produced in Texas in 1968 amounted to 8,534 short tons with a value of $42,663,000 (Netzeband and Girard, 1970). All production was from salt domes in the Gulf Coast and East Texas areas. The vast supplies of salt available in these areas is in close proximity to the industrial complex of the Gulf Coast. Salt, like limestone and other low-value resources, has little or no economic value unless located near existing heavy chemical complexes.

Salt has more uses than almost any other mineral. The chemical industry consumes two-thirds of all the salt produced; most of it is used in the production of chlorine and soda ash. The food-growing and processing industry uses large quantities of salt, as do state, county, and municipal highway departments for melting ice and snow on highways.

Exploration

The presence, depth, and thickness of the Permian salt have been determined almost entirely from data derived during the drilling of wells for oil and gas. Thousands of wells drilled through the Permian section have accurately defined the areal extent and volume of salt.

Prior to extensive use of rotary drilling methods, wells were drilled by standard rigs (cable tools), and drill cuttings of salt were recovered which could be examined and the quality of salt determined. In rotary drilling, water or mud is used to circulate the drill cuttings up from the well bore and little of the soluble material, such as salt, is recovered. Electrical logs, radioactivity logs, and other types of logging equipment used extensively in conjunction with rotary drilling can be used to identify the salt sections in the well bore.

Future Potential

Salt, in combination with other raw materials, can be a locating factor for large-scale industrial development. This combination of resources and transportation facilities occurs along the Gulf Coast. Several of the elements that located the industrial complex along the Gulf Coast are present in West Texas, notably energy resources (oil and gas), salt, and sulfur. Lacking, however, are two essential elements offered by the coastal region: easy and cheap means of transportation on a regional and international scale and a large supply of good-quality water. The isolation of the West Texas area from other industrial complexes and from domestic markets is another factor working against the establishment of an industrial complex in the area in the foreseeable future.

POTASH

Introduction

Potash is an important agricultural and industrial material obtained from evaporites and associated brines. Sources in the United States include brines in Searles Lake, California and in lakes in Nebraska, salt marshes near Salt Lake City, Utah, and Permian evaporite deposits in Texas, New Mexico, Oklahoma, Kansas, and Colorado (Ruhlman, 1960). The most extensive commercial development of potash is in the New Mexico portion of the Permian evaporites. Large areas of University Lands are within this same evaporite basin, and potash minerals have been reported from many oil and gas wells.

Definition

Potash salts are potassium-rich sulfate and chloride minerals generally containing significant amounts of magnesium, calcium, or sodium. The names and chemical compositions of some of the more common potash minerals are given in table 8.

TABLE 8. *Potassium minerals* (after Cunningham, 1934).

Carnallite	$KCl.MgO_2 \cdot 6H_2O$
Glaserite	$KNaSO_4$ or $K_3Na(SO_4)_2$
Kainite	$KCl.MgSO_4 \cdot 3H_2O$
Krugite	$K_2SO_4 \cdot MgSO_4 \cdot 4CaSO_4 \cdot 2H_2O$
Langbeinite	$K_2SO_4 \cdot 2MgSO_4$
Leonite	$K_2SO_4 \cdot MgSO_4 \cdot 4H_2O$
Pentasalt	$5CaSO_4 \cdot K_2SO_4 \cdot H_2O$
Polyhalite	$K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$
Schönite	$K_2SO_4 \cdot MgSO_4 \cdot 6H_2O$
Sylvinite	yNaCly Kcl (an eutectic mixture of halite and sylvite)
Sylvite	KCl
Syngenite	$K_2SO_4 \cdot CaSO_4 \cdot H_2O$

The potash mineral polyhalite is reported most commonly in descriptions of well cuttings, although carnallite, kainite, langbeinite, leonite, and sylvite have also been reported in the Permian salt deposits of southeastern New Mexico and West Texas (Schaller and Henderson, 1932).

Occurrence and Exploration

The first report of potash in Texas was made by J. A. Udden who identified potassium chloride in a sample of water taken from a well near Spur, Dickens County, Texas in 1912 (Udden, 1914). A later report (Udden, 1915) described drill cuttings from several wells that penetrated the Permian salt beds and had showings of potash salts. None of these wells, however, was on University Lands.

Prior to World War I, the United States depended largely on Germany for its supply of potash. Between 1918 and 1921 a cooperative effort by the Bureau of Economic Geology and the United States Geological Survey was undertaken to gather and examine well cuttings from evaporite sequences in the West Texas area as part of a program seeking new sources of potassium salts. The United States Congress in 1926 authorized funds for a five-year period of joint exploration for potash by the United States Bureau of Mines and the Geological Survey. Twenty-three core tests were made in the Permian Basin of West Texas and New Mexico. Seventeen of these tests showed enough polyhalite to be of possible economic interest; twelve revealed significant amounts of sylvite, carnallite, or langbeinite (Mansfield and Lang, 1935).

Since the period 1918-1934 potash exploration has been inactive, but potash has been reported from numerous wells in the West Texas portion of the Permian Basin including large areas of University Lands (table 9; Pls. IX, X). Polyhalite was the only mineral noted on the available drillers' logs, but generally mineral types were not recorded. Modern rotary drilling techniques, using mud or water as a circulating medium, do not lend themselves as readily to the detection of potassium salts as did older percussion methods that provided chips of material from soluble evaporite sections. Analytical techniques have been developed, however, to detect potassium in the drilling fluid in which the salts are dissolved during drilling (Anderson and Majeske, 1970), and gamma ray logging is also useful in detecting potassium minerals.

The general geology of the potash-bearing Permian salt beds is described in the previous section on salt. The commercial potash operations in New Mexico extract potassium minerals from sequences of interbedded halite and soluble potash of the upper Castile or Salado Formation that was deposited in shallow lagoons near the western margins of the Permian Basin behind and over the Capitan reef complex. The deposits are generally undisturbed, flat lying, and have a uniformly high potash content (Kroenlein, 1939); sylvite, which is highly soluble in water, is the chief ore mineral.

Polyhalite is the chief potash mineral in the Texas portion of the Permian Basin, and the Texas deposits are much less desirable than those in New Mexico. Although widespread, polyhalite has low potash content, has relatively low solubility in water, and is interbedded with insoluble anhydrite (Kroenlein, 1939). These factors make commercial exploitation unlikely, at least until the better grade New Mexico potash has been exhausted.

TABLE 9. *Potash shows, University Lands.*

Block	Section	Operator	Top Salt (feet)	Elevation (feet)	Subsea Top Salt (feet)	Thickness (feet)	Potash Shows (depth feet)
				ANDREWS COUNTY			
9	42	Skelly	1721	3154	+1433	1921	2310, 2416, 2833
10	14	Phillips	1590	3305	+1715	1145	2850
11	2	Stanolind	1776	3311	+1535	821	1905
11	35	Phillips	1866	3258	+1392	826	2677, 2875
13	10	Gulf	2097	3272	+1175	-	2240, 2632
				ECTOR COUNTY			
35	1	Cosden	1065	2921	+1856	1105	1480, 1560, 1650, 1705, 1945, 2050
35	2	Amerada	1245	2897	+1652	1235	1535, 1680, 1725, 1895, 2080
35	3	Landreth	1400	2870	+1470	1605	1530, 2000, 2100
35	4	J. P. Cusack	1170	-	-	1605	1170, 1180, 1275, 1460, 1590, 1790, 1990
35	5	Atlantic	1313	2854	+1541	1002	1313, 1350, 1467
35	6	Atlantic	1177	2841	+1664	1323	1400, 1650, 1670, 1834
35	7	Atlantic	1050	2831	+1781	1455	1209, 1358, 1380, 1463, 1678, 1825, 1876, 1926, 2425, 2505
35	8	Kewanee	1114	2822	+1708	1511	1150, 1165, 1235, 1270, 1285, 1345, 1365, 1385, 1415, 1505, 1560, 1580, 1590, 1685, 1720, 1740, 1860, 1920, 1924
35	9	CSO	1135	2825	+1680	1670	1285, 1335, 1350, 1485, 1500, 1510, 1615, 1645, 1685, 1825, 1835, 1925, 1960, 2005, 2030
35	10	J. E. Simon	1250	2810	+1560	865	1270, 1315, 1440, 1615, 1735, 1910, 2075
				CRANE COUNTY			
30	4	Gulf	1604	2660	+1656	1662	2387, 2633
30	5	General American	1910	-	-	215	1910
30	6	General American	1265	2666	+1401	980	1280, 1420, 1515
30	7	Texaco	1575	2642	+1067	493	1750
30	8	General American	1290	2628	+1338	810	1976, 2100
30	15	Mobil	1325	2637	+1312	775	1745, 1830, 1940
30	16	Mobil	1340	2634	+1294	795	1435, 1745
30	17	Atlantic	1398	2627	+1229	594	1788, 1992, 2100
30	18	Atlantic	1268	2630	+1632	872	1635, 1890, 2020, 2255
30	21	Kenwood	1260	2616	+1365	835	1355, 1870, 2010
30	22	Kewanee	1270	2627	+1357	805	1270, 1310, 1465, 1515, 1553, 1600, 1630, 1740, 1870, 2025
30	23	McMillan	1365	2615	+1250	1321	1495, 1541, 1570, 1679, 1693, 1738, 1822, 1837, 1848, 1970, 2000, 2085, 2162
30	24	Humble	1120	-	-	810	1260, 1350, 1365, 1450, 1520, 1555, 1630, 1715, 1775, 1930
30	27	R. D. Goldston	1320	2614	+1274	800	2120
30	28	Kewanee	1175	2597	+1422	1209	1175, 1260, 1380, 1550, 1638, 1695, 1805, 1865, 1879,1990
30	32	Atlantic	1125	2579	+1454	1375	1400
30	33	Gulf	1078	2562	+1484	817	1180, 1265, 1370, 1400, 1545, 1690, 1805, 1895

TABLE 9 (continued).

Block	Section	Operator	Top Salt (feet)	Elevation (feet)	Subsea Top Salt (feet)	Thickness (feet)	Potash Shows (depth feet)
			CRANE COUNTY (continued)				
30	34	Humble	1117	-	-	833	1235, 1350, 1405, 1480, 1690, 1835, 1890
30	35	Gulf	1165	2608	+1443	1338	1300, 1340, 1475, 1535, 1550, 1775, 1800, 1945, 1965
30	36	Signal	1667	2632	+965	925	2366
30	37	Humble	1459	2612	+1153	784	1702, 1982
30	38	Ballard	1240	2581	+1341	780	1420, 1475, 1587, 1690, 1800, 1910, 1965
30	39	Kewanee	1030	2553	+1523	810	1163, 1225, 1265, 1317, 1380, 1413, 1440, 1554, 1630, 1660, 1728, 1840
30	40	Humble	1020	-	-	1370	1110, 1120, 1150, 1215, 1250, 1340, 1390, 1420, 1475, 1495, 1570, 1635, 1795
30	41	Kewanee	1032	2542	+1510	811	1089, 1105, 1210, 1230, 1250, 1341, 1465, 1478, 1498, 1652, 1668, 1750, 1785
30	45	Amerada	1000	2540	+1540	775	1185, 1250, 1325, 1385, 1405, 1520, 1610
30	48	F. Frawley Drlg. Co.	1290	-	-	760	1740, 2050
35	9	Gulf	1100	2804	+1704	1500	1285, 1370, 1395, 1600, 1690, 1695, 1800, 1860, 1885, 1965, 1978, 2020, 2040
35	11	Gulf	1338	-	-	1412	1528, 1670, 1708, 1785, 1825, 1831, 1840, 1940, 1995, 2090, 2095, 2135, 2170, 2202, 2523
35	12	Atlantic	1343	2805	+1462	1260	1530, 1820, 1930, 2100
35	13	Sinclair	1660	2797	+1137	425	1665, 2035
31	2	Gulf	1397	2659	+1262	1303	1765, 2000, 2408, 2541
31	3	Gulf	1186	2668	+1482	1112	1553
31	22	Atlantic	1360	2589	+1229	670	2030
31	23	Beard & Tullous	1770	2588	+818	1200	1810
31	28	Atlantic	1050	2563	+1513	1474	1210, 1515
31	29	Atlantic	1375	2550	+1175	680	1858
31	34	Atlantic	1320	2559	+1239	700	1110, 1813
31	36	Prairie Oil & Gas	965	-	-	990	1190, 1230, 1420, 1705, 1850, 1950, 1955
31	39	Atlantic	1697	2549	+852	1209	1697
13	3	Gulf	1610	2654	+1044	935	1941
17	30	Hancock	1320	2618	+1298	1710	1960, 3030
40	30	R. A. Barger	1100	2556	+1456	615	1090, 1445, 1715
			CROCKETT COUNTY				
14	5	G. A. Henshaw	455	2297	+1842	500	580, 595, 605, 725, 800, 955
14	11	CSO	514	2332	+1818	146	514, 555, 570, 645, 660
14	12	T. P. Coal & Oil	435	-	-	290	435, 455, 480, 510, 600, 725
14	13	Harry Black	593	2321	+1728	162	593, 695, 705
14	15	Choate & Hogan	685	2356	+1671	80	685
14	17	Gilcrease	415	-	-	455	415, 490, 575, 600, 630, 670, 685, 775, 790
14	18	Gilcrease	475	2430	+1955	345	475, 820
14	19	Gilcrease	545	-	-	255	625, 680, 725, 755

TABLE 9 (continued).

Block	Section	Operator	Top Salt (feet)	Elevation (feet)	Subsea Top Salt (feet)	Thickness (feet)	Potash Shows (depth feet)
			CROCKETT COUNTY (continued)				
47	8	Renee	1115	2692	+1581	460	1160
50	2	McGinley et al.	1230	2676	+1446	670	1355
50	11	Stanolind	1578	2706	+1128	-	1875
50	15	Blue Danube	1440	2709	+1269	330	1440, 1770
51	8	Anton	1120	2663	+1543	215	1120, 1180, 1270, 1330
12	24	Hunt	-	2685	-	-	2070
12	26	Hunt	-	-	-	-	1753
7	31	T. P. Coal & Oil	1755	-	-	915	1755, 1980
			LOVING COUNTY				
19	4	Mobil	2340	2742	+401	1418	3558
			MARTIN COUNTY				
7	2	Gulf	2030	2912	+882	2145	2376
			REAGAN COUNTY				
1	1	Gulf	1490	-	-	1525	1490, 1545, 1755, 1860
1	8	Hiawatha	1360	2840	+1480	650±	1330, 1360, 1470
9	11	Pilot	1242	2663	+1421	653	1700, 1738, 1870
8	33	Skelly	1375	3157	+1782	895	1700
9	36	Texon	1070	2720	+1650	660	1070, 1640, 1700
9	22	Texon	1050	2643	+1593	-	1720
6	9	Arkansas Fuel	1200	2675	+1475	-	1350, 1400, 1500, 1625
2	1	Big Lake	1090	2702	+1612	540	1305, 1400, 1520, 1630
2	12	Big Lake	1085	2690	+1605	1585?	1215, 1625
2	13	Big Lake	1177	2744	+1567	1840?	1360
2	38	Big Lake	1038	2732	+1694	1782	1190, 1700, 2810
1	36	Big Lake	1205	2779	+1574	1666	1205, 1305, 1389, 1410, 1530, 1450, 1490, 1535, 1645
2	6	Associated	1300	2706	+1406	1343	1685, 1730, 2082, 2145, 2210, 2295, 2336, 2375, 2870
1	1	Gulf	1380	-	-	-	2239, 2243
9	1	Drilling Syndicate	-	-	-	-	1430, 1545, 1780
9	5	Hughes	1184	2662	+1478	333	1588
			UPTON COUNTY				
14	6	CSO	580	2388	+1808	896	580, 927, 1065
14	7	Ambassador	625	2435	+1810	860	715, 735, 755, 820, 940, 1010, 1060, 1120
14	10	CSO	430	2330	+1900	305	280, 550
14	18	CSO	1195	2335	+1140	100	1295, 1336
14	19	CSO	695	2361	+1666	110	695, 755
15	5	F. &. G. Frankel	825	-	-	1388	945, 1345, 1480
15	10	Evans & Wilbern	935	2401	+1466	1359	1550
15	14	Virginia-Texas	1055	2412	+1357	1530	875, 880, 1135, 1275, 1298, 1405, 1445, 1475, 1520, 1585, 1699, 1715, 1865
30	48	Mobil	2600	+890	800	3330 (in anhydrite)	

TABLE 9 (continued).

Block	Section	Operator	Top Salt (feet)	Elevation (feet)	Subsea Top Salt (feet)	Thickness (feet)	Potash Shows (depth feet)
				WARD COUNTY			
18	1	Lion	1405	2653	+1247	3195	1273, 1294, 1405
18	29	Humble	1325	2812	+1487	268	1325
18	43	Lion	1550	2655	+1105	3030	1460, 1685, 1895, 2035
16	1	S. W. Richardson	1509	2662	+1153	827	2336
16	2	Atlantic	1847	2655	+808	871	1909
16	5	Texaco	1950	2621	+671	95	2000
				WINKLER COUNTY			
20	11	Mobil	1110	2798	+1688	3673	1860

Production and Utilization

No potash minerals have been produced in Texas. Deposits in New Mexico are thicker, richer, and mineralogically more suitable than those thus far reported in Texas. All production from Permian Basin evaporites has been from the Carlsbad area of Eddy County, New Mexico; production in 1969 was 2,327,000 short tons of K_2O equivalent (Bishop, 1970). Potash is mined by conventional underground techniques at depths comparable to those at which potash has been reported from the Texas portion of the Delaware Basin. Production from the New Mexico mines has declined steadily during the past decade due to large imports of potassium chloride from Canada, France, and West Germany.

Agricultural uses account for approximately 95 percent of potash consumption in the United States. Potassium compounds are used in agriculture as essential components of mixed fertilizers and in direct application materials. The increased demands for food production imposed by an ever-growing population will undoubtedly require an accelerated use of fertilizers and a corresponding increase in the production of potash. Potassium is also used in the production of textiles, foods, medicines, soap, metals, cosmetics, and other commodities.

Economic Considerations

Major world production of potash is from the vast deposits in Canada, France, and West Germany. Domestic production, almost entirely from New Mexico, has declined substantially because of increasing imports. The U. S. Tariff Commission has ruled that the U. S. potash industry was being injured by such imports and suggested potash imports from the three countries be subject to special dumping duties retroactive to June 11, 1968 (Bishop, 1970).

Increased demand for potash is certain; increased demand for potash from the Permian Basin is less certain given the present price structure and availability of large supplies from foreign sources. Least certain is the availability of sufficient amounts of high purity potassium salts from the Texas portion of the Permian Basin. Until the foreign supplies are depleted or market price increases, or unless the federal government decides that complete dependency on foreign sources is not in the best national interest, exploration programs aimed at finding potash reserves in the University Lands area are not likely. The richer New Mexico deposits have received the most attention, and that part of the Permian Basin probably would receive the earliest and most intense exploration activity. Should there be a stimulation of interest in the Permian Basin potash potential, the West Texas orientation toward the production of oil and gas would be a great asset in exploration. The technology for drilling and for solution mining, should it become feasible, is already in the area and has been utilized for sulfur exploration and production as well as for oil and gas development.

GYPSUM

Gypsum is a mineral composed of hydrated calcium sulfate ($CaSO_4 \cdot 2H_2O$) that occurs in numerous varieties such as highly crystalline, cleavable, and transparent selenite; fibrous and silky satin spar; massive and fine-grained alabaster; compact or granular rock gypsum; and impure, earthy or sandy gypsite. Gypsum commonly occurs in lenses and other local bodies, but most economic deposits are bedded gypsum layers deposited as evaporites in saline ponds on mudflats and other shallow, near-shore environments under arid climates. Extensive gypsum deposits occur within rocks of Permian age in the West Texas region. Gypsum may result from hydration of anhydrite, a nonhydrated calcium sulfate ($CaSO_4$), when exposed to surficial weathering. Therefore, much gypsum at the surface in West Texas was probably deposited as anhydrite under certain ranges of salinity and temperature but later reverted to gypsum when exposed to surficial conditions.

Gypsum is used in the manufacture of plasters, wallboards, tile, portland cement retarder, and fillers. Principal production in west-central Texas occurs along the outcrop of Permian evaporites from Childress to San Angelo where much of the commodity is used in wallboard and plaster manufacturing. Gypsum is utilized in Culberson and Hudspeth counties (table 10) within the West Texas region where sources are Permian deposits on the flanks of the Delaware Basin (Castile Formation) and Upper Permian or Jurassic formations in the Malone Mountains.

Occurrence

Gypsum occurs in University Lands within Block 46. Two types of deposits are recognized: (1) banded rock gypsum of the Permian Castile Formation and (2) gypsite of Late Tertiary or Quaternary age. Deposits on University Lands are but small parts of extensive deposits throughout the general area and are not unique to University-owned areas.

ROCK GYPSUM OF EVAPORITE ORIGIN

Layered deposits of the Castile Formation consist of laminated or banded gypsum and calcite. Because of solution of salt in the section and hydration of anhydrite, the beds are highly contorted and brecciated for 30 feet below the surface; collapse structures are common. Utilization of the gypsum would require stripping of collapsed and brecciated material.

TABLE 10. *Commercial producers of clay and gypsum in West Texas* (from Texas Mineral Producers, 1970, compiled by Roselle Girard).

	Gypsum	Carbonaceous clay (soil conditioner)	Miscellaneous clay (brick and tile)
Manning Minerals Corp., Brewster County		x	
Elcor Chemical Corp., Culberson County	x		
Southwestern Portland Cement Co., Malone Mountains, Hudspeth County	x		
Southwestern Brick and Tile Co., Scurry County			x

GYPSITE DEPOSITS

A second type of gypsum deposit on University Lands in Block 46 occurs in the form of gypsite, a sandy and silty gypsum deposit with considerable quartz sand and silt content. The gypsum was derived from erosion of Castile and other gypsiferous Permian formations; gypsum was locally transported and deposited as detrital gypsum fragments. Subsequent solution and reprecipitation of gypsum locally provide a bonding cement for much of the deposit at the surface. This type of reworked gypsum deposit is impure and of low quality. The calcium sulfate can be calcined but separation from quartz sand, silt, and clays provides an added cost to such an operation. The deposit is more easily mined since it is part of the surficial cover, but quality is low.

Economic Considerations

More accessible and more easily exploited gypsum deposits in areas nearer to industrial and commercial users make the deposits on Block 46 of minimal value. Expense necessary in mining within the collapsed and brecciated evaporite deposits adds technical problems. Gypsite deposits provide problems involving separation of impurities from the calcium sulfate.

The Lower Permian gypsum deposits between Childress and San Angelo provide an unlimited supply of high-quality gypsum for manufacture of most products. The potential savings in rail costs for products sent westward from San Angelo would hardly be offset by the added expense of mining gypsum 150 miles farther westward in the area of Block 46. In addition, many other suitable sites in the West Texas region are nearer to railroads and highways.

CLAYS

Clay refers to mineral fragments or aggregates of hydrated aluminum silicate composition occurring in particles predominantly less than 2 microns in diameter. Clays display plasticity when wet and fire to permanently hard, vitrified materials. Clays may be classified on the basis of their crystalline structure as determined by X-ray diffraction. Three common groups based on structure include kaolinites (two-layered alumina and silica layers); montmorillonites (three-layered with a silica layer between two alumina layers); and illites (three-layered similar to montmorillonite but with stronger bonding between successive three-layer sheets). Kaolinite displays no expansion when wet; montmorillonite three-layer units are loosely bonded and expand significantly when wet as well as attract certain ions to clay surfaces; and illite exhibits three-layer units that are firmly bonded and do not expand significantly nor attract ions. Because it displays minimum expansion, along with other properties, kaolinite is the principal clay type used for most ceramic, refractory, and filler purposes. Montmorillonites, because of their ability to attract ions and to expand, are useful as drilling muds and adsorbents and for other special purposes.

Common industrial terms for clays that are of general kaolinite composition include china clay, ball clay, fire clay, and common or structural clay. Industrial terms for clays of general montmorillonite composition include fullers earth and bentonite. Principal uses for clays include the following, which depend upon the distinctive properties of the clay: structural clay products (brick, tile, sewer tile, glazed tile, and others utilizing mixed low-quality clays that show such specific properties as low firing ranges, plasticity for molding and extrusion, minimum shrinkage, and acceptable fired color); refractories (commonly kaolinites with ability to withstand high temperatures); whitewares (china clay and ball clays with certain blends of other materials to fire white or off-white); pottery and stoneware (mixed clays of high quality with good plasticity, low shrinkage, high strengths, and high density); porcelain (china clays and ball clays blended with feldspar); lightweight or expanded aggregate (bloating properties under low temperatures with release of gases commonly found to occur among illites and montmorillonites); bleaching and adsorbent clays (fullers earths of general montmorillonite composition able to attract impurities because of atomic replacement within the crystal structure); fillers and additives (kaolinites and montmorillonite clay groups); drilling muds (montmorillonites capable of expanding and maintaining fixed viscosity); pigments (kaolinites); and portland cement (most clays suitable if low in magnesium; calcium carbonate is acceptable).

Occurrence

Potentially commercial clays and clay materials are minor commodities occurring on University Lands. Two areas exhibiting different types of occurrences were sampled: (1) thin clay beds up to 18 inches thick interbedded with silts and sands within bolson fluvial and alluvial fan deposits east of Fabens in the Cornudas map area (Pl. VI, localities HB-2 and HB-4); and (2) thick, highly calcareous marine clays up to 70 feet thick interbedded with limestones in the Fort Stockton and Big Lake areas (Pls. I and II, Blocks 14-26). Properties of these clays are listed in the Appendix.

BOLSON CLAY DEPOSITS

Bolson clay deposits near Fabens display some properties of potential commercial value, but their thin, erratic distribution within sequences of sand and silt all but preclude foreseeable economic exploitation. In addition, better and more accessible deposits occur outside University holdings in the Fabens area and are nearer to areas of utilization. Sample HB-2 flash fired for 10 minutes at 2200° F with apparent specific gravity of 0.8-1.0 (50 to 62 lbs. per cu. ft.), indicating that the clay would serve as material for lightweight aggregate if the deposits were sufficiently thick and extensive. Sample HB-4 when activated with sulfuric acid showed an oil-decolorizing capacity equivalent to 67 percent of the official activated earth of the American Oil Chemists Society. It is possible that by degritting or removal of sand and silt during dry processing, the oil-decoloring capacity could be increased. Sample HB-2 would also serve as common structural clay material but fired material is unusually soft. Only sample HB-2 approached minimum swelling values necessary for drilling muds and other related uses.

MARINE CLAY DEPOSITS

Marine clay deposits are thick and abundant in the Big Lake and Fort Stockton areas (Blocks 14-26), but unusually high calcium carbonate content restricts significantly their economic importance. Carbonate content of clays from several localities ranges from 45 to 50 percent, which eliminates them from most clay uses. The deposits could at best serve as a source of low-grade material for certain soft ornamental bricks.

ECONOMIC CONSIDERATIONS

The clays occurring on University Lands are located far from any of the present producers (table 10), and it is doubtful if development and industrialization nearer to the localities would make the deposits economic. Many better sources of clay occur within the region for future utilization. The best clays from bolson deposits are also so thin and erratic that mining and processing problems all but preclude their eventual use.

CRUSHED STONE

Stone used for aggregate or other physical purposes should be durable, sound, nonporous, inert, and free of impurities such as chert, organic matter, and pyrite. Specifications for particle size and sorting vary according to specific uses; size and sorting are controlled during processing. Crushed stone is widely used in Texas as concrete aggregate, base material, road-surfacing material, railroad ballast, and riprap. Table 11 lists general chemical and physical specifications for various types of crushed stone and the distribution of suitable material on University Lands.

All major rock types, sedimentary, igneous, and metamorphic, are widely used for crushed stone. Annual stone production in Texas is in excess of 48 million short tons and is valued at more than $58 million; crushed stone accounts for more than 99 percent of the total stone production.

Within the University Lands boundaries, several materials suitable for crushed stone aggregate are available: limestone, sandstone, intrusive igneous rock, and volcanic rocks.

Deposits of limestone mapped in the Fort Stockton and Big Lake areas provide adequate reserves of suitable quality material for any crushed stone use. The units mapped in these areas that can be used for crushed stone are hard nodular limestone, granular limestone with chert, granular limestone without chert, and alternating hard and soft limestone. Locally, some of the colluvium and alluvium units are also satisfactory; however, these units are of lower quality and not as extensive as the bedrock units.

Units occurring within University Lands in the

TABLE 11. *Specifications and availability of crushed stone materials on University Lands.*

Use	Specifications		Availability from University Lands
	Chemical	Physical	
Crushed stone (aggregate, ballast, base materials, etc.)	Low alkalies, low surface organic matter, very low opaline silica for concrete aggregate	Clean, strong, durable, tough, low porosity; particle size variable but specified	Widespread in all areas
Stone sand	Same as aggregate where used in concrete	Clean, durable, free of flaky particles; uniform particle size distribution	Widespread in all areas
Stone chips (roofing granules, terrazzo, exposed aggregate, etc.)	Same as aggregate where used in concrete	Clean, free of dust and soft particles; pleasing appearance; particle size specified	Widespread in all areas
Filter stone	Generally none, depends on performance	Clean, free of dust; particle size range within 1" between minimum and maximum	Widespread in all areas

Cornudas and Van Horn areas that have potential applications as crushed stone include intrusive igneous rock, volcanic rocks, quartzose sandstones, and limestones. Limestone and sandstone are extensive throughout the University Lands in the Cornudas and Van Horn areas. Intrusive and volcanic rocks are restricted to relatively small deposits within these areas.

Calichified deposits of the Ogallala Formation in the Andrews area and similar deposits in the Monahans area provide a widely distributed source of material for crushed stone uses. Material from these units is used largely on a local basis for road base and road-surfacing materials.

Exploitation of aggregate sources within University Lands is controlled primarily by demand and local urban and industrial development rather than by specifications, requirements, and availability of materials.

Future production of crushed stone from University Lands probably will be restricted to road material and aggregate for local construction jobs.

INDUSTRIAL SANDS

Industrial sands include abrasive sand, blast sand, glass sand, chemical sand, molding sand, and filter sand. Physical specifications in addition to soundness and durability are based largely on grain size and distribution. Shape of individual grains is not critical except in hydraulic fracturing sand and certain abrasive sands where rounded to highly rounded and highly spherical grains are commonly specified. Chemical requirements are most critical in glass and chemical sands and in ground silica. General specifications and requirements for industrial sands are given in table 12.

The quality of most sands found on University Lands is unsatisfactory for those uses which require low percentages of impurities, especially iron. Some of the windblown sands in the Andrews and Monahans areas and bedrock deposits in the Fort Stockton and Big Lake areas are marginal for high-quality uses. Chemical purity alone eliminates these sands from several categories; grain size and distribution are also limiting factors for some sands. Iron oxide content is too high for high-grade industrial sands such as glass and chemical sands; however, beneficiation processes, such as attrition scrubbing and acid washing, could probably upgrade many deposits. Industrial uses for which sands in this area would qualify are fine grades of blast sand, foundry sand, molding sand, filter sand, and traction sand.

Sand and sandstone units tested for this report have grain sizes that range from coarse sand to silt-size material. In all samples tested more than half of the material was coarser than very fine sand (100 mesh); some samples were 95 percent coarser than very fine sand. Four samples contained at least 50 percent of the material in the medium and coarse fractions (larger than 60 mesh). Some sandstones found in the Fort Stockton and Big Lake areas were not tested because of their excessively fine character (maximum grain size was very fine sand or less). Other sandstones were not considered because of excess cementation by calcium carbonate or iron oxide.

Industrial sand raw materials on University Lands are at best marginal and would require beneficiation of some degree before standard requirements could be met. Such beneficiation would add significantly to costs. Local markets are lacking for those uses for which these sands qualify.

METALS AND MISCELLANEOUS NONMETALS

Metal deposits of economic importance have not been found on University Lands. Several areas of possible mineralization were examined during this study, but no significant deposits were discovered.

Contact mineralization around the nepheline syenite intrusions that trend northwestward across the Cornudas map area was considered to be the best possibility for metal or nonmetal ore occurrence. Outside of University Lands a commercial deposit of molybdenum ore occurs around the Cave Peak intrusion at Marble Canyon, the southeasternmost intrusion in this chain. Samples from all of the intrusions in the chain were analysed (representative results are in the Appendix) and the contact zones examined. Detailed study was made on the largest intrusive, Sierra Prieta. The igneous rocks were not accompanied by mineralizing fluids during their emplacement, and contact-mineralization effects are minimal. Fluorspar was observed near Sierra Prieta, but quantities are insignificant.

Copper mineralization is widespread in conglomerates and sandstone (Yucca or Las Vigas Formations) in the Indio Mountains in the Van Horn map area. Traces of lead and manganese occur in the same area. The area around the Indio ranch headquarters (Pl. V) has been extensively explored. Prospect pits dot the landscape, and the Black Diamond mine was developed to explore lead and copper mineralization in the conglomerate. Despite the abundance of copper shows, concentra-

TABLE 12. *Specifications and availability of industrial sands on University Lands.*

Use	Physical Requirements: Grain Shape	Grain Size	Particle-size Distribution	Miscellaneous	Chemical Requirements	Availability from University Lands
Blast sand	Rounded	-4 to +100 mesh for various grades	Narrow range for specified grades, e.g., -4 to +12 mesh, -4 to +30 mesh	Sound and durable, free of adhering clay and iron	Clean and relatively low in nonsilica impurities	Satisfactory deposits for fine grade in Andrews, Monahans, Fort Stockton, and Big Lake areas
Glass-grinding sand	Rounded	-30 to +100 mesh for various grades	Uniform, well sorted	Sound and durable, free of adhering clay and iron	Clean and relatively low in nonsilica impurities	None
Sawing and rubbing sand	Free from flat grains	-12 to +100 mesh	Uniform, well sorted	Sound and durable, free of adhering clay and iron	Clean and relatively low in nonsilica impurities	None
Glass sand	Angular grains may improve fusibility	-30 to +140 to locally +200 mesh	Narrow range, well sorted	Consistent composition	Fe_2O_3, <0.02 to 0.025% (flint glass), <1.0% (amberglass); Al_2O_3, <0.2%; CaO, <0.05%; alkalies, <0.01%	None
Chemical silica, sodium silicate, and silicon carbide	Angular grains may improve fusibility	-30 to +140 mesh; -20 to +80 mesh (soluble silicates)	Narrow range, well sorted		Specifications same as glass sand, except Fe_2O_3 not as critical (<0.05%) in sodium silicates	None
Foundry core sand	Not critical	-30 to +140 mesh	More than 90% -49 to +100 mesh	High permeability, high sintering point	Inert	Satisfactory deposits in all areas
Foundry furnace bottom sand	Not critical	-3 mesh to clay	Wide range desirable	Clay bond naturally or added	Inert	Satisfactory deposits in all areas
Processed molding sand	Not critical	Variable, specified by user	90% distributed over 4 adjacent sieves	High sintering point	Inert	Satisfactory deposits in all areas
Coal-washing sand	Subangular to rounded	-30 to +140 mesh	90% -30 to +100 mesh	Specific gravity not less than 2.64	Free from clay and organic matter	Satisfactory deposits in all areas
Filter media sand	Less than 1% flat grains; rounded	Fine: 0.35 to 0.45 mm Medium: 0.45 to 0.55 mm Coarse: > 0.55 mm	Uniform, well sorted	Durable	Free from clay and organic matter; <5.0% soluble	Sand units in all areas
Hydraulic-fracturing sand	Highly rounded	-16 to +60 mesh for various grades	Critical, well sorted, e.g., >80% -20 to +40 mesh	Maximum specific gravity of 2.7 desirable	Inert, free from clay and organic matter	Marginal deposits in Fort Stockton area
Traction sand	Low sphericity; angular	-20 to +70 mesh	Uniform, well sorted		Free from clay	Satisfactory deposits in all areas
Ceramic sand (ground)	Angular	98% -200 mesh			<0.05% Fe_2O_3	None

tions of mineralization sufficient for development have not yet been discovered. Duval Corporation has recently been drilling in this area, exploring for copper, but with disappointing results.

Lead, silver, zinc, and copper mineralization along veins, in fault zones, and adjacent to igneous bodies has been explored in the Eagle, Quitman, Indio, and Van Horn Mountains adjacent to University Lands, and mines have been developed (Pl. V). Limited ore production took place in some of these mines, but they have been inactive for some time. McAnulty (1970) reviewed the mineral resources and mining activity in these areas (table 13). Geological conditions similar to those where mines have been developed have not been found on University holdings in the mountains, but the possibility should not be ruled out that similar metal mineralization is present on University Lands. Based on present knowledge and the results of this study, however, prospects are slight for finding significant metallic ores on University Lands.

The Spar Valley area of the Eagle Mountains, located north of University holdings (Pl. V), has been mined for fluorspar. Activity was greatest from 1942 to 1950 when approximately 15,000 short tons were produced (Gillerman, 1953). The availability of lower priced fluorspar from northern Coahuila, Mexico, has prevented the development of the more than 100,000 tons of 30 percent or greater CaF_2 ore in the Eagle Mountains area. Most of the fluorspar occurs along faults in rhyolite and as replacement deposits in limestone; both types are concentrated near the Eagle Peak intrusive body. The possibility of fluorspar deposits to the south, on University Lands, is not great because most deposits are located near the intrusion. However, fluorspar does occur 5 miles north of Eagle Peak at Eagle Springs, and replacement and vein deposits of similar nature could be present in faulted limestone cropping out on University Lands.

Uranium has been reported in many parts of West Texas and the area has been actively prospected, but there has been no production (Eargle, 1956; Finch, 1967). Occurrences on or near University Lands are restricted to the King Mountain area north of McCamey where Eargle (1956) reported carnotite crusts on joint planes and coating the ferruginous residue that fills weathered cavities in the limestone. There has been no production from this area. There has been some prospecting activity on or near University Lands in Andrews and Ward counties with little success.

Figure 22 shows the location of several mines that have produced metals, of reported occurrences of metal ores, and of deposits of some other minerals of economic interest. The relation of these occurrences to the regional structural, stratigraphic, and igneous setting is an endeavor that must be undertaken before the full potential of the area for metals production can be evaluated.

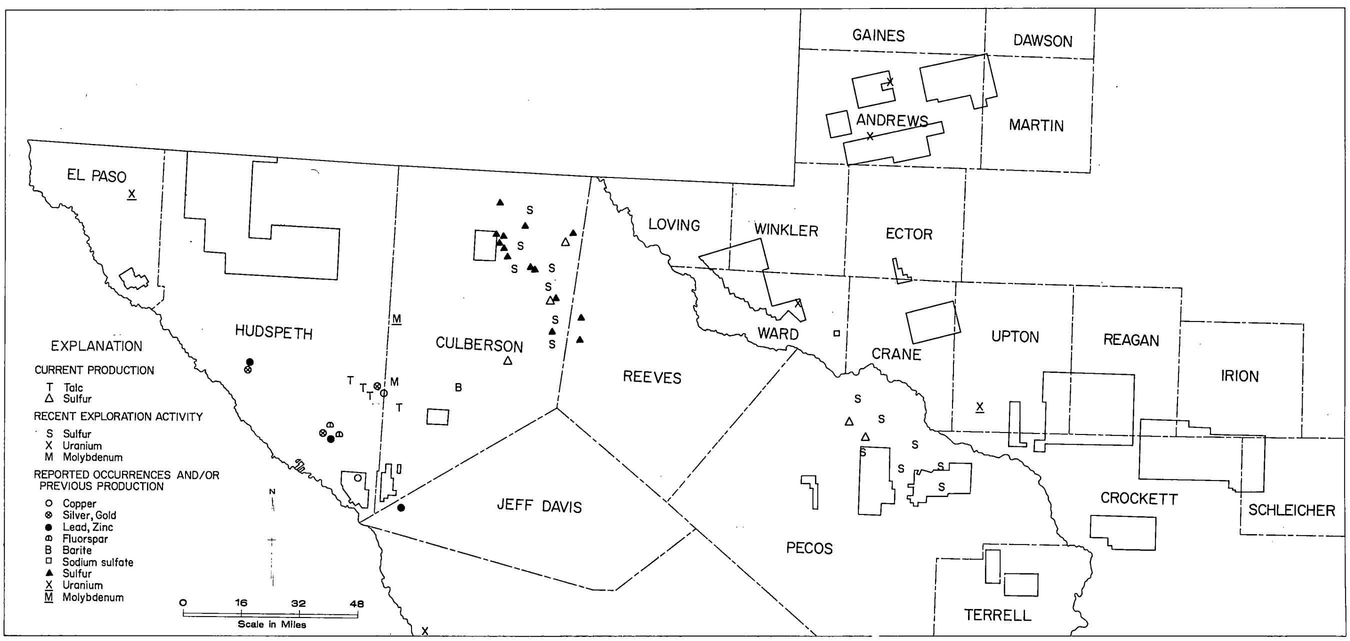


FIG. 22. Metals and selected nonmetals in University Lands area.

TABLE 13. *Productive metal mines and prospects in Trans-Pecos Texas* (modified from McAnulty, 1970)

Mine or Prospect	Ore Produced (tons)	Metals Sold	Copper (lbs)	Lead (lbs)	Zinc (lbs)	Silver (ozs)	Approximate Value (Current Prices)
HUDSPETH-CULBERSON COUNTY							
Van Horn--Allamoore district							
Blackshaft	13,000	Cu, Ag, Au	740,000			4,000	$ 375,000
Sancho Panza	8,500	Cu, Ag, Au	400,000			7,000	215,000
Pecos	100	Cu, Ag, Au	4,000			100	2,000
Mohawk	300	Cu, Ag, Au	12,000			300	6,500
St. Elmo	350	Cu, Ag, Au	14,000			350	7,500
Hackberry	610	Cu, Ag, Au	8,600			20,000	40,000
Hazel	110,000	Cu, Ag, Au	1,500,000			4,000,000	8,000,000
HUDSPETH COUNTY							
Northern Quitman Mountains district							
Bonanza-Alice Ray	5,000	Pb, Zn, Ag, Cd, Au	1,250,000	5,000	1,500	80,000	600,000
John Gilcrease	---	Cu	---				---
Eagle Mountains district							
Black Hill	500	Pb, Zn, Cu, Ag	---	---	---	---	---
Silver Eagle	66	Pb, Ag		---		---	---
CULBERSON COUNTY							
Plata Verde	10,000	Ag, Cu	---				---
Buck	---	Zn					---
JEFF DAVIS COUNTY							
Walter Mayfield	---	Mn (Pb, Zn, Ag)					---
PRESIDIO COUNTY							
Presidio (Shafter)	2,250,000	Ag, Pb, Au	8,000,000			30,000,000	60,000,000
San Antonio Canyon	---	Ag				---	---
Burney	---	Ag, Pb, Zn				---	---
Solitario							
Gleim, Perry, Chinati	---	Ag, Pb, Zn	---	---		---	---
Stauber, Montezuma, Ross, Last Chance, Sullivan							
BREWSTER COUNTY							
Bird	1,000	Pb, Ag	700,000			25,000	160,000
Terlingua	200,000	Hg					100,000,000

SUMMARY AND CONCLUSIONS

GENERAL

At present, nonfuel mineral resources are an insignificant factor in the economic development of University Lands, and this investigation did not discover any mineral resource potential that will alter this situation. The economy of the West Texas area is so strongly tied to oil and gas production that as this production declines, so will nearly all sources of income for the inhabitants. Only the discovery of a mineral resource that has value independent of its location, such as gold, molybdenum, or copper, would create an economic boom of any magnitude. Sulfur has done this to some extent, and the discovery of significant reserves of metals would greatly increase the value of University Lands; this study found nothing to indicate that this is probable.

There are large reserves of some low-unit value industrial minerals on University holdings; limestone materials are the most widespread and abundant of these. These rocks generally have significant value only when within reasonable transport distance of established markets in urban areas. Exceptions would be local and temporary construction projects. The conveyance facilities for the import of water from the Mississippi River to the West Texas area, as set forth in the proposed Texas Water Plan (fig. 23), would require a large volume of construction materials including cement and aggregate. If this plan is implemented, carbonate rocks and aggregate materials on University Lands are potentially marketable. This is probably the only possibility for large-scale use of these materials in the foreseeable future.

The greatest potential for mineral resource development on University Lands is probably in the subsurface where vast amounts of evaporite and related material have been located during the search for petroleum. Sulfur has already received much attention, and exploration will undoubtedly continue as demand increases. Potash has been encountered in many wells and may be a source for future development. The future for these and perhaps other subsurface resources is the most promising chiefly because much data have been gathered during exploration for oil and gas, and because the technology and facilities for subsurface exploration are already in the area.

Ground-water resources have been developed over much of the area that includes University Lands. Because any type of economy is dependent on water supplies, ground water must be considered as an extremely valuable resource. Expansion of

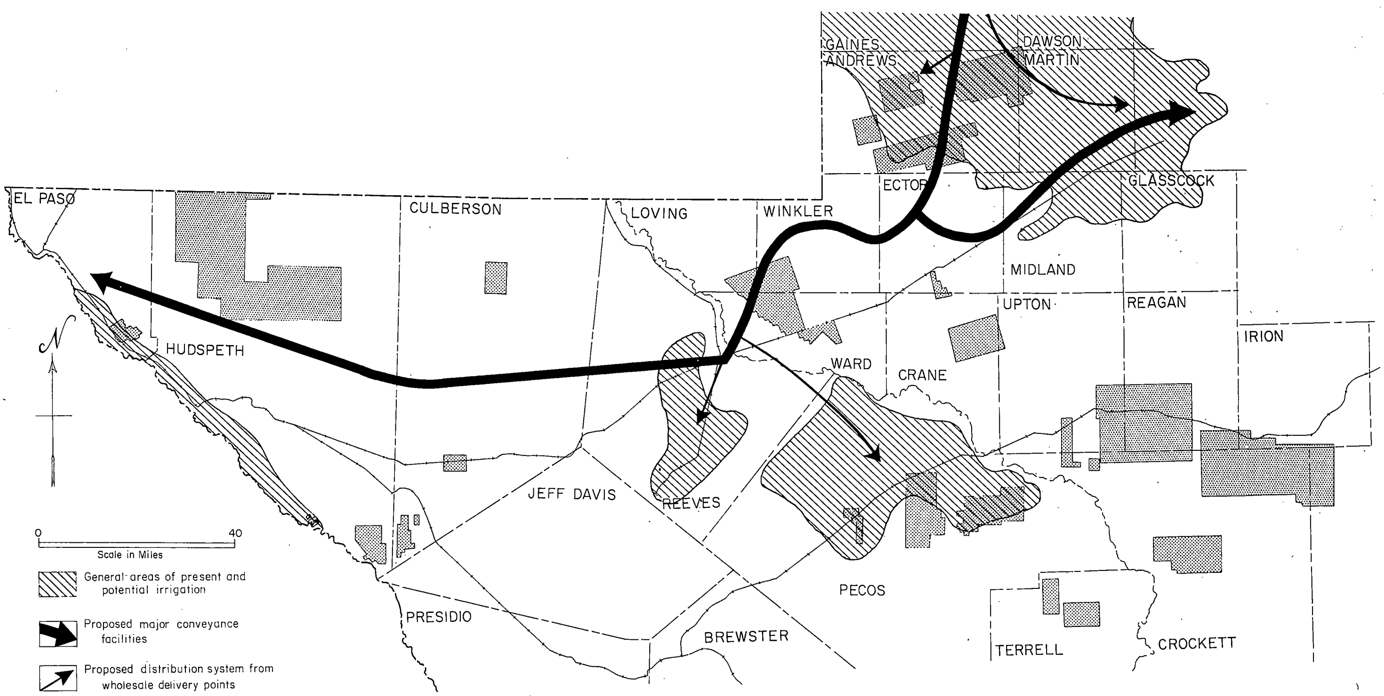


FIG. 23. Texas Water Plan in University Lands area, West Texas.

development is possible in several areas, but the best supplies of water are likely to be found in the limestone and sandstone aquifers of the Big Lake map area.

SUMMARY BY MAP AREA

Big Lake Area

Carbonate rocks suitable for most industrial uses are abundant in the Big Lake map area. The rocks are well exposed and readily available for quarrying. These same rocks also occur in privately owned land throughout the region, and The University would be in direct competition with local ranchers should a market for these materials ever develop. The most probable future use for these materials is as a local source of road metal.

Ground water of good quality is available over much of this area. It is being developed at an increasing rate for irrigation and is available beneath University Lands for similar or other uses.

Fort Stockton Area

Carbonate rocks similar to those in the Big Lake map area are abundant in the Fort Stockton area; ground water of fair to poor quality is also abundant. Ground-water levels are declining rapidly, however, and any development that requires large reserves of good-quality water is economically unsound.

Sulfur exploration has been intense in the Fort Stockton area and additional deposits may be discovered. Potash and salt are also present in the subsurface.

Monahans Area

Subsurface resources offer the only potential for development on University Lands in this map area. The evaporite sequence may yield minerals of value; possible sodium sulfate production has been explored by Ozark Mining Company. There has also been some uranium exploration in Triassic sands and clays. These rocks are present in the subsurface in some University blocks, but the economic potential is minimal.

Andrews Area

Only subsurface evaporite deposits have significant economic potential in the Andrews area. Aggregate materials are available as is ground water of varying quality.

Van Horn Area

The Van Horn map area contains a wide variety of rock types, but no mineral resources of economic significance have been observed on University Lands. Metals have been found in the mountainous areas, but reserves appear to be small and large-scale development has not occurred. This may be due in part to the complicated and restrictive prospecting laws that apply to publicly owned land. These laws do not encourage prospecting by the large companies that have the greatest capability for discovering ore. This may have been a significant factor in the lack of discovery of the more glamorous and more valuable mineral resources rather than a clear-cut absence of workable reserves. Discovery of significant ore bodies on University Lands is less likely than on adjacent lands, because of their location in relation to the structures and igneous bodies with which mineralization is most likely to be associated. An exception to this may be the copper mineralization in the Indio Mountains, but exploration by Duval Corporation has been unsuccessful.

Vast amounts of gypsum occur at or near the surface in the Delaware Basin, which includes University Block 46. Gypsum is an important industrial mineral used for the production of plaster and wallboard, but the remoteness of the Delaware Basin and especially of University Block 46 precludes development. The possible demand for gypsum as a raw material for sulfur production by the Elcor process could be satisfied by many better and more accessible gypsum deposits than those in Block 46.

Some sulfur may be present in the subsurface in Block 46, but prospects are poor. Dolomite in the University block east of Van Horn has been used as road material. Potential development of carbonate resources is probably tied to local demand for road material and aggregate. Ground water is present in limited quantities.

Cornudas Area

Neither surface nor subsurface rocks in the Cornudas area contain mineral resources of significant value. Mineralization associated with igneous intrusive bodies exhibits nothing of economic interest.

High-magnesium dolomite is present in the western part of the area but it is remote from potential markets. Clays with some properties of potential industrial interest are present in the Fabens area but are of erratic distribution and variable quality. More extensive and more homogeneous deposits are available much closer to El Paso.

SELECTED REFERENCES

ADAMS, J. E. (1963) Permian salt deposits of West Texas and eastern New Mexico, *in* Symposium on salt, Cleveland, Ohio 1962: Northern Ohio Geol. Soc., Cleveland, pp. 124-130.

ANDERSON, R. U., and MAJESKE, E. C. (1970) Detection of potash zones by drilling fluid analysis, *in* Proceedings of 6th Forum on Geology of Industrial Minerals: Geol. Survey Division, Michigan Dept. Natural Resources, pp. 34-36.

ARMSTRONG, C. C., and McMILLION, L. G. (1961) Geology and ground-water resources of Pecos County, Texas: Texas Water Comm. Bull. 6106, vols. 1 and 2, 548 pp.

BISHER, O. M. (1970) The mineral industry of New Mexico, 1969, *in* U. S. Bur. Mines Mineral Industry Surveys, Area Rept. (Preliminary), 5 pp.

CRONIN, J. G. (1964) A summary of the occurrence and development of ground water in the southern High Plains of Texas: U. S. Geol. Survey Water-Supply Paper 1693, 88 pp.

CUNNINGHAM, W. A. (1934) The potassium sulfate mineral polyhalite in Texas, *in* The geology of Texas, Vol. II, Structural and economic geology: Univ. Texas Bull. 3401 (Jan. 1, 1934), pp. 833-867.

DAVIS, M. E., et al. (1965) Reconnaissance investigation of the ground-water resources of the Rio Grande basin, Texas: Texas Water Comm. Bull. 6502, 213 pp.

EARGLE, D. H. (1956) Some uranium occurrences in West Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 27, 23 pp.

FINCH, W. I. (1967) Geology of epigenetic uranium deposits in sandstone in the United States: U. S. Geol. Survey Prof. Paper 538, 121 pp.

FISHER, W. L. (1965) Rock and mineral resources of East Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 54, 439 pp.

GARZA, SERGIO, and WESSELMAN, J. B. (1969) Geology and ground-water resources of Winkler County, Texas: Texas Water Comm. Bull. 5916, 216 pp.

GEORGE, W. D. (1940) Andrews County, Texas (Records of wells): Texas Water Comm. Misc. Pub. 4, 55 pp.

__________ (1942) Irion County, Texas (Records of wells): Texas Water Comm. Misc. Pub. 142, 41 pp.

GILLERMAN, ELLIOTT (1953) Fluorspar deposits of the Eagle Mountains, Trans-Pecos Texas: U. S. Geol. Survey Bull. 987, 98 pp.

GILLSON, J. L., et al. (1960) The carbonate rocks, *in* Industrial minerals and rocks: Amer. Inst. Min., Met., and Petrol. Engrs., pp. 123-202.

INGLEHART, H. H. (1967) Occurrence and quality of ground water in Crockett County, Texas: Texas Water Development Bd. Rept. 47, 150 pp.

JONES, B. R., and REASER, D. F. (1970) Geology of southern Quitman Mountains, Hudspeth County, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map 39, 24 text pp.

KING, P. B. (1965) Geology of the Sierra Diablo region, Texas: U. S. Geol. Survey Prof. Paper 480, 185 pp.

KNOWLES, D. B. (1952) Ground-water resources of Ector County, Texas: Texas Water Comm. Bull. 5210, 117 pp.

KROENLEIN, G. A. (1939) Salt, potash, and anhydrite in Castile Formation of southeast New Mexico: Bull. Amer. Assoc. Petrol. Geol., vol. 23, pp. 1682-1693.

MANSFIELD, G. R., and LANG, W. B. (1935) The Texas-New Mexico potash deposits, *in* The geology of Texas, Vol. II, Structural and economic geology: Univ. Texas Bull. 3401 (Jan. 1, 1934), pp. 641-832.

McANULTY, W. N., SR. (1970) Comments on some of the mineral resources of Trans-Pecos Texas, *in* Geology of southern Quitman Mountains: Soc. Econ. Paleontologists and Mineralogists, Permian Basin Section, Guidebook, Pub. 70-12, pp. 107-114.

McKEE, E. D., ORIEL, S. S., et al. (1967a) Paleotectonic maps of the Permian system: U. S. Geol. Survey Misc. Inv. Map I-450, scale 1:5,000,000, 164 text pp.

__________, __________, et al. (1967b) Paleotectonic investigations of the Permian system in the United States: U. S. Geol. Survey Prof. Paper 515, 271 pp.

MOUNT, J. R., et al. (1967) Reconnaissance investigation of the ground-water resources of the Colorado River basin, Texas: Texas Water Development Bd. Rept. 51, 107 pp.

NETZEBAND, F. F., and GIRARD, ROSELLE (1970) The mineral industry of Texas (in 1968), *in* U. S. Bur. Mines Minerals Yearbook, 1968, vol. 3, pp. 695-729. *Reprinted as* Univ. Texas, Bur. Econ. Geology Min. Res. Circ. No. 51.

RODDA, P. U., et al. (1966) Limestone and dolomite resources, Lower Cretaceous rocks, Texas: Univ. Texas, Bur. Econ. Geology Rept. Inv. No. 56, 286 pp.

RUHLMAN, E. R. (1960) Potash, *in* Industrial minerals and rocks: Amer. Inst. Min., Met., and Petrol. Engrs., New York, pp. 669-680.

SCHALLER, W. T., and HENDERSON, E. P. (1932) Mineralogy of drill cores from potash fields of New Mexico and Texas: U. S. Geol. Survey Bull. 833, 124 pp.

SHAFER, G. H. (1956) Ground-water resources of the Crane sandhills, Crane County, Texas: Texas Water Comm. Bull. 5604, 108 pp.

TWISS, P. C. (1959) Geology of Van Horn Mountains, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map 23, with text.

UDDEN, J. A. (1914) The deep boring at Spur (Dickens County, Texas): Univ. Texas Bull. 363, 101 pp.

__________ (1915) Potash in the Texas Permian: Univ. Texas Bull. 17, 59 pp.

UNDERWOOD, J. R., JR. (1963) Geology of the Eagle Mountains and vicinity, Hudspeth County, Texas: Univ. Texas, Bur. Econ. Geology Geol. Quad. Map 26, 32 text pp.

WHITE, D. E. (1968) Ground-water resources of Upton County, Texas: Texas Water Development Bd. Rept. 78, 132 pp.

ZIMMERMAN, J. B., and THOMAS, EUGENE (1969) Sulfur in West Texas: Its geology and economics: Univ. Texas, Bur. Econ. Geology Geol. Circ. 69-2, 35 pp.

APPENDIX

All laboratory analyses of rock and alluvium samples collected during the course of the University Lands project are presented in this Appendix. Analyses are grouped by rock type, and sample localities are keyed to county names. These localities are indicated on the geologic maps (Pls. I-VI) by a suitable county prefix (e.g., Hudspeth is HU) and a number. Two localities for which carbonate analyses are presented are not shown on the geologic maps because they are adjacent to University holdings in areas that could not conveniently be included on the maps. Location of these two sites (Hudspeth 11 and 12) accompanies the analyses.

SANDS

GRAIN-SIZE ANALYSES

U. S. STANDARD MESH NUMBER		ANDREWS 3	ANDREWS 6	CRANE 3	CRANE 4	PECOS 13	PECOS 14	UPTON 3	WINKLER 3	EL PASO 1	EL PASO 3
-10	+20									0.4	0.1
-20	+40	0.1	0.1	0.1	1.1	0.5	5.1	1.2	0	21.5	5.5
-40	+60	23.1	21.3	2.8	42.5	59.2	51.8	27.1	11.5	53.4	55.0
-60	+80	53.1	78.2	21.4	77.0	91.6	80.0	78.5	58.9	65.5	80.6
-80	+100	78.0	95.3	52.0	86.8	95.9	88.7	92.4	76.8	73.4	89.5
-100	+140	90.1	98.1	92.9	96.8	98.2	95.0	97.2	94.1	82.2	93.8
-140	+200	93.6	98.8	98.5	98.9	99.4	97.1	99.1	97.9	89.6	95.5
-200	pan	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

CLAYS

PHYSICAL, CHEMICAL, AND MINERALOGICAL TESTS OF CLAYS FROM UNIVERSITY LANDS

LOCALITY NO.	HB-2	HB-4
MINERAL STUDIES LAB. NO.	70046	70047
FREE LIME (CARBONATES)	+	+
COLOR (air dried)	tan	light buff
MOISTURE (water) (%)	7.92	6.07
IGNITION LOSS (%)		
110-300°C	0.48	1.03
300-450°C	0.46	0.60
450-600°C	2.10	2.99
600-900°C	3.06	8.15
900-1050°C	0.39	0.97
110-1050°C	6.49	13.74
pH VALUE	8.4	7.7
WATER OF PLASTICITY		
Plastic limit (%)	27	25
Rieke index (%)	13	13
Atterberg index (%)	151	37
SWELLING TEST (% increase in vol.)		
In distilled water	450	60
In salt water	90	40
In .25% Na_2CO_3	750	70
DECOLORIZING EFFICIENCY		
Natural (% of AOCS natural)	38	<20
Activated (% of AOCS activated)	29	67
DRYING TEST (extruded discs)		
Linear drying shrinkage (%, db)	7	1
BLOATING TEST (10 min.)		
App. sp. gr., 2000°F (1093°C)	>1.6	>1.6
App. sp. gr., 2200°F (1204°C)	0.8-1.0	fused
App. sp. gr., 2400°F (1316°C)	fused	fused
FIRING TESTS		
1800°F (982°C)		
Shrinkage (%, db)	2	4
Approx. cone 07		
Hardness (file)	=	<
Color	red	buff
2000°F (1093°C)		
Shrinkage (%, db)	bloated	fused
Approx. cone 03		
Color	dark brown	brown
GRAIN SIZE ANALYSIS		
Sand (%, on US sieve No. 200)	2.3	32.4
Silt (%, 5-74 microns)	15.8	44.8
Clay (%, minus 5 microns)	15.2	11.7
Colloid (%, minus 1.3 microns)	66.7	11.1
CLAY MINERALS		
Kaolinite (%)	10	
Montmorillonite (%)	90	100

+, harder than steel file
=, as hard as steel file

IGNEOUS ROCKS

CHEMICAL ANALYSES

(See Plate VI for sample localities.)

LOCALITY	HUDSPETH-1	HUDSPETH-2	HUDSPETH-9	HUDSPETH-10	HUDSPETH-13	HUDSPETH-14
LAB. NO.	69302	69300	69383	69384	70057	*
PLACE NAME	Red Hills	Sierra Prieta	Chatfield Mtn.	Washburn Mtn.	San Antonio Mtn.	Cornudas Sta.
ROCK TYPE	Trachyte	Nepheline syenite	Phonolite	Nepheline syenite	Nepheline syenite	Analcime trachyte
SiO_2	58.80	59.90	55.60	55.10	55.30	55.40
Al_2O_3	16.90	17.80	19.70	18.10	13.90	18.80
Fe_2O_3	5.65	3.09	3.41	3.34	4.94	4.69
FeO	0.40	2.60	0.99	1.46	1.46	1.68
TiO_2	0.46	0.10	0.34	0.28	0.01	0.08
CaO	1.80	1.04	1.30	2.90	2.20	1.55
MgO	0.95	0.03	0.40	0.40	0.34	0.56
Na_2O	5.70	7.80	10.30	6.40	7.70	6.62
K_2O	5.80	5.00	4.70	5.30	5.40	5.65
MnO	0.33	0.39	0.39	0.37	0.37	0.16
P_2O_5	0.14	0.07	0.12	0.18	0.07	0.45
H_2O	2.11	1.68	2.05	3.01	3.41	3.80
CO_2	0.47	0.08	0.22	1.14	0.49	0.47
TOTAL (percent)	99.51	99.58	99.52	97.08	95.59	99.91

*Analysis of Cornudas Station igneous rock by C. Hoops; supplied by D. S. Barker.

SPECTROGRAPHIC ANALYSES

All igneous rocks for which chemical analyses are listed were also subjected to qualitative spectrographic analysis. The intent was to determine the presence or absence of rare earths and minor elements of possible economic importance that might be associated with the alkalic igneous rocks in the University Lands area. Of particular interest were beryllium (Be), niobium (Nb), barium (Ba), strontium (Sr), titanium (Ti), and zirconium (Zr). The results were disappointing; the elements were either absent or present in only normal amounts.

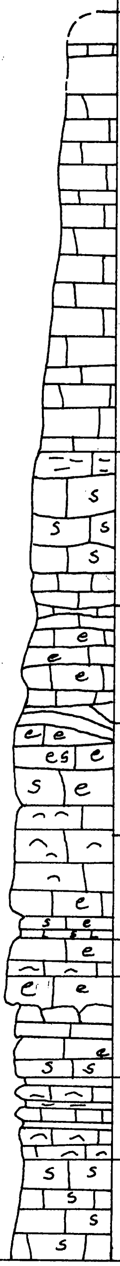
Hudspeth-15.--The Precambrian rocks exposed in the Pump Station Hills were of particular interest for the reasons presented in the chapter on the geology of the Cornudas area. It was felt that if trace elements or rare earths are present in the Diablo Plateau of University Lands, the vein materials in the Pump Station Hills rhyolite would be the most likely place to find them. As with the other igneous rocks, however, there is no indication that minor elements or rare earths have any economic potential in the University Lands area.

CARBONATE ROCKS

CROCKETT – 1. Road cuts, U.S. Highway 290 at Lancaster Hill, 30 miles west of Ozona, Crockett County. One mile west of southwest corner of University Lands Block 29

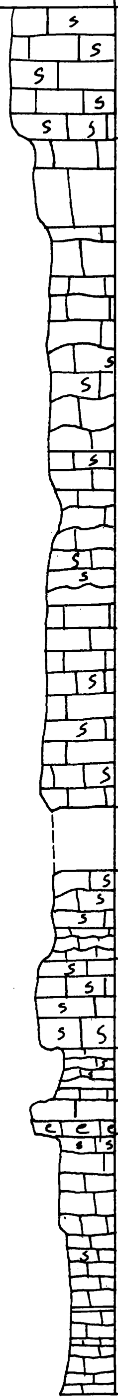
Segovia
Ft Terrett Fm

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69347	97.4	0.8	54.6	0.4		45	Fine to medium-grained shell-fragment limestone, hard, dense poorly exposed
69295	97.3	0.5	54.6	0.3		17	Granular limestone with filled burrows
69294	96.5	1.1	54.2	0.5			
69293	94.7	0.7	53.1	0.3		10	Medium to coarse-grained limestone, hard, massive, burrowed, flaggy at top and base
69292	96.5	0.7	54.2	0.3		13	Medium to coarse-grained limestone, burrowed, hard, massive, thick bedded, many shells
69291	98.2	0.5	55.1	0.2		10	
69290	96.5	1.4	54.2	0.7		5	Fine to coarse-grained, shell-fragment limestone, medium to thick bedded, hard
69289	96.5	0.8	54.2	0.4		10	
69288	93.8	3.9	52.7	1.9		6	Interbedded coarse-grained limestone and clay
69287	93.1	0.9	52.3	0.4			
69286	97.9	0.5	54.9	0.2		13	Fine to coarse-grained, shell-fragment limestone, burrowed, hard, dense

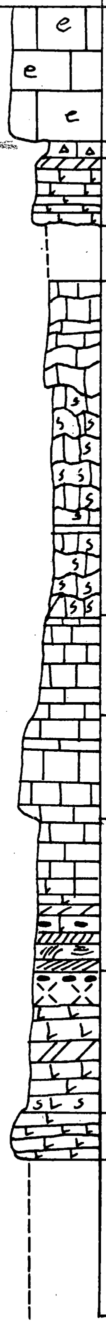


(CONTINUES)

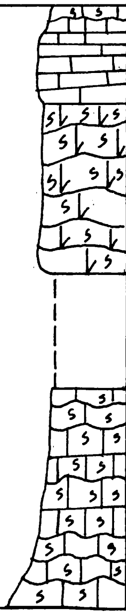
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69285	96.5	0.7	54.2	0.3		11	Fine to coarse-grained, shell-fragment limestone, burrowed, hard, dense
69284	95.7	0.7	53.7	0.3		66	Mostly fine to medium-grained limestone, medium to thick bedded, moderately hard, locally nodular, slope former
69283	91.8	0.7	51.5	0.3			
69282	92.6	0.8	51.9	0.4			
69281	93.4	0.8	52.4	0.4			
69280	96.3	0.8	54.1	0.4			
69279	96.0	0.8	53.9	0.4			
						6	Covered
69278	93.8	1.0	52.7	0.5		9	Limestone, hard to soft, mostly nodular
69277	90.1	1.0	50.6	0.5		9	Fine-grained limestone, burrowed, hard
						6	Limestone, soft, nodular, burrowed
69276	98.9	0.7	55.5	0.3		4	Limestone, hard, fine to coarse grained
69275	94.1	0.7	53.0	0.3		26	Limestone, fine to medium grained, medium to thick bedded, with burrows and abundant oysters
69274	86.2	0.9	48.4	0.4			
69273	89.1	0.8	50.0	0.4			



(CONTINUES)

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69272	95.3	3.4	53.5	1.7	Sey 	14	Shell-fragment limestone, fine to coarse grained, thick bedded, prominent scarp former
						1	Limestone breccia
69271	75.5	14.8	42.4	7.1	Rf Renet	6	Dolomitic limestone, fine to medium grained, thin beds at top
						6	Covered
69270	82.0	1.9	46.0	0.9			
69269	88.2	1.2	49.5	0.6		35	Limestone, soft, nodular, burrowed, abundant fossil clams and oysters
69268	87.4	1.2	49.1	0.6			
69267	98.1	0.9	55.0	0.4		10	Limestone, fine to medium grained, thin to thick beds
69266	97.9	1.0	54.9	0.5		10	Limestone, fine to medium grained, hard, prominent bench former
69265	97.8	0.9	54.9	0.4		16	Limestone, fine to medium grained, thin to thick bedded, cross bedded at base, nodular chert in lower part
69264	71.3	22.8	40.0	10.9		14	Dolomitic limestone and dolomite, fine to medium grained, thin to medium bedded, nodular chert at top
69263	78.7	20.4	44.2	9.8		5	Dolomitic limestone, fine to medium grained
						18	Covered

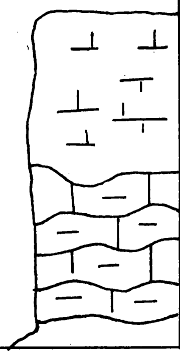
(CONTINUES)

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69262	84.1	13.2	47.3	6.3		13	Mostly fine-grained, thin-bedded limestone, soft, nodular at top
69261	77.4	14.3	43.5	6.8		18	Limestone, nodular, fine to medium grained, dolomitic.
69260	86.9	8.5	48.8	4.1			
						12	Covered
69259	95.6	1.4	53.6	0.7		63 22	Limestone, medium bedded, nodular, calichified
69258	88.2	5.2	49.4	2.5			

LAB NO.	% SiO_2	% Al_2O_3	% Fe_2O_3	% Ign. Loss	% H_2O
69270	9.0	3.2	1.0	37.88	0.39

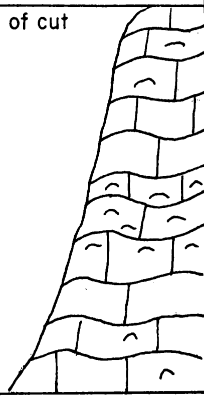
CROCKETT - 2. Small quarry on east side of State Highway 163, 2 miles south of intersection with State Highway 29, Crockett County Two miles south of University Lands Block 42.

kbu

LAB. NO.	% CaCO	% MgCO	% Ca O	% Mg O	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
	(Not	sampled)				3	Caliche
69296	86.8	0.9	48.8	0.4		3	Limestone, soft, nodular, marly

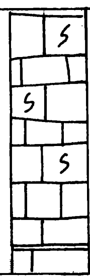
CROCKETT-3. Road cut, State Highway 137, 1 mile northwest of junction with State Highway 29, Crockett County. One mile west of the southwest corner of University Lands Block 51.

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69298	88.1	1.1	49.5	0.5	Top of cut 	40	Limestone, nodular, burrowed, numerous clams and oysters
69297	90.3	1.3	50.7	0.6			

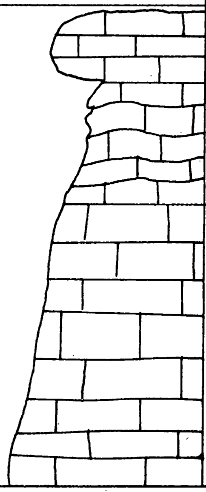
CROCKETT-4. Core taken by Texas Highway Department, north side of State Highway 29, 2½ miles west of the Schleicher County line, Crockett County. University Lands Block 56.

Segovia Ked

LAB. NO.	% CaCO	% MgCO	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69299	96.8	0.8	54.4	0.4		20	Limestone, fine to medium grained, hard, burrowed, numerous shells

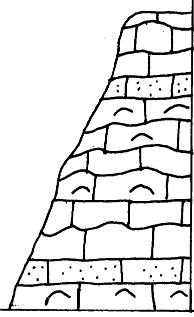
CROCKETT-5. Road cut on north side of U.S. Highway 290, 17 miles west of junction with Farm Road 2083, 22 miles west of Ozona, Crockett County. University Lands Block 30.

Segovia Kcd

LAB. NO.	% CaCO	% MgCO	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69346	97.2	0.8	54.5	0.4		4	Limestone, medium to coarse grained, hard ledge former
69345	91.6	0.9	51.4	0.4		12	Limestone, nodular, marly, burrowed, softer, more marly at base
69344	96.9	0.8	54.4	0.4		28	Limestone, dense, medium grained, hard, medium to thick bedded

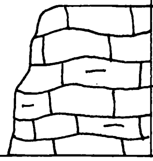
CROCKETT-6. Quarry on west side of State Highway 33, 4 miles south of Reagan County line, Crockett County. Two miles west of University Lands Block 50 and 1.5 miles south of Block 12.

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69348	93.3	2.0	52.4	1.0		30	Limestone, mostly fine grained, nodular, hard, burrowed; with minor amounts of medium-grained limestone

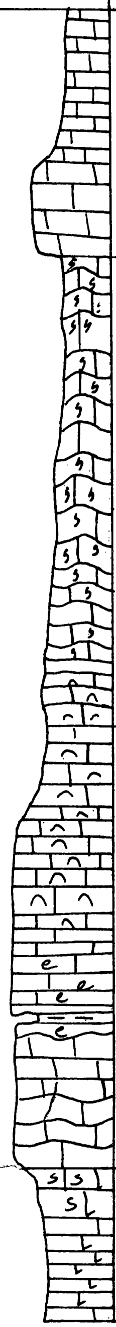
Buda

CROCKETT -7. Quarry on north side of U.S. Highway 290, 24 miles west of Ozona, Crockett County. University Lands Block 29.

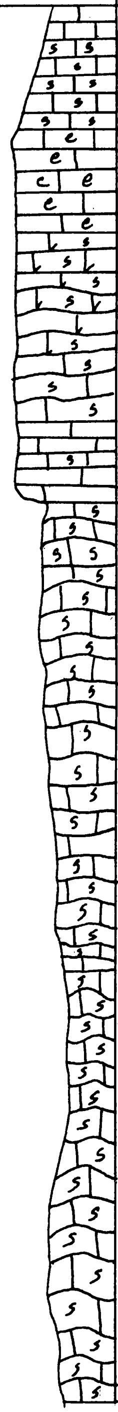
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69351	87.6	0.9	49.2	0.4		15	Limestone, fine grained, soft, nodular, burrowed

CROCKETT-8. Road cuts on State Highway 29, 5 miles east of Iraan, Crockett County.
Ten miles south of University Lands Block 5.

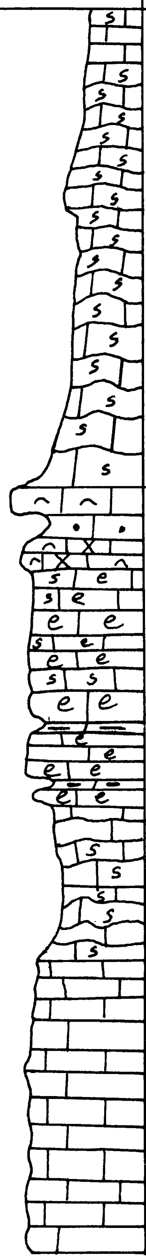
Ked Segovia/Ft T

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69371	95.5	0.9	53.6	0.4		25	Limestone, fine grained, thin to medium bedded, hard, dense, forms scarp at top of topography
69370	94.2	1.0	53.0	0.5		40	Limestone, mostly hard, nodular, burrowed, upper part poorly exposed
69369	93.7	0.8	52.6	0.4			
69368	95.4	1.1	53.5	0.5		52	Limestone, hard, dense, fine to coarse grained, shell fragments, with thin clay bed in lower part; forms prominent scarp
69367	97.0	0.9	54.4	0.4	Seg.		
69366	96.0	1.0	53.9	0.5	Ft. T.	15	Limestone, dolomitic, thin to thick bedded, burrowed

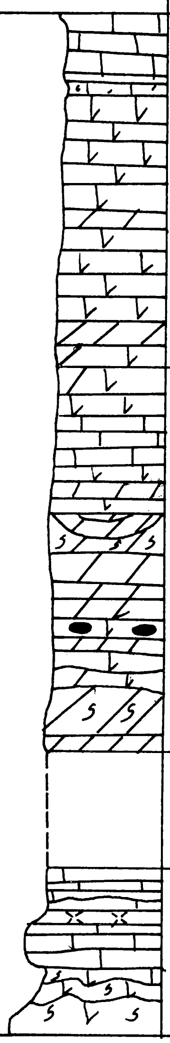
(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69365	96.6	0.9	54.2	0.4		12	Limestone, hard, dense, fine grained, burrowed
69364	98.0	0.6	55.0	0.3		12	Limestone, fine to coarse grained with shell fragments; cross-bedded, forms scarp
69363	94.9	0.7	53.2	0.3		27	Limestone, fine grained, hard, dense, burrowed, medium to thick bedded, forms scarp
69362	93.4	2.2	52.4	1.1		32	Limestone, fine grained, hard, burrowed
69361	90.7	1.5	50.9	0.7		61	Limestone, mostly soft, nodular, marly, with abundant oysters and other shells
69360	87.9	1.4	49.3	0.7			

(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69359	91.6	1.1	51.4	0.5		47	Limestone, mostly soft, nodular, marly, with abundant oysters and other shells
69358	94.1	3.5	53.0	1.7		26	Limestone, dolomitic, mostly hard, dense, fine to medium grained, with abundant shells, with thin interbeds of clay; forms scarp
69357	87.6	1.9	49.2	0.9		15	Limestone, nodular, marly, burrowed, with abundant shells
69356	90.8	9.3	51.0	4.4		30	Limestone, fine to coarse grained, shell fragments, hard, dense, dolomitic

(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
	(Not	sampled)				33	Dolomite and dolomitic limestone, thin to medium bedded; top of deep cut
69355	73.0	22.3	41.0	10.7		50	Dolomite and dolomitic limestone, thin to thick bedded, thin nodular chert in lower part
69354	56.4	35.2	31.6	16.8			
69353	63.8	29.5	35.8	14.1			
						15	Covered
69352	77.7	16.2	43.6	7.7		15	Limestone, dolomitic, fine grained, thin to thick bedded, mostly hard; calichified

CROCKETT- 9. Limestone ledge in shallow draw on north side of gravel road 7 miles southwest of the northeast corner of Crockett County. University Lands Block 52.

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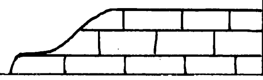
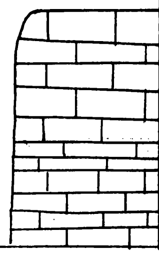
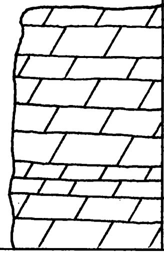
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% Ca O	% Mg O	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69372	95.8	0.8	53.8	0.4		2	Limestone, hard, dense, fine grained

CROCKETT-10. Quarry on the south side of State Highway 29 at east edge of Crockett County. University Lands Block 56.

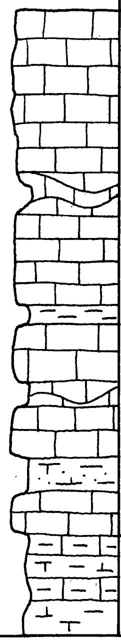
Ba

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% Ca O	% Mg O	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
70111	93.7	0.8	52.6	0.4		24	Limestone, mostly medium bedded, fine to medium grained, moderately hard

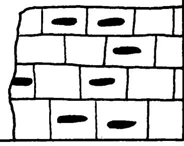
CULBERSON – 1. Victorio Peak Formation; quarry near north edge of Wylie Mountains; 0.5 mile south of U.S. Highway 80, about 6 miles east of Van Horn.

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69386	53.5	41.7	30.0	19.9		25	Dolomite, light to medium gray, medium to thick bedded, fine grained
69385	51.3	43.0	28.9	20.6			

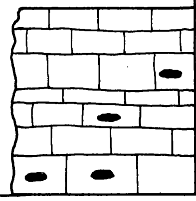
CULBERSON – 2. Finlay Limestone; east edge of Van Horn Mountains near Willoughby Wind Gap along unimproved ranch road.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
70035	93.8	1.0	52.7	0.5		55	Limestone, medium gray, fine grained, medium bedded; interbeds of marl, mudstone, and some sandy marl
70034	64.8	0.9	36.4	0.4			
70033	80.2	0.9	45.0	0.4			
70032	88.8	1.1	49.8	0.5			
						10	Marly limestone and marl

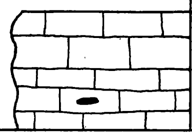
HUDSPETH-3. Hueco Limestone; road cut along U.S. Highways 62 and 180 about 26 miles west of Cornudas.

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69392	96.0	1.6	53.9	0.8		14	Limestone, medium to dark gray, fine grained, medium bedded, chert nodules abundant

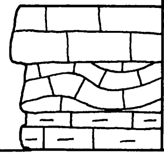
HUDSPETH-4. Hueco Limestone; road cut along U.S. Highways 62 and 180 about 25 miles west of Cornudas.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69393	97.7	0.8	54.8	0.4		18	Limestone, medium gray, fine grained, medium bedded; some chert

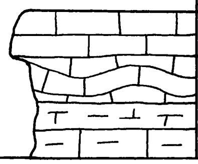
HUDSPETH-5. Hueco Limestone; road cut along U.S. Highways 62 and 180 about 24 miles west of Cornudas.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69391	97.1	0.7	54.5	0.3		12	Limestone, medium to dark gray, fine grained, medium bedded, chert minor

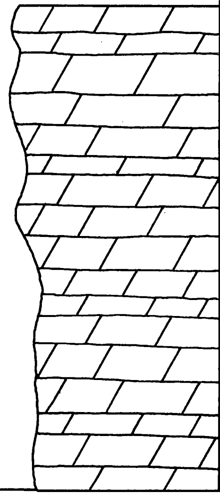
HUDSPETH–6. Finlay Limestone; southeast corner of Molesworth Mesa along FM 2317 about 6 miles south of Cornudas.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69389	96.8	1.6	54.4	0.8		15	Limestone, fine grained, medium bedded to nodular, some is marly; gray brown
Not sampled							

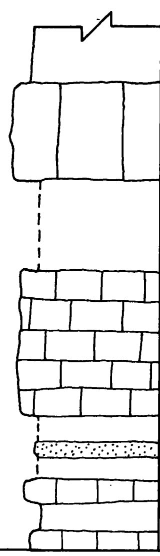
HUDSPETH–7. Finlay Limestone; northeast corner of Molesworth Mesa along FM 2317 about 4 miles south of Cornudas.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69390	93.2	1.2	52.4	0.6		4	Limestone, fine grained, light gray
Not sampled						10	Limestone, nodular to marly

HUDSPETH-8. Victorio Peak Formation; shallow stream cuts immediately south of U.S. Highways 62 and 180, 18 miles east of Cornudas.

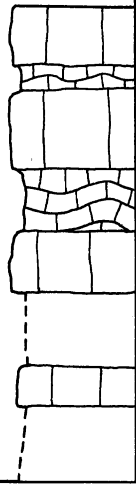
LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69388	54.1	43.0	30.4	20.6		25	Dolomite, grayish brown, fine to medium grained, medium bedded; some medium to coarse crystalline beds; petroliferous
69387	57.3	42.2	32.2	20.2			

HUDSPETH-11. Bluff Formation; northwest edge of Yucca Mesa near end of pavement on FM 1111; section is structurally complex; locality outside mapped area.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
	Not sampled						
70038	96.1	1.2	53.9	0.6		10	Limestone, massive, dark gray, fine grained; fossiliferous
						8-10	Covered
70037	74.7	1.5	41.9	0.7		15	Limestone, very fine grained, pinkish gray, medium bedded
70036	95.2	1.6	53.4	0.8		20-30	Limestone, dark gray, fine grained; interbedded nodular limestone and sandstone

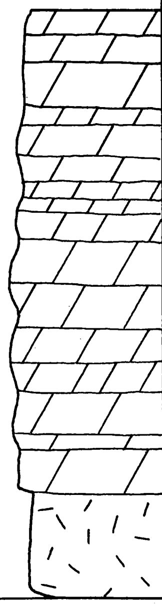
HUDSPETH – 12. Finlay Limestone; Texan Mountain at FM 1111 cut; section measured along ridge north of cut, 1 mile south of Sierra Blanca; locality outside mapped area.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
70043	95.8	0.8	53.8	0.4		6	Massive, dark gray, fine-grained limestone
						2	Dark gray nodular limestone
70042	94.9	1.2	53.2	0.6		8	Fine-grained, massive limestone
70041	91.8	1.3	51.5	0.6		6	Very fossiliferous, nodular limestone
70040	89.9	2.3	50.5	1.1		6	Fossiliferous, fine-grained, massive limestone
						7	Covered
70039	96.0	1.2	53.9	0.6		4	Massive limestone
							Covered

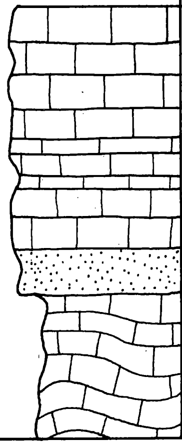


Vic. Peak HUDSPETH – 14. Isolated hill 1.5 miles southeast of Cornudas.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
70110	51.8	43.0	29.1	20.6		50	Dolomite, dark gray, fine grained, medium to thick bedded
70109	54.5	42.8	30.6	20.5			
See igneous rock analyses						10	Igneous rock; analcime trachyte



HUDSPETH – 16. Finlay Limestone; south edge of Molesworth Mesa along unimproved road on Molesworth Ranch about 6 miles southwest of Cornudas.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
70107	92.4	1.2	51.8	0.6		25	Limestone, light to medium gray, fine grained, medium bedded; very fossiliferous
						4	Sandstone, burrowed
70108	86.0	1.2	48.3	0.6		15	Limestone, fine grained, nodular, gray brown; fossiliferous

IRION-1. Quarry on west side of State Highway 163 at south edge of county, 3 miles south of Barnhart, Irion County. University Lands Block 40.

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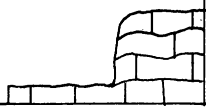
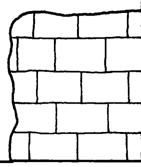
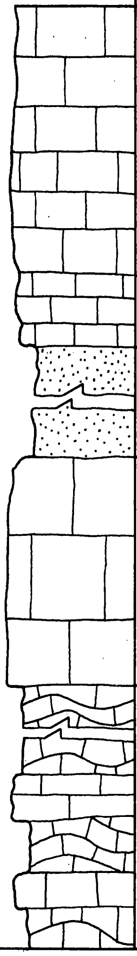
LAB. NO	% CaCO	% MgCO	% Ca O	% Mg O	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69229	94.1	0.8	53.0	0.4		4	Limestone, soft, nodular in upper part, hard, fine to medium grained at base

JEFF DAVIS – I. Buda Limestone; small quarries along Chispa Summit road about 6 miles southwest of its intersection with U.S. Highway 90.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
70024	95.0	1.0	53.3	0.5		15	Limestone, medium to light gray, medium to thick bedded, fine grained
70025	95.0	1.2	53.3	0.6			

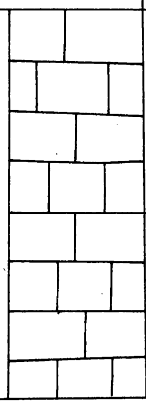
JEFF DAVIS – 2. Buda and Loma Plata limestones; first high ridge northwest of Chispa Summit road, about 8 miles southwest of its intersection with U.S. Highway 90.

LAB NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
							
70026	94.2	1.1	53.0	0.5		25	Limestone, medium gray, fine grained thick bedded; very fossiliferous in places. Buda.
70027	94.7	1.1	53.1	0.5		10	Limestone, medium gray, fine grained, medium bedded
						20–40	Sandstone. Eagle Mountain.
70028	98.3	0.5	55.2	0.2		22	Limestone, medium gray, fine grained, very thick bedded to massive; fossiliferous; forms prominent cliff. Loma Plata.
70029	97.6	0.6	54.7	0.3			
70030	95.2	1.2	53.4	0.6		40–50	Limestone, nodular, medium gray; fossiliferous, interbedded with medium-bedded, more resistant fine-grained limestone. Loma Plata.
70031	97.8	0.6	54.9	0.3			

PECOS-1. Debris piles from pipeline excavation, north side of U.S. Highway 290, 11 miles east of Fort Stockton, Pecos County. University Lands Block 24.

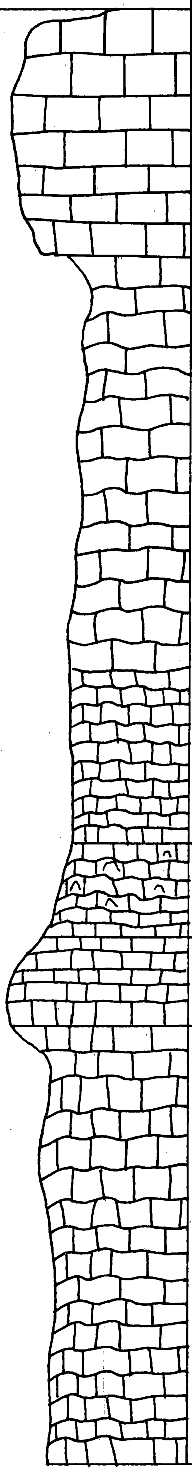
X

Segovia?

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69231	99.2	0.8	55.7	0.4		3	Limestone, hard, dense, coarse grained, abundant shell fragments, thin caliche cap
69230	98.8	0.7	55.4	0.3		3	Limestone, dense, hard, fine to medium grained

PECOS-2. Northeast slope of University Mesa 1.5 miles west of U.S Highway 385, 4 miles north of junction with U.S. Highway 290. University Lands Block 24.

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69242	95.5	0.5	53.6	0.2		25	Limestone, mostly fine grained, hard, dense, forms prominent caprock
69241	95.7	1.0	53.7	0.5		60	Limestone, hard, fine grained, slightly nodular, poorly exposed
69240	95.0	1.0	53.3	0.5		9	Limestone, fine grained, hard, slightly nodular, abundant shells
69239	97.8	0.9	54.9	0.4		9	Limestone, hard, medium to coarse grained, forms prominent scarp
69238	94.6	1.4	53.1	0.7		45	Limestone, slightly nodular, fine grained, hard, burrowed
69237	92.7	2.4	52.0	1.2			

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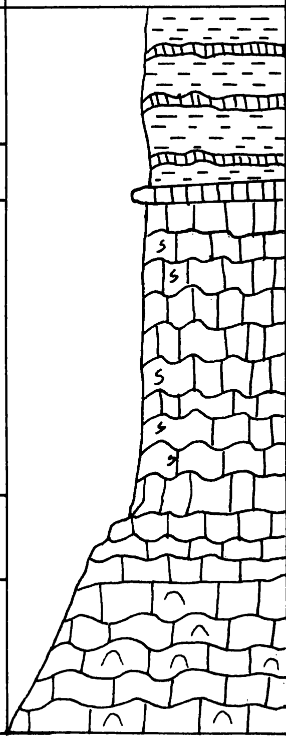
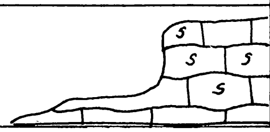
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69236	76.3	2.1	42.7	1.0		18	Limestone, soft, marly, nodular, and marl; abundant oysters
69235	93.0	1.6	52.3	0.8		2	Limestone, medium to coarse grained, hard, dense, orange brown
69234	88.0	1.5	49.4	0.7		36	Limestone, nodular, marly, soft, abundant oysters at top; marl interbeds
69233	92.3	1.4	51.8	0.7		8	Limestone, fine grained, hard, slightly nodular
69232	88.8	1.6	49.8	0.8		15	Limestone, nodular, soft, marly, burrowed, abundant fossil shells

LAB. NO.	% CaO	% MgO	% SiO_2	% Al_2O_3	% Fe_2O_3	Ign. Loss %	H_2O %
69236	42.7	1.0	12.0	4.6	1.2	36.05	0.83

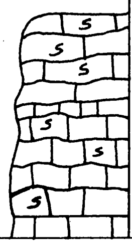
PECOS-3. Quarry, south side of Spur 194, 3 miles southwest of Fort Stockton, Pecos County. East edge of University Lands Block 27.

Caliche

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69243	89.2	1.5	50.1	0.7		3	Limestone, fine grained, nodular, calichified

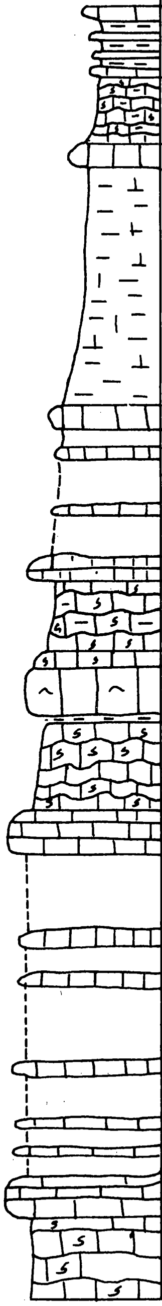
PECOS-4. Quarry, west side of U.S. Highway 385, 8 miles south of Fort Stockton, Pecos County. University Lands Block 27.

Segovia

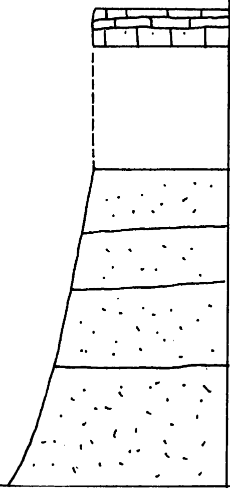
LAB. NO.	% CaCO	% MgCO	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69244	95.8	1.0	53.8	0.5		12	Limestone, fine grained, slightly nodular, hard, dense, burrowed

PECOS-5. Quarry, road cuts and slopes along and east of U.S. Highway 385, 9 miles northeast of intersection with U.S. Highway 290, Pecos County. University Lands Block 25.

Ft Terrett

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69257	93.2	1.2	52.4	0.6		6	Limestone, medium grained, hard, interbedded with soft, marly limestone
69256	72.6	1.4	40.7	0.7		7	Limestone, soft, nodular, marly, burrowed, abundant shells
69254	92.3	1.8	51.8	0.9			
69255	46.2	3.2	25.9	1.5		29	Marl, gray to tan; poorly exposed rubble-covered slope; hard, fine-grained limestone ledges at base and top
69254	92.3	1.8	51.8	0.9			
69253	91.0	1.5	51.1	0.7		15	Limestone, fine to coarse grained, dense, thin ledges, interbedded with marly limestone, mostly covered
69252	89.7	1.3	50.4	0.6		6	Limestone, nodular, marly, abundant oysters
69251	95.3	1.1	53.5	0.5		6	Limestone, hard, dense, fine grained
69250	96.0	1.0	53.9	0.5		9	Limestone fine grained, nodular, burrowed
69249	97.0	1.1	54.4	0.5		38	Limestone, fine to medium grained, dense, hard; in thin ledges; rest of section covered
69248	95.7	1.1	53.7	0.5		4	Limestone, fine grained, hard
69247	95.4	1.2	53.5	0.6		15	Limestone, fine grained, hard, slightly nodular, burrowed, abundant shell fragments
69246	92.5	1.3	51.9	0.6			

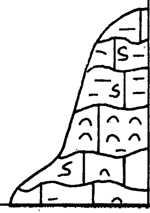
(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69245	82.9	0.9	46.6	0.4		3	Fine to coarse grained, sandy, shell fragments
						5	Covered
Not	analyzed					12	Sand and sandstone, soft to hard, fine to medium grained, gray to orange brown

LAB. NO.	% CaO	% MaO	% SiO_2	% Al_2O_3	% Fe_2O_3	% Ign. Loss.	% H_2O
69255	25.9	1.5	30.0	11.1	2.8	24.15	2.79
69256	40.7	0.7	18.5	2.3	1.9	32.75	0.51

PECOS-6. Well-site excavation north side of U.S. Highway 290, 17 miles east of Fort Stockton and 2 miles east of junction with U.S. Highway 67. Pecos County. University Lands Block 25.

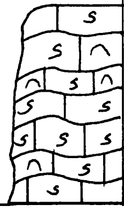
Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69305	63.2	2.7	35.4	1.3		20	Limestone, soft, nodular, marly, abundant oysters
69304	87.1	1.3	48.9	0.6			

Lab. No.	% CaO	% MgO	% SiO_2	% Al_2O_3	% Fe_2O_3	% Ign. Loss	% H_2O
69305	35.4	1.3	19.8	7.3	2.1	30.70	1.27

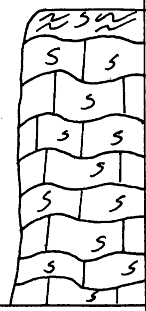
PECOS-7. Quarry, east side of Ranch Road 2023, 5.5 miles south of junction with U.S Highway 290, Pecos County. South edge of University Lands Block 21.

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69306	88.8	1.1	49.8	0.5		20	Limestone, soft, nodular, marly, abundant oysters

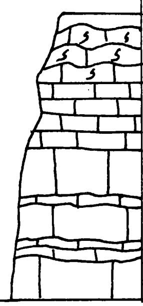
PECOS-8. Quarry, 0.5 mile north of U.S. Highway 290, 2 miles west of junction with State Highway 18 in Fort Stockton, Pecos County. Two miles north of University Lands Block 28.

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS FEET	ROCK DESCRIPTION
69307	88.4	2.0	49.6	1.0		30	Limestone, soft, nodular, burrowed, with caliche cap
69308	90.8	1.8	51.0	0.9	From stockpile		Same as above

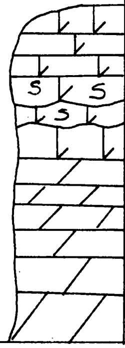
PECOS-9. Road cut, U.S. Highway 290, 4 miles east of junction with Ranch Road 2023, Pecos County. Two miles east of University Lands Block 21.

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69310	95.0	1.0	53.3	0.5		7	Limestone, fine grained, burrowed, nodular, hard; caliche cap
69309	97.7	0.5	54.8	0.2		22	Limestone, hard, fine to coarse grained, thick bedded at base to thin bedded at top

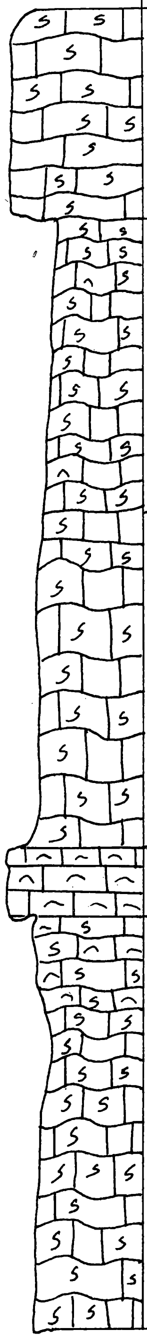
PECOS-10. Road cut, U.S. Highway 290, 1.2 miles east of Tunis Creek bridge, 3 miles west of Bakersfield, Pecos County. University Lands Block 18.

Ft. Terrett

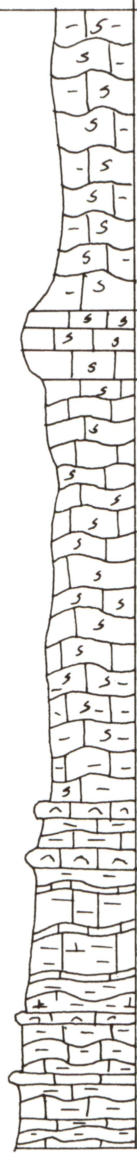
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69311	53.4	36.8	30.0	17.6		14	Dolomite and dolomitic limestone, fine grained, thin to thick beds

PECOS-11. Northeast slope of Squaw Tit Peak, north of U.S. Highway 290, 1.5 miles west of Bakersfield, Pecos County. University Lands Block 18.

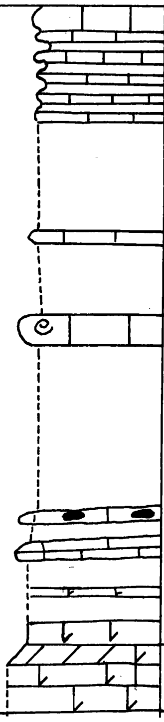
Ft. Terret

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69321	96.2	0.6	54.0	0.3		25	Limestone, fine grained, hard, dense, slightly nodular, burrowed, mostly thick bedded, forms cap rock
69320	94.4	1.2	53.0	0.6		30	Limestone, nodular, burrowed, fine grained
69319	93.2	1.6	52.4	0.8		35	Limestone, fine to medium grained, slightly nodular, burrowed, more granular upward
69318	96.5	0.9	54.2	0.4		6	Limestone, fine grained, hard abundant shells, forms scarp
69317	86.6	1.7	48.7	0.8		45	Limestone, marly, soft, nodular, more marly in lower part; abundant shells at top

(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69316	89.5	1.2	50.3	0.6		30	Limestone, marly, soft, nodular
69315	93.4	1.1	52.4	0.5		6	Limestone, fine grained, hard, forms scarp
69314	86.5	1.5	48.5	0.7		50	Limestone, soft, nodular, marly, and marl; lower part more marly with ledges of limestone with abundant shells
69313	82.0	1.9	45.9	0.9			
69312	39.0	4.2	21.9	2.0		31	Marl, gray to tan, soft, and limestone, soft, nodular, more marly in upper part; interbeds of hard, dense, orange-brown, fine-grained limestone in lower part
69326	84.5	1.7	47.3	0.8			

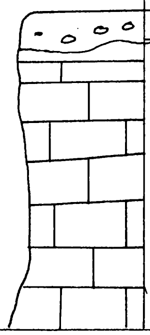
(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69325	96.7	1.8	54.3	0.9		48	Limestone, fine to medium grained, hard, dense, forms thin ledges separated by thicker covered intervals; chert nodules in lower part; lower part dolomitic
69324	96.4	1.8	54.1	0.9			
69323	83.9	13.2	47.1	6.3			
69322	59.0	37.1	33.2	17.7		2	Dolomite and dolomitic limestone, soft, thin to medium bedded

LAB. NO.	% Ca~~C~~O	% MgO	% SiO_2	% Al_2O_3	% Fe_2O_3	% Ign. Loss	% H_2O
69312	21.9	2.0	37.5	12.1	2.3	22.55	1.59
69313	45.9	0.9	9.0	3.1	0.9	37.78	0.37
69314	48.5	0.7	6.8	2.5	0.9	39.17	0.71
69326	47.3	0.8	8.8.	1.8	0.9	38.46	0.24

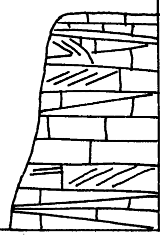
PECOS-12. Quarry 1 mile west of U.S. Highway 385 and south of an east-west gravel road, 4 miles south of Fort Stockton, Pecos County. East edge of University Lands Block 27.

Caliche

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
	Not	sampled				3	Gravelly soil
69382	82.9	1.3	46.6	0.6		7	Caliche, fine grained, gravelly

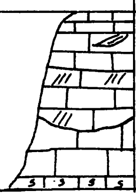
REAGAN-1. Road cut, State Highway 33, at south Reagan County line. East edge of University Lands Block 12.

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69327	98.6	0.7	55.3	0.3		22	Limestone, mostly coarse grained, hard, dense, shells, cross-bedded

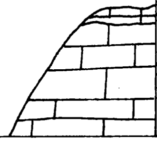
REAGAN-2. Quarry, south side of U.S Highway 67, 2 miles east of Big Lake, Reagan County. Two miles east of University Lands Block 11.

Bu

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69328	98.2	0.7	55.1	0.3		18	Limestone, hard, dense, medium to coarse grained, cross-bedded, abundant shell fragments

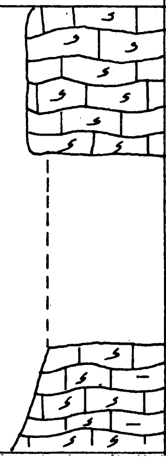
REAGAN-3. Low cut and blocks from road excavation, west side of Ranch Road 1555, 7 miles north of U.S. Highway 67, Reagan County, University Lands Block 58.

Ft. Terrett

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69373	96.2	0.7	54.0	0.3		6	Limestone, medium to coarse grained, hard, dense

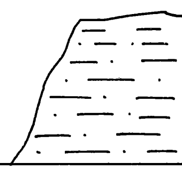
REAGAN-4. **Quarries on west side of gravel road, 0.5 mile south of Best, Reagan County. University Lands Block 9.**

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69374	97.6	0.8	54.7	0.4		15	Upper quarry: limestone, fine to coarse grained, slightly nodular, hard, dense, burrowed
						20	Covered
69375	92.3	1.4	51.8	0.7		10	Limestone, nodular, burrowed, moderately hard

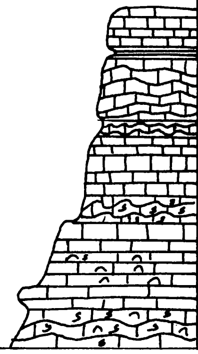
REAGAN-5. Road cut, east side of State Highway 137, 1.5 miles south of Big Lake, Reagan County. East edge of University Lands Block 11.

Caliche

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
70112	48.9	3.5	27.5	1.7		15	Silt and fine sand, calcareous, soft, loose; lake beds

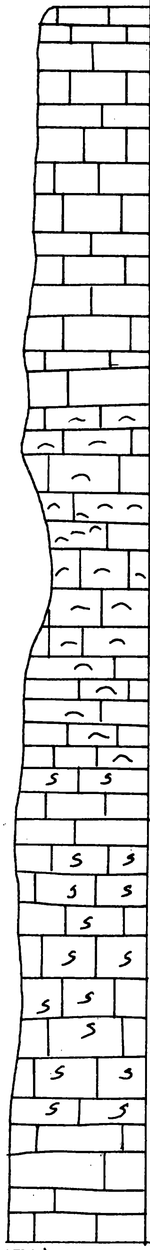
SCHLEICHER-1. Road cut, State Highway 29, 4.5 miles west of junction with Ranch Road 1828, 17.5 miles west of El Dorado, Schleicher County. University Lands Block 57.

Buda

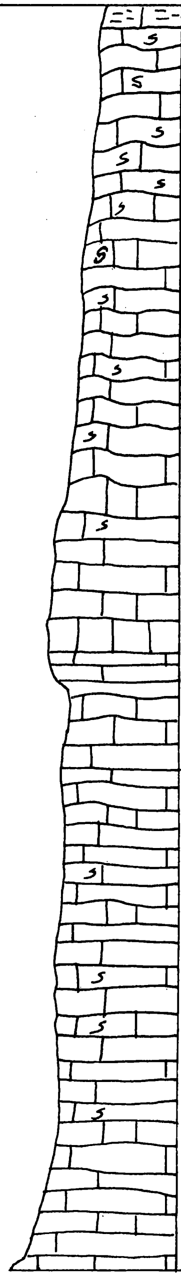
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69228	95.4	0.9	53.5	0.4		35	Limestone, fine to coarse grained, mostly hard, dense; upper part more granular, lower part finer grained and with abundant oysters
69227	81.2	0.6	45.6	0.3			
69226	93.8	0.7	52.7	0.3			

TERRELL-1. Well-site road, 1 mile west of State Highway 349, 5 miles south of junction with Ranch Road 2400, Terrell County. University Lands Block 34.

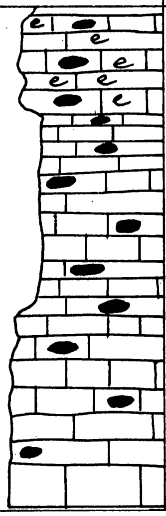
Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69329	95.2	1.0	53.4	0.5		52	Limestone, mostly medium to coarse grained, hard, abundant shell fragments, top of cap rock
						32	Limestone, mostly fine to medium grained, softer than above, with abundant oysters
69331	96.4	0.7	54.1	0.3		60	Limestone, mostly fine grained, shell fragments, abundant oysters, hard, forms base of cap rock

(CONTINUES)

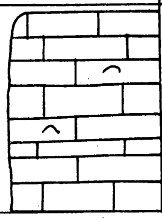
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69330	92.9	0.8	52.2	0.4		130	Limestone, mostly fine grained, thin to medium beds; harder, more resistant in middle; abundant fossil shells; poorly exposed
69332	96.3	0.9	54.1	0.4			

(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69333	96.5	0.6	54.2	0.3		50	Limestone, fine to coarse grained, thin to thick beds, hard, forms scarp; abundant shells in upper part; nodular chert abundant, middle part poorly exposed

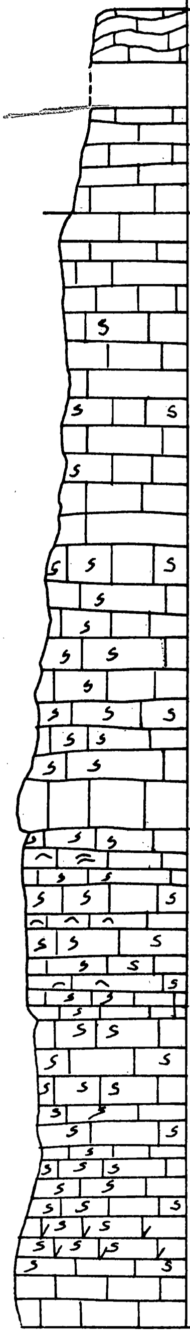
TERRELL-2. Quarry, west side of Ranch Road 2400, 10 miles southwest of junction with State Highway 349, Terrell County. East edge of University Lands Block 36.

Segovian

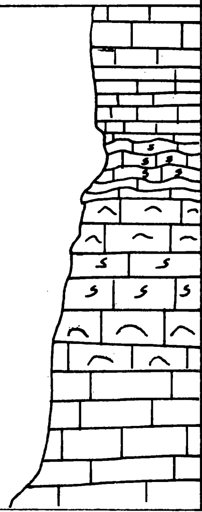
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69334	88.4	0.8	49.6	0.4		20	Limestone, fine grained, marly, thick beds, massive

TERRELL - 3. Road cut, Ranch Road 2400, 0.5 mile southwest of junction with State Highway 349, Terrell County. Four miles north of University Lands Block 34.

Segovia

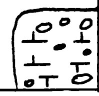
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS FEET	ROCK DESCRIPTION
69343	95.2	1.1	53.4	0.5		20	Limestone, fine grained, hard, nodular, burrowed; middle part covered
69342	95.3	0.8	53.5	0.4		64	Limestone, hard, dense, mostly fine to medium grained, slightly nodular, burrowed; lower part intensively burrowed; basal 6 feet coarse grained, massive, abundant shell fragments
69341	97.1	0.7	54.5	0.3			
69340	94.8	0.8	53.2	0.4		41	Limestone, fine to medium grained, hard, dense, burrowed; upper part with abundant oysters; lower part intensively burrowed; dolomitic at base
69339	96.7	0.7	54.2	0.3			
69338	97.0	1.1	54.4	0.5			

(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69338	97.0	1.1	54.4	0.5			
69337	93.0	0.7	52.3	0.3		34	Limestone, mostly hard, dense, fine to medium grained, burrowed; middle part marly, nodular, with abundant shells
69336	95.4	0.8	53.5	0.4			
69335	95.2	0.7	53.4	0.3		20	Limestone, hard, dense, fine grained, upper part with abundant shells

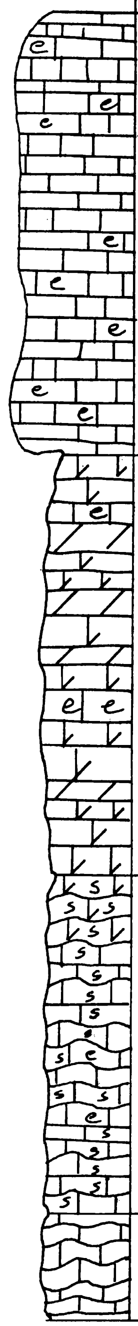
UPTON - 1. Quarry, north side of U.S. Highway 67, 3 miles west of junction with State Highway 349, 7.5 miles southwest of Rankin, Upton County. University Lands Block 15.

Caliche

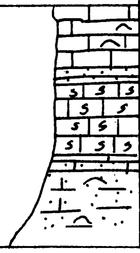
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69222	82.5	1.6	46.3	0.8		6	Limestone conglomerate; coarse-grained limestone debris cemented with caliche; hard, dense

UPTON-2. Quarry and road cuts on gravel road on east side of State Highway 349, 4 miles south of junction with U.S. Highway 67, Upton County. University Lands Block 14.

FtJ cont

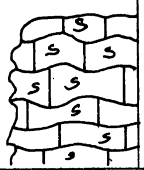
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
70115	93.1	1.8	52.3	0.9		45	Limestone, hard, dense, fine to coarse grained, thin to medium bedded, abundant shells; forms prominent scarp
70114	65.0	30.2	36.5	14.9		43	Dolomite and dolomitic limestone, mostly thin bedded
70113	83.6	10.3	47.0	4.9		35	Limestone, mostly fine grained, burrowed, nodular; dolomitic in upper part
69225	84.8	4.2	47.6	2.1		10	Limestone, mostly nodular, marly, burrowed

(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69224	90.0	1.6	50.5	0.8		12	Limestone, fine grained, sandy, burrowed
69223	86.4	1.3	48.5	0.6		9	Limestone, sandy, burrowed; and sandstone, calcareous, fine grained

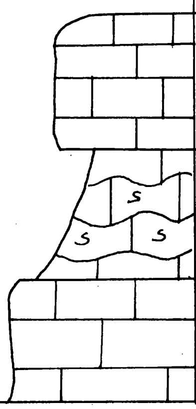
UPTON-4. Quarry, east side of gravel road, 8 miles south of junction with U.S. Highway 67, 2.5 miles east of Rankin, Upton County. University Lands Block 4.

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69376	89.2	1.9	50.1	0.9		15	Limestone, marly, nodular, burrowed

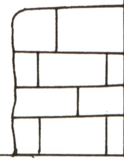
UPTON-5. Low cut, ditch, and slope on east side of gravel road, 2 miles north of Upton-4, Upton County. West edge of University Lands Block 4.

Segovia

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICKNESS (FEET)	ROCK DESCRIPTION
69377	98.0	0.9	55.0	0.4		15	Limestone, hard, dense, fine to coarse grained; forms prominent double scarp with soft nodular limestone between; one sample each taken from upper and lower hard limestone; soft limestone forms covered slope
	Not	sampled				35	
69378	96.8	1.1	54.4	0.5		15	

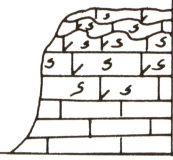
UPTON-6. Blocks from excavation for gravel road, 3.5 miles north of Upton-5 and 1.5 miles south of U.S. Highway 67, Upton County. West edge of University Lands Block 58.

Ft Terrett

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69379	97.3	0.7	54.6	0.3		4	Limestone, dense, hard, medium to coarse grained

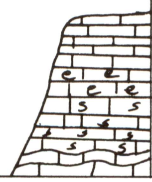
UPTON-7. Railroad cut, south side U.S. Highway 67, 0.5 mile east of gravel road leading to Upton-6 and 3 miles east of Rankin, Upton County. West edge of University Lands Block 58.

FT Terrett

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69380	82.9	11.7	46.5	5.7		13	Limestone, fine grained; upper part nodular, burrowed; middle part massive, burrowed; lower part flaggy; dolomitic

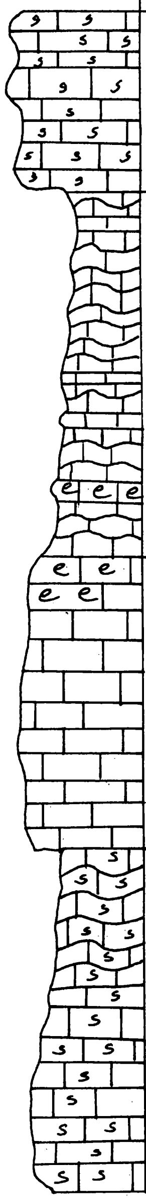
UPTON-8. Road cut, State Highway 349, 2 miles north of Rankin, Upton County. About 4 miles west of University Lands Block 58.

Segovia

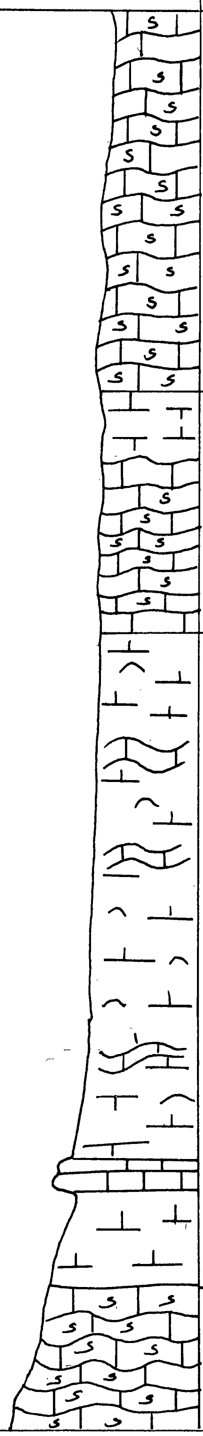
LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
69381	95.4	0.9	53.5	0.4		16	Limestone, hard, dense, fine grained; upper part flaggy; middle part with abundant shells; lower part burrowed, nodular

UPTON-9. Road cut, well-site road, east of State Highway 349, 9 miles south of Rankin, Upton County. University Lands Block 14. This section is a continuation of Upton-2, about 1 mile north

Segovia

LAB. NO	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
70123	95.3	1.3	53.5	0.6		18	Limestone, medium to coarse grained, hard, dense, burrowed, shell fragments, forms cap rock
70122	92.1	1.2	51.7	0.6		37	Limestone, mostly fine grained, marly, nodular; with interbeds of hard granular limestone
70121	95.1	1.0	53.3	0.5		30	Limestone, medium to coarse grained, abundant shells, cross-bedded; forms prominent scarp
70120	92.5	1.4	51.9	0.7		36	Limestone, fine to medium grained, burrowed; upper part nodular; lower part forms scarp

(CONTINUES)

LAB. NO.	% $CaCO_3$	% $MgCO_3$	% CaO	% MgO	DIAGRAMMATIC SECTION	THICK-NESS (FEET)	ROCK DESCRIPTION
70119	90.6	1.4	50.8	0.7		40	Limestone, fine grained, marly, nodular, burrowed
70118	83.8	1.0	47.1	0.5		25	Limestone, marly, nodular, soft; and marl; abundant oysters
70117	52.4	3.1	29.5	1.5		80	Marl, gray to tan, with interbeds of nodular, marly limestone; abundant oysters; thin ledges of hard, fine-grained, orange-brown limestone near base
70116	66.8	1.2	37.5	0.6		15	Limestone, marly, nodular, burrowed

LAB. NO.	% CaO	% MgO	% SiO_2	% Al_2O_3	% Fe_2O_3
70117	29.5	1.5	23.5	8.1	2.28
70118	47.1	0.5	7.8	2.3	0.6