

University of Texas Bulletin

No. 1857: October 10, 1918

Geology and Mineral Resources of Crockett County With Notes on the Stratigraphy, Structure, and Oil Prospects of the Central Pecos Valley

By

R. A. LIDDLE AND T. M. PRETTYMAN

BUREAU OF ECONOMIC GEOLOGY AND TECHNOLOGY
DIVISION OF ECONOMIC GEOLOGY

J. A. UDDEN

Director of the Bureau and Head of the Division



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The benefits of education and of useful knowledge, generally diffused through a community, are essential to the preservation of a free government.

Sam Houston

Cultivated mind is the guardian genius of democracy. . . . It is the only dictator that freemen acknowledge and the only security that freemen desire.

Mirabeau B. Lamar

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THE GEOLOGY AND MINERAL RESOURCES OF CROCKETT COUNTY

BY

R. A. LIDDLE AND T. M. PRETTYMAN¹

INTRODUCTION

LOCATION AND AREA

Crockett County, containing 3004 square miles, is situated in the southwestern part of the Edwards Plateau, east of the Trans-Pecos Plains, and southeast of Toyah Basin.

The Pecos River, flowing to the southeast along the boundary between Crockett County and Pecos and Terrell counties, on the southwest and west respectively, also forms the demarcation between the Edwards Plateau and the Trans-Pecos Plains. The extreme northwestern corner of Crockett County lies within Toyah Basin. To the north of the county are the southern boundaries of Crane, Upton, Reagan, and Irion counties, approximately along the 31st parallel north. To the east, Schleicher and Sutton counties bound Crockett County approximately along the 101st meridian west. Immediately to the south is Val Verde County.

Ozona, the county-seat and the only town in the county, is in the east-central part. It has a population of about 430, and is the location of the only school in the county. The school building, together with a number of other public and private institutions, is constructed of undressed native Edwards limestone. This is a very durable material, works readily, and on account of its hardness and homogeneous nature, weathers slowly and evenly. When first quarried, it is a very bright gray, but later turns to a pale straw color, due to a partial oxidation of the ferrous elements.

Ozona has no manufacturing industries, except a saddlery

¹Manuscript submitted October, 1919. Published December, 1920.

and a blacksmith shop. Its distance from a railroad makes any industry necessitating more than local transportation unprofitable. The Kansas City, Mexico and Orient Railroad runs east and west through the southern part of Irion, Reagan and Upton counties, parallel to the northern boundary of Crockett County and about 30 miles north of Ozona. Barnhart, in Irion County, is the nearest railroad station. All transportation within the county is by means of auto-truck lines or mule teams. The principal roads, being in good condition, materially assist in transportation to the interior.

The Government Military Highway from San Antonio to El Paso runs east and west across the north-central part of the county. From this, secondary roads lead to the interior.

GEOGRAPHY AND PHYSIOGRAPHY

The Pecos River, forming the west and southwest boundaries of Crockett County, and flowing southeast along the dip of strata, affords an excellent opportunity for studying the Comanchean-Cretaceous series. By extending the line of investigation along the river into the adjoining counties, a complete section of the Comanchean-Cretaceous can be obtained. The bluffs on either side of the river make desirable vertical sections.

Howard's Draw and Live Oak Creek are the two main drainage features of the county. The former is an intermittent stream and is dry the greater part of the time. Live Oak Creek, the only flowing stream in the county, is fresh water, and fed from springs in the Edwards limestone. Both of these drain into the Pecos River, which empties into the Rio Grande.

For a considerable time after each rain, the Pecos has a red, muddy appearance, due to the material being transported. As it flows for some distance through the Red Beds of the Permian, the Triassic, and the red sands and sandy clay of the lowest Comanchean-Cretaceous, the material which it and its tributaries have eroded colors the water to a deep red.

The alkali in solution renders the river water unfit for domestic use, but it is not present in sufficient quantities to be harmful to stock.

RELIEF

The chief topographic features of the Comanchean-Cretaceous, as developed in Crockett County, consist of deep, narrow, steep-walled canyons, high plateaus, and flat-topped hills in the river district. This area constitutes the greatest relief in the county. The boldness of the river district topography is materially modified as the distance from the river increases. At the river banks, it begins in precipitous bluffs and cliffs, carved out of the massive Edwards limestone, and grades back unnoticeably until it terminates in the broad expanse of the Edwards Plateau. These vertical bluffs of great height along the river are formed by the erosive agencies undercutting the softer clays and sands directly beneath the resistant Edwards limestone. Such a nature of erosion also renders it practically impossible to judge accurately the dip of the strata along the river, except over considerable distances, and then allowance for slumping is necessary.

All of the prominent relief in the county, such as hills, draws, canyons, ridges, peaks, and plateaus, is due to differential erosion. The harder strata, being more resistant, have remained in places, and have been little affected; while the softer material has been carried away.

The cliffs along the Pecos gradually give way to lower hills and ridges and less sharply defined canyons, the greater the distance is from the river, until at the northern boundary of the county the canyons have become broad valleys, and the steep banks and canyon walls have changed to grassy slopes. Farther to the north these become high plains, the cap-rock of which is the top of the third division of the Edwards limestone. The relief of this plateau is confined to very local slopes toward drainage channels, which are broad, shallow depressions when at some distance from the edge of the plateau. At the edge of the plateau, however, the drainage consists of short, narrow, steep-walled gullies, leading to the intermittent streams in the valleys. The stratigraphy of the county, as well as the agents of erosion, has had a great influence upon its relief. As the whole area of Crockett County, with the exception of the lower walls of the Pecos, is covered to a great thickness by the resistant homo-

geneous Edwards limestone, and since in the area examined the Edwards has only a very slight dip to the southeast, the result has been a dip slope of very low degree, to the southeast.

Transit examinations of extended areas, such as the University tracts, show a S 60°-70° E dip of from 0 minutes to 5 minutes. This slight departure from the horizontal is only obtained by very accurate measurements.

The agencies of erosion, of which rainfall, chemical action of ground and underground water, daily range of temperature, and the difference between day and night temperatures are the principal forces, also have a great modifying influence upon the appearance of the earth. The rainfall, coming as it does in cloudbursts which continue for only a very short time, and falling upon the sparsely vegetated soil, has dissected the Edwards limestone in this region to such an extent that for fifteen or twenty miles back from the river the topography is a continuous series of drainage channels, whose walls become steeper and steeper toward the river, where they finally terminate in high bluffs. The isolated buttes, mesas, and small conical peaks are the remnants of the Edwards Plateau. The change of temperature between day and night is considerable, and also assists the rainfall in dissecting the strata. Masses of rock as here exposed, being subjected to a rapid change of temperature amounting to as much as from 30° to 40°, are irresistibly expanded and contracted, and as expansion and contraction are not uniform, internal and external stresses are produced, thus exfoliating the outer surface. The material thus exfoliated is carried away, leaving the bed rock exposed at practically all times.

The chemical and physical actions of underground water are as important as are the mechanical factors. Numerous caves of all kinds have been dissolved out of the Edwards limestone, from cavities a few inches in diameter to great caves with miles of widening passages. This undermining of the rocks tends to break down the resistant cap, and gives the weathering agent better access.

About five miles south of Barnhart, on the Barnhart-Ozona road, an old sink-hole can be seen, where the solvent action of

the water has eroded a hole four hundred feet in diameter, and fifteen feet deep.

What remains of the high plains is called the Edwards Plateau, from the top of which the horizon of the surrounding country is almost level. This is due to the absence of any noticeable dip in the Edwards formation, in the region. This very resistant and uniform limestone forms a hard level cap which protects the Walnut clays and Basement sands, four to five hundred feet below.

The Basement sands are only exposed for some forty or fifty feet in the river banks, along the south and southeast part of the Pecos, forming the west and southwest boundary of Crockett County, and in a great many places where only a few feet are exposed, it is covered by the Edwards limestone, which has undercut and slumped to the stream bed. However, farther up the river, beginning about twenty miles north of Sheffield, and continuing to the northwest corner of the county, since there is some two or three hundred feet of these sands exposed, it has a marked effect upon the topography of the county. This is noticeable in the contour of the hills and valleys adjacent to the river.

The base of the Edwards limestone in the vicinity of the 102nd meridian crossing is about half-way up the slopes of the hills, and from this base there is a gradual gradient to the alluvial plain or the water-level. The valleys of both primary and secondary streams are low, wide, and rounded, as the debris has formed large talus slopes. The hills recede farther from the river, and strongly contrast the vertical bluffs farther toward the river mouth.

The tops of the hills are flat plateaus, mesas, and buttes, and the escarpments are formed by the Edwards limestone being much more resistant than the underlying Basement sands. From the southeast to the northwest corners of the county, along the river valley, there is a gradual transition from the severe topography of the true Edwards region to the more modified well-rounded valleys, capped by the lower part of the first division of the Edwards limestone. This is due to the southeastern dip of the Comanchean-Cretaceous strata, which reveals a proportionately greater amount of Basement sands, and less amount of Edwards limestone from southeast to northwest.

CLIMATE AND RAINFALL

Typical of the region embracing the western portion of the Edwards Plateau and the Trans-Pecos Plains, Crockett County has a climate that is semi-arid, quite warm, and very uniform. Weather reports from Fort Stockton in adjacent Pecos County to the west, and from Eagle Pass to the south, indicate an average annual rainfall of about 16 inches in the northwest portion of the county, and from 17 to 18 inches in the southeast part; the humidity increasing in this direction. The moderate elevation of 2000 feet, latitude of 30 degrees north, and a low humidity, cause relatively high temperatures to prevail during the day, which fall much lower at night. The county lies wholly without the pathway of storms and other meteorological disturbances, thus giving a uniformity of climatic conditions.

Precipitation occurs most often during the late spring and middle fall. Sudden torrential rains of short duration are characteristic of the region, though long periods of drought are not uncommon.

The wind is usually of moderate velocity and from the west or southwest, except during the infrequent rains which usually come from the southeast, and at the time of the 'northers', at which time it is from the north or northwest.

DRAINAGE

The drainage of Crockett County is toward the south and southeast, principally through Live Oak Creek, and Howard's Draw, into the Pecos River. Live Oak Creek and its tributaries drain the northwestern part of the county, while Howard's Draw, which flows across the entire county from northeast to southwest, drains the remainder; except for a number of dry creeks along the south, southwest and west, which drain directly into the Pecos. All of the drainage features ultimately find an outlet in the Pecos and Devil's Rivers.

SOILS

The topographic features of the county make it desirable to divide a discussion of soils into two parts: (1) top lands and (2) bottom lands.

Under top lands is classed the soil upon the plateaus, mesas, buttes, and that along the steeper slopes. Under the head of bottom lands are classed those soils which have accumulated on the more gentle slopes of the valleys and in the valley and river bottoms.

On the uplands there is little soil in any place, and in a great majority of instances there is nothing but the gray Edwards limestone, with a few broken fragments of the same material scattered about.

The intermittent rainfall followed by periods of extreme drought is anything but conducive to soil accumulation upon the highlands. The little calcareous soil in situ which has been decomposed from the underlying resistant Edwards limestone is quickly washed away by the deluge before it has had time to accumulate to any depth, or gain a protection of vegetable matter, which would increase both the depth of the soil and its productivity by adding carboniferous matter. Thus when present upon the plateaus and steeper slopes, the soil is poor and thin.

On the bottom lands, although the same forces are at work, there is considerable soil accumulation, due to the fact that the slopes are considerably less, and also to the dual source of the material. Because of the nature of the grades, the residual soil has a much better chance to accumulate than on the uplands, and the soil carried down from above is either deposited in the valleys or river bottoms. River overflows also add to this material. Vegetable matter which has had an opportunity to grow and collect holds the soil in place, adds to the amount, and enriches the soil to a great extent, so that in the bottom lands good soil for agricultural purposes can be found.

The principal ingredients, silica, lime, and vegetable matter in such forms and proportions as exist in these valleys and alluvial flats, form a clay loam, which is especially adapted to plant life.

From southeast to northwest in the Pecos valley, there is a gradual increase in the amount of sand in the soil, and a deepening of the reddish color, due to the increase in amount and area of the red Basement sands.

FLORA AND FAUNA

Vegetation upon (1) top lands and (2) bottom lands, though individual and characteristic of each, is nevertheless typical of the semi-arid climate of the county.

Two of the most important factors determining such a vegetation as here exists are the supply of moisture and the relative length of time in which it is available for plant life after each rain.

Lying almost at the center of the semi-arid southwest, over three hundred miles from the Gulf of Mexico, with the broad, high Edwards Plateau reaching to the Llano Estacado on the north, the dry mountains of northern Mexico on the south and the southern extension of the Great American Desert terminating in the foothills of the Cordilleras to the west, the vegetation of necessity must adapt itself to such an environment. The prevailing winds, being from the west and southwest, are wrung dry of all their moisture in passing over the mountainous regions, after which they cross the arid country to the west and south before reaching the Central Zone. Here they not only supply no moisture, but, being hot and dry, carry away from the soil and plant surfaces practically all the moisture brought from the southeast and east. The absence of clouds and vapor in the air over nearly all months of the year increases the intensity of the sunlight, and the white calcareous rock and soil reflect it with practically no absorption; so that the great daily extremes of temperature demand an adjustment of plant life to extreme conditions.

As a result of these combined environmental factors, together with the nature of the soil upon the uplands, there is a meagre vegetation. The rainfall from the southeast not only is very small, but in the uplands it is practically all run-off, thus giving even a less supply of moisture than in the bottom-lands.

The ability of scrub-cedar, mesquite, scrub-oak, cacti species, sotol, lechugilla, chaparral, Spanish dagger, greasewood, and yucca to withstand the severity of these conditions makes them practically the only vegetation upon the uplands. The past season, however, has been one of extreme precipitation over

the county, and there is a good supply of grass and a great number of wildflowers in addition to the plant life mentioned as the normal vegetation of the uplands.

As these lands are in excess, the vegetation upon them has also a great economic value, as this area because of its mild winters is available for the pasturing of stock throughout the entire year, and the capacity of the county has practically no stock limits except the supply of food and water. The long drought which lasted until the beginning of the recent rainy season has reduced to a minimum the goats, sheep, and cattle.

The bottom lands, receiving in addition to their soil in situ the wash from the uplands, and because of their better water storage facilities, support a more luxuriant vegetation; which in turn supplies humus to the soil.

Over the greater part of these bottom lands there is a good covering of grass, except in extremely dry seasons. Upon the alluvial flats are found live-oaks, a few cottonwoods, a great amount of mesquite, some willows, and hackberries.

Some of these alluvial flats are cultivated, the supply of water being in some cases artificial, and in others natural.

The Basement sands are exposed only in the Pecos Valley in Crockett County, in the central and southern part of the county on the river banks. Here they are in the form of vertical walls, and are undercut and carried away for some distance under the Edwards limestone, which has fallen to the stream bed. There is practically no opportunity for vegetation to exist. Farther up the river, however, where some 200 or 300 feet are exposed in the river valley, the lower part of the bluffs and hills along and near the river has smooth gradual slopes to the river. These gradients in the stream and river valleys are in marked contrast to the vertical walls in the southern part of the county, and support a flora which is more typical of a sandy soil. The high porosity of the soil also permits quick, deep penetration of surface waters, and a similar rate of drying through the atmosphere. These conditions, and also the abrasive effect of wind-blown particles, make it possible for only the hardier plants to exist. In places, a combination of this sand, silt from the river, and kaolin from the Edwards limestone above, forms a very productive sandy loam.

Animal life, typical of the southwest, is plentiful in all parts of Crockett County. An abundance of food, easy protection from their enemies, and freedom from long-continued severe climatic conditions permit of a varied fauna.

Several species of wolves are so plentiful as to necessitate great vigilance among the sheep ranchmen to protect their flocks from these marauders. Occasionally a panther or bob-cat is found, but only at rare intervals is such a large carnivorous animal encountered. Jackrabbits, cottontails, prairie dogs and ground squirrels are especially numerous and may be seen in great numbers in an hour's drive in any direction. Deer, foxes, gophers, coons, opossums, weasels and other wary creatures, make their homes in the more wooded and less frequented sections.

Along the sides of the numerous steep-walled canyons, the Edwards limestone usually weathers cavernous, making suitable caves where the animal life may be sheltered. The thorny nature of the vegetation as well as the many crevasses among the rocks offer protection from their enemies when pursued.

The bird life too includes a few species some of which have adapted their habits to the almost treeless region, building their nests among the rocks instead of in the branches of trees. Swallows make clay houses along the cliffs. Owls, hawks, and bats have their habitat in holes of the precipitous rock ledges. Pheasants, quail, paisano, larks, killdees, mockingbirds, blackbirds, scissor-tails, redbirds and sparrows are more or less common on the shrub-covered lowlands.

Reptile life during the warm weather is plentiful. Rattlesnakes, bull snakes, moccasins, and prairie runners are the most common. Chameleons, horned toads, lizards, scorpions, tarantulas, spiders and numerous insects are in abundance.

In the Pecos River and the lower reaches of Live Oak and Howard's creeks, several kinds of fish are found, but in this dry, semi-arid country with few streams, water fauna is comparatively insignificant.

STRATIGRAPHIC GEOLOGY

NATURE AND PURPOSE OF THE INVESTIGATION

In an investigation recently made by Dr. Udden in the Glass Mountains district of Brewster County, the trend of the Marathon Mountains was observed to extend from the Solitario Uplift on the Brewster-Presidio County line toward the northeast. The general direction and appearance of the fold suggested the possibility of its extending farther to the northeast and influencing the local or regional stratigraphy of the Edwards Plateau or Toyah Basin.¹ In the present survey a section along the Pecos River from Pandale Crossing to the Texas and Pacific Railway crossing near Barstow was given a detailed examination before any of the land in the valley was examined in reconnaissance for structure.

Although Permo-carboniferous structure antedating Comanchean-Cretaceous deposition may underlie the Pecos Valley, it is only through a subsurface examination that it can be detected, since folding which terminated at the end of the Carboniferous or Permian would not be reflected in the overlying strata.

Following the stratigraphic work, the three University tracts in Crockett County, namely, the Sheffield, Barnhart, and Big Lake tracts, were carefully examined in reconnaissance, as conditions did not permit a stadia survey of the entire areas. All observations for structure were taken with a transit.

Any movement later than the Paleozoic, which would influence the geology of the counties containing University land along the Pecos River would be evident in a section between Pandale and Barstow. As the purpose of the survey is to begin a series of county geologic reports on the southwest, including detailed structural examinations of University lands, it is not necessary to carry the stratigraphic work beyond the limits where it influences the area under examination. Later, if desirable, it can be continued the entire length of the Pecos Valley.

The Balcones fault on the southeast and the Rustler Hills on the northwest make it necessary to give those localities extremely careful study, and the time available and the nature of the work did not warrant an investigation of these two areas.

Representative collections of fossils have been made at various

¹The first known suggestion of the northeast extension of the Marathon Mountains was made by R. T. Hill in U. S. G. S Folio 3. Physical Geography of the Texas Region, p. 4. Washington 1900.

localities. Only such identifications were made in the field as were found necessary for correlation.

CONTROL

As the time did not permit the development of a triangulation system, and as no topographic work has been done in the county, it was necessary to establish control for both the stratigraphic and structural work.

At the point of observation $\frac{1}{4}$ mile north of the steel bridge across the Pecos River, three miles east of Sheffield on the Ozona-Sheffield road, the latitude is $30^{\circ}-43'-45''$ N.; longitude $101^{\circ}-54'-30''$ W; magnetic declination 11° E.

This control, from which traverses were run, was used for all the work along the Pecos River and on the Sheffield tract.

Since the majority of the counties containing University land border on the Texas portion of the Pecos Valley, throughout practically its entire length, and as the river affords the best opportunity for a geologic study of the region, a careful examination of the valley from Pandale to the Texas-New Mexico boundary was made, and horizontal and vertical sections were taken from Pandale to Barstow.

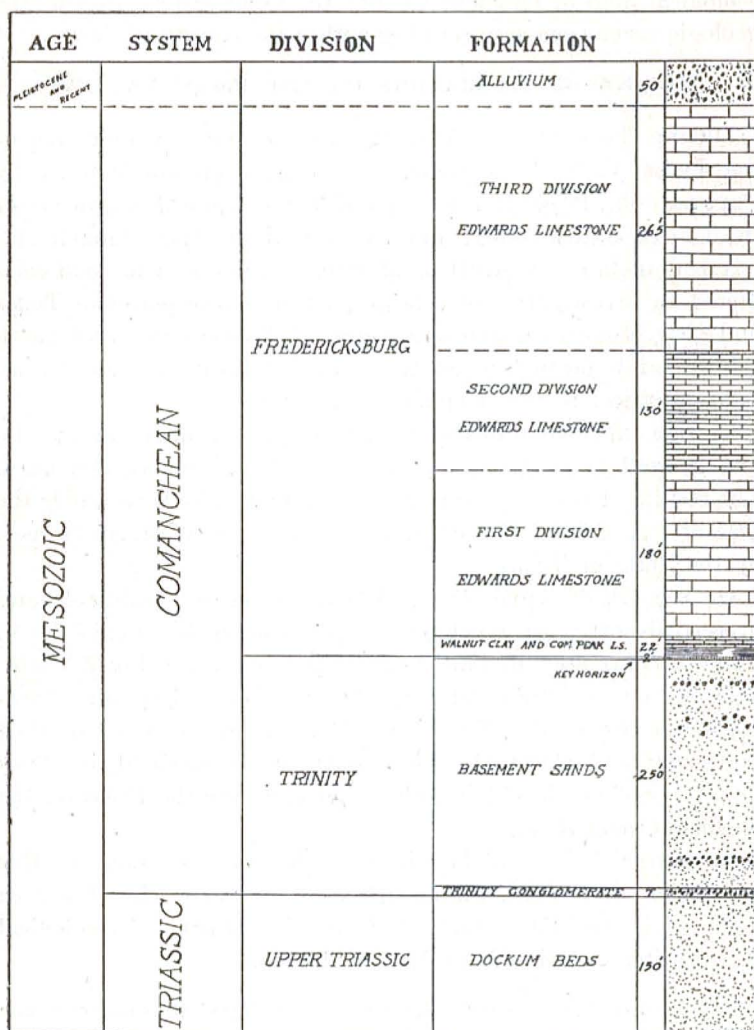
The following geologic column shows that formations ranging from the Triassic through the Comanchean and including Pleistocene and Recent deposits are exposed.

SYNOPSIS OF FORMATIONS FROM PANDALE TO THE TEXAS-NEW MEXICO LINE

Pleistocene and Recent		Alluvium and Conglomerate
		{ Edwards limestone
		{ Comanche Peak limestone
		{ Walnut clay
Comanchean	{ Fredericksburg	
Cretaceous	{ Trinity	{ Basement sands
		{ Trinity Conglomerate or equivalent
Triassic	Dockum	Upper Trujillo
Permian		Rustler, Red Beds

STRATA EXPOSED ON PECOS RIVER IN CROCKETT COUNTY

In Crockett County, only formations from the Basement sands through the Edwards limestone, including some Pleistocene



GEOLOGIC COLUMN SHOWING FORMATIONS EXPOSED ON PECOS RIVER BETWEEN PANDALE AND BARSTOW

Fig. 1.

and Recent alluvium and conglomerates, are exposed. On the geological map of Crockett County the areal distribution of the geologic formations outcropping within the county is shown.

REVIEW OF LITERATURE ON THE PECOS VALLEY

During the years 1855-1856 the first geological exploration of the Pecos Valley was made. An expedition commanded by Captain John Pope, of the Corps of Topographical Engineers of the United States Army, under orders of the War Department, left Indianola on the Gulf of Mexico, in 1855, and in 1856 completed an investigation of a large portion of the plains of Texas and New Mexico for artesian water. "To ascertain the practicability of building the Southern Pacific Railroad was also an especial object to this Expedition".¹

To this expedition, in the capacity of paleontologist and geologist as well as surgeon, was attached Prof. Geo. G. Shumard. The results of this exploration were published in 1886 under the title of "A Partial Report of the Geology of Western Texas", by the State of Texas.

On the 4th of April, 1855, the expedition left Indianola and proceeded northwest, reaching San Antonio on the 11th of April. After a short stay in San Antonio the party continued northwest and on the 12th of May reached the lower Emigrant Crossing of the Rio Pecos. This crossing is 3 miles northwest of Fort Lancaster, and about $3\frac{1}{2}$ miles southeast of Sheffield, in Pecos County, just north of the highway bridge over the Pecos on the Sheffield-Ozona Road.

No better digest can be given of the geology noted on this expedition than Prof. Shumard's own notes covering the area included in the Pecos Survey, from his *Journal of Geological Observations*, entries from May 9-21, 1855.

May 9.—Leaving Howard's Springs we continued to wind our way through the canyon, which varied from a few hundred yards to several miles in width, exhibiting an uneven floor, and in many places a moderately fertile soil.

About eight miles from the springs we again reached the summit of the table land, over which we traveled the remainder of the day.

¹Introduction, p. vii, *Geol. Western Texas*, by B. F. Shumard. Austin, 1886.

As before, the surface of the table land or plateau is here covered with coarse fragments of limestone, and is traversed by immense rocky canyons, some of them many miles in length. This feature, together with the almost entire absence of soil, imparts to the face of the country a remarkably sterile and forbidding aspect.

Distance, 15½ miles.

The route travelled from May 9-11th lies approximately between Pandale, the southernmost point reached on the present survey, and Live Oak Creek, near old Fort Lancaster. The canyon by Howard's Spring is one of the intermittent stream beds which empty into the Pecos, and the tableland over which they travelled is the Edwards Plateau, the top of the third division of the Edwards limestone.

May 10.—After a travel of about seven miles we entered another canyon, similar in all respects to the last. The strata of this canyon present a slight dip E. S. E. and assume a variety of colors—white, gray, yellow, brown, red, and black. In some places they are highly ferruginous, and contain nodules of flint in great abundance; at several points thin seams of selenite were observed traversing the limestone.

The principal fossils seen to-day are *Arcopagia Texana*, *Gryphaea Pitcheri*, *Janira quadricostata*, *Cardium multistriatum*, *Ammonites acuto-carinatus*, and *Pterodonta (Eulima) subfusiformis*.

Late in the day we came to Live Oak Creek, a beautiful stream of clear water, flowing over a rough, rocky bed. The temperature of this stream was found to be 70 degrees F.

The soil, during the greater portion of the day's march, was barren, being composed principally of disintegrated limestone; but in the vicinity of Live Oak Creek it is moderately fertile, and supports a sparse growth of oak trees.

Distance, 11 miles.

As previously mentioned, the Edwards Plateau generally supports a scanty vegetation, while that of the valleys is more luxuriant.

May 11.—Beyond Live Oak Creek our route lay over a broken, rocky region, characterized on all sides by rough hills and cliffs of thin-bedded Cretaceous Limestone, some of which attain a height of more than five hundred feet.

As we progressed through the canyon it widened rapidly, and finally opened into the broad valley of the Rio Pecos, which here pursues a tortuous course between rough hills and picturesque cliffs from four to six hundred feet high.

The water of this stream is of a deep red color, and contains some muriate of sodium. Its average width is about seventy-five feet. Temperature 70 degrees F.

The valley possesses a red clayey soil, which appears to be moderately fertile.

Near the bed of the river I observed a layer, a few feet thick, of coarse breccia, made up of fragments of limestone, loosely cemented with a calcareo-ferruginous paste.

Distance, $7\frac{1}{4}$ miles.

Live Oak Creek is the only permanent stream in Crockett County. The coarse breccia mentioned by Prof. Shumard was identified in situ, near the mouth of Live Oak Creek at the Pecos River, to be a recently cemented conglomerate, containing a great variety of material both igneous and sedimentary, deposited by the river and cemented as Shumard mentioned, with a calcareo-ferruginous paste.

May 12.—The greater portion of this day was spent in exploring the hills and cliffs in the vicinity of our camp on the Rio Pecos. The thickness of the Cretaceous Limestone here was estimated at not less than a thousand feet. In its lithological character it varies considerably from that previously encountered, consisting for the most part of hard, compact rock, often crystalline, and usually of a light bluish color. The greater portion of the mass is almost entirely destitute of organic remains, but near the summit of the highest hills I discovered a band of soft earthy limestone, of a bright yellow color, highly charged with elegantly preserved fossils, which have been determined by my brother, Dr. B. F. Shumard, to belong chiefly to the following species: *Ammonites acuto-carinatus* (Shum.), *Ceratites* (*Ammonites*) *Pedernalis* (Roem. sp.), *Pterodonta subfusiformis* (Shum.), *Scaloria vertebroides?* (Mart. sp.), *Natica* (*Globiconcha*) *tumida* (Shum.), *Arcopagia Texana* (Roem.), *Panopora Texana* (Shum.), *Janira quadricostata* (Sow. sp.), *Exogyra Texana* (Roem.), *Gryphaca Pitcheri* (Mort.), *Homomya alta* (Roem.), *Cardium multistriatum* (Shum.), *Hotectypus planatus?* (Roem.), and *Toxaster Texanus* (Roem.). In addition to these we found a number of species not yet described.

After leaving the Pecos crossing we wound our way amid rough hills and cliffs of the same geological constitution as those just described. Everywhere we found a barren soil, composed almost entirely of pulverized limestone.

Distance, $5\frac{1}{2}$ miles.

The area referred to under this date is in the vicinity of the Sheffield-Ozona highway bridge, and the formations exposed

are described in detail under Camp Section (Pl. 2). The soft, bright yellow, earthy limestone from which Shumard obtained a good collection of fossils also afforded the present survey a fine collection. It is described as Yellow Peak horizon from a small conical peak 4 miles east of the Sheffield-Ozona highway bridge, at which the majority of the collection was made. It is at the bottom of the second division of the Edwards limestone.

May 13.—During the entire day we traveled through the valley of the Rio Pecos. For the first six miles the rocks do not differ in general appearance from those observed yesterday. Beyond this the hills assume a more regular outline and the cliffs are less rugged in their aspect. The former are generally smooth, of a conical form with truncated apices. At first they are closely aggregated, but as we progress they become widely separated by smooth and gently undulating prairie. Their height is from five to eight hundred feet, and they present every indication of having once formed a portion of the elevated table land, now several miles distant, and from which they have been separated by denudation. The different strata composing them are found to agree in every particular with those composing the table land. Near the summits of the highest of them the strata are very prolific in well preserved organic remains. The following are the prevailing forms: *Ammonites vespertinus*, *Ammonites Marcyana*, *Pterodonta subfusiformis*, *Terebratula Wacoensis*, *Janira Texana*, *Lima Wacoensis*, *Cardium Sanci-Sabae*, *Trigonia* (undt.), *Gryphaea Pitcheri*, and *Hemister elegans*. With these I also found examples of *Gryphaea* which are not to be distinguished from those figured by Mr. Marcou under the names of *G. Marshii* and *G. Tucumcarii*.

Near the base of one of the hills I observed layers of soft, thin-bedded, quartzose sandstone, about twenty feet in thickness. This rock is fine grained, of a light yellow color, and is conformable with the limestone. Thin seams of white gypsum and selenite were observed to occur at several points.

The surface of the valley is for the most part thickly strewn with coarse angular fragments of limestone, which are not infrequently firmly cemented into calcareous breccia. Near the base of some of the hills this breccia often presents a thickness of twenty or thirty feet, and is of such extreme hardness as to be broken only with great difficulty.

Soil and sub-soil highly calcareous and barren.

Distance, 13 miles.

The quartzose sandstone is a local coarse deposit of the Basement sands.

May 14.—Continued our way through the valley of the Pecos, en-

countering the same character of hills and cliffs as seen yesterday. The hills are often separated by wide intervals, and vary much in altitude, the highest of them being from six to eight hundred feet above the level of the Pecos. The cliffs are often deeply excavated, and at a distance present the appearance of a succession of hills. From their summits the table land may be seen stretching away for many miles, its surface everywhere broken and divided by rude rocky canyons.

The Cretaceous Limestone as observed to-day was found to vary considerably in texture at different points. In some places it was soft, earthy, and of a light yellow color; in other places hard, compact, and more or less crystalline. Owing to their unequal hardness the different beds weather in such a manner as to leave horizontal bands projecting sometimes several feet, which in the distance give to the cliffs the semblance of lines of fortifications.

The yellow fossiliferous band, above mentioned, was again met with during the day, but organic remains are much more sparingly distributed. In a few places beds of coarse yellowish and reddish quartzose sandstone were interstratified with the inferior layers of limestone in beds from ten to thirty feet in thickness.

The Rio Pecos as observed during the day presented an average width of about seventy-five feet, and flows over a hard rocky bed, with low bluff banks of red loam on either side. The water is highly charged with red sediment and impregnated with common salt.

Soil moderately fertile.

Distance, $11\frac{1}{4}$ miles.

In this area no limestone was found interbedded in the sandstone.

May 15.—In its general appearance and geological structure the region of country traversed to-day differs but little from that of yesterday. In places the strata were found to be more or less arenaceous, and everywhere appear to be undergoing rapid disintegration.

The width of the valley of the Rio Pecos is from five to ten miles, the surface dotted over with truncated conical hills, occasionally grouped together in small clusters, but generally separated by intervals of five or six miles. Usually they are much smaller than those encountered yesterday, and everywhere present a strikingly uniform character.

The surface of the country still continues to be often thickly covered with coarse angular fragments of fossiliferous Cretaceous Limestone, occasionally cemented with great firmness by calcareous matter.

Soil thin and moderately fertile. Sub-soil calcareo-argillaceous.

Distance, 9 miles.

May 16.—Still continue to travel through the valley of the Pecos, which is observed to increase gradually in width, but otherwise does not differ from the portion traveled through yesterday. Geological for-

mation the same as before. The line of cliffs on either side of the valley exhibits an altitude of from six to eight hundred feet, and presents a less rugged outline than those seen yesterday. Fossils are abundant, but, as before, confined chiefly to two principal bands, one near the summit and the other near the base of the cliffs. With many of the species above enumerated, I collected examples of *Trigonia crenulata*, *Lima Wacoensis*, and *Janira Texana*.

The course of this part of the Rio Pecos is remarkably tortuous, and its average width about eighty feet. The banks are low and composed of red clay. Small lakes of clear water were met with at a number of points, which upon being tested proved to be strongly impregnated with salt, and the surface of the ground in their immediate vicinity is often whitened with saline efflorescences.

At our evening camp the valley of the Pecos presented a width of nearly twenty miles. Its surface is rough and broken, but sustains a good soil.

Distance, 16 miles.

Of the two fossiliferous bands one is near the top of the third division of the Edwards limestone, and the other in the Comanche Peak limestone and the Walnut Clay, underlying the first division of the Edwards limestone.

May 17.—Continued our course through the valley of the Rio Pecos, which is still characterized on either side by abrupt cliffs, but they are now often widely separated, and do not anywhere exceed four or five hundred feet in height. In places they are deeply fissured, and sometimes large detached portions of the table land are to be seen standing out several miles from the parent mass.

The strata present a slight but uniform dip to the E. S. E., and everywhere appear to be rapidly yielding to the influence of the weather. In the lower fossiliferous band I collected the following fossils: *Ammonites vespertinus*, *Scalaria vertebroides?*, *Turritella* sp., *Gryphaea Pichei*, *Ostrea crenulimargo*, *Janira Texana*, *Lima Wacoensis*, *Trigonia crenulata?*, *Terebratula Wacoensis*, and *Pygaster*, *Fusus*, *Opis*, and *Cardium* of undescribed species.

Toward the latter portion of the day we found nearly horizontal layers of red and blue indurated marly clay beneath the limestone. This clay agrees lithologically in all respects, save in color, with that observed in the vicinity of San Antonio, and is in several places crowded with an angulated variety of *Gryphaea Pichei*.

The valley as observed during the day varies from twenty to twenty-five miles in width, and the surface is in many places rough and broken.

Soil marly and fertile; sub-soil calcareo-argillaceous, in a few places arenaceous.

Distance, 15½ miles.

May 18.—After traveling a few miles from our camp of last evening the valley through which we have been passing for so many days widens rapidly, and soon terminates in a broad, open, and gently undulating plain. Here the Cretaceous Limestone, while still preserving a nearly horizontal position, terminates abruptly to the west and northwest in bold, rugged precipices, from four to six hundred feet in height.* These are to be traced, stretching somewhat irregularly north and southwest, as far as vision extends, marking the edges of the table land and serving to indicate the great extent to which the strata of this region have been removed by denudation.

The surface now assumes a deep red color, and is everywhere marked by small hills and ridges of indurated red marly clay, which are for the most part gently rounded and from ten to forty feet high. The summits of the highest of them are thinly capped with nearly horizontal layers of Cretaceous Limestone, generally soft, of light grayish and yellowish colors, and with imperfect fossils of the same character as those of the cliffs.

The Rio Pecos as observed during the day has a width varying from sixty to eighty feet, and still continues to flow between low bluff banks of red clay. The water is highly charged with deep red sediment, and still contains a small percentage of saline matter. On either side of the stream there extends a chain of small, shallow, saline lakes, and the adjacent ground is often covered with an efflorescence of chloride of sodium, usually about a fourth of an inch in thickness. Soil moderately fertile; sub-soil calcareo-argillaceous, occasionally arenaceous.

Distance, 16 miles.

The area referred to under this entry begins in the vicinity of Girvin, on the Pecos River southwest of the Castle Mountains.

May 19.—Our way still leads over rolling and gently ascending prairie, its surface often whitened with saline efflorescences, and presenting here and there small patches of Cretaceous Limestone and detritus. The former is usually soft, white or of a light grayish color, and resembles very closely the pulverulent limestone observed in the vicinity of San Antonio. From the harder varieties a few imperfect characteristic cretaceous fossils were obtained. The prevailing formation consists for the most part of indurated red and blue marly clay, with intercalations of soft yellow and pinkish fine grained quartzose sandstone. The sandstone does not anywhere exceed two or three feet in thickness. It is usually thinly laminated, and traverses the clay in

*These cliffs are laid down on some of the maps as the "Castle Mountains." It is hardly necessary to state that no mountains occur in this portion of Texas, the so-called Castle Mountains being nothing more than the abrupt borders of the Table Land.

nearly horizontal bands. During the day sections of sixty or eighty feet of these strata were exposed, and near the base of one of them the sandstone was found to contain small rounded pebbles of eruptive rocks.

The Pecos still pursues a tortuous course, and lakes of highly saline water abound in its vicinity. The ground is also frequently coated with white saline efflorescences. Soil marly, in some places arenaceous; sub-soil calcareo-argillaceous and argillo-arenaceous.

Distance, 16½ miles.

May 20.—In general appearance and structure the country traversed today differs but slightly from that of yesterday. As we advance the soft pulverulent limestone is better developed, and presents often a thickness of ten or fifteen feet. Its stratigraphical position is immediately over the marly clay.

At the distance of twelve miles we arrived at the rapids of the Pecos. Here the water descends impetuously for a distance of about twenty feet over coarse quartzose sandstone and conglomerate. The total amount of fall is about ten feet. On either side are high bluff banks of red marly clay, coarse quartzose sandstone, and pulverent limestone, in nearly horizontal strata. The sandstone is soft, friable, and of red and gray colors. Near the base it passes into a conglomerate of well rounded pebbles of quartz, red porphyry, granite, and other varieties of eruptive rocks.

Soil and sub-soil the same as before.

Distance, 21½ miles.

The rapids of the Pecos River were identified just north of the highway bridge near Grand Falls and the conglomerate described was referred to the Trinity conglomerate or its equivalent.

May 21.—General formation the same as before. After a travel of three miles, over a nearly flat and moderately fertile district, we arrived at a range of low hills, composed of red and blue clay, sandstone, and conglomerate, surmounted by about ten feet of hard grayish limestone, the latter containing a few imperfect fossils, of which the most common species is *Janira quadricostata*. Dip 2 degrees E. S. E. These hills constitute the remains of a once continuous plain, the borders of which, by denuding agencies, have been made to recede, gradually, many miles to the east, where, as we have already seen, they are abruptly defined by lofty and nearly vertical precipices.

As we progressed the surface became much more uneven, and sometimes covered with coarse drift deposits, consisting of quartz, jasper, chalcedony, and granite, often loosely cemented with calcareo-ferruginous paste, and with an average thickness of about three feet.

The red clay formation was seen in several places exposed to the

height of nearly a hundred feet. South of our road, and at a distance of perhaps sixty miles, are seen the bold rugged chain of the Linpea Mountains, whose lofty peaks and sharp outline denote, even at this distance, their igneous character.

During our day's travel the pulverulent limestone frequently presented itself on the surface, but nowhere exceeded five or six feet in thickness.

The accompanying section, taken from a deep depression in the prairie, shows the character of the strata observed during the day.

Soil and sub-soil calcareous and calcareo-argillaceous.

Distance, $12\frac{3}{4}$ miles.

The igneous pebbles covering the surface of the ground north of Grand Falls are fragments of the conglomerate which forms the falls. Its dip is slightly greater than the river gradient; sufficient to place it at the surface in this area.

In the Pecos Valley, Shumard referred all formations encountered in the present survey to the Cretaceous System, which then was assigned to the "Secondary period". This system he divided into the Lower Cretaceous, or Marly Clay Group, and the Upper Cretaceous, or Calcareous Group. As he included some sandstone in the Upper Cretaceous it is impossible to establish the contact between his two groups. It is very probable, however, that the base of the Upper Cretaceous was approximately at the base of the Walnut Clay, at the contact with the Basement sands, as the sands which he relegated to the upper group were not true sands but siliceous phases of the lime above.

In the lower or Marly Clay Group were placed all the remaining beds south of the Rustler Hills. Shumard thus included under the Upper Cretaceous or Calcareous Group the Edwards limestone, the Comanche Peak limestone, and the Walnut clay; and under the Lower Cretaceous or Marly Clay Group, at least all the Basement sands and Triassic sandstone south of the Rustler Hills. In his opinion there was not sufficient evidence to even indicate other than a Cretaceous age of all formations described.

At this time, Prof. Jules Marcou advocated the Triassic and Jurassic age of sandstones underlying the limestones of the Pecos Valley. His conclusions were based mainly upon the finding of fossil wood in the Marly Clay Group. This, however, is not

conclusive, as fossil wood is also recognized in unquestioned Cretaceous strata in Texas.

The Jurassic age of some of the Marly Clay Group was advocated by Marcou upon the presence of *Ostrea Marshii*, which he concludes to be typical of American Jurassic. However, Shumard finds this fossil in the Upper limestone at Fort Washita, associated with such characteristic Cretaceous fossils as *Gryphaea pitcheri*, *Hemiaster elegans*, *Holaster simplex*, and *Ammonites vespertinus*. Marcou to a great extent fixed the Triassic age of these strata upon their lithologic character and though this is not conclusive evidence, it is not without value. The Jurassic age of some of the strata, determined by paleontology alone, seems to be entirely refuted by Shumard. There probably is little to be said in defense of their Jurassic age.

Again in 1891 the formations of the Pecos Valley became the subject of investigation. W. F. Cummins explored the Pecos Valley from New Mexico as far south as Horsehead Crossing. The results of his investigation are embodied in the Third Annual Report of the Geological Survey of Texas, for the year 1891, under the title "Report on the Geography, Topography, and Geology of the Llano Estacado, or Staked Plains". Beginning at Pecos City, the county-seat of Reeves County, his notes on the geology of the country southeast to the Castle Mountains are as follows:

"We crossed to the east side of the Pecos river at Pecos City, and camped about fourteen miles below, where we found Permian beds of red clay and gypsum, with the bed of Quaternary drift on top of the red clay. This camp is about south of Quito station.

"Continuing down the river, at about three miles, we came to the massive beds of red sandstone that is being so extensively quarried west of Quito., I think this sandstone is Triassic. It is underlaid by red clay with selenite.

"We continued down the river to the falls. The valley on the east side is about one mile wide and widens to three or more on the south, and then closes in again at the falls to one-half mile. The escarpment on the east is not more than thirty feet high, and is always capped by the white conglomeritic limestone so characteristic of the Blanco beds. This rock here contains sand, siliceous pebbles, and pieces of red sandstone, and is from three to five feet thick.

"There are two falls in the river at this place, in a distance of about one hundred yards. The upper fall is about three and a half feet and

the lower about five and a half feet. The stone making the falls is a coarse conglomerate composed of carboniferous, porphyritic, and siliceous rocks with a light sand matrix slightly ferruginous.

"We continued down the river thirty-eight miles to Horsehead Crossing, traveling along on the flat valley of the river. The low escarpment facing the valley was red marly gypseous clay overlaid unconformably by ten feet of red slightly argillaceous sand, and this was overlaid by ten feet of the white conglomeritic limestone so characteristic of the upper beds of the Staked Plains.

"We here left the river and took the road to Castle Gap, camping ten miles farther on, and seven miles beyond passed through Castle Gap. The strata seen between Castle Gap and the Pecos River were the upper limestone of the Staked Plains and the deep sand beds that had formed above it. The following is a section of Castle Mountain:

Section 25.

1. Limestone, hard.....	6 feet
2. Clay and limestone.....	15 feet
3. Limestone	20 feet
4. Limestone	30 feet
5. Clay, yellowish.....	12 feet
6. Limestone	60 feet
7. Clay, yellowish white.....	20 feet
8. Limestone, rotten.....	5 feet
9. Limestone	80 feet
10. Sand, compact	50 feet
11. Calcareous sandstone.....	90 feet
12. Conglomeritic sandstone.....	30 feet
<hr/>	
418 feet	

"No. 1 of this section is firm, evenly weathering, white limestone, that would make very good building stone. The layers are about two to three feet thick.

"No. 2 is alternating clay and argillaceous limestone layers, containing a large number of *Diadema*, *Toxaster texanus*, *Pecten texanus*, some *Arca*, several species of gasteropods, and a small *Gryphaea pitcheri*.

"No. 3 is a white crumbling limestone, forming a prominent horizon that stands out beyond the rock below and above, as it resists the atmospheric influences better than they.

"No. 4 is a crumbling white argillaceous limestone, somewhat similar to the one above.

"No. 5 is a clay containing a great number of *Gryphaea pitcheri* and a few *Exogyra texana*.

"No 6 white crumbling limestone containing a few fossils.

"No. 7 is an argillaceous bed containing *Arcopagia*, *Lima wacoensis*, *Toxaster texanus*, *Arca*, *Ammonites*, *Diadema*, *Pecten texana*.

"No. 8 is a slightly ferruginous limestone containing many small *Gryphaea pitcheri*.

"No. 9 is a nearly uniform friable white limestone, though it has some layers of marly material that weathers more rapidly. The most common fossils are *Area*, *Toxaster texanus*, *Diadema*, *Pecten* and small *Gryphaea pitcheri*.

"No. 10 is a white compact sand containing a few siliceous pebbles and calcareous pink sandstone near the top, which is slightly fossiliferous. This stratum shows a graduation into the one below.

"No. 11 is a massive calcareous sandstone. It has much white sand, but the weathered surface of the rock is always brown. The rock varies in its proportion of lime, but this never becomes the principal ingredient of the stone, except in streaks. False-bedding occurs in places, and a few siliceous pebbles are found in the bed at some of the localities. The stone is generally firm and weathers into large boulders, yet there are one or two layers of friable stone in the middle of the bed.

"No. 12 is a red friable conglomeritic sandstone, very much resembling the characteristic Triassic bed at Dockum. Hardened small pieces of calcareous clay and sand, of yellowish and brown colors, and pieces of red sandstone and calcite make up the mass of rock. At the center and top of this stratum, as seen here, the rock is a shaly micaceous red sandstone and red marly clay."

The red clay beds at Pecos City were examined and found to be true clays. Part of the material evidently has been eroded from the Permian red clays of New Mexico and deposited here by the river as alluvium associated with Triassic clays formed by the decomposition of the feldspars which are present in great quantities in the Triassic sands.

The falls which Cummins observed are the same ones mentioned by Shumard and the coarse conglomerate has been referred, in the present survey, to the Trinity conglomerate or its equivalent.

The section of Castle Mountain is about four miles from the section at Red Point given in the following report.

The basal 20 feet of Cummins' bed No. 9 is Comanche Peak limestone and Walnut clay. The fossiliferous band mentioned under No. 10 is the key horizon, at the top of the Basement sands. As the Trinity conglomerate or its equivalent was identified at Grand Falls, all the sands here exposed are described in this report as Basement sands. They greatly resemble the Triassic sands, from which they undoubtedly were in part derived.

Again in 1891, E. T. Dumble, assisted by N. F. Drake, studied the formations of the Pecos Valley and the results of their in-

vestigations were published by Drake in the Third Annual Report of the Geological Survey of Texas for 1891, under the title "Stratigraphy of the Triassic Formation of Northwest Texas". Page 232 of his report describes the strata from Pecos City to the Castle Mountains as follows:

"East of Pecos City the strata lying between the Tertiary and the regular gypsum beds are red sandy clays and red sandstone of even grain and regular parallel bedding. The sandstone is tough and makes an excellent building stone, and is largely quarried. It is in two massive layers, three to four feet thick, with a great many thinner layers. The position of these beds places them with the Triassic, but their characteristics are so different from the Dockum beds material that I cannot say now just where they belong. If these are Triassic strata, as seems most probable, they undoubtedly belong to the lower bed, and have no outcrop in the eastern or northern border of the Dockum beds.

"Going on south along the lower escarpment facing the east bank of the Pecos River, these red sandstones come down to the base of the escarpment and pass out of sight, and red sandy and black gypsiferous clays come in under the overlying Tertiary and continue in an outcrop of eight or ten feet down to a point northwest of Castle Mountain, where the escarpment is lost in rolling lands that are often covered with sand beds. These sandy clays, or clayey sands, are probably a part of the lower beds of the Triassic."

Drake, in agreement with Cummins, places the red sandstones in the vicinity of Barstow and Quito in the Triassic. This also was found to be the case in the present survey.

Again on page 247 of the same report, Drake refers to the area between Pecos City and Castle Mountain:

"Our work from Black River south being on the west side of the river down to Pecos City, we saw no more of the western escarpment of the Plains till we reached the east side of the river opposite Pecos. The escarpment or sharply rolling land of the western limit of the Plains extends down by Quito on the Texas and Pacific Railway, and gradually sets nearer the river southward till only a narrow belt of level land is between it and the river.

"Usually but eight or ten feet of Tertiary strata caps this escarpment, and about the same amount of red sandy and slightly gypsiferous clay forms the base. At Quito the basal part is composed of two massive red sandstone layers, each three or four feet thick, with some thinner layers of sandstone and sandy clay between and below them.

These sandstone strata extend about sixteen miles southward, gradually getting lower till they pass under the base of the escarpment. They are quarried to a considerable extent near Quito, and shipped to distant points over the State for building purposes.

"The probability of these being Triassic strata and their position in that formation has already been given.

"At Castle Mountain the Cretaceous is underlaid by red sandstone, conglomeritic sandstone, and red clays of the Dockum beds. There is about thirty feet of this material exposed, and most of this is a red conglomeritic sandstone containing small pieces of calcareous clay, and sandstone of yellowish and brown colors; also pieces of reddish brown sandstone and calcite crystals. At the center of this thirty feet is red shaly sandstone and red marly clay. The shaly rock contains mica flakes. The outcrop of these beds is on the west side of the mountain and escarpment. The Cretaceous detritus hides them from view to the southward, leaving only a small area on the northwest side of the mountain where Triassic strata can be seen."

There seems to have been no disagreement between Cummins, Drake and Dumble as to the age of the red sandstone near Barstow and Quito. All three placed it in the Triassic, though no one attempted a more definite location.

At Castle Mountain it appears that Drake differs from Cummins, and does not refer all the sands underlying the Cretaceous limestones to the Triassic. In speaking of the amount of Triassic, he says, in the last paragraph quoted above, "There is about thirty feet of this material exposed." As the entire section at Castle Mountain affords some 230 feet of sands, it would seem that Drake places only the bottom 30 feet in the Triassic, and the overlying sands in the Cretaceous. This more closely checks the observations of the present survey, though in the latter the entire exposed strata underlying the Walnut clay at Castle Mountain have been placed in the Basement sand of the Comanchean.

DESCRIPTION AND AREAL DISTRIBUTION OF FORMATIONS IN THE PECOS VALLEY

PERMIAN

The Rustler formation of the northern Pecos Valley, because of structural complications of which time did not permit the

study, was not examined. Only its contact with the Triassic was noted.

Though at the surface in the immediate Pecos Valley, southeast of the Rustler Hills, the Permian Red Beds were not studied in detail. Their contact with the Triassic sands in the escarpment on the northeast side of the river was observed. The geologic sequence in the Pecos Valley is undoubtedly very similar to that along the east and northwest of the Llano Estacado.

TRIASSIC

Since the date of the first geological exploration in the Pecos Valley, in 1855 and 1856, there has been considerable controversy over the stratigraphic position of the formations underlying the limestones in this valley.

Shumard divides the Cretaceous System of the Pecos Valley, then assigned to the "Secondary Period", into two groups: The Upper Cretaceous or Calcareous group, consisting chiefly of limestone and sandstone; and the Lower Cretaceous or Marly Clay group, consisting of marly clay, sandstone, and gypsum. There seems to be no very definite line of demarcation between these two groups. However, it is very probable that the base of the limestones and clay in the valley is the line of contact, as the sandstone referred to in connection with the lime is a siliceous phase of the lime, rather than an individual sandstone. Discussing the appearance of the limestone, he adds: "In many localities it contains a good deal of silex, or sometimes passes into pure siliceous sandstone; in others it exhibits a more or less argillaceous character, though beds of clay are rarely observed in it".¹

On the contrary, Shumard's Inferior Division, or Marly Clay group, of the Cretaceous System embraces those true sandstones, marly clays, and gypsums, lying below the base of the Edwards limestone. At their first exposure, which Shumard records as being located in the vicinity of San Antonio, they agree lithologically and stratigraphically with the exposures in the Pecos Valley. Save at a few isolated points, the Marly Clay group does not ap-

¹A Partial Report on the Geology of Western Texas, by G. G. Shumard, p. 10. Austin, 1886.

pear until the Castle Mountains, in the vicinity of Horsehead Crossing, are reached. Here it underlies the Upper Calcareous, or Edwards group. From thence to the source of Delaware Creek, it is the only rock exposed.

Thus Shumard makes no distinction between the two formations underlying the Edwards limestone, but relegates both to the Marly Clay group. A distinction, however, was noted at this time on a lithological and paleontological basis, and advocated by Marcou.

In his *Journal of Geological Observations*, page 82, entry for May 19th and 20th, Shumard describes a sandstone in the vicinity of Grand Falls and concludes a sectional discussion with the statement that near the base of one of them the sandstone was found to contain small rounded pebbles of eruptive rocks.

At the Falls again, the Trinity conglomerate or its equivalent which marks the definition between the Cretaceous Basement sands and the underlying Triassic is described¹: "At a distance of 12 miles we arrived at the rapids of the Pecos. Here the water descends impetuously for a distance of about twenty feet over coarse quartzose sandstone and conglomerate. The total amount of fall is about ten feet. On either side are high bluff banks of red marly clay, coarse quartzose sandstone, and pulverulent limestone, in nearly horizontal strata. The sandstone is soft, friable, and of red and gray colors. Near the base, it passes into a conglomerate of well rounded pebbles of quartz, red porphyry, granite, and other varieties of eruptive rocks."

Farther up the river it is found covering the surface of the ground and continues so until about 1½ miles southeast of Pyote. For this area Shumard recorded²: "As we progressed, the surface became much more uneven and sometimes covered with coarse drift deposits, consisting of quartz, jasper, chalcedony, and granite, often cemented with a calcareo-ferruginous paste, and with an average thickness of three feet." Beneath this conglomerate lies the heavy massive red sandstone of the Triassic.

¹*Journal of Geological Observations: A Partial Report on the Geology of Western Texas*, by G. G. Shumard, p. 82, Austin, 1886.

²*Loc. cit.*, p. 83.

In 1891, Cummins explored the Upper Pecos Valley as far south as the Castle Mountains at Horsehead Crossing. He reported the presence of Triassic red sands as far south as explored by him, and in addition he placed the red beds adjacent to the river immediately to the south of Pecos City, in the Red Beds of the Permian. At the Castle Mountains, however, he placed all exposed strata below the limestone in the Triassic sands. However, he found no fossils in what he termed the Triassic and the Permian of the Pecos Valley.

In a subsequent paper¹ on the "Triassic Formation of Northwest Texas", Drake, who was formerly Dumble's assistant, maintains that the Triassic extends with some breaks to the Castle Mountains, regarding which he writes²: "At Castle Mountain the Cretaceous is underlaid by red sandstone, conglomeritic sandstone and red clay of the Dockum Beds. There is about thirty feet of this material exposed, and most of this is a red conglomeritic sandstone containing small pieces of calcareous clay, and sandstone of yellowish and brown colors; also pieces of reddish brown sandstone and calcite crystals. At the center of this thirty feet is red shaly sandstone and red marly clay. The shaly rock contains mica flakes".

Thus Dumble and Drake, exploring from the north, place all of the red sands of the Pecos Valley in situ west of Horsehead Crossing, in the Triassic. Cummins also records them to be Triassic, but he regards the red beds of the immediate river valley as Permian Red Beds.

Upon the general appearance of the sands and clays and the presence of some gypsum in the clays, Cummins bases his conclusions as to their Triassic and Permian age, respectively; while Drake, studying the same area, concludes them to be the Dockum beds of the Upper Triassic, from the presence of conglomeratic sandstone, conglomerate, and especially because they contain a considerable quantity of mica flakes.

Marcou in 1852 calls them Triassic from a lithologic and paleontological standpoint, but his evidence is not conclusive as

¹Third Annual Report, Geological Survey of Texas, p. 227, Austin, 1892.

²Loc. cit., p. 247.

it was obtained in the Canadian River region and applied to the upper Pecos Valley. Nowhere in the red sands or clays of the upper Pecos Valley in Texas has there been any organic life reported.

Shumard, three years later, disagrees with Marcou and states that he finds no evidence to substantiate an age other than the Cretaceous, as the red beds agree lithologically and stratigraphically with unquestioned Cretaceous sands in the vicinity of San Antonio, and also as the paleontological evidence offered by Marcou to support their Triassic age is an argument in favor of their being Cretaceous. Thus a variety of opinion has been expressed concerning the geological position of these red beds.

In the present survey the evidence offered by each predecessor has been carefully checked in the field, and this information added to that obtained from observations taken at different localities indicates that the Basement sands of the Cretaceous, the Dockum beds of the Triassic and the Permian Red beds are at the surface in the Pecos Valley of Texas, southeast of the Rustler Hills.

Excepting local areas, where a clay or an argillaceous sand is present which resembles the Permian red clays, there seems to be no reason why the red sands in the quarry at Quito and along the ridge northeast of the river in the upper Pecos Valley of Texas should be referred to the Permian, and the origin of this phase of the Triassic can be explained (see page 41.) The presence of massive gypsum would be indicative of their Permian age, but only a few thin layers of this mineral were found in the region. The massive beds, together with thick strata of rock salt, lie below the Triassic in what is conceded to be the Permian Red Beds. Professor Baker, in a complete discussion of the Upper Triassic,¹ distinguishes it from the underlying Permian Red Beds in that "The lower bed of sandy clay of the Triassic is generally a maroon or wine color, and is therefore darker than the underlying Permian. Other means of distinction of the Triassic from the Permian are the flakes of mica in the sandstone and the presence of conglomerate beds in the

¹Geology and Underground Waters of the Northern Llano Estacado, C. L. Baker. Bull. of Univ. of Texas No. 57, pp. 18-19, 1915.

Triassic, neither of which occurs in the underlying Permian. The following characteristics of the Triassic strata also serve to separate them from those of the Permian (1) The Triassic sandstones are gray and brown in color; (2) the lower Triassic shales are variegated, with maroon, wine, white, lavender, and yellow colors predominating, while the upper Permian shales are bright brick red; (3) the Triassic strata exhibit an extensive development of cross-bedding and local unconformities."

In differentiating these two formations in the Pecos Valley, Baker's characteristics readily distinguish them; the difficulty, however, lies in placing the line of demarcation between the Triassic and the Basement sands of the Lower Cretaceous.

From their most southern exposure five miles above Chandler in Terrell County, to Red Point in the Castle Mountains, at every section there is a perfect gradation from the Walnut clay into the Basement sands below. These in turn, without the slightest angular unconformity, continue into the sandstones of the Triassic. The lowest and heaviest conglomerate, about seven feet thick, is first seen in the beds of the river at Grand Falls and in the bottom of the irrigation canals, north of the Pecos River bridge. In the vicinity of Pyote it comes to the surface, and more clearly shows the igneous origin of the greater part of the pebbles which form it. There are in addition a few flints and some water-formed chalcedony. Above this conglomerate are found numerous others at various elevations. These lie in perfect conformity with the sandstones above and below them, and some massive sandstone ledges contain layers of these pebbles, while in others the pebbles are interspersed throughout the stratum.

Mica is also found in the sandstone, above and below the heavy conglomerate. Its highest occurrence is about 150 feet below the base of the Edwards limestone, while the pebbles continue to within fifty feet of the Walnut clays.

As the conglomerate at Grand Falls is the lowest one exposed in the Pecos Valley, and since its composition is the same as the Trinity conglomerate observed in other parts of Texas, it has been called the Trinity conglomerate or its equivalent, and placed as the base of the Cretaceous in the Pecos Valley. The

conglomerate containing mica or pebbles is probably to a great extent a re-worked product of the underlying Triassic.

In the Pecos Valley, there was almost continuous deposition from the Triassic through the Jurassic and lower Cretaceous. Whatever break in sedimentation occurred is represented by the heavy conglomerate. Both below and above this conglomerate, the strata are similar in composition and are conformable with each other. Thus Shumard, working from the southeast, could see no ground for making any division of the red beds of the Pecos Valley, but placed all in the lower Cretaceous or Marly Clay Group. Dumble and Drake, working from the opposite direction and finding the upper conglomerates and pebbles, placed all of the red beds west of the Castle Mountains in the Triassic. Cummins agrees with Dumble and Drake in that the Triassic extends with a few minor breaks to the Castle Mountains, but he is inclined to consider as Permian the red sand and clay in the immediate Pecos Valley below Pecos City.

The presence of this heavy basal conglomerate at Grand Falls, which is the lowest introduction of foreign igneous pebbles, records a break in sedimentation—a parallel erosional unconformity—and makes the contact of the Triassic and the lower Cretaceous sands.

The rugged topography of the lower Pecos Valley, with its numerous steep-walled canyons and precipitous cliffs, gives abundant exposures of all horizons near the surface.

From about eighteen miles above Girvin, at the Kansas City, Mexico and Orient Railroad crossing of the Pecos, to the New Mexico line, exposures are rare in the immediate vicinity of the river, because of the covering of Quaternary alluvium, and the majority of the work done was at widely separated exposures at some distance from the river.

The Edwards limestone cap, which has preserved a varied topography along the lower Pecos, on account of its southeast dip, has here exposed so much of the Basement sands and underlying Triassic that erosion has been extremely rapid, undercutting the Edwards limestone, which has been carried away, and leaving a broad flat valley with little relief. The re-worked Basement and Triassic strata form the red alluvium which conceals the underlying rocks.

All the strata are persistent over large areas, and lie in normal sequence from the Permian formation, near the Texas-New Mexico line, up through the column to the upper Edwards limestone.

Above the Permian Red Beds and immediately underlying the Trinity conglomerate or its equivalent, and having no angular unconformity, are the beds of the Upper Triassic. Since the time was so limited, these beds were not correlated in the field, but it is highly probable that they are the equivalents of Drake's Upper Dockum bed and Gould's Trujillo formation, which underlie the Comanchean-Cretaceous, form the base of the northern and eastern escarpment of the Llano Estacado, and extend westward into New Mexico.

They first come to the surface immediately under the Trinity conglomerate fifteen miles above Grand Falls, and as their southeast dip is a little greater than the gradient of the river, they rise to a sufficient elevation in Loving County and along the Pecos Valley in southeastern New Mexico to form the base of the southwestern Llano escarpment. Without further study it is impossible to say how much the upper part of this sandstone has been eroded, but it is probable that very little has been carried away from the exposed surface, since the deposition and erosion of the Cretaceous. The same grayish-red, cross-bedded ledge is found at about the same elevation and distance below the surface of the ground four miles below Barstow, where little post-Comanchean erosion has taken place, and at the Texas-New Mexico line. Also over this area, unless there has been extreme lateral variation, there probably has been no more erosion in the Triassic-Comanchean interval than over the other parts of the Llano, as the variegated shales of the Teovas formation are not exposed, and almost the entire thickness of the Trujillo is present.

The beds of the Upper Triassic exposed in the Pecos Valley of northwestern Texas, and southeastern New Mexico, are light red in color on freshly exposed surfaces, but readily weather to a very deep red, due to a more complete oxidation of the iron and its redistribution when the feldspar and silica decompose to clay.

They vary both laterally and vertically from hard, massive, evenly-bedded sandstone, to thin, cross-bedded, shaly sands. However, over the top of the entire area a hard, thickly-bedded,

homogeneous, deep red sandstone prevails. This can best be seen in the quarry four miles southeast of Barstow where a local vertical section of some seventy-five feet does not show the entire thickness. The general thickness of this cap, however, is only about ten or fifteen feet.

The texture does not show an extreme range, though in places it is rather coarse sandstone, but generally the grains are of medium size and well cemented. In all localities both muscovite and biotite were found, but they have no regularity of occurrence. In some places they cannot be identified with a lens, perhaps being too minute, or probably being absent; in others flakes from microscopic size to those 1 inch in diameter are present in great quantities.

The individual grains are mostly feldspar and quartz and are firmly held together with a highly calcareous cement. Upon weathering, the feldspar, which is a silicate of aluminum, potassium, sodium, and calcium, decomposes and forms the greater part of the clay found in the area. The additional kaolin probably comes from the underlying Permian clays farther to the north.

The remaining alkaline bases form the oxides which in turn change to the hydroxides, on presence of water; and furnish at least a part of the strong basic alkali, so characteristic of the region. A part of these surface alkalies in the region probably also has an origin in the underlying Permian.

The angle of sharpness in the weathering process of the sandstone cap is above the ordinary; in the lower sandstones it is about normal.

Two types of weathering are present: (1) a mechanical disintegration—a breaking down of the calcareous cement and liberation of the sand grains, forming the loose red sand; (2) a chemical decomposition, forming clays.

The thickness of the Triassic region is not known, as nowhere is the base exposed, but over a hundred feet are visible.

The areal distribution of the Triassic is shown on the accompanying map (Pl. 1). To the northwest of Barstow outliers of Comanchean limestones have been found overlying the older formations, but their relation has not been described in detail.

COMANCHEAN-CRETACEOUS

The Comanchean-Cretaceous System of that portion of the Pecos Valley included in the present survey has two components, a part of the Trinity and the overlying Fredericksburg divisions. No strata of the Washita Division have been identified within these limits. The aggregate thickness of the two divisions is about 850 feet.

TRINITY DIVISION

The Trinity Division of the Comanchean Cretaceous embraces all the strata in the Pecos Valley overlying the Triassic and underlying the Walnut clay. This division in the Pecos Valley includes the Trinity conglomerate which forms its base, and the Basement sands, which are the stratigraphic equivalent, although presumably not the entire time equivalent, of the Paluxy sands, Glen Rose, Travis Peak and Basement sands of east and central Texas.

In the absence of organic life to furnish paleontological definition and the lack of persistent lithologic features in every horizon, it was not found practicable to subdivide the Trinity division except to recognize the Trinity conglomerate, the remainder being referred to as the Basement sands.

The *Trinity conglomerate* or its equivalent, lying at the base of the Trinity division of the Comanchean-Cretaceous, owing to the rapidity with which its cementing material breaks down, does not outcrop intact at any point in the Pecos Valley, but may be best studied in the vicinity of Grand Falls. Here in the river bed just above the steel highway bridge over the Pecos River and in the irrigation canals, are found the recently cemented components of the conglomerate. This material also is scattered over a considerable area extending northward many miles, where the beds, with a thickness of some seven feet and a southeast dip only slightly greater than the slope of the ground, come to the surface.

In the Castle Mountains the re-worked products of this conglomerate are found in the overlying Basement sands to within fifty feet of the Walnut clay.

The nature of the material of which these fragments are com-

posed varies greatly. Igneous quartz, water-formed chalcedony and flint constitute about one-half of the material. The remainder consists of rhyolites and trachytes with their corresponding porphyries, and coarse-grained equivalents, granite and syenite, some of the more basic types of basalt and dolerite, and some few which have been so changed by weathering processes as to prevent classification.

The individual pebbles of this heterogeneous collection vary much in form, color, composition and texture. The well rounded shape of the greater part of them indicates the great distance they have been transported. The difference in texture between the almost glassy rhyolites and the coarse-grained granites and syenites shows all degrees of depth at which the cooling magma must have solidified. The highly acidie granites had their origin in a much different rock from the more basic dolerites and basalts. Water-formed strata contributed the chalcedony and flint, while igneous intrusions and extrusions furnished the other material.

The source of this material cannot be ascribed to any one locality or formation, but the Wichita-Arbuckle Mountains of Oklahoma are generally conceded to have furnished the greater part of the igneous fragments.

The *Basement sands*, with a thickness of about 250 feet, which overlie the Trinity conglomerate of Toyah Basin, first appear in situ about eighteen miles north of Girvin. They undoubtedly once covered the greater part of Toyah Basin, but because of their elevation north of this point and the argillaceous nature of the overlying Edwards in this region, they have been eroded. They form the greater part of Red Point, one of the prominent topographic features making up a semi-circular range of hills which constitute the most northwestern exposure of the Edwards in Toyah Basin. Overlying these sands at Red Point are the Walnut clay, the Comanche Peak limestone, and about twenty-five feet of the base of the Edwards limestone which forms the cap of the escarpment and protects the underlying strata. The most southern exposure of the sands is five miles north of Chandler in Terrell County, where they dip under the water level. The accompanying map shows their distribution. (Pl. 4).

The Basement sands are conspicuously variegated in color,

and vary extremely in hardness, texture, and composition. Adjacent zones of unequal oxidation and hydration of the iron, manganese and other bases give a range of colors and shades from light yellow through the browns, reds and purples. This variation is both lateral and vertical and also both abrupt and by gradual transition. The presence of an effective siliceous cement has locally produced a sandstone of such a quartzitic nature that fracture is through rather than around the grains, but by far the greater part is pulverulent, even between the fingers, when in small pieces. At no point was there observed any metamorphic action of the superimposed strata sufficiently great to produce even the slightest induration. This of course was to be expected in consideration of the relative youth of the Comanchean-Cretaceous and the absence of movements capable of producing intense pressures. In many places the sandstone is composed of pure silica grains while in others it contains much kaolin and could more correctly be called an arenaceous clay. The proportion of sand to clay varies between these wide limits, but as a whole the sandy nature predominates. The individual grains are small, of uniform size, and well rounded. Scattered pebbles and thin layers of reworked Trinity conglomerate are found at various elevations to within some fifty feet of the base of the Walnut clay.

At the top of the Basement sands immediately below the Walnut clay is a hard, dark brown, evenly bedded sandstone. Because of its wide distribution, fossil content, and uniform thickness of about 2 feet, it is readily identified wherever exposed and has been selected as a key horizon.

FREDERICKSBURG DIVISION

The Fredericksburg Division of the Pecos Valley included in the present survey is composed of the calcareous members, namely, Walnut clay, Comanche Peak limestone, and Edwards limestone. In ascending order, as given, they increase in amount of lime and in hardness, and decrease in clay content. Their total thickness is about 575 feet.

Walnut Clay and Comanche Peak Limestone. Lying on the Basement sands is the Walnut clay, conformable and somewhat blended, but generally with visible definition. Its areal distribu-

tion is equal to that of the Basement sands, for in the absence of a protective cap of the Edwards limestone they both disintegrate rapidly. Its lower beds contain an appreciable amount of sand which decreases upward with an addition of calcareous matter, passing imperceptibly into the nodular Comanche Peak with a slight loss in yellow color. The contact between these formations cannot be detected. Their aggregate thickness is from 2 to 24 feet; the beds of the northernmost exposures being thinner than those farther south. The Comanche Peak limestone in turn changes vertically from the argillaceous limestone with a loss in kaolin and an increase in lime and nodular texture into the true Comanche Peak, gray in color, with practically no sand, slightly argillaceous, moderately hard and distinctly nodular. Its areal distribution is the same as that of the Walnut clay.

The Edwards Limestone. Approaching the top of the Comanche Peak, the same gradual nature of change, so characteristic of the formations under observation, takes place. Without a break the nodular texture disappears and with practically no change in color the small amount of remaining sand and kaolin is no longer present and the massive ledges of the Edwards limestone are at hand. Its hundreds of feet of unbroken sequence contribute much to make the Comanchean-Cretaceous no mean rival of the Ordovician as a producer of limestone.

As indicated by the map, the Edwards limestone covers the lower half of the Pecos Valley. Only in small areas is it covered by later formations. From here it extends northeast into north-central Texas and southwest to, and in some places beyond, the Marathon region in Brewster County.

It is the chemical and physical properties of the Edwards which determine the surface contour of the area which it covers. Occasionally heavy ledges of hard, pure limestone, being slow to weather and intersected by fewer jointing and bedding planes, stand out as bold precipices or as cap rock for the flat-topped hills. Softer and more argillaceous beds are quickly disintegrated, giving gradual slopes and benches upon which the debris from above collects and in most cases, unless the erosive agencies are extremely active, covers the underlying rocks in place. Ledges of varying thickness from a few inches to twenty

feet are found and this factor greatly influences the rate of disintegration.

Over the southern Pecos Valley the Edwards generally weathers to one of three benches which are referred to in ascending order as first, second and third divisions of the Edwards limestone. In places other less definitely marked benches overlie the third. The cap of the third division forms the top of the Edwards Plateau which is the largest and most marked topographic feature of the lower Pecos Valley. These divisions of the Edwards are lithologic entirely but are useful in reference because of the great thickness which the limestone reaches. The lowest or first division is approximately 160 feet thick and is characterized by horizons of chert occurring as nodules in the form of concretions, or as sills by replacement. This division also supports a more luxuriant vegetation because of its more gentle slopes and deeper accumulation of soil. The second division is about 105 feet thick and more thinly bedded. Upon weathering it develops a netlike channeled surface resembling mud cracks which are not found to any extent in either of the other two divisions. The third division, about 180 feet in thickness, is more massively bedded than the others and its texture is more highly crystalline. It is filled with small calcite crystals and concretions.

PLEISTOCENE AND RECENT

Over the greater part of the Pecos Valley, especially in the lower lands, there are considerable depositions of Pleistocene and Recent age. The material eroded from the older rocks is re-deposited by the weathering agents in various forms. Only very locally are these deposits well stratified; deposits only a short distance from each other having practically no resemblance. Laterally and vertically they overlap and grade into one another. A sand, pure in one locality, will grade imperceptibly or abruptly into a gravel and boulder bed or a clay deposit. Practically all the alluvial deposits are lenticular and exhibit cross-bedding. In the valleys of the tributaries of the Pecos, over the Edwards Plateau region, the deposition is principally talus from the limestone. This is chiefly fragmental and the particles are often re-

cemented by calcium carbonate which has gone into solution when some of the limestone has decomposed, or it is found mingled with clay in places where the limestone has had a greater kaolin content.

Along the lower Pecos flood plains the deposition is more heterogeneous, for to the native material is added the wash from the older beds nearer the source of the river.

In the upper valley where the Edwards has been eroded for a considerable time, the limestone fragments are in a minority, as their only source is the Rustler formation. The assortment consists chiefly of sand and gravel from the Triassic and lower Comanchean sands and conglomerates, and, in addition, clay decomposed from the feldspar in the Triassic sandstone and some carried by the river from the Permian Red Beds of New Mexico. The deposits of the upper Pecos Valley in Texas are more homogeneous and regular. Layers of assorted pebbles are frequently found and the sands and clays are less frequently intermingled. Here also are wind-blown deposits of fine sand and unconsolidated fragments of igneous origin.

At the beginning of the Llano escarpment, a new accumulation in the form of "caliche" is encountered. This deposit immediately overlies the Triassic sandstone in the northern Pecos Valley. It is first noticed as a white pulverulent coating of the older limestones and sandstones in the valley, but at the Staked Plains it has cemented the soil material to a depth of ten or fifteen feet and forms the cap rock of the Llano Estacado.

The cementing matter is a precipitate of calcium carbonate brought to the surface by capillary attraction and re-deposited as a cement which binds the surface particles together.

STRUCTURAL GEOLOGY

Dynamic geology of the Pecos Valley is separable into two parts: (1) Pre-Comanchean movements and (2) post-Comanchean movements.

(1) Any folding antedating the deposition of the Lower Cretaceous system would not be reflected in the overlying strata but a structural and erosional unconformity would exist, with magnitude depending upon the amount and rate of disturbance,

the period of exposure to weathering agencies before the deposition of the overlying strata, the resistance of the beds, and the power of the decomposing elements.

Dr. Udden has given the following discussion of the possibilities of structural geology in the Pecos Valley:¹

"Looking at the ancient Marathon Mountain structure as a whole, it does not appear unreasonable to regard it as suggesting the possibility of the existence of buried structures in which oil may have accumulated, farther to the northeast. If we take into consideration all that is known concerning the trend of this structure of the ancient Marathon Mountains, all the way from the Solitario on the Brewster-Presidio County line to the northeast, the general trend of this structure, as near as it can be made out, is north 40° east. At the last exposure of the Pennsylvanian to the northeast, at a point near the Purington Ranch, where the Dimple Formation occurs, it has a trend in the direction of north 60° east. There can be no doubt that this structure extends a considerable distance northeast under the overlying Comanchean limestones. The last exposure seen shows the Carboniferous strata in an almost vertical position. There is no intimation in this or in any other exposures that the mountain structure developed in these old formations has undergone any modification except that it may have been cut down to a lower level in this direction. The same, we may say, is suggested also by the isolated uplift coming up through the Comanchean in the Madera Mountains, which suggests also that there is a narrowing of the folded region in this direction. From my observations on all parts of the Glass Mountains it appears that the formations from the Vidrio up are much less tilted and folded than the Gaptank and other formations of probable Pennsylvanian age. It would seem, therefore, that most of the folding of the Marathon Mountains antedated the deposition of the latest Permo-carboniferous sediments. I believe that the red beds exposed within the Pecos Valley overlie the Tessey formation. These and the overlying Comanchean, therefore, probably have been very little disturbed by the Marathon uplift. So that there should exist, under the Comanchean and under the Red Beds, some places northeast of the Marathon uplift where the Pennsylvanian and probably some of the Permo-carboniferous lie folded under the relatively undisturbed red beds and the Comanchean limestones. The red beds are entirely impervious and would make an excellent cover for an oil pool. How far such covered places of tilted petroliferous formations of the Pennsylvanian may be found away from the exposures in the Marathon country, no one could say, but it would be no surprise to find them at a distance of at least fifty or a hundred miles beyond

¹Notes on the Geology of the Glass Mountains, J. A. Udden; Bulletin Univ. of Texas No. 1753, pp. 56-58. Austin, 1917.

the Brewster-Pecos County boundary. The trend of the Marathon Mountains would run through the southeast part of Pecos County into Upton and Reagan counties, or even farther east than this.

"It will be remembered that on the west flank of the Glass Mountains the Comanchean limestones have been slightly tilted and that outliers of this formation occupy some of the highest points on the mountains. This cannot be altogether due to an overlap. It certainly represents a slight uplift in post-Comanchean times. From what is generally known of the geologic history of the mountain-building forces, it is quite reasonable to suppose that the post-Comanchean disturbances should have taken place over more than one part of a buried mountain system, such as the Marathon uplift. It ought for this reason to be practicable to find out how far in a northeast direction this uplift probably extends, for it can be expected to be marked by at least some slight elevation in the later Comanchean sediments. We have here a geologic problem, the solution of which may be of decided economic significance. In the distribution of the Comanchean along the North Concho and the Colorado rivers, there is nothing to especially suggest such an uplift. The conditions in the country to the northeast of the Glass Mountains, along the Pecos River, are singularly favorable for the testing of such a theory. The Comanchean limestones contain several sharply marked horizons that can be followed for long distances, in the southwest part of Pecos County, and in most of Upton, Reagan and Crockett counties. Quite accurate measurements of any structure present can certainly be made. It is, however, a region where very little work has yet been done, and in the absence of any accurate knowledge of the conditions involved, further speculations seem unprofitable. We can only see that in the buried unconformity which certainly must exist between the lower folded series and the overlying merely gently folded or quite undisturbed sediments there are natural chances for finding accumulations of gas as well as oil. Drilling should not be undertaken, however, before a thorough geologic examination has been made whereby the exceedingly small chance of making the right location for a test may be materially increased."

Professor Baker and Mr. Bowman¹ also have found evidence of folding in the Glass Mountains region which is later than the Permo-carboniferous and earlier than the Comanchean-Cretaceous. They place it in the Lower Triassic, probably about the time the Llano Estacado geosyncline was formed.

(2) Subsequent folding during the deposition of the Cretaceous and more recent formations would not only show structural features in these beds, but would at the same time be indic-

¹Geologic Exploration of the Southeastern Front Range of Trans-Pecos Texas. Univ. Tex. Bull. No. 1753, p. 112. Austin, 1917.

tive of folding beneath. Whether or not the conditions in the lower beds have been and are favorable for the accumulation of petroleum depends upon many factors, and will be discussed later.

Again Professor Baker has observed Cretaceous and post-Cretaceous movement in the Pecos Valley.² "Near the close of the Cretaceous, the Rocky Mountains were first uplifted and the entire Texas region, with the exception of the western Trans-Pecos country, was gently tilted in a southeastwardly direction toward the present Gulf of Mexico."

Undoubtedly there is both pre- and post-Cretaceous folding in the Pecos Valley. The former, however, cannot be discussed to any great extent because the lower formations do not give sufficient exposure within the present survey and a few isolated well logs furnish practically the only data for the subsurface work.

As the accompanying sections from Pandale to Barstow indicate, the Comanchean-Cretaceous over this area lies almost horizontal. The slight departure from the normal rate of dip, together with the gentle tilting of the whole formation to the southeast, are the only indications of Cretaceous or post-Cretaceous folding. That there have been only slight disturbances in the Pecos Valley after the deposition of the Permo-carboniferous, in contrast with the extreme activity of the Paleozoic, is in accord with the observation of Udden, Baker, and Bowman, in the Glass Mountain region and in the southeastern Front Range of Trans-Pecos Texas.

Even in the vicinity of the Marathon region and the Davis and Barilla Mountains, Comanchean strata lie practically horizontal upon the beveled edges of Paleozoic formations.

Igneous Activity. Though there has been little folding or tilting later than the Permo-carboniferous, igneous activity has been by no means absent. Great intrusive flows to the northeast and northwest from the Davis and Barilla Mountains are evinced by the rhyolite boulders and gravel which cover the lower part of the Comanchean to the west and northwest of Fort Stockton. About eighteen miles from Fort Stockton on the Fort

²Review of the Geology of Texas, J. A. Udden, C. L. Baker, Emil Bose. Univ. Tex. Bull. No. 44, 1916.

Stockton-Pecos road, the residual material from the intrusive first appears, as the Quaternary covering of the lower part of the Edwards formation. Although isolated outliers of the Comanchean limestone are found occupying greater elevations than the igneous, at no place was the limestone found to overlie the igneous, thus pointing to a late Cretaceous or subsequent flow. In the Marathon region fossil plants in associated tuffs prove them to be late Cretaceous or early Eocene.¹ The nature of the rock itself shows it to be intrusive rather than extrusive. The absence of acidic obsidian, cellular glassy rhyolite and surface lavas, and the presence of rhyolite porphyry, indicate an intrusion of moderate depth and an intermediate rate of cooling: since surface or shallow depth cooling would have produced the lighter textured crusts and lavas, and deep intrusions with a slow rate of cooling would have resulted in heavier textured sills with greater crystallization. The igneous activity was evidently a quiet intrusion, since little disturbance over any part affected has been observed, and it has been no greater in strata close to the source of activity than in those one or two hundred miles removed, and also as there is a noticeable absence of dikes and vertical intrusions. No contact metamorphism in the Edwards was noted, indicating that the flow was formerly in strata at a considerably greater elevation than it occupies at present. Because of its texture and hardness it has come down more or less intact as the underlying older, but less resistant, formations have been eroded. Only in relatively recent times has it broken up to its present condition, for it is spread evenly over the area occupied and its limits are well defined. Greater lapse of time since decomposition to its present state would have resulted in deep accumulations in some places and total absence of flow in others. Its boundaries also would be irregular from transportation. The present eastern boundary of the intrusion is remarkably even and lies in a northeasterly direction.

DESCRIPTION OF VERTICAL SECTIONS

Two sections, Camp Section and Red Point, have been de-

¹Review of the Geology of Texas, by Udden, Baker and Bose. Bull. Univ. of Texas No. 44, p. 100. Austin, 1916.

scribed in detail, as the strata there exposed give practically the entire geologic column from Pandale to the most western exposure of the Edwards limestone and Basement sands in the Pecos Valley. As there is no greater variation in the strata between sections than within the sections themselves, a repetition of descriptions is unnecessary. When necessary, descriptions of additional strata are given in their respective sections. The variation referred to is chiefly one of color and appearance of the Basement sands.

None other than a divisional description of the Edwards limestone is practical, as the divisions remain quite uniform, and the strata divide and unite very irregularly.

In all other sections the different formations are identified for correlation and their thicknesses given.

SECTION NO. 1

The Pandale Section

located on the south bank of the Pecos River at Pandale Crossing, 3 miles due west of Pandale, in Val Verde County.

Feet

Edwards limestone:

Third Division—Represents entire third division plus some excess over the normal. <i>Requienia</i> sp. <i>Cyprimeria texana</i> (Roemer)	264+
Second Division—Limestone. <i>Lima</i> sp., <i>Protocardia texana</i> Conrad, <i>Gryphaea navia</i> Hall, <i>Requienia</i> sp.	116
First Division—Not all exposed. Extends below river level. <i>Requienia</i> sp., <i>Lima</i> sp.	138

SECTION NO. 2.

The Chandler Section

at the junction of Independence Creek with the Pecos River at Chandler, in Terrell County, on the east or Crockett County side of the river. The cliffs afforded the following section:

Edwards limestone:

Third Division—Limestone plus excess. <i>Lima wacoensis</i> Roemer, <i>Requienia</i> sp., <i>Gryphaea navia</i> Hall.	362+
Second Division—Edwards limestone. <i>Requienia</i> sp., <i>Lima</i> sp.	106
First Division—Edwards limestone. <i>Protocardia texana</i> Conrad	164

Comanche Peak:

Nodular limestone. <i>Exogyra texana</i> Roemer and <i>Lunatia pedernalis</i> Roemer very common.	12
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Alluvium:

Red and yellow clay alluvium from water level to No. 2 covering Walnut clay. No fossils in place. Walnut clay and Comanche Peak fossils loose on surface.	18
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SECTION NO. 3

Fourteen Mile Point Section

was taken at the first prominent point on the Pecos River bank, about six miles above Chandler. The section is at the south end of the river trail along the east bank of the Pecos.

	Feet
<i>Edwards limestone:</i>	
Third Division— <i>Requienia</i> sp., <i>Gryphaea navia</i> Hall.....	170
Second Division— <i>Requienia</i> sp., <i>Gryphaea navia</i> Hall.....	106
First Division— <i>Exogyra texana</i> Roemer at base; <i>Requienia</i> sp.	150
<i>Comanche Peak:</i>	
Nodular limestone— <i>Exogyra texana</i> Roemer, <i>Protocardia texana</i> Conrad	10
<i>Walnut clay:</i>	
Yellow clay, soft, and containing a great number of <i>Exogyra texana</i> Roemer; <i>Protocardia texana</i> Conrad less common	12
<i>Basement sands:</i>	
Top four feet of Basement sands hard, brown, evenly bedded limestone. Upper four inches very fossiliferous. Used for key horizon. Oyster species not recognizable, present in great quantities; probably <i>Exogyra texana</i> Roemer settled to this position from the Walnut clay immediately above	4
Sandstone, vari-colored and showing much lateral and vertical gradation in color.....	14

SECTION NO. 4

Nine Mile Point

Nine Mile Point is at the water's edge, on the east bank of the Pecos River, nine miles below Sheffield and five miles southeast of the Ozona-Sheffield highway bridge. The river at this place turns immediately to the east and flows for a short distance along the base of a cliff, then turns due west for a quarter of a mile. The point is visible from the Ozona-Sheffield road, four miles east of the Ozona-Sheffield highway bridge.

	Feet
<i>Edwards limestone:</i>	
Third Division—Edwards limestone. <i>Lima</i> sp., <i>Requienia</i> sp., <i>Pecten</i> sp., <i>Gryphaea navia</i> Hall.....	216
Second Division—Edwards limestone. <i>Lima</i> sp., <i>Pecten</i> sp....	112
First Division—Edwards limestone. <i>Requienia</i> sp.; also containing considerable amount of flints near the top of the division	154
<i>Comanche Peak:</i>	
Nodular limestone. <i>Exogyra texana</i> Roemer, <i>Lunatia peder-nalis</i> Roemer, <i>Protocardia texana</i> Conrad.....	12

	Feet
<i>Walnut clay:</i>	
Yellow clay. <i>Exogyra texana</i> Roemer, <i>Protocardia texana</i> Conrad	14
<i>Basement sand:</i>	
Key horizon. Very fossiliferous; fossils not determinable....	4
Shaly sands, no fossils.....	10
Sand, no fossils.....	42
Sand and alluvium.....	18

SECTION NO. 5

Three Mile Point Section

below the Ozona-Sheffield highway bridge, at the point where the river turns from due east to almost due south; 200 yds. below the mouth of Live Oak Creek.

	Feet
<i>Edwards limestone:</i>	
Second Division—Edwards. Not all present. Top eroded. <i>Requienia</i> sp.	25
First Division—Edwards. Slightly softer and clayey. <i>Turritella</i> sp., <i>Lima wacoensis</i> Roemer, <i>Pecten</i> sp., <i>Exogyra texana</i> Roemer, <i>Cyprimeria texana</i> Roemer.....	169
<i>Comanche Peak:</i>	
Nodular lime. <i>Exogyra texana</i> Roemer. <i>Protocardia texana</i> Conrad	11
<i>Walnut clay:</i>	
Yellow clay. <i>Exogyra texana</i> Roemer. <i>Lunatia pedernalis</i> Roemer	12
<i>Basement sand:</i>	
Key horizon, fossils undeterminable.....	5
Alluvium and sands, no fossils.....	38

SECTION NO. 6

The Camp Section

on east bluff of Pecos River, $\frac{1}{4}$ mile north of steel highway bridge $3\frac{1}{2}$ miles east of Sheffield in Pecos County.

	Feet
<i>Edwards limestone:</i>	
Third Division—Edwards. Not all present. Color, composition, and hardness practically same as first division. Very little chert and great abundance of calcite crystals in places. <i>Requienia</i> sp., <i>Lima wacoensis</i> Roemer, <i>Pecten</i> sp.....	142
Second Division—Edwards. Practically a repetition of the first division though generally more thinly bedded. Noticeable absence of chert and a development of mud crack appearance in weathering. At Yellow Peak a short distance back from the river, by the Camp Section, the Ed-	

wards limestone has locally become soft, yellow, and clayey, and is very fossiliferous. In general, the Edwards is only slightly fossiliferous, and the hard crystalline nature of the limestone renders it impossible to procure unbroken specimens. This accounts for the greater part of the fossils from the Edwards limestone being referred to generically. The following fossils were collected from Yellow Peak, which is the lower part of the 2nd division of the Edwards limestone:

- Enallaster texanus (Roemer)
- Enallaster cf. bravoensis Boese
- Protocardia texana Conrad
- Lunatia pedernalis Roemer
- Schloenbachia belknapi (Marcou)
- Engonoceras sp.
- Cyprimeria texana (Roemer)
- Cerithium bosquense Shumard
- Pholodomya sancti-sabae Roemer
- Rostellaria texana Roemer
- Pecten subalpina (Boese)
- Pecten irregularis (Boese)
- Pecten cf. occidentalis (Conrad)
- Turritella sp.
- Lima wacoensis Roemer
- Homomya sp.
- Cucullea sp.
- Trigonia sp.
- Tapes sp.
- Exogyra texana Roemer
- Exogyra sp.
- Requienia sp.

..... 117

First Division—Varying in color from almost black to a very light gray. Freshly broken surfaces more uniformly gray in color. Quite uniform in texture. Bedding averages from three to four feet. Sometimes ledges are 30 to 40 feet. No regular system of jointing. Weathers into blocks from 8 to 12 inches or 25 to 30 feet. Much iron oxide stain on exposed surfaces. First division also has much chert. These aggregations vary from pebbles to medium-sized concretions with their horizontal axes parallel to the bedding planes, and are from 2 to 36 inches in length at the exposed edges. The shorter axes are generally 2 inches long and quite uniform through the strata and in fact throughout the entire horizon. In some layers they form almost continuous bands for 6 to 8 feet, being interrupted in

	Feet
places by the limestone in which they are formed. Several cavities filled with calcite crystals were observed. The limestone in weathering develops a pitted appearance and in places becomes almost honey-combed. <i>Lima</i> sp., <i>Requienia</i> sp.	162
<i>Comanche Peak:</i>	
Nodular argillaceous lime, grading imperceptibly into Edwards limestone above and Walnut clay below. <i>Exogyra texana</i> Roemer, <i>Protocardia texana</i> Conrad, <i>Lunatia pederalis</i> Roemer	10
<i>Walnut clay:</i>	
Yellow calcareous clay. At the bottom a clay conglomerate with matrix of yellow clay and pebbles and small boulders of limestone and sandstone similar to the upper Basement sands from which they may have been derived. The limestone pebbles may be fragments of older limes or chemically composed in place. <i>Exogyra texana</i> Roemer in great abundance; also contains <i>Protocardia texana</i> Conrad and <i>Lunatia pederalis</i> Roemer in considerable numbers.	12
<i>Basement sands:</i>	
Key horizon, top 4 feet of Basement sands, upper 4 inches very fossiliferous. <i>Exogyra texana</i> Roemer and other undeterminable species	4
Yellow calcareous sand. Base slightly clayey increasing in calcareous matter upward. Cross-bedding less evident. Lateral and vertical variation as in No. 2. No fossils.	7
Cross-bedded sands, prevailing light gray in color, weathering darker at surface, grading laterally and vertically into pink, purple, pale blue and vermilion sands. Probably the equivalent of the Basement glass sand in the Santa Anna Mountain in Coleman County, Texas. No fossils. . . .	23
Probably Basement sands concealed by red alluvium from river level to base of No. 2. No fossils.	21

SECTION NO. 7

Seven Mile Point Section

seven miles north of the Ozona-Sheffield highway bridge on the east bank of the Pecos River.

	Feet
<i>Edwards limestone:</i>	
Third Division—Eroded surface. <i>Requienia</i> sp.	76
Second Division— <i>Requienia</i> sp., <i>Pecten</i> sp.	98
First Division—Slightly softer. <i>Protocardia texana</i> Conrad, <i>Lima</i> sp., <i>Tapes</i> sp., <i>Pecten irregularis</i> Boese, <i>Exogyra texana</i> Roemer, <i>Requienia</i> sp.	140

	Feet
<i>Comanche Peak:</i>	
Nodular limestone, <i>Exogyra texana</i> Roemer.....	10
<i>Walnut clay:</i>	
Yellow clay. <i>Exogyra texana</i> Roemer, <i>Protocardia texana</i> Conrad	12
<i>Basement sands:</i>	
Key horizon, species not determined.....	4
Alluvium and sandstone, unfossiliferous.....	30

SECTION NO. 8

The Crossing Section

in Pecos County, on the west bank of the Pecos River, 1½ miles south of the 102nd west longitude crossing.

	Feet
<i>Edwards limestone:</i>	
Limestone. No distinction of division possible. About 175 feet above the base, the limestone becomes argillaceous, locally approximating the Yellow Peak horizon, and containing <i>Gryphaea navia</i> Hall, <i>Gryphaea Marcouii</i> Hill and Vaughan. <i>Exogyra texana</i> Roemer, <i>Pecten subalpina</i> Boese, <i>Lima wacoensis</i> Roemer, <i>Turritella</i> sp., <i>Cyprimeria texana</i> (Roemer), <i>Enallaster texanus</i> Roemer, <i>Homomya</i> sp., <i>Ichthyosarcodites</i> sp. locally in great abundance at the top of the section.....	334
<i>Walnut clay and Comanche Peak:</i>	
Yellow clay grading upward into the nodular clayey limestone. <i>Exogyra texana</i> Roemer.....	8
<i>Basement sands:</i>	
Key horizon, fossils not determined.....	3
Sandstone, top 50 feet, vari-colored, mostly lighter shades glass, some fissures and cross-bedded. Covered with alluvium at base and in places. No fossils.....	204

SECTION NO. 9

Round Point Section

on the west bank of the Pecos River four miles above the 102nd west longitude crossing.

	Feet
<i>Edwards limestone:</i>	
Limestone. Settling due to saline solution, places underlying strata beneath water level. No fossils observed.....	32

SECTION NO. 10

White Point Section

two miles above Round Point and the last prominence in Pecos County

near the river on the west side. The Basement sands, in weathering, have given the hill a distinctive white coloring.

	Feet
<i>Edwards limestone:</i>	
Limestone. <i>Requienia</i> sp., <i>Cyprimeria texana</i> (Roemer) <i>Enalaster texanus</i> Roemer, <i>Lima wacoensis</i> Roemer.....	164
<i>Walnut clay and Comanche Peak:</i>	
Yellow clay and nodular limestone. <i>Exogyra texana</i> (Roemer)	4
<i>Basement sand:</i>	
Key horizon, very fossiliferous. Fossils undeterminable.....	2
Sandstone at base covered with alluvium from water level to 30 feet; variegated sandstone, lighter in color, to 78 feet. Equivalent of glass sand at Santa Anna Mountain, Coleman County, Texas.....	78

SECTION NO. 11

(See W plus 1 on plate 2)

at the east bank of the Pecos River, $2\frac{1}{4}$ miles above White Point. Feet

<i>Edwards limestone:</i>	
Limestone	42
<i>Walnut clay and Comanche Peak:</i>	
Yellow clay and nodular limestone. <i>Exogyra texana</i> Roemer	
Protocardia texana Conrad, Lunatia pedernalis Roemer..	4
<i>Basement sands:</i>	
Key horizon, fossils undetermined.....	2
Alluvium and sandstone, no fossils.....	28

SECTION NO. 12

(See W plus 2 on plate 2)

$4\frac{1}{2}$ miles above White Point on the east bank of the Pecos River. Feet

<i>Walnut clay and Comanche Peak:</i>	
Clays and eroded surface of nodular limestone. <i>Exogyra Texana</i> Roemer	2
<i>Basement sands:</i>	
Key horizon, oyster species not determined.....	2
Alluvium and sandstone, no fossils.....	24

SECTION NO. 13

(See W plus 3 on plate 2)

eight miles above White Point, on the east bank of the Pecos River. Feet

<i>Walnut clay and Comanche Peak:</i>	
Yellow clay and eroded surface limestone. <i>Exogyra texana</i> Roemer, <i>Protocardia texana</i> Conrad.....	2

	Feet
<i>Basement sands:</i>	
Key horizon. Fossils undetermined.....	2
Alluvium and sandstone, no fossils.....	30

SECTION NO. 14

(See W plus 4 on plate 2)

twelve miles above White Point at a small hill at the water's edge, on the east bank of the Pecos River.

	Feet
<i>Edwards limestone:</i>	
Limestone, unfossiliferous	8
<i>Walnut clay and Comanche Peak:</i>	
Yellow clay and eroded surface of limestone. <i>Exogyra texana</i>	
Roemer in abundance	3
<i>Basement sands:</i>	
Key horizon, fossils not determined.....	2
Alluvium and sandstone, no fossils.....	25

SECTION NO. 15

Diamond Y Draw Section

at the mouth of the Diamond Y draw, on the east side of the Pecos River.

	Feet
<i>Edwards limestone:</i>	
Limestone. <i>Requienia</i> sp., <i>Lima wacoensis</i> Roemer.....	33
<i>Walnut clay and Comanche Peak:</i>	
Yellow clay, thin layer of hard limestone. Yellow clay contains	
<i>Exogyra texana</i> Roemer. Layer of limestone unfossiliferous	3
<i>Basement sands:</i>	
Key horizon. Fossils not determined.....	2
Alluvium and sandstone, unfossiliferous.....	24

SECTION NO. 16

Girvin Highway Bridge Section

on the west side of the Pecos River, at the Girvin steel highway bridge.

<i>Edwards limestone:</i>	Feet
Limestone. <i>Requienia</i> sp., <i>Pecten subalpina</i> , Boese, <i>Pecten</i> sp.	80
<i>Walnut clay, Comanche Peak, Basement sands:</i>	
Alluvium covering sandstone at base and clay and lime at top.	
No fossils	16

SECTION NO. 17

Red Point Section¹

taken at Red Point 4 miles north of west from Castle Gap, Upton

County. The point is 18 miles north of Girvin and 9 miles northeast of the Pecos River.

Feet

Edwards limestone:

Limestone. *Lima wacoensis* Roemer, *Lima* sp., *Pecten subalpina*, *Homomya* sp..... 36

Walnut clay and Comanche Peak:

Yellow clay and nodular limestone. *Exogyra texana* Roemer, *Cyprimeria texana* (Roemer)..... 4

North of section 16 the red silt alluvium from the river conceals all outcrops at river banks, making further sections impossible. Vertical sections of the Triassic are not given, as the thickness of the formation could not be determined and the distance below the Comanchean could not be measured.

Red Point being farther removed from the river has not been affected by the slumping and the position of the strata in this section shows the position of the same formations along the river northwest of section 16 before the slumping occurred.

Feet

Basement sands:

Key horizon, very fossiliferous. No fossils below key horizon.
 Vari-colored sand, white, gray, brown, drab, purple, vermillion, blue, extremely variegated, some cross-bedding. The glass sand horizon and the equivalent of the top 50 ft. of sand at the crossing section..... 42
 Conglomerate of igneous pebbles and sandy matrix..... 2
 Heavily bedded sandstone, cross-bedded in places, some igneous pebbles, gray, brown..... 116
 Igneous pebbles with sand and siliceous cement..... 2
 Sandstone varying extremely from thin evenly bedded layers to massive cross-bedded ledges, moderately hard, color grayish-brown weathering red, some mica flakes..... 142
 Grayish-brown cross-bedded sandstone, weathering deep red, containing innumerable pebbles and considerable mica..... 10
 Conglomerate of igneous pebbles cemented into siliceous sandstone, light brown and gray in color..... 2
 Red alluvium and brown sandstone weathering to a deep red, contains mica flakes and scattered igneous pebbles..... 18

SALINE SOLUTION

Beginning at Round Point section, (Pl. 2) three and a half miles up the river from 102nd west meridian crossing and extending five miles beyond the highway bridge over the Pecos at Girvin, at which point the Quaternary alluvium renders explo-

ration in the immediate vicinity of the river impossible, there is slumping of various sizes and degrees, from some scarcely noticeable to a maximum of some fifty square miles just north

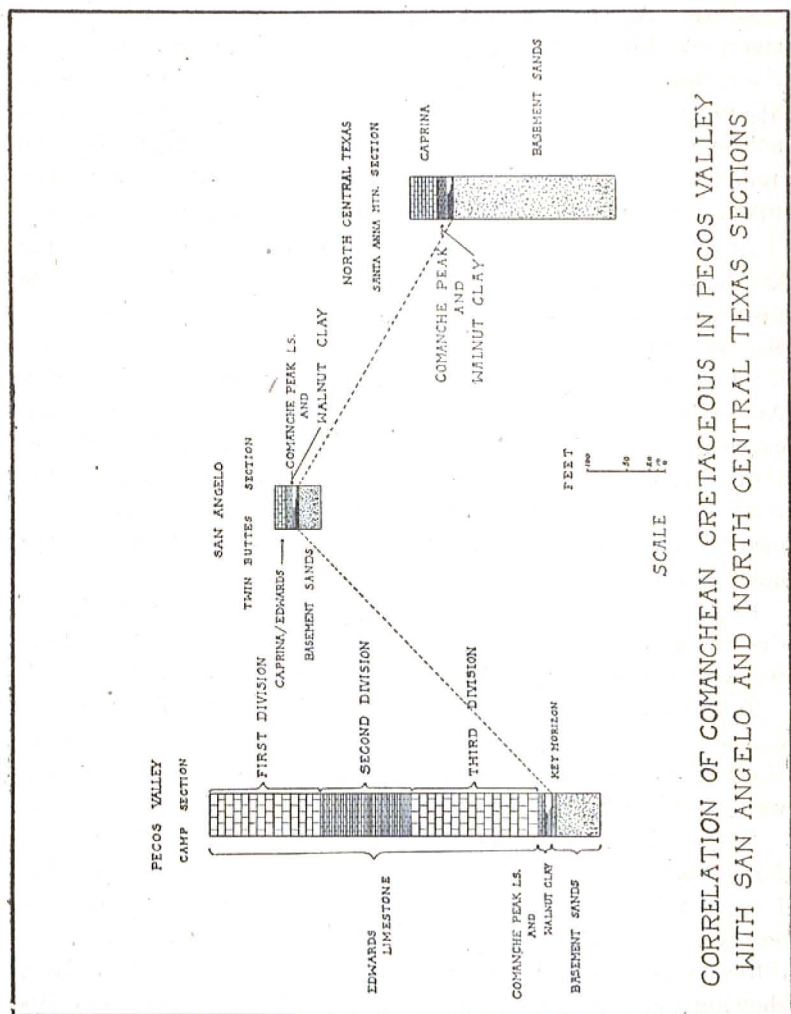


Fig. 2.

of the steel highway bridge. In fact, there is no place immediately on the river above the 102nd W. longitude crossing where the strata are in place. At the Crossing section, the top of the key horizon, the upper fossiliferous four inches of a hard brown

sandstone two feet thick at the top of the Basement sands and immediately below the Walnut clay, is 210 feet above the river. This elevation increases normally to the 102nd West meridian crossing. At the next station, three and a half miles up the river, the Edwards limestone extends below the surface of the river, thus indicating a vertical displacement of over 250 feet in $3\frac{1}{2}$ miles. How far below the river level the key horizon lies cannot be determined, but it probably lies at no great depth, for at a hundred yards distance it is some twenty feet above water. The strata here are also slightly inclined toward the northwest.

At White Point, a little over a mile above Round Point, the key horizon is 100 feet above the river and in less than a mile upstream the top of the Basement sands is found 30 feet above the river and remains at about this distance above the water to the Kansas City, Mexico and Orient Railroad crossing at Girvin. At the steel highway bridge over the Pecos at Girvin, alluvium conceals the Walnut clay-Basement sands contact, but 15 feet above the river the Edwards lies nearly horizontal, and in the river bed at the southwest pier of the bridge the sands are exposed. Thus somewhere between these two elevations lies the key horizon.

Five miles east of Girvin in the escarpments on either side of the highway and railroad, the strata are in place and continue so, to and beyond Rankin, as far as observed in Upton County.

To the west of Girvin on the south side of the railroad, about two miles from the town, the strata are again in place and continue as far as the investigation was carried to the southwest, west, and north of Fort Stockton.

During its history the Pecos has meandered sufficiently to form the present river valley. The river itself is responsible for the erosion of the entire river valley here as no streams empty into it near the area, and also as pot-holes are found at different elevations in the walls of the bluffs facing the river, showing that the river at some of its stages occupied these different positions.

Farther down the stream where the base of the Edwards dips under the water, the river valley narrows to a steep-walled canyon, as the limestones afford less opportunity for lateral migration than the Basement sands. To the northwest of Girvin,

the valley again broadens in proportion to the amount of sand exposed.

The meandering of the river over this great area, thus producing the equivalent of an intermittent lake and standing water, is responsible for the gigantic slumping west of the 102nd meridian. The erosion of the Basement sands underlying the Edwards limestone and causing it to be depressed is responsible only for the minor slumping, and that, too, along the edge of the present river course. Slumping of this nature can be identified from the other in that the latter occurs only in numerous short distance slumps and the strata are never horizontal; while the former extend over vast areas occupying the entire valley and the strata are usually horizontal or practically so. In numerous instances there is a combination of both forms.

In well logs outside the limit of that portion of the river valley which at some time has been the channel of the river itself, there are recorded strata of almost pure rock salt interbedded with red Permian clays. The highest of these beds, some one hundred to one hundred and fifty feet thick, lies about four hundred feet below the present river level. Above it are only a few layers of Permian clays and limestone overlaid by the porous Triassic and Basement sands. Lying at such a short distance below the surface of the river valley, and with very little impervious covering, the water from the river, at the various horizontal and vertical positions which it has assumed during its history, has had little difficulty in penetrating in considerable quantities to a sufficient depth to dissolve at least the greater part of the upper stratum of salt.

The present position of the strata over this area was not reached at once, but by a gradual settling as the salt was taken into solution. Such a process would keep the strata practically horizontal at all times, and upon the complete solution of a part or the whole of the salt layer, the overlying strata would come to a position about one hundred and fifty feet lower than was formerly occupied, as is now the case. As far as known, no other salt layers lie close beneath. This thickness probably represents the amount of vertical displacement which has taken place. Along the present river course where the slumping has occurred, the Basement sands are practically all present except for a few feet which

have been undercut; and this would not be the case if they were accountable for the great settling.

Conditions similar to this are known to exist in the salines of the Gulf Coastal Plains. Harris, Veatch, Udden, Deussen, Dumble, and others in various publications on the salines of Louisiana and Texas have discussed the theory and process.

Underground waters have carried away in solution great amounts of salt from the top of the salines, causing a slump in the overlying strata. Later this has become filled with water, forming the lakes and ponds characteristic of the salt dome country.

The strata overlying the salt in the Pecos Valley are even more pervious than those covering the masses of salt in the Gulf Coast region, and both surface and underground waters would have greater access to the salt stratum.

Ten miles above the 102nd West longitude crossing and one mile southwest of the present river channel is a sink hole at the edge of the escarpment. The west side of the hole is cut vertically down in the edge of the bluff for 135 feet; the east wall, being on the river plain, is only 20 feet high. The diameter of this circular hole is 150 feet.

Only a few feet away from the sink are a number of potholes, showing that the river was once at this position, and undoubtedly it has been the greatest factor in forming the hole. The Edwards limestone which is exposed above and in the walls of the sink is very argillaceous, and therefore would not go into solution readily; and it would also tend to fill the pores in the sand below and render it impervious. It is highly improbable that this great hole was eroded by the river, or the material from the hole transported underground either mechanically or in solution. The more probable theory is the solution of a great thickness of underlying Permian salt, thus permitting a sinking of the overlying bed. Wash has so filled the bottom of the pit that it is impossible to determine if this is the case.

To the north, northeast, and northwest of Fort Stockton, as far as the Edwards limestone is visible, about twenty miles, a careful examination of the strata showed them to be in place and to have the slight southeast dip of the normal Comanchean. As the strata over this area are in place and show no evidence of fold-

ing, it is impossible that any movement from the Glass Mountain region or the Davis and Barilla Mountains could have influenced this displacement.

Since there is no sign of block faulting and much evidence of slumping from solution, it is quite evident that a dissolving of the underlying Permian salt has caused a settling on this gigantic scale. Unfortunately no wells in this area are of sufficient depth to record the presence or absence of the salt.

Seven Mile Mesa, near the southwestern extremity of the last main Cretaceous escarpment which forms the northern boundary of the Trans-Pecos Plains portion of the Edwards Plateau, is placed in the Edwards instead of the Georgetown, to which it has previously been referred¹. A paleontologic examination of this mesa would at first give the impression that the formation is Georgetown, but a more detailed study of the Comanchean fauna has shown that the fossils have a greater vertical range than was anticipated. Fossils considered characteristic of the Georgetown strata in this region, such as *Terebratula wacoensis* Roem., *Lima wacoensis* Roem., *Pholodomya texana* Con., *Gryphaea pitcheri* Mort., *Vola (Janeria) wrightii* Shum., have been found throughout the Edwards also.

Shumard too, in his Journal of Geological Observations² has identified *Terebratula wacoensis* Roem., *Lima wacoensis* Roem., and *Gryphaea pitcheri* Mort. in undoubted Edwards limestone along the Pecos in the vicinity of Sheffield. Stratigraphically the top of Seven Mile Mesa has been traced east and southeast where it forms the cap of the Edwards Plateau, which is the top of the third division of the Edwards. However, in the present survey, a number of Georgetown fossils were identified from the upper part of Seven Mile Mesa, associated with fossils which evidently are of Edwards age. The establishment of the boundary between the Edwards and Georgetown divisions can only come through a thorough and detailed study of both the paleontologic and lithologic characters of each. A careful comparison of the section at Seven Mile Mesa, and the area to the

¹Geologic Exploration of the Southeastern Front Range of Trans-Pecos Texas. C. L. Baker, W. F. Bowman, Univ. Tex. Bull. 1733, p. 115.

²A Partial Report of the Geology of Western Texas, by G. G. Shumard, Austin, 1886.

south, with the original sections, would not be without benefit. Horizontal sections from areas where the demarcation between the two formations is known, if possible parallel to the shore line at the time these strata were deposited, would give the least amount of lateral variation, and perhaps simplify the problem materially.

The general section at Seven Mile Mesa afforded the species listed below:

Cyprimeria texana (Roemer)
Epiaster cf. *aguilerae*? Boese
Lunatia pedernalis Roemer
Enallaster cf. *mexicanus* Cotteau
Hemiaster sp.
Pyrina sp.
Holeyctypus sp.
Pecten cf. *occidentalis* (Conrad)
Nerinea sp.
Turritella sp.
Pleurotomaria cf. *Austinensis* Shumard
Gryphaea navia Hall
Gryphaea marcoui Hill and Vaughan
Gryphaea sp.
Schloenbachia belknapi (Marcou)
Exogyra texana Roemer
Schloenbachia sp.
Protocardia texana Conrad
Codiopsis sp. aff. *texana* Whitney
Pyrina sp. aff. *inaudita* Boese
Lima sp.
Lima wacoensis Roemer
Pecten subalpina Boese
Pecten texanus Roemer

SHEFFIELD TERRACE

In the Pecos Valley, Comanchean and post-Comanchean movements have only to a slight extent influenced the structural features of the area. The greater part of this disturbance probably occurred at about the time the Rocky Mountains were first uplifted, during late Cretaceous or early Tertiary time. Then the sediments of the entire valley were tilted toward the southeast to their present position, and any deviation from the normal southeast dip also probably occurred.

As the accompanying sections (Plate 2) indicate, there is a slight flattening in the dip of the surface formations near Sheffield, between Seven Mile Point and Nine Mile Point. At the 102nd west longitude crossing the strata increase above the normal in rate of dip toward the southeast until they reach Seven Mile Point; thence to Nine Mile Point they lie practically horizontal. Below Nine Mile Point for about four miles the dip again increases above the normal till below Fourteen Mile Point, when again it reverts to the normal dip as found west of the 102nd west longitude crossing.

The longer axis of this terrace extends northeast and southwest, showing that the diastrophic movements were from the southeast toward the northwest. Had the forces acted from the southwest, the longer axis would have been at right angles, thus placing it northwest and southeast. Pressure exerted from the northwest would have placed the longer axis of the terrace in its present position, but all deviations in dip would have been in excess of the normal, and this is not the case. The shorter axis of the terrace is about eleven miles long and lies northwest and southeast between Seven and Nine Mile points. The longer axis, at right angles to the former, extends at least for some fifteen miles to the east of the river and passes immediately northwest of the northwestern half of Block 29 of the Sheffield tract of University land, as observations on this tract have shown. Its extent into Pecos County on the west has not been traced as far as is possible, though it has been observed to continue for six miles.

Plate 3 shows the location of the Sheffield terrace and the bearing of its axes.

STRUCTURAL FEATURES OF THE PECOS VALLEY IN THEIR RELATION TO PETROLEUM ACCUMULATION

The economic significance of surface structure in the Pecos Valley to a great extent lies in the relationship existing between surface and subsurface formations.

In that portion of the Pecos Valley covered by the Permian Red Beds, Upper Triassic, and Comanchean, there is little value in surface structure as a concentrator and container of indigenous petroleum, since in the Comanchean and underlying Upper

Triassic there are no petroliferous horizons. Below the Upper Triassic, Baker records an unconformity,¹ but this probably does not modify to any great extent, in the lower horizons, any structure present in the overlying strata.

How great an unconformity there may be between the Permian Red Beds of the Pecos Valley and the overlying Triassic is not known, but in the Llano Estacado region, Baker finds that there is no great amount of angular unconformity between these two systems, and this is probably true in the Pecos Valley, as the geologic history of both areas has undoubtedly been very similar.

This being true, the period through which the Permian Red Beds were subject to erosion and the amount of material which was carried away from their exposed surfaces has no effect upon their structural value except as it influences the depth at which lower horizons are placed.

If Professor Baker's observations in the Llano Estacado region also hold in the Pecos Valley, as there is every reason to believe that they do, surface structure in the latter will remain practically the same through the Permian Red Beds to the Tessey formation which is the uppermost of the Permo-carboniferous formations, and is believed to underlie the Permian Red Beds of the Pecos Valley.

Although unconformities exist above the Tessey formation and some undoubtedly record great breaks in sedimentation and extensive erosion, they do not show any angular unconformities which would either increase or decrease the value of surface structure.

Below the Upper Triassic, which is the lowest horizon exposed in the Pecos Valley included in the present survey, and the Tessey formation, there are even less possibilities of petroliferous strata than in the Upper Triassic or Comanchean. The occurrence of thick cross-bedded, vari-colored sandstones, conglomerates, red, yellow and purple arenaceous clays, gypsum, and massive layers of rock salt, is indicative of subaerial conditions and deposition mainly by rivers, which are very unfavorable for the formation of oil and gas, as such a complete oxidation of organic

¹Review of the Geology of Texas. Bull. Univ. Texas No. 44, 1916.

matter would ensue as to cause its complete dissemination and consequent escape.

As surface structure in the Pecos Valley continues with little increase or decrease to the upper Permo-carboniferous strata, and since the underlying beds are steeply inclined, a structure at the surface would concentrate any hydrocarbons migrating along the inclined strata within the limits of the folding. There are no surface disturbances in the Pecos Valley which are sufficiently great to have any noticeable effect upon underlying strata that are not angularly conformable with those above or nearly so. Again, since there are relatively small exposures of the lower Permo-carboniferous and upper Pennsylvanian strata in the Glass Mountain region where it is possible to study them, and also as these places are so near the center of igneous activity, they afford little opportunity for determining the exact nature and position of the strata. It is impossible to say what relation the lower beds bear to the upper Permo-carboniferous and overlying strata at any distance from the outcrop. The amount of their disturbance undoubtedly decreases as the distance from the Marathon region increases, if that disturbance was entirely accountable for their folding, which Dr. Udden has found to be intense and extended over a considerable area. In the older formations the disturbance is much greater and decreases upward till at the surface the Triassic and Comanchean show practically none.

If more were known concerning the attitude and relationship of the lower layers to each other, the structural geology of the Pecos Valley would be much simplified. There are, however, a few general conditions revealed in the development of the somewhat similar geologic field of north-central Texas which are undoubtedly applicable in the Pecos Valley. There an angular unconformity of unknown magnitude separates the lower anthracitic series from the upper, so that there, as here, it is impossible to determine from surface structures the nature and attitude of the strata below the unconformity. A folding in the strata at the surface in both fields only indicates movement later than the deposition of the youngest beds which are affected. Of what value it has been in forming favorable structure below depends upon the amount of angular unconformity between the

different formations. In north Texas, it is only necessary to allow for one angular unconformity, but in the Pecos Valley there are several, some of which are of unknown angular size.

Though little is known of the exact relations between the Bend and Strawn formations in north Texas, the vast amount of data obtained from well logs indicates a large plunging anticline extending northward from the Central Mineral Region, which is a large igneous intrusion and which has folded the younger formations in a manner similar to the Marathon region. Along the axis of this fold are located numerous small inclined terraces and plunging arrested anticlines whose presence is due to the last slight movements in the region. These have taken place along the axis of the fold which, as it has been subjected to the most severe bending, has weakened and become the line of least resistance.

In the Pecos Valley, though it is geologically more complicated and more steeply folded in the lower formations, similar conditions exist. From the Marathon Mountain region there extend one or more folds whose lower formations are much disturbed and this disturbance relatively decreases toward the surface till, in the Triassic or Comanchean, the course of the extreme folding beneath is merely indicated by a slight terracing or flattening of the dip due to a line of weakness being formed in the direction of the excess folding in underlying strata before later deposition. These terraces may have been formed previous to or subsequent to the tilting of the formations of the Pecos Valley to the southeast, but it is more probable that they occurred contemporaneously with it.

As in the north Texas field, nothing can be definitely stated concerning the exact attitude of the strata below the uppermost angular unconformity, without a great amount of data from well logs which at present are not available. Prospective testing of the Pecos Valley for petroleum should at first be confined to the surface structures, however slight they may be, for they may either form the impervious covering for hydrocarbons which have migrated upward along the lower inclined strata, if the beds are sufficiently inclined to permit escape to the upper beds through faults or the eroded edges of petroliferous strata; or

they may merely be indicative of the direction of extensive folding beneath.

Dr. Udden has traced one fold—the general direction of the Marathon Mountains—to a point near the Purington Ranch. Its trend is from N 40° E to N 60° E, and it undoubtedly extends for a considerable distance to the northeast under the overlying Permian Red Beds, Triassic, and Comanchean. He states that the trend of the mountains would run through the southeast part of Pecos County into Upton and Reagan counties, or even farther east than this.¹ Such has been found to be the case. The flattening of the dip in the vicinity of Sheffield, between Seven and Nine Mile Points on the Pecos River, and a proportionate steepening on either side of the flattened area form a terrace which indicates the position and course of the fold to which Dr. Udden refers. In accord with his observations taken in the Glass Mountains region, where it is possible to measure the direction of the fold in the Pennsylvanian strata themselves, the trend of the axis lies between N 40° E, and N 60° E. This is confirmed by position of the terrace and the bearing of its axes.

Careful examinations of the region to the southwest between the terrace and the Glass Mountains will undoubtedly reveal surface structures increasing in degree and magnitude toward the southwest. The direction of the fold is indicated by the slight disturbances or surface structures in the Comanchean which have been noted. Other surface foldings along the axes undoubtedly exist outside the area included in the present survey and their determination will more definitely fix the exact trend of the Pennsylvanian fold.

With the present subsurface data it is impossible to throw much light upon the thickness of formations below the surface in the Pecos Valley. The unconformities which Dr. Udden mentions in the Glass Mountains region probably continue to the northeast for a considerable distance, but how much of the geological hiatus and erosion of the strata they represent is not known. Again, the greatest amount of erosion as well as of folding will have taken place along the axis of the Pennsylvanian fold, so

¹University of Texas Bulletin 1753, pp. 56-58.

that along this axis formations may be reached at a shallower depth than elsewhere.

A few accurate well logs will assist materially in determining what may be expected structurally below the surface and will reveal the depth and value of petroliferous horizons, if present.

Nothing can be stated now except in a very general way. The most desirable areas, only, can be indicated. If there are petroliferous horizons of commercial value in the Pecos Valley, it will be along this fold that they can be reached at the shallowest depth and in this area that they will be most productive.

Since in the lower formations the Pennsylvanian fold is undoubtedly irregular, all places along the axis will not have the same value for prospective drilling. The development of the Sheffield Terrace is the most logical area in which to begin the testing of the Marathon fold, as the surface formations at that place indicate a folding upward in the lower strata. Along the axis of the fold there probably exist areas of depression, or relative synclines, which will not in all probability be productive. These areas in general will be found between the more pronounced surface disturbances. The Sheffield Terrace is so distant from the Marathon igneous activity that the Pennsylvanian formations in the Marathon fold underlying it were not broken by the folding to which they were subjected.

As data from drillings increase, a subsurface map can be constructed and quite definite information given regarding the location of tests. The value of keeping accurate well logs, with samples of formations penetrated, cannot be over-emphasized, as, from the information thus afforded, the unpromising areas can be eliminated and a complete test of the area be made at a minimum outlay of time and expense.

The accompanying areal geological map of the Pecos Valley shows the location and trend of this fold. In locating tests, either this or similar folds should be studied and locations made accordingly.

ECONOMIC NOTES

ROADS

The amount of material hauled, and the distance to a railroad from the greater part of Crockett County, warrant the construction and maintenance of good roads. To some extent the lack of improved roads throughout the county is compensated by the Government Military Highway from San Antonio to El Paso, which enters the county at the northeastern corner, runs south thirty-two miles to Ozona, about the center of the county, and thence westward forty miles to the western boundary of the county. In addition, there are two other improved roads—the road east from Ozona to Sonora in Sutton County, and the road south from Ozona to Comstock in Val Verde County.

Over these routes the majority of the material is transported and practically all travel takes place. From these highways other roads lead to various parts of the county. With the exception of a few places, which could be readily repaired, the main routes are passable at all times.

The location of these highways, in general, is very good. The topography of the country makes it possible to lay out the roads over the shortest distances and at the same time to locate them on relatively elevated, but not high or rough, ground. Over practically their entire length these roads are eighteen feet wide, smooth and with sufficient crown, grade and ditching for drainage. The few places which render the roads impassable after heavy rains are where intermittent streams cross the roads. These could easily be remedied by placing concrete bottoms in those crossings where there is not too much water to make them fordable; and culverts of sufficient size to conduct the water in others. With a very little expenditure, these roads could be made permanently passable.

The remaining roads in Crockett County seem never to have been definitely and properly located. The number of locations which the road has had is evidenced by the old road beds. Whenever a road becomes impassable from wearing down to a ledge, or where there is a broken culvert, or a soft place, or some

other obstacle, a new road is made around the impediment and the former track abandoned. The solution of such a problem can only come, first, through a survey and definite and correct location of the roads themselves, thus prohibiting the establishing of new ones; and second, the repairing of all breaks or bad spots, thus keeping the surveyed roads passable at all times.

The condition of the roads in the county, in consideration of the lack of provision for maintenance, is sufficient evidence that the material at hand is adequate for construction and repair wherever needed.

The most economic roads that can be built in the county are gravel and dirt roads, as the soil over which the roads pass is a sufficient binding material to hold the gravel in place under traffic. In practically all places the soil alone is of such mixture that when graded into the road bed it will pack sufficiently to remain in place and be resistant enough to withstand wear. Thus over the greater part of the county all that is needed to improve the roads is a proper location of the road bed itself, and then a grading of the material in place, from the sides to the center, forming a sufficient crown to shed water from the road bed and adequate grade and ditches along the sides of the road to carry the water along and away from the road bed.

In passing over a ledge of rock it may be necessary to blast the obstacle and grade more extensively. In crossing a marshy place it will be necessary to sub-grade. In this case, the road bed is finished roughly at a lower elevation than the proposed bed, and brought to the required elevation by filling with gravel and other material. The size of material and amount necessary will depend upon the nature of the marsh to be crossed. In all cases the roads should be compacted by rolling or ~~travel~~ before being opened. Also in putting in a sub-grade each layer should be rolled before the next is added. Culverts and concrete bottoms should be put in so that it will be possible to cross intermittent streams at all times when the remainder of the road is passable. If a more permanent but expensive road is desired, the Edwards limestone can be broken and a macadam road constructed.

GRAVEL

The gravels of Crockett County for the most part are a product of the Edwards limestone and the deposits of commercial value are confined to the stream and river beds.

In the valley of the Pecos, the gravel which has the properties necessary for concrete or road material is in the stream bed itself where it is washed clean of impurities. When deposited in the form of gravel beds or pits in former courses of the river, it is intermingled with clay, fine sand, and silt. The Pecos River carries such an amount of fine sediment from Permian, Triassic, and lowest Comanchean beds that the gravel with which it is deposited is rendered unfit for practically any use.

There are no worked gravel pits along the river in Crockett County and at no place was there observed a deposit of sufficient size to warrant the opening of a pit. Gravel sufficient for the slight local demand can be obtained from the river bed, where accessible.

In and adjacent to the stream beds, along the courses of Live Oak Creek and Howard's Draw, there is an abundance of gravel in assorted sizes from small boulders to fine gravel. As there is no flowing stream in the county except Live Oak Creek, and no intermittent stream of noticeable size except Howard's Draw, the deposits of gravel are naturally confined to these limits. Since at no place along their courses have these streams cut to the base of the Edwards limestone, and as there is but a small amount of soil covering the Edwards limestone, the gravel deposited by these streams is an assortment of boulders and pebbles with practically no impurities. This is especially true of Live Oak Creek, as deposition is going on continually, rather than intermittently in times of high water when there is a greater amount of impurities transported.

There has been practically no gravel used in the building or maintenance of the roads of Crockett County, and therefore little need of opening a pit. Gravel for concrete and for occasional repairing of the roads can be obtained in practically any amount along the course of the two streams mentioned. A few smaller intermittent streams or draws nearer places of use have supplied the demand. There is an adequate amount of

gravel of fairly good quality from sedimentary rocks, widely distributed over Crockett County, to supply any demand in the county.

WATER SUPPLY

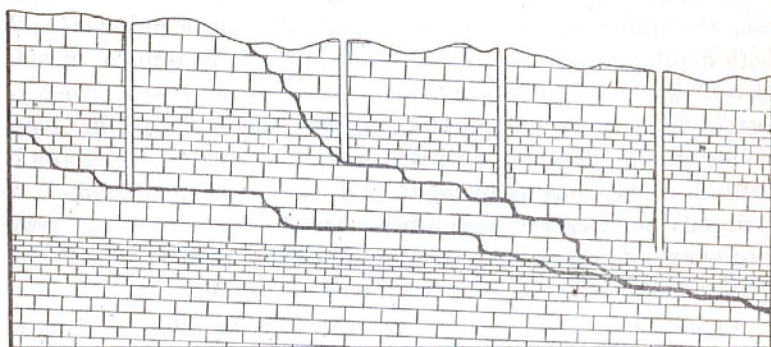
The economic importance of a permanent and adequate water supply in a county whose chief industry is stock-raising can hardly be overestimated. Water supply in Crockett County is dependent upon (1) surface and (2) underground water. Surface water, or "run-off," is that portion of rainfall which passes directly over the surface to the rivers and lakes, while underground water is that part which sinks deeper into the earth. Rainfall upon the area itself serves a twofold purpose—a stimulus for vegetation and a supply of drinking water for stock; but as there is not enough rainfall in Crockett County to produce more than exceedingly intermittent streams, practically its only value as a supply for stock lies in the possibility of its being conserved in artificial tanks. Periods of extreme drought make necessary a more permanent and uniform supply, and this is obtained from the underground source.

In portions of the county some of the underground water is recovered through flowing springs. The most important example is Live Oak Creek, a permanent stream of excellent water fed from springs in the Edwards limestone. The greater part of the permanent supply, however, is obtained from wells by windmills. As this is the chief supply and considerable drilling is necessary, knowledge of the geology of the county has an increased value.

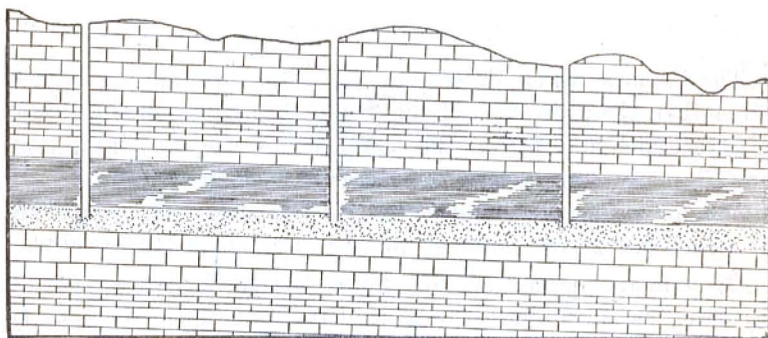
Practically the whole of the data available relates to the depths of some of the wells drilled, and their production. From this evidence it is possible to conclude that with the exception of the immediate valley of the Pecos River, all water wells in Crockett County derive their supply from the Edwards limestone. In the northern Pecos Valley, however, a few wells are supplied from the Basement sands.

As is to be expected, there is no uniformity in depth or production of wells in the Edwards limestone. The Edwards limestone is practically impervious, and surface water must work downward along the joints and fissures which become enlarged by the solvent action of the water. Coming to a more argillaceous and

insoluble layer, the course of the water is directed laterally along bedding planes till a joint or fissure is reached whereby descent



NO DEFINITE AND UNIFORM WATER BEARING HORIZON. CHANNELS DISSOLVED
ALONG JOINT AND BEDDING PLANES FURNISH PRACTICALLY THE ENTIRE SUPPLY.



DEFINITE AND UNIFORM WATER BEARING HORIZON. DEPTH AND AVAILABLE
SUPPLY CAN BE ESTIMATED.



LIMESTONE



SANDSTONE



SHALE

Fig. 3. Diagrams showing conditions encountered in obtaining water from the Edwards Limestone.

through the more impervious layer is afforded. Thus there are no definite and uniform water-bearing horizons, and no uniformity in production of wells, as is the case where a definite water sand can be relied upon.

Plate 7, the diagrams, contrasts the two general conditions. In the lower diagram a definite water-bearing horizon can be depended upon and the depth at which the water will be found can be computed from the depth at a known point, the dip of the horizon, and the difference in the surface elevations. In such a case the water-bearing horizon is generally quite uniform, and both depth and amount of available water can be quite accurately estimated. In the upper diagram the reverse is true. No persistent water horizon is present and the irregularity of the channeling in size, depth, and direction makes it impossible to reach definite conclusions as to depth and amount of production. A well only one location from a producer of certain rate may vary to any extent from a large well to a dry hole. Wells drilled in the Edwards limestone in Crockett County encounter this situation.

As jointing and bedding in the Edwards limestone follow no regular system, little geological assistance can be rendered. In case of a small well or dry hole, shooting may materially increase the production, as cracks and fissures can be established which may reach to the water-bearing channels.

BUILDING-STONES

The factors which determine the value of building stones, other than the properties of the stones themselves, are: the cost of procuring and fitting the material for use, transportation, and, in more recent years, the change of fashion of using certain stones for constructive and decorative purposes. The properties of stones themselves, however, to a great extent fix their value.

Of primary importance in stones desired for masonry construction is durability, which is dependent upon strength to compressive and transverse forces; hardness, texture, chemical content and color. For buildings and for decorative purposes, color assumes a great importance.

In Crockett County the Edwards limestone furnishes the entire supply of building stone. The Basement sands are generally too soft and variable to be of any use, and moreover, their surface distribution is confined to the immediate valley of the Pecos River. In some places ledges from two to fifteen feet thick are extremely hard and could be used for construction, but they are

of no value in comparison with the Edwards limestone, which has a surface distribution over the entire county and is practicable for nearly all purposes.

The durability of the Edwards limestone, both dressed and rough, is attested by its state of preservation in some of the oldest ranch houses in the county. Though no data on strength are available, the normal crushing strength of about 3000 lbs. per square inch is probably preserved throughout the Edwards, with the exception of the soft argillaceous, fossiliferous layers. The grains are moderately small, firmly cemented, and practically unmixed with weakening minerals. Because of its toughness the Edwards possesses sufficient transverse strength to withstand the normal transverse pressure of ordinary buildings. The hardness of the lime varies widely. In some places it is exceedingly clayey and soft, but generally the grains are so firmly cemented with lime that the rock has a sub-crystalline appearance and it is difficult to break it with a hammer. Its resistance to both mechanical and chemical weathering is above the average, while its homogeneity causes it to wear evenly. The density of texture also adds to the value of the Edwards for building purposes. Its texture is moderately fine and even, causing it to split and dress well, and its density is sufficient to lower the ratio of absorption to the surface exposed below that of the ordinary limestone.

The color of the Edwards limestone is remarkably uniform and constant, except near the surface and along joint planes, when it is stained by ferruginous or carboniferous matter. Like most other limestones it weathers lighter on exposure. This change is not particularly noticeable for it is a light gray when freshly quarried and weathers to a pale straw color. The absence of minerals other than a great amount of calcite crystals in places and local occurrences of ferruginous and carbonaceous matter in others, eliminates the streaked and blotchy appearance that some stones assume on weathering.

The chemical composition of the Edwards shows that it is not dolomitic.

The cost of quarrying building stone depends upon the accessibility of the rock and its structural features. The accessibility of the Edwards is at the maximum, for it lies practically hori-

zontal and at the surface over the entire county with the exception of the immediate Pecos Valley, and affords an unlimited supply. Its resistance to weather in situ makes it unnecessary to strip more than a few feet of the surface, and its uniformity and homogeneity eliminate the expense of quarrying waste layers to uncover good stone below. If good judgment is used in locating a quarry, practically the entire content can be used for building purposes.

Jointing and bedding planes also influence the cost of quarrying. If they are moderately regular and not too numerous they greatly facilitate extracting the stone. If too frequent the blocks will be too small to be of value and if the ledges are too thick and joints few, the expense of quarrying is much greater. In the Edwards limestone the bedding is generally from one to four or five feet thick, though sometimes it is as much as twenty to thirty feet. The jointing varies from four to eight or ten feet. There seems to be no system or regularity of either jointing or bedding.

In the Edwards limestone, Crockett County has a material of wide distribution and great accessibility, requiring a minimum expense for quarrying and transportation, and possessing properties that make it valuable for practically any building or decorative purpose. Its distribution makes it available with practically no transportation and its use both for private dwellings and public institutions shows it to be a desirable material. There is not, however, sufficient building within the county to warrant the expenditure necessary for opening and maintaining a working quarry, as there is no means of more than very local transportation of the stone. It is less expensive to open a new quarry when stone is needed than it is to haul the material any distance.

CLAYS

The clays of Crockett County are both residual and transported. *Residual* is used in the restrictive sense and applied only to the mantle covering the native rock as it has decomposed in situ. Transported clays are residual clays which have been carried from their place of origin and deposited elsewhere. The transporting agent is chiefly running water, though much wind-

blown material settles in the form of clayey deposits known as aeolian clays. Residual material, however transported, when permitted to settle and accumulate in water is called sedimentary clay.

The source of the residual clay in Crockett County is confined to the Comanchean limestone, sand, and clay. The greater part is supplied by the liberation of kaolin as the Edwards limestone decomposes. The Comanche Peak limestone and the Walnut clay supply a proportionately greater amount of clay in comparison to their mass, as there is present in them a greater amount of kaolinite and less of silica.

In the Basement sands there is very little clayey material present. Although varying considerably in composition, these sands are high in silica, low in alumina. However, in localities some of the grains are feldspathic, being chiefly orthoclase feldspar reworked from the Triassic; and these form the most typical kaolin.

The transported clays, principally the sedimentary type, originate in the Comanchean and are really residual clays which have only been carried outside of the boundary of the formation from which they are derived, or carried down by the river from the Triassic sands in the northern Pecos Valley or from the Permian clays farther to the north.

These clays originally were more pure, containing kaolin, some quartz, and a little mica, and stained red by some ferruginous minerals; but being moved together with other rock fragments have become intermingled with them and when not assorted by water at or before their present deposition are in the form of loam with various sized boulders included.

There are then, in the county, clays of igneous origin transported from the Triassic and Permian, and clays of sedimentary origin; that is, residual clays or those which have not been carried outside the limits of the Comanchean formation from which they were derived. The transported clays are more or less impure and are typical flood-plain clays, formed during the different flood periods along the lower valleys of the streams. The sedimentary clays are known as adobe and are used for building purposes in the form of sun-dried bricks. There is very little wind-blown or aeolian clay in the county.

Other than their use as adobe bricks, mentioned above, the clays of Crockett County have no commercial value.

LIME AND CALCAREOUS CEMENTS

In Crockett County the slight cultivation and wide distribution of limestone demand a very small amount of lime for fertilizers. There is, however, a sufficient quantity present in the Edwards limestone, if calcined, to supply any local demand.

The same source is also adequate to furnish practically all the ingredients for Portland and natural rock cement.

SALT

Common salt, the chloride of sodium, underlies Crockett County both as a soluble, occurring in some underground water as a natural brine, and as a solid in masses of rock salt. In either form its source is in the Upper Permian beds some 800 to 1200 feet below the surface, and the conditions under which these associated clays were deposited assists in explaining the presence of the salt.

The conditions of the deposition of the Upper Permian of the Clearfork and Double Mountain formations, which contains lenses of rock salt, have been described by Professor Baker as follows:¹

"In Clear Fork and Double Mountain time, there came on a marked change of the conditions under which the strata were deposited. This is indicated by the beds of anhydrite, gypsum, rock salt, and limestone deposited from the evaporation of the sea water and imbedded with the red clays and sands. The beds of anhydrite, gypsum, rock salt, and limestone (generally dolomitic) indicate an arid climate during the latter part of the Permian, at intervals during which the waters of the sea evaporated and thereupon deposited the various minerals which they carried in solution.

"The amount of anhydrite and gypsum in the Clear Fork formation increases as one goes westward from its area of outcrop. The same may also be said of the dolomite. This indicates that the sediments derived from the erosion of the land and deposited near the shore line of the sea gradually decrease to the westward as the Llano Estacado is approached, implying deeper and clearer waters in the latter locality.

¹Geology and Underground Waters of the Northern Llano Estacado. Univ. Texas Bull. 57, pp. 10-11. Austin, 1915.

There is also a large amount of anhydrite and gypsum in the Red Beds of the Pecos Valley in New Mexico. A marked characteristic of all the Permian red clays is the presence in them of streaks and spots of bluish and bluish-green color.

"The beds of salt, anhydrite, gypsum, magnesian limestone and dolomite are markedly lenticular in form. No one layer of these can be traced very far in a horizontal direction. The beds of rock salt are not found in the upper strata of the Permian, although they may have been originally deposited there and subsequently removed by solution. The solution of rock salt and gypsum beds forms caverns into which in many cases the overlying clays and sands collapse, thus forming the sink holes and salt and alkali lake basins so common in the regions surrounding the Llano. We shall see that these sink holes are also found on the Llano."

The solution of the upper Permian salt in the Pecos Valley has already been referred to under saline solution. In the southern Pecos Valley, the argillaceous base of the first division of the Edwards, the Comanche Peak limestones, and the Walnut clay form a practically impervious covering so that in Crockett County the upper salt lenses are undoubtedly present.

The log of the Reilly well across the Pecos River in Pecos County shows a 230-foot stratum of anhydrite and remarkably pure rock salt interbedded in lime and red clay at 820 feet below the surface. Other tests in Pecos County show thick lenses of salt at varying depths. At present no holes in Crockett County have been carried to a sufficient depth to reach the Permian salts. Undoubtedly Crockett County has lenses of rock salt, however, at corresponding depths.

Exploration for the salt should be carried on with a diamond drill if mining of the salt by shafts is contemplated or by standard or star rig, if it is intended to obtain the salt from artificial brines. These brines are formed by warm water, capable of maximum solution, being forced down to the salt strata which it dissolves and carries to the surface in solution. Re-evaporation of these brines deposits the salt. In the re-evaporation, care must be taken to separate gypsum and other minerals present in solution, which precipitate more readily than the salt.

GYPSUM AND ANHYDRITE

Associated with the lenses of rock salt in the Permian clays farther to the north are beds of gypsum and anhydrite. These

minerals probably exist with the salt in Crockett County. However, there is no positive proof of this.

CALCITE

In some localities the third division of the Edwards lime contains abundant crystals of calcite from microscopic size to crystals 1-1/8 inches in diameter. No vein calcite has been noted in the Edwards limestone, but it sometimes occurs in the Basement sands.

GLASS SAND

The equivalent of the white glass sand mined from the Basement sand at Santa Anna Mountain in Coleman County, Texas, is found along the Pecos River in Crockett County. Locally it has sufficient qualities to be used for the making of glass, but it is of no commercial value on account of its inaccessibility and extreme variation.

FLINT OR CHERT

Grains of quartz compose the greater part of the Basement sands and to some extent form the Edwards limestone. In the latter, the most common quartz form is flint or chert. This mineral is composed of a microscopic mixture of crystallized silica and non-crystalline silica plus water and some organic matter in the form of coloring. It varies in color from black to brown, red, and gray, depending upon the nature and amount of coloring present. It is not found in commercial quantities.

OIL POSSIBILITIES ON UNIVERSITY LANDS

LOCATION AND AREA

The University lands in Crockett County comprise some 660 square miles, and are located in three tracts. The first tract examined lies about four miles north of east from Sheffield and contains 144 square miles, including Blocks 29, 30, 31, 32, and 33. This land will be referred to as the Sheffield Tract.

Thirteen miles north of Ozona on the Ozona-Barnhart Road is the southern boundary of the Barnhart tract which contains about 375 sections. With the exception of a strip about two sections deep and twenty sections long, across the northern side of this body of land, the Barnhart tract lies in Crockett County. It contains Blocks 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 55, and 56.

Immediately to the west is the Big Lake tract, one township deep and four townships long. A strip about two sections deep along the northern boundary of this tract lies in Reagan County. The Big Lake tract includes Blocks 5, 6, 7, and 12.

The exact location of these lands is shown on the geological map of Crockett County. The Kansas City, Mexico and Orient Railroad runs about 6 miles north of the Barnhart and Big Lake tracts. Girvin is the nearest railway point to the Sheffield land.

TOPOGRAPHY AND DRAINAGE

The relief of the county is such that practically any point on the University lands is easily accessible. The Sheffield tract has a more varied topography than either the Barnhart or Big Lake bodies. The latter have practically no exposures, and the reconnaissance can only indicate in a very general way the geology of these lands. On the Sheffield tract the abundant exposures made it possible to do quite detailed work.

The roads leading to the University lands are in moderately good repair and passable at practically all times.

The entire water supply for any development on the Big Lake or Barnhart tracts will be dependent upon wells. The location of these is such that it will not be necessary to lay an

excessively long water line. By installing pumps in place of the windmills, an adequate water supply can be obtained. For the western side of the Sheffield tract, water can be obtained from Live Oak Creek, but the greater portion of the area will also be dependent upon wells.

GEOLOGY

The Edwards limestone of the Comanchean Cretaceous furnishes the only exposure upon the University Lands in Crockett County. On the Big Lake and Barnhart tracts a covering of soil conceals practically all the strata. As there is no individual structure upon any one of these tracts, a more comprehensive view can be obtained by discussing the three tracts together.

The axis of the Pennsylvanian fold extending northeastward from the Marathon uplift crosses the Pecos River near the highway bridge on the Sheffield-Ozona Road. Its position is determined by the Sheffield terrace, which has its shorter axis lying between Seven and Nine Mile points on the Pecos River.¹ The longer axis, which is coincident with the trend of the fold itself, extends from southwest to northeast. Its extent into Pecos County to the southwest has not been traced for more than six miles, but it has been observed to continue for some fifteen miles into Crockett County along the northwestern edge of the Sheffield tract. The structural reconnaissance map of that tract (Fig. 4) shows that the strata lie horizontal over practically the northwestern half of Block 29 of the Sheffield tract. To the east the strata increase in amount of dip and at the eastern part of the tract have a maximum dip of 5 minutes S 70° E.

The proximity of the axis of the Pennsylvanian fold is responsible for this flattening in dip. The terrace indicates the last slight movements along a line of weakness established by excessive folding in the lower formations. The trend of the axis carries it past the Sheffield tract immediately to the northwest of Block 29. Surface observations on the University land also con-

¹A more complete general discussion of this fold and the possibility of petroleum can be found on pages 67-72. Its location and extent are indicated on the areal geological map of the Pecos Valley (Pl. 1). The location of the Sheffield Terrace, which lies along the axis of the Marathon fold, is shown on the accompanying land map (Pl. 3).

firm the location. How far to the southeast and northwest of the axis the flexures of this fold extend beneath surface formations is not known. However, from the magnitude of the fold it is reasonable to presume that they may be locally reached at a considerable distance from the axis. At least, they extend for some five or six miles on either side of the axis, as is indicated by the width of the Sheffield Terrace, the shorter axis of which lies approximately at right angles to the trend of the fold.

As there are no petroliferous strata above the first angular unconformity, the surface structure mentioned is of no value as a concentrator of petroleum originating above the uppermost angular unconformity. However, it indicates the position and trend of a fold beneath, which may be structurally adequate to retain any petroleum present, or the slightly folded strata of the overlying formations may form the impervious covering and retainer of petroleum migrating upward along the inclined strata, if the lower formations are sufficiently broken and faulted from excessive folding.

The trend of the fold would carry it approximately diagonally from southwest to northeast across the Barnhart tract of University land. However, as there are only a very few isolated outcrops on this tract, it was impossible to determine if the trend of the fold remains constant and if it extends as far from the Marathon uplift as to the Barnhart tract. It is probable that if sufficient outcrops were present, the fold would be found to cross Crockett County and extend into the adjoining counties to the north, or even farther. A similar fold in north-central Texas, of less magnitude extends even a greater distance than this from its point of origin.

Immediately to the southeast of the Barnhart tract, a small terrace has been reported, after a stadia survey. It was impossible, in the limited time allowed for the work, to check this report in the field, but from the source of information it is very probable that the terrace is present. This would also indicate that the fold extends farther to the northeast than was possible to trace it in reconnaissance.

There is, then, in Crockett County, a large fold in the buried Carboniferous strata some 2000 feet below the surface, entering the county at about the highway bridge over the Pecos River,

three and a half miles east of Sheffield, and bearing approximately N 50° E. It passes immediately to the northwest of the Sheffield tract of University land and although it could not be located farther in reconnaissance, because of the lack of exposures, it probably extends across the entire county, diagonally from southwest to northeast through the Barnhart tract of University land and into the adjoining counties to the north. Near its point of origin, in the Marathon Mountains, the lower formations have been observed to be strongly inclined and this folding decreases in the upper strata, so that at the surface the trend of this Pennsylvanian fold is marked by slight departures from the normal in rate of dip of the surface formations.

The value of this fold as a concentrator of petroleum cannot be estimated as there is no sub-surface data for a basis. However, the evidence supplied from the development of a similar geological fold in north-central Texas is positive. It is possible to state that if petroleum is present in any of the formations underlying the Pecos Valley, the most desirable area for testing is along the axis of this fold. As the fold is undoubtedly irregular in the lower formations, as is indicated by the surface strata, all locations along the fold will not be of equal value, but it is impossible to make more definite statements. The few tests under operation in the region record shows of oil in the Carboniferous strata, but no completions have been made, nor has petroleum in commercial quantities been reported.

As has been mentioned, the lower formations of the Marathon fold are not regularly flexed, but plunge to the northeast, from the Marathon region, in a series of plunging, arrested anticlines, or "noses", and synclines. These "noses" along the trend of the general fold very probably have a definite relationship to the terrace areas of the surface formations. Between the surface terraces, the lower formations are probably relatively lower. Thus the exploration of the Pennsylvanian strata in the Marathon fold should at first be confined to the surface disturbances.

The formations underlying the Sheffield Terrace, at its distance from the steeply folded strata of the Marathon region, should be more gently inclined and favorable for the concentration of petroleum.

A testing of the University lands in Crockett, Schleicher,

Irion, Reagan, Upton, and Terrell counties should first be begun in the northwestern half of Block 29 of the Sheffield tract of University land, as this is the most promising area. Next in order of value are the Barnhart tract in Crockett County, extending into Schleicher, Irion and Reagan counties; and the two tracts in Terrell County. Although no structural maps were made of the University lands in Terrell County, observations upon the University lands and the area to the northeast show definite disturbances in the surface formations. These two tracts undoubtedly lie on the Marathon fold and further investigations may show them to be favorable areas.

The Big Lake tract in Crockett County extends into Reagan and Upton counties on the north. The reconnaissance of the area within Crockett County afforded little information, because of lack of outcrops. A more careful survey should be made before being reported upon in detail. From what is known, it would appear that the southeastern part of the tract is the most favorable, as it lies nearest the Marathon fold.

In testing the Sheffield tract of University land, the locations should be made preferably on the northwestern half of Block 29, as the axis of the fold passes nearest this area, as is indicated by the general trend of the fold from the southwest and the terracing of the surface formations in the northwestern half of the block. More definite information cannot be given till the geology of the individual areas is outlined by sub-surface data from well logs. It will then be possible to determine the structural features of the fold more closely.

The lack of surface exposures on the Barnhart and Big Lake tracts makes it impossible from a reconnaissance to define closely the most favorable area. However, from the reported terrace to the southeast of the Barnhart tract and the general trend of the axis of the fold, it would seem advisable to make detailed stadia surveys for the location of this fold from southwest to northeast across the Barnhart tract, as this is the normal course, if the fold continues across the county.

The uniformly slight dips to the southeast on both the Barnhart and Big Lake tracts, observed at widely separated points, indicate that the surface formations in general are normal. However, departures from the normal rate of dip may exist between

points of observation in reconnaissance, and this can be determined only by detailed surveys.

The accompanying structural reconnaissance maps (Figs. 4, 5, 6) indicate the results of the investigations upon the University lands in Crockett County.

No more than an approximate depth to which a test should be carried can be given, as insufficient drilling data are available. However, the information afforded by a few deep tests near Sheffield and San Angelo indicates that in the vicinity of the Sheffield terrace, and in general along the axis of the Marathon fold, a test should be carried 4000 feet. This depth, in most instances, should carry the hole well down into or through the Carboniferous.

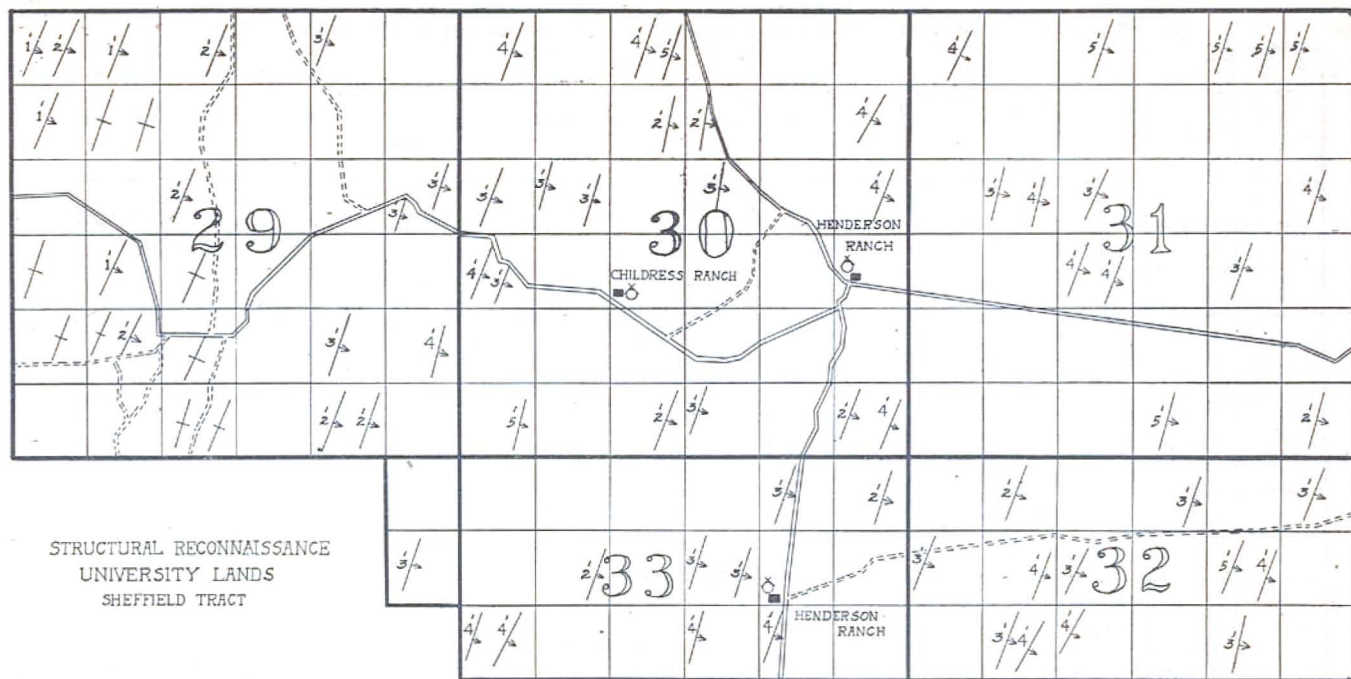


Fig. 4. Structural Reconnaissance Map of the Sheffield Tract of University Lands.

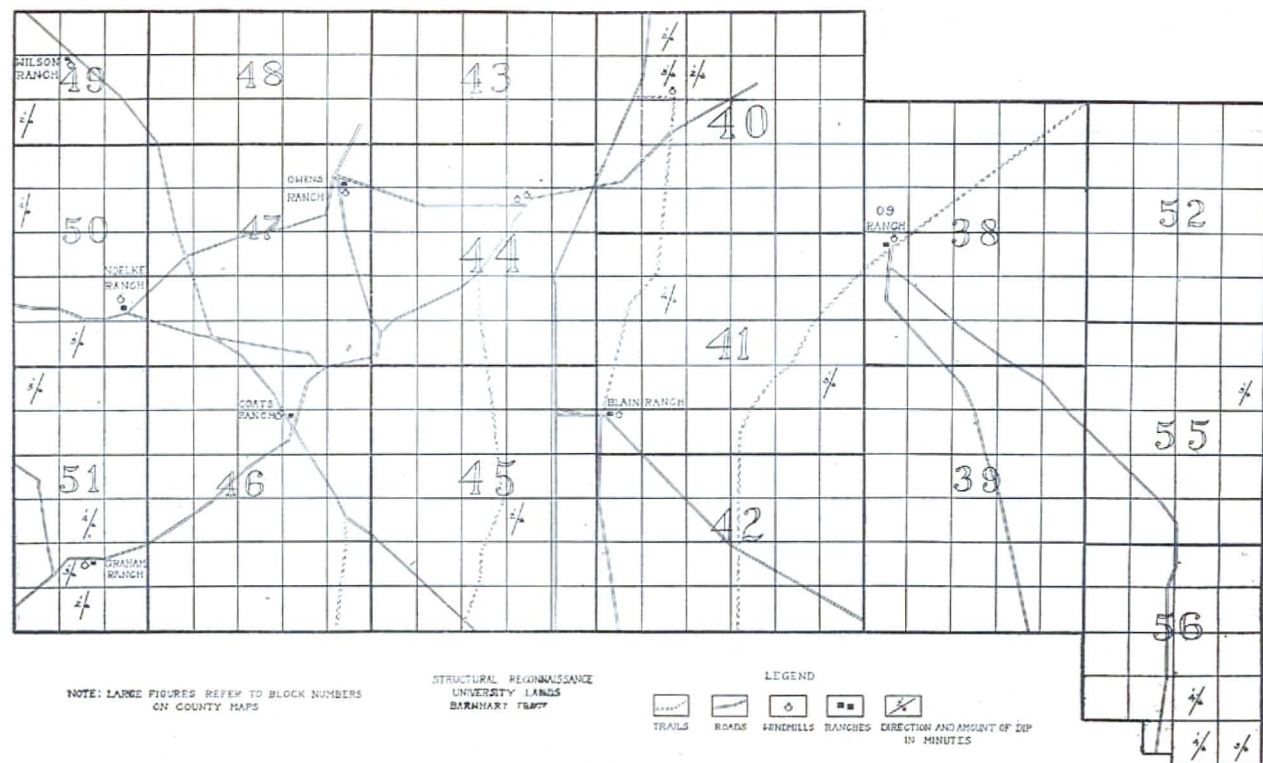
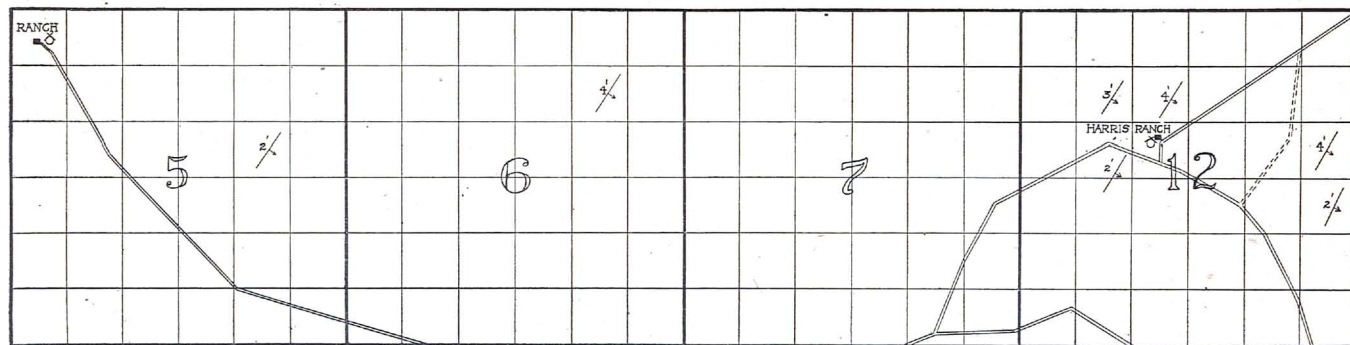


Fig. 5. Structural Reconnaissance Map of the Barnhart Tract of University Lands,



NOTE: LARGE FIGURES REFER TO BLOCK NUMBERS
ON COUNTY MAPS

STRUCTURAL RECONNAISSANCE
UNIVERSITY LANDS
BIG LAKE TRACT

LEGEND



TRAILS



ROADS



WINDMILLS



RANGES



DIRECTION AND AMOUNT OF DIP
IN MINUTES

Fig. 6. Structural Reconnaissance Map of the Big Lake Tract of University Lands.

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