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EXPLORATORY GEOLOGY OF A PART OF SOUTHWESTERN TRANS-PECOS TEXAS

By

CHARLES LAURENCE BAKER

Bureau of Economic Geology

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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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EXPLORATORY GEOLOGY OF A PART OF SOUTHWESTERN TRANS-PECOS TEXAS[1]

BY CHARLES LAURENCE BAKER

INTRODUCTION

The present bulletin completes the work of preliminary exploration of the mountain region of Trans-Pecos Texas begun twenty years since by the University of Texas Mineral Survey and completed by the University of Texas Bureau of Economic Geology. The region treated in the present paper is bounded on the north by the line of the Texas & Pacific Railway, on the west by the Malone Mountains, on the southwest by the Rio Grande, and on the east practically by the line 104° 30′ west longitude. The field work was done at the rate of about thirty-five square miles per day. Much of the mapping was schematic and thicknesses of rock sections were estimated. The structure proved to be complicated and only the main structural features were determined. The main new results of the present work are four:

1. The determination of the probable Permian age of the gypsum beds of the Malone Mountains.

2. The classification in a general way of the Comanchean sediments, a work very greatly aided by the fossil determinations of Professor W. M. Winton.

3. The discovery of complicated structure in the Quitman and Eagle mountains, with overturning and overthrusting of strata.

4. The assignment of the epoch of this intense deformation to Cretaceous time later than Taylor and before the final disappearance of Cretaceous dinosaurs.

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[1]Manuscript submitted September, 1922; published October, 1927.

REVIEW OF PREVIOUS EXPLORATIONS

The northwestern part of this region was first geologically explored by W. H. von Streeruwitz,[2] who entered the region in 1878. He visited the region at various times during a period of thirty years or more and no man has surpassed him in knowledge of the mineral deposits of the region. J. A. Taff was a member of von Streeruwitz's party in 1890 and published his results in 1891.[3] F. W. Cragin studied the Malone Mountains in 1897 and published a report in 1905.[4] T. W. Stanton in 1897 and 1899 studied an area from the Finlay Mountains on the north to where the Rio Grande cuts through the Quitman Mountains on the south and from the western foothills of the Malone and Quitman mountains on the west to Devil's Ridge and the Eagle Mountain on the east. His observations were included in Cragin's paper.[5] With one exception Stanton identified correctly the beds which he saw south of the Southern Pacific Railroad, but he erred in referring the Cretaceous sediments of the Finlay Mountains to the Fredericksburg for their true position is Trinity. This error was repeated by George B. Richardson in 1904.[6]

T. W. Vaughan and T. W. Stanton visited together the San Carlos region in 1895. Vaughan published his observations shortly afterward.[7] Dr. J. A. Udden studied the San

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[2]Streeruwitz, W. H. von, Geology of Trans-Pecos Texas. Geol. Surv. Texas, 1st Ann. Rept., pp. 217–235, 1890; 2d Ann. Rept., pp. 665–713, 1891; 3d Ann. Rept., pp. 381–389, 1892; 4th Ann. Rept., pt. 1, pp. 139–175, 1893.

[3]Taff, J. A., The Cretaceous Deposits of El Paso County. Geol. Surv. Texas, 2d Ann. Rept., pp. 714–738, 1891.

[4]Cragin, F. W., Paleontology of the Malone Jurassic Formations of Texas. U. S. Geol. Surv. Bull. 266, 1905.

[5]Stanton, T. W., Stratigraphic Notes on Malone Mountains and the Surrounding Region near Sierra Blanca, Texas. U. S. Geol. Surv. Bull. 266, pp. 23–33, 1905.

[6]Richardson, G. B., Report of a Reconnaissance in Trans-Pecos Texas, North of the Texas & Pacific Railway. Univ. Texas Min. Surv. Bull. 9, 1904.

[7]Vaughan, T. W., Reconnaissance in the Rio Grande Coal Fields of Texas. U. S. Geol. Surv. Bull. 164, pp. 1–88, 1900.

Carlos coal field in 1913 and the writer has incorporated some details from his map.[8] The only geologic map of the region heretofore published was made by J. A. Udden and Benjamin F. Hill.[9]

STRATIGRAPHY

PRE-CAMBRIAN

CARRIZO SCHIST

There are four exposures of Pre-Cambrian rocks within the area mapped. The Pre-Cambrian consists of the Carrizo schist in places intruded by pegmatites, quartz veins, granitoid, and basic rocks.

One exposure is in the northeast front scarp of Eagle Mountain, south of Hot Wells station on the Southern Pacific. The rocks here are quartz and amphibolite schists, quartzites, cherts, and a very basic dark green intrusive. These rocks are cut by quartz veins, one of which has been prospected for the copper minerals which it contains. The amphibolite schists strike N 70° E and dip steeply S–SE.

North and northeast of Dalberg section house the schists are exposed along Bass Cañon. There are mica-schists, quartz-schists, chlorite-and epidote-schists with lenses and veins of quartz and dikes of dark green basic intrusives. Some of the schists contain garnets. The strike is northwest to north-northwest.

At the west base of the Wiley Mountains there are knotted schists of pink color, composed of orthoclase and quartz, light pink quartz-muscovite-schist, quartz-biotite-muscovite-schist, chlorite-schist, and amphibolite-schist, with quartz veins and lenses. The strike is nearly east-west and the dip 20 to 30 degrees south.

The Pre-Cambrian is exposed in the heart of a small faulted domical area on the northwest side of the Van Horn

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[8]Udden, J. A., Unpublished Map, 1913.

[9]Udden, J. A. and Hill, B. F., Geologic Map of a Portion of West Texas. Univ. Texas Min. Surv., 1904.

Mountains. This is the Mica Tanks or Mica Mine locality, celebrated for its rather exceptional variety of pegmatites. There is some light pink orthoclase-muscovite-granite with sheared structure but most of the rocks exposed are quartz-schists, muscovite-schists, biotite-schists, quartz-mica-schists, garnet-schists, biotite-muscovite-schists, chlorite-schists, and hornblende-schists. In the latter, some specimens show hornblende altered to epidote. The predominant rock is a finely-foliated aggregate of muscovite and flesh-colored or white feldspar. At the north the banding runs in a general north-south direction, but a set of prominent joints dips steeply southward to southwestward and gives the rock from the west the appearance of a steeply-dipping, heavy-bedded, reddish-brown sedimentary. In the southern part of the area the schist banding dips south-southwest. At the extreme south end the bands strike north and dip 60 degrees east. The average general dip appears to be east.

There is great profusion of pegmatite, graphic granite, and quartz dikes. Some of the pegmatite veins are more than 100 feet wide. The vein quartz is mostly milky-white and subordinately transparent. The texture of the pegmatites varies from ordinary graphic granite, an intimate intergrowth of feldspar and quartz, to crystals of feldspar and mica a foot or more in size. The feldspar varies in shade from flesh color to pearly-white. The micas are muscovite, biotite, and a relatively small amount of phlogopite. Biotite is sometimes aggregated in lenses. One locality contains large tabular masses of black tourmaline. Crystalline hematite is found sparingly.

UPPER CAMBRIAN(?)

VAN HORN SANDSTONE

Remnants of the Van Horn sandstone, as mapped by Richardson in the Van Horn folio,[10] are found lying between

[10]Richardson, G. B. U. S. Geol. Surv. Geol. Atlas, Van Horn folio (No. 194), 1914.

Pre-Cambrian and Permian in the Bass Cañon region north of Dalberg section house, in the lower western slopes of the Wiley Mountains, and southwest of the Mica Mine near the western foot of the Van Horn Mountains.

In the Bass Cañon locality there are very dark purplish-red micaceous sandstone and conglomerate of angular schist and quartz. The maximum thickness is not over 250 feet. A few feet of the red micaceous sandstone occurs in small remnants on top of the Carrizo schists of the Wiley Mountains. There is one exposure not over 150 feet thick of red and green very micaceous arkoses near the southeast corner of the Pre-Cambrian area on the west side of the Van Horn Mountains.

PERMIAN

It is probable that the Permian sea covered the entire area but subsequent earth movements and erosion have exposed Permian rocks at the surface only in the great dome of the Wiley, Diablo, Eagle and Van Horn mountains in the north, in the intrusive uplift of Chinati Mountains at the south, and in the Malone Mountains at the extreme northwest. There is only a relatively small amount of detrital material in the Permian and that at its base. The bulk of the sediments are limestones, implying clear waters, considerable distance from land areas, and a basement topography of low relief.

The lower strata are exposed only in the great northern dome. On the south side of Bass Cañon the following basal beds rest on the Van Horn sandstone, in descending order:

	Feet
1. Limestone, usually medium-bedded blue-grey, weathering dove-color, succeeded by heavier-bedded, buff-weathering, blue-grey limestone forming cliffs.	
2. Limestone, thin-bedded, grey	6
3. Limestone, thin-bedded nodular, brownish-yellow	5
4. Sandstone, shaly-bedded, micaceous, limy	5
5. Sandstone, irregular-banded, red and grey	20
6. Sandstone, grey, coarse, conglomeratic, lying unevenly on (7)	8
7. Van Horn dark purple sandstone.	

Here, as elsewhere, the basal beds derived their detritus from the immediate vicinity. Only a few feet of arkoses and sandstone are found in the base of the Permian in the Van Horn and Wiley mountains.

The lower great limestone member of the Eagle, Van Horn, and Wiley mountains, and in the Bass Cañon region is everywhere characterized by numerous echinoid spines and plates. This limestone is of dark blue-grey color and is medium-bedded. Northeast of Eagle Spring the fauna consists of *Derbya, Productus, Bellerophon, Omphalotrochus, Pugnax, Composita, Schwagerina,* and *Fusulina elongata.* About the same assemblage of fossils, generally silicified, occurs in the other localities. The full thickness of this limestone is perhaps about 1000 feet. It is overlain in the east slopes of the Wiley Mountains by a very much lighter grey limestone, weathering almost creamy with some light brown chert and a few fossils, among them *Fusulina elongata,* sponges, *Productus, Hustedia,* and a coarse-ribbed *Spirifer.* Dr. Beede has noted this same *Spirifer* in the Permian west of the Jones Ranch House on the east side of Salt Flat, south of Seven Heart Gap, and in Brackett Draw, east of the edge of the northern Diablo Plateau.[11] This limestone contains some small quartz pebbles in a small isolated exposure south of the southeast end of the Wiley Mountains.

Supposedly higher Permian, perhaps belonging to the Word formation, is exposed in a great anticline and faulted into contact with Comanchean on the west side, along Pinto Cañon at the north base of the Chinati Mountains. The highest beds exposed are dark blue-grey, medium-to-thin-bedded limestones, black shales and nodular and bedded black chert. These beds, about 200 feet in thickness, are very bituminous and have large *Fusulina elongata,* a small *Fusulina,* and large *Omphalotrochus.* The limestone and shales are often coal black from the bitumen. Large elliptical clay-ironstone concretions occur in the shales. The

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[11]Beede, J. W., Notes on the Geology and Oil Possibilities of the Northern Diablo Plateau in Texas. Univ. Texas Bull. 1852, p. 24, 1920.

middle member is thin-bedded black chert with some thin limy shales, limestones, and brownish sandstones aggregating about 250 or 300 feet in thickness and weathering rusty-brown. The lower member, perhaps 400 feet thick, consists of very dark brown to black thin-bedded muscovitic sandstone intercalated with sandy shales.

The gypsum beds of the Malone Mountains, long considered Jurassic, are proved to be Permian by the discovery in the limestone overlying the gypsum one-half mile north-northeast of Torcer (formerly Malone station) of the characteristic Permian fossil *Richthofenia*. Members (3) to (5) of Stanton's[12] main Malone section and members (18) to (21) of Taff's section[13] are adjudged Permian. So far as known, the Permian of the Malone Mountains consists only of interbedded limestone and gypsum. The gypsum is now being quarried at Gypsum (Briggs) Switch at the northwest end of the mountains. It is found also in the anticline, for the most part overturned, in the valley southwest of the main northeast ridge, also from one-half mile to one mile northeast of Torcer railroad station, and at the southeasternmost extremity of the mountains at the foot of the main ridge.[14]

SUMMARY OF MESOZOIC STRATIGRAPHY

There can be no reasonable doubt that the Malone beds contain strata of both Upper Jurassic and pre-Trinity Cretaceous (Lower Neocomian) age. "The predominant forms of *Idoceras* are certainly middle Kimmeridge, while the

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[12]Stanton, T. W., Stratigraphic Notes on Malone Mountain and the Surrounding Region near Sierra Blanca, Texas. U. S. Geol. Surv. Bull. 266, p. 25, 1905.

[13]Taff, J. A., The Cretaceous Deposits of El Paso County, Texas. Geol. Surv. Texas, 2d Ann. Rept., p. 723, 1891.

[14]The Torcer locality was visited early in 1927 by Dr. J. W. Beede and the writer and about 15 Permian species, including ammonoids, were collected. Gypsum lies between limestone strata, but either overturning or overthrusting is suspected.

'Olcostephanus' (Lithacoceras) and *'Aspidoceras'* (Simaspidoceras?) may well be of the same age or upper Kimmeridge. The doubtful *'Perisphinctes aguilerai'* only could be a little later, possibly even a Tithonion (Portland) *Kossmatia (pronur* zone of the Somaliland zones)."[15] Dr. Kitchin in the paper just cited considers the *Trigonias* and *Ptychomya* of Cragin's "Theta" subdivision as undoubtedly Lower Cretaceous not older than Valanginian. Also the *Astieria* found lately by the writer in the Malone is apparently of the Hauterivian-Valanginian stage of the Lower Cretaceous. It is therefore probable that the Malone beds comprise the same conformable sequence from Kimmeridge Upper Jurassic to the base of the Trinity Cretaceous which the writer has found in numerous places in northeastern Mexico.

The Malone beds consist of conglomerates, sandstones, shales, marls and limestones. Thicknesses cannot be given until very detailed paleontologic and stratigraphic work has been done.

The Trinity strata of this area belong to a near-shore mainly marine facies comparable in thickness and character to that found in southeastern Arizona and northeastern Sonora. The Etholen conglomerate or Campagrande formation is the lowest group of the Trinity found unconformably overlying the Permian and older rocks, although it possibly may not be the oldest Trinity in the Malone Mountains.

The tops of the Etholen and the next succeeding formation, the Cox sandstone, cannot be drawn with exactitude since they intergrade into higher beds. There is a thickness of at least more than 1900 feet of the two in the northern Eagle Mountains. There is at least 250 feet of conglomerate alone in the Etholen on the north flank of the Quitman Mountains. North of the Chinati Mountains there is 600 feet of Lower Cretaceous with Trinity fossils at the top. There is 1500 feet of Cox sandstone in the eastern

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[15]Dr. L. F. Spath on p. 458 of Kitchin, F. L., the So-called Malone Jurassic Formation of Texas. Geol. Mag., Vol. LXIII, pp. 454–469, 1926.

Van Horn Mountains and about 2000 feet on the southwest flank of the southern Quitman Mountains. Both the Etholen and the Cox formations contain beds of limestone, sandstone, shale, marl and conglomerate.

The uppermost formation of the Trinity group is the Finlay limestone. It is much thinner in the Van Horn Mountains than elsewhere, and not over 400 feet in total thickness, and probably reaches its greatest thickness in the southern Quitmans where it is probably not less than 1500 feet thick. The Finlay is not all limestone but contains some interbedded sandstone and shale.

The maximum thickness of the Trinity group is probably more than 3500 feet, which so far as known is the greatest thickness in Texas.

The Walnut Clay is not over 100 feet in thickness and is composed of grey marls, nodular limestone and an upper sandstone.

The Comanche Peak and Edwards are limestones with some marls and clays. The Edwards is but 25 feet thick in the northern Van Horn Mountains, but thickens farther south.

The Washita of the northwest part of the area consists of shore line deposits much like in northeastern Texas. The strata consist of limestones, sandstones, marls and shales of variable thickness. There would appear to be from 500 to 800 feet of Georgetown limestone, marly limestone, marls, shales and locally at least a basal sandstone, which may be upper Fredericksburg. The Del Rio is about 300 feet thick and made up of sand, clayey limestone and clay. The Buda is limestone and 30 feet in thickness.

The maximum thickness of the Lower Cretaceous is probably greater than 5000 feet.

The Upper Cretaceous (Eagle Ford, Austin and Taylor) thickens southward to the Rio Grande where it probably attains at least 3000 feet. The strata are clays, shales, and flaggy limestones in the Eagle Ford and Austin and mainly clays, sandstones and coal in the Taylor. The Austin of this area contains no chalk and the Taylor is more sandy than anywhere else in Texas except in the Big Bend region.

JURASSIC

MALONE BEDS

The main or northeastern ridge of the Malone Mountains is a syncline overturned on the southwest flank. On the northeast limb of this syncline on its southeast end near the gypsum exposure an overthrust to the northeast is seen near the foot of the ridge. The axis of the overturned syncline lies generally along the summit ridge. The valley to the southwest of this ridge is occupied by an anticline overturned to the northeast. The northwestern part of the mountain mass, on the southwest side of the over-turned anticlinal valley is anticlinal, the main structure plunging southeastward. The main anticlinal axis here passes near the gypsum quarry just south of Gypsum or Briggs Spur on the railroad.

There is considerable minor crumpling, perhaps the consequence of overthrusting, at the southeastern end of the main northeastern ridge. Here the Permian gypsum, occupying partly the flat between the southeastern end of the ridge and the Quitman intrusive mass and partly the lowermost foothills of the southeastern end of the Malone Mountains, is overlain by a heavy limestone and chert conglomerate with brown chert as part of the matrix cementing materials. Boulders in the conglomerate are as large as 8 inches diameter. Two of the limestone boulders contained *Fusulina elongata*. This conglomerate is apparently the basal bed of the Jurassic. Above come mainly limestones with some conglomerates and brown sandstones; the limestone locally contain chert pebbles. The gypsum here is apparently overlain on its eastern side with a southwestward-dipping brown sandstone with brecciated pebbles upon which rests a blue limestone.

At the northwest end of the mountains near Gypsum (Briggs) Spur the gypsum is overlain by about two hundred feet of conglomerate and light brown conglomeratic sandstone. The pebbles are well water-worn and consist of limestone and chert. Serpulid borings were noted near the base. Next upward in the section comes dark grey fossiliferous limestone with interbeds of light brown conglomeratic and quartzose sandstone, the pebbles of which are quartz and chert.[16]

The northeast main ridge of the mountains exhibits a section of 1800 feet of strata according to Taff and of 1000 feet according to Stanton. The interbedded gypsum and limestones are not included in these thicknesses. Both sections were made near the middle of the ridge. The strata are limestones with several beds of conglomerate and a subordinate amount of shales. There is a noteworthy conglomerate with quartzite and chert pebbles 40 feet in thickness outcropping on either side of the overturned *Astieria* syncline of the summit ridge. This is overlain by about 100 feet of blue limestone which is the highest bed at that locality.

The fossils described by Cragin[17] were found in low hills outside of this area on the north side of the railroad. Böse refers two of the fossils of Cragin's Theta subdivision to the pre-Trinity Cretaceous.[18] The base of Cragin's Kappa limestone is a pisolitic-like member, No. 9 of Taff's Malone section, which occurs 275 feet below the top of his section.[19] The writer found the Finlay limestone member of the Trinity in the southward plunging anticline two miles southwest of Finlay station.

LOWER CRETACEOUS

ETHOLEN CONGLOMERATE

The Etholen conglomerate, wherever its base has been seen, rests unconformably on Permian limestone. The con-

[16]The writer early in 1927 found an *Astieria* in the sandstone near the top of the ridge south of the Gypsum Spur. This indicates the Hauterivian-Valanginian pre-Trinity Cretaceous age of the sandstone.

[17]Cragin, F. W., Paleontology of the Malone Jurassic Formation of Texas. U. S. Geol. Surv. Bull. 266, p. 13, 1905.

[18]See also Kitchin, F. L., The So-called Malone Jurassic Formation in Texas. Geol. Mag., London, Vol. LXIII, pp. 454–469, October, 1926.

[19]Taff, J. A., Cretaceous Deposits of El Paso, Texas. Geol. Surv. Texas, 2d Ann. Rept., p. 723, 1891.

glomerate was found by Taff[20] in the Etholen Knobs just northwest of Etholen section house and in nearby small hills south of the railway, in the small hill at the south base of Sierra Blanca peak, in the clump of hills one and one-fourth miles south of Etholen, the small hill three-eighths of a mile east of Etholen, on the flank of Quitman Mountains at the south side of Big Spring Gulch, on the east side of Devil Ridge and on the northwest side of Eagle Mountain south of Judge Love's ranch house. The writer also includes in it the lower Trinity conglomerates at Eagle Spring and south of Hot Wells station in the northeastern part of Eagle Mountain as well as the lowest Cretaceous beds exposed in the northern Van Horn Mountains. The Etholen conglomerate is probably the same as the Campagrande formation of Richardson the basal beds of which on the north side of Finlay Mountains contain similar conglomerates, although not so thick.[21]

The following section of the Etholen conglomerate here arranged in descending order was measured at Eagle Spring:

		Feet
1.	Sandstone, brown with three thin beds of limestone with a sill just above the highest limestone	150
2.	Sandstone, coarse, brown	65
3.	Limestone, grey, finely crystalline	2.5
4.	Sandstone, brown, hard	40
5.	Sill	10
6.	Sandstone, light brown, large *Turritella*, cut by dike; upper part contains some clays and limestones	80
7.	Limestone, massive, blue-grey, weathering light brown, rich in foraminifera	40
8.	Limestone, marly	10
9.	Sandstone, brown, lower half conglomeratic and with a sill; upper half contains some interbedded limestones	75
10.	Limestone, blue-grey, lenticular	0–10
11.	Sandstone, brown, medium-bedded	50

[20]Taff, J. A., Cretaceous Deposits of El Paso County, Texas. Geol. Surv. Texas, 2d Ann. Rept., p. 723, 1891.

[21]Richardson, G. B., Report of a Reconnaissance in Trans-Pecos Texas. Univ. Texas. Min. Surv. Bull. 9, p. 47, 1904.

		Feet
12.	Limestone, very light in color, fine-grained and geodic	15
13.	Mudstone and shale, dark reddish-brown	55
14.	Sandstone, light brown, friable, fine-grained	5
15.	Conglomerate with fine limestone pebbles	3
16.	Mudstone and shale, dark reddish-brown, cut by igneous stringer	20
17.	Limestone and shale interbedded, brown, sandy	15
18.	Sandstone, brown irregular-bedded, calcareous	23
19.	Conglomerates of coarse limestone, chert, and quartz, and calcareous brown conglomeratic sandstones. Cut by dike striking N.	15
20.	Clays, brown, limy and sandy, thinly laminated	10
21.	Sill, light-colored	0–20
22.	Sandstone, light grey-brown, cut by dike running nearly E–W	25–30
23.	Limestone, light blue-grey	
24.	Sill, very light-colored, aphanitic	50
25.	Limestone, light blue-grey, cherty at top	30
26.	Sandstone, coarse, greyish-brown, cut by cream-colored aphanitic dike	3–5
27.	Sandstone, conglomeratic, brown, hard, small pebbles of limestone, chert, and quartz	2
28.	Limestone, earthy and marly, blue-grey, weathering brown, with fossil casts	20
30.	Intrusive sill, extremely light grey, weathering brown	30
31.	Lower Permian limestone.	

One-half mile to the east the lowest bed contained *Porocystis pruniformis*, a characteristic Trinity fossil.

The section contains relatively little conglomerate, as do all the exposures noted in the eastern part of the area. There is much more conglomerate on the north side of the Quitman intrusive. On the contact with the intrusive is cherty limestone and brown sandstone succeeded by a heavy conglomerate of brown chert and grey limestone blocks up to eight inches in size. This grades above into a chert conglomerate. The limestone blocks carry numerous Permian fossils. The full thickness of the conglomerate must be at least 250 feet. Hills of Del Rio and Buda lie just south of the railroad between two areas of conglomerate. It seems likely that the conglomerate was first thrust over the

Washita beds and later tilted to the northeast by the intrusion. The tilting was accompanied by folding, the axes of which follow the peripheral outline of the intrusive.

The conglomerate in northwest Eagle Mountain south of Judge Love's ranch house is overthrust to the northeast over the Eagle Ford and cut by dip faults of great horizontal displacement. Heavy conglomerate beds and much conglomeratic red and brown sandstone are found in the lower part. Above comes pink limestone, very often brecciated and containing rounded pebbles up to four inches in size of chert and blue-grey limestone. The color varies from lavender through pink to bright red. There are some light grey beds. Near the top is a layer about twenty feet thick of grey conglomerate with rounded pebbles of dark blue limestone and chert. Five hundred feet or so above the base is a heavy brown-grey weathering limestone referred to the Finlay. Unless a second overthrust occurs the Cox sandstone is apparently missing from the section.

The basal Cretaceous south of the eastern end of the Wiley Mountains is red and brown conglomerate and sandstone with small well-rounded quartz and chert pebbles. It rests directly on the Permian. Higher up are some beds of limestone.

North of the Chinati Mountains basal Cretaceous 600 feet in thickness is exposed in the north slopes of Pinto Cañon. Resting upon the Permian is a conglomerate with many Permian limestone and chert fragments. Another thin conglomerate was noted about 400 feet above the base. The strata consist mostly of alternating limestone, marl and sandstone. *Orbitulina texana* occurs 600 feet above the base.

COX SANDSTONE

The beds herein referred to the Cox sandstone are unquestionably the same as those mapped with that formation name by Richardson[22] north of Sierra Blanca. The thickness of the Cox is variable and because of very gradual gradations no sharp line of demarcation can be drawn between

[22]*Op. cit.*, p. 47.

it and the underlying basal strata and between it and the overlying Finlay limestone. The formation is found all along the southwestern flank of the southern Quitman Mountains; and at the base of the hogbacks south of Sierra Blanca station; and forms the hogback of the Devil Ridge. It is found in various localities on the north side of Eagle Mountain; makes up most of the southern Eagle Mountains south of the great volcanic mass and is very extensively developed in the Van Horn Mountains. It is largely brown sandstone, somewhat conglomeratic, in many places cross-bedded and containing a number of interbeds of limestone and shale. Lithologically, it is very similar to the Dakota of the Rocky Mountains and Great Plains regions.

A section in the eastern Van Horn Mountains two miles south of Van Horn Wells measures 1500 feet in thickness. At the base is a coarse conglomerate with pebbles and boulders of Permian limestone. This may be part of the Etholen conglomerate. The lower portion of the sandstone contains some pink nodular limestone. Sandstones with an occasional layer of earthy limestone follow. The sandstones in some layers contain small rounded pebbles of quartz, chert and jasper. Near the top some silicified wood and plant remains occur. The rusty-brown weathering of the sandstone is characteristic.

The Cox in the northern Eagle Mountains appears to be about 1000 feet in thickness. From top to bottom are layers of conglomerate with small rounded pebbles of quartz, chert and limestone. The texture of the sandstone varies from fine through coarse-grained into grit and conglomerate. It is in many places inclined-bedded and cross-bedded. There are also interbeds of blue-grey fossiliferous earthy limestone. Three light buff aphanitic rhyolite sills are present in the strata in the high scarp south of Hot Wells station.

The formation contains beds of dark maroon sandy clay in the southern Eagle Mountains and in the southern Quitman Mountains. There is a thick section repeated in an overturned anticline along the southwest flank of the southern Quitmans. This is well exposed in Quitman Gap, formed by an arroyo which cuts entirely across the ridge which was followed by the old Fort Quitman stage road. The strata belong to what Taff[23] called the Mountain Bed and erroneously regarded as the top of the Washita. There are about 2000 feet of strata in this section to be referred to the Cox. Taff's section repeats the beds either side the base of No. 2 of his middle alternating horizon (V).

Strata underlying the thick beds of limestone in the hogbacks east of the Quitman intrusive are referred to the upper part of the Cox. The section nearest the intrusive shows below several hundred feet of light green-brown, medium-grained sandstone with a few weathering rusty-brown, thin interbeds of grey limestone. This sandstone member passes into medium-bedded grey limestone and greenish sandstone interbedded. The full thickness of this exposure is about 750 feet. The large hogback from three to five miles southwest of Sierra Blanca station shows under the thick caprock limestone thin to medium-bedded limestone, sandstones, and conglomerates totaling about 1000 feet in thickness. The limestones weather pink or red, grey or yellowish-brown, the sandstones are brown and green and the conglomerates are both coarse and fine. Some limestones are cherty. The northeast base of the hogback just south of Sierra Blanca station shows sandstones with a few interbedded limestones.

The Cox occupies most of the area of the southern Eagle Mountains. It there contains heavy conglomerate layers, some of them with pebbles of quartz, jasper and chert and others with pebbles of limestone and chert. The dark maroon sandy clays are found on both flanks of the southern Eagle Mountains as well as on the southwest flank of the Quitmans in Quitman Gap and along the Hot Springs road. Some pink limestone occurs in the section one mile east of Oxford Mountain, on the northeast flank of the southern Eagle Mountains.

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[23]Taff, J. A., Cretaceous Deposits of El Paso County, Texas. Geol. Surv. Texas, 2d Ann. Rept., p. 730, 1891.

FINLAY LIMESTONE

The Finlay limestone was named by George B. Richardson.[24] The type locality is the Finlay Mountains. North of the Finlay Mountains, in the vicinity of the Finlay-Tampico boring, the writer found, seventy feet above the base of the Finlay limestone, the same silicified *Radiolites*-like fossil that occurs in undoubted Trinity beds south of Sierra Blanca. The strata which south of the railroad were referred by Stanton[25] and Richardson[26] to the Fredericksburg, north of the railroad carry undoubted Trinity fossils at the base and in the upper limestones. However, Stanton[25] correctly referred to the Trinity the strata belonging to the Finlay limestone south of the railroad. Taff[26] expressly mentions that the strata in the Quitman and Eagle mountains are probably overfolded and faulted but he described the strata from northeast of Sierra Blanca to the southwest flanks of the Quitmans as if they occurred in regular and normal succession. This treatment is not surprising when consideration is given to the complexity of structure and to the fact that, when Taff worked, the range of the fossils had not yet been determined. Taff's Mountain, Quitman, Bluff and Yucca beds and all four of his *Caprotina* horizons are now found to be Trinity. Of these all but the Mountain bed and the lower part of the Yucca bed, which belong to the Cox, are to be included in the Finlay limestone. Bearing the above in mind future students of the area will find Taff's stratigraphic observations very useful and accurate. All but the uppermost part of Udden's Shafter beds are the equivalent of the Finlay.

The Finlay limestone is exposed in the main ridge of the southern Quitman Mountains, in the hogbacks east of the Quitman intrusive, in the northern and western part of the

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[24]*Op. cit.*, p. 47.

[25]Stanton, T. W., Stratigraphic Notes on Malone Mountains and the Surrounding Region near Sierra Blanca, Texas. U. S. Geol. Surv. Bull. 266, pp. 29–32, 1905.

[26]Taff, J. A., Cretaceous Deposits of El Paso County, Texas. Geol. Surv. Texas, 2d Ann. Rept., pp. 725–730, 1891.

Eagle Mountains, in the southwestern part of the southern Eagle Mountains, and at the extreme west end of the Malone Mountains. The formation is much thinner in the Van Horn Mountains than elsewhere. It probably reaches its greatest thickness in the southern Quitmans.

The Finlay is relatively more of a limestone in the northeastern Eagle Mountain, where only a few interbeds of sandstone occur. The limestone is, however, argillaceous. South of the Eagle Spring fault there is more detrital matter. The structure is complicated and much of the bedrock is concealed by débris. The prevailing dip is southwestward and the angles of dip range from 20 degrees to more than vertical. Thin dirty green sandstones and intercalated clays stand vertical on the fault contact south of Eagle Spring. To the southeast along the arroyo are exposed mainly dull dirty green sandstones and shales with a few blue-black carbonaceous shales and thin beds of blue-grey, weathering brown-grey, crystalline, calcite-veined limestone with fragments of *Exogyra quitmanensis*. These beds contain the coal prospected thirty years or more ago along the arroyo about one mile southwest of Eagle Spring. The coal bed strikes N 75 W and dips 82 degrees N 15 E, the dip a short distance down the creek varying from 55 degrees to 80 degrees. All limestones of the entire region have much secondary calcite, mainly in veins. There is a thickness of three feet of coal exposed in the old tunnel, now so filled in that the hanging wall side cannot be seen, although there is flaggy green sandstone on this hanging wall side three feet above the top of the coal now exposed. The footwall is clay. The coal is almost semi-anthracite, partially metamorphosed probably by the intense deformation and possibly by heat from igneous intrusion. The coal on the old dump is still fresh, shiny and hard. A short distance up the arroyo beyond the small seep spring heavy beds of limestone with *Exogyra quitmanensis* and *Orbitulina texana* dip 70 degrees in the same direction as the coal. One-half mile to the southeast the limestone is again exposed under the volcanic tuff-breccia in another arroyo. The dip is here 55 degrees N W and the limestone has under it dirty green sandstone and shale. The other dips in the vicinity are southwest. A mile to the northwest shale and sandstone, the shale blue-grey, are exposed and small outcrops of the shale, sandstone and *Orbitulina* limestone, separated by débris, are found for three miles to the west, on the south side of the fault. Prospect holes a half-mile west of the coal opening are mainly in blue-grey shale, which to the north is interbedded with thin limestones and dirty green sandstones. Carpenter Spring is about four miles south-southwest of Eagle Spring. Tuff-breccia forms the upper and major part of the eastern wall of the arroyo there. To the north and west débris masks all connections with the bedrock south of Eagle Spring. The lowest beds in the bottom of the arroyo (provided the strata are not overturned) appear to be on top of the limestone at the north, where the tuff-breccia ends, but the contact is not well exposed. The presumably lowest beds following the limestone are dirty green interbedded sandstones and clays, some of the clays being dark blue. Above come rusty-brown thin to medium-bedded sandstones, succeeded by a few limy beds and then follow several hundred feet of dark blue-grey sandy brittle and splintery clays. Taff[27] gives a section of this region which is probably correct, but if so, the clays rest on limestone which certainly belongs to the Finlay and cannot be of Dakota and Eagle Ford age, as thought by Taff. Taff found a small *Gryphea* and a small *Inoceramus* in the clays. The most obvious structural interpretation is that the strata at Carpenter Spring are the same as those seen a mile east of the coal opening and that they are exposed in the trough of a syncline.

The limestones on the northeast side of Eagle Mountain are blue-grey, argillaceous and nodular, and contain some interbeds of brown sandstone. Among the fossils are *Enallaster texanus, Pecten subalpina, Orbitulina texana,* and *Tylostoma.*

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[27]Taff, J. A., Cretaceous Deposits of El Paso County, Texas. Geol. Surv. Texas, 2d Ann. Rept., pl. XXVII, p. 736, 1891.

The Finlay in the southern Quitman Mountains appears to be not less than 1500 feet in thickness. The lower portion in Quitman Gap is for several hundred feet transitional upward from the Cox, containing many interbeds of sandstone with the limestone. Above the overthrust on the east flank at a place about one mile south of the road fossil rudistids are found in strata lying between an horizon of *Exogyra quitmanesis* and one of *Orbitulina texana*. The Finlay forms the summit range of the southern Quitmans from Quitman Gap to the crossing of the Hot Springs road and is overthrust to the northeast on the northeast flank over the Fredericksburg. The Finlay strata are mainly limestone with *Orbitulina texana* and *Exogyra quitmanesis* but there are numerous interbeds of sandstone and shale.

The Finlay is closely folded, with dips ranging from 40 degrees to vertical and overturned, in its exposure in the upper and middle sections of the cañon of the Rio Grande across the southern Quitmans. The Cox sandstone is exposed for about a mile east of Hot Springs. This is succeeded in the uppermost gorge by limestone with interbedded sandstone. Between the first and second gorges is a strike valley about four miles in length of an arroyo entering the Rio Grande at right angles. Blue-grey clayey marls interbedded with thin clayey limestones with *Exogyra quitmanensis*, a large *Pecten*, a large *Pholadomya* and *Alectryonia* outcrop in the valley. The second gorge is made of a series of mainly heavy-bedded limestones some 700 feet thick with many *Orbitulina texana*. This limestone is repeated farther downstream on the east flank of a closely-pressed syncline. Still farther down stream the Finlay is again repeated in an anticline on the east side of which are exposed members (15) to (19) of Stanton's section[28] which are 1050 feet in thickness and apparently all belong to the Finlay.

The Finlay is exposed in the Rio Grande Cañon across the southern Eagle Mountains and is extensively developed in the Mexican ranges beyond the cañon. The limestones exposed on the southwest side of Eagle Mountain proper

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[28]Stanton, T. W., *op. cit.*, p. 31.

are apparently Finlay. Most of the exposures at the northwest foot of Eagle Mountain are Finlay, with *Exogyra quitmanensis*. The strata are sandy limestone and limy sandstones, some conglomeratic, and with some sandy clays. In the normal south-southeast anticline lying between the overturned strata the basal rock is a massive dove-colored cherty limestone. A covered interval follows and then about 200 feet of dark grey clays with thin interbeds of fossiliferous marly clays with rill marks. Overlying come nodular earthy limestones. The caprock of the hogbacks north of the main fault is heavy Finlay limestone and with the exception of the main Devil Ridge nearly all the hogbacks extending northwestward to Sierra Blanca and Etholen are capped with or entirely composed of the Finlay. The summit rock of the large mass nearest the Quitman intrusive about five miles south of Etholen is mainly heavy beds of limestone containing *Orbitulina texana*. Two hundred feet above the base of this limestone is an horizon of interbedded brownish sandstone and limestone with green chert and silicified wood near the base. Bluff Mesa, lying east of the last-mentioned exposure is capped by basal Finlay heavy limestone, 200 feet thick with a heavy shell breccia of *Exogyra quitmanensis* at the top. Other fossils of this limestone are *Orbitulina texana*, *Pecten*, *Pholadomya* and *Alectryonia*.

The total thickness of the Finlay in the Van Horn Mountains is not over 400 feet. On the west flank it is grey earthy limestone with *Requienia*, echinoids, pelecypods, and gastropods. Some marls occur in the section on both flanks. On the east side there is at the base a rusty-brown sandstone fifty feet in thickness referred to the top of the Cox sandstone. The overlying Finlay impure limestones and marls contain *Exogyra quitmanensis*, *Tylostoma*, *Enallaster texanus*, *Gryphea marcoui* and *Requienia*.

Blue-grey limestone succeeded by gritty and finely conglomeratic sandstone and limestone outcrop in the southward-plunging anticline west of the Malone Mountains and two miles southwest of Finlay railroad station. The limestones carry silicified rudistids apparently the same as those found in the Finlay north of the Finlay Mountains. The same forms occur in the caprock of the hogback just south of Sierra Blanca station and in the very low hills from four to five miles to the south-southeast of the station.

Stanton[29] lists the following additional fossils from the Trinity of this region: *Trigonia taffi*, *Trigonia stolleyi* (?), *Remondia* and *Natica praegrandis*. The *Exogyra quitmanensis* (Cragin) is a very abundant and characteristic fossil. When full size it is six to eight inches in length. The most perfect specimens found occur in numbers in marly and limestone strata at the summit of the Hot Springs road crossing the southern Quitman Mountains.

FREDERICKSBURG

Fredericksburg strata occur below the overthrust on the northeast flank of the southern Quitman Mountains, in the lower part of the Rio Grande Cañon across the Quitman Mountains and in the southern part of the Van Horn Mountains.

The Walnut Clay horizon is not over 100 feet in thickness. The fossils found in it are *Exogyra weatherfordensis*, *Gryphea marcoui* and *Holectypus*. The strata are grey marls with interbedded nodular marly limestone succeeded by fine-grained, grey, reddish-brown weathering sandstone twenty-five feet in thickness.

The Comanche Peak is fine-grained limestone, thin to medium-bedded, grey and nodular. *Lima wacoensis* and *Schloenbachia* sp. occur from 100 to 150 feet above the base. The upper limit of the formation is not known and is probably difficult to determine, except on faunal evidence.

The Edwards limestone is thin in the Van Horn Mountains. West of the fault south of Chispa summit it is heavy-bedded, hard and bluish and perhaps only about twenty-five feet thick. It is probably somewhat thicker in the southern part of the Van Horn Mountains, where it was not separated from the Comanche Peak and lower Georgetown. Twelve miles to the southwest in the mesa on

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[29] Stanton, T. W., *op. cit.*, p. 29.

the Rio Grande one mile south of the mouth of Green River (Glenn Creek) there is a massive limestone about 500 feet thick which in part at least is Edwards and may be in part Comanche Peak and Georgetown. The same limestone is probably about 300 feet thick in the summit ridge of the southern Quitman Mountains some five miles south of Quitman Gap where it contains *Schloenbachia belknapi* and *Pecten subalpina.*

In Stanton's section[30] in the lower part of the Rio Grande Cañon across the Quitman Mountains members (6), (12) and (13) are referred to the Walnut and Comanche Peak, and (7) and (11) to the Edwards. Member (6) lies under the Del Rio along an overthrust and the section is repeated in an overturned syncline to the westward of member (6).

The common fossils of the Edwards are *Radiolites, Requienia* and *Monopleura.*

Strata, probably Fredericksburg, occur on the west side of the fault cutting off the Permian in lower Pinto Cañon. The basal beds exposed are clays with an alternating zone at the top passing up into heavy-bedded limestone.

WASHITA

Washita strata occur in the same localities as those given for the Fredericksburg and in addition are found in the valley of the Rio Grande near the White ranch from twelve to fifteen miles down the river in a southeastward direction below old Fort Quitman.

The detailed stratigraphic and paleontologic section made by Böse[31] in the Cerro de Muleros near El Paso will be taken as the basis for the division of the Washita in this region. In downward succession Böse's section is as follows:

9. Limestone, hard, white and light grey with *Exogyra whitneyi* —30 to 65 feet—Buda.

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[30]Stanton, T. W., *op. cit.*, p. 31.

[31]Böse, E., Monografla Geologica y Paleontologica del Cerro de Muleros, etc. Mex. Inst. Geol. Bol. 25, 1910.

8. Marls, yellow, with *Exogyra whitneyi, Hemiaster calvini*—30 to 65 feet.
7. Sandstone, red-brown and white, thick-bedded with *Exogyra whitneyi*—65 to 320 feet—Pottsboro and Del Rio.
6. Marls, brown, shaly, sandstones and limestones with *Alectry onia quadriplicata*—30 to 65 feet—Weno.
5. Marls, sandy, with marly shales and beds of limestone with *Schloenbachia trinodosa*—100 to 165 feet—Fort Worth and Denton.
4. Shales, marls, and beds of limestone with *Schloenbachia nodosa*—100 to 165 feet—Kiamichi.
3. Limestones, sandy, thick-bedded, calcareous grey sandstones, brown and yellow marls and black shales with *Schloenbachia* cfr. *belknapi*—30 feet—upper Fredericksburg.
2. Marls, brown, with beds of limestone and limy sandstones with *Schloenbachia bravoensis*—30 to 65 feet—upper Fredericksburg.
1. Limestone, hard, thick-bedded, grey with *Turritella vibrayeana*—65 to 85 feet—Edwards.

Böse's horizon (4) Kiamichi, marking transition between Fredericksburg and Washita, is exposed in the White ranch locality and about two miles east of the lower end of the cañon of the Rio Grande across the southern Quitmans. It is also likely represented in part by number (9) of Stanton's section[32] in the lower cañon. At the White ranch locality the base of the exposed section begins with laminated, light grey, fine-grained, clayey and calcareous sandstones, perhaps the equivalent of Böse's number (3). Blue-grey finely fissile shale with thin interbeds of sandy and calcareous ripple-marked strata with *Gryphea corrugata*, 300 feet thick, follow and represent the Kiamichi. Next upward comes about a hundred feet of nodular, marly, thin-bedded limestone with *Schloenbachia trinodosa* and *Pecten subalpina* representing Böse's number (5) and the Fort Worth and Denton of the north Texas section. Capping the section is three to four hundred feet of blue-grey fine-grained thin to medium-bedded earthy limestone which is middle to upper Georgetown.

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[32]Stanton, T. W., *op. cit.*, p. 31.

Practically all the Washita section is exposed in an anticline midway between the Quitman arroyo and the lower end of the Rio Grande Cañon in the southermost Quitman Mountains. *Inoceramus*-bearing, very bituminous Kiamichi shale, fissile and passing up into flaggy-bedded limestone and calcareous shale is seen in the axis of the anticline. Next in upward succession is very fine-grained blue-grey medium-bedded Georgetown limestone. This division on the west bank of Quitman Arroyo three miles above the Rio Grande has *Enallaster texanus, Pedinopsis symmetrica, Pecten subalpina, Diplopodia texana.* This faunule is middle Georgetown. Overlying the limestone in the anticline is Del Rio ferruginous, laminated and flaggy calcareous sand, argillaceous limestone and clay, with *Nodosaria texana*, about 300 feet thick. On top is the Buda fine-grained light buff, brittle, medium-bodied limestone, thirty feet in thickness.

The Georgetown in the southern Van Horn Mountains is nodular limestones and marls underlain by a bed of brown sandstone and has at the top more resistant heavier-bedded limestone. The total Georgetown section is 500 feet or more thick. In ascending order up the mesa nine miles south-southwest of Van Horn Wells the following fossils were collected: from lower Fort Worth-upper Duck Creek *Schloenbachia* sp. 1, Adkins and Winton, *Schloenbachia* sp. F. Adkins and Winton, *Holaster simplex*, low phase; from Fort Worth, *Schloenbachia graysonensis;* from Weno-Pawpaw *Nautilus texanus* and *Schloenbachia wintoni* Adkins; from Main Street *Holectypus limitis*. Three miles west of Chispa summit the sandstone noted above rests on the Fredericksburg and is followed by nodular clayey blue-grey limestone with *Enallaster texanus* and *Holectypus planatus, Kingena wacoensis, Neithea texana* and *Cypricardia texana* followed a little higher by a middle Georgetown horizon with *Schloenbachia* sp. *J* cf. *elobiensis, Enallaster bravoensis, Hemiaster calvini* and *Gryphea corrugata*. This is succeeded by limy shales with thin beds of limestone carrying *Inoceramus*. The strata lie on the west side of the fault east of which is upper Cretaceous.

On the north side of Eagle Mountain, midway between Eagle Spring and the Judge Love ranch house strata referred to the Georgetown are blue-grey, fine-grained, nodular, medium to heavy-bedded limestones. The base was not seen, the thickness of exposed strata being about 550 feet. Hard brown sandstone, about 100 feet thick, follow and appear to be the lower part of the Del Rio. Underlying the Eagle Ford is brittle, fine-grained clalky limestone referred to the Buda. Similar limestone, certainly Buda, extends from Chispa summit to the fault two and one-half miles to the west.

Some Washita outcrops along the lower northeast flank of the southern Quitman Mountains. The Kiamichi clays and overlying lower Georgetown impure limestone occur ten miles southeast of Quitman Gap.

UPPER CRETACEOUS

Eagle Ford beds outcrop in the upper valley of Van Horn Creek to the west and south of Chispa summit, east of the lower end of the Rio Grande Cañon across the Quitman Mountains, in a narrow strip along the outer western flank of the southern Van Horn Mountains, and northwest of Eagle Mountain east and northeast of the Judge Love ranch house.

The Eagle Ford of the Chispa summit locality begins with thin impure flaggy limestones, clays and shales resting on the Buda. Succeeding strata are greenish, calcareous, rill-marked sandstones and sandy shales. The shales are grey-blue when fresh and yellowish-brown when weathered. They have septarian concretions, fish scales and many fragmentary Inocerami and regularly spaced layers of secondary selenite about one inch in thickness. The fossils are *Inoceramus labiatus*, a large *Placenticeras* and two other genera of ammonites. Similar strata occupying a narrow outer zone on the west bank of the southern Van Horn Mountains have *Inoceramus labiatus* and *Metoicoceras* (?). Northwest of Eagle Mountain the dark blue-grey and drab shales contain some sandy and limy layers. The fossils collected are

Inoceramus labiatus, Inoceramus (several species) and *Prionocyclus*(?). Below the mouth of the Rio Grande Cañon across the Quitmans are dark fissile shales with thin limy flags weathering reddish-brown. One horizon of the flags shows numerous casts of ice crystals. *Inoceramus labiatus* is the most abundant fossil. The Eagle Ford strata are everywhere markedly bituminous.

The Austin south of Chispa summit appears to be mainly shales with some interbeds of thin limestone. No chalk was noted.

The Taylor occurs west of the cap rock in the vicinity of the abandoned town of San Carlos and to the north and south. Exposures near the middle of the outer northeastern flank of the southern Eagle Mountains under the overthrust sheet of Cox sandstone are referred to the Taylor because the Inocerami and ammonites in them appear to be different from those found in the Eagle Ford. Just above the probable Taylor strata are rudistid and echinoid-bearing limestones which may be lower Finlay. Provided the section is not overturned the lowest exposed beds referred to the Taylor are clays with large cannonball sandy concretions interbedded with thin layers of brown-weathering light grey finely crystalline limestone. The next member is ripple-marked dirty green-brown sandstone with *Cardium* and plant fragments. The highest beds are thinly-laminated *Inoceramus*-bearing shales with limy ammonite-bearing concretions.

Sections of the Taylor in the San Carlos area are given by Dumble[33] and Vaughan.[34] The strata are clays and sandstones, the former weathering greenish-yellow or tan and the latter brown. About 2000 feet of Taylor strata are exposed. Two beds of coal occur about 900 feet below the top.

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[33]Dumble, E. T., Cretaceous of Western Texas and Coahuila, Mexico. Bull. G. S. A., vol. 6, pp. 375–388, 1895.

[34]Vaughan, T. W., Reconnaissance on the Rio Grande Coal Fields of Texas. U. S. Geol. Surv. Bull. 164, pp. 73–83, 1900.

Taylor time brought to a close a cycle of marine deposition inaugurated with the Trinity. There was no break in the sequence of marine deposition between the Comanchean Cretaceous and the upper Cretaceous, although it appears that no species pass from the Buda into the Eagle Ford. The Buda is always found beneath the Eagle Ford over an area measured in hundreds of thousands of square miles in west Texas and northeastern Mexico. The Buda is everywhere thin and only a relatively slight amount of erosion would have removed it, at least from some places, before the deposition of the Eagle Ford took place, provided a break in the depositional sequence existed. The Upper Cretaceous sediments of the region are prevailingly detrital and the sediments become coarser in upward succession. The upper part of the Taylor, including the coal beds and overlying strata, are of fresh water terrestrial origin and contain bones of dinosaurs, animals which lived on the land.

LATE CRETACEOUS MOUNTAIN-MAKING

An epoch of mountain-making followed the deposition of Taylor sediments. The deformational movements were very intense in the Malone, Quitman and Eagle mountains, much less intense northeast of this area in the Davis and Barilla mountains and appear to have come to an end almost entirely before we reach the Chisos Mountains in the southern Big Bend country, southeast of this area. It is to this latter region that one must now go to find the upper time limit of the mountain-making epoch.

Udden[35] found in the Chisos country that the lower part of the Rattlesnake formation is marine Taylor. The marine sediments grade up into fresh water terrestrial deposits in the upper part of which are layers of volcanic ash and bones of Cretaceous dinosaurs. The Tornillo clays overlie the Rattlesnake beds, contain dinosaur remains and are largely composed of very fine débris resulting from the disintegration of volcanic rocks. On the Tornillo clays rests a great

[35]Udden, J. A., A Sketch of the Geology of the Chisos Country, Brewster County, Texas. Univ. Texas Bull. 93, 1907.

thickness of volcanic tuffs, sandstones, clays and a few layers of conglomerate—the Chisos beds. No fossils have yet been found in the Chisos beds.

At first glance, it is somewhat surprising that no greater proportion of coorse conglomerates occurs in the post-Taylor sediments of the Chisos country. But upon interpretation of the geologic history we find that the sea vanished about the close of the Taylor, leaving a very flat and low district in which sedimentation still went on. The Tornillo clays were probably deposited in a lake. The basin of the lake may have formed by gentle deformation concomitant with the more intense deformation farther west or by formation of a dam of volcanic rocks, either lavas or tuffs. The tuffs of the upper Rattlesnake and of the Tornillo settled in this body of water and were somewhat altered in it. The Tornillo basin must have been relatively of small extent and local importance. The exposures of the Tornillo we now know were away from the shore lines of the basin or else no great amount of coarse detritus was contributed by the drainage entering the basin. The significant points are that the deposits are so largely tuffs and that they contain dinosaurs which are characteristic of the Cretaceous.

For the rest of the story we turn farther west to the region included in this report. Here we find the intense mountain-making movements accompanied and followed by an epoch of great subaerial erosion. Even the Pre-Cambrian was in places exposed at the surface by this erosion. At one place or another in the region the rhyolitic lavas and tuffs comprising the basal volcanic series rest directly upon strongly tilted and eroded edges of every one of the older rock series. The mountain-making movements and the concurrent and subsequent erosion were processes operating through many thousands of years, compared with which the eruption of rhyolite lavas and tuffs may have been of comparatively short duration. The record indicates the greater part by far of the mountain-making and erosion was completed before the main volcanic eruptions began. Yet the dinosaurs in the volcanic tuffs show that eruptions began before the close of the Cretaceous; hence one cannot escape the conclusion that the mountain-making and erosion epochs occupied that part of later Cretaceous time comprised between the end of the Taylor and the final extinction of the dinosaurs. The only escape from this conclusion is by supposing great volcanic eruptions occurred before the mountain-making but this is contrary to everything yet known in western North America.

The progressive coarsening of the sediments upwards in the Taylor implies a rising of the land areas and increase of the activities of erosion on the land areas from which the Taylor sediments were derived. The rise in the land was presumably the beginning of the mountain-making movements.

The sediments derived from the great erosion accompanying and following mountain-making were mainly transported to areas outside of those of the Trans-Pecos Texas mountains. Thousands of feet of detrital sediments—sandstones, sandy shales and conglomerates—were deposited as post-Taylor marine and brackish water Cretaceous strata in northeastern Mexico and in the Rio Grande embayment around Eagle Pass. In these regions we get the depositional history complementary to the erosional epoch in Trans-Pecos Texas.

VOLCANISM

Lava flows, pyroclastics (tuffs and tuff-breccias) and intrusive igneous rocks cover a very large percentage of the surface of southwestern Trans-Pecos Texas. The sequence begins with the ultra-acid, passes into less acid and closes with the more basic intermediate. Igneous rocks reached the surface from vents in the Davis and Chinati Mountains, probably also in the Quitman and Eagle Mountains and possibly in some other places. The volcanics of rhyolitic composition exceed in bulk all others. These, being earliest, have been more preserved than the later overlying volcanics. The basalts, especially, have been almost totally removed by erosion subsequent to their outflow. The rhyolitic lavas have a thickness of over 3000 feet in the Chinati Mountains, where they lie on from 100 to 200 feet of rhyolitic tuffs and tuff-breccias. The rhyolitic volcanics in the Rim Rock country have a total maximum thickness of 4000 feet or more but more than half the total is tuff. Tuff-breccias hundreds of feet in thickness form the base of the rhyolitic series in Eagle Mountain. Pyroclastics are not nearly so prevalent in the igneous succession younger than the rhyolitic. Bones of land tortoises are found in the rhyolitic tuffs.

Interbedded with the rhyolitic volcanics are a number of conglomerates, sandstones and clays. In the Rim Rock country these sediments make up nearly half the lower 1000 feet of the volcanic series. They are much less in amount in the upper 3000 feet of the volcanics. Lava flows, ranging in texture from obsidian through pitchstone and vitrophyre to porphyritic with finely-crystalline groundmass are interbedded with the tuffs, tuff-breccias and sediments in the Rim Rock country, in Eagle Mountain, in the Van Horn Mountains and in the region south of the Wiley Mountains. Originally, the rhyolitic volcanics probably covered the entire surface. Some of the rhyolitic breccias contain fragments of basalt, which probably came from volcanic rocks older than the rhyolites. The Rim Rock, forming the summit ridge of the Tierra Vieja Mountains, is an extensive lava flow about 300 feet in maximum thickness of quartz-pantellerite,[36] an extremely rare volcanic rock.

Numerous rhyolite sills and dikes are intruded into the pre-volcanic sedimentary rocks on the north slopes of Eagle Mountain. Coarsely-crystalline granite of a large intrusive mass is found in the Quitman Mountains and probably was intruded during the time of the rhyolitic eruptions.

Trachytic, phonolitic and andesitic eruptions follow the rhyolitic. As yet we do not know if any considerable time intervened between the two. There is a dioritic intrusive

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[36]Lord, E. C. E., Report on Igneous Rocks from the Vicinity of San Carlos and Chispa, Texas. U. S. Geol. Surv. Bull. 164, pp. 90–95, 1900.

mass in the western Chinati Mountains and a small plug near the head of the Pinto Cañon.

A large intrusive mass of quartz-syenite lies south of the Wiley Mountains and a number of other similar intrusives outcrop to the north and northeast of Wendell section house.

The northern Quitman Mountains comprise the largest intrusive mass of Trans-Pecos Texas. The granite, already mentioned, occurs at both the north and south ends. In between and probably later than the granite is a large intrusion of quartz-syenite. Probably still later in age are dikes of diabase and augite-porphyrite, cutting the other intrusives of the Quitmans.

Basaltic lavas were found in the Van Horn Mountains and also form the capping of three sharp peaks just south of the west end of the Wiley Mountains. Diabase dikes are especially numerous in the Rim Rock country and in Pinto Cañon north of the Chinati Mountains. They were also found in northern Eagle Mountain and in the Van Horn Mountains. Two series of diabase dikes, one series running north-south and another east-west, cut the upper Cretaceous sediments in the territory between the Rim Rock and Rio Grande. Many of the diabase dikes are very fine-grained.

Contact Metamorphism.—The diabase dikes generally have hardened and changed the color of the sediments for a foot or two beyond the contact. A rhyolite dike cutting Permian limestone in the arroyo about one-half mile north of Eagle Spring has changed the limestone into marble for an average distance of twenty-five feet from the contact. Trinity limestone has been changed to marble on the contact with an intrusive seven miles north-northeast of Wendell section house.

The greatest amount of metamorphism occurs on the contact between syenitic, monzonitic or dioritic intrusives and the argillaceous limestones. Silica and compounds of the metals are added to the limestones, increasing notably their mass. The greatest contact metamorphism known in Texas has taken place in the zone of contact between the quartz-syenite intrusive of the Quitman Mountains and the

Finlay limestone. These contact zones occur on the east side but the metamorphism is best seen in the Big Gulch draining a low saddle across the intrusive mass from two to three miles south of the S. P. Well. The upper surface of the intrusive here lies lower than to the north and south and there still exists a portion of the sedimentary roof. A great grossularite garnet zone is developed on the contact. Subordinate contact-metamorphic silicates are vesuvianite and actinolite. Beyond the garnet zone the limestone is changed to marble. Sandy beds on the contact are changed to hornfels. Much secondary silica in the form of quartz, chalcedony, hyalite, and chert has been added. Iron, manganese, copper, zinc, lead and silver minerals, originally probably oxides and sulphides, have also been added to the contact deposits. Hematite, both the specular and amorphous variety, often marks the actual contact and is found in fissures and other forms of cavities. Long acicular quartz crystals were often formed in cavities. Latest of all to form was botryoidal and mammillary chalcedony which encrusts the other minerals. The minerals added in greatest amount to the sedimentary rocks are silica and iron oxide.

MID-TERTIARY DEFORMATION

After the eruption of all the igneous rocks, except possibly the basalts, they were faulted and folded. The faulting was most extensive in the Van Horn and Tierra Vieja mountains and in the district between those mountains and the Rio Grande. The volcanics were gently folded and the Big Bend syncline was formed. The greater relief features seen at present in the region were made by those mountain-making movements.

EPOCH OF BASIN-FILLING AND RIO GRANDE BASIN LAKE DEPOSITS

The uplifting of the present mountain ranges destroyed in large part pre-existing drainage lines. Structural basins were formed between the mountain ranges. Some of these are yet basins of interior drainage. Parts of two of them, the Salt Basin and the Eagle Flat Basin, exist in the region we are considering. Originally, they existed all the way between the San Luis Park of southern Colorado and central Mexico and in Mexico some of them, like the Bolson de Mapimi, still exist. The basin of the Rio Grande, all the way from its source to the Boquillas Cañons at the eastern side of the Big Bend syncline was dammed and a lake or a series of lakes was formed along the present valley of the river. The lake deposits occur all along the valley of the river above the Boquillas Cañons.

The lake deposits are largely silts, fine-grained and pulverulent, ranging from flesh-color to orange-brown and light greenish-grey. They contain much crystalline gypsum (selenite) in small films or irregularly-distributed clusters. Sometimes the silts are imperfectly-bedded; sometimes they are laminated. Some beds are sandy, others contain little or no sand. Light grey, lime-cemented, cross-bedded sand layers a few inches in thickness are sometimes interbedded with the finer sediments. Where they rest directly against the bed rock flanks of the mountains they are often conglomeratic or contain talus breccia from near by steep slopes of the bedrock. In Mexico two miles southeast of the upper end of the Boquillas Cañons fine silts rest directly against a steep, high scarp of Comanchean limestone. Exposures 50 to 100 feet in thickness are common. The highest exposures on the flanks of the Malone, Quitman and Eagle mountains are about 500 feet above the present river level, but as the silts have been tilted and greatly eroded data on their original thicknesses are lacking.[37] They are much too fine and too well-assorted to be stream deposits. The deposits are dissected into badlands by the arroyos.

Likely contemporaneous with the lake beds are high-level alluvial débris gravels now 800 to 1300 feet above river

[37]North of Fort Bliss, near El Paso, water wells have penetrated 2300 feet of these deposits without reaching their base. A well drilled near Newman, N. M., in the Hueco Basin just north of the Texas line, was still in the lake beds at a depth of 4910 feet.

level, forming the divide between the middle course of Van Horn Creek and the Rio Grande in the vicinity of the Presidio-Jeff Davis county line. The surface of these gravels slopes toward the Rio Grande with an angle of one degree. The gravels on the divide are 100 feet or more in thickness. They are very coarse, ill-assorted and cross-bedded; in short a typical alluvial fan deposit. There are boulders and pebbles of all sizes up to three feet; the larger are subangular to angular in contour. The gravels are igneous rocks and Cretaceous limestones and sandstones. On surface exposure the limestones have been greatly dissolved by weathering agencies; silicified fossils sometimes project as much as an inch beyond the limestone matrix, giving the boulders a strongly etched appearance. The gravels are partly cemented by caliche (calcium carbonate). Their margins have been greatly dissected by arroyos. Their average angle of slope is less than that of the modern débris slopes, which suggests their formation at a time when the local base-level was higher than at present.

No fossils have yet been found in these deposits in Texas. The great vertebrate paleontologist, E. D. Cope, found fossil mammals of upper Miocene (Loup Fork) age in them nearly fifty years ago in the upper Rio Grande valley near Santa Fe, N. M. Very likely they are not all of the same age. The precise date of the mountain-making movements and of the formation of the lake or lakes has never been determined. The earlier unconsolidated deposits of the Llano Estacado of west Texas and eastern New Mexico were transported from the Trans-Pecos mountains. The deposits of the Llano Estacado range in age from lower or middle Miocene to early Pleistocene. Other evidence in the Rocky Mountains proper apparently agrees with the assignment of the beginning of the making of the present mountains to the Mid-Tertiary, not far from the middle of the Miocene.

Except in the Rio Grande drainage area these earlier basin deposits are entirely concealed from view by the later.

A well at Hot Wells in Eagle Flat was sunk 1000 feet without reaching their base, another at the very head of Green River (Glenn Creek) failed to reach their base at 1100 feet and another well ten or twelve miles north of the Figure 2 ranch failed to reach the base of the unconsolidated Salt Basin deposits at 1620 feet. Bed rock of lava lies at a depth of 872 feet beneath the town of Valentine.

LATEST EPOCH

Subsequently the lake of the Rio Grande Basin was drained, presumably by the cutting down of its outlets. When its surface became dry land the streams spread a covering of alluvial gravels and sands over the surface of its deposits. Earth movements, if, indeed, they were ever entirely quiescent during the later Tertiary, were renewed and the lake silts were tilted and faulted to some extent. On the west side of the Eagle Mountains near the bedrock contact they are tilted towards the mountains. They are tilted eastward, away from the bedrock, on the east side of the mountains. As the various Rio Grande cañons were excavated to lower and lower levels by erosion, arroyos above the cañons cut deeper into the alluvial capping and underlying lake silts until today both are greatly dissected with remnants left as high alluvial benches or stream cut terraces. In the Salt and Eagle Flat basins the process of filling-in still continues, but tributaries of the Rio Grande are gradually lengthening their courses headwards and capturing the borders of the interior basins.

PROBABLE EARTHQUAKE CRACKS

Close to the head of Green River, between the Taylor ranch house and the road to the Mica Mine there is a series of deep, straight and narrow cracks. These cut straight across country in a general north-south direction. They cut the clays of the arroyo beds and the gravels of the benches. Earthquakes are the only agency known to cause such cracks. They may have been formed during the great earthquake in northeastern Sonora in 1887.

STRUCTURE

(1) The northeastern area, comprising the Wiley Mountains, the northern Van Horn Mountains, the southern Carrizo Mountains and the northeast flanks of Eagle Mountain, constitute with the northern Carrizo Mountains and the southern and southeastern margin of the Diablo Plateau to the north of the region herein treated, an irregular domical uplift. The Pre-Cambrian rocks herein outcrop and the dome is the highest uplift in Texas. The great dome is much faulted. An area of overthrusting and overfolding in a northeastward direction bounds it on the southwest. There are a few faults running slightly north of east on this flank. These are characterized by great horizontal displacements. Both the above series of faults were formed by the late Cretaceous mountain-making. The second series, of dip faults, displace the overthrust and overfolded strata; hence are later in date. Another series of faults runs northwest-southeast. These are of the normal or gravity type and date from the mid-Tertiary epoch of mountain-making.

(2) Igneous intrusions have produced high structural areas in the regions of the Chinati and Quitman mountains. The Chinati intrusion has brought the Permian and Trinity to the surface within the limits of the area included in this report and Pennsylvanian strata to the surface southeast of its limits. The Quitman intrusions have uplifted the Trinity on their summits and eastern flanks and may have greatly aided in bringing the Permian and Jurassic to the surface west of the intrusions. The granite at the south end of the Quitman intrusive mass breaks sharply across the strike of the Trinity and at the north end has folded the Washita into a syncline between it and the Sierra Blanca intrusion but has not brought to the surface the Trinity and Fredericksburg. It is suggested that the intrusive absorbed with its mass ("stoped") the sediments at their north and south ends and to the east and west lifted the sediments. It was mechanically easier to lift the sediments along strike lines than at right angles to those lines.

(3) The most complicated structure is in the Malone, Eagle and Quitman mountains. Close folding, overturning and overthrusting are common in those mountains. The structural axes run northwest to southeast and the overturning and overthrusting is to the northeast. In age these structures belong to the late Cretaceous mountain-making epoch.

(4) In the southern Van Horn Mountains and the Rim Rock country the structures run from north-south to northwest-southeast. The folding is gentle to medium in its intensity but faults are extensively developed and some of them have great amounts of displacement. There are some minor east-west faults in the San Carlos coal area. These structures are of Mid-Tertiary date of formation.

Each of the areas above outlined are therein shown to have rather definite structural characteristics and may be regarded as different structural and physiographic provinces.

There is a fault scarp marking the west base of the Wiley Mountains. The displacement here is between Pre-Cambrian and Lower Permian and amounts to at least 300 feet. The fault runs a few degrees west of north. The Wiley Mountains and the region south of it and north of the line of the Southern Pacific Railroad has gentle dips with no pronounced structural lines. The Permian of the Wiley Mountains has a general gentle eastward dip.

Three faults of moderate displacement were mapped in the southern Carrizo Mountains east of Dalberg section house. Here the Permian has a general southwest dip. These faults run north-northwest. The Pre-Cambrian of the Mica Mine locality forms the center of a small dome with the overlying Permian strata tilted away from the center of the uplift. The uplift is bounded on the east-northeast by a north-northwest running fault, which brings the Cox sandstone down to the northeast in contact with the Pre-Cambrian and Permian. A broad and gentle anticline with north-northeast major axis crosses the Permian outcrop west of Lobo station. The Cox sandstone on the east flanks of the Van Horn Mountains dips southward at the rate of about four degrees. On the north and west flanks of the northern Van Horn Mountains the Cox has some broad and gentle folds with axes running from north-south to the north-northwest. The wind gap in the mountains about twelve miles south-southeast of Van Horn Wells is apparently crossed by an east-west fault increasing in displacement to the west. The folding becomes more intense on the west flank both north and south of the probable fault. There is a very sharp and narrow anticline running nearly north-south through the summit ridge. South of this the structural lines curve to the southeast.

A great line of faulting begins about five miles northwest of Chispa summit. This fault first runs southward for about eleven miles, the amount of displacement steadily increasing in that direction. East of the fault the Washita and upper Cretaceous dip almost due south at the rate of about seven degrees. West of the fault the Fredericksburg and Washita dip westward at the rate of about twenty degrees and within half a mile to a mile the dip flattens to one-third that amount. The Fredericksburg along the fault line has been dragged down to the east by the movement, which appears to have been largely of the nature of an upthrust. Some two miles south-southeast of where the rhyolitic volcanics are brought down to the level of the Taylor the fault line or zone turns southeast for seven miles, still running between the volcanics and the Taylor. Beyond this it was not traced but it appears to continue some forty miles in a general southward direction though not in a straight line to the southern limit of the area included in this report. Just west of the old town of San Carlos the displacement between the quartz-pantellerite on the west and the coal-bearing Taylor on the east is 2000 feet more or less. About seven miles southwest of Brite Postoffice and ranch headquarters and also on the Candelaria road the lava is faulted down into contact with probable Taylor. In Pinto Cañon the fault brings the probable Fredericksburg into contact with the Permian. There may be several faults or a zone of faulting instead of one continuous fault. Minor faults some north-south, others east-west and some north-northwest are common in the country between the Rim Rock and Rio Grande. There are also gentle folds with axes ranging in direction from northeast to north and northwest. A syncline with northwest axis runs for about nine miles through the volcanics near the divide between upper Van Horn Creek and Rio Grande. Lower Van Horn Creek follows the axis of a northeast-southwest anticline of rhyolitic tuffs. A number of smaller anticlines and synclines are found in the coal-bearing Taylor near old San Carlos and to the north and south. A north-south anticline exposes the Permian in Pinto Cañon. The Rim Rock quartz-pantellerite lava flow dips east or east-northeast at angles up to eight degrees and this same general direction of dip continues to the trough of the Big Bend syncline far to the east of the area included in this report.

The great structural trends of the northwestern section are northwest-southeast although along the Rio Grande they become more nearly north-south. The structure of the Malone Mountains has already been described in the section on the Malone beds. On the southwest flank the Trinity dipping southwest apparently follows in upward succession the older rocks. In Devil Ridge and the Quitman and Eagle mountains changes in strike lines often take place along lines of overthrusting.

There has been considerable crumbling as a consequence of intrusive forces later than the first epoch of folding in the sediments adjoining on the east the Quitman intrusive mass. The structures formed by the intrusion have north-south strikes parallel to the east side of the intrusive mass. The structural influence of the intrusion comes to an end about four miles southwest of Sierra Blanca station.

An overthrust runs just to the northeast of the summit ridge of the northwestern two-thirds of the southern Quitman Mountains, bringing strata of the Finlay formation over those of the Fredericksburg. Southwest of the overthrust the Trinity strata are overturned for a distance of some fourteen miles southeast of Quitman Gap. Farther southeast there is close folding with some local overturning and the strike swings until it is north-south along the Rio Grande. To the east in the lower half of the Rio Grande Cañon across the mountain ridges the strata are again overturned and there is at least one overthrust. Still farther east, near the lower end of Quitman arroyo the structure again becomes normal but the dips are steep. Just west of the divide on the Hot Springs road there is an east-northeast fault of large horizontal displacement. To the northeast of the main overthrust area in the northwestern two-thirds of the southern Quitmans the dips range from medium to vertical.

An overthrust on the southwest side of Devil Ridge brings the Cox sandstone over the Finlay. The Cox sandstone in Devil Ridge is either in an overturned anticline or else is overthrust over the Finlay in the small hogbacks to the northeast. Two and one-quarter miles southwest of Grayton section house, the Finlay is horizontal. From two miles to the east of the south end of Devil Ridge southeastward to the north base of Eagle Mountain the lower Trinity is overthrust on top of the Eagle Ford. The overthrust fault is cut and displaced by three faults running in general slightly north of east. The southern of these runs through Eagle Spring and has a horizontal displacement of something like a mile. It is well exposed near the middle of its course. Here the dip of the fault plane is sixty degrees to the north. Beds are dragged down on the fault plane as if displacement were of the normal type. Brittle, brecciated, brown sandstone capped by heavy-bedded brecciated Finlay limestone forms the hanging wall and medium-bedded limestone, brecciated, and succeeded by rusty brecciated sandstone forms the foot wall. The fault plane is exposed for several hundred feet vertical distance in the walls of an arroyo. The zone of brecciation extends fully 100 yards from the fault. The northern fault, which passes near the Judge Love ranch house, has a horizontal displacement of approximately 2000 feet. It is probable that these and the other cross faults in the Quitman and Eagle mountains were caused by thrust movements slightly later in date than the overfolding and overthrusting.

By far the greater amount of the strata in the southern Quitman Mountains, the Devil Ridge and adjoining territory and on every side of Eagle Mountain proper are isoclinal in structure and dip southwest. This is markedly changed about five or six miles southwest of the summit of Eagle Mountain, where the strike abruptly turns at a right angle to the northeast-southwest. Cross faulting with horizontal displacement may be found in the vicinity of Oxford Springs, which lies in the zone of transition. To the south the strikes run north-northwest and folding is mainly normal except to the east of Oxford Mountain where there is some overfolding and where an overthrust brings the Trinity over the Upper Cretaceous.

The Texas zone of intense folding is circumscribed within narrow limits. None of it is visible northwest of the railway line, although in the territory between the Finlay Mountains and the Franklin Mountains the structures may be deeply buried beneath bolson deposits.[38] The northeastern visible boundary is the débris flat at the northeast foot of Eagle Mountains. The southeastern boundary runs from the northern end of the Upper Cretaceous exposure, about seven miles east-southeast of Eagle Mountain summit, west-southwest to the mouth of the Rio Grande Cañon across the Quitmans. To the south, east and north there are areas of much gentler folded or scarcely deformed strata. The high Diablo Plateau, an immense area of nearly flat-lying competent anthracolitic limestone with average thickness of a mile bounds the intensely deformed area on the northeast and east. This may have served as a buttress against which thrusts operating in a northeastward direction piled up or perhaps they partially overrode this buttress. It is commonly thought that such thrusts have come from a direction at right angles to the structural lines

[38]The zone extends at least as far as Alarcon Hill, 7 miles northwest of Finlay station.

which they form. Accordingly in this instance there would have been an overthrust from the southwest, an underthrust from the northeast, or simultaneous movements from the two opposite directions. Still it is possible that the main force or opposedly-directed forces operated parallel to the structural axes formed or diagonally to the latter. There are also to be taken into consideration the thinning-out of all the Cretaceous sediments to the northwest and the passing of the Trinity and Fredericksburg strata to the southeast into very competent heavy limestones some 3500 feet thick. Also there was about a mile thickness of Upper Cretaceous strata over the Comanchean strata when the deformation began. The direction of yielding of rocks under deformatives forces is a resultant of the direction and strength of the deformative forces, the resistance of the rocks deformed and of those of neighboring areas and the original loads over the deformed rocks now exposed at the surface. Such intense deformation will not reach to any great depths and in it rocks move laterally more than they do vertically.

The great valley areas between the folded bedrocks of the mountains southwest of the Quitman Mountains, between the Quitman and Eagle mountains and to the northeast of the Eagle Mountains are probably synclinorial areas of Upper Cretaceous rocks buried beneath the alluvium. Such at least is the case in northeastern Mexico.

PHYSIOGRAPHY

Minor physiographic features of Trans-Pecos Texas and their origin have already been discussed in previous reports by Dr. Udden and the writer.[39] The same processes operating on the same rocks under the same climatic conditions as in other parts of Trans-Pecos Texas are found here also and their discussion would be unnecessary repetition. The larger relief features and the course of the Rio Grande will be briefly described and explained.

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[39]Reports on Chisos, Shafter, and Southeastern Trans-Pecos Texas districts.

Some of the mountain ranges of this region are erosion residuals in the sense that they owe their present forms and base and summit outlines to erosive agencies that have been in operation so long that the original features of the deformed mountains have for the most part been destroyed. These are the older mountain ranges in which the physiographic erosion cycle has reached to the stage of maturity or beyond that stage. In such, inequalities in resistance of the various rocks to erosion are mainly responsible for both major and minor relief features. The structural attitudes of the rocks, formed by deformative forces, determine the shape and form and direction of the relief—of the hills, ridges and drainage lines,—both major and minor. The more resistant rocks form the topographic projections and the less resistant the topographic depressions.

In the eastern part of the Van Horn Mountains the sedimentary rocks lie nearly horizontal resulting in a terrace-step and mesa topography. The more resistant layers form the abrupt steps on the side or the cappings. The less resistant rocks in between form the gentler slopes and consequent to their more rapid weathering and removal undermine overlying more resistant rocks, causing them to fall off and give steep cliff faces along fractures and joints. Valleys and drainage lines form in regions of less resistant and more easily removed rocks. Less resistant rocks have smoother, more subdued, surface topography; more resistant rocks steeper and higher topography.

When strata are tilted as in most of the region, especially in Devil Ridge, the southern Quitmans and in the Eagle Mountains except the lava-covered areas, the more resistant layers form cuestas or hogbacks, with the dip slopes of the upper surfaces of the more resistant layers forming one flank and the escarpment, where the resistant rock breaks off by undermining, the opposite, generally steeper, flank, followed, however, on the lower slopes by more gentle gradients wherever there are less resistant rocks. The valleys run parallel to the strike, beginning their history on the less resistant rocks. When strata become vertical the more resistant form perpendicular coxcomb-like ridges, like the long ridge of heavy-bedded Finlay limestone from four to six miles southeast of Eagle Mountain summit. In the arid climate heavy well-cemented limestones and sandstones are the most resistant rocks and form the boldest relief features.

The mature or post-mature ranges are the Malone, Quitman, Eagle and Van Horn mountains. These are characterized by lack of continuity in their summits and, more specially, by base lines neither regular nor straight.

The Wiley and Tierra Vieja mountains are younger ranges and in outline and major relief show more the direct effects of mountain-making forces and less the effects of erosion. A fault scarp forms the west cliff and highest summit ridge of the Wiley Mountains. Another great fault lies between and parallel to the Rim Rock summit of the Tierra Vieja Mountains and the course of the Rio Grande. This fault probably begins at the north between Lobo station and Van Horn wells and extends a little east of south all the way to the Chinati Mountains. The scarp of Cox sandstones forming the eastern base of the central Van Horn Mountains has a fairly straight base-line and is not a strike escarpment, as it would be if formed primarily by erosion, but is a scarp at right angles to the strike; hence appears to have formed primarily by faulting. South of Chispa summit the scarps along the fault are formed by the more resistant rocks. It must necessarily be so unless the faulting were very recent, since most of the rocks along the fault are unconsolidated volcanic tuffs or soft clays and shales, which are rocks of extremely poor resistance.

There are two kinds of fault scarps and the difference between them is mainly a matter of age. In fault scarps of recent faulting the upthrown side forms the scarp or topographic prominence, regardless of which side may have the more resistant rock. In other words, the faulting has been so recent that erosion subsequent has played but a minor rôle. The second kind of fault scarp may well be termed the erosion-fault-scarp, the scarp being situated at or near the fault but the topographic escarpment may be either on the upthrown or downthrown block and is always formed of more resistant rock. The scarp owes its prominence to differential erosion and the faulting itself may be of ancient date. In the Great Basin region of the United States many of the fault scarps were formed by very late faulting. These fault scarps are very little eroded. They often have perched or hanging valleys with greater gradients where they cross the scarp than higher up their courses. The scarp front shows triangular facets with straight bases formed by the fault and steep undissected slope surfaces. The triangular facets are separated from each other by steep, deep and narrow, V-shaped in cross section, ravines and cañons. Minor drainage lines on the scarp front are either for the most part wanting or else as yet but poorly developed. Furthermore, many of the young faults and fault scarps of the Great Basin cut diagonally across rock structures of older date and drainage lines on the fault scarps and often in their upper courses in the highlands back of the fault scarps show relatively little adjustment to inequalities of rock resistance. Some of the best examples of scarps produced by late or recent faulting are found in the Wasatch and neighboring ranges in the vicinity of Salt Lake City.

The Trans-Pecos ranges of Texas and New Mexico exhibit fault scarps and these ranges are rather typical Basin ranges. But in general the Trans-Pecos fault scarps are more greatly modified by erosion than the younger portion of the fault scarps of the Great Basin. In nearly all the Trans-Pecos fault scarps the faulting is parallel to the strike of the rocks. Also, the summits of the scarps have receded a considerable distance from the fault lines. A number of high limestone scarps of the Trans-Pecos country have been called fault scarps although no faults can be found. Such scarps in some instances may be purely erosion scarps, since the decisive criteria of fault scarps are wanting.

That at least the major part of the faultings producing the fault scarps in the Trans-Pecos ranges of Texas and New Mexico are of older date than the faulting producing the younger and more perfect fault scarps of the Great Basin may be deduced from the following considerations, although some of the Great Basin fault scarps are likely as old as those of the Trans-Pecos country:

1. Drainage lines on the Trans-Pecos fault scarps and in the highlands back of the fault scarps are much more perfectly adjusted to inequalities of rock resistance.
2. The scarps have receded farther from the faults.
3. Triangular facets are conspicuously lacking.
4. The formation of the fault scarps was one of the processes forming the basin of interior drainage and deposits formed after the faulting occurred are Upper Miocene age in the Santa Fe Basin.

There is nothing known in the Great Basin to preclude and, indeed, there is considerable evidence to favor the view that fault scarps began to form there as long ago as the Miocene. But it should be emphasized that post-Miocene faulting is relatively much more important in the Great Basin region than in the Trans-Pecos region. In the latter region the mountain-making movements—probably the faulting also—did not end with the Miocene but the main structural features were formed by Mid-Tertiary movements and those Mid-Tertiary movements may have been greater in intensity than all subsequent movements. The point most important, however, is that both regions are similar in structure and that these structures were formed during the later Cenozoic. Fault scarps are youthful features and under any known or conceivable climatic conditions no fault scarp could have lasted throughout the entire Cenozoic.

Where fault scarps are known or suspected, in the region between the Rio Grande and the Pecos, no strong deformation took place between the upper Pennsylvanian and the Mid-Tertiary. The rocks forming the scarps are very largely heavy, solid limestones of the Pennsylvanian and Permian. Whatever strong deformation these rocks have suffered, either by folding or by faulting, has taken place during that epoch herein referred to the Mid-Tertiary or to later movements parallel to the Mid-Tertiary lines of deformation. Therefore the longer faults of greater displacement are parallel with the strike and with the major axes of the folds. The great faults occur almost invariably along the highest portions of the anticlinal axes. There were first formed the anticlines, which became unsymmetrical with steeper dips on one flank. When the steeper dip locally approached the vertical the continuity of the strata was broken and displacement by faulting took place. The faults formed along the axes on the flanks of the steeper dip. The faults therefore represent the places of highest structure on unsymmetrical anticlines, where deformation was intense enough to cause fracturing and displacement.

Anticlinal areas suffer greater erosion than synclinal. They are higher and the streams have greater transporting power, rainfall is greater, and abrupt changes in temperature are greater. Furthermore, the rocks on the upper flanks and axes of anticlines are stretched during the folding. The stretching forms joints and other fractures which are lines of weakness where erosion is more active. Hence erosion makes great strides in regions of higher structure on anticlines and before long valleys are formed. Erosion scarps of the more resistant layers are formed and recede in precisely the same way down the dip and with their fronts coinciding with the strike along the anticlines as along the fault scarps. This is why the geologist must be cautious in the Trans-Pecos country or he will mistake ordinary scarps of erosion for eroded fault scarps.

The top of the west scarp of the Wiley Mountains has receded from one-half to three-fifths of a mile back from the fault line at the base. Three-fourths of the scarp is formed of resistant limestone; the lower one-fourth is less resistant schists. Undermining has played an important rôle in the recession but since it is a process mostly concentrated in one zone recession has been less rapid than in the average case. The Rim-Rock escarpment has receded from one-half mile to six miles from the fault. Here recession is a very rapid process; the dip being low and displacement measured in thousands of feet gives high relief and facilitates erosion. There are only one or two layers of resistant rock—the lava flows—in the section of the upthrown block; the Upper Cretaceous shales and the volcanic tuffs are extremely susceptible to mechanical disintegration, wearing of erosion and are easily transported. Recession has therefore been rapid. The gradient between the Rim-Rock and Rio Grande averages about three hundred feet to the mile, which means rapid erosion and transportation. The upper slopes are so steep there is a great deal of slumping. Pinto Cañon, which has very steep gradient in the bedrock sections of its course, has accomplished a great amount of erosive work and that in rocks relatively more resistant than those of the upthrown block farther to the north. The second greatest amount of absolute relief within a short distance in Texas is that between the summit of Chinati Peak and the Rio Grande twenty miles distant. This amounts to 5000 feet, 3500 feet of which comes in a distance of three miles. This upper gradient is surpassed in Texas only by that of the western fault scarp of Guadalupe Mountains which falls 4500 feet in one and one-fifth miles.

The country between the Rim Rock and river is very picturesque and extremely rough. It is well exhibited along the road from Brite's ranch to Candelaria. The Rim Rock forms a steep precipice from 150 to 300 feet in height, the scarp side of a long and lofty cuesta, gradually rising westward above the basin flat near Valentine. Westward from the Rim Rock the country falls rapidly to the river. The upper slopes are strewn with a wild jumble of great rocks which have toppled off the cliffs. Lesser hogbacks and terraced buttes and mesas form the most striking features of the intermediate regions. These are separated by steep and deep gorges. The lava flows are dark reddish-brown. The interlayered tuffs often weathering into a minutely dissected, gullied, badland topography range in hue from white to almost every shade of red, yellow and green, the colors being distributed in broad layers. The relief features are visible in greater detail and the colors blend more harmoniously when the sun is near the horizon.

Pinto Cañon has cut a gorge about five hundred feet in depth in the Permian bedrock below the level of the gravel benches of the lacustrine epoch. This gives a measure of the erosive work accomplished since the draining of the Rio Grande interior basin. It forms but a fraction of the total erosion since the Mid-Tertiary mountain-making. The down-cutting action alone of that cañon in the time between the beginning of the mountain-making and the draining of the basin amounted to 2000 feet. Very striking is the contrast between the rough and steep topography of the headwaters tributaries of Pinto Cañon falling down the steep erosion scarp and the flowing curves of the low, rounded hills on the opposite side of the divide in the drainage area of the Salt Basin as seen along the Cuesta del Burro on the Marfa-Ruidosa road. On the one side are the bold and youthful erosion forms of the Rio Grande drainage and on the other the subdued, old age topography of the older cycle of erosion still operative over the region of interior drainage.

Terraces of rejuvenation are found almost everywhere along the Rio Grande and its principal tributaries. Gullying is so common the unconsolidated deposits exhibit some of the roughest and most wearisome sections of the entire region. Rejuvenation has not yet reached back more than twenty miles up Green River, at the head of which the basin filling is yet undissected and at least 1100 feet thick. Before the rejuvenation the Trans-Pecos mountain country greatly resembled the Great Basin region of today with alluviated basins merging around the ends of the mountain ranges and débris slopes rising gently from the lower basin flats towards the bedrock of the mountains, which they largely or in some cases entirely covered. This old-age stage of the interior basin erosion cycle is still developing at the head of the Salt Basin in the country around Marfa.

Where lava is the predominant or the only rock exposed in a section of great thickness two types of topography are developed, one older and somewhat more subdued in the region of interior drainage and the other with great cliffs in the rejuvenated regions now tributary to the Rio Grande. The greatest contrast is that between the precipices of the Chinati Mountains and the rugged but less steep slopes on the north side of Eagle Mountain. When tuffs are interbedded with the lavas the erosion forms are much like those produced in sedimentary rocks where beds of clay or shale alternate with heavy limestones. Erosion forms in the thick lava flows free from interbeds of tuff are similar to those in thick massive limestone.

Erosion forms in intrusive igneous rocks are distinctive. The Quitman intrusive mass is the best illustration the region presents. The surface is strewn with rough-surfaced but rounded-edged boulders of disintegration. Rounded bosses of the bedrock give rough surfaces. The bedrocks rise abruptly above the alluviated lower slopes. The climate is desertic and the ground-water level lies hundreds or even thousands of feet deep and the intrusive rocks, of heterogeneous mineral composition, are partially disintegrated and decomposed to great depths. Extensive jointing develops partly on original cooling, partly through deformative stresses and strains and partly by the varied processes of weathering. On the surface the zones of weakness are rapidly attacked by weathering agencies. At the intersection of joints these processes working inwards from both sides penetrate most deeply along the edges. The rock already distintegrated spalls off largely as the effect of strains caused by expansion and contraction during the rapid changes of temperature in an arid region. Rounded edges at the intersection of planes of weakness thus develop. When a block becomes separated from its neighbors the disrupting influences have full play on all sides. Then the rock begins to fall apart by the detachment of small thin concentric surface layers. These constantly tend to give a more rounded surface contour and the boulder of disintegration finally becomes more spherical. The form assumed is the same in an almost rainless desert as in the most humid tropical, temperate or even arctic climate. But there is much less decomposition of the minerals in the arctic and deserts. Deposits of disintegrated minerals, little decomposed, form in both the desert and the arctic region from the breaking down of crystalline rocks. Many of the finer of the disintegrated minerals are transported by the desert winds. Others roll down the steep slopes and accumulate in hollows or along the bases of the cliffs and remain there until removed by running water or until upon further disintegration they become fine enough to be removed by the wind. The vegetation is generally so scant and moisture so scarce that the disintegrated particles do not remain long on steep slopes, hence the surfaces are prevailingly bedrock.

The course of the Rio Grande from El Paso to Presidio follows the structural basins, flanked on the Mexican side by high, steep, long and narrow folded mountain ranges, with the exception that it cuts in cañons across the Quitman and Eagle mountains. The Quitman ridges die out in the flat a short distance south of the river but the Eagle Mountains south of the river rise into a high mountain ridge which continues all the way south to beyond the Conchos River which cuts across it in a cañon.

We know nothing whatever of the drainage courses previous to the Mid-Tertiary deformative epoch, except that the drainage flowed in the same general direction as now. The ridges through which the Rio Grande cut its cañons across the Eagle and Quitman mountains do not rise more than 500 feet above the present river-level. As the lake beds filled the valley to a height of fully 500 feet above the river level there is no need to postulate an antecedent course of the river through the cañons. Sites of the present cañons appear to have been low saddles at the end of the deformative epoch, later they were covered by the lake and when the lake was being drained the channels began to be cut and continued gradually to cut lower until the present day. It is then probable they began as the drainage outlets of the lake. Tilting towards the Gulf of Mexico, which certainly happened at the beginning of the Lafayette epoch in the region east of the mountains may also have taken place in the mountains and if so, aided in the draining of the lake. Otherwise, the gradual advance of the Rio Grande drainage upstream accomplished it.

GEOLOGIC HISTORY

The later Pre-Cambrian was a time of intense folding, dynamic metamorphism, igneous intrusion and long-continued erosion which swept away former surface rocks to a depth of at least two miles and perhaps several times that amount. At least parts of the region were probably covered by seas during the Upper Cambrian (?), Lower and Upper Ordovician, Middle Silurian, late Mississippian and Pennsylvanian, deposits of which are still left in adjoining regions. In this region, however, with the exception of remnantal portions of the supposed Upper Cambrian Van Horn sandstones, all sediments of the early Palaeozoic seas so far as known were removed by erosion before the Permian, although such sediments may lie buried under some parts of the region. The Upper Pennsylvanian epoch of mountain-making known in other parts of the Trans-Pecos country probably affected this region also, although when the Permian sea advanced over it the land had been reduced to low relief. The Permian deposits contain very little detrital sediment which shows there was clear water during lower Permian time in this region. Gypsum beds in the Malone Mountains were laid down where evaporation of the water took place at a more rapid rate than it was supplied. Deposits of the Lower Permian sea are known from north-central Mexico to northern Kansas and they covered the entire Trans-Pecos region.

The region was land during the first half of the Mesozoic and the erosion was great and long-continued, so that deposits of later Mesozoic seas rest at different places in the Trans-Pecos country on all the Palaeozoic rocks of the region as well as the Pre-Cambrian. This sea advanced from the Mexican region, reaching the Malone Mountains in the Upper Jurassic. During the Trinity epoch high land existed to the west, for the Trinity deposits of southwesternmost Trans-Pecos Texas are thicker than elsewhere in the State of Texas and contain a large proportion of detrital material. Eastward they thin and become more characteristically clear water, the Trinity in the southeastern part of the Big Bend country being 2000 feet in thickness and mostly limestone. The great Cretaceous epicontinental sea continued its advance over the western interior region of North America until near the close of Eagle Ford time but it shallowed somewhat and contained more land detritus after the Washita epoch. The Austin in this region apparently contains none of the chalk so characteristic in other parts of Texas. The land began to rise in central or western Mexico at the beginning of the Austin and fine shales denoting somewhat turbid and shallow water were deposited in this region. The sea continued to shallow during the Taylor, surrounding land areas continued to rise and towards the end of the Taylor epoch coal beds were laid down, perhaps in a shallow lagoon or estuary. At the close of the Taylor the sea withdrew completely and a mountain forming epoch was initiated. The strata were intensely folded and overthrust, the newly-made mountains were deeply eroded and tremendous volcanic activity ensued, all during the later Cretaceous. Erosion and volcanic activity continued during the early Tertiary. Then, near the middle of the Tertiary the mountains were again uplifted, although the deformation was less intense this time than before. The present mountain ranges were formed, between which there were large basins of interior drainage the lower parts of which were covered by lake waters. Near the close of the Tertiary, probably during the Lafayette epoch, the lakes were drained and the Rio Grande formed its present course. Erosion has continued in the highland areas until the present day. Deposits are still forming in the Eagle Flat and Salt basins, which are still undrained.

ECONOMIC GEOLOGY

OIL AND GAS PROSPECTS

Generally a region affected by igneous intrusions and badly faulted is not regarded very favorable for oil and gas by the geologist. Still every region must be judged by its own particular conditions. There are places in the world yielding profitable supplies of oil or gas which are badly faulted or intruded by igneous rocks or both. Profitable oil occurs in faulted areas in Galicia, Rumania, Russia, Mexico, and Peru. Faulted areas in compactiy-cemented rocks generally permit the escape of oil and gas to the surface. But in loose or poorly-compacted sediments the faults are often sealed by by "gouges" of impervious material and may thus form structures somewhat analogous to anticlines and favorable for accumulation of oil or gas or both. Some oil is found in the vicinity of igneous dikes and other intrusive masses in certain Mexican fields. In some instances dikes may form dams behind which oil and gas accumulate and sometimes the metamorphism of the sedimentary country rock by the intrusive effectively seals up the contacts between igneous and sedimentary rocks. For the above reasons, it is certainly poor policy to condemn offhand without close field examination any district faulted or intruded by igneous rocks in which bitumen-bearing strata occur beneath otherwise probably impervious cover.

In the southwestern part of Trans-Pecos Texas there are two bituminous formations and there is a possibility of others.

The most bituminous strata are those of Eagle Ford age, oil-bearing all the way from the Athabaska River in Canada to central Mexico. All or nearly all sections of Eagle Ford in the Trans-Pecos country contain bituminous material. The Kiamichi Clay horizon, 300 feet in thickness, underlain by sandy beds and overlain by porous limestones, is bituminous in its upper part where exposed in the axis of an anticline two miles east-northeast of the mouth of the Rio Grande Cañon across the Quitman Mountains. The same clays are reported to carry oil on the White Ranch in the valley of the Rio Grande about twelve miles below old Fort Quitman. Lower Permian limy shales, probably the equivalent of the Word formation, are very bituminous where exposed on the east flank of the anticline, near the Trinity contact, in Pinto Cañon along the Marfa-Ruidosa road.

The Austin and Taylor strata, following in upward succession the Eagle Ford, are lithologically very similar to the

Eagle Ford in the territory extending south from Chispa summit to Candelaria and exposed at various places between the Rim Rock and Rio Grande. The bulk of the strata are dark clays and shales with some interbedded and lenticular sandstones and limestone, the latter more typically thin and flaggy. Whether some of these sandstones and limestones are of sufficient thickness and areal extent for storage of sufficiently large quantities of oil is not known. The total thickness of the Eagle Ford, Austin and Taylor strata is several thousand feet. There is sufficient pressure of superincumbent beds to force oil and gas out of the shales into more porous strata in the lower part of the section where the Taylor or the overlying volcanics form the surface. Besides the region has been subjected to strong deformative pressures. Since many of the porous reservoir strata are lenticular it is not absolutely necessary to have anticlinal structure, although a number of anticlines are known.

A two-inch diamond drill hole was bored to a depth of 800 feet in the hopes of finding coal by Thomas Detweiler in 1881 near the Ninety Six Canon ranch about one and one-third miles east of Van Horn Creek and about seven miles south by east from Chispa summit. Gas was encountered in the lower Taylor strata in this well and is reported to have burned with a large flame for months. There is an anticline in this vicinity, and another one in the vicinity of the long abandoned San Carlos coal prospects. In both these and a number of other anticlines Austin and Eagle Ford strata will almost certainly be found beneath the Taylor strata outcropping on the surface.

Great thickness of rhyolitic volcanic ash, tuff, breccia and lava now cover the Taylor in places between the Rim Rock and Rio Grande. No dikes or plugs which could have been vents by which the rhyolitic volcanics reached the surface were found in the Rim Rock country between Chispa summit and San Carlos, but much of the country was not examined. The nearest rhyolitic volcanic center now known is that of the Chinati Mountains, at the extreme south end of the Rim Rock country. But the Upper Cretaceous strata and overlying rhyolitic volcanics are cut by rather numerous diabasic dikes of which there are two systems, the one north-south and the other east-west.

The Rim Rock lava flow dips gently to the east or slightly north of east for a distance of many miles and the same general direction of dip seems to continue to the trough of the Big Bend syncline, which trough is probably some fifty miles east of the Rim Rock. The western limb of the great syncline should give a great collecting area. However, there is a time break between the Taylor and the later Cretaceous rhyolitic volcanics with great angular unconformity in the region to the west and northwest in the Eagle and Quitman mountains. In the Chinati Mountains, also, the Upper Cretaceous and some of the underlying strata were eroded away before volcanism began. Yet in the heart of the Big Bend syncline in the Davis and Chisos mountains and in the Rim Rock country we find Taylor strata underneath the volcanics and an angular unconformity is either not apparent or inconsiderable. If the great mountain-making movements of post-Taylor Cretaceous are mainly confined to the western marginal areas of the Big Bend syncline, oil and gas may be found under the covering of volcanics in territory between the Rim Rock country and the trough of the great syncline. The volcanics are folded but folds in the underlying sediments may not occupy the same positions as folds in the surface volcanics. There is, however, rather marked parallelism in all the structures, although not all formed during the same epoch of deformation. Where volcanics form surface rocks drilling alone can determine underground conditions, such as concealed structures, extent of the unconformity at the base of the volcanics, effects of igneous intrusions and presence or absence of porous reservoir rocks of sufficient areal extent and thickness.

A line or zone of great displacement by faulting extends from the north through a point about two miles west of Chispa summit and southeastward, passing just west of the old town of San Carlos, a short distance west of the Capote ranch where it crosses the road from Brite's ranch to Candelaria and crosses lower Pinto Cañon where the Marfa-

Ruidosa road finally attains to the summit after climbing out of the cañon. The displacement on thie fault at San Carlos is some 2000 feet. Northward from San Carlos the displacement appears to gradually decrease; south of that point the amount of displacement is not known but it is large in amount in lower Pinto Cañon. The western is the downthrown fault block. At San Carlos the upper 800 feet of the downthrown block is volcanic, probably too porous to prevent escape of oil or gas, but at depths greater than 800 feet we should find the Taylor underlain by the older Upper Cretaceous strata. Since most of the Upper Cretaceous strata are soft and clayey in nature, the fault plane itself at depths greater than 800 feet may be effectively sealed. If so, we have a general eastward dip for many miles and the great sealed fault preventing movement of oil westward beyond its line. There are a number of minor faults between the great fault zone and the Rim Rock to the east but it is likely these are at least in large part effectively sealed up.

Summarizing for the territory between the Rim Rock and the Rio Grande, the general structural conditions may be favorable, although anticlinal structure may not be necessary, the Eagle Ford strata are certainly bituminous and Upper Cretaceous strata overlying the Eagle Ford may also be oil-bearing or gas-bearing or both. We do not know how unfavorable the diabasic dikes may be and we do not know whether there are thick enough, extensive enough, or porous enough reservoir rocks in the Upper Cretaceous strata. The Upper Cretaceous strata can be seen in outcrop from Chispa summit southwards along the valley of Van Horn Creek, where they dip gently southwards, the Eagle Ford overlying the Buda at Chispa summit and Austin and Taylor following the order to the south.

The broad valley flats between the Van Horn, Eagle and Quitman mountains are probably underlain by synclinoria of Upper Cretaceous strata but there is a mantle of lacustrine beds and alluvial débris covering them to depths varying from hundreds to over a thousand feet. It is possible that oil may be sometime found under these broad flats, but drilling for it at present is not to be recommended.

The possible occurrence of Permian oil is questionable. There is great unconformity between basal Trinity and older rocks. A great deal of erosion took place during the first half of the Mesozoic. In the southwestern part of Trans-Pecos Texas the Trinity rests on Lower Permian limestones wherever the contact has been exposed, with the exception of the Pinto Cañon locality, where the Permian appears to be of a higher horizon. On the eastern margin of the Big Bend syncline there are thousands of feet of Permian and older Paleozoic strata exposed but forty miles to the south and two miles across the Rio Grande in Mexico, in the Sierra del Carmen, the Trinity rests directly on Pre-Cambrian mica-schists. So one does not know, without drilling, what may underlie the Trinity in places where older rocks are buried.

The topography of the Rim Rock country is extremely rugged. It is possible to rebuild the old road to San Carlos, perhaps utilizing for part of it the old railroad grade. The roads from Brite's ranch to Candelaria and from Marfa to Ruidosa are very steep where they ascend the Rim Rock. The country has a number of large springs and in a number of places shallow wells will get water. The Rio Grande is not far distant. Prospecting for oil with the diamond drill is very feasible and desirable here.

ORE DEPOSITS

Lead, Silver and Copper.—No mines are operating at present in this region, but there are many prospects, some of them forty or fifty years old. The nearest productive mines are the Hazel Mine, north of Van Horn, now idle, and the Shafter Mine, which has been a producer for forty years. The prospects are in contact metamorphic deposits, in veins and in more or less irregular replacement deposits, the latter generally in limestones.

Some copper prospects, reported to carry values in gold and silver, are in the Pre-Cambrian Carrizo schists. These are generally in narrow stringers or lenses or irregular disseminations carrying oxidized copper minerals.

The intrusives and surrounding sedimentary rocks of the Quitman intrusive mass have been more prospected than any other district of the region. The ores are of iron, zinc, lead, copper and silver with small amounts of nickel, uranium, tungsten, gold, and molybdenum. They are largely contact-metamorphic deposits but there is at least one fissure vein. In general those on the east side are lead and zinc; those on the west, copper, lead and silver; those on the north side, copper.

The Bonanza and Alice Ray prospects occur on the same fissure vein in the northern part of the mountains a short distance south of the road from Etholen to the S. P. Well, which road passes through the lowest divide across the Quitman intrusive. The Bonanza is situated at the east foot of the mountains near the head of the broad flat valley. The Alice Ray lies across the divide on the western slope. The two differ in altitude over 500 feet. The vein occupies a sheeted zone with several quartz veins, the main vein of which is from an inch to a foot or more in thickness, striking N 80 E and dipping 60–65 degrees N 10 W. The country rock is medium to coarse-grained quartz-syenite-porphyry. The outcrop of the sheeted zone is marked by a pronounced topographic trench. Slickensides are found on the walls of the main vein. The outcrop is marked by gossan-stained quartz. The gangue is quartz which on the vein walls often exhibits large crystalline comb structures and in places an intergrowth of nearly amorphous quartz and pyrite. The ore in the Bonanza near the surface consists of galena, wulfenite, sphalerite and oxidized copper minerals. Assays of silver in the upper zone ran from twenty to thirty ounces. At greater depth the main ore mineral is brown and black sphalerite, with galena, tarnishing purplish, pyrite in both large and small crystals and chalcopyrite, all apparently minerals of the zone of secondary sulphide enrichment, as they occur below the water level which is about 200 feet beneath the surface. The oxidized zone has a vertical range of about 700 feet. Ore shipped from these two prospects ran 30 per cent or more in lead, 25 to 30 per cent in zinc, 20 to 30 ounces of silver and traces of gold.

The extensive contact-metamorphic deposits of Big Gulch, a low saddle across the mountains two miles south of the vein above described, have already been partly discussed. On the contact between the porphyry and limestone is generally an irregular zone of hematite, the most abundant ore mineral. There are also argentiferous galena, black oxides of manganese, and chalcopyrite, the latter of which has often altered to malachite, azurite and crysocolla. Free sulphur, probably derived from sulphides, sometimes occurs in the porous quartz and iron oxide deposits. Grossularite and specularite are often intergrown.

Other contact-metamorphic deposits occur on or near limestone contacts in the low hills about a mile east of the east foot of the northern intrusive mass, between the main intrusion and Etholen section house. These contain iron, copper, lead, zinc, nickel, uranium and silver ores, according to Von Streeruwitz. Some 18 per cent copper ore has been shipped. Other contact-metamorphic deposits are found to the south end of the intrusion, on the west side of Quitman Gap and north of the road. The intrusive is here a granite. Some iron oxide has been added to the limestone, which is thoroughly cemented and brown in color. A little grossularite was noted on fracture planes. The gangue is mainly calcite and iron oxide. The primary sulphide is galena, embedded in barite. The barite is incrusted with wulfenite. Large masses of calamine crystals occur in open cavities.

The intrusive-sedimentary contact on the northeast side of the Quitmans certainly should be further prospected. Mineralization has been extensive and great thicknesses of limestone must be concealed and in contact with the intrusive.

One mile southwest of Sierra Blanca there are contact-metamorphic deposits on both sides of the intrusive sills. The contacts of the upper and thickest of the three sills show the most mineralization. Garnet and amorphous hematite with some specularite occurs on the contact. The ore minerals are copper carbonates filling cracks and forming thin seams and stringers in the metamorphosed limestone. Both hematite and copper carbonates form a cement for breccias. Chalcedonization was a late phase and there are some botryoidal, mammillary and radiating thin coatings of crysocolla.

The Plata Verde prospect is north of the mica mine and at the west foot of the northern Van Horn Mountains. There is a slickensided plane or zone of movement, dipping about 50 degrees W, following approximately the bedding planes of a country rock mainly grey muscovitic sandstone, some of it finely conglomeratic, dark red or green sandy shale and thin interbeds of grey crystalline limestone. The rocks belong near the base of the lower Permian. Malachite and subsidiary azurite are irregularly disseminated through sandstones. The limestones, particularly in the cross-cuts at the base of the 200 feet incline following the deposit are cavernous with calcite and much black iron and manganese oxides in the caverns. Some silver values are reported.

The Dick Love prospect, lately discovered, lies on the west side of the Eagle Mountains. The country rock is Finlay limestone cut by a fault with horizontal slickensides running nearly east-west. The outcrop shows black oxides of manganese and iron. Near by are a number of the usual calcite veins. Ore on the outcrop is said to have run from 1000 to 1600 ounces in silver. The gangue is mainly calcite, wad and iron oxide. There are some faint copper stains of malachite and azurite. Argentiferous galena occurs, both crystalline and as a fine amorphous disseminated powder. Calamine incrusts the walls of cavities. There are also considerable aggregations of a canary-yellow, powder which was determined by J. E. Stullken as massicot (lead monoxide). There was only a thin stringer visible on the sixty-foot level at the time of visit. It is characteristic of the silver haloids in a desert climate to be present in greatest amount at the surface.

NON-METALLIC MINERALS

Nitrate.—Lavas in the general vicinity of Candelaria contain variable amounts of nitrate but so far it has not been found in paying quantities. According to Prof. W. F. Cummins the nitrate was precipitated by hot springs or as a volcanic sublimate. This hypothesis is probably preferable to that advanced by Dr. W. B. Phillips, who thought they had come from organic sources, because considerable of the nitrate is found in solid lavas in situations where organic waste products could hardly have penetrated. The climate is not of the requisite aridity to prevent the solution of the nitrates; hence it is probable that they will not be found in large quantity, especially at or near the surface.

Gypsum.—The gypsum deposits of the Malone Mountains are extensive. The mineral is now being quarried within a stone's throw of Gypsum or Briggs railway switch. This deposit is hence readily accessible and probably lies nearer the city of El Paso than any of the numerous southern New Mexico gypsum deposits.

Coal.—Coal occurs in the Finlay limestone of the Trinity one-half mile south of Eagle Spring and in the Taylor in the Rim Rock country in the vicinity of the abandoned town of San Carlos.

The coal at Eagle Spring has been partly metamorphosed into a semi-anthracite. It contains a large percentage of ash. A thickness of three feet is exposed in the abandoned workings. The coal dips 82 degrees N 15 E. The vicinity is strongly folded and the coal is likely to be badly crushed or faulted. It is only a few miles from a railway switch, with the road down grade all the way. There is not much likelihood of there being an extensive deposit of workable coal, but it could perhaps be profitably mined in a small way.

The San Carlos coal has been described by Vaughan in the report noted in the introduction. There are two horizons, the coal beds are quite variable in thickness, the ash content is both variable and rather high and faults occur in such numbers that mining is both expensive and no very large areas of workable coal are yet known. It is possible that further prospecting may find larger areas of workable coal. Mining costs are apt to be high.

Building Stones, Road Materials and Mica.—The more consolidated rocks, such as the limestones, intrusive igneous rocks, sandstones and lavas, afford in this region an excellent supply of good building materials. The syenites of the Quitman Mountains and south of the Wiley Mountains are very desirable building and monumental stones. Some of the partially consolidated rhyolitic tuffs can be easily sawn into building blocks, will withstand the arid climate well and have pleasing colors.

The harder limestones of the Permian are good road materials. There is abundance of sand and gravel along stream courses.

The mica of the Van Horn Mountains has been utilized for sheet mica and electrical appliances. It makes also an excellent lubricating mica. At present it is being developed along with the other minerals of the pegmatites and enclosing schist with the view of making facing coats for artificial stone. Many pleasing color effects have been obtained.

Water.—Water wells are generally most successful where the valleys of long draws reach the outer foothills of the mountains. Where the underlying bedrock is limestone, sandstone or volcanic tuff water is not apt to be obtained in large quantity. A much larger supply of water than is now developed can be obtained by damming the mouths of large draws. In order to prevent excessive leakage precaution must be taken that the drainage areas of the draws are not underlain by porous bedrock such as volcanic tuff, sandstone and limestone and that dams are not constructed on bedrocks of porous nature. The reservoirs will rapidly fill up with débris unless their sites are located where drainage gradients are relatively slight. Evaporation from open bodies of water is excessive in this region, probably amounting to about twelve feet per year. There are places, however, where the valleys have considerable débris filling. In such dams may be constructed on bedrock and their tops made about even with the surface of the débris. In such manner excessive evaporation may be avoided, the water being drawn off by pipes leading from near the bases of the dams.

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