University of Texas Bulletin

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Geologic Exploration of the Southeastern Front Range of the Trans-Pecos Texas

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C. L. BAKER and W. F. BOWMAN

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IN MEMORIAM

Just as these pages go to press, announcement is made of the death of Dr. William B. Phillips at his home in Houston, June 7. Dr. Phillips was the director of this Bureau from 1909 to 1914. He was the director of the University of Texas Mineral Survey from 1901 to 1905. He organized both of these institutions. The present bulletin was planned under his direction. Whatever prestige the present Bureau has, it owes to the strong personality, to the versatility and accomplishments of its first director. He was a man of great energy and of extensive learning. The members of this Bureau, past and present, keenly feel, in his untimely departure, the loss of a kind friend and of a strong supporter of scientific work. This issue is dedicated to his memory.

NOTES ON THE GEOLOGY OF THE GLASS MOUNTAINS

BY

J. A. UDDEN

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NOTES ON THE GEOLOGY OF THE GLASS MOUNTAINS.

BY J. A. UDDEN

INTRODUCTORY.

The Glass Mountains is a designation given to a hilly and mountainous belt running in a direction from northeast to southwest for a distance of about 24 miles, extending from Altuda and Lenox on the Southern Pacific Railway across and beyond the boundary line between Brewster and Pecos Counties to near the main highway between Stockton and Marathon. The belt is from six to fifteen miles in width. The Glass Mountains have a gentle slope to the northwest, which is a dip slope, and have abrupt, but broken, erosion cliffs to the southeast. Drainage is from the crest of the mountains in both directions. There are two canyons which run from the northeast to the southwest, nearly across the mountains. These are known as the Gilliam and the Hess canyons. The Gilliam canyon is fairly open and is traversed by a wagon road across the mountains. The Hess canyon, some six miles east of Gilliam canyon, is narrow and at one point almost impassable by wagon.

GENERAL GEOLOGIC CONDITIONS.

As early as in 1900 Prof. R. T. Hill had made observations in the Marathon country, and in his "Physical Geography of the Texas Region," he published some of the results of his studies. "The Caballos and Glass Mountains," he says, "are exposures of ancient paleozoic structures of Appalachian type and age, which have been revealed by the erosion of the Cretaceous sediments that probably once imbedded them." He notes the direction of the ridges resulting from the folding and erosion of the Paleozoic terranes and recognized in these features a true mountain structure.* In 1904, the author of this paper passed across the Marathon plain and in a later report on the Chisos country, he published some notes on the features seen south of Marathon.† Attention was called to the fact that the rocks and

* Folio 3, page 4, U. S. Geological Survey.

†"The town of Marathon lies near the center of a triangular plain, which extends for about fifty miles to the northeast from the Ord range. Against this range the plain abruptly terminates on the west. On this plain the Cretaceous sediments have been entirely removed and the ancient floor, on which these were laid down and which they once covered, is now bared. This floor consists of sharply folded and highly tilted strata of Palaeozoic sediments. All around the plain the slightly raised edges of later sediments form a well-marked escarpment. The folds of the older strata trend in a northwest-southeast direction and extend the whole length of the plain. They exhibit such regularity and persistency of direction that they have all the appearance of being a small part of an extensive [mountain] system. Their axes point on the one hand straight to the Solitario uplift, which is forty miles distant to the southwest, and which exposes similar sediments, underlying Cretaceous strata, folded in nearly the same trend. In the opposite direction the folds point toward the Ouachita system of mountains in Oklahoma. . . . .

"While there is probably no continuity between the Caballos folds and the Ouachita system there seems to be good ground for the belief that they were made at the same time. The Caballos ridges were made and cut down by erosion during the time which elapsed between some period (probably the late Carboniferous) of the later half of the Palaeozoic era and the beginning of the Cretaceous age. They no doubt furnished a part of the material in the making of the Triassic and Jurassic deposits elsewhere.

"It was after the Caballos ridges had been cut down to almost a peneplain and after this peneplain had been buried under all but the

the structure of the Marathon plain were like those appearing in the Solitario uplift, nearly forty miles farther southwest, and that the folds in these areas represented a mountain system much older than the Rockies. In the course of some work done in 1914 for the purpose of outlining the Paleozoic area, further facts were gathered from which it became evident that this structure was largely developed before the end of the Permian age, and that it probably is the result of a progressive movement which decreased rapidly during the late Paleozoic but was continued as late as in post-Comanchean times.

The width of the folded belt, as at present exposed, is some twenty miles. It so happens that the most strongly folded formations consist to a great extent of shales and soft materials, while the less strongly folded, or merely tilted flanks of this folded belt, consist of heavy limestones. For this reason we find the axis of the folded belt eroded to the stage of a hilly plain, while the flanking limestones rise to the height of low mountains. The Glass Mountains consist of these resistant limestones which come up on the northwest flank of the old mountain system. They are tilted so as to have a general dip of about ten degrees to the northwest. The uppermost of these limestones is quite resistant to weathering under present climatic conditions. It rises to a

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latest Cretaceous sediments, that the movements began which resulted in the making of the Rocky mountains. Folds and faults were made, which crossed diagonally the axis of these earlier flexures. Now it seems clear that where a fold is developing along an axis which crosses a belt that has been previously compressed and folded in a direction more or less vertical to the axis of the later disturbance, the belt so affected will less rapidly yield to the forces at work than the country on either side. For on either side of such a system of folds the strata lie more nearly horizontal, while they stand edgewise in the folds. One can easily bend a block of paper in a direction which is vertical to the plane of the sheets, but not in a direction which is parallel with this. Rather than to bend in this direction, the sheets will break. Between Altuda and the Carmen range the rigidity of the folded Palaeozoic strata caused them to break in a single sharp dislocation forming the Santiago and the Ord ranges, rather than bend into several folds or flexures by several smaller faults, as seems to have happened on either side of this belt of the ancient mountain structure." Bulletin Univ. of Texas No. 93, April 15, 1907, pp. 76-78.

height of from two thousand to three thousand feet above the Marathon plain. There is good reason to believe that the Glass Mountains are to some extent the result of differential erosion effected before Comanchean times, and that they rose for some time above the surrounding country in the Comanchean sea.

That mountain-making forces have continued long after Comanchean age is evident from the fact that we find several outliers of the base of the Comanchean rocks on the highest elevations of the Glass Mountains. No doubt most of this later elevation occurred during the Tertiary age.

Stratigraphy

In the order from below upward, the formations which go to make up the Glass Mountains are the Gaptank, the Wolfcamp, the Hess, the Leonard, the Word, the Vidrio, the Gilliam, and the Tessey. The maximum thickness of these formations is about 11,640 feet, and 9,640 feet of these sediments are evidently post-Pennsylvanian in age, as indicated below:

Permian (?) and Permo-Carboniferous.	
Tessey	1,400
Gilliam	740
Vidrio	1,700
Word	(?) 1,400
Leonard	1,800
Hess	2,100
Wolfcamp	500
Pennsylvanian.	
Gaptank	2,000

Before proceeding to define and describe these formations, I shall present some descriptions of natural sections that were measured in the course of the field work on which this account of the stratigraphy of the mountains is based. Most of these sections extend in a direction from north-northwest to south-southeast, crossing the trend of the formations at approximately right angles. These sections are arranged in the order from west to east, beginning with a section near Altuda and ending with a section near Gaptank, on the Marathon-Stockton road.

Collections of fossils were made from many of the strata described in these sections, but excepting the cephalopods, these have so far been but little studied. The correlations which have been made are based in the main on lithologic characters and on a few of the main characteristic fossils. The lithologic distinctions between the different formations are quite marked and some of the formations are separated by unconformities. No doubt more accurate correlations will be made when the existing faunas shall have been more thoroughly explored and fully described.

In the descriptions of the rocks appearing in these sections, a feature has been introduced which may appear out of harmony with established usage. The writer believes that observations on the microscopic structure, especially of limestones, may be an aid in correlating formations where fossils are absent, or impossible to secure, as in the case of drilling explorations. Equivalents of parts of the Glass Mountain section underlie extensive areas in the northwestern part of the state, and in the hope that it may aid our studies of borings from that region, I have placed on record in these sections some descriptions of microscopic preparations of limestones from known horizons. Observations on such features were, of course, not made in the field, and may appear not called for, in the present text. To introduce them in the sections seems to me the simplest way to place them on record, and their presence there is, perhaps, as proper as the introduction of records of fossils which may characterize individual beds that are encountered in the field.

Section 1

Section of strata shown on the southwest point of the main ridge of the Glass Mountains, beginning below, at a point about one and a half miles southeast of Altuda, and extending north-northeast.

		Thickness in feet.
1.	Sandy flaggy limestone........................	10
2.	White limestone, in which was noted a large Fusulina, a Productus, a bryozoan, and a small Hustedia.	8
3.	Not exposed, probably shale....................	85
4.	White limestone in thick, irregular layers, and in	

		Thickness in feet.
	places brecciated. The upper part of the limestone forms a vertical cliff some sixty feet high.........	239
5.	Thin-bedded, laminated limestone...............	20
6.	Somewhat thick-bedded white limestone, indurated (from pressure?), dipping at high angles. Thickness not known..............................	?
7.	Mostly limestone, dip very irregular and, higher up, reversed. Estimated at........................	70
8.	Gray limestone, somewhat thick-bedded. In this limestone were noted some poorly preserved ammonoids, and a cyathophyllid..................	30
9.	Gray limestone	65
10.	Thick-bedded white limestone..................	55
11.	Sandy, thin-bedded limestone..................	35
12.	Shale	5
13.	Sandy, thin-bedded limestone..................	10
14.	Brown, sandy, thin-bedded limestone.............	12
15.	Sandy, thin-bedded limestone. A crinoid stem and a cup coral noted in upper half................	33
16.	Hard, sandy, thin-bedded rock..................	10
17.	Thin-bedded, yellow, sandy limestone, with some white layers. One thin section of this rock was seen to be oolitic and organic fragmental. It contained very little sand, a Trochammina, and many sponge spicules	16
18.	Hard, thin-bedded, sandy, and yellow limestone. In a thin section of this rock, the sand grains were seen to be angular and mostly from 0.1 to 0.2 mm. in diameter. This member is marked off from the member above by a peculiar unconformity........	22
19.	Limestone in apparently one single, structureless layer, in which a Fusulina and some bryozoa were seen	60
20.	Thin-bedded limestone	21
21.	Thin-bedded limestone, in which a crinoid stem and a spine of a palechinid were noted................	5
22.	Thin-bedded limestone	11
23.	A layer of peculiar lumpy structure............	2
24.	Limestone in thin layers......................	45
25.	A layer of white limestone....................	1
26.	Thin-bedded limestone with a spine of an Archeocidaris	6
27.	Limestone in alternating thin and thick layers.....	45
28.	White limestone showing a peculiar kneaded or	

		Thickness in feet.
	lumpy structure	11
29.	White limestone	16
30.	One entire layer of light gray dolomitic limestone, in which a Fusulina was noted. The rock is in part dolomitic. In a thin section it was seen to be compact and fine in texture, and there were obscure traces of minute fossils, probably foraminifera.....	45

The lowermost part, which measures more than 724 feet, from number 1 to number 18, inclusive, is believed to include most of the Word formation. The total thickness of this section is uncertain, owing to the existence of a fold and possibly of a fault, near the middle of this section. It is probable that the pressure causing this fold may have served also to thicken and to harden the rock, to have squeezed out some of the shale, and to have caused the calcareous sandy beds to appear more like limestone. The almost total absence of soft and argillaceous material, known to characterize the Word formation farther east, is otherwise difficult to explain. The texture and the general appearance of the upper sandy beds in this part of the section leaves, however, no room for doubt that at least this part of the section is to be referred to the Word formation. Not counting an unmeasured part of the section, it consists of 67 per cent. of limestone, 20 per cent. of sandy limestone, or calcareous sandstone, and 12 per cent. of shale.

The upper part of the section, from number 19 to number 30, inclusive, in all 268 feet, clearly represents the Vidrio. At this point the formation shows more clear bedding planes than at points farther east. Spines of an Archeocidaris were noted, as well as crinoid joints and a Fusulina.

Section 2

A section beginning at the foot of the ridge running northeast from Lenox, at a point about three miles northeast from Lenox, and extending north 20° west to the crest of the Glass Mountains. (The starting point of the section is on the east side of an arroyo running south past an outcrop of Caballos Novaculite.)

		Thickness in feet.
1.	A conglomerate of mostly limestone boulders with some flint. The limestone boulders average from 2 to 3 inches in diameter, range up to 2 feet, and are mostly rounded. They are evidently derived mostly from the Dimple and the Gaptank formations. The flint pebbles are smaller in size than the limestone boulders, and are less rounded, and consist of material from the pre-carboniferous rocks of the region as well as from the Pennsylvanian. The conglomerate is firmly held together by a cement of calcareous material, in which fossils are imbedded in some places. In this conglomerate occurs *Prothallassoceras Welleri Böse*..	35
2.	Covered by talus	68
3.	Sandstone	4
4.	Concealed under talus	153
5.	Limestone conglomerate, with the smaller pebbles mostly of chert. In the matrix of this conglomerate were crinoid stems, a Hustedia, a cup coral, and some bryozoa.......	68
6.	Shale, in part covered. Large crinoid stems were noted.	18
7.	Thick-bedded limestone, in part conglomerate, and in part an organic fragmental rock interbedded with shale. A large crinoid stem noted..........................	73
8.	Organic breccia interbedded with sandstone and shale..	17
9.	Mostly shale with sandy organic fragmental rock above. A thin section of the latter shows it to consist of a finely crystalline matrix permeated with bituminous material. In this were noted pieces of crinoid joints, a Fusulina, a Nodosaria, and a spine of a brachiopod.....	40
10.	Shale, partly concealed.............................	150
11.	Coarse limestone breccia below, with compact limestone above. Crinoid stems noted..........................	14
12.	Cherty sandstone showing sponge spicules on its upper surface	2
13.	Limestone, only partly exposed. Syntrielasma (?) noted	17
14.	Thick-bedded gray limestone containing Fusulina, crinoid stems, cup corals and a large Productus................	48
15.	Soft rock, in part sandy..............................	11
16.	Thick-bedded and in part brecciated limestone, containing a fairly large Fusulina..........................	58
17.	Limestone breccia, very coarse, changing to a somewhat cross-bedded, sandy, and conglomeratic rock above. It weathers yellow	55
18.	A sandstone containing much lime and weathering yel-	

		Thickness in feet.
	low. It contains some shale	34
19.	Not exposed, probably marly shale	10
20.	A limestone conglomerate with chert pebbles showing on the upper surface	7
21.	Cherty and sandy shale with streaks of organic fragmental limestone	157
22.	Gray limestone with a cherty layer on top. In thin section this is seen to be an oolitic limestone, the ooliths lying in a copious crystalline calcareous cement	6
23.	Cherty and sandy shale and gray limestone of fine texture. In one place this rock is a sandy limestone and was seen to contain Leptodus, some ammonoids, and cup corals. The sandy phase of this rock was seen to be also oolitic. The sand grains are angular and mostly from 0.5 to 1 mm. in diameter. The ooliths are of about the same size. Indistinct outlines of ostracods and bryozoa were noted in a thin section. The member appears identical with a sandy limestone on the ridge of a hill a half mile to the southeast from which were collected such ammonoids as Waagenoceras	34
24.	Gray dolomitic limestone of somewhat uniform texture. The rock contains a small amount of poorly sorted, angular quartz sand. In a thin section traces of crinoid stems and of other organic fragments were noted	66
25.	Shale and layers of organic fragmental limestone, in places cherty	50
26.	Not exposed. Evidently mostly shale	650
27.	Limestone	5 (?)
28.	Not exposed	250
29.	Moderately thin-bedded gray bituminous limestone of fine texture with some thicker beds above. The uppermost layers contain cup corals, Spirifer, Hustedia, and large and smooth spines of palechinids. Loaf-like concretions of flint were noted in upper part	254
30.	Limestone, with irregular loaf-like bodies of flint. A large Productus costatus (?) noted	99
31.	Limestone consisting of a coarse organic breccia. In a thin section were noted many Fusulinas and some bryozoa and a Nodosaria and spicules of sponges, imbedded in a partly re-crystallized finely fragmental matrix	45
32.	Thin-bedded sandstone of fine texture, weathering yellow, and cemented with calcareous material. The lowest hundred feet of this member has thin layers of organic fragmental limestone in its upper 70 feet. Small clay-iron-	

		Thickness in feet.
	stone concretions of symmetrical oblate form were noted in the calcareous layers	490
33.	Gray shale containing small oblate concretions of very regular form. The shale itself is silty and contains some grains of organic calcareous material and a few scales of mica. When heated in a closed tube, some of this shale gives strong fumes of ammonia	150
34.	Sandy shale	15
35.	Yellow sandy dolomite, in thick beds below and thin beds above. The middle part of this member contains lenticular bodies of calcareous rock from six inches to one foot thick and six feet wide. These show cross bedding and have a tendency to weather out with a concretionary appearance. In thin section this rock is seen to be secondarily crystalized, and there appears a number of small bodies of fine indistinct texture	47
36.	Shale with some thin calcareous layers below. It contains small concretions of very regular form	230
37.	Yellow sandstone in thick beds, becoming calcareous above. An imprint of a whorled and ribbed cephalopod noted. In thin sections the sand grains are seen to be angular, and well sorted, mostly less than 0.2 mm. in diameter	170
38.	A single bed of coarse grained white dolomite showing in a thin section obscure traces of organic fragmental texture. Much of the rock consists of calcite, which apparently has been introduced into the dolomite. This calcite occurs in irregular tracts from the smallest up to some inches in size. The crystalline cleavage of the calcite was seen to be continuous for an inch or more on some fractures	136
39.	Dolomite in moderately thick beds, coarse-grained, yellowish white, with scattered small bodies of clear calcite. The rock is granular in texture and has a larger lumpy structure. In a thin section the dolomite was seen to consist of crystals 0.1 mm. in diameter. It contains some sand grains	10
40.	Unstratified dolomite, in which a crinoid stem was noted. The dolomite crystals in a thin section were seen to be distinctly grouped in clusters less than 0.5 mm. apart	155
41.	Bedded dolomite. Some layers are sandy, and weather like sandstone, others cherty. A few bryozoa and other indistinct fossils were noted	672
42.	Unstratified dolomite	90

The numbers from 4 to 28 in this section represent the Leonard formation, which here measures 1845 feet in thickness. It consists of 51 per cent. of argillaceous sediments, 21 per cent. of limestone, 22 per cent. of rocks not exposed, 4 per cent. of sandstone, and 2 per cent. of conglomerate.

The Word formation is represented by numbers 29 to 37, inclusive, and is made up of about 44 per cent. of sandstone, 31 per cent. of shale and 25 per cent. of limestone. The thickness of the formation in this section is 1500 feet.

Numbers 38 to 42, inclusive, represent the Vidrio formation, which here has a thickness of 1063 feet. It consists of limestone, which is mostly dolomitic.

Section 3

A section extending from a point about one mile southwest of Iron Mountain northwest to the summit of Glass Mountains, beginning below, at the foot of the main outermost ridge of the mountains.

		Thickness in feet.
1.	Coarse limestone conglomerate, containing boulders and pebbles of limestone from one inch to one foot in diameter. Some of these are well rounded. Most boulders consist of limestone from the underlying Dimple formation	10
2.	Oolitic limestone, light gray, containing small specimens of Fusulina, Productus semireticulatus and crinoid stems. In thin section it is seen to have oolitic and organic fragmental texture. It has undergone extensive secondary crystallization and much of the original clastic material is destroyed, and dimmed by secondary crystallization. Traces of gastropods, of crinoid stems and of bryozoa were noted. The sizes of the ooliths vary from 0.3 to 0.8 mm. Some organic fragments are much larger	10
3.	Limestone, less resistant to weathering, not well exposed	75
4.	Conglomeratic limestone, in thick beds	5
5.	Coarse white limestone, containing a large Fusulina, large crinoid stems, a large Euomphalus and Retzia	50
6.	Limestone conglomerate	10
7.	Not well exposed, some limestone	93
8.	Limestone conglomerate	10

		Thickness in feet.
9.	Limestone	85
10.	Calcareous conglomerate in thick beds. The material in this rock is sand, pebbles and boulders. The latter range up to several inches in diameter. The typical rock is a conglomerate of rounded limestone boulders from one to two inches in diameter. These are imbedded in a matrix of finer chert gravel and the whole is cemented in a calcareous paste which contains crinoidal and other organic remains. There are some black chert pebbles and some green, evidently derived from the pre-Pennsylvanian	20
11.	Not well exposed, in part clayey beds	210
12.	Conglomerate containing much chert	15
13.	Conglomerate, consisting mostly of boulders of limestone, cemented by a calcareous matrix	83
14.	Limestone	78
15.	Limestone containing much crinoidal material, some large crinoid stems, and many unrecognizable fragments of brachiopods and other organic material. The upper part is in thick beds	162
16.	Sandy limestone and calcareous sandstone containing a few pebbles of limestone and flint, and a few stems of crinoids	21
17.	Limestone in thin layers, containing Fusulina, a Hustedia, and some crinoid stems	52
18.	Limestone in thick beds, containing various fossils, especially in its upper half. The upper surfaces of several layers in this limestone are exposed in the crest of the first ridge west of Iron Mountain, and are studded with brown silicified cup corals and some brachiopods. The fossils noted resemble the following forms: Fusulina cylindrica Fisher, large spicules of Sponges, Campophyllum torquium Owen, C. texanum Shumard (?) Cladopora sp., Polypora sp., Enteletes globosus Girty, E. sp. c. Girty?, Leptodus americanus Girty, Productus walcottianus Girty, P. probably semireticulatus, P. like indentatus Girty, P. sp., like popei Shumard, Geyerella (?), Chonetes subliratus Girty, C. permianus Shumard, Pugnax Shumardiana Girty, P. elegans Girty, P. sp., Hustedia meekana Shumard, Dielasma sp., Spirifer sp., Nucula sp.?	80
19.	Limestone containing a few scattered pebbles of quartz and in places sandy. Fossils noted: Productus, Pugnax,	

		Thickness in feet.
	Leptodus americanus Girty, Meekella, large crinoid stems, and remains of sponges..............................	40
20.	Yellowish, sandy, and shaly rock, containing two layers of limestone, each about 4 feet thick. The limestone is organic fragmental, and was seen to contain Producti and various bryozoa................................	50
21.	Shale and limestone, not well exposed, estimated thickness	30
22.	Layer of conglomerate	1
23.	Shale with some beds of limestone, mostly concealed. In thin section one of these limestones was seen to be a rock of laminated structure and of close texture, containing many sponge spicules and some spherical cavities filled with calcite, measuring about one-sixth mm. in diameter. A section of another somewhat crinoidal layer showed much clear and granular calcite, in which lay rounded bodies of finer texture, marked off by irregularly curving lines. This rock also showed indistinct traces of organic fragments and ooliths. Another thin section shows organic fragments and oolitic bodies, together with Trochammina gordialis and a Nodosaria imbedded in a matrix of granular calcite. Other fossils noted in these thin limestones resembled Fusulina, Campophyllum (?), Meekopora, Fistulipcra, sp. (?), Polypora, Enteletes globosus Girty (?), Leptodus, Productus multistriatus Meek (?), P. subhorridus var. rugatulus Girty, P. guadalupensis var. comancheana Girty, P. waagenianus Girty, P. semireticulatus var. Spirifer cameratus Morton, S. mexicanus Shumard (?), Squamularia guadalupensis Shumard, Pleurotomaria sp. (?). The shale contains some yellow sandstone layers about 200 feet below its top. Some of the shale is stony and micaceous and of bluish gray color. The sand contained in sample was angular and measured mostly from 0.08 to 0.25 mm. in diameter of the grains. Some of the shale is slightly calcareous, but most is not. A zone just above the sandstone referred to yielded fossils resembling the following forms: cup corals, Productus multistriatus Meek, P. semireticulatus Martin (large), P. popei var. opimus Girty, P. guadalupensis Girty, Spirifer cf, cameratus Morton, Spirifer sp., a fragment of a large Murchisonia(?), Bellerophon nodocarinatus White, Worthenia tabulata Conrad, Medlicottia Whitneyi Böse, and	

		Thickness in feet.
	Perrinites vidriensis Böse. Estimated thickness........	640
24.	Black or very dark limestone weathering to light gray, laminated in layers from two to eight inches thick. When heated in a closed tube, this rock yields oil and gas. It has a close and compact texture. One thin section was seen to contain a close tangle of minute sponge spicules. Another contained fragments of thin tests, probably from ostracods, lying flat with the lamination. In another outcrop of these layers they are partly silicified and cherty. In one place it was seen to contain cherty seams traversing the sedimentary laminations obliquely for several feet. Fusulina sp., Chonetes punctatus(?), a trilobite of small size (Brachymetopus?) was represented by four pleurae. Some layers contain small quadrangular fish scales. What appeared to be a part of a large jaw of a vertebrate, perhaps an early amphibian, was also noted................................	50
25.	Thick-bedded dark limestone, in part sandy (?) and cross-bedded. One cross-bedded layer was four feet thick. Fossils like the following were noted: Fusulina elongata Shumard, Campophyllum texanum Shumard, Lindstroemia permiana Shumard, Fenestella sp., Enteletes dumblei Girty, Streptorynchus sp., Productus limbatus Girty (?) P. walcottianus Girty(?), Productus sp., Seminula argentea Shepard, Spirifer sp.	25
26.	Not exposed. Thickness considerable	?
26a.	Laminated, shaly and calcareous sandstone, of fine texture, in layers from one-eighth inch to three inches thick. The percentage of sandy and calcareous material is variable in these beds. Peculiar markings were noted in the seams of the layers, about one sixth inch wide, running in meandering curves, so as to resemble worm tracks...	340
27.	White, irregularly-bedded, massive, and brecciated dolomite	50
28.	Brownish yellow, laminated, sandy and shaly, calcareous rock. (Estimated)	250
29.	Gray, laminated limestone of fine texture, containing fine sand and much chert in small nodules. A coral like Zaphrentis was noted	77
30.	A complex of dolomite and limestone consisting of members from ten to a hundred feet thick. The heavier members are mostly coarsely brecciated and dolomitic. Some of the thinner members are distinctly stratified	

		Thickness in feet.
	limestone, in which stems of crinoids and a fusulina were noted. This rock forms the uppermost high cliff of the Glass Mountains.	500
31.	Red sandstone, frequently absent. The basal sands of the Comanchean. Greatest thickness seen was.	2
32.	A layer of marly limestone, containing an Exogyra, like E. texana. This layer appears to be absent in places. . . .	2
33.	Limestone in moderately thick benches, and containing few fossils, as far as seen.	96

The lower 1855 feet of this section represent the Leonard formation and, perhaps, in part, the Hess formation, comprising numbers 1 to 23, inclusive. It consists of some 32 per cent. of limestone, 46 per cent. of shale, 8 per cent. of limestone and other conglomerate, 6 per cent. of sandstone, and 8 per cent. not exposed, probably mostly shale.

The part of the section which is described under numbers 24 to 29, is referred to the Word formation, a part of which appears to be not exposed. The exposed part measures 792 feet. This consists of 74 per cent. fine-grained and mostly closely cemented sandstone, and 26 per cent. of limestone.

Number 30 is the Vidrio limestone.

Numbers 31 and 33 are the basal part of the Comanchean Cretaceous.

Section 4.

A section in the Gilliam Canyon, extending from the west end of the Leonard Mountains north along its east side, to where it opens on the plains south of the site of the old Tessey postoffice.

		Thickness in feet.
1.	Mostly limestone, in part dolomitic, with some sandstone and conglomerate. This is the rock exposed in the south scarp of Leonard Mountain, as far down as to the base of the Leonard formation. The measurement is over the west end of the mountain. In the east end of the mountain it appears that the formation is much thickened by lateral pressure, which apparently also has caused some layers to coalesce. A thin section from the upper part of	

		Thickness in feet.
	this limestone is oolitic, and organic fragmental, the matrix being somewhat coarsely crystalline. Fusulina, crinoid stems, Trochammina gordialis and Valvulina decurrens, were noted.	908
2.	Limestone, in places conglomeratic, shale and some sandstone. Some of these limestones are fossiliferous and contain an abundant fauna. The thickness of these beds has not been separately measured, but they are estimated at.	350
3.	A rock changing from limestone to sandstone and containing silicified ammonoids and other fossils. Conglomeratic in places	20
4.	Mainly shale, with several sandy limestones, in part slightly conglomeratic, and measuring mostly only a few feet in thickness, and occurring at intervals of from 20 to 200 feet. The limestones contain Waagenoceras and a large Productus, with various other fossils	600
5.	Unknown interval of probably only a few feet	?
6.	Limestone, with a large fusulina	27
7.	Sandstone, with shale above	23
8.	Limestone	7
9.	Sandy and shaly limestone	13
10.	Limestone	5
11.	Sandstone	8
12.	Shaly rock	7
13.	Limestone. The pygidium of a phillipsia (Proteus major Shumard?) was noted	5
14.	Yellowish, light gray, and unctuous marl, seen to contain fragments of sponge spicules and of other microscopic organic material. Heated in a closed tube, some gray silty shale from the lower part of this member gave strong fumes of ammonia. When washed it yielded joints of crinoid stems, dimeres of sponge spicules, spines of brachiopods, tests of Nodosaria and Endothyra Bowmanni and a great number of spherical calcareous bodies from one-sixteenth to one-fourth mm. in diameter, possibly segments of Nodosellina	20
15.	Conglomerate with sandstone	10
16.	Sandstone, in places containing calcareous material. In the uppermost 30 feet narrow traversions resembling worm tracks were noted on many layers of this rock	210
17.	Limestone in thick layers. Among the fossils noted were some ammonoids, spines of palechinids with club-shaped terminations, various brachiopods, sponge spicules, and a	

		Thickness in feet.
	large-sized fusulina	27
18.	Sandstone	8
19.	Limestone	7
20.	Sandstone	8
21.	Limestone	5
22.	Sandstone	7
23.	Limestone. Ammonoids noted	22
24.	Sandstone	8
25.	Limestone	10
26.	Sandstone	12
27.	Limestone	13
28.	Sandstone	8
29.	Gray limestone, in part sandy, thick-bedded, containing many ammonoids, Richthofenia permiana, various other brachiopods, and fragments of palechinids. The ammonoids have been described by Dr. Böse as: Adrianites marathonensis, Agathiceras Girti, Gastrioceras n. sp. undet., G. roadense, Medlicottia Burkhardti, Stacheoceras gilliamense, S. Bowmanni, Waagenoceras Dieneri	64
30.	Unknown interval. Not well exposed, probably measuring near	68
31.	Dolomitic, calcareous sandstone, of fine texture above	14
32.	Dolomitic and arenaceous limestone, with concretions of chert. Fossils: small crinoid joints, a crinoid plate, an Orthoceras, fragments of bryozoa and of cup corals	12
33.	Yellowish, brown, dolomitic rock, responding slowly to acid. In some layers this rock is arenaceous, fine-grained. Layers from 3 to 12 inches thick	24
34.	Coarse-grained dolomite. The upper part is mostly stratified, and contains at least one layer of sandstone. The lower part of the formation is a coarse-grained, gray, massive dolomite, without marked stratification, but showing cross-bedding in places on a grand scale, through layers, with a vertical measure of 40 feet. Crinoid stems were noted in a cave in this limestone; a large fusulina was also noted in some layers about 1400 feet above the base	1700
35.	Dolomitic, yellowish, and in places pinkish-colored limestone; mostly in layers from 2 inches to 2 feet thick, with a 15-foot stratum of yellow sandstone near the middle, and some small layers of sandstone near the base. In its lower part, some layers are cross-bedded	743
36.	Massive limestone, in part dolomitic, in part thin-bedded, largely brecciated, and in one place seen to be oolitic, and	

		Thickness in feet.
	to contain shreds of bryozoa and some foraminifera....	1358
37.	Thinly laminated limestone, showing folding above. Lower down there is brecciated limestone..............	120
38.	Brecciated limestone..................................	158
39.	Somewhat dark gray, dolomitic limestone..............	98
40.	Massive dolomitic limestone, without bedding planes. Some small gastropods and a Myalina were noted. The rock resembles somewhat the Rustler Hills limestone...	158

This section includes the longest continuous series of sediments exposed in any part of the Glass Mountains. The lower 1878 feet represent the Leonard formation; the next 684 feet, the Word; the next 1700 feet, the Vidrio; the next 743, the Gilliam; and the uppermost 1850 feet represent the Tessey formation. The thickness of the whole section measures 6855 feet. This total is believed to be a fair approximation of the actual facts. It was obtained by instrumental determinations on distances, dip, and elevation at 83 stations, extending from the overlying Cretaceous at the north end of the canyon a distance of about thirteen miles, to the west end of the Leonard Mountain. This work was done independently by Mr. W. F. Bowman under the personal direction and supervision of Dr. Emil Böse in 1916. The year before, the author of this paper made a rough traverse of the same route and estimated the thickness of the section to be about 7,000 feet. It is not believed that any important concealed structure occurs that will much affect the measurements. At the contact of the Word and the Vidrio there is evidently some faulting. This may have resulted in throwing out three or four hundred feet of the sandy beds of the section which may be missing. Elsewhere the section appears to be perfectly continuous. It was not possible to take the time needed for measuring and delimiting the Leonard and the Word separately, or to make out any detailed descriptions of the strata in the Leonard in this section, but it is believed that their combined thickness is measured with greater accuracy than in any of the other sections.

The lithologic character of the different parts of the Leonard sediments in this section can be only roughly indicated. More than half (61 per cent.) seems to consist of limestone, less than one-third (30 per cent.) is probably shale; sandstone may make up six per cent. of the whole, and conglomerates two. The argillaceous beds are here, as elsewhere, in the upper part of the formation.

The Word formation may not be quite entirely exposed. On the south side of the ridge which lies immediately south and between the head branches of the Gilliam Canyon draining north, there is a gap which separates this ridge from a longer ridge extending from southwest to northeast, a distance of nearly four miles. The ridge on the north side of this gap is capped by probably the most resistant rock in the Word formation. This is the limestone numbered 29 in the section.

The west end of this gap is drained by a narrow arroyo that descends rapidly and that has laid bare a fairly clear section which represents the larger part of the Word formation. The strata exposed in this arroyo probably extend to near the base of the formation. These beds furnish a fairly good idea of the nature of the sediments of which the Word formation consists. Examining what is exposed of the whole formation, it is found to be made up of about 48 per cent. of arenaceous rock, 33 per cent. of limestone, 15 per cent. of materials not exposed, possibly largely shale, and four per cent. of shale.

The Vidrio formation is almost entirely limestone, mostly dolomitic. Less than two per cent. consists of arenaceous material and it contains no layers of shale or clay. It is not markedly stratified.

The Gilliam formation consists of dolomitic limestone which shows straight and trenchant bedding. It contains a single sandstone, which makes up less than one per cent. of the formation.

The Tessey formation is all limestone, mostly dolomitic, and without marked bedding planes.

Section 5.

A section of the south bluff of the main ridge of the Glass Mountains, beginning at its base at a point about three miles northeast of Leonard Mountain, and extending northward up the escarpment.

		Thickness in feet.
1.	A limestone conglomerate which contains rounded boulders and pebbles of chert and quartz. Some of the boulders contain Fusulina. The exposure of this conglomerate is small and was seen in a gully some 100 paces south of the line where the overlying limestones begin to appear in continuous exposures. This conglomerate is believed to be the basal conglomerate of the Hess formation	10
2.	Not exposed. Probably shale	20
3.	Hard, calcareous rock, with a lumpy structure, sheared vertically	2
4.	Dark bluish gray clay	2
5.	Gray dolomitic limestone. The crystals measure about 0.1 mm. in diameter. Small bodies of limestone remain unchanged in the dolomite. These are sharply marked off from the rest of the rock and show traces of organic fragments. These small bodies are also sheared vertically	2
6.	Not exposed	20
7.	Compact, impure, gray dolomitic limestone, showing white specks. In thin section this rock is seen to consist of a fairly uniform mass of crystals measuring about 1 mm. in diameter. The white specks are unaltered organic fragmental limestone, sharply marked off from the rest of the rock	8
8.	No exposure	5
9.	Gray limestone. Crinoid stems and spines of palechinoids noted	4
10.	Gray impure limestone, in part in thin layers. In thin section this rock is seen to be oolitic and to also contain organic fragments. Fifty per cent of the mass of the rock consists of ooliths from .3 to .6 mm. in diameter, their outlines being poorly defined and the containing matrix secondarily crystallized. Crinoid fragments and pieces of ostracod shells and other shells were noted. Trochammina gordialis, Endothyra and a Nodosaria were noted	15
11.	Gray, compact limestone in thick beds, the upper 25 feet dolomitic. In thin section this rock is seen to have an obscure oolitic structure of fine texture and to contain minute sponge spicules	34
12.	Very compact, gray limestone, containing Fusulina, crinoid stems, and spines of sea urchins. In thin section this rock is seen to be oolitic and organic-frag-	

		Thickness in feet.
	mental in nature, of fine texture and to contain sponge spicules, fragments of ostracod shells, Trochammina gordialis, and spines of brachiopods..................	22
13.	Gray limestone, dolomitic in places, with many Fusulinas imbedded. In thin section it is seen to be very fine in texture, organic-fragmental, and to contain spicules of sponges, Trochammina gordialis, Nodosaria, and spines of brachiopods................................	3
14.	Gray, compact limestone.............................	8
15.	Light gray and in part pinkish gray limestone, cut by many small fissures, filled with calcite. Fossils noted: many foraminifera, crinoid stems, Fusulina, bryozoa, shells of ostracods, and spicules of sponges............	4
16.	Gray, compact limestone in somewhat thin layers, and containing some dark chert...........................	38
17.	Gray, compact, dolomitic limestone, calcareous in places. It contains small calcareous shell fragments and small crevices filled with quartz and calcite. Above it is more thin-bedded than below...............................	35
18.	Gray, in part oolitic, limestone studded with Fusulina and other foraminifera in profusion. The rock contains imbedded lumps, differing in texture from the body of the rock. In thin section this rock shows much re-crystallized material in which can be seen distinct ooliths and fragments of organic remains, and entire foraminifera, among which Trochammina gordialis, Nodosaria, and Fusulina were noted. In some of the gray lumps referred to above, a Fusulina occupied the center	7
19.	Soft beds not well exposed. In thin section some limestone from this member is seen to be considerably altered, but shows many organic fragments, some ooliths, sponge spicules, pieces of valves of ostracods and many fragments of echinoderms...........................	11
20.	Compact, gray limestone of dim organic-fragmental texture, and containing some fine angular sand grains, measuring from 0.2 to 0.3 mm. in diameter.............	78
21.	Somewhat dolomitic, organic-fragmental limestone, with Fusulina in profusion. In thin section the rock is seen to be traversed by irregular tracts of secondarily crystallized material. Trochammina gordialis and spicules of sponges were noted................................	8
22.	Soft limestone	6
23.	Compact, organic-fragmental limestone, with foraminifera in the upper six inches in profusion...................	11

		Thickness in feet.
24.	Gray limestone, dolomitic above	28
25.	Mostly dolomitic limestone	30
26.	Gray limestone of fine texture, in part dolomitic	44
27.	Organic-fragmental limestone, containing many Fusulina	33
28.	Organic-fragmental limestone with minute concretionary structures and containing Fusulina. In thin section the rock is seen to be oolitic. Three-fourths of the mass of the rock is secondarily crystallized, and its original structure is only partly preserved	66
29.	Two well-marked ledges of organic-fragmental white limestone	10
30.	Light gray limestone. In thin section this rock is seen to be oolitic, with ooliths poorly preserved and irregular in form. Fossils noted: Trochammina, Nodosaria, bryozoa, brachiopod spines, sponge spicules, shells of ostracods and fragments of crinoid stems. Much of the rock is secondarily crystallized	33
31.	Light gray limestone mostly of fine texture and with two thin layers of dolomite. In thin section the rock is seen to be considerably altered by crystallization. Shells of ostracods, Nodosaria and Fusulina were noted	72
32.	White, mostly dolomitic limestone. In thin section a piece of this rock is seen to be crystalline, with crystals averaging a half mm. in diameter	66
33.	Gray limestone of fine texture. In thin section this rock is seen to be oolitic, but largely secondarily crystallized, and with the ooliths poorly preserved. Crinoid fragments, Trochammina gordialis, Nodosaria, fragments of ostracod shells, and of various spines, and sponge spicules, were noted	36
34.	Gray limestone of fine texture, in part dolomitic. In thin section shells of ostracods, a Nodosaria, and a Fusulina were noted	55
35.	Organic-fragmental limestone of fine texture	63
36.	Dolomitic limestone	8
37.	Limestone of fine texture, in part dolomitic	77
38.	Gray organic-fragmental limestone, containing concretionary structures or lumps up to one-fourth inch in diameter. Fusulina and crinoid stems noted	3
39.	Gray limestone of fine texture, in part dolomitic. The uppermost layer contains sub-cylindric concretionary bodies, with a porous central tract, one-fourth to one inch in diameter. Casts of a small high-spired gastropod noted. In thin section the rock is seen to contain angular cavities filled with calcite	38
40.	Limestone of fine texture, in part dolomitic	78

This section consists mainly of limestone. About one-eighth of this limestone is dolomitic. Only some two per cent. consists of conglomerate and shale. It represents the lower part of the Hess formation and measures 1092 feet.

North from the ridge where this section was taken, is a valley which separates it from another ridge that is in part made up of the Leonard beds. In the valley mentioned there is an intrusion of syenite porphyry, like that of Iron Mountain. This has caused some dislocation in the sedimentary series. Part of the north ridge consists of a great thickness of a very coarse conglomerate, which evidently belongs to the Leonard formation. The following section (Number 6) may be regarded as a continuation of this section (Number 5) with the Leonard and the upper part of the Hess omitted. The distance between the top of section Number 5 and the base of Section Number 6 is nearly two miles. As the average dip to the north is at least 10 degrees, it would appear that the thickness of the omitted beds is near 2000 feet. This would make the combined thickness of the Hess, the Leonard, and the Word, on the line of these two sections, about 3760 feet.

Section 6

A section from the top of a small hill about one mile east-northeast of Hess Tank and extending north 20 degrees west for about a mile and a half. (By Mr. Bowman).

	Thickness in feet.
1. Brownish, coarse dolomite in heavy ledges dipping 6 degrees north, 20 degrees west. The rock is exposed along the top of the hill for 1250 paces. On the weathered surface such fossils were found as: Fusulina elongata Shumard, Cystothalamia? sp., Campophyllum texanum Shumard, Cladopora? sp., Fistulipora sp., Domopora ocellata Girty, Enteletes dumblei Girty, Acanthocladia guadalupensis Girty, Leptodus americanus Girty, Productus guadalupensis Girty, Productus meekanus Girty, Richthofenia permiana Shumard, Rhynchonella? (Pugnax) indentata? Girty, Pugnax? bisulcata Shumard, Dielasmina guadalupensis Girty, Spirifer cameratus Morton, S. cf. kentuckiensis Shumard, Ambocoelia planoconvexa Shumard, Orthoceras sp.	50

		Thickness in feet.
2.	Reddish brown, sandy limestone interbedded with shale..	20
3.	No exposure. Aviculopecten carboniferus Stevens was found on the talus on this member....................	190
4.	Ledges of dark dolomite. The fossils found here were: Crinoid stems, Productus texanus Girty, Paraceltites aff. elegans Girty, and P. multicostatus Böse................	46
5.	Yellow, laminated, sandy limestone, alternating with a few layers of shale. "Worm tracks" were noted in sandy limestone	150
6.	Dark limestone alternating with a few streaks of fine-textured yellow sandstone at the bottom ,and with a few dolomite ledges at the top. Fossils noted were: Fusulina elongata Shum., crinoid stems, Fenestella capitanensis Girty, Fistulipora? sp., Bryozoa 2 sp., Enteletes dumblei? Girty, Chonetes sublicatus Girty, Richthofenia permiana Shumard, Productus guadalupensis Girty, P. walcottianus Girty, P. sp., Spirifer cameratus Morton...............	215
7.	Massive dolomite ledges. Bryozoa noted.................	47

The 671 feet included in numbers 1 to 6 of this section represent the Word formation. It consists of about 80 per cent. of mostly sandy limestone, with some shale, and some sandstone of fine texture.

Section 7

A section extending north-northwest from Wolfcamp. (Wolfcamp is located at the south foot of the westernmost of several hills, exposing a white, heavy-bedded limestone member of the Gaptank formation. These hills constitute a line of foothills below the main escarpment of the Hess limestone, which extends from the Hess Tank to Gap Tank. The locality is about six miles east and one-half mile north from the east foot of Leonard Mountain, and is marked by an old excavation for an open well.)

		Thickness in feet.
1.	Beginning below. Greenish-gray shale exposed in the base of the bluff, and explored in an open well. Ammodiscus was found in this shale....................	100
2.	Benches of dark limestone, interbedded with layers of shale. Some large joints of crinoid stems noted. A piece of thin limestone was found to contain shells of	

		Thickness in feet.
	Ostracods in profusion, and some imbedded sand grains.	20
3.	Limestone conglomerate, weathering yellow in places. This contains various fossils such as cup corals, several brachiopods, crinoid stems, Fusulina, Athyris, and spines of echinoids	10
4.	Probably mainly shale. Not well exposed	10
5.	Limestone in thick layers, fossiliferous	10
6.	Probably mostly shale. Not well exposed	32
7.	Thick ledges of white limestone, containing large brachiopods, and cup corals, conglomerate in places	17
8.	Shale, silty, and somewhat calcareous. When washed and closely examined it yielded sponge spicules and a typical Ammodiscus. This shale contains a rich fauna, largely new. Eight genera and twelve species of ammonoids have been recently described by Dr. Böse. These were collected from less than a half acre of ground immediately on the north side of a small butte capped by the limestone of the preceding member. These were: Agathiceras Frechi, Daraelites texanus, Gastroceras modestum, Marathonites J. P. Smithi, M. sulcatus, M. vidriensis, Paralegoceras diversicostatum, Uddenites Schucherti, U. minor, Vidrioceras Uddeni, V. irregulare.	80
9.	A limestone which weathers brown and consists largely of fragments of shells	1
10.	Shale containing various ammonoids	18
11.	Thick-bedded limestone, in part conglomerate, in places fossiliferous. The thickness of this member varies from 16 to 60 feet in the immediate surrounding of the section.	20
12.	Shale.	22
13.	Shell breccia limestone, weathering brown	2
14.	Shale, in part very dark and almost black. It apparently contains some thin calcareous layers, in which crinoid remains occur.	88
15.	Shell breccia limestone, containing bryozoa, brachiopods, and crinoid stems	1
16.	Shale, not well exposed	44
17.	Shell breccia, changing to a conglomerate with some rounded quartz pebbles to the east	3
18.	Shale.	4
19.	Yellow limestone	3
20.	Shale.	4
21.	Yellow limestone, containing many fragments of shells	5

		Thickness in feet.
22.	Shale, not well exposed	55
23.	Yellow limestone	1
24.	Shale, not well exposed	77
25.	Yellow limestone, somewhat a shell breccia	1
26.	Shale, not well exposed, in part greenish gray in color, and calcareous	100
27.	A conglomerate consisting mostly of pebbles from one to five inches in diameter, and varying in thickness from 27 to 45 feet. It contains crinoid stems in a marly matrix in some places. (This no doubt is the basal conglomerate to the overlying Hess limestone.)	40
28.	Not well exposed, probably mostly shale. Some of this shale was seen to be very fine in texture and slightly calcareous.	200
29.	Gray dolomitic limestone of fine texture, weathering brown, and containing pockets of calcite	6
30.	Layers of dolomitic, conglomeratic and other limestone, not well exposed and probably interbedded with some shale. A thin section of a limestone from this member shows partial alteration to a rock of coarse crystalline texture. In this occur various organic fragments, including Fusulina. Three thin sections are oolitic limestone, with imbedded shell fragments of ostracods and foraminifera. Still another thin section shows organic fragmental material with Fusulina, sponge spicules and tubular foraminifera, like Trochammina, and also ostracod valves	187
31.	Thin-bedded gray limestone with some layers containing Fusulina in profusion	132
32.	Hard, compact, gray limestone	5
33.	Thin-bedded, gray limestone	15
34.	Hard, compact, gray limestone	4
35.	Thin-bedded gray limestone, of somewhat compact texure.	21
36.	Two layers of compact, gray limestone	8
37.	Thin-bedded limestone, not well exposed	11
38.	Compact, thick-bedded, gray limestone, with pockets filled with calcite	6
39.	Thin-bedded, gray limestone	16
40.	Compact, gray limestone	4
41.	Compact, gray limestone. Thick and thin layers interbedded.	38
42.	Compact, gray limestone in a single layer	6
43.	Not well exposed, probably soft limestone or marl	45

		Thickness in feet.
44.	Compact, gray limestone	5
45.	Thin-bedded limestone	12
46.	Limestone in one single layer	4
47.	Layers of gray limestone, alternating with softer limestone in thin layers	55
48.	Thin-bedded gray limestone interbedded with some shale above	210
49.	Thick beds of gray limestone, interbedded with limestone of thin layers	236
50.	Thin-bedded, gray, compact limestone. A flat-coiled gastropod was noted	88
51.	Thin-bedded, gray, compact limestone, with two well-marked layers of thick-bedded limestone below, and with some shale above. A bed about forty feet below the top of this member is oolitic and foraminiferal. The uppermost layers contain Bellerophon, Myalina, Archeocidaris, Pinna, various gastropods, crinoid stems, producti, and cup corals. A thin section of the oolitic rock about forty feet below the top of this member shows the ooliths to be oval and mostly from 0.2 to 0.5 mm. in longest diameter. It has cavities filled with clear calcite that have the shape of thin shells, such as those of ostracods. These lie flat with the bedding of the rock	350
52.	Massive limestone, somewhat dolomitic. Plates and spines of palechinids were noted in some shale in this member, which also contains stems and plates of crinoids and a Fusulina. Two strong limestone layers appear in this member	77
53.	Limestone, moderately thin-bedded, alternating with dolomite.	50
54.	Gray limestone in two thick beds, capping the escarpment.	16
55.	White limestone containing many ostracods and foraminifera.	2
56.	Thin-bedded limestone containing many fusulinas in many cases surrounded by a thick envelope of concentrically laminated structure, the whole forming nodules from one-eighth to one-fourth inch in diameter. The encrusting laminations consist of granular calcareous material	16
57.	Fusulina-bearing limestone, light gray in color	16
58.	Dolomitic limestone	11
59.	Thin-bedded fusulina limestone	55

		Thickness in feet.
60.	Gray dolomitic limestone in which one layer contains many scattered crystals of calcite about one-eighth inch in diameter. In thin section this rock is seen to be minutely granular in texture, showing obscure traces of organic fragments originally contained. The imbedded crystals range from 1 to 10 mm. in longest diameter. .	11
61.	Thin-bedded gray limestone with some dolomitic layers.	38
62.	Alternating layers of gray limestone and dolomitic limestone layers. In the upper part of this member balls of flint from 3 to 6 inches in diameter occur. A Fusulina of large size occurs in places in abundance and in association with the chert. A Seminula, some bryozoa and crinoid stems noted	77
63.	Gray dolomitic limestone, and other limestone, in moderately thick layers	182

At this point there is a sudden increase in the dip and this may be due to a fault with downthrow to the north. This would explain the absence of the greater part of the Leonard formation.

64.	Gray, marly, soft limestone, containing pebbles of white quartz, of black fissured quartz, and of limestone. In places this rock is indurated and contains silicified fossils like those found in the Delaware and the Guadalupian formations	5
65.	Red sandstone and sandy limestone, in which a Productus was noted	23
66.	Yellow and reddish sandstone	25
67.	A gray limestone of granular texture, containing some sand. Some bryozoa and several Valvulina were noted in some thin sections. Another thin section is compact oolitic and organic fragmental limestone, in which the ooliths are from 0.3 to 0.9 mm. in diameter, of somewhat irregular shape and lying close together, among shells of ostracods and fragments of other shells. Much of the rock in this thin section is secondarily crystalline. .	3
68.	Red sandstone	5
69.	Crinoidal, crystalline limestone.	1
70.	Reddish and yellow sandstone	12
71.	Gray, fossiliferous limestone	1
72.	Reddish sandstone	8
73.	Gray, marly, and fossiliferous limestone	1

		Thickness in feet.
74.	Yellow sandstone	11
75.	Impure limestone	1
76.	Marly, gray sandstone	11
77.	Concealed.	(?)5
78.	Fossiliferous limestone	2
79.	Yellow sandstone, in part marly	7
80.	Sandy limestone	1
81.	Not exposed, perhaps shale	33
82.	Fossiliferous limestone, studded with a large Fusulina on upper surface. Bryozoa and a small cup coral were noted.	7
83.	Not well exposed, probably shale	46
84.	Limestone in a single bed, with silicified fossils	3
85.	Very thin-bedded, dark gray limestone of compact texture	40
86.	Crinoidal limestone	1
87.	Very fine-textured, hard, almost black, bituminous limestone, showing very thin and even laminations, and containing cherty and sandy layers which weather red.	47
88.	Blue sandy and calcareous layers of rock, in part cherty and weathering red throughout. Thickness about	200
89.	Massive dolomitic limestone, with apparently some softer inter-bedded layers. Cup corals, spirifers and producti were noted	137
90.	Sandstone, weathering red, and containing much chert.	8
91.	Cherty limestone	3
92.	Cherty sandstone, weathering red	12
93.	Gray dolomitic limestone, containing a large Fusulina and other fossils	16
94.	Sandy and cherty limestone weathering red, and containing a small Productus in profusion in a three-inch chert layer	5
95.	Dolomitic limestone	8
96.	Sandy limestone, weathering red	5
97.	Dolomitic limestone, weathering gray, and having a Fusulina.	4
98.	Cherty dolomite, weathering red	13
99.	Cherty dolomite, weathering gray, and containing Fusulina in nests	25
100.	Sandy and cherty dolomite, weathering red and alternating with calcareous, cherty and concretionary, thin-bedded limestone	55
101.	Irregularly bedded dolomite in thick strata, containing considerable chert in mostly irregular and varying shapes. It weathers to a rough ground. Fusulina and some other fossils occur sparingly	540
102.	Limestone of Cretaceous age overlies the north end of the section	

The numbers from 1 to 9, inclusive, represent the Gaptank; in all, 280 feet. These consist of 81 per cent. shale and 19 per cent. limestone. In one case the limestone is conglomeratic.

Numbers 10 to 26, inclusive, have been called the Wolfcamp. This measures 448 feet in thickness, and appears to be unconformable with the Gaptank. Shale makes up 92 per cent. of the Wolfcamp. The remaining 8 per cent. consists of thin limestones which in many places are conglomeratic, or consist of sorted and well worn fragments of organic remains of small size.

The numbers from 27 to 63, inclusive, represent the Hess formation, which here measures some 2150 feet. This formation, here, as farther west, is made up chiefly of limestone, which constitutes about 68 per cent. of the whole; and of dolomite, which makes some 16 per cent. The remaining 16 per cent. is mostly shale, or, at any rate, beds yielding more readily to the destructive process of erosion, so as to be more or less concealed.

The greater part of the Leonard formation is either eroded away or faulted out of this section. A sudden change of dip which was noted between numbers 63 and 64 suggests the presence of a fault that may have thrown most of this formation below the surface. The rocks described as numbers 64 to 84, inclusive, are believed to represent the upper part of the formation. These have a thickness of no more than 20C feet, and consist of 49 per cent. of sandstone, some 38 per cent. of shale and unexposed beds, and only 13 per cent. of limestone. A Waagenoceras was noted in the upper part of this division of the section.

The part of this section which is referred to the Word formation comprises numbers 85 to 100, with a thickness of 579 feet. It is made up of about 60 per cent. of limestone with 40 per cent of sandstone or sandy limestone of fine texture, and apparently no shale. It is evidently the upper part of the Word formation which here mainly comes into view. Very likely also, the shaly beds of the formation have been very much reduced by being squeezed out or by being compressed. Some of the soft calcareous shales may also have become indurated to the extent that they can no longer be recognized as shales but resemble impure limestone. Some exposures in an arroyo farther west, which drains into the Hess Canyon, show, at any rate, evidences of shearing on an extensive scale, in the horizon of the Leonard and the Word formations.

The 540 feet described under number 101 in this section represent the Vidrio limestone which is capped at this place, as farther west, by the basal beds of the Comanchean Cretaceous. It is nearly all limestone.

Section 8

A section of the face of the east extension of the main escarpment of the Glass Mountains at a point about five miles west from Gap Tank. The section begins at the foot of the escarpment, where there is a small water tank, and from where a wagon road leads past some dwelling places up the face of the escarpment and northward.

		Thickness in feet.
1.	Shaly beds	15
2.	Brownish sandstone	8
3.	Shale.	55
4.	Sandstone, calcareous, brownish in color	80
5.	White, hard limestone, containing a few pebbles of crystalline texture, above. Crinoid stems, a Myalina and a Seminula were noted near the base	30
6.	Soft, marly beds	25
7.	Limestone.	15
8.	Soft limestone	17
9.	White limestone, largely crystalline in texture	35
10.	Laminated, soft limestone	15
11.	Hard, white limestone	10
12.	Thin-bedded, marly limestone, and shale	30
13.	White limestone	20
14.	Conglomerate of coarse rounded limestone boulders, mostly three inches in diameter. This is apparently the basal conglomerate of the Hess formation	20
15.	Marly, soft limestone and shale, not well exposed	11
16.	Red shale	6
17.	Greenish gray shale, or clay	2
18.	Gray marl	6
19.	Yellow limestone	1
20.	Reddish and yellow shale or clay	14
21.	Yellow limestone	1

		Thickness in feet.
22.	Shale	4
23.	Yellow limestone	3
24.	Shale.	11
25.	Yellow limestone	1
26.	Shale.	16
27.	Yellow limestone	1
28.	Shale, in part reddish	18
29.	Yellow limestone	2
30.	Gray sandstone, cross-bedded	24
31.	Shale, mostly blue, in part reddish	17
32.	Yellow limestone	1
33.	Gray sandstone.	12
34.	Gray sandstone and shale	16
35.	Gray, cross-bedded sandstone	17
36.	Greenish shale with streaks of red shale and calcareous material	55
37.	Yellow, sandy limestone	1
38.	Gray shale	40
39.	Gray sandstone of fine texture	5
40.	Gray shale.	11
41.	Gray limestone of very fine texture, containing Fusulina	38
42.	Shale	2
43.	Limestone	2
44.	Shale and limestone	8
45.	Gray limestone with many Fusulina	3
46.	Shale	13
47.	Gray limestone of fine texture	22

The lower 355 feet of this section including the numbers 1 to 20, consist of the Gaptank formation. It will be seen that this part of the section consists of about 43 per cent. of limestone, 25 per cent. of sandstone, 23 per cent, of shale, and 9 per cent. of marl. The upper 402 feet represent the basal part of the Hess formation, and this consists of about 55 per cent. shale, 19 per cent. limestone, 17 per cent. sandstone, 5 per cent. conglomerate, and 4 per cent marl.

Section 9

A section along a line running approximately northwest from a point about two miles west of Gap Tank. This section begins some 100 *yards south from the foot of the east extension of the main Glass Mountain escarpment and continues up the face of this escarpment to the base of the basal conglomerate of the Hess formation.*

		Thickness in feet.
1.	Dark gray limestone in layers of from one to two feet in thickness. Small brachiopods and crinoid stems noted	66
2.	Light gray, coarse-grained, irregularly-bedded limestone	70
3.	Not exposed	80
4.	Dark gray limestone, weathering yellow	2
5.	Yellow clay or shale, exposed in some places	7
6.	Dark gray limestone, weathering yellow. Bryozoa and crinoid stems noted	2
7.	Nothing exposed, probably shale	17
8.	Dark gray limestone, weathering yellow	1
9.	Mostly not exposed, but containing some beds of soft yellow limestone and shale	50
10.	Gray limestone, weathering yellow	4
11.	Not exposed, probably shale	20
12.	Gray limestone containing crinoid stems and having many peculiarly interwoven fragments of shells. These are about a sixteenth inch thick and mostly about one-fourth inch in diameter. They lie in all positions in a matrix of finely granular calcareous material in which were noted a few indistinct traces of organic fragments. This rock resembles a limestone occurring in the Cisco formation at Cisco, in Eastland County	3
13.	Compact, dark gray limestone	14
14.	Sandy, gray limestone	7
15.	Slightly indurated, marly rock, with thin layers of yellow limestone	5
16.	Dark gray limestone	1
17.	Yellow limestone in thin layers	88
18.	Gray, soft limestone containing crinoid stems and peculiarly interwoven fragments of thin shells. Like the rock described under number 12, above	15
19.	Covered by talus, probably consisting of rock like that described under number 18, above	28
20.	Apparently a single bed of massive white limestone	50

This section includes the uppermost 525 feet of the Gaptank formation, which, if all is counted that is known from other exposures, probably measures four times as much as this section.

This section contains about two-thirds limestone, varying from marly, soft rock to hard white limestone; and one-third argillaceous rock, varying from marly to non-calcareous deposits.

DESCRIPTION OF THE FORMATIONS.

The Gaptank Formation

Above the Haymond formation, which has been described by Mr. C. L. Baker in the accompanying paper, there is a thick deposit of shale underlain and overlain by some limestones and sandstone. These deposits are estimated to measure in the neighborhood of 2000 feet. The sequence of the different parts of the formation has not been wholly made out. In its lower part are limestones, marls, and sandstones with a considerable fauna. These outcrop at a point about three miles south of Gaptank where they are tilted at high angles and are overlain by the Comanchean, which caps a projecting angle of the Glass Mountain escarpment. It is believed that these beds are also exposed over an area lying just outside of the older Paleozoic about four miles west of Marathon, mostly north of the railroad. Some of the shale is calcareous, some is free from calcareous material. In color it varies from light to dark gray, in places being greenish. The limestones are mostly less than five feet thick, and in places they are studded with Fusulina. There were also found stems and pinnules of crinoids, an Ammodiscus of very symmetrical spiral form, *Endothyra Bowmanni, Trochammina incerta, Haplophragmium rectum* (?), *Bigenerina, sp., Climacammina, sp., Lituola Bennieana, Valvulina bullodies* (?), various tubular foraminifera and spicules of sponges. The shale and the limestone layers contain a large fauna from which Dr. Böse has described *Schistoceras Smithi*, and in which Dr. Beede has identified the following forms:

Axophyllum
Chaetes, sp.
Helcrocoelia aff. Beedi Girty
Coelocladia? sp.
Chonetes mesolobus N. and P.
C. verneuilianus, N. and P.

Pustula punctata (Martin)
Productus, several species
P. cora d'Orb
Fusulina, sp.
Wewokella, sp.
Composita argentea (Shep.)
C. cf. mexicana Girty
C. cf. mexicana guadaloupensis Girty
Enteletes aff. Waageni Gemm.
Marginifera splendens (N. and P.)
Meekella cf. difficilis Girty
Pugnax rockymontana (Marcou)
Pustula nebrascensis Owen
Spirifer cameratus Morton
Spirifer musakheylensis Dav.
Spiriferina kentuckiensis Shumard?
Squamularia perplexa McChesney?
Chenomya leavenworthiana Meek
Nuculopsis ventricosa (Hall)
Bellerophon percarinatus Conrad
B. tricarinatus Conrad
B. var. tricarinatus Shumard
B. crassus M. and W.
Euphemus nodocarinatus (New Harmony var.) White
Euphemus cf. carbonarius Cox
Pleurotomaria, group of *P. altaica* Vern.
Porcellia sp.
Trachydomia wheeleri (Swall.)
Trachydomia, sp.
Trepospira cf. illinoiensis Worthen
Worthenia aff. tabulata Conrad

From the locality where these fossils were taken Professor C. L. Baker has identified also a Tegulifera, a form somewhat closely related to Richthofenia.

This division Dr. Beede correlates with the coal-measures of Kansas.

The middle half of the formation is not well exposed in the localities visited. No doubt it consists of very little else than shale, which in all probability extends as a belt a half mile or more in width south of the foot of the southernmost escarpment of the Glass Mountains, excepting in the region of the Iron Mountain. The softness of this part of the formation has permitted it to be generally eroded away and it is rarely exposed, occupying, as it does, low places on the plains.

The upper part of the formation is exposed at Gaptank, and westward from this place it rises one or two hundred feet in the main escarpment for the first five or six miles. For the next six miles its uppermost member, which is a hard, thick limestone, appears discontinuously in a southwestward direction and forms a row of low hills that rise from the plain half a mile or more south of the main escarpment.

This upper part of the Gaptank is alone represented in the sections 7, 8, and 9, previously given. It constitutes the lower 525 feet in the last of these three sections. There are some differences in the rocks of the three sections. As described, the sediments consist of about 43 per cent. limestone, 34 per cent. shale, and clay, in part marly, and 23 per cent. of sandstone. The smaller limestones are all impure and some of them border on marls. Two layers about a hundred feet apart are characterized by the occurrence of what appears to be a number of fragments of some brachiopod shell, which lies in a tangled profusion in the rock. A layer of this kind of limestone is seen at Cisco, in the central part of this state. Near the top of the formation there is a thick white limestone, almost without bedding planes, measuring from 10 to 40 feet. In the westernmost exposures there appear under this limestone some thin limestones which contain a small amount of conglomeratic material.

In a collection of fossils taken from this upper part of the Gaptank, Dr. Beede has identified fossils from which he concludes that the formation probably reaches up into the Elmdale of the Kansas section. His list of identified forms is as below:

Fusulina aff. longissimoides Beede
Fusulina, two other species
Schwagerina aff. princeps
Meekopora, two species
Rhombopora lepidodendroides Meek?
Chonetes granulifer Owen
Composita argentea (Shep.)
Enteletes Oelerti Semm.
Geyerella? sp.

Marginifera splendens (N. and P.)
Meekella, two species
Productus guadaloupensis comancheanus Girty
Pustula punctata (Martin)
Spirifer cameratus (Mort.)
Euomphalus pernodosus M. and W.
Euphemus aff. carbonaria Cox
Omphalotrochus? sp.

It will be convenient to refer to the two calcareous members of this formation respectively, as the lower Gaptank and the upper Gaptank. Dr. J. W. Beede's studies show that there must be a considerable interval between the two, and it may be found that they should be treated as separate units. The lower fossil-bearing horizon of the Gaptank is certainly Pennsylvanian, and from the present studies it seems likely that the upper Gaptank represents our uppermost Pennsylvanian in the western part of the state.

Sufficiently clear exposures near the lower limit of this formation have not been seen by the writer, and he can not at present say whether or not an unconformity exists between the Haymond and the Gaptank. The Haymond is not only tilted at high angles, but its exposures lie nearer to the center of the axis of disturbance than those of the Gaptank. The same comparison may be made between the lower Gaptank and the upper Gaptank. The upper Gaptank has not been seen to dip at a higher angle than one of about 25 degrees, but it is known only on the northwest flank of the Marathon disturbance where it goes under the gently dipping series of the Permo-carboniferous. Dr. Böse and Professor Baker report that the Haymond and the Lower Gaptank are separated by an unconformity.

The Wolfcamp

Overlying the Gaptank there are some beds which I have called the Wolfcamp. These measure nearly 500 feet in the section taken at Wolfcamp, and this represents, so far as known, the greatest thickness of this formation in the Glass Mountains. Observations on this formation have been made chiefly at Wolfcamp, from which it takes its name.* It has been identified by characteristic cephalopods also in a terrace-like foothill at the east end of Leonard Mountain. From the aspect of the local topography it seems likely that the formation will be found to extend for several miles eastward from Wolfcamp. The Wolfcamp consists mostly of shales which vary in color from almost black to gray and greenish-gray. Interbedded with this shale are several layers of limestones which are cemented shell breccias, in places conglomeratic. There are also layers of calcareous sandstones. In the Wolfcamp section the formation consists of about 92 per cent. of shale, 6 per cent. of limestone, and 2 per cent. of calcareous conglomerate.

The basal part of the formation is a shale or clay in which there is a large fauna of cephalopods. Dr. Böse has described the following forms:

Agathiceras Frechi
Daraelites texanus
Gastrioceras modestum
Marathonites J. P. Smithi
M. sulcatus
M. vidriensis
Paralegoceras incertum
Schistoceras diversecostatum
Uddenites minor
U. Schucherti
Vidrioceras Uddeni
V. irregulare

In Dr. Böse's opinion, this fauna indicates that there is a considerable interval of time between the underlying Gaptank and this basal clay of the Wolfcamp. Dr. Beede, who has examined and identified other invertebrates, is of the same opinion, and he is inclined to refer this formation to the basal Permo-carboniferous. Several of the fossils he has examined come from the upper calcareous members of the formation. The forms he has identified are as follows:

*Wolfcamp is the site of an old dwelling-place, just to the south of the two buttes located about 6½ miles east and some 2 miles north of the east end of Leonard mountain. The place is not now inhabited, but it is marked by an old open well some hundred feet deep. "Lobo" wolves are said to frequent the place.

Fusulina, sp.
Schwagerina, sp.
Syringopora, sp.
Cladopora? (2 or 3 specimens)
Lyttonia, sp.
Aulosteges aff. guadalupiensis Girty
Productus aff. purdoni Dav.
P. semireticulatus, 2 or 3 varieties.

Though the evidence is not quite clear, it is believed that there is an unconformity between the Wolfcamp and the Gaptank. As has been already shown, the upper part of the Gaptank is a thick limestone, which does not occur in a continuous exposure but caps some buttes that form a chain extending in front of the principal escarpment from Gaptank to a couple of miles west of Wolfcamp. Their appearance suggests that this limestone was once outliers capping buttes carved out of the Gaptank formation There is a suggestion that the Wolfcamp extends down the edges of these capping limestones, but the evidence is not clear and so far no basal conglomerate of the Wolfcamp has been discovered.

The Hess Formation

In that part of the Glass Mountains escarpment which begins with the southernmost ridge east of Leonard Mountain and extends northeastward to Gaptank and from there to the north-northeastward some three miles along the Marathon-Stockton road, we have a continuous exposure of a limestone that I have called the Hess formation. It was measured in greatest development in the old Hess Ranch. It forms the main part of the south face of this ridge and continues in the valley followed by the Stockton road some two or three miles farther north This limestone is quite distinct from other limestones in the Glass Mountains. It overlies the Gaptank and Wolfcamp unconformably, and this unconformity represents an old erosion plane which in the Gaptank region has come to lie several hundred feet below the top of the Wolfcamp beds. This formation is best developed in the old Hess ranch. At least three of the natural sections describe these beds: sections numbers 5, 7 and 8. In section 5, the

Hess beds attained their maximum thickness. measuring 2150 feet. An average of the different kinds of material shown in these sections consists of 58 per cent. of limestone, 8 per cent. of dolomite, or dolomitic limestone, 25 per cent of shale, 6 per cent. of sandstone, and 3 per cent. of conglomerate.

The limestones of the Hess are mostly thinbedded, but the formation contains also several layers that measure from five to ten feet in thickness. In almost all parts of the formation. Fusulina occurs, sometimes in abundance. The beds contain also various other foraminifera. A good part of the limestone is oolitic, but the oolitic grains are as a rule very small, and can hardly be distinguished with the naked eye. In the upper part of the formation there occur in some of the layers encrustations of calcareous material, which seem to have been rolled around organic fragments, mostly fusulinas, which appear in the center of these encrustrations. The encrusting material is thinly laminated.

The color of this limestone is mostly light gray. The individual beds have a uniform development and can be traced for comparatively long distances. It can also be said that the general aspect of these limestones resembles that of the Hueco formation farther west in the state, but sufficient collections of fossils have not been made from this formation for the purpose of verifying such a correlation. In its upper part, fossils are quite plentiful in certain layers. It appears that dolomitization of the limestones in this formation has proceeded at quite unequal rates in different places. At the west end of the escarpment, dolomitization is quite general. As we go away from the disturbance near the igneous intrusions extending northeast from Iron Mountain, dolomitic layers appear less frequently than at its west end. The sandstones and shales of this formation are present mostly in the lower four hundred feet. Most of the shale is bluish-light gray in color. The sandstones are usually free from limey material, have an open texture, and are moderately fine-grained. In places they show cross-bedding. The basal conglomerate of the Hess consists mostly of limestone boulders, but it also contains some boulders of flint and other quartz. All the underlying formations are represented. It varies from ten to forty feet in thickness.

In section 7, the strata referred to this formation measure twice as much as in section number 5, and in the section numbered 8, extending north from a point five miles west of Gaptank, a thickness of only 402 feet was measured. Erosion has here extended much farther down than at the previously mentioned places. The extension of the Hess westward from Leonard Mountain is uncertain. It may be present in the lower part of Leonard Mountain. Some exposure seen in the base of the southernmost ridge west of the Lion Mountain should, perhaps, be referred to the Hess, but further studies will be necessary to determine whether or not this is the case. On the map, such an extension is indicated, but from the knowledge that the present writer has of the conditions in that direction, it is certain that the Hess should occupy a more narrow belt than that indicated. Probably it will be found to appear merely as small remnants here and there along the line where the outcrop of this formation is looked for in this part of the area under consideration.

That the Hess formation is separated from the Gaptank and Wolfcamp by a considerable erosional unconformity is quite evident. The differences in dip between the two formations is not very marked. It is hardly to be inferred that this unconformity of erosion represents any great lapse of time, for the underlying beds are mostly shales with thin limestones and would readily yield to destructive forces.

The Hess formation can be said to be distinguished from the underlying Gaptank and Wolfcamp by a quite small development of argillaceous and sandy material and by an absence of conglomeratic material, except in its basal conglomerate. Especially in the upper part of the formation, it may be distinguished from the overlying Leonard in having well defined bedding planes. Some of these are so straight and so well-marked that the rock on weathering may split into large separate leaves not more than one-sixteenth inch in thickness. Such lamination I have never seen in the Leonard. The following brachiopods have been identified by Dr. J. W. Beede:

Rhipidomella sp. (very abundant)
Pugnax? sp.
Camarophoria aff. Purdoni Dav.
Enteletes aff. Waageni Gemm.
Hustedia papillata Shumard
H. meekana Shumard(?).
Squamularia sp.

A persistent feature of the fauna of this formation is the general presence of ostracods and of foraminifera.

The Leonard Formation

The formation which makes the greater part of the south face of the Leonard Mountain has been given the name of this prominent feature in the landscape north of Marathon. It is described in four of the preceding sections: 2, 3, 4 and 7. In section number 2 it has its greatest development, measuring, with an undetermined part of the underlying Hess, 2100 feet in thickness. In sections 3 and 4, the same sediments measure 1855 feet and 1878 feet, respectively. The determination of the base of the Leonard in each of these sections must, however, await further studies in the field. Evidently the entire formation is shown in these three sections. In Section 7 it is represented by a thickness of only 206 feet. At this point the larger part of the formation is likely faulted out, and it does not appear on the surface, except for a small part of its uppermost shales and limestones. Lithologically this formation is characterized by the presence of boulders, pebbles and sand in nearly all of its limestones. From top to base, it contains layers of coarse elastic material, such as conglomerates consisting of boulders and pebbles of limestone and chert, derived from all the older formations exposed in the region, but with a preponderance of limestones from formations immediately underlying. In the lower two-thirds of the formation the limestones and conglomerates are predominant. In the remaining one-third, shale constitutes the larger part of the formation, intercalated by well cemented calcareous shell breccias. Throughout the Leonard, fossils are quite abundant. In the lower limestones, crinoidal material is relatively abundant and joints of large crinoid stems are common, measuring up to two inches in diameter. The middle part of the formation contains many cup-corals and the intercalated thin limestones in the shales of the upper part of the member are characterized by the presence of a large Productus and a Waagenoceras. Many of the limestones are oolitic. From the underlying Hess formation, the Leonard can be distinguished by its less regular development of bedding planes, by the far less perfect sorting of its clastic components, as well as by the general abundance of fossils. It can be distinguished from the overlying Word formation by the coarser and less well sorted nature of its sands, and also by a relatively less amount of bituminous material impregnating its limestones and sands.

An average of the different kinds of material that go to make up the Leonard formation is about as follows: limestone 38 per cent.; dolomite, 4 per cent.; shale, 42 per cent.; sandstone, 5 per cent.; conglomerate, 4 per cent.; not known, 7 per cent.

Dr. Böse has described several ammonoids from this formation. These occur in two horizons. One of these is in its lower or middle part, in some sandy limestones; the other is in the basal part of the clay shale, which forms the upper 600 feet of the formation. From the latter we have *Medlicottia Whitneyi, Perrinites vidriensis,* and apparently also *Perrinites compressus. Paralegoceras altudense* and *Gastrioceras altudense* occur in what appears to be the Leonard, south of Altuda Mountain.

The corals, the bryozoa, the pelecypods, and especially the brachiopods of the Leonard are many, and in places profusely represented. Many are yet unknown. Dr. Beede has provisionally identified the following known forms:

Domopora terminalis Girty?
Camarophoria aff. gigantea Diener
Chonetes Hillanus Girty
Hustedia papellata Shum.
H. meekana Shum.
Productus subhorridus regulatus Girty?
Productus group indicus or sino-indicus
P. meekanus Girty
Richthofenia permiana Shum.
R. Uddeni Böse
Spiriferina hilli polypleurus Girty
Strophalosia hystricula Girty
Aviculopecten sp.
Nucula sp.

It is believed that the Leonard is to be correlated with the Clear Fork in the west central part of the state. Perhaps it also includes the basal part of the Double Mountain, and the upper part of the Albany limestones. It certainly also contains many of the forms noted in the Delaware formation by Girty.

The Leonard formation underlies a belt from three to six miles wide, extending from the Mount Ord range west of Lenox, northeastward in the fronting range of hills which border the Marathon plain on the north. It widens to the north in the Gilliam canyon, and then continues in the same direction as before, forming the main part of the sediments in the second ridge east of Hess Tank. From here it narrows rather abruptly and is believed to be faulted down from the surface. It at last disappears below the surface at a point about five miles northeast of the boundary line between Pecos and Brewster counties.

The Word Formation.

The Word formation is named from the Word ranch, through which it extends. It consists of some 800 feet of sediments which extend in a belt a quarter to a half mile wide, from the Ord Range, crossing the Southern Pacific a little south of Altuda and extending under the main escarpment of the Glass Mountains, past the heads of the Gilliam, Road, and Hess canyons, to some distance beyond the Pecos County boundary line, where it disappears under the Comanchean cretaceous. The principal lithologic feature which characterizes the upper part of this formation is the presence of an arenaceous rock different from the sandy members in any of the other formations shown in the Glass Mountains. It is a rock that changes from sandy limestone to calcareous sandstone in which the sand is well sorted and fine-grained. The rock is usually evenly bedded and in places finely laminated. In the laminated phases of this rock, there appear traversions which follow the bedding planes and resemble worm tracks. Frequently they form crossed irregular networks. The traversions are narrow, usually measuring about one-eighth inch in width. In places this phase of the rock is bituminous and shows sharply marked straight lamination. The cementing material present renders the rock firm and impervious. In the middle part of the formation the sand ingredient is coarser and is often mixed with oolitic material where the ooliths measure 0.5 mm. in diameter. The lower part of the formation consists mostly of shale with interbedded layers of sandstone and limestone. These sandstones are of coarser texture than the uppermost sandstones. The Word formation is present in most of the natural sections examined, as in the sections numbered 1, 2, 3, 4, 6, 7, and possibly 8. On an average all of the sections examined in this formation consist of about 38 per cent. of limestone, 12 per cent. of dolomitic limestone, 8 per cent. of shale and clay, and 40 per cent. of sandstone, of the indeterminate and variable nature indicated above. In section number 2, the beds measured show a much thicker development of the upper sandy member and these uppermost beds are characterized by concretionary and lenticular structures not noted in any of the other sections. It is therefore believed that they represent a part of the formation which is eroded in the other sections, and that the maximum thickness of the Word is nearly 1500 feet. Similar conditions seem to prevail in section number 1, southeast of Altuda, but at this place some faulting has occurred and it was not possible to accurately determine the thickness from the outcrops examined. In the other sections, the thickness of the Word, as measured, ranges from 579 to 792 feet.

The lower member of the Word consists of a thin-bedded, compact, bituminous limestone which weathers white. In this a doubtful fragment of a saurian bone was noted, and small fish scales which occurred together with the pygidium of a small trilobite. Some 500 feet above the base of the formation there is a sandy oolitic limestone which contains a rich cephalopod fauna. From this Dr. Böse has described the following ammonoids collected mostly from a locality immediately southeast of the junction of the Road and the Gilliam canyons:

Adrianites marathonensis
Agathiceras Girtyi
Gastrioceras n. sp.
G. roadense
Medlicottia Burkhardti
Paraceltites aff. elegans Girty
P. multicostatus
Stacheoceras Bowmanni
S. gilliamense
Waagenoceras Dieneri

Other invertebrates which have been determined by Dr. Beede are as follows:

Guadalupia cylindrica Girty?
Fusulina elongata Shumard
Chonetes subliratus Girty
Enteletes globosus Girty
Lyttonia americana Girty
Meekella skenoides Girty
Productus cf. signatus Girty
P. orientalis Newb
Richthofenia permiana Shum.
R. Uddeni Böse
Spiriferina Billingsi Shum.

Apparently there is no doubt that the Word formation belong to the Delaware deposits of Girty in the Guadalupe Mountains. It also represents the main part of the Double Mountain in central Texas.

The Word formation seems to be conformable with the Leonard, which underlies. It will be remembered that the upper 600 feet of the Leonard consisted essentially of shale. After the deposition of this shale the conditions in the ancient Permo-carboniferous sea changed abruptly at the beginning of the Word, permitting the accumulation of calcareous deposits mostly free from argillaceous material. Later, there was a return to the former conditions. The geographical condition indicated by the fine-textured and sandy, calcareous material is that of a shallow sea with drifting bottom currents.

The present author believes that an unconformity between the Word and the Vidrio is indicated by the unequal development of the upper part of the Word, under the overlying Vidrio.

The Vidrio Formation

The Vidrio formation takes its name from the Spanish word for glass, often used among the local Mexican population as the name for the Glass Mountains. The formation is the most conspicuous part of the Glass Mountains. It caps the highest ridges and small plateaus of the range, from east of Altuda to the Hess canyon, and extends beyond this over the north slope of the mountains to near the Stockton-Marathon road. Its full thickness has been seen only in the Gilliam Canyon section, where it measures 1700 feet.

This limestone is mostly dolomitic and forms thick beds in which bedding planes are poorly developed, if at all present. Individual beds may measure a hundred feet. At its northernmost exposure, on the east side of Gilliam Canyon, it is obscurely cross-bedded on a large scale. In many places the rock is clearly brecciated, also on a large scale, and consists of large broken blocks, strongly cemented by finer material. It is to be noted that brecciation is less common, and bedding planes are better developed in the east and west end of the mountain, than in the region nearest Iron Mountain. This circumstance suggests that tectonic forces may have contributed to the obliteration of bedding planes, and may have caused the faintly marked layers in the original deposits to have become welded together, as it were, by pressure, which in other places caused fracturing and brecciation.

In thin sections this limestone is characterized by clear crystalline texture throughout, mostly quite fine-grained, the crystals measuring frequently no more than 1 mm. in diameter. In a few imperfectly dolomitized layers crystallization is not complete and there appear traces of an original clastic texture. In other strata, again, the dolomite contains small pockets of calcite, evidently formed after the rock became dolomitic.

The Vidrio consists almost entirely of dolomitic limestone. It contains no shale, and but a single layer of sandstone in its upper part. Some sand is also found in scattered grains in some layers in the lower part of the formation.

In places where the rock is least dolomitic, fossils are sometimes to be seen, and it does not appear unlikely that some of these places may on close examination yield fossils that may throw some light on the age of this member. So far no collections have been made that do this. The entire known fauna of the formation consists of a few crinoid stems, a Fusulina, traces of some other foraminifera, some obscure bryozoa, and spines of an Archeocidaris. As already stated, it is believed that an unconformity separates the Vidrio from the underlying Word formation. The principal reason why I believe such is the case is, as has also been explained, the great thickness of the Word in sections 2 and 3, and especially the occurrence of several hundred feet of sediments in the upper part of the Word in section 2, that are different from any beds examined in the upper part of the Word elsewhere. The contact between the two formations is sharply marked almost in every place where it has been seen. Almost everywhere the upper layers of the Word are found to be beveled off, if followed any distance, and the Vidrio comes down across the beveled edges of the layers. In places this beveling extends down across the edges of twenty feet of rock, or more, in a short distance, as seen in the vicinity of Sullivan Peak. In fact, this contact would seem to be typically unconformable. But on close examination it is frequently found that the beveled edges of the underlying rock, which is always softer than rocks of the Vidrio, have been compressed laterally and are sometimes squeezed into recesses of the solid limestone of the Vidrio. Such features suggest that these apparent unconformities may be due, not to erosion of the underlying rock, but to incidental gouging into the less competent underlying rock by the much more competent massive limestone above. Even if this contact represents an erosional unconformity, as I think likely, many of the apparently typical unconformable contacts of the two formations are, in my opinion, the result of squeezing, and gouging of this kind.

The Gilliam Formation

The Gilliam formation takes the name from Gilliam canyon, where it is exposed in the bluffs of the narrowest part of the canyon, beginning at a narrowing of the canyon about ten miles north of the south end of Iron Mountain, and continuing for nearly two miles northward. It is exposed in an irregular belt extending from east to west on the north slope of the Glass Mountains, and probably southwestward on the northwest slope of the mountain. Its areal extent has not been mapped, and in the map accompanying this report, this formation has not been separately indicated from the overlying Tessey formation.

The Gilliam consists of yellow dolomitic limestone, in places pinkish, and even brownish in color. The stratification planes are sharply marked and straight, and especially in the lower part, the rock is quite thin-bedded. Southwest of the White Elephant tank there occurs in this formation a brown sandstone some twenty feet in thickness. This sandstone has also been observed in the Gilliam canyon, and it seems to be quite persistent. The sand in this rock is well sorted and is of the average texture of sandstones. The Gilliam formation has a thickness of about 740 feet.

From the appearance of several thin sections of the dolomite in this formation, it seems to have undergone considerable change after it was laid down as a calcareous mud in the sea. Its crystalline texture is relatively coarse, in its upper part, consisting of crystals mostly from 0.6 to 1 mm. in diameter. A very thinly laminated piece of rock from the lower part of the formation showed traces of some foraminifera, such as Trochammina and Ammodiscus, which appeared to have been abundant in the original sediment. In another thin section was observed a grouping of the crystals suggesting an original clastic texture of the rock In most sections all traces of such texture have disappeared. In places, sections can be obtained that show minute pockets of calcite, evidently introduced after dolomitization.

So far no recognizable large fossils have been found in this formation.

The contact between the Gilliam and the Vidrio is well marked in the Gilliam canyon and in localities father east where it has been observed. The two formations appear everywhere to be conformable. Upward there is a gradual transition from the laminated rock of the Gilliam to less distinctly stratified limestone of the Tessey formation.

The Tessey Formation

The Tessey formation has been so named from a postoffice now defunct, but once located about two miles north from the mouth of the Gilliam canyon. It consists of a mostly unstratified dolomitic rock, quite like the Vidrio in general appearance. Along the Gilliam canyon it measures at least 1400 feet in thickness. It goes to make up the rocks exposed on both sides of Gilliam canyon, at its mouth. In places, this formation frequently has well marked bedding planes. In places it is brecciated. A considerable part of the rock is only slightly dolomitic. Some of the formation is finely oolitic and was found in some thin sections to contain shreds of bryozoa and a few minute foraminifera. In its upper part near the mouth of the canyon one layer is entirely calcareous and has an abundance of Fusulina. Not far from this same layer the writer observed, some years ago, an imperfectly preserved ammonoid of unknown relationship.

It is believed that the Vidrio, the Gilliam, and the Tessey formations are in part the equivalents of the Capitan limestone in the Guadalupe Mountain. Together they have a thickness of 3800 feet, which is more than twice the known thickness of the Capitan limestone. The three formations are conformable and dip to the northwest with an angle of about eight degrees.

The Comanchean Cretaceous

But few observations were made on the Comanchean sediments, which generally overlie the Paleozoics farthest out on the west and north slopes of the Glass Mountains. These have also been tilted, but to a lesser extent than the older rocks. Dips of two and three degrees are most frequently observed. The ancient erosion plane cuts slantingly across first the Tessey, and the Gilliam formations, and into the Vidrio. We find outliers of the Comanchean basal deposits on some of the highest summits of the mountains. The basal beds vary from sand and marl of small thickness, immediately overlain by limestone on one of the summits, to thick, coarse boulder conglomerates at the mouth of Gilliam canyon. In some buttes near this place, the Comanchean contains thick beds of bright red sandy marls. This variation in the nature of the material as well as the different fossil contents of the Comanchean at different points, shows, I believe, that there is here a local overlap of the Comanchean caused by the existence of considerable relief in the land at the time of the transgression of the Comanchean sea

The Pleistocene

On the south side of the narrow alluvial bottom in Gilliam Canyon, right above the point where it enters the Gilliam limestone, there is a terrace which rises perhaps fifty or sixty feet from the alluvial bottom, and follows it for a mile or more. This terrace consists of mostly calcareous material, from soft marl to boulder conglomerate. In some places it is soft and in other places quite indurated and cemented so as to resemble layers of limestone. Terraces of this kind are not otherwise often seen in the region. It is mentioned merely for record.

ECONOMIC NOTES

Metallic Minerals.

The mountain-making forces which resulted in the Marathon uplift do not seem to have been accompanied with any notable mineralization in these mountains. The limestones of the Permo-carboniferous have been but slightly altered. They have nowhere been changed to marble, not even in proximity to the local intrusives. They have not been much faulted and still less fissured. The only locality where anything like mineralization has been noted is on a spur of limestone near the contact of the Paleozoics with the Comanchean, extending from northwest to southeast about six miles north and two miles east of Altuda. At this point there is a vein of fairly clear calcite, nearly forty feet wide, extending in an east and west direction. Not far from this vein there are some fillings of red iron ore in what appears to be cavern-like openings in the Vidrio limestone. On one side of this ferruginous filling it is impregnated with carbonate of copper, which has been exploied in a shallow excavation. In the calcite vein no impregnations of either iron or copper were noted. The locality was for some years owned by Mr. S. D. Bissett, one of the old prospectors in Brewster county. Some small bodies of red iron ore are also to be seen on the point of a ridge extending westward three miles northeast of Leonard Mountain. All of these mineral occurrences are so small as to offer no inducement to development.

Oil and Gas.

Oil has been found in some wells west of Marathon; the most important find being, perhaps, the test made on the Hargis ranch, south of the railroad, and a few miles west of Marathon. The boring which yielded the oil is near the contact of the Pennsylvanian rocks with the Ordovician, and it has not been possible to determine from which of these two formations the oil really is derived. Both are known to have a bituminous content. Other attempts to locate an oil pool have been made north of the railroad on the Wedin ranch. In 1909 Mrs. Ava G. Scribner leased some land and began drilling. A hole 1045 feet deep was finished in 1911. This boring is in the northeast part of Section 43, Block 4, G. C. & S. F. Ry. Co. lands. The surface rock here is some part of the Gaptank, which dips at a high angle to the northwest. Later, another well was bored on the northwest quarter of Section 44, in the same block, to the depth of some 600 feet. Salt water was reported in the first well at from 600 to 700 feet, and some fresh water is said to have been encountered below this. There were small showings of both gas and oil. The location of none of the foregoing explorations was selected with reference to geological structure, and the borings cannot be regarded in any sense as any tests proving or disproving the possibility of finding oil in the formations explored. There is a well defined anticline at a point about four miles west of Marathon, which crosses the country from northeast to southwest. No doubt some other anticlines exist in the area between this point and the southernmost ridges of the Glass Mountains.

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

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

Water

The great thickness of the limestones on the north slope of the mountains makes this region dry. It offers small chance of finding water by drilling. Several attempts to make deep wells have proved failures. The only chance for finding deep water in these mountains would appear to be on the shaly beds of the Word and the Leonard formations, where these can be reached at suitable depths. Any supply thus secured will probably be small, and it is apt to be salty. A boring into the Hess formation in the Hess Canyon has given negative results. Another location for a test well in this formation would, perhaps, be in the Gilliam Canyon about seven miles north from the north end of Iron Mountain. The most reliable water supply in these mountains will no doubt always be stored surface water.

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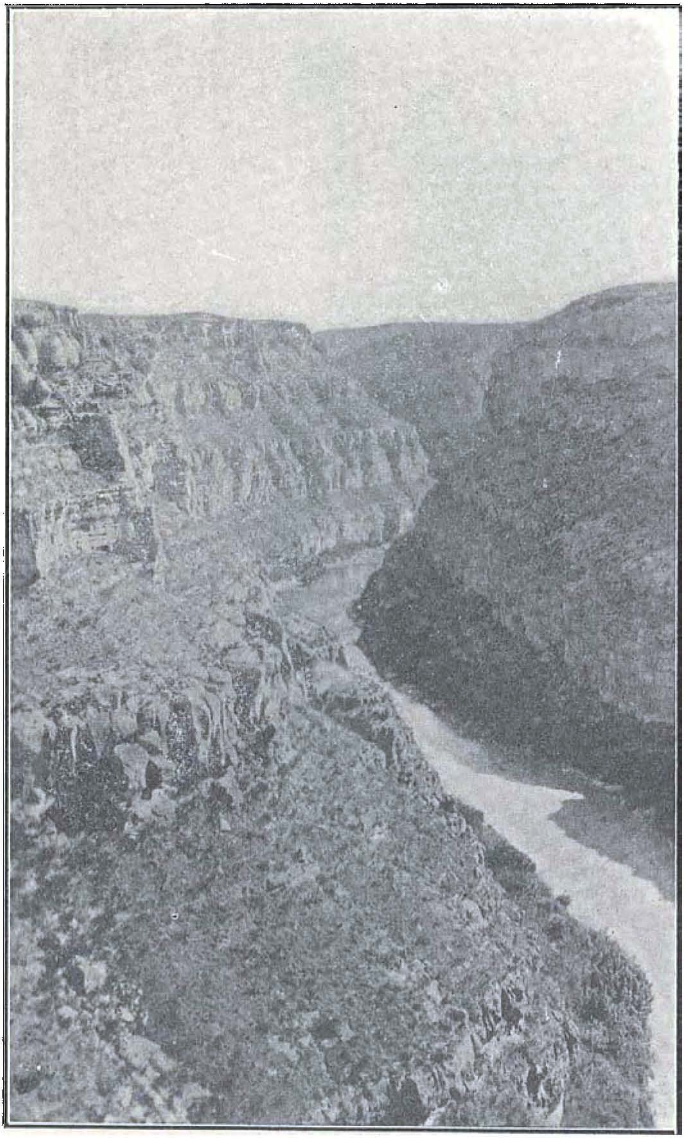
GEOLOGIC EXPLORATION OF THE SOUTHEASTERN FRONT RANGE OF TRANS-PECOS TEXAS

BY

C. L. BAKER, and W. F. BOWMAN



Antecedent canyon of the Rio Grande, cut in Comanchean limestone, about one mile up stream from the Terrell-Brewster county line

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GEOLOGIC EXPLORATION OF THE SOUTHEASTERN FRONT RANGE OF TRANS-PECOS TEXAS

BY CHARLES LAURENCE BAKER AND W. F. BOWMAN

Introduction

The eastern Front Range of the Western Cordillera in southern Trans-Pecos Texas is the easternmost portion of that great mountain system within the territory of the United States. It is also the only known region in the entire Western Cordillera of North America where the later Paleozoic foldings of the mountain ranges of the eastern United States are found together with the mountain-making movements, of much later dates, which formed the Western Cordillera. Every mode of mountain formation is there represented. Furthermore, the Permo-Carboniferous rocks have in this region a greater development than in any other known region. For these reasons the southern Trans-Pecos country is one of exceptional interest to the geologist.

General Characteristics of the Front Range

Trans-Pecos Texas is that part of Texas situated west of the Pecos River. It is a region made up of two kinds of country: a southwestern or mountainous portion, and a northeastern or plains portion. The mountainous region is a part of the great Western Cordillera of the Western Hemisphere, which stretches all the way from Alaska to Tierra del Fuego, and has its greatest width in the central belt of the western portion of the United States. The Trans-Pecos portion of the Cordillera lies on the eastern margin of the belt and begins at the New Mexico line just north of the line where the individual ranges of the Cordillera begin to change from a southward to a southeastward direction. The dominant structural feature of the Trans-Pecos Texas is the eastern Front Range of the Cordillera. The portion of the eastern Front Range included between the line of the Texas and Pacific Railway and the Rio Grande will be the subject of this report.

The Front Range is the most impressive feature of the entire Trans-Pecos country. In the peak of El Capitan, just south of the New Mexico boundary, it rises to the highest elevation in Texas. Nearly everywhere south of the Texas and Pacific Railway the Front Range rises abruptly above the plains on the east. There are, however, a number of gaps through this mountain barrier. These gaps as a rule are not breaks in the general structure, but have been produced by stream erosion. The broadest of all the gaps is that through which the Texas and Pacific Railway runs. Next to the south is the gap made by Limpia Canyon through the lava flows of the Davis Mountains. The road from Alpine to Fort Davis runs in the gap of Musquiz Canyon. The Southern Pacific Railway utilizes the valley of Paisano Creek. The road to Terlingua climbs the lava ridge south of Alpine. The next road to the south, crossing the range, passes through Doubtful Canyon of Dugout Creek. The road from Marathon to Terlingua passes through Del Norte Gap and the road from Marathon to Boquillas through Persimmon Gap. Another pass, followed by a wagon road, is afforded in the southern end of the Santiago Range by Dog Canyon of Calamity Creek. For the entire length of the Sierra del Carmen there is not a single pass utilized by a road.

The structural trend of the Front Range determines the courses of the Rio Grande and Pecos rivers. The parallelism of the courses of the Front Range and of the Rio Grande from El Paso to the southernmost point of the Big Bend is extraordinarily striking. When the effect of the subsidiary structure of the Marathon dome is taken into account, the parallelism of the Front Range and the Pecos River is hardly less striking. The Front Range also determines the structure of the plains east of it, the rock strata of which dip gently away from it.

The Front Range north of the line of the Texas and Pacific is not so striking a feature from the east, because the Delaware and Guadalupe mountains which form it rise with gentle slope from the plains and have their precipitous slopes facing west. They are conspicuous examples of hogback ridges or cuestas formed of gently dipping resistant rock of monoclinal structure with escarpments facing on the side opposite to the dip of the rock strata.

The Front Range between the two railroads is formed by the Davis Mountains and their northeastern offshoot, the Barilla Mountains. The surface rocks in these mountains are heavy, massive lava flows of red color which form almost everywhere steep cliffs at their outer edges. The Davis Mountains extend no farther south than Paisano Pass, but the lava flows continue to the southward far into Mexico.

The summit range of the Davis Mountains is generally known as the Sawtooth Range. The highest peak is Baldy or Livermore Peak, 8,382 feet in altitude, which is probably the second or third highest summit in the state, being surpassed only by one or more peaks in the Guadalupe Mountains. The Davis Mountains are essentially a broad plateau or mesa of lava, the surface of which has been gently folded. The margins of this tableland rise abruptly to a considerable height above their surroundings. The streams draining the plateau cut through its margins in deep and steep-walled canyons. One of these, Madera Canyon, is 2,000 feet in depth and perhaps the deepest canyon in Texas.

The Barilla Mountains are separated from the Davis Mountains by an area of depression followed by the southeastward-flowing Limpia Creek, and a northwestward-flowing tributary of Toyah Creek. This depression is a structural downfold or syncline in the lava and underlying rocks. The Barilla Mountains are made up of three anticlines or arched folds of lava and underlying rocks with two intermediate synclines.

Some of the sharp peaks in the southern part of the Davis Mountains, as for instance, Mitre Peak, in their form and position suggest necks of old volcanoes. The only volcanic neck yet known for a certainty, however, occurs just west of the Alpine-Fort Davis road near the mouth of Musquiz Canyon.

South of the Southern Pacific Railroad the Front Range is followed in a southeastwardly direction successively by the Mt. Ord, Santiago and Carmen (Sierra del Carmen) ranges. The northernmost of these, the Mt. Ord Range, is covered on its western flank by massive red lava. The Mt. Ord Range may be considered to end at Del Norte Gap and Elephant Mountain. The southern end of the range is a westwardly-dipping cuesta of limestone of Comanchean Cretaceous age. The trend of the

Mt. Ord Range is a very little east of south. The range derives its name from Mt. Ord, one of its highest summits, 6,650 feet in height. This peak forms the highest pinnacle of a westwardly-dipping cuesta of red lava, with an abrupt descent on the eastern side. The highest summit of the range is Cathedral Mountain. South of Ord Mountain the main ridge and axis of the Front Range shifts to the east and continues southward as a sharp serrated crest. The main axis of the Mt. Ord Range of the Front Range lies east of the lava-covered country and runs from Altuda Mountain a little east of south to Del Norte Gap.

The Santiago Range begins at Del Norte Gap on the north and trends first southeast, then due south, and again southeast to Dog Canyon, where it turns rather abruptly to a little west of south and then comes to an end. The range derives its name from Santiago Peak, an intrusive mass of igneous rock about 6,450 feet in altitude. The highest summit of the Santiago Range is a limestone mountain southeast of Santiago Peak. The axis and crest of the Santiago Range is a single anticline of Comanchean Cretaceous limestone. Locally the anticline is overturned to the west, and conspicuously so at Dog Canyon. The same anticline is also locally overturned in the southern part of the Mt. Ord Range. Doubtful Canyon of the Dugout Creek branch of the Maravillas Creek in the southern Mt. Ord Range and Dog Canyon of the Calamity Creek branch of the Maravillas, near the southern end of the Santiago Range, both cut entirely through the Front Range and are antecedent in their origin. Persimmon and Del Norte gaps may possibly once have been occupied by antecedent streams, but they are now wind gaps. There is only a minor amount of igneous rock in the Santiago and Carmen ranges.

The Sierra del Carmen is a mountain range which has most of its development on the Mexican side of the Rio Grande. In its Texas portion it consists of a number of blocks, probably eight at a maximum, of very heavy and massive Comanchean Cretaceous limestone, downfaulted on the east sides, which are precipitous; and with gentle westward slopes of the typical cuestas. The structural and orographic trend of the range is south-southeast. The range begins southeast of the Santiago

Range in a series of monoclines, passing to the southeast into anticlines, and still farther southeast into faults. The antecedent Rio Grande crosses the Sierra del Carmen in a series of deep and narrow canyons.

The above is a description of the various portions of the Front Range as separated by current usage. Fundamentally, on the basis of both structure and orography, there are but three ranges; the northernmost, composed primarily of rather gently deformed volcanic rocks, extending from the Texas and Pacific to beyond the Rio Grande, and comprising the Front Range only in the Davis and Barilla Mountains*; the central, composed of the single anticlinal ridge of limestone from Altuda Mountain southward and southeastward to the structural and orographic end of the Santiago Range beyond Dog Canyon; and the southeasternmost, or Sierra del Carmen, with its fault blocks.

General Characteristics of the Plains Country East of the Front Range

The Front Range as above defined is not coincident with the eastern limit of folding of the Cordilleras. The latter lies east of the former in the region between the Texas and Pacific railroad and the Rio Grande. East of the Front Range proper, lower folds are found. These diminish in number and importance to the east, until finally the structure becomes a gentle dip of the rock strata away from the mountains.

The subsidiary folds play a minor part north of the line of the Kansas City, Mexico and Orient Railway. One is known just east of the Barilla Mountains and another east-northeast of the Musquiz Canyon through which the Orient Railroad runs. But from the Glass Mountains southward and southeastward to the Rio Grande are a number of these folds which form important elements in the structure and topography. The Sierra Madera is a small dome of massive Permian limestone. Another

*Other Texas mountains made up of this general lava flow are the Ord, Sierra Bofecillos, Tierra Vieja, Chisos, Rosillos, and Corazones Mountains, Whirlwind Mesa, Frenchman, Oak, Rancheria and Black Hills, and a number of small peaks north and northwest of the Chisos. In these mesas and cuestas are the prevailing physiographic types.

dome of far greater extent is that which was once existent over the region of the Marathon basin but the top of which has been removed by erosion. The Marathon basin is a conspicuous topographic feature. From it streams drain both to the Pecos and the Rio Grande, and it is rimmed in on all sides by cuesta escarpments of limestone, the strata of which dip away from the basin itself. The center of the basin is made up of a series of miniature mountain ranges, trending northeast and southwest in white-crested ridges of rough and jagged outline. Between these central ridges and the bounding escarpment is, on all sides except the southeast, a low, flattish, soil and gravel-covered area.

On the south and southeast margins of the Marathon dome are some low subsidiary anticlines with their axes trending parallel to that of the Front Range in their latitude. East of the Sierra del Carmen, four long low anticlines cross the Rio Grande in that part of its course between the mouths of the Maravillas and San Francisco creeks. These anticlines arch up the massive strata of the Comanchean Cretaceous limestone and form long swells or ridges in the topography. Across their axes the antecedent Rio Grande cuts in a series of canyons over a thousand feet in depth, affording probably the most impressive scenery in the State (Frontispiece). The upper reaches of the major drainage courses, the Maravillas and San Francisco creeks, are broad, meandering valleys but upon entering the region of recently folded limestones, they develop deep and narrow canyons, often with vertical or nearly vertical walls.

The meandering course of the Rio Grande from its crossing of the Sierra del Carmen to the mouth of the Devil's River, at the southern margin of the Balcones Escarpment, is one continuous canyon carved through the massive beds of Comanchean Cretaceous limestone. The Pecos River is a very inconspicuous and minor stream at the crossing of the Kansas City, Mexico, and Orient Railway, where it occupies a broad valley the bottom of which is excavated in Permian Red Beds. Lower down it enters the massive Comanchean Cretaceous limestone, and occupies a canyon for the remainder of its course.

The Toyah Basin in Reeves and Pecos counties is both a structural and physiographic basin. Its surface is covered with loose gravel, sand and clay debris of Pleistocene and Recent age, brought down by streams from the mountains; and the underlying rock is Permian red beds. East of the Guadalupe, Delaware, and northern Davis Mountains, the strata dip eastwardly underneath the basin, north of the Glass Mountains they dip northwardly, thus forming a basin-shaped structure. The Toyah Basin is really the southern end of the great geo-synclinal basin of the Llano Estacado. This geosyncline was formed long previous to the latest deformation of the Front Range region.

The dominant physiographic type of the Trans-Pecos plains is the limestone-capped mesa. In the arid climate of the Trans-Pecos region, limestone, because of its homogeneity in composition and its imperviousness to water, is the most resistant rock and forms the topographic prominences.

The extreme range in elevation in the southern Trans-Pecos region is from 8,382 feet in the summit of Baldy or Livermore Peak, to 1000 feet at the mouth of the Pecos.

Climate.

Trans-Pecos Texas possesses a more equable climate than any other portion of the United States except southern New Mexico, the immediate coast of southern California, and the peninsula of Florida. The mountainous portion possesses as typical a continental climate as any portion of the North American continent except possibly the Great Basin. Nearly all varieties of climate due to the ranges in altitude and latitude may be found, from the nearly semitropical heat of the Rio Grande and Pecos valleys to the cooler air of the higher mountains; but the region lies without normal storm tracks and the sequence of weather changes is much more uniform than in more northern latitudes or on the same latitude farther east. Great extremes of temperature are uncommon, occurring for the most part during the short-lived "northers" and to a lesser extent with thunderstorms. The air is dry and pure under nearly all conditions and exerts a tonic or bracing effect upon animal life. The dryness modifies the effect of both heat and cold. The nights are cool even in the lower levels of the river valleys.

The average annual precipitation ranges from less than ten inches in the valley of the Rio Grande to twenty inches or slightly more in the higher mountains. The general precipitation, not considering the effects of differences in altitude, increases toward the east, reaching an average of about fifteen inches in the valley of the Pecos. Precipitation occurs mostly as local showers of comparatively short duration and often of great violence. Hailstorms are frequent. Precipitation is caused mostly from condensation of the air as it rises and cools upon encountering the mountains. For this reason the mountains are favored with a higher amount of moisture than the plains, basins and valleys of lower altitude. The driest season comprises the winter and early spring months of December, January, February, March and April. Over three-fourths of the precipitation comes in the months from May to October inclusive. Locally, a period of a year or longer may pass with very little precipitation.

High winds and dust storms are rather prevalent during the early spring and summer months. The mean relative humidity* of the entire region is probably about 50 per cent., but is only 40 per cent. in the Rio Grande valley at El Paso. The sun shines for 81 per cent. of the daytime at El Paso. It can readily be understood from these figures why the air is so dry and the lowlands are prevailingly arid.

The combination of a prevailingly arid climate and of local thunderstorms often of cloudburst intensity, is responsible for two of the most conspicuous of the minor physiographic features, the canyon type of stream course in the highlands, and the alluvial debris fan at the foot of the mountain slopes. The development of these will be explained in the section on physiography.

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*The relative humidity is the percentage of moisture which the air contains at a given temperature of that amount which it would contain at that temperature if it were saturated. Precipitation takes place only on saturation of the air with moisture.

SUMMARY OF CLIMATOLOGICAL DATA.
(U. S. Weather Bureau)

Precipitation.

Place	No. of yrs.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
El Paso	41	.40	.45	.30	.20	.26	.58	1.66	1.85	1.56	.82	.55	.43	9.13
Fort Davis	31	.54	.50	.39	.54	1.04	1.95	3.44	3.59	2.95	1.34	.60	.58	17.46
Ft. Stockton	30	.38	.39	.61	.46	1.41	1.87	2.19	2.23	2.95	1.39	.69	.67	15.15
Kent	16	.46	.46	.27	.36	.70	1.57	2.14	2.17	1.93	1.28	.97	.48	12.79

Mean Temperatures

Place	No. of yrs.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
El Paso	33	44.1	48.9	55.9	63.8	72.1	79.6	80.5	78.6	72.7	62.4	50.9	44.8	62.9
Fort Davis	29	43.8	48.6	55.0	62.5	70.3	74.9	75.1	73.9	68.6	61.0	51.3	45.2	60.8
Ft. Stockton	28	45.3	49.7	58.0	64.4	73.5	80.0	80.9	79.4	70.9	64.3	53.2	46.2	63.8

Lowest Temperatures

At El Paso 5° below zero in December.
At Fort Davis 3° below zero in January.
At Fort Stockton 2° above zero in January.

Highest Temperatures

At El Paso 113° in June.
At Fort Davis 111° in June.
At Fort Stockton 114° in June.

Mean Relative Humidity

Place	No. of yrs.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
El Paso:														
8 a. m.	22	61	54	43	38	35	42	61	64	64	60	60	61	54
8 p. m.	22	33	26	17	13	13	16	30	43	33	31	34	35	26
Ft. Davis	10	52	46	44	40	43	47	53	56	61	56	54	51	50
Ft. Stockton	9	57	53	52	48	59	57	54	55	62	61	59	59	56

Sunshine (Percentage)

Place	No. of yrs.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
El Paso	5	73	78	82	88	90	93	74	74	86	86	73	71	81

Elevations

El Paso	3,762 feet	Ft. Stockton	3,050 feet
Ft. Davis	**5,000 feet**	Kent	4,218 feet

Vegetation.

In the higher mountains junipers, and cedars of several species, piñon, Texas madroño, a number of species of oak, mulberry, hackberry, wild cherry, mountain sugar maple, and several species of ash compose the sparse and scattering forest. Rocky Mountain white and yellow pines occur in the Davis Mountains. In the stream valleys and canyons are found cottonwood, willows, walnuts, Spanish buckeye, Arizona buckthorn and Mexican persimmon. The flats, covered by fine soil, are characterized by creosote bush, greasewood, mesquite, sagebrush, and cat's claw (Acacia). The grassy plateaus with the deeper soils have the short grass vegetation of the Llano Estacado.

The most characteristic and abundant vegetation of the region is that of the rock-strewn foothills and mountain slopes, on gravel terraces, and where the limestone has been dissected into round-topped hills, draws, valleys, and ridges, and more or less covered by rock debris. This vegetation abounds in plants of the cactus, yucca, and agave types, with many of the most characteristic desert shrubs and chaparral species. Some of the commoner plants encountered are sotol (bear grass), lechuguilla, ocotilla, ephedra, euphorbia, allthorn ,mescal (Agave), and many species of cacti. The resurrection plant (Selaginella) occurs on bare limestone surfaces. The sotol is cut and fed to stock and was also used as food for the aborigines. The guayule plant is used for the manufacture of rubber and the candelilla (candelaria) for the making of wax. The lechuguilla is used for fibre, especially in northern Mexico. This vegetation has a markedly dwarfed and scattered aspect.*

Animal Life.

There is a surprising amount of animal life in this desert country but it is best seen early in the morning and late in the evening. There is a large number of birds, but the raptorial species are most often seen. One of the characteristic birds of the region is the road-runner or paisano. The mammals include prairie dogs, jack and cotton-tail rabbits, squirrels, gophers, mice, rats, opossums, peccaries, armadillos, foxes, coyotes, raccoons, badgers, skunks, and wildcats. Big game is scarce but the following are occasionally found: whitetail and mule deer, prongbuck (antelope), Mexican mountain sheep, Mexican cougar, wolf, and small black bear. Lizzards, snakes and desert tortoises are fairly abundant. The only venemous reptile is the rattlesnake. Scorpions, tarantulas and centipedes are common.

*For a more complete account of the vegetation of the debris-strewn slopes see Bray, W. L., Vegetation of the Sotol Country in Texas, Bull. Univ. of Texas, No. 60, 1905.

Scenic Features.

Desert scenery in general has a forbidding and monotonous aspect to most of mankind. The general color is ashy, the effect desolate, and the landscape bare. There are, however, two features of desert mountains which are remarkable and not devoid of either beauty or charm. The one is the forms assumed by the bare rock surfaces especially in the canyons; and the other, the light effects in early morning and late afternoon.

The canyons of the region are carved out of two kinds of rock, the one buff or grayish limestone, and the other deep red lavas. The two rocks give rise to entirely different erosion effects. More resistant beds generally alternate with less resistant ones in the limestones. The more resistant limestones form steep, often vertical, much fretted cliffs. Weathering is more effective along joints and in more soluble or less compacted portions and the general effect produced is that of ancient massive masonry. The less resistant beds form less steep slopes often covered with debris from higher layers. The entire limestone series gives the buttressed effect characteristic of Gothic architecture. In the hazy sunlight of the late afternoon the canyon walls glow and assume shadowy outlines, the colors and contrasts of form merging into a harmonious whole. The light becomes opalescent, the whole landscape takes on a ghost-like appearance, and solid objects appear evanescent. At midday the glare is intense and the light almost blinding, especially when it falls on whitish rocks, such as the limestones. The hazy opalescence of the atmosphere is a distinct peculiarity of early morning and late evening in the desert, and to it the arid landscape owes its chief charm.

The Davis Mountains can be taken as the best example of the lava canyon region. The lava flows and associated tuffs there reach a maximum thickness of 2,000 feet, and some of the canyons on the north side of the range cut through the entire thickness. In the mountains, because of their superior elevation, the rainfall is greater and there is more vegetation and, in some places, running water. Where the flows are interbedded with less resistant tuffs, there is some approach to a terraced profile of canyon walls. This is never as complete as in the limestone; the lava is more massive and joisted in columnar fashion; the erosion effects are chaotic, and by no means as regular as in the stratified limestones. Where the removal of underlying tuffs brings about undermining of massive lava, irregular, hummocky, landslide topography is frequent. The tuffs are light in color, grayish white, pink, or green, and afford agreeable contrast with the dark somber tint of red lava, which latter contrasts with the bright green of the vegetation.

The much-eroded mountains exhibit themselves to best advantage in the shadows of morning and evening. It is then that the details of structure stand forth with the clearness of an etching. The distant valleys are immersed in gloom and the rocky divides between them are clothed with a soft light which serves to emphasize all the intricate details of their sculpturing and structure. Many minor details in the physiography are only apparent at such times, for the glaring light of the midday sun causes details to merge into one bewildering whole. During the middle of the day, the mirage, especially in the lower areas, is seldom ever absent. In the deserts, then, as in the higher mountains, the most pleasing landscapes are due to the effects of lighting. The desert seldom makes its greatest appeal to the stranger. One must first learn to know it and know it in every season and all hours of the day and at night as well, to thoroughly appreciate its charm, which is an ever-growing thing. The rich, flooding moonlight of the cloudless sky and dry transparent atmosphere gives perhaps the greatest contrasts of all, for anything in the shadow is of inky blackness, and anything lighted up is flooded with a rich and glowing light. In the absence of the moon, the clearness of the desert atmosphere renders visible many more of the stars than are seen in more humid regions.

Nature of Work Accomplished

During the course of the four month exploration in the summer of 1915, about 4,500 square miles of areal geology were mapped; and for the most part of this, no base maps were available, but had to be constructed by means of triangulation. In

Correlation Table, Showing Relations of Paleozoic Formations in the Marathon Basin, of Texas, to Sections in Oklahoma, Arkansas and the Appalachian Region.

BY E. O. ULRICH.

Generalized Appalachian				Arkansas	Central Oklahoma	Marathon Basin
Mississippian	Waverlyan	Kinderhookian or Chattanoogan	Chattanooga	Fork Mountain shale and cherty shale, at top of Arkansas novaculite	Woodford chert	
Devonian	Upper Devonian					
Devonian	Middle Devonian					
Devonian	Lower Devonian		Oriskanian	Arkansas novaculite	?	Caballos novaculite
Devonian	Lower Devonian		Hilderbergian		Hilderbergian (Hunton)	
Silurian	Cayugan			Missouri Mt. shale position doubtful	late Cayugan (Hunton)	
Silurian	Niagaran			St. Clair limestone (N. Arkansas)	Upper Niagaran (Hunton)	
Silurian	Medinan		Albion	St. Clair limestone (N. Arkansas); Blaylock sandstone	Brassfield (Hunton)	
Silurian	Medinan		Richmond	Maquokota shale; Fernvale (N. Arkansas)	Sylvan shale; Fernvale	Fernvale at top
Ordovician	Cincinnatian			Polk Creek shale		
Ordovician	Mohawkian		Trenton	Big Fork chert	Viola limestone	Miravillas chert, with Fernvale at top
Ordovician	Mohawkian		Black River		Bromide	
Ordovician	Chazyan		Blount	Stringtown shale; Blakely sandstone	Simpson formation 2,000 ft.	
Ordovician	Chazyan		Stone's River		Simpson formation 2,000 ft.	
Ordovician	St. Peter, or Buffalo River Series					
Canadian	Upper Canadian				Arbuckle limestone 5,000 ft.	
Canadian	Middle Canadian			Ouachita shale	Arbuckle limestone 5,000 ft.	Phyllograptus zone
Canadian	Lower Canadian				Arbuckle limestone 5,000 ft.	
Ozarkian	Upper Ozarkian					Synphysurina zone
Ozarkian	Middle Ozarkian					
Ozarkian	Lower Ozarkian				? Represented	
Cambrian	Upper Cambrian				Reagan	Zone of Dunderberg shale
Cambrian	Middle Cambrian					?
Cambrian	Lower Cambrian			Crystal Mountain sandstone		?

M.L.J.

covering territory of fairly complicated structure at the rate of over 1000 square miles per month, of a necessity much of detail must escape the observer. In such an arid region, exposures are generally good, aiding much in rapid work. Geologic structure is, however, complicated, rock strata are more or less metamorphosed, and the broad valleys are largely covered with loose debris in the Marathon Basin region; so that to adequately investigate the geology of this one region will take several times as long as the whole time spent in the entire exploration. Enough was accomplished in the Marathon Basin to work out the general sequence and ages of the rock formations and to decipher the leading elements in the structure. Very little time could be spent on the Cretaceous formations where only the mapping of the areal distribution and leading structural features was attempted. The same may be said of the igneous rocks which in themselves present an intensely interesting field for careful investigation. Effort was made to collect leading types of unaltered rocks for petrographic investigation, which has been undertaken by Prof. G. E. Marsh, of the Armour Institute of Technology.

THE SEDIMENTARY ROCK SERIES

The sedimentary rocks of this area embrace representatives of Upper Cambrian, Ordovician, Devonian (?), Pennsylvanian, Permian, Cretaceous and Pleistocene ages. There is a formation of novaculite and chert in the Marathon Basin, which is underlain by upper Ordovician and overlain by Anthracolithic rocks, but the exact age of which is unknown. The presence of numerous beds of chert in formations of all the Paleozoic periods except the Cambrian, is a very remarkable feature of the Marathon Basin region. There is probably no other region in the world which exhibits so much and so wide-spread chert in its Paleozoic formations. The total thickness of Paleozoic and Mesozoic sedimentary rocks is about 30,000 feet.

PALEOZOIC

The pre-Permian Paleozoic formations here described are yet known only in the Marathon Basin, but some of them may be present in the Solitario, an area of similar folded Paleozoics, northwest of Terlingua. In the Marathon Basin the pre-Anthracolitic rocks are almost entirely confined to the central region, around which is a ring of the Anthracolitic. The Permian rocks are found in the Glass Mountains and northern part of the Mount Ord Range, and fringe the Marathon Basin on the northwest.

The older Paleozoic outcrops extensively in the central and western portions of the Marathon Basin on both sides of the line of the Southern Pacific (G., H. & S. A.) railroad. Along the line of the railroad it is found in cores of anticlines from Warwick siding to Lenox section-house. Most of the exposures are south of the railroad, and the best exposures are southeast, south and southwest of Marathon station. Along the southwest margin of the Marathon Basin, between Del Norte Gap and the summit of the Santiago Range, the older rocks appear in the cores of steeply folded, overfolded, or overthrust folds of the lower Comanchean Cretaceous. The folds in the early Paleozoic there continue their strike toward the Solitario and probably underlie part of the synclinal basin in the Big Bend country west of the Front Range. In the central portion of the Marathon Basin the older Paleozoic is exposed beneath the site of the former summit of the Marathon dome of Comanchean rocks, which latter are now removed by erosion. The general structure of the early and middle Paleozoic rocks is that of a series of isoclines overturned to the northwest, accompanied by overthrusts and dip faults. In the very heart of the Basin, however, in a line extending northeast from the junction of the Peña Colorado and Maravillas Creeks to a point more than five miles southeast of Marathon, a series of anticlinal folds, though flanked by very steep dips, is more nearly symmetrical and in general the folds are not overturned. The pre-Pennsylvanian rocks outcrop in three anticlinoria between which lie synclinoria of early Pennsylvanian rocks.

UPPER CAMBRIAN—BREWSTER FORMATION

The name Brewster formation, from Brewster County, Texas, is applied to the oldest rocks yet found in the Marathon Basin.

The formation outcrops in two anticlinal axes both of which lie south of Peña Colorado Creek, the one about one and a half miles northeast of the junction of the Peña Colorado with the Maravillas, and the other eight miles northeast of the junction.

The base of the Brewster formation has not been found, nor can its top yet be determined with certainty. The thickness of the strata exposed is between one and two hundred feet. The strata consist of flaggy and thin-bedded sandstones, mostly brownish in color, interbedded with dark green shale. The formation much resembles the overlying Ozarkian, from which it is separated on paleontological considerations. Upper Cambrian fossils were found in both anticlines in a fine-grained brownish limestone. The following were identified by E. O. Ulrich:

Lingulella manticula
Lingulella desiderata
Acrotreta idahoensis
Acrotreta sp.
Acrocephalites aff. A. aoris

Mr. Ulrich says: "The first three species of this list are typical Upper Cambrian fossils in Nevada and elsewhere. Although they are said to range upward into the lower beds of the Pogonip, my comparisons indicate that the higher occurrences are not strictly the same forms as those held by the species during Upper Cambrian time. This conclusion is corroborated by the trilobite (Acrocephalites) which is of a genus unknown above the Cambrian."

"So far as it goes this association all through is decidedly like that found in the Dunderberg shale of the Nevada Upper Cambrian section."

ORDOVICIAN—MARATHON SERIES

The name Marathon series is given to a little-known group of rocks of lower and middle Ordovician age. These may not constitute a natural group, for there may be one or more unconformities within the series. Important paleontological gaps are indicated by the collections, but in some cases there are strata lying between these gaps which have yet yielded no fossils. No continuous or complete section of the series has yet been found, hence the apparent gaps may be accounted for by lack of knowledge of the real succession.

The series, so far as now known, comprises in ascending order the following members:

1. Flaggy and thin-bedded sandstones, mostly brownish in color, but some dark gray, interbedded with dark green sandy shale, the whole having a thickness of 300 to 500 feet. Grains of glauconite occur in the series. On exposed surfaces the sandstones often have lavender color. At the top is a dark-colored grayish and blackish shale interbedded with thin shaly and flaggy light brown sandstones, sometimes very fine-grained, but generally coarse-grained, gritty, or conglomeratic. Near the top are layers of a white and brown spotted, soft, flaxseed-like, fossiliferous, phosphatic limestone, originally oolitic. Twenty to thirty feet below the top are thin-bedded light brown sandstones, containing *Lingula* and other brachiopods, and flaggy arenaceous shales of the same color as the sandstones. About 100 feet below the top is a conglomerate carrying seams of calcite, both rhombohedral and fibrous in form, small pebbles of quartz, bryozoans and brachiopods, and specks of glauconite. The matrix appears to be limestone In this conglomerate are angular fragments up to an inch in diameter of light brown or green, very fine-grained sandstone or decomposed chert, very firmly welded to the light brown matrix so that the rock breaks across the conglomerate fragments. The following fossils were determined by E. O. Ulrich;

Obolus rotundatus Walcott
Lingulella pogonipensis Walcott
Schizambon typicalis Walcott
Eoorthis desmopleura Meek (Orthis hamburgensis Walcott)
Symphysurina mesleri Ulrich
Symphysurina spicata angusta Ulrich
Symphysurina brevifrons n. sp. Ulrich
Conokephalina inexpectans (Walcott)
Apatokephalus finalis (Walcott)
Hungaia ? sp. (pygidium only).

Of these he says: "This faunule represents unquestionably a well-marked zone in the lower part of the Pogonip limestone of Nevada. All save the last species of the list are found also in this zone in Nevada; and the last also is there represented by a closely allied species. In Nevada it underlies beds with Canadian faunas. In Quebec similar species are contained in boulders included in slates of the Levis shale containing myriads of early to middle Canadian graptolites. No similar types are known in any Canadian fauna. Evidently, then, this Symphysurina zone is older than the base of the known Canadian. As it is obviously younger than any true Upper Cambrian fauna, it must belong to some intermediate Ozarkian stage. Now, because the genus Symphysurina—recently established by me with 26 species—occurs outside of Nevada, Texas and Quebec only in the Oneota dolomite, an Upper Ozarkian formation in the Mississippi Valley containing three species of this genus, the present state of the evidence permits of only one conclusion respecting the age of this lower Pogonip fauna, namely, that it is Ozarkian, and most probably Upper Ozarkian."

Ulrich correlates the fauna of the Symphysurina zone of the Marathon series with the Upper Ozarkian of the Mississippi Valley, the Chepultepec chert of the southern Appalachian valley, and with erratics in the Levis shale of Quebec.

The above described lowermost beds of the Marathon series were noted only in the axis of an anticline one and one-half miles northeast of the junction of Peña Colorado and Maravillas Creeks, where they overlie the Upper Cambrian Brewster formation and are unconformably overlain by the Maravillas chert.

The next locality showing a younger sequence of the Marathon series is at the north base of a hill three and one-third miles in a straight line northeast of Maravillas Gap:

2. At least 300 feet of beds with fine quartz conglomerate on top, grading down through conglomerate to coarse-grained to fine-grained sandstone with much muscovitic or sericitic mica, interbedded with green or light bluish-gray arenaceous shale, much crumpled, much discolored by seams of red and brown oxide and traversed by thin seams of platy, transparent selenite. The base of the member was not exposed.

3. Dark gray thin-bedded limestone, both crystalline and very fine-grained, at the base of which is two and one-half feet of rather uniform-sized pebble conglomerate, scarcely one of the pebbles of which is over one-fourth inch in size, composed of clear quartz and fine-grained limestone in a limestone matrix. There are a few thin beds of black chert near the top of the limestone. A species of the Obolidae is found above and graptolites near the base of the limestone. The member is 130 feet thick and has the following fossils, as determined by Ulrich:

Didymograptus cf. extensus
Tetragraptus aff. fruticosus
Phyllograptus cf. ilicifolius and angustifolius
Paterula sp
Acrotreta sp.

Ulrich states that "Even though the preservation of the fossils in this lot is not so good as one might wish, it is yet amply good enough to establish the age of the bed beyond any reasonable question. In other words, it is a small but unmistakable representation of the Phyllograptus fauna which marks the median zones of the Canadian system."

Ulrich correlates the Phyllograptus zone of the Marathon series with the middle to upper part of the Ouachita shale of Arkansas, the middle part of the Levis shale of Quebec and New York, and the Skiddaw (Arenig) shale of Scotland.

4. Rotten, soft, very dark dirty green, gray or black shales, interbedded with layers of sandstone from one-fourth inch to one foot in thickness, generally friable but sometimes hard, and dark greenish-brown, grayish, or russet in color. The thickness exposed is about 500 feet and the member is unconformably overlain by the Maravillas chert.

5. About five miles southwest of the town of Marathon Dr. Böse found, in the cores of steeply-dipping anticlines, still higher strata below the horizon of the Maravillas chert. These consist of thin layers of grayish-white generally sandy limestone passing into fine-grained conglomerate or coarse calcareous quartz sandstone, varying from four inches to two and one-half feet in thickness; interbedded with very thinly-laminated dark yellowish brown, gray and yellow arenaceous and calcareous shales

in beds from five to 50 feet in thickness; and some very thinly-laminated yellowish sandstones. The upper and middle parts are principally shales. The exposed thickness is about 375 feet, the base not being exposed.

About eight layers of limestone can be distinguished. There are thin layers of limestone in the lower part which frequently contain grains of quartz, sometimes almost conglomeratic. The thickest limestones are unfossiliferous. Fossils were found in the two lowest layers of limestone, stratigraphically about 100 feet below the base of the Maravillas chert, about two miles southwest of the Lockhausen ranch. The following were determined by Ulrich:

Crinoidal fragments
Anolotichia aff. A. revalensis
Nicholsonella sp. (ramose, branches slender)
Phaenopora cf. incipiens
Stictoporella cf. exigua
Rhinidictya sp.
Plectambonites aff. P. quinquecostata
Eurychilina sp.
Aparchites sp.

Ulrich notes that "This zone reminds mostly of early Trenton types of northeastern New York and latest Black River species in Pennsylvania and Minnesota. It does not seem to be quite as old as the lowest of the Viola faunas in central Oklahoma."

About one to one and a half miles to the east of the above fossil locality there are about 200 feet of shales with hardened layers, dark brown to yellowish, sometimes olive in color, overlain by the Maravillas chert.

At the southeast base of the series of chert ridges in which are the Garden Springs, at a point about 5 miles south, 55 degrees east, of Marathon, north 20 degrees west from the summit of Caballos Mountain and north 35 degrees east from the summit of Santiago Peak, the upper strata of the Marathon series are rotten, dirty green shales with thin, rusty, greenish-brown, flaggy sandstone layers passing down into alternating beds of thin layers of rusty brown or blue gray fossiliferous phosphatic limestone which alternate with layers several feet thick of a greenish-blue or dirty green, brittle shale. There may here be a gradation upward from the Marathon series into the lower or Trenton portion of the overlying Maravillas formation, since the strata at the contact are thin-bedded limestone with banded, nodular or lenticular chert, interbedded with a dirty-green to bluish green, brittle, siliceous shale. The limestone and shale portion of the Marathon series here exposed has an estimated thickness of 300 feet and is underlain by shale. A layer near the top about one foot in thickness is full of small fossils. In the anticlinorium in the low country extending south from here to the next high ridge, the limestone and shale member of the Marathon series is repeated a number of times in the lower areas separated from each other by low ridges of the Maravillas formation.

Part of the Marathon series is exposed on the south slope of Caballos Mountain and probably in places between the ridges to the southwest of that mountain.

On the northeast slope of the ridge east of the wagon bridge on the Peña Colorado Creek, southeast of old Ft. Peña, the following section of the Marathon series is exposed:

		Thickness in feet.
Top.	Maravillas Formation.	
1.	Very finely laminated, dark green shale with local hardened and discontinuous thin blocks of finely crystalline brown limestone, for the upper 15 feet. These blocks are from ¼ to 1 inch thick and carry fossils.................	50
2.	Thin-bedded, nodular, greenish-brown limestone, carrying fossils, interbedded with dark green shale............	2
3.	Thin-bedded, dark green shales, more sandy than above, with local irregular, soft, brownish-green sandstones, about	65
4.	Greenish, thin-bedded limestone and shales with fossils in the limestones	2
5.	Like No. 3, to base of ridge.....................about	50

A part of the higher portion of the Marathon series is exposed in the axis of a normal anticline located partly on the Granger, and partly on the Gage ranch at a locality some five miles southeast of the town of Marathon. Here a thickness of about 500 feet of beds is exposed beneath the overlying Maravillas formation. The upper two-thirds of this thickness may be designated as dark green shale, although it has frequent interbeds of peaty sandstone, rusty or greenish brown in color, and of laminated brown limestones in beds up to one foot in thickness. Some of this limestone is phosphatic. There are also phosphatic limestone nodules in the shales which contain fossils, are oolitic, and when unweathered, are very dark brownish-black, or blue-black in color; but generally have a surface-weathered shell of a rich brownish-yellow color. Limestones increase in thickness and number toward the base of the section. They are, in the lower portion, mostly phosphatic; range in thickness from an inch or less up to three feet or more; weather either brownish or dove-colored; and are separated by intervals of shale and thin, flaggy sandstones which probably average 10 feet in thickness. The shales are also often phosphatic. The limestones sometimes give off a fetid odor upon being struck with a hard instrument. They are often oolitic. Small rounded pebbles of black chert are found in the limestones about 100 feet above the base of the exposure. The unweathered limestone is very dark brown, or blue-gray. Fossils are abundant in the lower limestones, especially in some beds about a hundred feet above the base of the exposure.

ORDOVICIAN—MARAVILLAS FORMATION

The Maravillas formation consists of dark gray, thin-bedded, alternating chert and limestone with some beds of rather fine conglomerate of chert and quartz in a limestone matrix. There is generally a basal conglomerate from one to three feet in thickness, made up of boulders and pebbles of dark-colored chert, sandstone, limestone and clay iron-stone. Some angular chert boulders are as large as one foot in diameter, but in general the conglomeratic material ranges from one-eighth inch up to six inches in size.

The type locality of the Maravillas formation is Maravillas Gap on the Marathon-Terlingua road, about fourteen miles in a straight line southwest from Marathon. There the Maravillas Creek cuts across the strike ridges of chert at a point near their southwestern end. The following description is of a section between one and two hundred yards east of the Gap (Plate 1 a).

The base of the formation here, as elsewhere, is marked by either an erosional unconformity or a plane of shearing. At the base is a layer of conglomeratic and finely arenaceous limestone carrying angular and rounded dark chert fragments, ranging up to six inches in diameter. The limestone is finely crystalline and traversed by thin seams of crystalline calcite. Crystals and stalactitic forms of calcite coat exposed surfaces of both limestone and chert. The basal conglomerate averages about one foot in thickness and is mainly made up of rather large, often flattened, angular and subangular fragments of black chert which range from one-eighth inch up to six inches in size. Subordinately, are fragments of chert of other colors, fragments of the underlying Marathon series sandstones, and clay iron-stone, the latter alone generally rounded. Locally the basal conglomerate may be two feet or more in thickness and carry angular chert boulders of one foot in size.

Near the base is some fine-grained light gray material with a pinkish cast, thinly and imperfectly laminated, aggregated in relatively thin beds a few inches in thickness and interbedded with the cherts. This somewhat resembles the Monterey Miocene shale of California. Above are layers of dark-colored brownish or blackish chert, banded in layers ranging from eighteen inches to less than one inch in thickness. The bedding is rather irregular and sometimes slightly contorted. The chert is greatly fractured and traversed by thin seams of crystalline calcite, often no thicker than fine pencil lines. Some of it is stained reddish or pinkish, apparently with iron oxide. There are many layers of fine-grained light gray limestone, often showing fine laminae on weathered surfaces. Thin layers of chert are either plastered on this limestone or firmly welded in interbeds with it. On the whole the member is chert.

The limestones contain fossil bryozoans, corals, and brachiopods, generally arranged in thin layers. The Bryozoa form thin reefs. The limestones are literally packed with fossils, mostly of Bryozoa and small corals. Another characteristic of the limestones is thin seams and lentils of blackish chert which weathers brown. Some of the limestone layers are only a few inches in thickness.

In the upper half are layers of fine-grained dark gray quartzite, ranging up to two inches in thickness, interbedded with chert, a large portion of which is of lighter color than lower down, being of a rather light blue-gray or mouse color. Some layers are of a rather coarse-grained light gray sandstone which has been metamorphosed to a quartzite. Both the quartzite and sandstone possess lentils, irregularly shaped masses and thin bands of chert, which weathers brownish. The sandstone is composed of clear-grained angular particles of quartz. Bedded black cherts continue to the top of the formation. The measured thickness of the Maravillas formation at Maravillas Gap is 325 feet.

At a locality about eight miles northeast of the junction of the Peña Colorado and Maravillas creeks, there is at the top of the Maravillas formation, just under the Caballos novaculite, a small amount of light brown arenaceous shale, weathering pinkish, which may possibly be the equivalent of the Sylvan shale in the Arbuckle Mountains of Oklahoma. Fine conglomerate appears to be sparsely distributed more or less throughout the entire Maravillas chert. This conglomerate is gray in color and composed of fine angular to subangular quartz grains, averaging about one-sixteenth inch and less in size, in a matrix of finely crystalline limestone. This conglomerate also contains small pebbles of chert. On the south side of the Peña Colorado Creek a stadia measurement gave the Maravillas formation a thickness of 270 feet. At the site of old Fort Peña, five miles south of Marathon, it is less than 150 feet thick. The greatest thickness was observed by Dr. Böse in a normal, steeply-folded anticline about five miles southeast of Marathon, where there is between seven and eight hundred feet with the base not exposed. Here the lower beds are mainly limestone and the upper beds mainly chert. The horizon of later Trenton fossils here is fully 300 feet above the base and the lower 300 feet of strata do not occur in the sections farther southwest. In a neighboring locality Dr. Böse found the total thickness of the Maravillas to be only about 100 feet.

Fossils and Age. The following fossils, determined by Mr. E. O. Ulrich, were found at the type locality 200 yards northeast of the north end of Maravillas Gap:

Hallopora aff. H. elegantula
Anaphragma mirable?
Hemiphragma imperfectum

Bythopora cf. delicatula
Crepipora hemispherica?
Rhombotrypa subquadrata
Lioclema wilmingtonense
Constellaria maculata
Constellaria sp.
Favositella cf. epidermata
Pachydictya sp.
Rhinidictya sp.
Eurpdictya cf. sterlingensis
Phaenopora wilmingtonensis
Helopora sp.
Arthroclema angulare
Screptopora facula
Dalmanella aff. testudinaria
Dinorthis cf. subquadrata
Hebertella insculpta
Platystrophia sp.
Plectambonites transversalis elegantula?
Plectambonites cf. saxeus
Rhynchotrema capax manniense
Rhynchotrema cf. anticostiense

Ulrich says "This is a typical Fernvale-Richmond fauna. The Bryozoa are particularly characteristic. Their abundance in this collection suggests very shallow reef-like conditions."

Other collections made, add to the above list the following:

Leptaena rhomboidalis var.
Platystrophia
Hebertella insculpta
Crinoids
Zaphrentis and Streptelasma, 3 or 4 species
Columnaria aff. C. alveolata
Streptelasma sp. with angular dorsum
Cyathophylloides thomi (Hall)

The coral zone of the Richmond occurs in lenticular masses of conglomerate about fifty feet above the graptolite horizon of the later Trenton at the localities about six miles southeast of Marathon.

Ulrich discusses the stratigraphic position of the Fernvale-Richmond zone as follows: "In the Tishomingo, Oklahoma, folio, the Fernvale-Richmond zone holds precisely similar relations to the typical Viola limestone of Oklahoma as does this zone in the Maravillas chert to the underlying Trenton portion of that chert. Though seldom, if ever, exceeding 20 to 50 feet in thickness, and often less, the Fernvale zone is recognizable in many places from Texas to Alaska and Missouri. As it rests on various preceding formations and thus marks a great transgression following a more or less long period of emergence, I have placed it at the base of the Silurian."

A lower horizon in the Maravillas formation contains Trenton fossils. Ulrich determined the following from a locality one-half mile north of Payne's ranch on the east side of Maravillas (Dugout) Creek, 300 yards from the creek:

Diplograptus cf. amplexicaulis Hall
Fragment of a unicellular graptolite stipe suggesting a Didymograptus like D. sagitticaulis
Lingula sp.
Probably new genus of discinoid brachiopod
Leptobolus sp.
Probably two other undetermined species of inarticulate brachiopods
Scenidium cf. anthonense
Leptaenoid shell of undetermined genus
Leptaenoid shell of undetermined genus (a second species)
Strophomena ? n. sp.
Strophomena ? n. sp. 2
Plectambonites aff. sericeus
Parastrophia aff. hemiplicata
Bythocypris
Krausella arcuata
Aparchites aff. labellosa
Eurychilina aff. ventricosa
Eurychilina sp. 2
Dicranella cf. spinosa and simplex
Cryptolithus sp. fragments of shield
Fragments of 3 undetermined sp. of trilobites

Referring to these determinations, Ulrich says: "Most of the 25 species of the above list are recognized as forms belonging to the as yet undescribed fauna of the Viola limestone of Oklahoma. The general aspect of the fauna is that of the Atlantic facies of the Trenton; and as it contains some identical species it is assigned to that age.

"The Viola contains four or five distinguishable faunal zones. Most probably the equivalent beds in the Marathon Basin are similarly marked by slightly different faunal associations. Furthermore, some of the layers contain a little besides Diplograptidae, others chiefly fragments of the trilobite *Cryptolithus*, where others have a more varied fauna. The various collections here indicate like variations in fossil contents in the Marathon Basin region.''

Two and a half miles north of Woodhollow tank, six miles southeast of Marathon, was found a species of graptolite of the genus Climacograptus, which is remarkable in that the lower side of the mouths of the cells of the lower half of its stipes is drawn out into a long spine. This species seems to be new.

At the east base of the Mount Ord Range, near its southern end, were collected the following:

Fragments of diplograptids
Lingulops cf. Norwoodi
Dalmanella cf. testudinaria
Zygospira cf. modesta
Plectambonites cf. sericeus
Fragments of cryptostomatous Bryozoa
Fragments of trepostomatous Bryozoa
Cryptolithus intermedius? (fragment only)
Cryptolithus explanatus
Fragment of free cheek of Ceraurus ?

Ulrich states: ''This faunule is regarded as of Trenton age. One of the trilobites is identical with a characteristic species of the Viola limestone of Oklahoma.''

One mile northeast of the junction of Peña Colorado and Maravillas creeks were collected the following:

Leptobolus cf. walcotti
Acrothele ? sp.
Probably new genus of discinoid shells. Reminds also of Acrothele.

Ulrich correlates the lower portion of the Maravillas formation with the middle and upper Viola limestone of the Arbuckle Mountains of Oklahoma and the Trenton of New York.

Stratigraphic Relation. The lower or Trenton portion of the Maravillas formation marked a transgression of the sea over a number of older formations. In the normal anticline about eight miles northeast of the junction of Peña Colorado and Maravillas creeks and one mile southwest of the Peña Colorado at its nearest point the unconformity at the base of the Maravillas lies only a few feet above the horizon of the Upper Cambrian fossils. In the anticline one and one-half miles northeast of the junction of the Peña Colorado and Maravillas creeks the Upper Ozarkian crystalline limestone is succeeded by about one hundred feet of beds of unknown age before the horizon of the unconformity at the base of the Maravillas is reached. Three and one-third miles northeast of Maravillas Gap five hundred feet of sandstones and shales of unknown age overlie Middle Canadian limestones and are overlain unconformably by the Maravillas chert. Finally, near the northeast end of the earlier Paleozoic area about five miles southeast of the town of Marathon, Dr. Böse found a section with Lower Trenton at the base and above three hundred feet of dark gray limestone, on top of which lay the Maravillas chert. Since the lower part of the Maravillas chert carried later Trenton fossils everywhere noted, there may be no unconformity in the region five miles southeast of Marathon.

Since the deformation of the earliest Paleozoic strata is everywhere intense, there is a possibility that some of the relationships interpreted as unconformities may have been produced by shearing between the beds.

As the Maravillas is of quite variable thickness, it is probable that it is separated everywhere by an unconformity from the overlying Caballos novaculite. But such unconformity between the two was actually observed only in the vicinity of old Fort Peña.

LOWER DEVONIAN (?)—CABALLOS NOVACULITE

The Maravillas formation is unconformably overlain by cherts. These cherts were originally divided* into two formations, the Caballos novaculite below and the Santiago chert above, but later work by the senior author appears to indicate that they are really one formation, two members of both the original Caballos and Santiago being included in the section in some localities. It is now thought that in the localities first examined, erosion has removed the upper novaculite and upper predominantly green chert. However, in a region so intensely deformed as this, in which there is almost everywhere slickensiding and brecciation of the brittle chert, there is a possibility of duplication of beds by shearing or thrusting. Should this finally prove to be the case in the regions where the section exhibits two members, both of the white novaculite and the banded, vari-colored chert in the same succession, the name Santiago may be re-applied to the latter.

The type locality of the Caballos novaculite is Caballos Mountain, the highest point in the folded Paleozoic area of the Marathon Basin, which rises in the southeastern portion of that basin to a height of 1200 feet above its surroundings. The entire northern face of Caballos Mountain is made up of the white Caballos novaculite. The thickness of the lower three members of the formation here, not including the upper member of vari-colored chert, is probably more than 300 feet. Here the lower novaculite member is the thinner. Overlying the lower novaculite member are interbedded thin layers of green and black chert. Upon the latter rests the upper novaculite member, which is much the thicker in the Caballos Mountain ridges, but appears to be thin at Woodhollow Tanks. The upper member is, as usual, very similar to the lower variegated chert member. In places the lower green and black chert and novaculite member contain some black manganese dioxide.

The white novaculite, because of its resistance to the forces of erosion, forms the most prominent exposures and the best horizon marker in the folded Paleozoic rocks of the Marathon Basin. Its thickness is variable and most of the original formation was probably removed by erosion before the deposition of the overlying Santiago chert. In the western portion of its area of outcrop, the lower bed of white novaculite is generally about 90 feet in thickness, the lower 40 feet con-

*Review of the Geology of Texas, Bull. Univ. of Texas No. 44, pp. 39, 41.

sisting of rather thin-bedded light brown chert with some white novaculite, and the upper 50 feet of massive-bedded, much fractured, often brownish-stained, white novaculite, with its upper surface often conspicuously ripple-marked. In the southeastern area of its outcrop the formation appears to be thicker and there may be more than one bed of white novaculite, interbedded with thin-bedded gray and blue cherts. The folding is there complex and time was not available in which to work out the intricacies of structure necessary to a better knowledge of the stratigraphy.

In the anticlinal ridge northeast of the junction of the Peña Colorado and Maravillas creeks, the lower 40 feet of the novaculite member is thin-bedded and brown in color. This is followed by 50 feet of white novaculite, in turn overlain by the lower green chert member. The upper novaculite and vari-colored chert members are not present in the section. In the normal anticlines on the Gage and Granger ranches, and about five miles southeast of Marathon, the section of the Caballos novaculite is as follows:

	Thickness in feet
Base—Maravillas formation, here 300 or 350 feet thick	
1. .Novaculite, lower 30 feet thinner-bedded. All stained brownish	90-100
2. .Thin-bedded, vari-colored chert, green color predominant	150
3. .Whitish or cream-colored novaculite	25
4. .Thin-bedded brown, greenish, black, or reddish chert	60+

The bedding surfaces of the novaculite are very often hummocky, a feature which may possibly have been produced by deformation.

There is no doubt that the Caballos novaculite is the equivalent of the Arkansas novaculite of the western Ouachita Mountains of Arkansas. The Caballos novaculite is, however, thinner than the Arkansas novaculite. Ulrich assigns the Arkansas novaculite to the Oriskany or upper part of the lower Devonian. If he is correct in this, the Caballos novaculite is the first and only Devonian formation to be discovered in Texas.

The White Novaculite. In describing more fully the characteristics of the Caballos novaculite, comparison will be made between it and the Arkansas novaculite. Specimens of the latter were collected by the writer from several localities in the vicinity of Hot Springs, Arkansas. In the following table are given chemical analyses of both the Arkansas and the Caballos novaculites:

Comparative Table of Analyses of Caballos and Arkansas Novaculite.

Number	1	2751	2752	2753	2754
Silica (SiO_2)	99.45	97.32	97.80	97.00	96.80
Alumina (Al_2O_3)	.26	.90	1.07	1.18	1.18
Oxide of iron		1.70	.53	1.02	1.02
Lime (CaO)	.12	1.19	.83	.71	.71
Oxide of Sodium (Na_2O)	.54	.90	.13	.70	.94
Sulphuric acid		.28	.41	.55	.28
Loss on ignition	.06			.06	.02
Total	100.62	102.39	101.20	101.55	101.09

No. 1 is of white novaculite, Hot Springs, Arkansas, from "Whetstones and the Novaculites of Arkansas", by L. S. Griswold, Ann. Rept., Geol. Surv. of Arkansas, Vol. III, 1892.

Nos. 2751 to 2754 are of white novaculite one mile south of Warwick Siding, Brewster County, Texas, and were made in the laboratory of the Bureau of Economic Geology and Technology, by J. E. Stullken.

No. 2751 was pure snow white, rather coarse-grained, with small quartz crystals lining small cavities, and rather porous. Resembles the "soft Arkansas" grade.

No. 2752 was fine-grained and semi-translucent, resembling the "hard Arkansas" grade.

No. 2753 was fine-grained and translucent, with small brown spots, perhaps of manganese dioxide, and resembled the "hard Arkansas" grade.

No. 2754 was snow white to semi-translucent, fine-grained, with resemblances especially to the "hard Arkansas" although also somewhat resembling "soft Arkansas."

All specimens of Caballos novaculite available for the various investigations were from surface outcrops subject to the influence of the weather. Just what effects weathering in the arid climate may have had on these very fine-grained predominant quartz rocks is not known. The Arkansas novaculite analyses appear to have been made from unweathered commercial specimens.

Following exactly the methods used by Griswold and Wait in determining the amounts of soluble silica in Arkansas novaculite and described on pages 162 to 164 of the Annual Report of the Geological Survey of Arkansas, Volume III, 1892, Mr. Stullken of this Bureau made tests the results of which are given in the following table, in which the results of the Arkansas tests are given for comparison:

Table showing soluble silica found by digesting 0.5 gram in a solution of

	27.5% potassium carbonate for 6 hours Per cent.	20% sodium hydroxide for 30 mins. Per cent.	20% sodium hydroxide for 3 mins. Per cent.
Caballos No. 1	2.00	5.20	2.76
Caballos No. 7	2.40	5.72	3.20
Caballos No. 10	2.52	7.04	2.64
White Arkansas	0.44	3.56	1.63
Gray Arkansas	0.62		
Black Arkansas	1.14		
Red Arkansas	0.93		
Fine Ouachita	0.43		
White Ouachita	0.28		
Black Ouachita	0.54		
Mottled Ouachita	0.53		
Hard Ouachita	0.51		
Quartzite	0.74		
Quartz crystals	1.47		
Quartz crystals (2)	0.71		

Only one test with sodium hydroxide is given in the Arkansas Geological Survey report, which does not mention the grade of novaculite used. Ordinary nodular cherts in sediments, generally regarded as of clearly secondary origin, contain a larger proportion of soluble silica than do the Caballos and Arkansas novaculites. Chemical analyses of both Arkansas and Caballos novaculites support the microscopic evidence that they are almost entirely made up of crystalline quartz. It would be interesting to know whether bedded cherts in general, as distinguished from nodular and concretionary cherts, contain as high a percentage of insoluble silica as the novaculites. We do not seem to have sufficient data to come to any definite conclusion in regard to this. The analyses given above show that weathered specimens of Caballos novaculite contain less total percentage of silica and a larger percentage of soluble silica than do unweathered specimens of commercial Arkansas novaculite.

Every one of nine samples of different grades of Arkansas novaculite, analyzed by the Geological Survey of Arkansas, has over ninety-nine per cent. of silica, and in fact, hàs as large a percentage of silica as crystalline quartz or the general run of purer grades of chert. In fact, from analyses alone, no distinction can be drawn between novaculite, quartz, and chert. One striking fact brought out by all analyses of Arkansas and Caballos novaculite, is the very small amount of water present which shows that they contain very little hydrous silica. The greater percentages of iron oxide in the analyses of the Caballos novaculite is due to some extent at least to weathering and lack of leaching. The higher percentage of lime in the Caballos novaculite is explained by the arid climate in which lime is not dissolved as rapidly as in a humid climate.

There is a general difference in physical appearance, however, between cherts and novaculites, although this difference is not a constant one. The lustre of chert is either earthy or vitreous, while that of novaculite is dull-resinous or waxy; chert seems to have a smooth surface looking as if it were glazed when the specimen has a vitreous lustre, while the surface of novaculite appears minutely rough.*

All of the Caballos novaculite yet seen resembles the grades of Arkansas novaculite known commercially as the "hard" and "soft" Arkansas, and the "fine" Washita. The coarser Washita grade has not yet been found. The Caballos novaculite can be broadly grouped in four varieties. The first variety is very light blue or blue-gray in color and is the

*Griswold, Geological Survey of Ark., Ann. Rept., 1892, Vol. III p. 162.

most translucent, always having, however, a clouded or hazy appearance. This variety is sometimes darker gray, in which case the darker shade is caused by thin films of oxide of manganese on joint cracks or by minute dark specks scattered through the rock, probably also of oxide of manganese. This first variety shows no structure, even under the most powerful hand lens. It has a close resemblance to the "extra hard" and "hard" Arkansas stone.

The second variety is milky-white, semi-translucent on thin edges only, has the most perfect conchoidal fracture, shows finely granular structure under a powerful hand lens, and has the appearance of unglazed porcelain. This resembles the "soft" Arkansas stone.

The third variety exhibits characters intermediate between the first and second. It is very finely granular, bluish-white in color, and much resembles milky quartz of very fine grain, but its lustre is dull and not vitreous as in quartz. This third variety seems to most nearly resemble the ordinary run of the "hard" Arkansas stone.

The fourth variety is generally spotted and is apt to be darker in color. It is apparently rare and resembles ordinary flint or chert.

The numerous joint planes in the Caballos novaculite are coated with thin seams of brownish-red iron oxide or of black oxide of manganese. Some weathered surfaces of the novaculite show a glazed or wax-like appearance. Crystalline quartz is often found on joint planes, as thin veins, often hardly thicker than a sheet of paper, and aggregated in small spots or "eyes." One specimen of the first variety, of darker gray color, was firmly welded to black siliceous shale, and both shale and novaculite were traversed by a thin vein of vitreous yellowish chert.

Under the microscope some specimens of Caballos novaculite are fully as fine and *uniformly* grained as any of the Arkansas commercial novaculites. Both appear to be entirely composed of quartz and both exhibit occasional, sparsely distributed, single fragments of quartz. Other specimens of Caballos novaculite exhibit a very uneven texture with the coarser grains often bunched together with some of the grains producing undulatory extinction or with a finely fibrous appearance. These knots or aggregates were originally radiolarians, but now their original structure has been partly destroyed by subsequent metamorphism. A specimen of the non-commercial Arkansas novaculite exhibits the same spotted and knotted appearance under the microscope.

The microscopic study shows that the Caballos novaculite is mainly or altogether a holocrystalline aggregate of interlocking granules of quartz, forming a very fine-grained mosaic. The rock was probably originally made up of amorphous silica which has reached its present form by a process of crystallization analogous to that of the devitrification of extrusive igneous rocks. The finer and more uniform-grained commercial varieties were either originally a pure siliceous ooze or else a radiolarian chert in which all evidence of Radiolaria has been removed by subsequent metamorphism (recrystallization).

The Vari-colored Cherts. Two members of thin-bedded and ribboned chert, with layers of almost every conceivable color but of dull shades, predominatly light green, overlie the Caballos novaculite members. At the top of the lower member the chert becomes thinner-bedded and splintered, with a fine-grained texture, and gradually loses its vitreous lustre. The lower chert member has been named the Santiago chert from a locality at the east base of the Santiago Range east of the range's summit, where it was first seen. A stadia measurement in one of the anticlines south of Peña Colorado Creek, about half way between old Fort Peña and the mouth of the creek, gave the lower chert member a thickness of 450 feet. In places, however, the formation is very much thinner, having been in large part removed by erosion before the deposition of the overlying Pennsylvanian formations.

Microscopic examination reveals the fact that the vari-colored chert is, in structure, much like the uneven-textured varieties of the white novaculite. In the vari-colored chert the knots of coarser quartz grains are circular or sub-circular. Each knot is a single radiolarian, larger than the radiolarians of the white novaculite. Photomicrographs of vari-colored chert radiolarians are given in Plate II. In the slides examined, the radiolarian remains make up from less than ten to nearly fifty per cent. of the rock.

Since the Caballos is entirely a chert formation and pure siliceous oozes containing radiolarians are known to form only in the deep sea, it is most probable that it is a true pelagic formation.

ANTHRACOLITIC

PENNSYLVANIAN

Tesnus Formation

The Tesnus formation unconformably overlies the Caballos novaculite. The lower part of the Tesnus has been called the Rough Creek shale member, of hard, compact, brittle, dark green, occasionally black shale, 865 feet thick. This shale is named from Rough Creek, a tributary of San Francisco Creek, and the type locality is along the lower course of that creek in the southeast portion of the Marathon basin. There is considerable black, dull hornstone in the Rough Creek shale member.

The upper part of the Tesnus is sandstone, shale, dark dull hornstone, and a few thin lenticular layers of conglomerate. The sandstones are soft to highly indurated, thin-bedded to massive, in color predominantly dark dirty green or rusty brown, but sometimes white. The shales are dark dirty green or black, in some layers carbonaceous, and well-laminated when more clayey, roughly jointed when more sandy. Dense, dull-lustred hornstone occurs in thin layers and is prevailingly black or brownish-black in color. The conglomerate is made up of subangular, angular, and rounded fragments derived from the older formations of the region, predominantly of cherts from the Santiago, Caballos and Maravillas cherts. The only fossils found in the Tesnus are remains of land plants, principally *Calamites*. A stadia measurement on the southeast flank of the second anticline northeast of the mouth of

Peña Colorado Creek and on the southeast side of the creek gave the Tesnus formation, including the Rough Creek shale member, a thickness of 3,370 feet. The Tesnus formation may possibly be, in part, the correlative of the Stanley shale of the Ouachita Mountains of Arkansas and Oklahoma. The type locality of the Tesnus formation is in the vicinity of Tesnus station on the Southern Pacifiic Railroad.

The Tesnus weathers to a rather deep reddish-brown color, which is very characteristic and easily recognizable. At Shiele's ranch, near where the Southern Pacific Railroad passes out of the Marathon basin on the east side, are light gray, fine-grained, micaceous sandstones with blue-black shales. In the northeast part of the Marathon basin thin beds of chocolate-colored compact shale are found with the Tesnus quartzitic sandstones.

Some thin layers in the greenish lower Tesnus shales have cone-in-cone concretionary structure. In the heart of the anticline, between the junction of Rough and San Francisco Creeks, the lower beds of the Tesnus have been considerably disturbed and crumpled by pressure. The fine-grained, dirty green, micaceous sandstones have become fissile, knotted, and gnarled; the shales are still shales, but are much disturbed and crumpled. Secondary quartz and calcite seams have been developed in the dark, dirty green, blue-gray and blue-black shales, as well as in the sandstone. The sandstone also has cone-in-cone structure. Some brownish-black breccia of angular chert is found here. It also contains in its lower part some thin bands of hard, dense, compact and fine-grained dark green and blue-black hornstone, almost chert-like in its fracture. The formation contains massive as well as thin-bedded sandstone. Locally there is a rather fine-grained, almost pure sandstone of transparent quartz, cemented with quartz, locally to a quartzite, but perhaps on the whole, more of a sandstone than a quartzite. It is stained on exposed surfaces with Indian red hematite.

In the core of the anticline on Rough Creek from four to six miles above its mouth is exposed much crumpled Rough Creek green shale stained heavily with iron oxide and wad.

Near the outer border of the crumpled shale zone is a thin layer of flax-seed rock which may have been originally garnetiferous. Next is a 10-foot bed of hard whitish and blue-black chert, fractured into small angular and whitish particles and cemented with a matrix of darker color. Cracks and small cavities are coated with small quartz crystals. This fractured chert also contains considerable fine pyrite. This chert grades up into interbedded hornstone and shale, predominantly black and green in color (Plate II). The hornstone carries considerable small rounded masses of pyrite, also thin bands of waterworn fine-grained quartz conglomerate. The shales are micaceous. Small seams of quartz continue and some crumpled and much smashed layers transgress bedding planes. The only material that can be called slate is a dense blue-black fine-grained claystone occurring in thin beds averaging about 2 inches in thickness. Minor faults, crumpled beds, and slickensides are common. Thin quartz stringers with comb structure are also common. There is notable jointing, particularly in diamond pattern, but slaty cleavage is not developed. The Rough Creek shale appears to grade up into the Tesnus proper.

Hornstone, bluish-black sandstone, shaly and finely arenaceous light gray shales, stained on the surface various shades of pink, red, and brown, overlie older Paleozoic rocks at the edge of the foothills N 10°-15° E of the summit of the Santiago Range. These belong to the Rough Creek shale member.

The Tesnus formation is distributed around the northeast, east, southeast, south, and southwest margins of the Marathon Basin outside of the area of the older Paleozoic rocks, and it also outcrops in the synclinal areas between the anticlines of the older rocks. In the heart of the anticline in the Santiago Range at Persimmon Gap, the Tesnus forms a small elliptical area about two miles in length, mostly north of the road through the Gap and to the east of the crest of the range. About one-half mile north is another narrow exposure about one-half mile in length.

The Tesnus formation has marine fossils in the northwestern part of the Marathon basin, where its exposures lie between the older Paleozoic rocks, and the Permo-Carboniferous. Its contact on the southeast with the early Paleozoic strata is everywhere that of an overthrust, the Dugout strata being overturned at the contact. Along the southern edge of the outcrop, alluvial covering hides the relationships with other formations. Fossils found in limestone layers in the Tesnus belong to the Coal Measures portion of the Pennsylvanian. The Tesnus strata were folded at the same time as the first recognized folding of the older Paleozoic strata. The older strata were overthrust from the southeast on the Tesnus strata, the latter being compressed into sharp, often overturned folds. The structure in the northwestern portion of the Marathon basin is similar to that of the Tesnus in the southeast portion of the basin. In both places there are a number of consecutive folds in which is exposed only a single formation.

In the northwest, the formation consists mainly of thin beds of hard, rusty, brown, medium-grained sandstone interbedded with olive-green and blue-black arenaceous shales, with a few thin beds of brown conglomeratic limestone which sometimes contains fossils. In the anticline on the Hargis ranch just south of the Southern Pacific track (mile post 580), three miles west of Marathon, there are many fragments of Santiago chert in the conglomeratic limestone. There are also small quartz pebbles and small masses of light green clay in the limestone. The thickness of the formation here was not determinable, since nowhere was either its base or its top seen. The formation appears to be hundreds or even thousands of feet in thickness.

The following fossils were collected in the beds exposed from the vicinity of the Dugout creek at Payne's ranch westward to the Permo-Carboniferous contact:

Fusulina "cylindrica"
Lophophyllum profundum
Campophyllum torquium
Crinoid stems, large and small
Archaeocidaris agassizi
Archaeocidaris, 2 species
Polypora submarginata
Marginifera lasallensis.
Marginifera splendens?
Dielasma bovidens
Composita subtilita
Ambocoelia planoconvexa
Fenestella shumardi ?
Fenestelloid bryozoans.
Spirifer cameratus
Spiriferina ?
Meekella striatacostata ?
Productus cora
Productus punctatus ?
Productus nebrascensis ?

The following fossils were collected in the vicinity of the drilling for oil on Wedin's ranch, northwest of Marathon:

Fusulina "cylindrica"	*Marginifera splendens*
Crinoid stems, large and small	*Enteletes hemiplicatus*
Lophophyllum profundum	*Squamularia perplexa*
Archaeocidaris sp.	*Productus cora*
Synocladia biserialis	*Spirifer cameratus*
Fenestelloid bryozoans	*Spirifer texanus* Meek
Chonetes granulifer	*Conocardium* sp.
Bellerophon sp.	

(*Spirifer texanus* is abundant in the Canyon and Cisco formations of north-central Texas).

The following fossils were collected near the axis of the anticline on the Hargis ranch, 3 miles west of Marathon, south of mile post 580 on the Southern Pacific:

Fusulina "cylindrica"	*Composita subtilita*
Crinoid stems, large and small	*Chonetes granulifer*
Campophyllum or *Lophophyllum* sp.	*Derbya* sp.
Pachypora sp.	Productus, 2 or 3 species
Spirifer cameratus	

Dimple Formation

The Dimple formation was named by Udden from the Dimple Hills in the northeastern part of the Marathon basin. The Dimple consists of alternating beds of dark gray limestones, black chert and black shales, with a few beds of chert conglomerate. The limestones carry a few marine fossils of Pennsylvanian age, the exact horizon of the Pennsylvanian represented being not yet known. A stadia measurement of the formation in the gap of San Francisco Creek followed by the Southern Pacific Railroad between Warwick and Haymond stations gave a thickness of 925 feet. The Dimple overlies the Tesnus, apparently conformably.

The formation is exposed one and one-half miles south of Marathon, where the dip is about 70° S. 55° E. Here the formation varies in composition and texture from very compact, dense and fine-grained blue-gray limestone, through a rather coarse calcareous and quartzose sandstone carrying small bluish-green angular grains, perhaps of glauconite, to a rather coarse angular chert conglomerate with a coarse quartzose sand matrix. Layers of chert are interbedded with the limestone. The following fossils were collected in the limestone:

Chonetes sp.
Productus sp.
Derbya or *Orthotetes* sp.
Derbya cf. *crassa*
Spirifer sp.
Campophyllum torquium
Corals and bryozoa

An overturned or possibly doubled section of Dimple along San Francisco Creek one and one-fourth miles west of Haymond station consists of blue-gray compact limestone, fine-grained brownish-black banded shale, and blue-black chert with conglomerate and breccia beds of chert from the older formations, particularly Caballos novaculite and Santiago chert. All of the above are interbedded. The limestone layers range in thickness from an inch up to two feet or more, the shales from less than an inch to several feet, and the bedded cherts from a fraction of an inch up to several inches. Some of the limestone layers have small rounded pebbles of chert. The chert bands are more common towards the top. The limestones carry a small fauna of diminutive forms of sponges, bryozoans, brachiopods, corals and crinoid stems.

The blue-gray Dimple limestone is generally quite cherty and locally grades into a calcareous quartzite. Beds of a remarkable chert breccia are rather frequent in the Dimple. The angular or subangular fragments of chert range up to more than an inch in size and are white, green, black, and brown in color. The matrix of the breccia is also chert and the rock fractures across the fragments.

The Dimple formation usually outcrops in sharply-contoured strike ridges generally along the axes or flanks of anticlines. Its outcrops are most numerous in the eastern half of the Marathon basin.

Haymond Formation

The strata referred to the Haymond formation were seen only in the eastern part of the Marathon basin in a region extending from the Dimple Hills southward to the head of Rough Creek. The main outcrops lie in the synclinal areas north of Haymond station. The formation consists of sandstones and shales similar to those of the Tesnus. The maximum thickness seen did not exceed 500 feet. The Haymond overlies the Dimple in the synclinal areas.

There is some doubt whether the Haymond is not really a part of the Tesnus formation overthrust over the Dimple formation. But as no proof of such overthrusting could be found, it is here named a separate formation. Later work has thrown a little more light on the problem, but conclusive evidence is not yet at hand. At the locality where the long strike ridge of the Dimple formation is crossed by the Marathon-Sanderson road north of Haymond Station, the Dimple formation is flanked on both sides by some thin brown limestones interbedded with the sandstones and shales of the usual Tesnus facies. These limestones carry many small angular fragments of green chert which average about 1/8 inch in size, and also a few small fossils. The fossiliferous limestone at the southeast base of the strike ridge was also encountered just south of the Marathon-Haymond road about five miles south-southwest of the Marathon-Sanderson road. It may possibly be found that the strike ridge of the Dimple formation here is in reality the trough of a syncline instead of the flank of a fold, as first interpreted. If this proves to be the case, the strata referred here to the Haymond are in reality Tesnus.

The Mid-Pennsylvanian Diastrophism (Plate III)

The region of the Marathon Basin was next folded into a mountain range. The diastrophism producing the folding was very intense, the rocks being overthrust from the southeast toward the northwest so that isoclinal folds overturned toward the northwest and overthrust faults were developed. The longer axes of the folds trend northeast-southwest. Four anticlinoria of pre-Pennsylvanian strata were developed between synclinoria of Pennsylvanian strata. As we view the region today, the greatest amount of uplift seems to have taken place in the center of the basin, where the oldest rocks are now exposed, but this may be partly or wholly the effect of a much later doming. The folds again appear 35 miles to the southwest in the domical uplift of the Solitario, north of Terlingua, and it is probable that they underlie the intervening region. The full extent of the folded area is unknown, for it is covered on all sides by later strata. The fortuitous circumstances of later mountain-making movements and subsequent erosion have uncovered the old mountain range only in the Marathon Basin and the Solitario.

The details of structure cannot be given until far more detailed work, based on a large-scale topographic map, has been accomplished. The scale of the map accompanying this report is much too small to permit the areal delimitation of the rock formations or of structural details. Only enough work has yet been accomplished to make apparent the main structural facts, the stratigraphic succession of the rock formations, and a rather general idea of the areal distribution of the formations. The more resistant rocks are well exposed in the higher areas, but the less resistant rocks occupying the lower areas are often covered with a mantle of alluvium, which, though generally thin, is yet thick enough to entirely hide the bedrock in many places.

Many local complexities of folding occur within the main structural features. The more consolidated rocks exhibit much fracturing and slickensiding, many abrupt changes in strike and dip, and much buckling. In the cherts, extensive jointing, locally approaching true cleavage, is developed at right angles to, and almost as well as, the bedding. Often the cherts have been shattered into breccia the fragments of which have been re-cemented by silica. The shales are almost everywhere intensely crumpled into minor folds. There is great development of veins of quartz, calcite, iron oxide, and manganese oxide along planes of jointing and displacement. Many of these veins are scarcely thicker than a sheet of paper.

The overfolds are developed on the northwest limbs of overturned anticlines. The general dip is southeastward, almost everywhere at high angles. The only anticlines not overturned were noted in the Peña Colorado sub-range, extending northeast from the mouth of the Peña Colorado Creek, in the Tesnus formation on the northwest and southeast sides of the basin, and in the Tesnus formation in the vicinity of mile post 580 on the Southern Pacific Railroad, three miles west of Marathon. Several overturned anticlines and synclines in which are exposed only the thick strata of the Tesnus formation occur on the eastern, southeastern, and northeastern sides of the Marathon basin. At the southeast corner of the basin, folds in Tesnus strata are closely pressed, with dips along the axes ranging up to the vertical, but are not overturned. But even where overturning or overthrusting of the main folds does not occur, single formations may exhibit complex deformation. Thus the anticline just southeast of the junction of Peña Colorado and Maravillas creeks is as symmetrical and has as low normal dips on its flanks as any in the region, and yet on the northwestern flank the strata of the Maravillas chert are intensely crumpled into minor folds with small overthrust faults.

The most extensive overthrust noted was along the northwest base of the Peña Colorado anticlinorial complex. This overthrust fault runs for considerable distances both northeast and southwest of the site of old Fort Peña. A broad area of lower country between the lower Garden Springs and the Maravillas Gap is occupied by a complex anticlinorium of the Marathon and Maravillas formation, which is repeated a number of times, the entire anticlinorium, except in its extreme northwestern flank, being overturned to the northwest. With this exception, the broad lower areas appear to be synclinal or synclinorial.

Around the northeastern end of the large anticlinorium just noted the Caballos novaculite plunges in a broad regular anticline exhibiting none of the minor folds of the underlying formations. Evidently there must have been much lateral shearing between the Caballos novaculite and much more extensively crumpled lower formations. The latter also must have slid extensively over lower-lying rocks of more competent structure.

A series of slip faults with displacements at right angles to the strike were noted in the low hogback of Caballos novaculite on the northwestern limb of the anticlinal ridge next northeast of the one beginning at the junction of the Peña Colorado and Maravillas creeks. The locality is about one mile northwest of Garden Springs. These faults have a horizontal displacement of one hundred to two hundred feet. Each is the site of a saddle or small valley crossing the hogback of Caballos novaculite, and forms a right angle offset in the line of outcrop.

Date of the Deformation. The Tesnus, which is the older of the Pennsylvanian formations folded by the deformation, is post-Pottsville in age. The folds were greatly eroded and the region submerged again beneath the sea before the unconformably overlying Gaptank formation was deposited. In the basal beds of the Gaptank formation was found *Chonetes mesolobus,* which Dr. G. H. Girty considers characteristic of the lower portion of the Pennsylvanian Coal Measures of Kansas. In the higher beds of the Gaptauk formation occurs an abundant fauna of the same species of foraminifera, Bryozoa, corals, brachiopods, gastropods and pelecypods, as are found in the Canyon and Cisco formations of north-central Texas, and also an ammonite, *Schistoceras cf. hyatti* Smith, very similar to *Schistoceras hyatti* Smith, occurring in the Cisco formation at Graham, Young County, Texas. The fauna of the higher beds of the Gaptank is apparently of upper Pennsylvanian age, but that of the lower Gaptank may possibly be a little older. It is therefore fairly certain that the folding occurred at sometime within the Coal Measures portion of the Pennsylvanian. The deformation cannot yet be closely correlated with the Hercynian (post-Westphalian-pre-Stephanian) diastrophism of central and southern Europe, but it falls within the general Hercynian epoch.

The Pennsylvanian epoch of folding in the Marathon basin may be contemporaneous with or later than the folding and faulting in the Central Mineral Region of Texas, which occurred between Bend and Strawn times. It appears to be older than the first epoch of Anthracolitic deformation in the Arbuckle and Wichita mountains of Oklahoma, provided the age of the Franks conglomerate is correctly assigned to the early Pennsylvanian. It may very likely be contemporaneous with the second epoch of deformation in these Oklahoma ranges, which occurred in pre-Cisco time and furnished the coarse sediments of the Cisco and Wichita formations in southern Oklahoma and northern Texas. The structure of the Marathon basin area is the counterpart of that of the Ouachita Mountains of east-central Oklahoma and west-central Arkansas and the axes of the folds on the southwestern margins of the Ouachita Mountains strike southwest toward the Marathan basin, and have the same strike as the folds in the Marathon basin. The very thick series of lower Coal Measures Pennsylvanian strata in the Arkansas Valley were also folded at the same time as the Ouachita Mountains to the south. So it seems very probable, though not yet perhaps absolutely certain, that the deformation of the Marathon basin and the Ouachita Mountains was contemporaneous. Whether a continuous folded mountain range once extended from Little Rock, Arkansas, southwestward to the Marathon basin, or whether the two ranges now known only in the two widely-separated regions were distinct cannot be told, for between the two lies a broad geosyncline (Llano Estacado geosyncline) formed of younger rocks deformed at a later date which entirely hide from view the older Paleozoic. The oldest Paleozoic rocks outcropping in the intermediate area belong to the Strawn formation, which was deposited later than the folding, but the exact age of which is yet unknown, although it is regarded as Pennsylvanian of a date later than the Pottsville. The late Paleozoic folding of the Appalachian Mountains of the eastern United States, if correctly dated, is later than the folding of the Marathon Basin and Ouachita Mountains regions.

Events of the Late Pennsylvanian and Early Permian

An extensive epoch of erosion followed the Hercynian mountain-making epoch. Then came a resubmergence beneath the waters of the sea, during which the Gaptank formation of the late Pennsylvanian was deposited. Again the sea withdrew from the region, sub-aerial erosion followed, and a resubmergence brought about the deposition of some 8,000 feet of Permo-Carboniferous sediments. This epoch of marine deposition was twice interrupted by uplift which brought about renewed erosion, as is indicated by two unconformities and basal conglomerates in the Permo-carboniferous series.

Post-Permo-Carboniferous Folding

The region of the Glass Mountains was gently folded at some time after the deposition of the Permo-Carboniferous strata. The date of folding was pre-Comanchean Cretaceous. It may have occurred at the same time that the Llano Estacado geosyncline was formed. The latter occurred at some time before the Upper Triassic (Keuper).

MESOZOIC

EARLY MESOZOIC EROSION

There is a gap in the sedimentary record of the Front Range region between the Permo-Carboniferous and the Comanchean Cretaceous. A great amount of erosion was accomplished in this interval for the basal sediments of the Comanchean rest everywhere (except at Altuda Mountain) on a rather even surface cut on the older rocks. The upper Comanchean rests unconformably on the upper Hueco (Pennsylvania) limestone in the region north of the Davis Mountains at the northwestern corner of the area mapped. In the Glass Mountains the Fredericksburg Comanchean rests on different formations of the Permo-Carboniferous and to the east on the Gaptank and Tesnus formations. Farther south in the Marathon basin region the Trinity Comanchean rests on all the older Paleozoic formations. The

Permo-Carboniferous Vidrio formation appears to have been an island when the Fredericksburg sea first advanced over that region but later became entirely covered with Comanchean sediments.

CRETACEOUS

Comanchean Cretaceous

The Comanchean sea gradually advanced northward, the oldest Comanchean sediments being found at the south. Basal Comanchean beds of Trinity age rest on the bevelled edges of the closely folded Tesnus formation at Persimmon Gap in the Santiago Range. The basal Comanchean beds in the Glass Mountains belong to the Fredericksburg division. At the next place to the northward where basal Comanchean strata are exposed in the region of the Davis Mountains, they belong to the Washita division, or if older Comanchean beds occur they are very thin and are covered by later deposits.

The limestones of the Fredericksburg and Washita thicken greatly and gradually become more massive from the Davis Mountains southward to the Rio Grande. Strata of the Fredericksburg division do not seem to have been deposited much farther north than the Glass Mountains. In the region between Mt. Ord and a line an unknown distance south of Santiago Peak the Del Rio clay overlies the Edwards limestone. Southward in the Sierra del Carmen and along the Rio Grande, the heavy limestone becomes 2,000 feet in thickness and probably includes most of both the Fredericksburg and Washita divisions, and the Del Rio clay has an irregular development.

The basal beds of the Comanchean resting on the older formations in the Marathon basin region are sometimes, but not always, conglomeratic. Around the east margin of the basin a member of buff, resistant, medium-grained, well-indurated and much jointed sandstone, 40 feet in thickness, is very persistent. On Cedar Mountain this sandstone is underlain by 215 feet of limestone and marls and overlain by 130 feet of massive white chalky limestone. There is here no basal conglomerate, marly limestone beds resting directly upon bevelled edges of steeply tilted Dimple formation.

In a low anticline of Comanchean at the southeastern corner of the Marathon basin the basal Comanchean consists of arenaceous light buff limestone, weathering gray, interbedded with yellowish-buff marl, and in the upper third, cross-bedded medium-grained soft buff sandstone with sugary texture. This is succeeded above by the massive Edwards limestone facies, very cherty and containing many crystals of fibrous calcite. The chert, which is generally iron-stained on the exterior, contains impressions of Radiolites, Caprina and Turritella.

A short distance north-northwest of Persimmon Gap the basal Comanchean is a hard, reddish-brown conglomerate of waterworn pebbles and boulders ranging up to eight inches in diameter. The basal beds of yellowish-brown rough limestone and marl overlying the Tesnus at Persimmon Gap contain upper Trinity fossils (*Orbitulina texana, etc.*).

The Comanchean fringing the Marathon basin on the west is broadly divisible in three mapable units. At the base is a white or buff chalky limestone with locally a basal conglomerate, some calcareous sandstone and then mainly a rather massive limestone with a characteristic blue-gray weathered surface. The top of this is of Georgetown age. Above is yellowish marly clay with thin flaggy beds of limestone, not more than 100 feet thick, forming low mounds or mesas of a tawny yellow color.

At the base of the lava escarpment southeast of Mt. Ord a white chalky limestone about 50 feet thick overlies the yellowish marly clay and probably represents the Buda horizon.

The base of the Comanchean west of Altuda Mountain is a limestone conglomerate made up of fragments up to six inches in size of the underlying Permo-Carboniferous with a limestone matrix which renders the conglomerate difficultly distinguishable from the Permo-Carboniferous limestones.

The basal Comanchean beds in the northwest corner of the area mapped (south of a point between Boracho and Plateau section houses on the Texas and Pacific Railway) are of conglomeratic sandstone with pebbles of sandstone and chert of various colors, well-rounded and ranging up to two inches in size, with a brownish to reddish matrix, prevailing dark red in color, micaceous, and fine to coarse-grained, with a maximum thickness of 100 feet. This overlies some 300 feet of bluish, brecciated, and cherty limestone, which is probably upper Hueco.

At the Seven Mile mesa northeast of Fort Stockton is the following section of Georgetown strata:

Top.		Thickness in feet.
1.	Heavy, chalky limestone	50
2.	Limestone and marls, containing the following fossils identified by Dr. Emil Böse:	
	Schloenbachia trinodosa — *Gryphaea navia*	
	Schloenbachia aff. acutocarinata — *Cardium multistriatum*	
	Schloenbachia sp. — *Gryphaea pitcheri var tucumcarii*	
	Tylostoma chihuahuaense	
	Vola indet. 2 species	90-100
3.	More resistant, thin-bedded buff limestone	10
4.	Thin-bedded, gnarly limestone above with thin-bedded, brown, sandy, ferruginous flagstone below	120
5.	Lower beds, covered by debris	60

The following fossils were collected from marly beds at the Comanche Spring at Fort Stockton by Mr. W. F. Henninger and were identified by Dr. E. Böse:

Exogyra texana
Exogyra sp. nov ?
Exogyra sp.
Enallaster texanus ?
Engonoceras sp.
Trigonia sp.
Cala subalpina
Lima wacoensis
Pholadomya sp.
Vola irregularis
Lima sp.

This horizon is the lowest part of the Georgetown. The following Georgetown fossils were collected in the middle of Sec. 3, Block 114, Pecos County, and identified by Dr. Böse:

Schloenbachia of *nodosa* group
Epiaster elegans
Alectryonia marconi
Gryphaea pitcheri
Vola sp.
Tapes ?

A total of 980 feet of Comanchean strata occurs between the top of the northwestern part of the Twelve Mile Mesa, southwest of Fort Stockton, and the bottom of the Davenport Land and Irrigation Associates well at Belding station on the Kansas City, Mexico and Orient Railway. The section is as follows:

Top	Thickness in feet.
1. Heavy chalky limestone	80
2. Marly limestones, with following Georgetown fossils, identified by Dr. Böse, at top: *Kingena wacoensis* *Diplopodia cf. texanum* *Pyrina parryi*	190-220
3. Brown layer at top, mostly light buff or cream-colored thin-bedded limestone in the middle, and medium-grained brown ferruginous sandstone at base	140

The log of the well at Belding follows. Elevation at the well is about 250 feet below the brown ferruginous sandstone. (No. 3 of above section).

6 ft. alluvial soil
37 ft. light yellow clay
2 ft. gravel
15 ft. hard blue limestone
8 ft. yellow clay with small gravel
6 ft. hard limestone
13 ft. light pink clay with gravel
24 ft. no data
2½ ft. lime conglomerate.
4½ ft. gravel.
2 ft. limestone
95 ft. no data
Clay and gravel at 215 ft.
46 ft. soft and hard limestone in alternate strata from six inches to two feet thick. The hard limestone is like flint and soft limestone is like shale.
8 ft. yellow limestone
16 ft. hard blue limestone
3 ft. clay
6 ft. yellow sandstone
38 ft. light gray limestone
7 ft. blue sandstone
14 ft. blue limestone and yellow sandstone
35 ft. white and yellow sandstone in alternating strata from six inches to two feet thick.
4 ft. white limestone
53 ft. shale, sandstone, clay, and limestone
11 ft. very hard sandstone

The hogback just south of the Texas and Pacific Railway from Kent westward to beyond Boracho section house is capped with a thin bed of whitish limestone, underlain by yellowish and buff marly beds. In the strata from the base to the top of the escarpment, just south of Kent, the following fossils were collected by Dr. Böse, and the writer, and identified by the former:

1. Lower strata (lower Georgetown):

Schloenbachia burkhardti	*Epiaster elegans*
Schloenbachia rostrata	*Lima wacoensis*
Schloenbachia cf. nodosa	*Lima sp.*
Schloenbachia sp. nov. .	***Vola subalpina***
Schloenbachia sp.	*Vola sp. nov.*
Engonoceras sp.	*Cardium multistriatum*
Nautilus sp.	*Gryphaea pitcheri*
Pyrina parryi	*Pholadomya sp*
Pyrina sp. nov.	*Tapes sp.*
Enallaster texanus	*Tylostoma sp.*
Holectypus planatus	*Cardita sp.*

2. Middle Georgetown:

Schloenbachia trinodosa	*Enallaster texanus?*

Arca sp.

3. Upper strata (highest Georgetown):

Schloenbachia trinodosa	*Enallaster bravoensis*
Ostrea quadriplicata	

Upper Cretaceous

The Upper Cretaceous was found only in the region underlying the lavas in the Davis and Barilla mountains and in the syncline between the mouths of the Maravillas and San Francisco creeks. In the latter area only the Benton (Eagle Ford) thin flaggy limestone beds are found, overlying the Comanchean. The base consists of 20 feet of yellowish-brown arenaceous limestone, succeeded above by 80 feet of white chalky marls and irregular-bedded knotted and marly limestone. At Hovey station, on the Kansas City, Mexico and Orient Railroad, a well abandoned at a depth of 600 feet was in blue shale, probably Benton. The Benton also probably underlies the country in the vicinity of Alpine. A thin section of Benton was noted underlying the lava near the Bow McCutchin ranch house. Here were characteristic blue-black bituminous shale interbedded with thin layers of chalky limestone passing up into the Niobrara chalk. The lava remnants east of Brogada and Balmorhea are underlain by Benton or Pierre. According to Dr. J. A. Udden, the Boquillas flags phase of the Benton, consisting of thin-bedded, yellowish-brown, flaggy limestones, overlies the Buda limestone in the trough of the syncline south and southeast of San Martine station on the Texas and Pacific Railroad. Typical Niobrara (Austin) chalk underlies the valley of Limpia Creek between the Davis and Barilla mountains, is exposed under the lava in the heart of the main anticline of the Barilla Mountains, and small exposures were noted at the X ranch at the mouth of Adobe Canyon and at the mouth of the Little Aguja Canyon.

The Pierre is found under the lava at Wild Rose Canyon and in the vicinity of the McCutcheon ranch house in Limpia Canyon, also in the valley of Limpia Creek between the Davis and Barilla Mountains and in a number of localities underneath the lava in the Barilla Mountains. The Pierre strata are greenish-gray calcareous clays, weathering greenish-yellow and containing *Exogyra ponderosa* and other fossils.

Late Cretaceous Diastrophism

Sometime after the deposition of the Pierre formation and before the outbreak of volcanic activity, the lower and upper Cretaceous rocks were folded, faulted and eroded in the region of the Davis and Barilla mountains. The axes of deformation were directed northwest-southeast. The Cretaceous rocks often dip in directions opposite to the dips in the overlying volcanics, the latter having been deformed at a much later date. The volcanics rest unconformably at different places on all the Upper Cretaceous rocks and on all the younger Comanchean Cretaceous rocks of the Washita and Fredericksburg divisions. The later Cretaceous diastrophism appears to have been confined to the region of the Davis and Barilla mountains, only extending to a few miles south of the line of the Kansas City, Mexico and Orient Railway. In the Delaware-Guadalupe Range a broad uplift may have occurred at the same time but there is no evidence of folding and faulting.

The age of this deformation may be Laramide, but no definite evidence of Laramide diastrophism is yet certainly known south of the latitude of Las Vegas, New Mexico. West of Lampazos, in the State of Nuevo Leon, Mexico, in the Mesa de los Cartinjanos, Dr. Böse reports that the Upper Cretaceous, including the Pierre, is strongly folded and unconformably overlain by flat-lying Navarro (Ripley or Fox Hills) strata. The deformation in Nuevo Leon is therefore older than Laramide. In the Chisos country, according to Udden, there is apparently no unconformity between the Pierre and overlying later Cretaceous sediments. The same conditions of conformity are reported by Vaughan in the San Carlos coal field of the Tierra Vieja mountains region farther west. East of the Chisos country and at the east base of the Sierra del Carmen basaltic lava unconformably overlies upper Comanchean strata. This implies the erosion of all the upper Cretaceous before the outpouring of the basalt. This basalt may, however, be later in age than the other volcanic rocks of the region.

The Late Cretaceous—Early Tertiary Volcanic Epoch

The late Cretaceous folding and faulting in the Davis and Barilla mountains was followed by a long epoch of erosion during which the entire Front Range region was a land area. Then volcanic activity on a large scale began and covered the greater part, if, indeed, not all, of the region with flows of lava. These lava flows are found today in great development in the Davis and Barilla mountains, in the region westward from the Mt. Ord Range to Sierra Blanca and southward far into Mexico. Small remnants of volcanic rock northeast of the Barilla Mountains and east of the Santiago Range and Sierra del Carmen show that the lava once covered a much greater territory than now. When the volcanism began the region probably had both a wetter and warmer climate than at present for leaves of palms are found in the basal volcanic tuffs in the Barilla Mountains, which tuffs unconformably overlie clays of Pierre Cretaceous (Upson clay, Taylor marls) age. Silicified logs of trees, some of which are three feet in diameter, are found in a "fossil forest" which grew on upper Comanchean limestone four to five miles northeast of the Duncan ranch house, north of the Davis Mountains. The epoch of erosion following the marine deposition of the Pierre Cretaceous was a very long one, since in most places the lavas rest upon upper Comanchean strata. Nearly all of the Upper Cretaceous rocks were removed by erosion during this interval around the north and east sides of the Davis and Barilla mountains, east of the Mt. Ord Range from Altuda Mountain southward to Elephant Mountain, and east of the Sierra del Carmen. The lavas rest on strata of Benton, Niobrara, and Pierre Cretaceous age at various places in the Barilla Mountains, between the Barilla and Davis Mountains, in the vicinity of the McCutchin ranch houses in Limpia Canyon, between Limpia postoffice and Wild Rose Canyon, and east of the line of the Kansas City, Mexico and Orient Railroad in the locality from six to eight miles north of Strobel siding on the Southern Pacific Railroad. It is probable that in the vicinity of Alpine the lavas rest on the Benton Cretaceous, for a blue shale resembling the Benton is reached in wells there.

The igneous rocks are mostly lavas but tuffs, tuff-breccias, tuff-agglomerates, and tuff-conglomerates are interbedded with the rhyolite lavas, and many intrusive rocks occur, very often in places where no lavas are now found. Rhyolite lavas are especially abundant in the Davis and Barilla Mountains. Near the mouth of Madera Canyon the rhyolites and interbedded tuffs have a thickness of at least 2,000 feet. Trachytes and phonolites appear to be the most abundant lavas in the region west of the Mt. Ord Range where, however, are also rhyolites. Only basaltic lavas are found in the region east of the Sierra del Carmen and west of the canyon of the lower Maravillas Creek. In most, but not all, places in the Davis and Barilla mountains, volcanic activity began with explosions, beds of tuffs being first deposited. It is probable that these basal tuffs originally covered practically the entire territory, but in some places they were washed away by erosion before the coming of the lava flows. These tuffs often contain stream-transported pebbles of rocks older than the lavas. The pebbles are generally small in the basal tuffs. The basal tuffs seldom contain coarse fragmental or pyroclastic materials blown out of the volcanoes, but they often contain fine lapilli. The basil tuffs are often finely laminated. So far as known the basal tuffs contain less quantities of water-transported pebbles than the tuffs higher up in the volcanic series. They are whitish, buff, light green, pink, or blue in color.

The tuffs, tuff-breccias, tuff-agglomerates, and tuff-conglomerates higher up in the volcanic series contain more coarse pyroclastic and water-transported conglomeratic material than the basal tuffs. Some of the pebbles in the higher volcanic series are six inches or more in diameter and were deposited by streams in the intervals between lava flows. The damming of drainage courses by the lava flows formed lakes in which fresh-water limestones containing *Planorbis* and other fresh water gastropods were deposited. A large amount of very coarse pyroclastic material was noted along the middle course of Madera Canyon in the Davis Mountains, in the vicinity of Paisano Pass, and other localities.

The volcanoes or fissures from which flowed the great volumes of rhyolitic lavas have nowhere been found and in most cases have probably been covered by later lavas or else the syenitic plugs of later age may in some cases occupy the sites of the older rhyolitic volcanoes. Dikes of rhyolitic facies occur in the southern Davis Mountains and in the vicinity of Alpine and Paisano Pass. Felsitic lavas and obsidian are in some places interbedded with the rhyolites in the Davis and Barilla mountains.

A syenitic plug has domed up the rhyolitic lavas at a point a short distance west of the Alpine-Fort Davis road where it enters Musquiz Canyon. The intrusive syenite forming the summit or Sawtooth Range of the Davis Mountains appears to be along a line of volcanoes or of fissure eruptions. Iron Mountain, north of Marathon, is a plug of syenite-porphyry and several dikes and sills, apophyses of this plug, occur north, east and south of Iron Mountain. A plug-like mass of syenitic rock on the north side of Altuda Mountain is responsible for a contact-metamorphic deposit of hematite along the intrusive contact with the Word Permo-Carboniferous limestone. A similar contact metamorphic deposit of hematite occurs at the contact of a syenitic intrusive with the Leonard Permo-Carboniferous limestone on the northeast side of Leonard Mountain. Two laccolites of syenitic rock occur in the Ord Mountain Range, west of Captain James's ranch house. The eastern of these is a typical laccolite, which has domed up the Leonard Permo-Carboniferous formation. The western one has broken through the Permo-Carboniferous and Comanchean more like a plug. The pulaskite of Santiago Peak and other mesas in the vicinity appears to have formed a thick sill from the top of which the Cretaceous rocks have been removed by later erosion.

The basic rocks noted by the writer all occur east of the Santiago Range and the Sierra del Carmen. Between the latter range and the canyon of the lower Maravillas creek is a flow of highly vesicular basalt. North of the basalt flow, in the region between the head of the canyon of the lower Maravillas and the Marathon basin, are a considerable number of small intrusions of basic rocks, which were not examined by the author but were mapped by Mr. W. F. Bowman. Some of these are certainly plugs.

Chemical analyses made include thirty-eight analyses of rocks made in the laboratory of the Bureau of Economic Geology, three analyses made in the laboratory of the United States Geological Survey, and three analyses given by Osann and made in the laboratory of Heidelberg University, Germany.* These analyses show that all of the rocks of the region are deficient in magnesia, even including some of the more basic rocks. In all but nine of the analyses, soda is in excess of potash.

Osann* gives the order of the volcanic eruptions as follows: first, basalt; second, rhyolite; and third, trachytes and phonolites. He found a basalt flow underlying the rhyolites in Limpia Canyon near Fort Davis. The oldest lava found by the present writer occurred at the base of the syncline of volcanics north of Limpia Canyon. This appears to be an orthoclase-oligoclase trachyte, with typical trachytic structure with alkali-calcic feldspars (orthoclase predominant) and about one-eighth magnetite. The amygdules are lined with a green mineral finely fibrous, with fibres perpendicular to the walls, which is probably

*Beiträge zur Geologie und Petrographie der Apache (Davis) Mtns., West Texas. Tschermak's Min. und Petr. Mitthl., vol. 15, pp. 394-455.

chrysophrase. The basic rocks east of the Sierra del Carmen and the Santiago Range are likely the oldest igneous rocks noted by the writer, but their relationships to other igneous rocks are not known.

The fossil leaves found in the basal rhyolitic tuffs overlying unconformably the Pierre Cretaceous in the Barilla Mountains were submitted to Prof. E. W. Berry of Johns Hopkins University, who reports as follows:

"The most abundant leaves in the collection are those of *Oreodaphne pseudoguianensis Berry,* a Wilcox type. A few forms, not so certainly identified, I have referred to *Mespilodaphne puryearensis Berry,* another Wilcox type. The third form identified with a previously described form, is *Juglans rugosa Lesquereaux,* a basal Eocene form of the Rocky Mountain region, occurring in the Raton and Denver formations, and at Evanston, Black Buttes, etc. The remainder include the very abundant fragments of a large fan palm (*Sabalites*), which I hesitate to name specifically, since they are almost impossible to determine with precision, and occur in this general region throughout the late Upper Cretaceous, Eocene and Oligocene. The Barilla form, however, suggests what Lesquereaux called *Flabellaria Eocenica* from the Raton formation. There are, in addition, two specimens of what appears to be a new species of *Quercus* and some fragments of a feather-veined palm of the genus *Geonomites,* also apparently new, but possibly represented in the recent collections from the Raton formation since I know the genus is abundant there. *Geonomites* (a different species) occurs in the Upper Cretaceous of southwestern Texas and is especially characteristic of the Raton and Denver formations, in which there are several species.

"Thus you see your tuffs appear to be of the same age as those disputed horizons along the Rocky Mountain front which I would call Eocene but which you, judging by your remarks on vertebrate bones, will probably consider Upper Cretaceous. The Barilla tuffs appear to be rhyolitic while those of the Denver are chiefly andesitic, but I don't suppose that makes any difference. There is the additional possibility that they are contemporaneous with the great orogenic activity that marks the boundary between the Fort Union and true Wasatch, since the

Wilcox plants indicate a later horizon than the Raton. I shall certainly call the plants Eocene if I describe them, as I may do, later on.''

In the Chisos country, Udden found volcanic tuffs in strata of Navarro Upper Cretaceous age. In the Tierra Vieja Mountains the rhyolitic lavas (quartz-pantellerite) rest on the San Carlos coal series, which overlie Pierre strata. In Uvalde and Travis counties, Texas, basalts and phonolites intrude Taylor marls of Pierre age.

Physiographic Features Characteristic of the Arid Climate.

The two most striking physiographic facts presented by this region are (1) that the structures produced by the latest deformation determine in large part the present orography, and (2) that a great amount of subaerial denudation has taken place since the latest deformation.

The slow, almost imperceptible erosion of running water, aided by the abrasive force of the rock fragments transported; the action of gravity on steep slopes causing the rocks exposed to slowly slump or roll down; the undermining of the more resistant cliff-forming rocks by the removal of less resistant rocks beneath; the shattering caused by unequal expansion and contraction of heterogeneous materials under comparatively rapid changes of temperature working on bare rock surface of an arid and high mountainous region; the joints, faults and minute cracks already present in the rocks, caused by earth movements, and permitting more rapid weathering and erosion; the removal of finer clay particles by the almost incessant wind; together with on the whole a relatively subordinate amount of chemical decomposition: all have combined their forces and aided in fashioning form and feature of the landscape.

In the more humid regions chemical weathering, or decomposition is relatively of great importance; in the desert decomposition is relatively of little importance and mechanical weathering or disintegration and corrosion are the great factors in rock destruction. It is probable that for slopes of equal steepness and equal amounts of water, transportation in the desert is greater than in humid climates, because in the desert there is more disintegrated material ready for transportation, less plant growth to inhibit or check wash, and more concentration and erosion force to rainfall. Observers familiar with both regions would probably agree that there is a greater amount of erosion now taking place in the western and more arid half of the United States than in the eastern and more humid half, but the general gradient of the land surface is of course steeper in the west than in the east.

There is also a greater amount of deposition taking place on subaerial surfaces in the desert than in regions of humid climate. This is demonstrated by the greater importance of alluvial debris fans in the desert. The causes of deposition of fan material, which forms at places where steep slopes give way to gentler ones, are lowering of gradient, distribution of the stream water over a larger surface, and evaporation and absorption of the water. A larger proportion of the stream water is evaporated in the dry atmosphere and absorbed by the dry soils of the desert; and these are causes for the greater development of alluvial fans in an arid climate.

The nature of the erosion is similar in this region to that in the enclosed basin areas farther west, but the amount of deposition on the lower land surfaces in our region can by no means compare with that of enclosed basin areas. For all our region has exterior drainage to the sea, and much of the transported material is carried away by the Rio Grande.

Alluvial fans are being dissected here as they are in the Great Basin.* The causes of this have been noted by the writer in a previous paper** and will not be repeated here. But the writer is now inclined even more than formerly to attribute the deep, steep-sided trenches cut in unconsolidated debris fan material to the work of cloudbursts, which are a common form

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*For some of the causes of this dissection not considered here see Udden, J. A., Sketch of the Geology of the Chisos Country, Brewster County, Texas. Bull. No. 93, Univ. of Texas, 1907, pp. 9-15.

**Notes on the Later Cenozoic History of the Mohave Desert Region in Southeastern California. Univ. of Cal. Publ., Bull. Dept. Geol. Vol. 6, No. 15, 1911, pp. 371-377.

of rainstorm in these arid regions. Concerning the action of cloudbursts, Gilbert in his Lake Bonneville monograph writes as follows:

"As in other desert regions, precipitation here results only from cyclonic disturbance, either broad or local, is extremely irregular, and is often violent. Sooner or later the 'cloud-burst' visits every tract, and when it comes the local drainage-way discharges in a few hours more water than is yielded to it by the ordinary precipitation of many years. The deluge scours out a channel which is far too deep and broad for ordinary needs and which centuries may not suffice to efface. The abundance of these trenches, in various stages of obliteration, but all manifestly unsuited to the every day conditions of the country, has naturally led many to believe that an age of excessive rainfall has but just ceased—an opinion not rarely advanced by travellers in other arid regions."—Page 9.

The sun temperature in the dry atmosphere often becomes very hot during the hours of midday, and rocks, especially the darker-colored ones, become quite hot. At night the rocks rapidly lose by radiation the heat they have absorbed during the day and strains are set up in those composed of different minerals with different co-efficients of expansion, which are often sufficient to disrupt the other portions. Von Streeruwitz tells of hearing rocks in this region burst at night with loud reports.* A rock composed of homogeneous material like limestone, which is rather easily destroyed by chemical weathering in a humid climate, here in the desert becomes one of the most resistant rocks and forms topographic prominences.

The finer products of weathering are either blown away by the wind or washed away by the rain-water and the coarser blocks are left where they have weathered or fallen and rolled. These fragments of rocks, so hard as not to be easily worn away by abrasion, so large that they cannot be transported either by wind or water, or so resistant to decomposition that they are not easily dissolved, form the "desert pavements". Their surfaces and the surfaces of bare rock in cliffs are often coated with the

*Trans-Pecos Texas, 4th Ann. Rept. Geol. Surv. of Texas, 1893, pp. 143-146.

"desert varnish" of brown or black color, composed of manganese and iron hydroxides.

The most abundant substance carried in solution in the waters is carbonate of lime. The shallower underground waters carrying this and other substances in solution are brought to or near the surface by capillary action, there evaporated and the mineral matter carried deposited as a cement, binding together the rock fragments. This cementing substance, mainly composed of carbonate of lime, is called "caliche", "tepetate", or "terra alba".

Cliffs are often sharper in contour in the desert than in a more humid climate, but this sharpness is perhaps even more largely characteristic of certain kinds of rocks than of different climatic conditions. Lack of soil covering gives a rugged surface to the highlands while the contours of the lowlands are smoothed out by deposits of debris.

Physiographic Features Characteristic of the Nature of the Rocks

Five different types of rocks in this region weather into as many different erosion forms. These five different types are (1) the intrusive igneous; (2) the lava flows; (3) the pyroclastic igneous (tuffs and coarser fragments produced by volcanic explosions); (4) the more resistant sedimentaries, comprising the Paleozoic and Cretaceous limestones and the Caballos novaculite; and (5) the less resistant sedimentaries, comprising shales, clays, gravels, sands, sandstones, marls, and the thinner-bedded cherts. All these rocks, with the exception of the limestones (which are more resistant in arid climates) are eroded much the same under any climatic condition.

It is not intended here to give a general description of the weathering forms produced on these different classes such as may be found in almost any textbook of geology but only of such features as aid in explaining the physiography and make up the more striking features of the landscape. The intrusive igneous rocks, the lava flows, and the massive limestones and Caballos novaculite are more resistant to weathering and erosion than the other rocks and so form the topographic prominences.

The intrusive igneous rocks weather with rounded contours and these contours are most rounded in those rocks which are wholly made up of crystal forms visible to the unaided eye. The most coarsely crystalline rock in this region is found in a laccolith in the northern Mt. Ord Range some three miles west of Capt. James's ranch house, which weathers in rounded knobs like a granite. The thick sill or laccolith forming Santiago Peak is a porphyry with a finely crystalline groundmass, which weathers with angular faces and sharp edges much like a lava. The porphyritic syenites of Iron Mountain (Plate IV), and the Sawtooth Range of the Davis Mountains weather in somewhat more angular shapes than the laccolith west of Capt. James's and the Santiago Peak rock, but their crystals are intermediate in size and degree of development between these two extremes.

The intrusive igneous rocks are much jointed, they weather more rapidly along the joints, and so form irregular-shaped blocks resembling rude masonry. The perpendicular or nearly perpendicular joints often give rise to precipitous cliffs.

In Iron Mountain, north of Marathon, two forms are assumed by the porphyritic syenite. The southern part of the mountain is rounded in outline and shells off (exfoliates) in concentric sheets. (Plate IVb). The northern part of the mountain has more conspicuous perpendicular joints and the most conspicuous weathering forms are pinnacles and spires, also present in Sawtooth Mountain of the Sawtooth Range.

The porphyries with phenocrysts of sanidine and nepheline weather with pitted surfaces. The pits were once filled with these more soluble minerals, which have been dissolved out.

The lavas weather with flatter faces and sharper edges than the intrusive igneous rocks. The more massive and thicker flows form escarpments of dark-colored rim rocks, especially at the edge of the Davis and Barilla Mountains, the country between Alpine and Marfa, and at the edge of the lava flow from Mount Ord southward to Elephant Mountain. The upper surfaces of the lavas form mesas when they are horizontal or nearly so, and cuestas when they are tilted. The scarps rimming the lava-covered surfaces are formed in the same way as the erosion scarps of the heavy-bedded limestones. The underlying tuffaceous and fragmental volcanic material or underlying non-resistant sedimentary rocks are more easily removed by the action of running water and their removal removes the support for the overlying lava which thereupon fractures along joint cracks and falls or slumps down the steep slope. Many such landslides or slumps are seen near the edges of the lava escarpments or along the walls of canyons, producing hummocky surfaces and small undrained depressions on the gentler slopes below the cliffs and often completely covering the underlying rocks.

The soda-trachyte of Elephant Mountain has columnar structure, produced by contractional cracking when the lava cooled, and forms cliffs at its edges made up of long vertical, many-sided columns. (Plate IVa).

Joints in the lava absorb most of the rainwater falling on the flattish surfaces. Consequently few drainage channels have been cut through the lava mesas and more gently sloping cuestas. By far the greatest amount of denudation in any region except an absolutely rainless desert is accomplished by running water. So here the flatter surfaces of the original lava flows have persisted throughout entire Cenozoic time and the broad flats of the lava-covered regions remain today much as they were when the lava first solidified.

The water absorbed by the lavas in the Davis Mountains region seeps downward through the rocks until its further progress downward is checked by non-porous beds. At the junctions of the impervious rocks below and the porous tuff bed which generally underlies the lowest lava flow the water accumulates and escapes as springs at the edges of the lava escarpment and where the canyons have cut as deep as the basal tuff bed. So it is that the Davis Mountains rims and deeper canyons have more springs than other portions of the region. These spring waters are on the whole quite pure because little soluble mineral matter can be dissolved by the water in its passage through the lavas and tuffs.

The process of gradual recession of the lava cliffs is slow but the cliffs will always be steep until all of the lava is finally removed by erosion. All of the country not protected by the lava capping can be reduced to a low and featureless plain while steep lava cliffs remain, and the upper surfaces of the lava still preserve their original flatness. So far as we know, the entire region aside from the lava and limestone mesas may have been reduced to a peneplain before the last folding forming the present mountains took place. Above such a flat and featureless peneplaned surface the lava and more resistant limestone plateaus and mesas would still persist as monadnocks and rise in steep escarpment cliffs above their peneplaned surroundings. Such a lava surface can only be destroyed by the slow undermining of its rims, for wind abrasion plays only a subordinate part even in a desert such as this. There is no erosion process operating on the flat lava surfaces except extremely slow solution and wind abrasion. Exfoliation of course was operative for a time when the lavas were young but it was soon checked and finally practically stopped by a surface accumulation of angular disintegrated blocks too large to be removed by the wind. These made a surface even more porous to rainwater, and thus aided in preventing the formation of surface drainage channels.

The upper surfaces of the heavy-bedded limestones, particularly the Edwards-Georgetown and the Vidrio (Permo-Carboniferous or Permian), have been preserved throughout the Cenozoic much as have the lava surfaces. The limestone is an even more porous rock than the lava, and the process of exfoliation operates little on it because it is a homogeneous material composed of a single mineral. The less resistant strata overlying these heavy limestones were removed early in the Cenozoic erosion epoch from all places where they occupied topographic prominences. The Edwards-Georgetown was immediately overlain by the Del Rio, which contains a large amount of clayey material impervious to the passage of water. The Del Rio is thin and flaggy-bedded and hence comparatively little resistant, especially to the erosion of running water. But when once the Del Rio became removed from the underlying Edwards-Georgetown, downcutting by the corrosion of running water became greatly inhibited or even checked because the water was absorbed by the Edwards-Georgetown limestone. A few of the larger streams with greater water supply did persist and are today the antecedent streams of the region. But even they must have lost a very large proportion of their waters by seepage when they crossed these limestones. It is of course true that the limestone is one of the most soluble rocks of the region, but it has been already pointed out that solution is a relatively unimportant process as compared with mechanical erosion processes, especially in desert regions. The limestones have a rough, grooved and pitted (Karst) surface here, but this is only a very minor feature. Limestone sink-holes also occur and a couple of underground erosion channels with their floors covered with water-worn pebbles were found in the Comanchean limestone in the vicinity of Phantom Lake, north of the Davis Mountains and south of Toyahvale.

The St. Solomon Spring at Toyahvale, the spring at Phantom Lake, and the Comanche and Leon Springs at and near Fort Stockton, reach the surface through limestone beds and are either fissure springs rising on fault lines or springs rising in solution channels in the limestones. The great limestone areas of the region, such as the Glass Mountains, the Sierra del Carmen, the area covered by the Edwards-Georgetown east of the Carmen Range and east of the Marathon Basin, and a number of other areas have the more barren surfaces supporting only the most drouth-resistant vegetation. These limestones have bare rock surfaces, all soil materials being removed as fast as formed by the wind and the rain. The moisture that falls is quickly absorbed by the limestones so no moisture is afforded to support any but the most drouth-resistant plants. The lack of a thick cover of vegetation leaves nothing to hold the finer products of rock weathering, so no soil can be formed either to hold moisture or support the growth of any but the hardiest types of vegetation, which manage to get their roots down cracks and crevices and through the softer portions of the limestone.

There is no hope of getting well-water in these regions until the drill penetrates the entire thickness—often too great to drill through—of the limestones and strikes an impervious stratum somewhere beneath. In the great monoclinal cuestas all the water absorbed by the limestones is carried away down the dip to contribute to the underground water supply of some other region. So it often happens in these regions that the strata which are the good carriers of underground water have carried it all away to some other region.

A large number of the "tinajas" or small surface water-holes are either potholes formed by erosion at the base of falls or rapids along the stream courses, or else they are shallow cavities formed by solution often somewhat aided by wind erosion, in the less consolidated portions of the limestones. In the limestone regions these are often the only places where any naturally accumulated water can be found. In most of them the water entirely evaporates within a few hours or a few days after the rain.

The limestone cuestas and mesas are being destroyed only by the slow process of cliff recession, just as the lavas. Therefore they can persist even until the very end of a cycle of erosion. Now it is precisely because these limestone and lava surfaces are the most resistant rocks of the region that they form today the only remains of the old surface which existed at the time the latest mountain-forming movements, which are responsible for the present mountains, began. They were the surface rocks of the region when they were folded and so they give us excellent data as to how competent surface rocks behave under deformation. But unfortunately they tell us little of the stage of development of the general erosion surface at the time the mountain-making movements began their work. Their original surfaces could have been preserved throughout the entire erosion cycle from youth to old age. All the definite information now afforded us by the stage of erosion reached in a cycle lasting practically throughout the Tertiary is afforded by the meandering courses, now intrenched, of the antecedent streams of the region. Such meanders are not developed in young stream valleys but only in mature old stream valleys. The general stage of erosion reached in the Tertiary cycle of erosion may have ranged anywhere from late youth to late old age. No Tertiary deposits are known in Trans-Pecos Texas and it is now certain that no wide spread ones occur there. It is therefore most probable (1) that the entire region had exterior drainage to the sea throughout Tertiary time and (2) that the Tertiary was entirely a time of erosion in Trans-Pecos Texas. The whole extent of Tertiary time is certainly long enough for the development of a peneplain. But whether such a peneplain had been formed near the close of the Tertiary is yet a matter of opinion and not of definite proof.

As a general thing the more resistant limestones alternate with less resistant strata. The more resistant beds form steep, often verticle, much fretted cliffs. Weathering is more effective along points and in more soluble or less compacted portions, and the general effect produced is that of huge stone walls of so ancient a date that they have crumpled into ruins. The less resistant beds form less steep slopes covered with debris from overlying more resistant layers and the whole escarpment or canyon wall gives a buttress effect like that of ruined Gothic architecture.

The minor features in the topography of alternating more resistant and less resistant beds in the Permo-Carboniferous and Comanchean rocks present some noteworthy characteristics. The steep-sided mesa and cuesta escarpments stand out apart from each other, separated by the drainage courses, generally with their lower slopes less steep and more covered with debris. The concavity of the profile of the lower slopes abruptly flattens at the base from which it gently slopes towards the drainage courses, and in the valleys proper changes from concave to convex upward. The lines of the courses of the narrowly and shallowly trenched arroyos are marked by a line of dark green herbaceous vegetation, affording the deepest and most vivid color in the entire landscape. The limestone cliffs are ashy-gray or light buff in color. Flat-topped columns or pinnacles often stand a little in advance of the main cliff walls or are isolated by drainage courses. The valleys are not flat-floored but have considerable relief. But viewed from commanding points above them, they appear flat and featureless. Portions which have slumped along fractures parallel to the faces of the cliffs are sometimes taken at first sight for normal faults of tectonic origin.

The low-lying flat areas are not always developed out of nonresistant rocks. They are often only the places recently uncovered by retreat of higher escarpments. When a number of escarpment-making rocks occur in the same section, the highest ledge has retreated the most, the next highest not so far as the highest but farther than the next lowest, and so a series of benches and terraces is carved out.

Structure and Physiography Produced by the Latest Deformation

All the physiographic and structural subdivisions of the region, with the exception of the Marathon erosional basin, have both structure and physiography produced largely as results of the latest mountain-making movements. Named in order from north to south these subregions are:

1. The Toyah Basin with a general eastward and northeastward monoclinal dip.
2. The Delaware-Guadalupe dome, upthrust on the west.
3. The generally lava-covered mainly synclinal area of gentle folding, extending from the Barilla and Davis Mountains to the Big Bend of the Rio Grande.
4. The Marathon Dome, with steepest dips or overfolds on the west side, including the Glass, Mt. Ord and Santiago mountains.
5. The Trans-Pecos Plains east of the Marathon Dome and Sierra del Carmen, gently folded near the mountains on the west and with gentle eastward and southeastward monoclinal dip on the east.
6. The Sierra del Carmen Dome with a series of upthrusts on the east flank in Texas and on the west flank in Coahuila.

The Delaware-Guadalupe and the Sierra del Carmen domes are elliptical in ground plan with their longer axes trending northwest-southeast.

The Toyah Basin

The Toyah Basin, as named by R. T. Hill, comprises a broad basin-like area in northeastern Trans-Pecos Texas and southeastern New Mexico. Its natural boundary on the northeast is the southwestern erosion escarpment of the Llano Estacado, running parallel with and a short distance east of, the course of the Pecos River. On the west it is bounded by the Delaware and Guadalupe Mountains, on the southwest by the Davis and Barilla mountains, and on the south by the Comanchean rocks of the Trans-Pecos Plains (Stockton Plateau of Hill). The greater part of its broad flat surface is covered with an unconsolidated or caliche-cemented mantle of Quaternary alluvial debris derived from the erosion of the mountain bounding it on the west and southwest. It is underlain for the most part by Permian clays, limestones, sandstones, salt and gypsum, covered locally by outliers of Washita Comanchean. In the southwest portion the Comanchean rocks are found in greater amount and it is probable that some Upper Cretaceous rocks are also present, for instance, northwest of Toyahvale.

The Toyah Basin appears to be mainly a physiographic and not a structural basin. It is really the southwest portion of the great Llano Estacado geosyncline and is monoclinal in structure with a general dip eastwardly towards the Pecos River. Along its western and southwestern margins are a number of low folds, with their axes parallel to the axes of the mountains. A number of these folds which have been stripped of their former covering of lava occur in the country around Toyahvale, northeast of the Davis and Barilla mountains. Another was noted just east of where Limpia creek crossed the farthest eastward extension of the Davis Mountain lava flow. Another runs in a general eastward direction from mile-post 925 of the Kansas City, Mexico and Orient Railroad. The last two anticlines may possibly have been formed by the late Cretaceous deformation.

The Toyah Basin has been formed by the erosion of the little resistant Permian and Washita Comanchean rocks, effecting a local base-level along the Pecos and its tributaries. The resistant Edwards-Georgetown limestone is reached by the down-cutting of the Pecos River at a point near the Pecos-Terrell county line and the inhibition of erosion by this resistant formation, by checking the rate of down-cutting, has allowed the formation of a local base-level above this point.

It is as yet impossible to say whether or not any anticlinal fold of domical structure crosses the course of the lower Pecos between the points where it is crossed by the Kansas City, Mexico and Orient and the Southern Pacific railroads. In the vicinity of Sheffield, Pecos County, and of the Orient Railroad bridge the Comanchean appears to be very nearly horizontal.

So far as is known, no geologist has ever explored the canyon portion of the lower Pecos from the Pecos-Terrell county line to the mouth of the river. Folding athwart of the Pecos in this region during the latest deformation would have undoubtedly aided in the formation of the Toyah Basin.

The Balcones faulting has almost certainly aided in the formation of the Toyah Basin and the canyon of the lower Pecos, as it has in the formation of the canyon of the Rio Grande between the mouths of San Francisco Creek and the Devil's River. The canyons in this portion of the Rio Grande, on the lower Pecos and on the lower Devil's River, are extremely tortuous and deeply intrenched. Now, however resistant the Edwards-Georgetown limestone is in the regions of these canyons—and we have already noted that it thickens greatly in going southward towards the Rio Grande—it is entirely out of the question for these deep, narrow, and tortuous canyons to have persisted throughout most of the Cenozoic. Hence, one is practically forced to conclude that at least that much of the Balcones faulting as is responsible for the present Balcones escarpment must have occurred near the end of the Tertiary and that the canyons have been cut since that date.

The downthrown portion of the Balcones fault is the southern block, mainly of Upper Cretaceous and Tertiary rocks. There are three possible movements causing the faulting: (1) the southern block settled downwards; (2) the northern block rose; (3) the southern block moved downward simultaneously as the northern block moved upwards. Any one of these movements would explain the formation of the canyons of the Rio Grande, Pecos and Devil's rivers.

The next question is whether the canyons were developed by headward erosion of streams which came into existence after the faulting or by antecedent streams the courses of which were in existence before the faulting. If the streams were antecedent and the northern or upthrown block actually rose in altitude, the canyons cut in the upthrown block would be cut all along their antecedent portions simultaneously (that is, as the uplift progressed). If the streams were antecedent and the northern or upthrown block remained stationary, the southern or downthrown block having moved downward, canyon-cutting would begin first only along the southern margin of the fault and gradually work headwards and the portions of the valleys near the fault lines would be older and broader than towards their headwaters; provided that the same resistant rock was found throughout the canyons, as it is in this case. Streams coming into existence after the faulting and gradually extending their courses by headward erosion into an uplifted northern upthrown block would behave as antecedent streams in the last-mentioned case. But the intrenched meander-like canyons would not develop by normal headward erosion in a valley cut out of rock of homogeneous resistance. Furthermore, the lower canyon portions seem to have reached no greater stage of development, that is, they do not appear to be older, than the upper canyon portions.

The valley of the headwaters of the Devil's River is much broader, much shallower, and at first sight looks much older, than the lower canyon valley. But the older appearance of the upper valley may be deceptive. In the first place, it is cut out of less resistant Comanchean rocks of probably later age than the Edwards. And in the second place the down-cutting of the valley lower down is inhibited by the superior resistance of the Edwards where the stream crosses that formation, permitting more side-cutting and less down-cutting above the resistant barrier and thus allowing an older-appearing valley to develop. There is nothing to indicate that the upper valley may not really be older in point of age, but on the other hand, these two factors make it difficult to definitely prove it without further data.

One can hardly escape the conclusion, furthermore, that the Rio Grande is a very old river. Its upper course in southern Colorado seems to have existed as long ago as the Eocene and either the Rio Grande or a stream occupying nearly the same course was supplying sediments to the Rio Grande embayment throughout the Cenozoic. If one accepts as antecedent the course of the Rio Grande between the mouths of San Francisco Creek, and the Devil's River, it looks extremely probable that the lower canyon courses of its tributaries, the Pecos and Devil's rivers, are antecedent also. So it is altogether most probable that all three of these canyons are antecedent.

We will now return to the question of the origin of the Toyah Basin. If the original Gulfward dip of the Comanchean of the southeastern Trans-Pecos Plains and the western Edwards Plateau was lessened in amount by an upward movement of the north block of the Balcones fault, it is probable that the greatest amount of upward movement occurred in juxtaposition with the fault plane at the southern margin of the northern block and that the amount of movement somewhat gradually decreased toward the north. The river, confronted with a gradual rising of the country to the southward by movements of the Balcones faulting, would be forced to expend most of its erosive energies in cutting down its channel to keep pace with the gradual rise of the country in its path. Until the channel of the lower portion was considerably lowered not much progress could be made in lowering the barrier in its path beginning where it first entered the resistant Edwards. As long as that barrier was not lowered the channel of the river above the barrier would more and more tend to approach a base-leveled condition and this approach to a base-level would permit the formation of the Toyah Basin. If the lower Pecos is antecedent, the development of the Toyah Basin by erosion would have taken place before, during, and after the Balcones faulting. But if the lower canyon portion of the Pecos has been entirely cut by headward erosion since the time of the faulting, erosion of the lower levels of the Toyah Basin would have ceased until the headwaters of the newly-formed stream had reached back and entered the Toyah Basin.

We as yet know nothing of the age of the sediments forming the southern portion of the Llano Estacado. We do know they were deposited by streams flowing eastwards from the Cordilleras, probably in later Cenozoic times. And we know that when the Miocene, Pliocene and Pleistocene sediments of the northern Llano Estacado were deposited, by streams flowing eastward from the Cordilleras, the middle Pecos in its course through southeastern New Mexico could not have been in existence.*

*Geology and Underground Waters of the Northern Llano Estacado, by C. L. Baker, Bull. Univ. of Tex., 1915, No. 57.

The alluvial debris covering most of the surface of the Toyah Basin, and derived from the erosion of the mountains to the west, was begun to be deposited only upon the beginning of the last deformation of the Trans-Pecos Cordillera. Erosion of the lower portion of the Pecos Valley may have been taking place when the alluvial debris was being laid down on the western and higher portions contiguous to the mountains. But if the deposits of older alluvial debris of the Toyah Basin were contemporaneous with those of the southern Llano Estacado the Pecos River of northern Trans-Pecos Texas had not yet come into existence. It is of course possible that the lower canyon portion of the Pecos River was the entire course of the river at the time of the Balcones faulting—that is, was antecedent to that faulting—and that in only comparatively recent years, by headward growth, it has come to drain the Toyah Basin.

It appears that we have not yet enough evidence to satisfactorily solve the problems raised above. The writer will, however, state his personal opinion that the canyon course of the Rio Grande between the mouths of the San Francisco Creek and Devil's River and the lower canyon sources of the Pecos and Devil's rivers are antecedent to the Balcones faulting that has made the present Balcones escarpment; and that the Balcones faulting producing the present escarpment occurred at nearly the same time—if it was not contemporaneous—as the latest deformation of the Cordilleran Front Range in Trans-Pecos Texas. It is almost absolutely certain that much smaller streams than the Pecos, Rio Grande and Devil's River—in fact, tributaries of the Rio Grande and Pecos—did preserve their antecedent course at this time across whole mountain ranges uplifted athwart their paths. These will be described in the sequel. And the physiographic development of the Pecos, Rio Grande and Devil's River canyons is the same as of these almost certainly antecedent canyons crossing the Front Range and, in fact, they have been developed in the same rocks.

The Delaware-Guadalupe Dome (Southern End)

The long axis of the Delaware-Guadalupe dome trends in general from 10° to 20° west of north. Most of this mountain mass appears to be a gently eastward-dipping monocline.* It is perhaps more accurate to call the general structure an elliptical, unsymmetrical dome, with much greater dip on the western than on the eastern flank. In fact, much of the west flank is perhaps formed by an upthrust fault, along which the mountains have arisen east of the Salt Basin. Only the southern portion of this dome, or that portion lying south of the Texas and Pacific Railway, falls within the scope of this paper.

The escarpment of a southward dipping cuesta of Washita Comanchean limestone, underlain by calcareous marls, rises from one half to two miles south of the Texas and Pacific Railway from five miles west of Boracho section eastward to beyond Kent. The strike of the Washita beds is here practically east and west, and the southward dip is about 2°. This cuesta is separated from the northern lava escarpment of the Davis Mountains by an alluvium-covered valley under which the Benton (Eagle Ford) shale probably lies, since Niobrara (Austin) chalk was found underneath the lava at the Reynolds (X) ranch at the mouth of Adobe Canyon.

South of Kent Station the strike in the Washita Comanchean beds changes to northeast and there is a syncline with northeast axis running at right angles to the Front Range folding in this vicinity. This cross-fold may be taken as the southeast corner of the nearly square-ended southern limb of the Delaware-Guadalupe dome. At the northeast end of the cross-fold and just south and east of Tatum's ranch is an area of probably intrusive igneous rock. This lies about six miles south of southwest of San Martine section-house. In the vicinity of San Martine the Washita Comanchean rocks are folded into low anticlines and synclines with their major axes running north-northwest.

About four miles south of the Texas and Pacific Railway at a point about midway between Boracho and Plateau section-houses there is a low syncline with its major axis running about N 15° W. This syncline is really a portion of the western flank of the Delaware Mountains dome. About one half mile east of this

*Richardson, G. B., Report of a Reconnaissance in Trans-Pecos Texas, Bull. Univ. of Texas. Mineral Surv., 1904, pp. 53-55, and Van Horn Folio, U. S. Geological Survey, 1914, p. 7.

syncline is a small outcrop of igneous rock. Two miles south the Washita Comanchean dips 9° in about a N 10° E direction.

The two synclines above noted, one at the east and the other at the west end of the southwardly-dipping cuesta of the Washita, mark the southeast and the southwest corners of the broad, almost square-ended Delaware-Guadalupe dome. Gently folded Washita Comanchean beds with their longer axes northwest-southeast, flank, on both east and west, the flat which is probably underlain by Benton between the northern lava escarpment of the Davis Mountains and the Washita cuesta south of Kent and Boracho.

Lava-covered Area of Davis and Barilla Mountains

The Davis and Barilla mountains as far south as the latitude of Fort Davis, are a part of the Front Range of the Cordillera. The lava-covered areas south of Fort Davis, in the country from east of Strobel siding on the Southern Pacific Railroad westward to beyond Valentine, the lava-covered portion of the Mt. Ord Range and to the westward, and the lava area west of the Santiago Range and west of the Sierra del Carmen all belong to the great synclinal area lying westward of the Cordilleran Front Range and extending from central New Mexico southward to beyond the Big Bend of the Rio Grande. This great synclinal area of lava extends westward as far as the Van Horn, Tierra Vieja, and Chinati mountains. The lava area once extended east of its present limits in the Davis and Barilla mountains but has there been removed by the erosion of Cenozoic time.

The backbone or summit ridge of the Davis Mountains is the Sawtooth Range of intrusive porphyritic syenite which reaches in Baldy or Livermore Peak (8382 feet), the second highest altitude in Texas. From the summit of Baldy Peak one gets the impression that the Sawtooth Range from Blue Mountain, west of Fort Davis, northwestward to Sawtooth Mountain is a broad low anticline with major axis running northwest-southeast. In all probability at the close of the volcanic epoch the intrusive porphyritic syenite of the Sawtooth Range marked a line of volcanoes or of fissure eruptions. The latest deformation appears to have followed the lines of the last Cretaceous deformation and of the later volcanoes of the Sawtooth Range.

A broad synclinal area lies between Sawtooth Mountain and the northern lava escarpment of the Davis Mountains. This is marked by a broad basin south of the canyon portion of Adobe Canyon. The northern escarpment of lava from Gomez Peak westward to Boracho Peak is a gently south-southwestward-dipping cuesta on the south flank of the Delaware-Guadalupe dome. To the northwest lies another anticline which runs southeast from near San Martine section-house on the Texas and Pacific Railway east of Gomez Peak through the Washita and Niobrara rocks southeastward through the summit of Star Mountain, crossing Limpia Canyon about three miles south of Limpia post-office and to the southeastward crossing Horsethief Canyon near its mouth. This anticline is succeeded on the east by a syncline which runs parallel with it and from two to four miles distant from it. The trough of this syncline is covered with lava between Phantom Lake and the mouths of Cherry and Madera canyons. The lava begins on the southeast of the San Augustine ranch and forms the trough of the syncline as far as the divide between Limpia Canyon and Toyah Creek. The headwaters of Toyah Creek between the Davis and Barilla mountains and Limpia canyon from the divide separating it from Toyah Creek east-southeastward as far as the original McCutchin ranch are synclinal valleys in the trough of this syncline. This syncline is the orographic valley which separates the Davis from the Barilla mountains.

The lava flows forming this syncline at the divide between Toyah Creek and Limpia canyon dip 20° northeast on the southwestern limb and 10° southwest on the northeastern limb. A west-northwest trending anticline runs through the center of the Barilla Mountains, where the lavas are underlain by Niobrara and Pierre. Southwest of the main Barilla Mountains anticline lie another syncline and anticline and another syncline lies southeast from Toyahvale and northeast of the main anticline. The folds continue for an unknown distance and gradually die out in intensity northeast of the Barilla Mountains.

The longer canyons of the Davis Mountains are apparently antecedent to the latest folding. Among those of probably antecedent origin are Adobe, Cherry, Madera and Limpia canyons. Adobe canyon rises on the northern slopes of Sawtooth Mountain very probably as an originally consequent stream. In its middle course it flows through a broad synclinal basin. Its lower course is a canyon cut through the southward-dipping cuesta which bounds the Davis Mountains on the north. Cherry Canyon has a broader and shallower valley in the middle and upper portions of its course but cuts a steep and deep canyon lower down through the southwestward-dipping cuesta south of the mouth of the canyon at Duncan's Ranch. Madera Canyon is steep, narrow and deep in its middle and lower portions, but steeper, deeper and narrower a couple of miles above Kingston's Ranch; being there 2,000 feet in depth. Its valley is both shallower and broader in its headwaters portion, north of Baldy or Livermore Peak.

It is most likely that Adobe, Cherry and Madera Canyons developed as consequent streams on the lava surface after the cessation of the volcanic activity. The Sawtooth Range appears to have been the site of most of the old volcanoes or lava fissures in the western portion of the Davis Mountains and hence the original lava surface probably sloped downwards away from the Sawtooth Mountains, which by volcanic accumulation formed the original divide.

Limpia Canyon cuts entirely across the Davis Mountains and flows in a northeasterly direction from its head until, at a point about two miles northeast of Limpia postoffice, it enters the syncline separating the Davis and Barilla Mountains. About two-thirds of the way between Fort Davis and Limpia postoffice there is a narrows in Limpia Canyon known as Wild Rose Canyon. One and a half miles below Wild Rose Canyon the valley widens considerably in the poorly resistant Pierre shale which has there been stripped of its lava covering. As one goes upstream from Wild Rose Canyon toward Fort Davis the valley both widens and shallows. Southwest of Fort Davis the head of the Limpia valley lies in a flattish basin from eight to ten miles broad. This broad basin extends as far south as the northern foot of the Puertacitas Mountains. The west fork of the Limpia entering the main stream about two miles below Fort Davis heads on the eastern slopes of Baldy or Livermore

Peak, which peak, as we have already seen, is the highest summit and the main orographic divide of the Davis Mountains. The valley of the head of the west fork is in the same stage of topographic development as the heads of Adobe and Madera Canyons. Southeast of Fort Davis at a distance of three to four miles there runs a very broad and shallow tributary valley parallel to the Limpia Canyon at Fort Davis. It is the head of this tributary which extends farthest south of all the streams in the Limpia drainage area. The two eastern tributaries of this tributary suggest a drainage reversal for their headwaters and for most of their courses run slightly south of west, instead of northwestward as we would expect if they had been originally developed as tributaries of a northeastward-flowing stream. The divide between the eastern tributary of the Limpia heading farthest south and the southward-flowing Alamita Creek is both low and broad. The suggestion seems at least pertinent that at a former time this eastern tributary drained to the south into Alamita Creek but was later captured by Limpia Canyon. This possible stream capture may have been aided by an upwarp during the latest deformation at the site of the present Alamita-Limpia divide.

Musquiz Canyon, now followed by the Alpine-Fort Davis road, may also have undergone a recent change of drainage. Musquiz Canyon heads on the northeastern flanks of the Puertacitas Mountains and flows for three-fourths of its course in a northeasterly direction and then abruptly turns at more than a right angle to a southeastward course. At the point of the abrupt turn a southeastwardly-flowing tributary also enters Musquiz Canyon. Between this tributary and the next eastern tributary entering Musquiz Canyon farther downstream is a low broad divide, and the head of this latter tributary is separated from the head of the northeastwardly flowing Horsethief Canyon by a broad divide not more than 50 feet high. The lower end of the southeastwardly-flowing portion of Musquiz Canyon is a deeper-walled canyon than any other drainage course in the Musquiz drainage area. Altogether it seems likely that the lower portion of Musquiz Canyon has captured and diverted to itself the former headwaters of a northeastward-flowing stream the lower course of which is the present Horsethief Canyon.

The high sharp peaks rising above the general surface of the lava-covered area, such as the Sawtooth Range, Puertacitas Mountains, Mitre Peak, Twin Mountains, Paisano Peak, Cathedral Mountain, Cienega Mountain, Goat Mountain and Elephant Mountain, may be all old volcanic plugs or they may be remnants of a higher lava flow which once covered the region. Their summits now range in altitude from slightly less than 6,000 to 6,860 feet, average about 6,500 feet, and rise on the average a thousand feet or more above the lower lava-covered country. The writer was not able to visit any of these peaks to determine whether they were volcanic plugs, the sites of old volcanoes, or remnants of higher, once more extensive, lava flows. So the question must be left open for future investigation. If they are the sites of old volcanoes from which came the lavas and tuffs of the lower country, it seems probable that most of the present drainage, with the possible exceptions noted above, was originally consequent to the land surface at the end of the volcanic epoch.

But whether originally consequent or not, it is practically certain that Adobe, Cherry, Madera and Limpia canyons, and perhaps some others, are antecedent to the gentle folding of the lava-covered area during the last deformation. For they cross the folds at right angles, neither they nor their tributaries show any important amount of adjustment to the latest structures, and when they cross the anticlines their valleys are in all respects physiographically younger and deeper than in the synclines. The shorter streams dissecting the edges of the bounding lava escarpments are probably not consequent, but extended streams, gradually lengthening their courses by headward erosion; and in some cases, aided by greater gradient, destined to capture older consequent or antecedent streams.

The basin north of Alpine, known generally as the Alpine Valley, has a lower altitude than the flat west of Paisano Pass which seems held up as a local base-level by a resistant lava flow crossed by Alamita Creek about twelve miles south of Marfa. Aided by their greater gradient, Barillas Creek and the stream flowing northeastward from Paisano Pass, both tributaries of the Alpine Valley, have been able to cut back to the western limit of the higher lava-covered region between Alpine and Paisano Pass.

The Marathon Dome

The Marathon dome is an unsymmetrical structure with gentle outward dips on the north, east and southeast flanks, and steep or overturned dips on the southwest. In some places in the Mt. Ord and Santiago Ranges, which form the southwestern flank of the Marathon dome, there has been a minor amount of overthrusting. Orographically, the Mt. Ord and Santiago ranges, which are structurally one range, make up a portion of the present Cordilleran Front Range. A broad erosion basin has been cut through the summit of the Marathon dome.

The Glass Mountains form the northern and northwestern flanks of the Marathon dome and form a compound erosion cuesta, the southward and southeastward escarpment of which forms the north and northwest boundary of the Marathon Basin. The Glass Mountains may be considered to end on the east at Gap Tank, twenty-six miles northeast of the town of Marathon, where a low erosion gap forming the divide between the Pecos and Rio Grande drainages is followed by the Marathon-Fort Stockton road. Structurally, however, the range continues a few miles farther east to beyond the Purington ranch. The west end of the Glass Mountains may be taken as the broad valley at the head of Dugout Draw followed by the line of the Southern Pacific Railroad in the vicinity of Altuda section house. Structurally, the Glass Mountains are continuous with the northern Mt. Ord Range, beginning at Altuda Mountain. North of the porphyritic syenite mass of Iron Mountain, eight miles north of Marathon, the east-west strike of the eastern portion of the Glass Mountains changes rather abruptly to a southwest strike in the southwestern portion of the range. The main summits and southern and southeastern escarpments of the Glass Mountains are formed of Permo-Carboniferous and possibly early Permian rocks, in all about 8,000 feet in thickness and mainly limestone. At the east in the vicinity of Gap Tank, Comanchean rocks cover the summits and the upper Pennsylvanian Gaptank formation outcrops at the base of the escarpment. Much of the northern slope of the cuesta is covered with Comanchean rocks.

From just west of Iron Mountain southwest nearly to Lenox section-house on the Southern Pacific Railroad, there is a lower northwestward-dipping cuesta of the Leonard lower Permo-Carboniferous formation, separated on the northwest by a strike depression from the higher main cuesta of the Glass Mountains. In this depression a number of valleys adjusted to the strike has developed, draining southeastwards through deep and narrow gaps across the lower cuesta. Dugout Creek, possibly antecedent to the last deformation, has excavated a broad valley floored with a thin covering of alluvium through the lower cuesta in the vicinity of Lenox section-house. Southwest of Lenox, west of the valley of the Dugout, the lower cuesta again appears. A number of lower and minor cuestas and hogbacks lie on or just south of the main Glass Mountains escarpments. These are capped by the more resistant layers of more massive limestones.

Dugout Creek has the only valley entirely cutting across the Glass Mountains. All other valleys tributary to the Rio Grande have a southward or southeastward course and cut back greater or less distances into the erosion escarpment, forming the southern and southeastern slopes of the range. The main valleys on the north gentle monoclinal slopes of the range are consequent ones, running down the dip. They drain through the northern Trans-Pecos Plains to the Pecos River. Their tributaries are adjusted valleys parallel to the strike. The two lowest gaps across the range east of the valley of the Dugout are formed by low divides between Pecos and Rio Grande drainages. One of these is at the head of the rather broad valley of Gilliam Canyon which heads northwest of Iron Mountain. The other is at the head of the valley of Gap Tank and is followed by the Marathon-Fort Stockton road.

The *Mt. Ord Range* extends from Altuda Mountain on the north southward to the wind-gap of Del Norte Gap. The main anticline begins near the line of the Southern Pacific about halfway between Lenox and Altuda section-house. The dips are rather gentle at the north. Between Altuda Mountain and Mt. Ord two domes are developed, the northern one by a laccolithic intrusion about five miles west of Altuda section-house, and another, two miles south of the first, which may be caused by an underlying laccolith. About three miles south of the southern dome the axis swings to the southeast, the dips here being about 30° on either flank. Six miles to the southeast the axis again swings south and the dips become nearly or quite vertical on the crest of the anticline but flatten rapidly on the flanks. Six miles south of the point of turning of the axis to the south the dips along the crest locally become quite gentle, 8° on the west flank and 5° on the east. Five miles south where the range is crossed by the Doubtful Canyon of Maravillas Creek, the strata on the crest are vertical or even overturned toward the west, but a mile west of the crest the westward dip is only 8°. From five miles north of Del Norte Gap to Del Norte Gap, the anticline is paralleled on the west by a monocline with a slightly south of west dip of 45°. At Del Norte Gap the strata are overturned to the west, just west of the axis of the main anticline.

Halfway between Del Norte Gap and Doubtful Canyon the monocline crosses the topographic summit of the range to its east side and northward becomes vertical and even overturned. At the mouth of Doubtful Canyon the strata dip gently westward but about one mile north of Doubtful Canyon on the east slopes of the range, strata of Edwards-Georgetown age are turned vertical against the gently dipping westward monocline. North of here the orographic summit is again a simple monocline, and the crest of the fold originally passsed east of the present range crest, and has been removed by erosion. Between Doubtful Canyon and the point where the monocline passes to the east front of the present range, the orographic crest is lower than to the north and south. Doubtful Canyon is almost certainly antecedent, though fed by adjusted tributaries parallel with the strike. The lava cuesta extending from Strobel siding southward through Mt. Ord to Elephant Mountain lies on the west flank of the Mt. Ord Range proper and dips westward towards the great synclinal area west of the Cordilleran Front Range.

From the laccolithic intrusion south-southeastward to five miles southwest of Lenox, a syncline runs parallel with the anticline at a distance of about two miles to the east. Southwest of Lenox five or six miles, this syncline is met at right angles by the northwestward-dipping lower cuesta of the Glass Mountains.

The *Santiago Range* (Plate Va and VI) begins at Del Norte Gap and extends southeastward to beyond Dog Canyon. The anticline of the Mt. Ord Range continues southward into the Santiago Range as the main structure responsible for the present orography of the latter range. Just as in the Mt. Ord Range, so in the Santiago Range, from its northern end as far south as its summit peak, the axis of the main anticline lies east of the northeastern foot of the range; the Comanchean rocks once covering the axis of the fold having been removed by later erosion. The anticlinal axis forms the orographic summit ridge only between the highest summit and a point two and a half miles northeast of Persimmon Gap and farther southeast in the vicinity of Dog Canyon. The structural trend of the northern end is first southeastward for three and one half miles and then turns south to a point northeast of Santiago Peak and then again trends southeastward to Dog Canyon, with, however, an abrupt offset to the southwest northeast of the highest summit. South of Dog Canyon the trend again swings to the south and the range ends by a dying out of the folding three miles south of Dog Canyon.

The summit ridge begins at the north in a northeastward-dipping southwestern flank of an overturned anticline of lower Comanchean, upthrusted against Upper Comanchean on the southwest. The Edwards-Georgetown is entirely faulted out. The fault plane dips about 65° in a N 65° E direction, being therefore of the overthrust type. For the first two and a half miles south of Del Norte Gap the dip on the east side of the fault plane is steeply to the southwest. Along its southward continuation the dip on both sides of the fault is very steep to the east, the strata on the western side of the fault being overturned. West of the fault the dips rapidly flatten to a few degrees in a westward direction. The axis of the anticline, which lies east of the fault, is occupied by a narrow canyon which has cut down into the Tesnus formation, the latter dipping steeply to the south with the isoclinal structure of the Ouachitan deformation. East of the anticlinal valley is an outlier of Comanchean folded into a rather gentle syncline, and with two small faults on its northeast and north sides, northeast of the synclinal axis. Northeast of Santiago Peak the dips on the west side of the overthrust fault change to the westward with a low angle.

South of Del Norte Gap the overthrust fault lies at the west base of the Santiago Range. At Del Norte Gap at the east base of the range, the strata are overturned to the westward, and from Del Norte Gap north the overthrust fault lies east of the present east base of the southern Mt. Ord Range.

Northeast of Santiago Peak the trace of the overthrust fault becomes S-shaped in ground plan and from east of Santiago Peak southeastward to the broad re-entrant valley heading on the southeast slopes of the summit peak of the range is a remarkable straight and undissected scarp. At the northwest end of this straight scarp the strata of the summit ridge are overturned to the westward but pass to the southeastward into a steeply-dipping southwestward monocline, the dip decreasing to 20° one-half mile northeast of the re-entrant valley. This straight scarp is probably the recently uncovered plane of the overthrust fault. It cannot be a "block" fault scarp of the Great Basin type for at its northeastern foot the Paleozoic rocks are exposed, striking southwestward in either vertical position or steeply dipping southeastward.

At the re-entrant canyon the trend of the main anticline of the Santiago Range abruptly turns at right angles southwestward and continues in that direction as far as the summit peak of the range and then turns again to the southeast. The re-entrant canyon occupies the axis of the anticline along its southwestward trend. On the highest summit of the range, the anticline again becomes overturned to the southwest and remains overturned in most places from there southeast to near the south end of the range beyond Dog Canyon. From an unknown distance northwest of Persimmon Gap southeast to near Dog Canyon the summit of the anticline is marked by an overthrust fault. At Persimmon Gap, the Tesnus formation is exposed along the anticlinal crest near the northeast base of the range. At Dog Canyon the overturned Edwards-Georgetown is overturned in a steeply-dipping recumbent fold (see Plate VI, No. 18).

At Persimmon Gap the Santiago Range forms a sharp and narrow anticline with an almost vertical upthrust fault on the west flank very close to the anticlinal axis, which here trends N 30° W. Southwest of Persimmon Gap the downthrow is to the southwest and Upper Cretaceous is exposed in the downthrown block, in which are also a number of intrusions and volcanic outflows. Five miles northwest of Persimmon Gap the Front Range widens, with a long gentle eastwardly dip on the east flank and a vertical or nearly vertical dip on the steeper western face. At Persimmon Gap the Edwards-Georgetown is entirely faulted out, the lower Comanchean on the northeast lying in juxtaposition with the upper Comanchean on the southwest foot. Just south of Persimmon Gap the Front Range is less than a mile in width. Only the lower Comanchean is exposed from east of the Tesnus outcrop at Persimmon Gap to the Maravillas Creek on the east.

The Santiago Range is one long single-crested arch of lime stone from about five miles north of Persimmon Gap to its southern extremity. Just north of Dog Canyon a nearly vertical fault striking N 32° W separates igneous rock from Comanchean limestone on the west. About three miles north of Persimmon Gap a block fault of 200 feet displacement begins a syncline in the Comanchean east of the Front Range anticline. Near the junction of Calamity Creek with the Maravillas are a number of outcrops of igneous rocks.

Northeast of the major axis of the Santiago Range between the summit peak and the south end of the range, two minor anticlines lie between the Santiago Range and Maravillas Creek. These apparently rise on the south flanks of the Marathon dome and are a continuation of the general structural trends of the Sierra del Carmen, although their axes are deflected to the south parallel with the main Santiago anticline south of Dog Canyon.

The crest of the Front Range from Ord Mountain southward to beyond Dog Canyon is nearly everywhere a narrow ridge or arête of Comanchean limestone. But it is only in the southern Santiago Range from the summit peak southeastward to its southern end that the present crest is also the structural crest. Between Ord Mountain and the summit peak of the Santiago Range, the orographic crest lies west of the structural crest, either at the top of an erosion escarpment of a westward-dipping cuesta, or at the top of a steep, eastward-dipping cuesta of overturned beds. As the Edwards-Georgetown limestone becomes thicker southward toward the Rio Grande, it becomes more resistant to erosion and so preserves better the anticlinal folds of the latest deformation.

Del Norte Gap and Persimmon Gap are low wind-gaps in the Front Range. They appear to have been sites of streams crossing the site of the present range when the latest deformation began, which were not able, for some unknown cause or causes, to maintain their courses during the uplift. Doubtful Canyon and Dog Canyon of Calamity Creek are apparently antecedent streams which were able to maintain their courses during the uplift.

The eastern and southern flanks of the Marathon dome have respectively eastward and southward dips of 2° to 5°. At the southeast corner of the dome, just south of where San Francisco Creek first enters the Comanchean, there is a subsidiary anticline striking northwest-southeast and plunging southeastward. The dip on the northeast flank is about 10° and on the southwest flank is more gentle. The axis of this anticline is occupied by a valley which drains to the San Francisco through a gap crossing the northeast flank.

Folds South of the Marathon Basin and East of the Sierra del Carmen

East of Maravillas Creek at the south margin of the Marathon basin long dip slopes of basal Edwards-Georgetown dip southerly, at an angle of 5° on the north flank of a broad synclinal basin running east-southeast and west-northwest. In this basin are a number of sharp-peaked remnants of basic intrusive rock, probably of a sill, in the neighborhood of Broke Tanks. This broad structural basin is bounded on the south by the high, broad anticline crossing the Rio Grande just below the mouth of Maravillas Creek, on the north by the southward-dipping flank of the Marathon dome, and on the west by the westward-overturned anticline of the Santiago Range. Nearly all, if not all, of this basin is crumpled into minor folds which appear about its periphery, but in the center the bedrock is concealed by a mantle of alluvium. This bedrock is, however, probably Comanchean.

The northeastern foot of the easternmost Carmen Range is bounded by a normal fault with downthrow on the northeast side, where in the structural valley, the Del Rio (?), capped by basalt, is exposed. The basalt has been both folded and faulted by the latest deformation. The northern limit of the basalt flow is about two miles south of the Maravillas Creek, at a point shortly below its entrance into its canyon in the recently uplifted Fredericksburg-Washita. Between the northern end of the basalt and the Maravillas is a fault running approximately S 15° W with downthrow on the west side and a displacement of about 100 feet. This fault and the faults displacing the basalt west and southwest of its northern end have their downthrows on the west side and the individual blocks dip eastwards in a series of tilted slices. The downthrow and dip of these fault blocks are opposite to those of the Sierra del Carmen, a short distance to the west of them. They lie on the western flanks of the anticline crossing the Rio Grande between the mouths of Maravillas Creek and Reagan Canyon.

The anticline just noted, which crosses the Rio Grande in the local widening of its canyon known as the Vegas, is the westernmost of four long, broad anticlines crossing the Rio Grande east of the Sierra del Carmen and west of the mouth of San Francisco Creek. The easternmost of these crosses the river about one and one-half miles above the mouth of the San Francisco in a long swell running S 60°-65° E with the steeper dip on the northeast flank. The Rio Grande cuts across this anticline in a narrow and tortuous trench in the Fredericksburg-Washita, fully 1,000 feet deep. (Frontispiece.) About four miles upstream another anticline, also with steeper dip on the northeast, crosses the river. A third crosses the river farther up and below the mouth of Reagan Canyon. These folds begin southeast of the Marathon dome and extend for an unknown distance into Mexico. Possibly they are the northeastern continuation of the folded Sierra del Burro, which forms the Cordilleran Front Range in northern Coahuila. The broad arching in the heavy Fredericksburg-Washita limestone east of the Sierra del Carmen was apparently at least in part accomplished by a series of faults of very small displacement parallel to the longer axes of the folds. These small fissures are filled with calcite veins, often colored reddish or blackish by iron oxides. Slickensiding is abundant on the fault planes.

The local widening of the Rio Grande canyon in the Vegas, where the westernmost broad anticline crosses the river, was accomplished because this fold, the highest of the four, brought the lower Comanchean less resistant limestone and marls underlying the Fredericksburg-Washita within reach of the erosive action of the Rio Grande. The easier erosion of the lower Comanchean has aided by undermining action in the recession of the cliffs of Fredericksburg-Washita. Below the mouth of Reagan Canyon the folds gradually become lower toward the east, and erosion has not yet cut to the base of the Fredericksburg-Washita; consequently, the Rio Grande Canyon is there everywhere a deep, narrow, and winding trench.

The surfaces of the folds are little dissected except where crossed by the canyons of the major streams with their short tributaries. It is a land surface of the top of the limestone here called Fredericksburg-Washita, which is likely to be the top of the Buda, the Del Rio and Buda formations being perhaps here inseparable on broad lithologic grounds from the Edwards-Georgetown. In the synclinal depressions between the anticlines a formation of flaggy, arenaceous limestones weathering yellowish-brown, with a thickness of 20 feet, overlain by 80 feet of white chalky marls, and irregular-bedded knotty and marly limestone, outcrops in low buttes from fifty to one hundred feet in height. This formation resembles lithologically the Eagle Ford of the southern Trans-Pecos country.

The canyons of the Rio Grande, Maravillas, Santiago, and probably Reagan canyon also, must certainly be antecedent to the formation of the folds. The Rio Grande crosses all of the folds at right angles to their major axes in very tortuous trenches a thousand or more feet in depth (see frontispiece). The anticlinal folds are the broad, very little eroded, orographic ridges. The canyon on the lower Maravillas begins shortly below the Miller Ranch as the westernmost of these folds begins to lift at its northwest end. The lower San Franscico cuts a short canyon with intrenched meanders——the summit of the canyon walls being of Edwards—when it leaves the Palezoic rocks of the Marathon basin. The Comanchean rocks there dip downstream with a dip greater than the gradient of the creek so that a short distance below the valley shallows and widens where it runs through less resistant overlying Cretaceous rocks. A short distance below the Russell ranch the valley again cuts into the lower resistant limestone, which has here become thicker, and then falls to the level of the Rio Grande in a series of precipices interrupted by rock terrace flats of the more resistant limestone layers. The top of the Fredericksburg-Washita forms a very pronounced terrace-bench one-half mile wide at the junction of Maxon and San Francisco creeks.

The Rio Grande canyon in the Vegas (Plate VIIb) is about 1250 feet deep, the lower 450 feet being of less resistant limestone and marls of the pre-Edwards Comanchean. On top of the upper surface of the heavy Fredericksburg-Washita limestone, back from the river, are old shallow valleys which are hanging over the canyon walls, not having been able to cut their courses down to the level of the Rio Grande, and which, consequently, probably antedate the latest deformation. If so, the old erosion surface seems to have reached the stage of middle old age. At the mouth of the San Francisco, the Rio Grande has a narrow tortuous box canyon cut in Fredericksburg-Washita to a depth of at least 800 feet. At the bottom is barely space for the river water to pass; at the top the canyon is not more than one-fourth mile across from wall to wall. The south canyon wall is a sheer cliff of heavy-bedded limestone. These are typical conditions for all the canyons of the Rio Grande.

In the distance of a mile and one-half above the mouth of San Francisco Creek, a downfold brings down the upper surface of the Fredericksburg-Washita a full 200 feet.

The Sierra Del Carmen

The general trend of the Texas portion of the Sierra del Carmen is south-southeast The northern end of the range lies east of and in *en echelon* arrangement with the southern end of the Santiago Range, the two ranges being separated by a low, broad syncline of the Fredericksburg-Washita. The backbone range of the Texas portion of the Sierra del Carmen is the Sierra del Caballo Muerto, which is the longest and highest of the individual ranges and the one which extends farthest to the northwest. The Sierra del Carmen in Texas consists of eight fault blocks of west-southwestward-tilted Edwards-Georgetown limestone downthrown to the east in a series of step-faults. (Plate VI, Nos. 20 and 21, Plate Vb and Plate VIIa). All these fault blocks are located on the east flank of the great domical uplift, the west flank of which is a very sharp downfold into the broad synclinal area of the Chisos country.* The latter is a portion of the great synclinal area west of the Cordilleran Front Range.

The block or upthrust faults begin at the north in *en echelon* arrangement, the one at the east base of the Sierra del Caballo Muerto (Dead Horse Range) being farthest to the northwest, the next one to the east at the east base of the Sierra Larga being next farthest northwest, and the second succeeding one to the east being farther southeast. All pass to the northwest into low folds of strata and die out in the structural basin of Maravillas Creek above the canyon. The faults first run for about two miles in a S 50° E direction and then turn more towards the south.

In a direction S 30° E of the north summit (Sue Peaks, 5630 feet) of the Sierra del Caballo Muerto and across the Rio Grande in Coahuila, is a magnificent scarp of Fredericksburg-Washita limestone certainly not less than 1500 feet in height and running

*Udden, J. A., A Sketch of the Geology of the Chisos Country, Brewster County, Texas. Bull. Univ. of Texas, No. 93, 1907. Scientific Ser. No. 11.

very nearly north-south. Southeast of this perhaps ten miles may be seen the top of a considerably higher scarp. The strata in the first-mentioned are tilted either easterly or northeasterly and the downthrow is on the west side of the scarp. This scarp first makes a broad re-entrant gulf to the east and is then again seen swinging westward far away in a S 20° E direction. West of this scarp is a broad basin dotted with a few rather low hills and mountains. East of the tilted block is a rather constricted synclinal area in which some sharp-peaked dark-reddish igneous masses outcrop. In the Coahuila portion of the Sierra del Carmen across the Rio Grande the faults are on the west flank of the structural axis, with scarps facing west and downthrows to the west-southwest. At Boquillos Canyon, where the Rio Grande crosses the Sierra del Caballo Muerto and where the river crosses Hubert Ridge in another canyon, the downthrow on the Coahuila side of the river is still to the east and the dip of the strata to the westward.

In the Texas portion of the range the prevailing dip is west-southwest with the rise in the strata accomplished by upthrusts or block faults with downthrow to the east-northeast. A short distance south of the Rio Grande the faults change from the east to the west flanks. At the south end of the Sierra del Carmen in Coahuila Dr. E. Böse reports that the faults pass into anticlines, just as they do at the north end in Texas. So a clear conception is afforded of the essentially broad and elliptical domical nature of the Sierra del Carmen as a whole, the "structural high" of the dome, as far as known, coming a short distance south of the Rio Grande. North of this "structural high" the faults have their downthrows to the east on the east flank and south of it to the west on the west flank. On the higher part of the structure, where the deformation was most intense, the very competent, massive-bedded Fredericksburg-Washita limestone has yielded to the folding by fracturing, along the lines of which great upthrust faults have been formed.

The two most striking physiographic features of the Sierra del Carmen are the remarkable straight, precipitous and scarcely-dissected fault scarps (Plate VIIa), and the antecedent canyons both of the Rio Grande (Frontispiece and Plates Vb and VIIb) and some of its tributaries across these scarps. These tributary streams are mainly becoming adjusted to the structure by shifting their courses down the west-southwestward dip of the strata nearer and nearer to the base of the fault scarps. Most of them probably occupy real structural valleys formed during and after the faulting, however. The adjusted streams are prevented from reaching to the very bases of the fault scarps by the debris accumulating there, of which the supply is too great to be removed by the streams as fast as it accumulates. Their tributaries for the most part flow west southwestwardly down the structural slopes, and are therefore consequent to the structure of the latest deformation. Wherever the Rio Grande cuts across the resistant limestone of one of these fault blocks its rate of downcutting is lessened, permitting the formation of a transient local base-level upstream. In these areas of local base-level, the bolson debris deposits are accumulating. The greatest of the bolson plains extends outward to the north, northeast, east, southeast, and south of the base of the Chisos Mountains west of the Sierra del Caballo Muerto, but a fine example of one of these delta-formed alluvial fans is found at the mouth of Heath Creek at the east foot of Hubert Ridge.* Along the adjusted drainage courses between the fault blocks are fine examples of alluvial terraces. The highest system of alluvial terraces along lower Stillwell Creek and along the Rio Grande at its mouth is 40 to 50 feet high and a lower series is about 10 to 15 feet high. The debris is often cemented with caliche. The cutting of these terraces either marks more rapid stages in the down-cutting of the limestone barriers in the canyons, or stages of intermittency in uplift.

The consequent streams cut narrow V-shaped valleys below the generally even surfaces of the top of the Fredericksburg-Washita which slope west-southwestward toward the structural or adjusted drainages. Most of these surfaces are still even and undissected by erosion. Hence the topography is still in the stage of early youth.

An antecedent valley crosses the fault scarp of the Sierra Larga in a deep and narrow canyon about one and one-half

*These and other physiographic features are finely shown on the Chisos Mountains Topographic Sheet of the U. S. Geological Survey.

miles south of the northern margin of the Chisos Mountains. (Topographic Sheet.) Heath Creek, which rises on the eastern slopes of Sue Peaks in the same structural valley as Ernst Valley, crosses both the Sierra del Caballo Muerto and Hubert Ridge in antecedent canyons.

Short hanging valleys of recent development hang over the walls of Boquillas Canyon, not being able to excavate as fast as the more powerful perennial Rio Grande. These are very much shorter than the hanging valleys of the canyons between Reagan Canyon and the mouth of San Francisco, which are considered to be at least in part, valleys of the former erosion cycle.

The Marathon Erosional Basin

The present Marathon Basin occupies the site of a former broad arch covered by Comanchean rocks, which have been nearly altogether removed by later erosion which has exposed the closely folded Paleozoic rocks lying beneath the Cretaceous. The axes of folding in the Paleozoic rocks are directed at right angles to the axes of the latest deformation.*

The three most conspicuous topographic features of the Marathon basin are: (1) the long, jagged strike ridges of the Caballos novaculite, (2) the area of lowland of the Pennsylvanian formations in the synclinal areas, completely surrounding the Caballos novaculite ridges; and (3) the bounding escarpment of outwardly-dipping Comanchean or Permo-Carboniferous rocks encircling the Marathon basin of erosion. In the eastern and northeastern portions of the basin the Tesnus formation, which elsewhere forms lowlands, makes up a number of hills either still capped with remnants of the Comanchean or from which the cap of the Comanchean has been lately removed by erosion. The only resistant Pennsylvanian formation is the Dimple limestone which forms strike ridges like the Caballos novaculite.

The bounding escarpment of Comanchean rocks is everywhere, except in localities already noted in the Mt. Ord and Santiago

*Udden, J. A. A Sketch of the Geology of the Chisos Country, Brewster County, Texas. Bull. Univ. of Texas, No. 93, 1907, pp. 76-78, and 87-89.

ranges, an escarpment of erosion. Portions of the Permo-Carboniferous limestone escarpment of the Glass Mountains both east and west of Iron Mountain much resemble fault scarps in their long, straight and steep fronts. An examination of structure and stratigraphy proves that there are no faults here. The physiographic evidence is also fairly conclusive. The strike of the strata in the scarps is parallel with the direction of the scarps and at no place does the line of the escarpment front cut the strike of the strata at an angle. The dip of the strata is always at right angles to the face of the scarp and in the opposite direction from that toward which the escarpments face. The small gullies dissecting the scarp faces, although having very steep gradients becoming even vertical when hard layers are crossed, are not in any sense hanging valleys. They owe their characteristics entirely to erosional features in rocks of differential hardness. The scarp lying between Iron Mountain and the first lower hogback of the Permo-Carboniferous east of Iron Mountain is remarkably straight, steep, and even-contoured, being for a considerable distance not even dissected by gullies. It has been cut in a rather thin-bedded, remarkably homogeneous limestone, apparently everywhere offering the same degree of resistance to erosion. The angle of the escarpment slope is too steep to permit the lodgment of coarse loose rock fragments. So only the finer rock material is afforded as tools for the water flowing rapidly down the slopes in times of rainfall. As in all these cuestas the divide between the top of the escarpment and the dip slopes is sharp and ridgelike. On such an escarpment slope as this there is no chance for drainage lines to develop.

On the eastern and northeastern sides of the basin low windgaps in the Comanchean rocks are the sites of divides between consequent drainage down the dip slopes and drainages forming embayments in the scarp and tributary to the streams of the Marathon Basin. Within the basin the valleys are generally broad and alluviated and the hills and divides in the less resistant rocks are low, infrequent, and well-rounded. The lower slopes of the hills, erosion escarpments and valleys are mantled with alluvial debris, often cemented with caliche, especially below a few inches beneath the surface. The alluvial debris is dissected into benches and terraces along the main present drainage courses. At no place is the alluvial covering of any considerable thickness. Occasionally low ridges are formed by the outcrops of igneous sills and dikes. Very often the drainage channels have cut into the underlying bed rock, although the valley slopes are mantled with alluvium. The heads of both the San Francisco and Maravillas creeks are broad alluviated flats.

On the west side of the basin the western tributaries of the Maravillas exhibit similarity with those of the enclosed basin areas of the Great Basin. They head as canyons or gullies in the Comanchean escarpment, exhibit a sudden decrease in gradient when they enter the debris slopes at the escarpment base, cut deep, steepwalled trenches with few lateral tributaries in the heterogeneous materials of the debris fans, and lower down spread out in broad, almost imperceptible channels in the finer materials beyond the foot of the debris slopes. They resemble in all respects the drainage channels crossing the alluvial fans in the Chisos country, so well described by Udden* that another description is not necessary here. Here as well as in the Chisos country they are to be explained in the same way. Formation of local base-levels is responsible for their characteristic features.

The broad flat south of the Miller ranch and north of Bee Cave Tank and Black Gap, crossed by the road between Marathon and the mouth of Stillwell canyon, is bounded by low alluvial benches from ten to twenty feet in height. The flat is from one to three miles in breadth and drains northward to the Maravillas. It lies in an area of structural downfolding. The benches, some of which are found in the middle of the flat, are remnants of a former epoch of alluviation, since which time the inner flat has been cut beneath their levels. A number of such flats are found in other portions of the basin.

The Maravillas cuts short gorges at two places through the Caballos novaculite ridges near their western ends. The San Francisco also cuts a gorge through the Dimple limestone along

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*Udden, J. A. Sketch of the Geology of the Chisos Country, Brewster County, Texas. Bull. Univ. of Texas, No. 93, 1907.

the line of the Southern Pacific between Warwick and Haymond within one and one-half miles of the south end of a syncline. Farther southeast it again cuts through the Dimple on the southeastern limb of the anticline just southeast of the syncline. Since the tributaries of the Maravillas and San Francisco have generally become adjusted to the structure and flow either in strike valleys or the axes of anticlines, it is most probable that those portions of the valleys of the two major drainages where they cut gorges across the strike of the resistant rocks are superimposed. At a former time these streams flowed on the Comanchean rocks and upon cutting through them encountered the most resistant Paleozoic rocks of different structure lying unconformably beneath the Comanchean. Were the Maravillas and San Francisco consequent or entirely adjusted streams, their courses would have passed around the ends of these obstructions. But they are in reality antecedent-superimposed streams.

Canoe-shaped anticlinal valleys are developed in the two anticlines exposing upper Cambrian east of Comb's ranch, and south of Peña Colorado Creek. The longitudinal valleys head at opposite ends of the elliptical anticlines, flow toward each other, meet near the center, and drain toward the north through deep and narrow gaps in the resistant Maravillas chert. The drainage basins are cut in the little resistant upper Cambrian much crumpled shales and sandstones, rimmed in on all sides by an elliptical ridge of Maravillas chert. The region exhibits, however, both anticlinal and synclinal valleys and ridges alike, the topography of the Marathon Basin area being the result of the differential resistance to erosion of the various rocks outcropping, rather than caused directly by deformative processes.

The long strike ridges of the Caballos novaculite of the anticlinorial areas have low steep, jagged outlines, bare of arboreal vegetation. Clothe them with a thick forest covering and they would present all the characteristics of the Ouachita Mountains of Arkansas and Oklahoma. But in their setting amidst the grander features of Trans-Pecos Texas they must be regarded as mountains in miniature, resurrected of late to a mere shadow of their one time glory by the fortuitous circumstance of being denuded of the mantle accumulated upon them by the sea, which had formerly entirely buried their ancient summits.

South of the line of the Southern Pacific are four well-defined groups of the northeast-southwestwardly trending ridges of Caballos novaculite. In more detailed work these would be raised to the dignity of separate sub-ranges. At the northeastern end of the second ridge series south of the railroad is Caballos or Horse Mountain, their highest summit. North of the railroad the novaculite ridges are lower and of less importance.

Next in importance to the Davis Mountains in this respect, the Marathon Basin is a fairly well-watered portion of the Trans-Pecos desert. The complicated folded structures of the bed rock is such that it does not appear to allow the ready transportation of the water away from the region. Often, also, as in the Peña Colorado valley between the site of old Fort Peña and Comb's ranch house, in the headwaters valley of the San Francisco and between the northern Santiago Range and the Maravillas Creek, ground water of fairly good quality is found in the alluvial mantle. As the alluvium in these local ties is generally underlain by the Tesnus formation, it seems likely that fracture spaces, which are quite abundant in the brittle sandstone in this formation, must be filled with ground water.

Ordinarily there is no continuous stream running in the upper drainage course of either the Maravillas or the San Francisco. Water runs for short distances or stands in holes over bedrock surfaces or where the alluvial mantle is very thin. At other places it sinks into sands and gravels, appearing sometimes at the surface farther down stream where bedrock again rises to the surface of the channel. When these streams enter the Comanchean limestones, the water disappears, being carried away to other regions by the limestones. In time of excessive rainfall the streams may flow for a short time throughout their courses.

The springs of the Marathon basin generally occur at those places where drainage channels cut down into the bedrock and permit the ground water accumulated in the alluvial mantle to seep or flow out at the junction of mantle and bedrock. The ground water at the outer periphery of the basin is constantly being lost through seepage into the outward-dipping limestones.

The bounding escarpment of the Marathon basin, which is in a youthful stage of erosion, is in physiographic unconformity with the lower-lying interior of subdued relief, which is in an old age stage of erosion. This physiographic unconformity is caused by the superior resistance of the rim rock limestones under prevalent climatic conditions. These limestones will, we have already seen, persist in steep rugged escarpments under unchanging climatic conditions until near the end of the present cycle of erosion operating in the Marathon Basin. But the escarpments will gradually become lower and lower and the areas of escarpments and cuestas gradually become less and less. However, since the base-level now controlling the physiographic development of the Marathon Basin is a local base-level, brought about by the resistant Edwards-Georgetown limestone where it is crossed by the Rio Grande and all its tributaries, it is apparent that the present cycle of erosion will never be brought to anything like a completed stage. In fact, the testimony of the alluvial terraces in the Marathon basin and along the Rio Grande shows that a transitory series of successively lower and lower base-levels is being developed. Every important tributary drainage has its own local base-levels, while the development of the tributary drainage as a whole is dependent on the local base-levels developed along the course of the master stream, the Rio Grande. The Rio Grande, possessed of a permanent supply of water and abundant supply of sediment as tools for corrosion, may be expected to cut down its resistant rock barriers at a greater rate than any of its tributaries, which are relatively weak, especially in the matter of water supply. The local base levels are therefore likely to persist longer along the tributary streams than along the Rio Grande and in the upper courses than in the lower courses of the tributaries. But of course all the barriers to down-cutting of streams are not equally resistant. The less resistant ones will be removed faster than the more resistant. Ultimately and far in the future, unless renewed uplift or change of climate takes place, the entire region will come under the influence of the final and lowest base-level of all, the surface of the water in the Gulf of Mexico, and a general peneplain of the entire region would finally and very slowly be developed. Above the general level of erosion remnantal masses of the more resistant rocks will rise until very late in the old age stage of the erosion cycle.

The ridges of resistant Caballos novaculite in the Marathon basin will also persist as topographic prominences until the land surface has been worn very low and reduced nearly to a general level.

The Marathon basin has reached a stage of physiographic development considerably more advanced than any other portion of the Front Range region. This immediately raises the question whether the Marathon dome is not an older structure than those found in other portions of the Front Range. Although it cannot definitely be asserted that the Marathon dome was formed at the same time as the Sierra del Carmen, Davis Mountains, and the Mt. Ord and Santiago ranges, there are several considerations which render it probable that it was contemporaneous with the formation of these ranges.

The Edwards-Georgetown limestone, to the superior resistance of which much of the youthful condition of the topography in the Sierra del Carmen, the anticlines east of the Sierra del Carmen, and the great trenches of the Rio Grande and Pecos rivers, must be attributed, is much thinner about the rims of the Marathon basin than farther south where this limestone, probably including also both the Del Rio and Buda, reaches a thickness of some 2,000 feet along the Rio Grande. Also, it should be recalled that a number of antecedent streams continued to erode the Marathon dome from the time it first began to be uplifted until the present. Also, the Marathon dome is the largest of all the single structures of the region and hence had a greater supply of water available for purposes of erosion than any other single structural unit. When the capping of the Edwards-Georgetown limestone had once been cut through, subsequent erosion of the underlying lower Comanchean and Paleozoic rocks was easy and rapid. The erosion of the latter aided much by its undermining effects in the removal of the overlying Edwards-Georgetown. Finally, it is possible that a considerable part of the Edwards-Georgetown once capping the Marathon dome may have been removed in the previous cycle of erosion before the last deformation began. Or the Marathon basin may have been subjected to an earlier doming either near the end of the upper Cretaceous or sometime during the Tertiary. But at any rate it seems most probable that the doming most apparent today occurred during the later deformation, for the Mt. Ord and Santiago ranges are really the western flanks of the Marathon dome and their structures, viewed by the evidence of their physiography, are of late date.

The Date of the Latest Deformation.

Since there are no Tertiary deposits known in any part of Trans-Pecos Texas and it is now reasonably certain that only small areas, if any at all, will ever be found, it is not possible to date the latest deformation by stratigraphic evidence. The youngest rocks which have been deformed are the volcanics of late Cretaceous or very early Eocene age. All the evidence given by stratigraphy, therefore, is that the latest deformation occurred sometime during the Cenozoic.

Throughout the entire southwest, from the Pecos River westward until we reach the Coast Ranges of California and from the 35th parallel of latitude southward to far beyond the Mexican boundary, as well as throughout the Great Basin region of Utah, Nevada, and California, no marine strata later than Cretaceous are found. However, terrestrial strata of a number of Tertiary periods are found in Nevada and California. In various places in the Great Basin region of Nevada and California, Miocene, Pliocene, and even Pleistocene strata are folded and faulted in the later deformations of the mountain ranges.

Climatic conditions in the Great Basin of Nevada and California are very comparable in kind with those of the ranges of Trans-Pecos Texas. In amount the precipitation in the lowland areas of the Great Basin is less than in the lowlands of Trans-Pecos Texas. On the other hand, a notable proportion of the mountain groups of the Great Basin have higher altitudes than those of Trans-Pecos Texas, and if we except the Mohave and Colorado desert areas of lower ranges, it is likely that the average precipitation on the mountain areas of the Great Basin is not far different in amount from that on the lower mountains of Trans-Pecos Texas. In both regions we can consider physiographic evidences of age of the latest deformation only in the mountain areas, for the lowlands of the Great Basin have no outlets to the sea and hence are covered quite generally with comparatively recent deposits, sometimes to great depths, while in the portion of Trans-Pecos Texas we are considering, recent deposits on the lowlands are relatively subordinate, as all of the region has exterior drainage to the ocean. The rocks of the Great Basin mountains are also of the same nature as those of Trans-Pecos Texas. Both regions have consolidated sedimentary rocks of varying degrees of resistance, large areas of lava flows and tuffs, and of intrusive igneous rocks.

Now, under conditions in every respect essentially similar, the degree of physiographic development in the Great Basin and in Trans-Pecos Texas mountains is the same. Hence it appears to be a sound conclusion that the mountain ranges of both regions came into existence about the same time. We can definitely date the latest Great Basin deformation at about the end of the Pliocene, continuing into the Quaternary.

The canyons of the Rio Grande, Pecos, Maravillas and San Francisco, no matter how great the resistance of the rocks out of which they are cut, no matter what climatic conditions they have undergone, could not have preserved their extremely youthful aspect during anything like the entire Cenozoic or even a large fraction of the Cenozoic. The fault scarps in the Sierra del Carmen are too little eroded to have persisted for a large fraction of Cenozoic time. And the anticlinal folds of the Davis Mountains and east of the Sierra del Carmen are too little eroded and the existing drainage courses show too little amount of adjustment to structure to have come into being in the earlier Tertiary.

The Lafayette formation of Texas contains a large percentage of gravel which must have come from the western mountains. The Lafayette unconformably overlies at one place or another practically every older formation in Texas. In age it has been supposed to be Pliocene, but no definite paleontological evidence is yet at hand. In southwest Texas the Reynosa equivalent of the Lafayette unconformably overlies Upper Pliocene Lagarto strata. So far as yet known, the Lafayette may prove to be in part or in whole Pleistocene. However that may be, the Lafayette epoch ushered in a new change of conditions throughout the Texas region, when a period of erosion was ended by the deposition of the Lafayette sediments. A part of the Lafayette sediments came from the western mountains and the supply of this portion was furnished by an uplift of the western mountains either contemporaneous with or immediately previous to the beginning of the Lafayette epoch of deposition.

So we may fairly safely conclude that the latest deformation of the Cordilleran Front Ranges of Trans-Pecos Texas occurred at or near the close of the Tertiary. The deformation belongs to the diastrophic epoch named by Joseph Le Conte, the Sierran.

Explanation of Structures Produced by Latest Deformation.

The structures formed by the latest deformative movements range all the way from broad gentle folds in the Davis and Barilla mountains and east of the Sierra del Carmen and broad domical uplifts broken with upthrust or block faults on one or both flanks in the Delaware-Guadalupe mountains and the Sierra del Carmen to overturned folds and overthrust faults in the Mt. Ord and Santiago ranges. Since the block or upthrust faults lie on the west flank of the Delaware-Guadalupe mountains, the overturned folds and overthrust faults of the Mt. Ord and Santiago ranges lie on the southwest flank of the Marathon dome, and the steepest dips in the Sierra del Carmen are also on the southwest flank, it is apparent that there was a tendency either to an overthrusting from the east and northeast towards the west and southwest, or to an underthrusting in the opposite direction.

Evidence has already been presented to show that the present surface rocks in all the Front Ranges of Trans-Pecos Texas were also the surface rocks at the time the latest deformation began This is in itself an evidence of the relative recency of the deformation. It also permits us to learn how surface rocks deform under diastrophic movements and pressures. How a given rock formation will deform depends on three factors: (1) the strength of the deformative forces; (2) the resistance of the rock mass to the deformative forces; and (3) the load of superincumbent rocks over the rock formation which is being deformed. A thick and well-consolidated rock formation is relatively resistant to deformative forces and is known as a "competent" rock formation. In our region the surface rocks in the mountain areas are all competent and had no load of superincumbent rocks at the time of the latest deformation. The structures formed are all of rather gentle type and hence the deformative forces were probably of only medium intensity.

The thick and solid lava flows in the Davis and Barilla mountains were deformed in gentle anticlines and synclines. The deformation there was relatively gentle, as shown by the gentle nature of the folding and by the fact that the Comanchean rocks there have been uplifted to lesser heights than in the other Front Ranges. The heavy lava flows appear to have yielded to the deformative forces by the extensive development of jointing. Such a competent rock as the lava, without any superincumbent load, could yield only by jointing, which under more intense deformation would have passed into tensional faulting such as took place in the Sierra del Carmen. The Delaware-Guadalupe dome can be conceived as a broad structure developing, because of a tangential thrust from the east, with steeper dips on its western flanks. The greater stretching of the competent Delaware Mountain and Capitan limestones on the western flanks of the dome permitted the development, as deformation went on, of upthrust or "block" faults of great displacement. Had the tangential thrust from the east been even more intense the upthrust fault would have passed into an overthrust and the Delaware Mountain and Capitan strata would have been overthrust to the westward over the Salt Basin. Such overthrusting has actually occurred along the western flanks of the Mt. Ord and Santiago ranges. In these ranges the Edwards-Georgetown limestone is less thick and consequently less competent than the same strata in the Sierra del Carmen or the lava flows in the Davis and Barilla mountains. Consequently the resistance to deformation offered by the surface rocks was less in the Santiago and Mt. Ord ranges than in the other mountains and overthrusts could there be developed under conditions of less intense deformation than in the other ranges. The Comanchean rocks may have slid westward along the contact with the underlying steeply-folded Paleozoic strata.

Upthrust faulting is developed on perhaps as great a scale in the Sierra del Carmen as in any of the ranges of the Western Cordillera of North America. The broad domical structure of the range is unsymmetrical in that the southwestern flanks have the steeper dips. The great upthrust faults occur on both flanks as well as along the summit of the structural axis. The very competent Comanchean limestone is 2,000 feet in thickness and when arched at the surface could deform only by the formation of tensional faults parallel with the longer axis of the folding. When once the breaks in the strata had been brought about by the deformational stresses, it was comparatively easy for movements of displacement to take place along the lines of least resistance of the breaks. If the surface rocks in the Sierra del Carmen had been comparatively non-competent the sites of the faults would have been the sites of minor anticlines making up *in toto* an anticlinorium instead of the present domical structure. Non-competent strata underlying the surficial competent strata, and with the load of the surficial strata upon them, have probably been deformed by folds. The four long anticlines east of the Carmen Range, the superficial rocks of which are of Fredericksburg-Washita age and of competent nature, have been deformed into folds by a series of breaks of small displacement running parallel to the longer axes. The deformation there on the east flanks of the Front Range was less intense than farther west in the main Front Range, and the surficial rocks yielded by the development of a series of very small step faults.

The Cordilleran Front Range is essentially formed by three large domes with greatest dips on the western and southwestern flanks. Named in order from north to south these are the Delaware-Guadalupe, the Marathon, and the Sierra del Carmen domes. The greatest amount of uplift was at the north in the Guadalupe Mountains and increases northward in New Mexico.

The amount of uplift gradually decreases to the southeast, toward the Rio Grande. The average width of the Cordilleran Front Range, including subsidiary structures to the east, ranges from 40 to 50 miles. In the region between Alpine and Fort Davis, the Front Range structurally either does not exist or the latest deformation has been there less intense than elsewhere.

Summary of Chief Geologic Events

1. .Marine deposition of Upper Cambrian and Lower Ordovician.
2. .Withdrawal of the sea and subaerial erosion.
3. .Marine deposition of Trenton and Fernvale-Richmond in Middle and Upper Ordovician times.
4. .Withdrawal of the sea and subsequent erosion.
5. .Deposition of radiolarian cherts of the Caballos novaculite.
6. .Erosion.
7. .Deposition of Tesnus, Dimple, and Haymond in early and middle Pennsylvanian time.
8. .Hercynian epoch of diastrophism: formation of the Ouachitan mountain ranges of the Marathon basin in mid-Pennsylvanian time, accompanied and followed by great erosion.
9. .Resubmergence beneath the sea and deposition of the Gaptank formation in Upper Pennsylvanian time.
10. .Erosion.
11. .Marine deposition of thick series of Permo-carboniferous strata interrupted by two epochs of erosion.
12. .Deformation by gentle folding.
13. .Long epoch of sub-aerial erosion during the first part of the Mesozoic.
14. .Gradual advance of Comanchean Cretaceous sea over the region from the south and marine deposition continuing until at least Pierre Upper Cretaceous time.
15. .Folding and faulting in northern part of region, accompanied and followed by erosion.
16. .Outbreak of volcanic activity in late Cretaceous-early Eocene beginning with outflow of basalt, followed by rhyolite,

and concluded with trachyte and phonolite.

17. Long-continued sub-aerial erosion during most or all of Tertiary time.

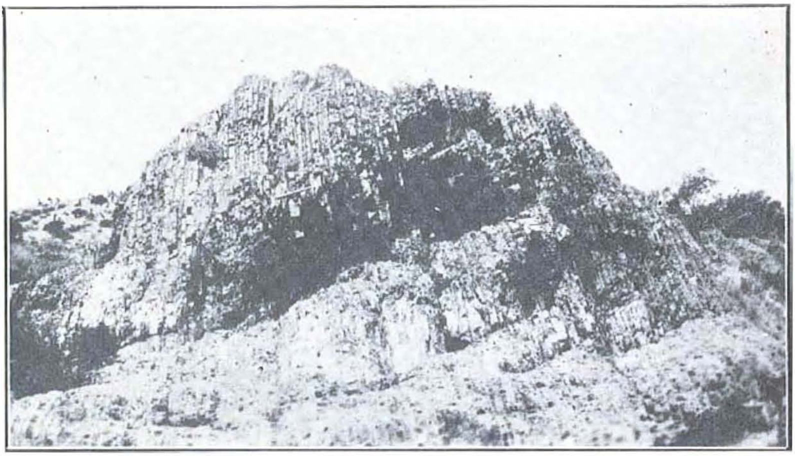
18. Formation of the present mountain ranges by folding and faulting near or at the close of the Tertiary.

19. Widespread erosion of Pleistocene and Recent time.

Plate 1a

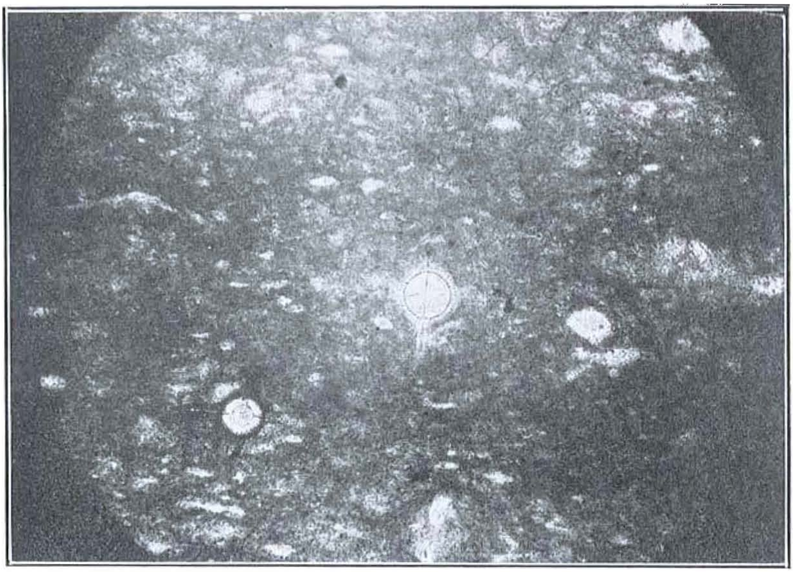
Ordovician-Maravillas formation at its typical locality in Maravillas Gap

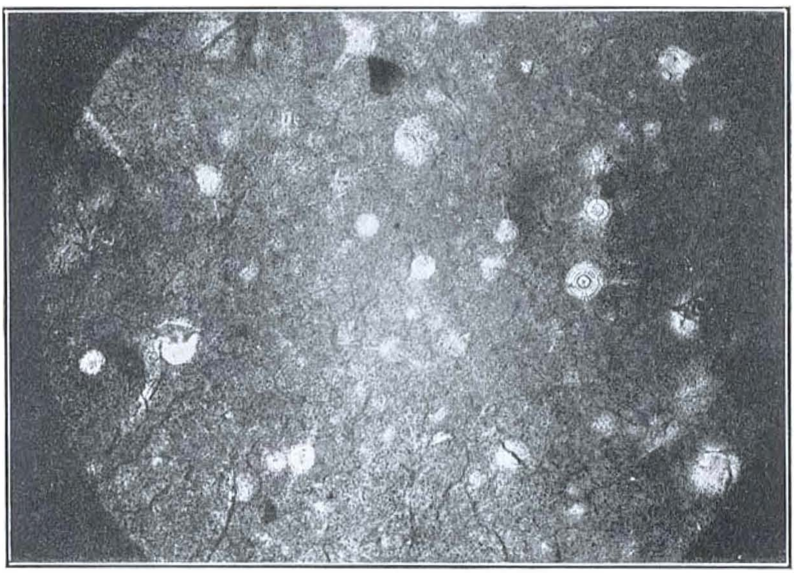
Plate 1b



Banded cherts in Rough Creek shale member of Tesnus formation. Type locality on Rough Creek

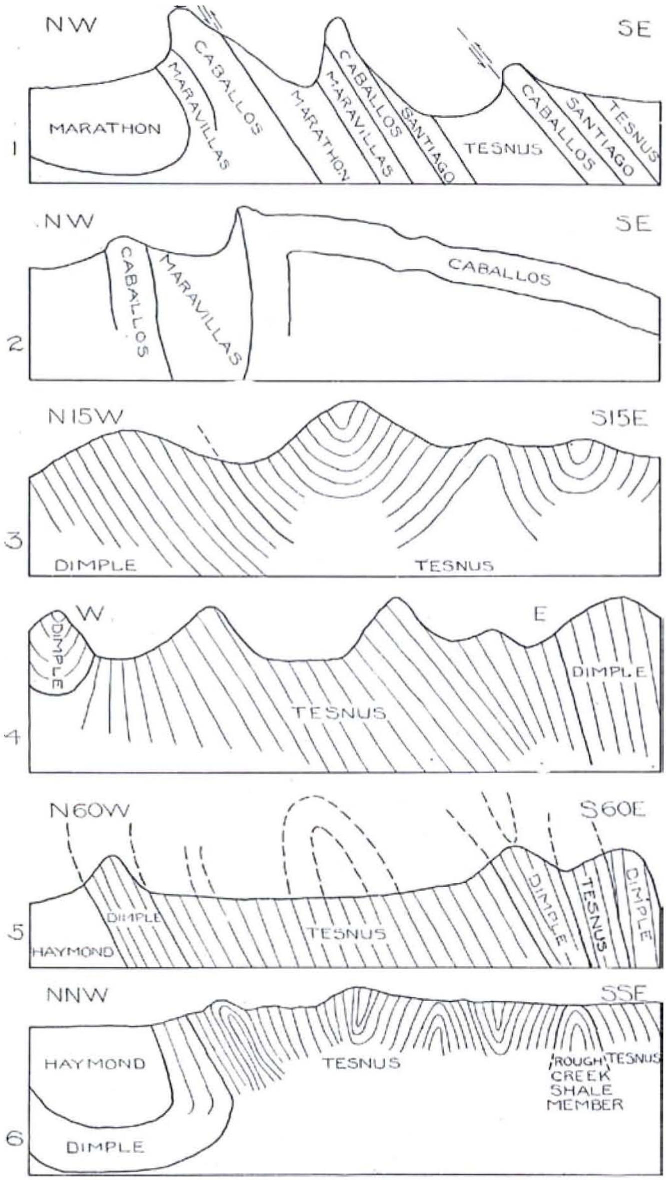
Plate 2





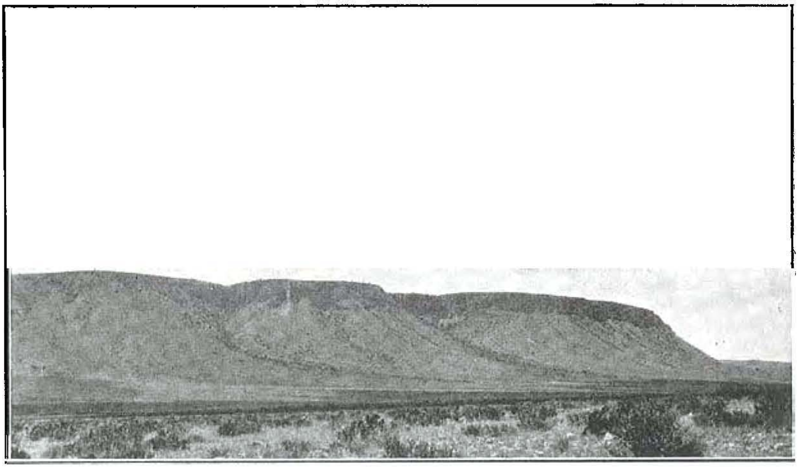
Photomicrographs of Radiolaria in Santiago Chert
(Magnified 50 times.)

Plate 3



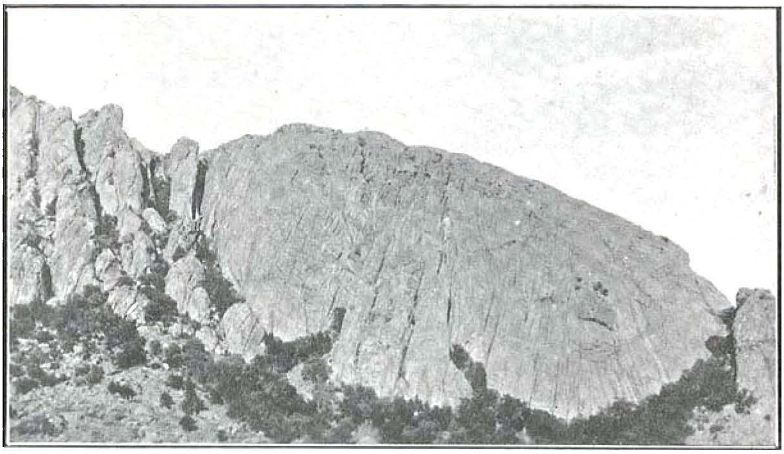
Sketch sections of Hercynian folding in the Marathon Basin. The members give locations of sections on geologic map

Plate 4a



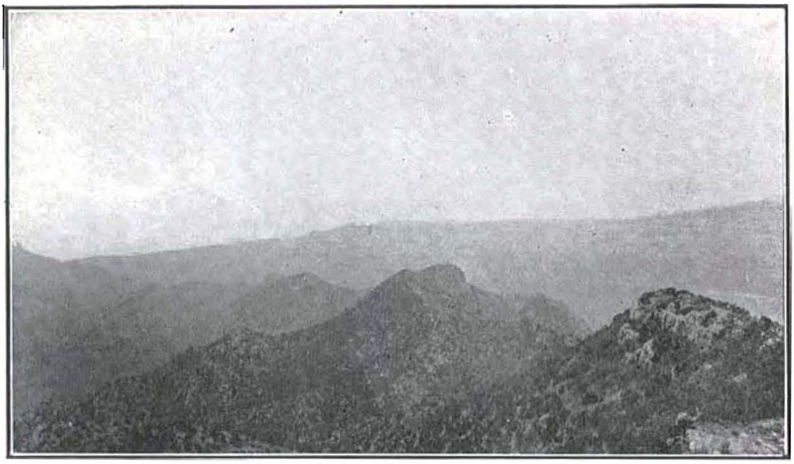
Elephant Mountain, a mesa of trachytic lava

Plate 4b



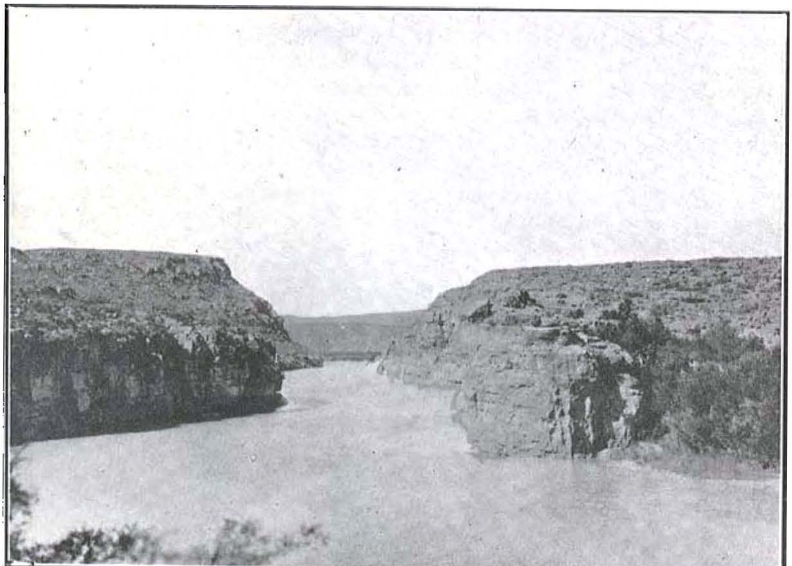
Southwest face of Iron Mountain showing weathering of intrusive syenite-porphyry by exfoliation and along nearly vertical joint planes

Plate 5a



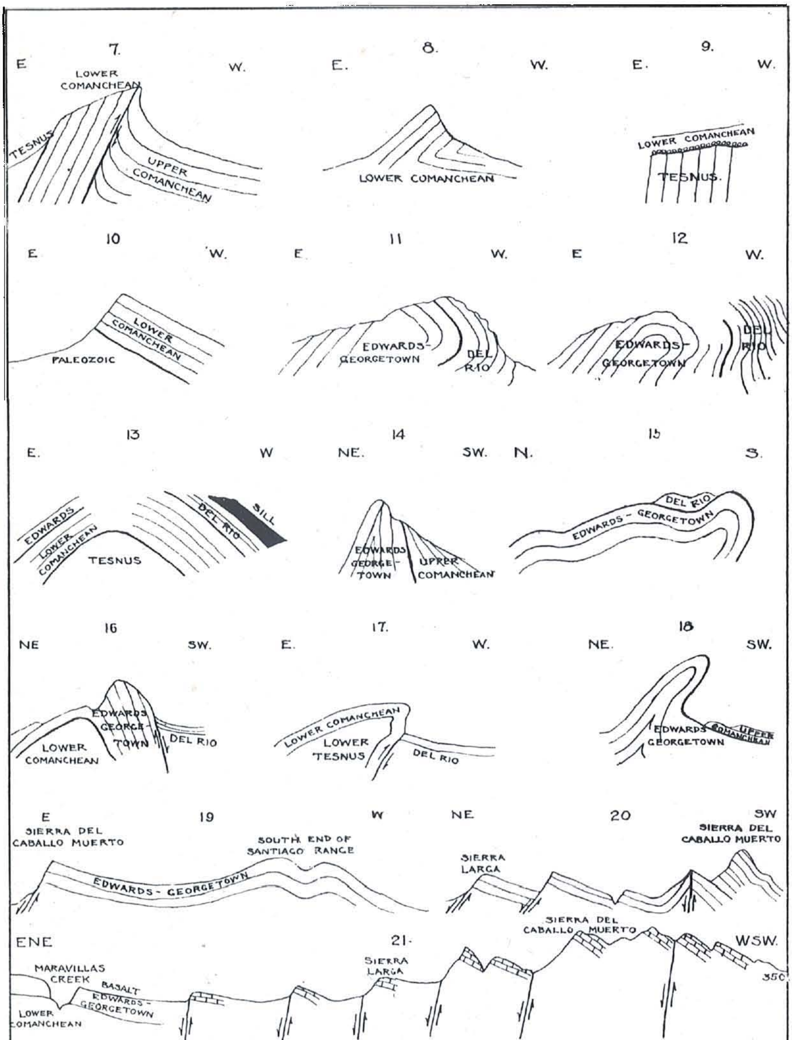
Summit ridge of Santiago Range, composed of sharply folded Fredericksburg Comanchean limestone

Plate 5b



Rio Grande river entering a canyon in westwardly-tilted fault block just east of the mouth of Stillwell Canyon

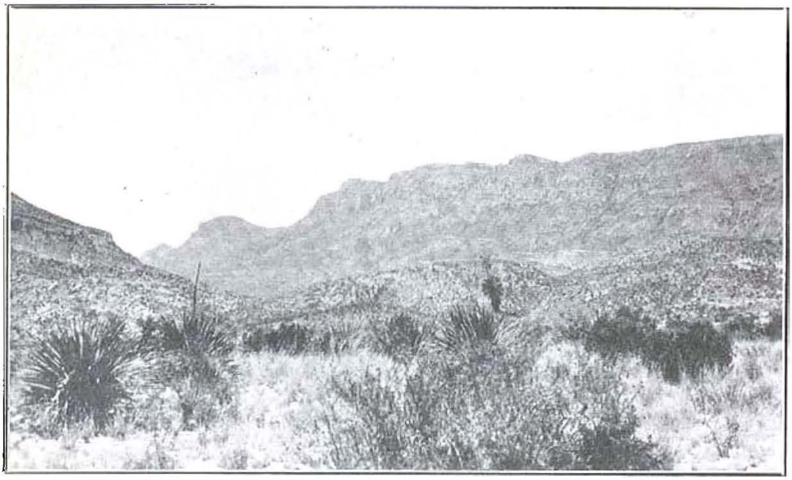
Plate 6



SKETCH SECTIONS OF SANTIAGO RANGE SOUTH OF SANTIAGO PEAK, AND OF NORTHERN SIERRA DEL CARMEN. FOR LOCATIONS SEE MAP.

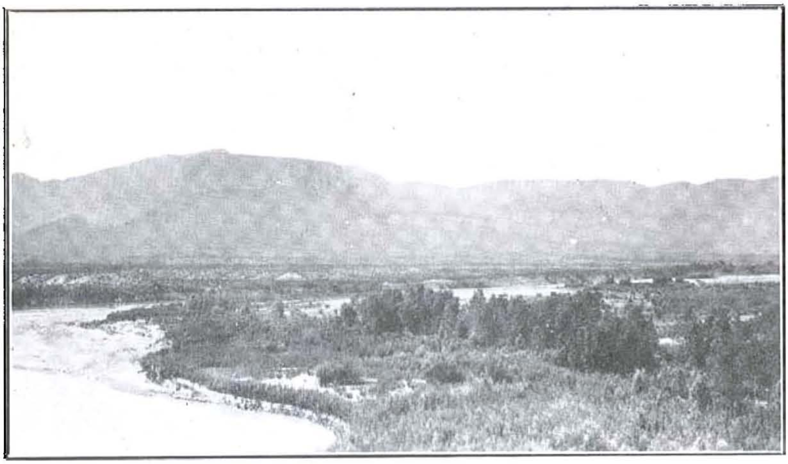
Sketch structure sections across the Santiago Range and the Sierra del Carmen. The numbers give location on geologic map

Plate 7a



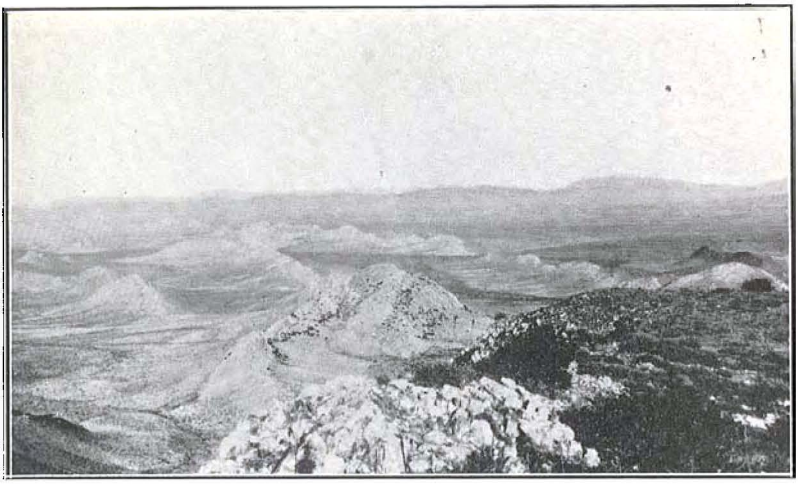
Fault scarp of later Comanchean limestone forming east side of Sierra Larga, Sierra del Carmen

Plate 7b

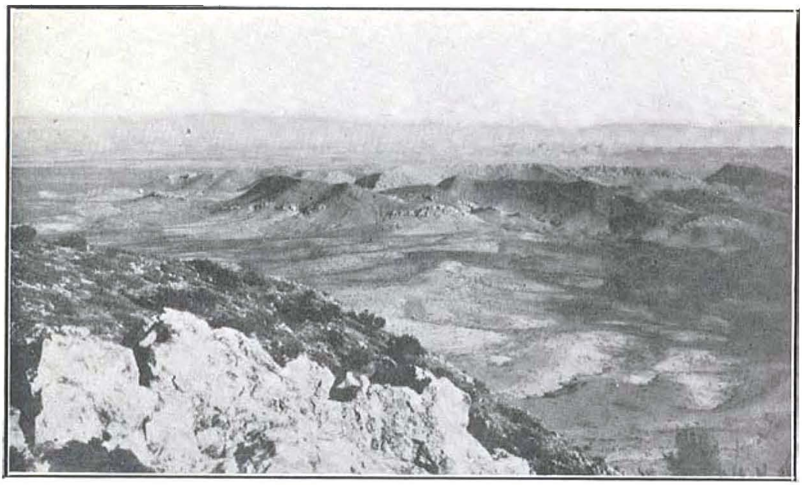


Widening of Rio Grande valley in the Vegas, showing alluvial terraces. Bluff walls are of later Comanchean limestones

Plate 8a



Caballos Mountain ridges of Caballos novaculite, looking south 75 degrees west from the summit of Caballos Mountain. Elephant Mountain is on the horizon to the left. The outcrop in the foreground is Caballos novaculite



Strike ridges of Hercynian folding in the southeastern part of the Marathon Basin. View looking north 20 degrees west from summit of Caballos Mountain directly toward Altuda Mountain. The light colored outcrops are Caballos novaculite

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