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GEOLOGY OF THE MARATHON REGION, TEXAS

BY

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By Philip B. King

ABSTRACT

This report describes the geology of the Marathon region, in trans-Pecos Texas. The Marathon region lies on the edge of the Mexican Highlands province, where that province merges into the Great Plains on the east. Structurally, the region is a broad dome of Cretaceous rocks, from whose central part the Cretaceous cover has been stripped away, leaving an area of low country in the center, the Marathon Basin. Here strongly folded Paleozoic rocks are exposed. The Monument Spring and Marathon quadrangles, described in detail in this report, extend across the basin area.

The Paleozoic rocks exposed in the basin and in the Glass Mountains, which flank it on the northwest, have a thickness of 21,000 feet. The greater part of them were laid down in a subsiding area, the Llanoria geosyncline. The oldest rocks are Upper Cambrian sandstones and shales, whose base is not exposed. Overlying them are 2,000 feet of Ordovician rocks, composed of shaly limestone and shale, with some beds of chert, whose chief fossils are graptolites. The Ordovician is overlain by the Caballos novaculite, possibly of Devonian age, which reaches 600 feet in thickness. This white siliceous rock is the chief ridge maker in the Marathon Basin.

The Caballos novaculite is overlain by a great series of clastic rocks of Pennsylvanian age, as much as 12,000 feet thick in the southeastern part of the area but much thinner in the northwest. Two of the lower formations are a mass of arkosic sandstone and shale and are separated by a widespread thinner limestone formation. The two formations contain few fossils other than land plants. The upper of the two contains a remarkable layer of mudstone, in which are embedded large blocks of older rocks. The blocks are believed to have been derived from the erosion of advancing thrust sheets and to have marked the first strong uplift in the region; they may have been transported to their present positions either by glaciers or by mud streams. The uppermost Pennsylvanian formation consists of conglomerate and sandstone derived from the erosion of rising folds and contains abundant upper Pennsylvanian marine fossils.

The strong deformation to which the Paleozoic rocks of the Marathon Basin have been subjected apparently culminated after the deposition of this uppermost formation of Pennsylvanian age. The Permian rocks of the Glass Mountains, to the northwest, rest, at least in places, with great angular unconformity on the disturbed older beds. The structural features seen in the basin consist of close folds, trending northeast and overturned to the northwest, which are broken by numerous thrust faults. The faulting culminated on the northwest in the nearly flat-lying Dugout Creek overthrust, with a known displacement of more than 6 miles. Farther southeast are other great thrusts, also with miles of displacement, some of which are folded and therefore older than the frontal fault. The folds of the Marathon region are a part of a system of structural features formed from the rocks of the Llanoria geosyncline, which extends northeastward in sinuous courses to the Ouachita Mountains of Oklahoma and Arkansas. Northwest of the geosyncline and folds of the Marathon region, during Paleozoic time, there was a foreland area, which was gently folded at the same time as the movements at Marathon. Southeast of them was a region underlain by pre-Cambrian crystalline rocks. Both these areas are now mostly concealed by Cretaceous and Tertiary rocks.

The Permian rocks of the Glass Mountains, 5,000 feet or more thick, consist of limestones, siliceous shales, clay shales, and sandstones, which interfinger in a most complex manner. The most striking stratigraphic features of the series as exposed in the mountains are limestone reefs, constructed in large part by lime-secreting organisms. The reefs apparently had a marked influence on the development of the other lithologic facies. The Permian rocks contain marine fossils, in places very abundantly. Most of the faunas are similar to the Guadalupian fauna originally described by Girty from northern trans-Pecos Texas. The Permian rocks are tilted to the northwest, away from the Marathon Basin, and are apparently in greater part younger than the folds in the basin.

The Cretaceous rocks that surround the Marathon Basin have a maximum thickness of about 1,200 feet and are mostly limestones. They were laid down on the eroded edges of the folded or tilted Paleozoic rocks, whose surface had been reduced to a peneplain during Triassic and Jurassic time. Over the Cretaceous west of the Marathon region lie lavas and tuffs of early Tertiary age. Within the region small masses of igneous rock, in part of alkalic composition, have intruded the Paleozoic and Cretaceous rocks.

The Cretaceous rocks dip gently away from the Marathon dome on its north, east, and south sides. On the west side they are sharply buckled and locally overthrust toward the west. The structural features on the west side of the Marathon dome are in part older and in part younger than the early Tertiary lavas. All the rocks of the dome are broken by normal faults that are younger than post-Cretaceous folds and probably of later Tertiary age.

No rocks younger than the Tertiary igneous rocks exist in the vicinity of the Marathon region except gravel deposits that cover part of the lowlands. These were deposited on various surfaces of erosion. The oldest stands several hundred feet above the present streams, and the gravel on it is probably of Pleistocene age.

The rocks of the Marathon region contain relatively few materials of economic value. Locally there are some metallic minerals, chiefly near the igneous intrusions. The hard siliceous novaculites of the Marathon Basin may be of use for whetstones or road metal. The jointed bedrock of the basin and its cover of gravel contain a supply of underground water. The area does not seem to be favorable for the accumulation of oil or gas.

INTRODUCTION

Location.—This report deals with the geology of the Marathon region, which lies in the northern part of Brewster County, in western Texas. Particular attention is paid to the geologic features exposed in the Monument Spring and Marathon quadrangles, which extend across the central part of the region and cover an area more than 30 miles east and west by 20 miles north and south. In order to complete the description of the Marathon region, some of the stratigraphic and structural features to the north and south of the two quadrangles are also noted.

The region is crossed from east to west by the main line of the Sunset Route of the Southern Pacific Railroad, upon which, about halfway across the area, is the village of Marathon, the only settlement. (See fig. 1.)

Previous work.—The Marathon region was mentioned in 1890 by Von Streeruwitz,[1] who noted northeastward-trending ridges south of Marathon composed of "quartz and quartzite, strongly metamorphosed limestone, and semifused siliceous conglomerations." He mistakenly correlated these with the Cretaceous rocks cropping out to the east and west, which he thought had here been "fused and thrown up by protrusive volcanic rocks."

A good description of the geologic features of the area was given by Hill [2] in 1900. After noting the character

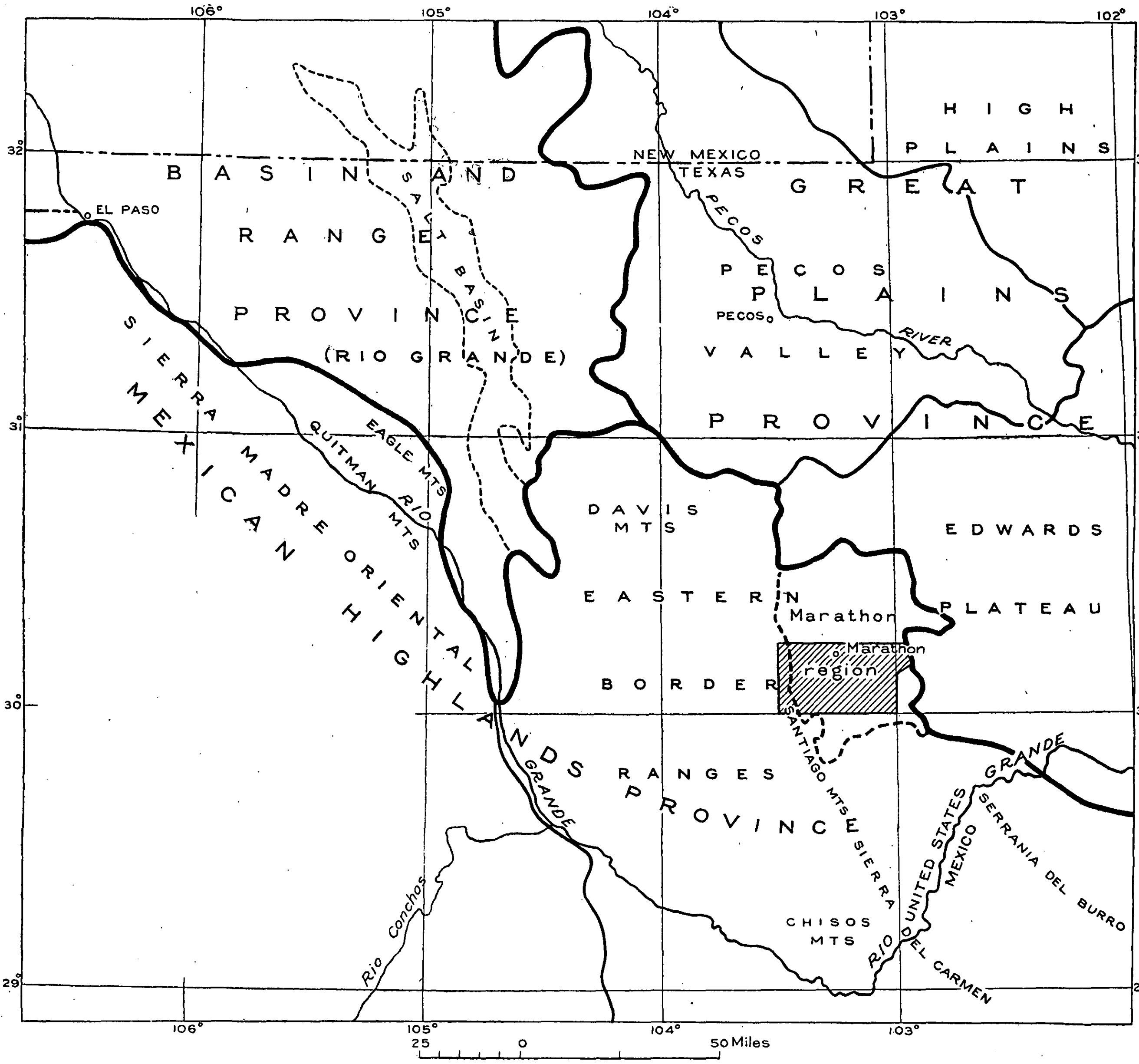


FIGURE 1.—Index map of trans-Pecos Texas showing location of Marathon region. The shaded area is that covered by the detailed geologic map (pl. 24).

[1] Von Streeruwitz, W. H., Report on the geology and mineral resources of trans-Pecos Texas: Texas Geol. Survey 2d Ann. Rept., for 1890, p. 686, 1891.

[2] Hill, R. T., Physical geography of the Texas region: U. S. Geol. Survey Top. Atlas, folio 3, p. 4, 1900.

of the Comanche or Glass Mountains, he described the Caballos Ridges, to the south. These were said to be "low ridges * * * rising from the floor of the Marathon plain * * . * composed of the degraded vertical edges of Paleozoic limestone, shales, and cherts * * * trending northeast and southwest. The cherts are often white in color and form the backbone of long ridges." On the south and east he found the region to be bordered by scarps and cuestas of "subhorizontal Cretaceous limestone unconformably resting on the subvertical edges of the Paleozoic rocks." He concluded that "the Caballos and Glass Mountains are exposures of ancient post-Paleozoic structure of Appalachian type and age, which have been revealed by the erosion of the Cretaceous sediments that probably once embedded them."

Observations made by Udden [3] in 1905 in the course of a journey to the Chisos country amplified the results of Hill. Udden noted the discovery of Ordovician and Carboniferous fossils in the Marathon region.

The comprehensive work in the region by Baker and Bowman [4] in 1915, as a part of their exploration of the southern front ranges of trans-Pecos Texas, revealed the broad outlines of the physiography, stratigraphy, and structure. Rocks of Cambrian age, Ordovician strata with fossils at four horizons, a probable Devonian formation, and four thick Pennsylvanian formations were recognized.

During the same period Udden [5] and Böse [6] studied the Glass Mountains, to the north of the Marathon Basin, and described the upper part of the Paleozoic section exposed there, which includes a great thickness of Permian strata.

The writer began work in the area in 1925. During this and two succeeding summers, associated with R. E. King, he studied the Glass Mountains and the adjoining part of the Marathon Basin for the Texas Bureau of Economic Geology.[7]

Field work.—The investigation that has provided the results for the present report was an extension of the earlier studies with R. E. King into an area adjoining on the south. The report is based on 8 months' field work in the region in 1929 and 1930 under the auspices of the United States Geological Survey. The season of 1929 was devoted to a reconnaissance of the entire Marathon Basin. In 1930 the Monument Spring and Marathon quadrangles were mapped in detail. Further observations were made during short visits in 1931.

At the beginning of the present investigation only the broader features of the structure and stratigraphy of the region were known. Because of the extreme complexity and small scale of the folds, the wide areas of valley fill, and the confusion that had arisen on some of the stratigraphic problems, many of the minor features of the region were poorly understood. The geologic mapping was therefore done with considerable care. Fortunately, excellent topographic maps were available for most of the area and could be used as a base for plotting geologic observations. The mapping was done pastly by an elaborate system of pacing traverses, and partly by recording the observations on enlargements of the topographic sheets. Stratigraphic sections were measured mostly by Brunton compass and by pacing. Where there were exceptionally good exposures, however, a tape measure was used.

Acknowledgments.—A small part of the field observations on which this report is based were taken from notes made by the writer when he was connected with the Texas Bureau of Economic Geology and from data furnished by E. H. Sellards, C. L. Baker, and others. Mr. Baker has also made available many recent fossil collections from the older rocks of the region, for study by paleontologists of the Geological Survey, and has joined the writer on several field conferences that made it possible to correlate the present work with that of Baker and Bowman in 1917. Much information on the fossil plants of the region has been afforded by collections sent to the Geological Survey by Sidney Powers. The report has also been materially improved by visits to the field with various members of the staff of the Survey, including David White, G. H. Girty, Edwin Kirk, G. R. Mansfield, and H. D. Miser.

After this report had been written the writer had the privilege of examining some excellent aerial mosaic maps of part of the Marathon Basin made by the Edgar Tobin Aerial Surveys, of San Antonio, Tex. Through the courtesy of this organization, he has been permitted to reproduce two of the single photographs from which the maps were made. (See pls. 17, 18.).

GEOGRAPHY

PHYSICAL FEATURES OF TRANS-PECOS TEXAS [7a]

The Marathon region is in trans-Pecos Texas, the westward-projecting part of the State that lies along the Rio Grande west of the Pecos River (fig. 1). Geographically, this arid and mountainous region is

[3] Udden, J. A., A sketch of the geology of the Chisos country, Brewster County, Tex.: Texas Univ. Bull. 93, pp. 18-21, 76-78, 1907.

[4] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern Front Range of trans-Pecos Texas: Texas Univ. Bull. 1753, pp. 67-172, 1917.

[5] Udden, J. A., Notes on the geology of the Glass Mountains: Texas Univ. Bull. 1753, pp. 5-59, 1917.

[6] Böse, Emil, The Permo-Carboniferous ammonoids of the Glass Mountains, West Texas, and their stratigraphical significance: Texas Univ. Bull. 1752, 1917.

[7] King, P. B., The geology of the Glass Mountains, part 1, Descriptive geology: Texas Univ. Bull. 3038, 1931. King, R. E., The geology of the Glass Mountains, part 2, Faunal summary and correlation of the Permian formations, with description of the Brachiopoda: Texas Univ. Bull. 3042, 1931.

[7a] For a description and classification of the physical features of the trans-Pecos region, based on somewhat different criteria, see Carter, W. T., and others, Soil survey (reconnaissance) of the trans-Pecos area, Texas: U. S. Dept. Agr., Bur. Chemistry and Soils, ser. 1928, no. 35, pp. 1-7, 1928.

more closely related to Mexico and New Mexico than it is to the rest of Texas. It is a region of rugged sierras, of high plateaus and broad cuestas, and of gently sloping intermontane plains. The mountains have no timber except in sheltered valleys and on the higher summits.

In the clear air of the desert the mountain masses loom with sharp outlines and clear detail from a distance of many miles, and the plains that surround them are deceptively foreshortened. More than half of the region is a lowland. These intermontane areas are either bolsons (structural depressions filled by mountain waste) or destructional plains that slope upward as pediments toward the mountain masses from which they have been carved.

Ephemeral streams, which are dry gravel beds most of the year, discharge from the mountains and flow across the plains. Some of these drain into bolsons with no outlet to the sea, such as the Salt Basin, in the northwestern part of trans-Pecos Texas (fig. 1). Most of the drainage channels, however, lead to the two master streams of the area, the Rio Grande and its major tributary, the Pecos River. Their waters flow to the Gulf of Mexico. The Rio Grande is noteworthy more for its persistence through long stretches of desert land than for its breadth or volume. In its southeastward course across the area the river traverses a succession of desert basins and passes from one to the next through separating mountain barriers in which it has cut narrow and imposing canyons.

The mountains, plains, and plateaus of trans-Pecos Texas have been formed by interaction between various crustal movements of post-Mesozoic age and by the forces of erosion working upon the disturbed crust. The forms thus produced are of varying character, and the area may be divided into several geomorphic and structural provinces.

Basin and Range province.—North of the Texas & Pacific Railway the mountain areas are broad and in part plateaulike, with one side presenting a steep escarpment and the other forming a gentle back slope descending from the crest. Between them are intermontane plains 5 to 15 miles across, whose margins rise as bajada slopes toward the mountains. These mountains are composed of rocks which have been very little folded but which have been broken in the later part of Cenozoic time into numerous fault blocks (pl. 22). Movement along the faults has served to outline the form of the mountain areas, and this form has been modified but slightly by subsequent erosion. The intermontane plains are mostly depressed areas filled by waste carried down from the mountains.

The mountains and desert plains of this part of trans-Pecos Texas resemble those in the adjacent part of central New Mexico, to the north, near the Rio Grande. They are also similar to those in the typical basin and range country farther west, and this part of trans-Pecos Texas is included in the Basin and Range province.

Mexican Highlands province.—South of the Texas & Pacific Railway block mountains of basin and range type are well developed in only a few areas. The mountains and plains are not caused directly by the uplift or depression of blocks of the earth's crust, but mostly by the differential erosion of bedrocks of varied character. The sedimentary rocks and the lava flows have been tilted, flexed, and in places strongly folded by crustal movements older than the block faulting of the basin and range province. In many places there are also masses of intrusive igneous rock. The nonresistant rocks of this region have been worn down into valleys and plains, and such harder rocks as limestones, thick lava flows, and igneous intrusions have been left as ridges, plateaus, and peaks. This area is the northern edge of a region of rugged highlands, whose greatest extent is in Mexico, south of the Rio Grande. It is here termed the "Mexican Highlands province."

The western part of the Mexican Highlands province in trans-Pecos Texas, comprising the Quitman and Eagle Mountains (fig. 1), consists of narrow parallel ridges and mountain chains of resistant, steeply tilted limestone and sandstone, between which are longitudinal lowlands carved from less resistant strata. In places the lowlands are covered to a moderate depth by later Cenozoic lake beds and alluvial deposits, but on the whole they seem to have been formed by erosion rather than by downfaulting or downwarping of the earth's crust. Similar parallel mountain ranges and intermontane lowlands are present southwest of the Quitman and Eagle Mountains, on the Mexican side of the Rio Grande, where they extend from the vicinity of El Paso southeastward past the great bend of the river and on into the interior of the State of Chihuahua (pl. 22, fig. 1). The two mountain ranges in Texas and the similar ranges to the southwest and south of them form the north end of the Sierra Madre Oriental of Mexico.

The eastern part of the Mexican Highlands province, comprising the eastern border ranges, is of greater diversity. Toward the north are the Davis Mountains (fig. 1), a high plateau broken up by canyons and in its more eroded parts separated into mesas, ridges, and isolated peaks. The Davis Mountains are carved from flat-lying or gently flexed lava flows. South of the Davis Mountains are various irregular mountain groups, some of them consisting of sharp peaks, and others of plateaulike blocks or narrow ridges. Between the mountains are lowland areas, some of which are smooth, gently sloping plains, whereas others have been greatly dissected and in part form picturesque badlands. The most conspicuous mountain group in the area, the Chisos Mountains, is a group of sharp peaks that stand in the center of a dissected lowland and are composed of masses of intrusive igneous rock and remnants of lava flows.

Southeast of the Davis Mountains and east of the Chisos Mountains are the narrow ridge of the Santiago Mountains and the high broken mountain mass of the Sierra del Carmen. These trend southeast and extend beyond the Rio Grande into Mexico. Northward the Santiago Mountains die out near the line of the Southern Pacific Railroad. The Santiago and Carmen Mountains are composed of folded, resistant limestones. East of the folds of these mountains are several domical uplifts (pl. 22). One of these, expressed topographically as the Serrania del Burro, lies wholly in Mexico, with its northern edges reaching up to the Rio Grande. It is a high dissected plateau, for the limestone cover of the dome is complete over its crest. Farther northwest, on the Texas side of the Rio Grande, is the Marathon dome. Here the limestone cover has been stripped from an extensive area on the dome's crest, and a lowland, the Marathon Basin, has been excavated from the nonresistant underlying beds.

Great Plains province.—East of the Marathon Basin are escarpments of limestone which form the west edge of an extensive plateau area. The plateau summits descend gently eastward from the flanks of the Marathon region and the Serrania del Burro. The 50- to 75-mile belt between the Marathon region and the Pecos River on the east consists wholly of such plateau country, which has been carved into a maze of canyons and low tablelands. The plateau region is the western edge of the Edwards Plateau section of the Great Plains province, which extends far eastward into central Texas.

CLIMATE

Trans-Pecos Texas has an arid or semiarid climate. The average annual rainfall at Marathon and nearby stations is about 17 inches. However, this figure is the average of greatly varying observations of many years, and the amount of rainfall is erratic in both extent and time. Some spots may receive half a dozen rains within a year, whereas others may remain nearly rainless for several years. The yearly rainfall at Fort Stockton, not far north of Marathon, has been as slight as 4 inches and as great as 34 inches, although its average is 15 inches.

One-half or more of the year's rainfall comes during the summer, when most of it is of torrential character. The precipitation during any one of such rains may amount to several inches. Now and then during this time there may be one or more weeks of continuous rain, when the mountains are cloaked in clouds. The entire rainfall of a year may be produced by only a few storms. During the winter some snow falls in the mountains, but as this is the dry part of the year, the amount of such precipitation is not great.

Temperatures at Marathon range from 110° in the summer to below zero in the winter, but ordinarily the variation is not so large. In the summer the diurnal temperature range is as much as 50°. Winds are strongest in the spring, when violent gales, without rain, may persist for a week or more. Violent wind storms of short duration at times accompany the summer thunder showers.

VEGETATION

The Marathon region and surrounding parts of trans-Pecos Texas have a vegetation adapted to the semiarid climate.[8] The smooth plains of the Marathon Basin are grass-grown, but in the low places, where ground water is nearest to the surface, there are expanses of creosote bushes (*Covillea*) and dense thickets of mesquite (*Prosopis juliflora*) and catclaw (*Acacia greggi*). Low rocky ledges in the plains and terraces of limestone gravel that fringe the mountains support clumps of sotol (*Basylirion wheeleri*), lechuguilla (*Agave lecheguilla*), and other yuccas. Prickly pear or nopal (*Opuntia*) and ocotillo (*Fouquieria splendens*) grow on the low foothills. Higher in the mountains a sparse growth of juniper and piñon spreads over the exposed surfaces and summits and gathers in groves on the northern shaded slopes. Small clusters of live oak and manzanita (*Arctostaphylos pungens*) grow in protected valleys. Near water holes and stretches of flowing water in the stream channels is a lush growth of reeds and alders, shaded by cottonwood trees. The giant cacti that characterize the Sonoran Desert farther west are lacking in trans-Pecos Texas, but otherwise there is much similarity in the vegetation of the two regions.

The region is most attractive in the spring when numerous small plants come into blossom, covering the hillsides with a mat of brightly colored flowers. After the summer rains also, the brown and barren hills turn green as the vegetation comes to new life. Some of the plants, by reason of desert adaptation, show an immediate and wonderful rejuvenation after these unexpected downpours. The leafy clumps of resurrection plants (*Selaginella pringlei?*), matted over many of the limestone surfaces, are dry and brown most of the year, but unfold and turn green within an hour after a rain.

[8] For a useful discussion of the vegetation of this part of Texas see Bray, W. L., The vegetation of the sotol country in Texas: Texas Univ. Bull. 60, 1905. A concise summary is also given in Carter, W. T., and others, op. cit., pp. 7-11.

EROSIONAL AGENCIES

Agencies observed in the Marathon region.—The sedimentary rocks of the Marathon region, especially the greatly deformed strata of Paleozoic age, have been prepared for weathering by previous jointing. Where they are least fractured and have the fewest bedding planes they stand as bold cliffs and hogbacks. The dominant rocks of the region, which are limestones of various sorts, weather chiefly by solution, despite the low humidity. Solution widens joints and fractures, makes channels, pits, and shallow depressions [9] on the exposed surfaces, and undermines ledges. In places, some of the granular limestones of Pennsylvanian age and crystalline dolomites of Permian age show a well-developed exfoliation of undetermined origin. The older Paleozoic cherts and novaculites are not affected greatly by either solution or exfoliation, but in most places they break down readily along closely spaced joints. Rock breakage by diurnal temperature change does not appear to be an important agent of weathering in any of the rocks of the region.[10]

The fractured blocks of limestone and chert are loosened from their parent ledges by frost action. Gravity and rain wash help carry them down the steep slopes below the outcrops. Many rock masses may also be broken from the cliffs by lightning, for scars apparently produced by its impact may be seen on the faces of the steeper bluffs at many places in the area.

Because of the dry climate, there is but a thin cover of vegetation and, in comparison with humid regions, a small amount of rock decay. The soils on the hillsides and mountain slopes are therefore thin and are full of angular rock fragments. Rock ledges are abundant on the slopes, except in the shaly formations, and even here gullies only a few feet deep lay bare the underlying strata. Talus is generally lacking.[11] In the plains the surficial material forms a thicker cover over the bedrock, but most of this has been washed in from the surrounding hillsides.

The surfaces of all the mountains, hills, and plains are covered with a network of watercourses, ranging from small gullies to broad, gravel-covered creek channels. This strongly suggests [12] that the dominant erosional agent of the region is running water. In the semiarid climate, however, the work of water is spasmodic, and the drainage channels are dry most of the year. After rains the water runs rapidly down the mountain slopes, discharging into rocky gorges in the mountains or directly onto the plains. There is so little vegetation and soil that not much rain water is absorbed where it falls. The drainage channels leading away from the storm area become rushing turbid rivers, with the flood waters at times advancing down the hitherto dry channel like a wall.[13] Sometimes the writer has heard these torrents emit a rumbling sound, doubtless from the impact of boulders against each other while in movement. Nearly all the erosion accomplished by the streams of the region takes place during the flood periods. Banks are deeply undercut at the stream bends, depressions are hollowed out in the channels, and gravel bars are shifted downstream. The undercutting is a phase of lateral corrasion, which, according to Blackwelder,[14] is "geologically * * * rapid, apparently more so than most other processes in the desert."

On the level plains the flood waters may spread far beyond the insignificant swales on the surface and flow down the slope as a mass of interlacing rivulets, or even as sheet floods a few inches to a few feet deep and several miles in width. In the path of sheet floods the writer has seen on the steeper slopes closely spaced shallow gullies and on the gentler slopes small heaps of sticks, rubbish, and fine mud. Erosion and deposition of this sort, accomplished by sheet floods, appears to be of minor consequence, and in the Marathon region at least sheet floods are not the important agent of erosion that McGee suggested.[15]

The flood waters eventually disappear into the gravel channels of the streams or in the alluvium of the plains. Very little of the run-off reaches the Pecos River or the Rio Grande by surface flow. However, there is much continuous underflow within the gravel beds of the channels. In the larger creeks there are stretches of permanently flowing water where the underflow is raised to the surface by sills of bedrock.[16]

During years of normal climate the wind is not an important agent in the erosion of the Marathon region. The most striking wind storms are the great gusts that precede summer thundershowers. These carry great quantities of dust into the air and sometimes even across the lower mountain ridges, but they are local in extent and erratic in direction. In dry years wind storms may occupy several weeks of the spring and may carry much suspended matter into the air. During the exceptionally dry winter and spring of 1933–34 such dust storms were more prominent than usual in trans-Pecos Texas. Many storms were observed by

[9] Udden, J. A., Etched potholes: Texas Univ. Bull. 2509, 1925.

[10] Blackwelder, Eliot, Exfoliation as a phase of rock weathering: Jour. Geology, vol. 33, pp. 793–806, 1925; Insolation hypothesis of rock weathering: Am. Jour. Sci., 5th ser., vol. 26, pp 97–113, 1933.

[11] Blackwelder, Eliot, Talus slopes in the Basin Range province [abstract]: Geol. Soc. America Proc., 1934, p. 317, 1934.

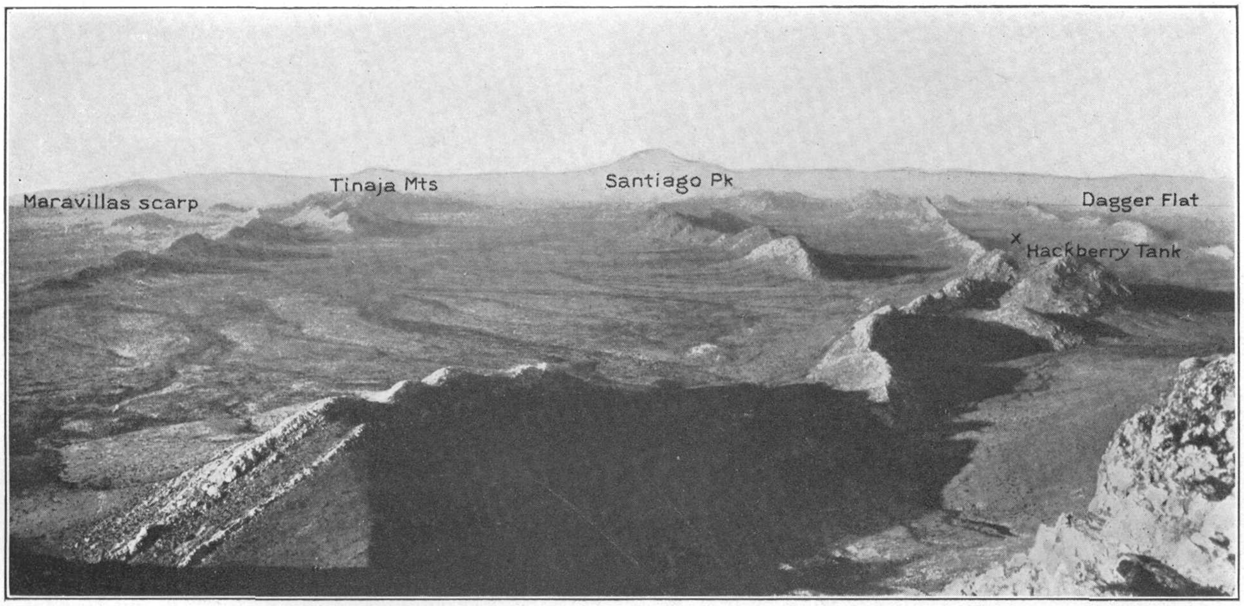
[12] The same criterion has been used by Bryan, Kirk, Wind erosion near Lees Ferry, Ariz.: Am. Jour. Sci., 5th ser., vol. 6, pp. 303–305, 1923.

[13] Shuler, E. W., A rise down canyon [Davis Mountains]: Sci. Monthly, vol. 31, pp. 129–133, 1930.

[14] Blackwelder, Eliot, Desert plains: Jour. Geology, vol. 39, p. 138, 1931.

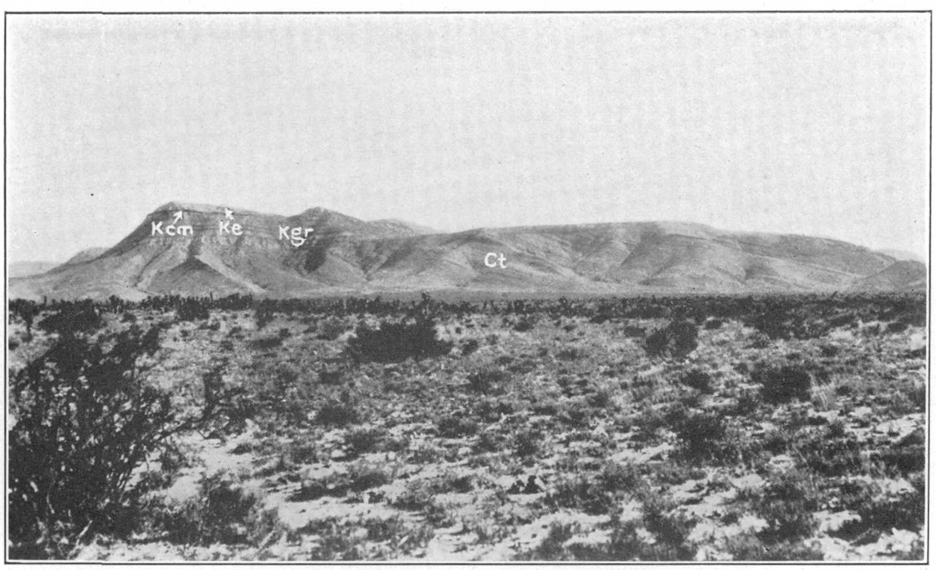
[15] McGee, W J, Sheetflood erosion: Geol. Soc. America Bull., vol. 8, pp. 87–112, 1897.

[16] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 163, 1917.



A. VIEW LOOKING SOUTHWEST FROM SUMMIT OF HORSE MOUNTAIN.

Shows novaculite ridges.



B. HOUSETOP MOUNTAIN FROM SOUTH.

Shows angular unconformity between Lower Cretaceous (Ke, Edwards limestone; Kcm, Comanche Peak limestone, Walnut Clay, and Maxon sandstone; Kgr, Glen Rose formation) and Pennsylvanian (Ct, Tesnus formation).

the writer during this period in the Guadalupe Mountains, northwest of the Marathon region. Most of them were accompanied by sharp changes in temperature; some were associated with strong winds, but in others the movement of air currents did not exceed 10 miles an hour. In all of them there was a persistent movement of air in some one direction, so that transportation of dust from one region to another apparently took place on a grand scale.

Such dust storms are exceptional under present climatic conditions, but they suggest that a relatively slight decrease in annual rainfall might permit much fine material to be carried from the region by deflation [17] and that this process may have been active during dry times in the past.

The only features that can be definitely attributed to wind work are the "charcos" found in low places on the plains, generally in areas of fine-grained alluvium. They are steep-banked circular or oval depressions, 10 to 25 feet in diameter, and 2 or 3 feet deep. They are probably caused by cattle in search of water trampling a wet place after a rain. The vegetation is thus destroyed, leaving mud exposed, and during dry seasons this is carried away as dust by the wind.[18] More conspicuous features ascribable to wind work, such as sand-blasted rocks and sand dunes, are entirely lacking.

Comparison of erosional agencies in arid and humid regions.[19]—In regions of arid climate, as a general rule, mechanical weathering dominates over chemical weathering, and on the steeper slopes rill wash is more effective than soil creep. Because of the lack of creep, steep mountain slopes tend to endure in the unconsumed areas of such regions until well along in the cycle of erosion, whereas in regions of humid climate they have at this stage changed to subdued forms. In arid regions the streams of both mountains and plains areas are intermittent rather than permanent, but because of the lack of vegetation the subdivision of the more steeply sloping areas into watercourses is much more minute than in humid regions. When the streams flow the material carried by them is larger in amount and coarser in texture than that of streams in humid regions. The profile of such streams, even at grade, is therefore relatively steep.

The erosional agencies of arid regions, being unlike those of humid regions, produce unlike land forms. Davis [20] notes that "the rocky and boulder-clad slopes of maturely dissected mountains in arid regions, together with the barren pediments below them", contrast strongly with "the soil-cloaked and forested slopes of maturely dissected mountains in humid regions, together with the fertile valley floors below them." He believes, however, that "their unlikeness is rather a matter of degree than of kind" and that "the unlike features are really homologous."

According to Davis,[21]

a very baffling problem is concerned with the relative rates of erosion and degradation in humid and arid regions. It seems as if humid stream erosion must * * * be more rapid than arid stream erosion in the early stages of an erosion cycle; also that, in a much later stage, degradation may be more rapid on the bare slopes of an arid region than on the plant-covered slopes of humid regions.

MARATHON REGION

GENERAL FEATURES

The Marathon Basin, on the crest of the Marathon dome, is 30 miles wide and 40 miles long and consists of plains, hilly lowlands, and low mountain ridges, carved from folded Paleozoic strata. The basin is surrounded by limestone escarpments, which stand higher than any of the ridges in the basin. On the east, south, and west sides the limestones of the escarpments are of Cretaceous age and are mostly gently tilted away from the uplift. On the north the Paleozoic rocks beneath the Cretaceous contain a resistant mass of limestone and form the broad cuesta-like upland of the Glass Mountains.

The Cretaceous rocks now found on the escarpments bordering the Marathon Basin at one time extended entirely over the crest of the Marathon dome. They have been stripped off the higher parts of the dome by recession of their cliffs and by the excavation of the weak underlying Paleozoic beds to form the Marathon Basin. These processes are still going on.

The northern part of the Marathon region slopes northward and northeastward toward the Pecos River, but the greater part slopes southward and is drained by Maravillas, San Francisco, and smaller creeks, which flow into the Rio Grande (fig. 9, B). The maximum relief in the Monument Spring and Marathon quadrangles is 2,700 feet. The lowest point, 3,450 feet above sea level, is on San Francisco Creek where it leaves the southeast corner of the Marathon quadrangle, and the highest summit is an unnamed peak in the Del Norte Mountains, 6,151 feet high, in the northwestern part of the Monument Spring quadrangle. Horse Mountain, the summit of one of the ridges of Paleozoic rock, is the highest peak in the Marathon Basin. Its crest, 5,010 feet high, is lower than the summits of any of the limestone escarpments on the rim. Most of the ridges in the basin are not more

[17] Blackwelder, Eliot, Yardangs: Geol. Soc. America Bull., vol. 45, pp. 164-165, 1934.

[18] This and other possible origins of charcos are discussed by Kirk Bryan (The Papago country, Arizona: U. S. Geol. Survey Water-Supply Paper 499, pp. 121-123, 1925).

[19] This subject has been treated at some length by W. M. Davis (Rock floors in arid and humid climates: Jour. Geology, vol. 38, pp. 146-149, 1930). It is also discussed in less technical form in his Physiographic contrasts, east and west: Sci. Monthly, vol. 30, pp. 501-519, 1930.

[20] Davis, W. M., Rock floors in arid and in humid climates: Jour. Geology, vol. 38, p. 145, 1930.

[21] Idem, p. 158.

than 700 feet above their surroundings, but the escarpments that encircle the basin rise 1,000 to 1,500 feet above the floor.

The physical features of the Marathon region have been formed by the differential erosion of resistant and nonresistant rocks by streams. Among the more resistant rocks are limestones, which, because of the semiarid climate, stand as hogbacks, steep-sided plateaus, and high mountains. The region as a whole has reached a mature stage of erosion. There are, however, wider areas of sloping plains and much steeper and more rugged unconsumed areas than would be present in similar areas at the same stage of erosion in a humid climate.

Superb views of the Marathon Basin are to be had from the high escarpments on its east and west sides (fig. 2). The panorama is particularly impressive from Housetop Mountain (fig. 2, A), a projecting tongue of the Cretaceous plateau on the east edge of the basin, whose western face rises as a bold cliff 1,500 feet above the basin floor. From this eminence, in the clear air of the desert, the whole basin and its surroundings appear spread out like a map.

On the sky line to the west and south rise the mountains of the Mexican highlands, which lie beyond the Marathon Basin. To the southwest are the rugged peaks of the Chisos Mountains, to the south the domelike mass of the Sierra del Carmen, gashed by the canyon of the Rio Grande. Farther east the Serrania del Burro and other ranges stretch far away into Mexico until they are lost in the bright haze of the horizon.

Between the observer and the mountains of the horizon are ridges and plateaus of lesser order. To the southeast are Cretaceous tablelands, sloping toward the east, intricately carved into canyons, whose sides are banded by limestone ledges, as straight as if drawn by a rule. Westward the tablelands rise and project in long promontories into the Marathon Basin. The limestone ledges at the ends of the promontories are broken into disconnected tables and conical buttes, perched on reddish rounded slopes and hillocks of Paleozoic rock. Here and there ledges are discernible in the lower beds, but these run at a steeper angle than those of the Cretaceous limestones.

In the middle distance, between the tablelands and the observer, are the hills and plains of the Marathon Basin. The flats, streaked in places by white gravel deposits, are covered by a lacy network of drainage channels, with fringes of dark vegetation. Between the flats are bare rocky ridges and miniature mountains, each of which assumes a color and form determined by the nature of the rock from which it has been carved. Near at hand are reddish hills and ragged ledges of sandstone and narrow hogbacks of limestone. Farther away, in the center of the basin, is a broad cluster of hills, streaked by white ledges of novaculite. From this distance, most of the hills have no evident plan or arrangement, and they are apparently turned and twisted in greatest confusion. Here and there, however, the eye can distinguish sharp ridges and chains of knobs in the white rock, and in places a spine of vertical strata projects above the rest.

Such a distant view, in a region of great complexity, can only reveal the outlines of the geography and geology and serve to arouse the imagination of the observer. If he should wish to untangle the geologic history of the land, he must descend into the plains, in order to analyze its many features.

ESCARPMENTS BORDERING THE MARATHON BASIN

Escarpments and plateaus on the east and south sides.—The Cretaceous limestone escarpments on the east and south sides of the basin stand 500 to 1,500 feet above the basin floor. These are parts of the high western dissected margin of the Edwards Plateau. East of the basin the plateau surface inclines gently eastward on the stripped bedding planes of resistant layers (pl. 1, *B*, and fig. 3, A). To the south the inclination of the strata is steeper, and here two prominent parallel limestone cuestas, called the Maravillas scarp by Hill,[22] face northward toward the basin (pl. 14, *B*, and fig. 3, B).

The rocks of the plateau consist of an alternation of resistant limestone layers with weaker beds of marl. Near the basin the cap rock of most of the escarpments is the Edwards limestone (pl. 13, *D*). The resistant beds of the Edwards and other limestones resemble "huge stone walls of so ancient a date that they have crumbled into ruins. The less resistant beds form less steep slopes covered with debris from the overlying more resistant layers, and the whole escarpment or canyon wall gives a buttress affect like that of ruined Gothic architecture."[23]

Drainage in the plateau country adjacent to the Marathon region is prevailingly consequent; the streams follow the slope of the Cretaceous surface and radiate from the Marathon dome (fig. 9, B). Several of the consequent streams head in the Marathon dome and flow eastward or southward into the plateau country. These have broken the escarpments at the edge of the Marathon Basin into separate segments and in places have reduced the segments to narrow promontories. The streams in the plateau have carved innumerable canyons, which have broken the originally continuous plateau surface into small areas of tableland.

In one of the canyons east of the Marathon Basin there is evidence of a relatively recent drainage change.

[22] Hill, R. T., Physical geography of the Texas region: U. S. Geol. Survey Top. Atlas, folio 3, p. 4, 1900.

[23] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 133, 1917.

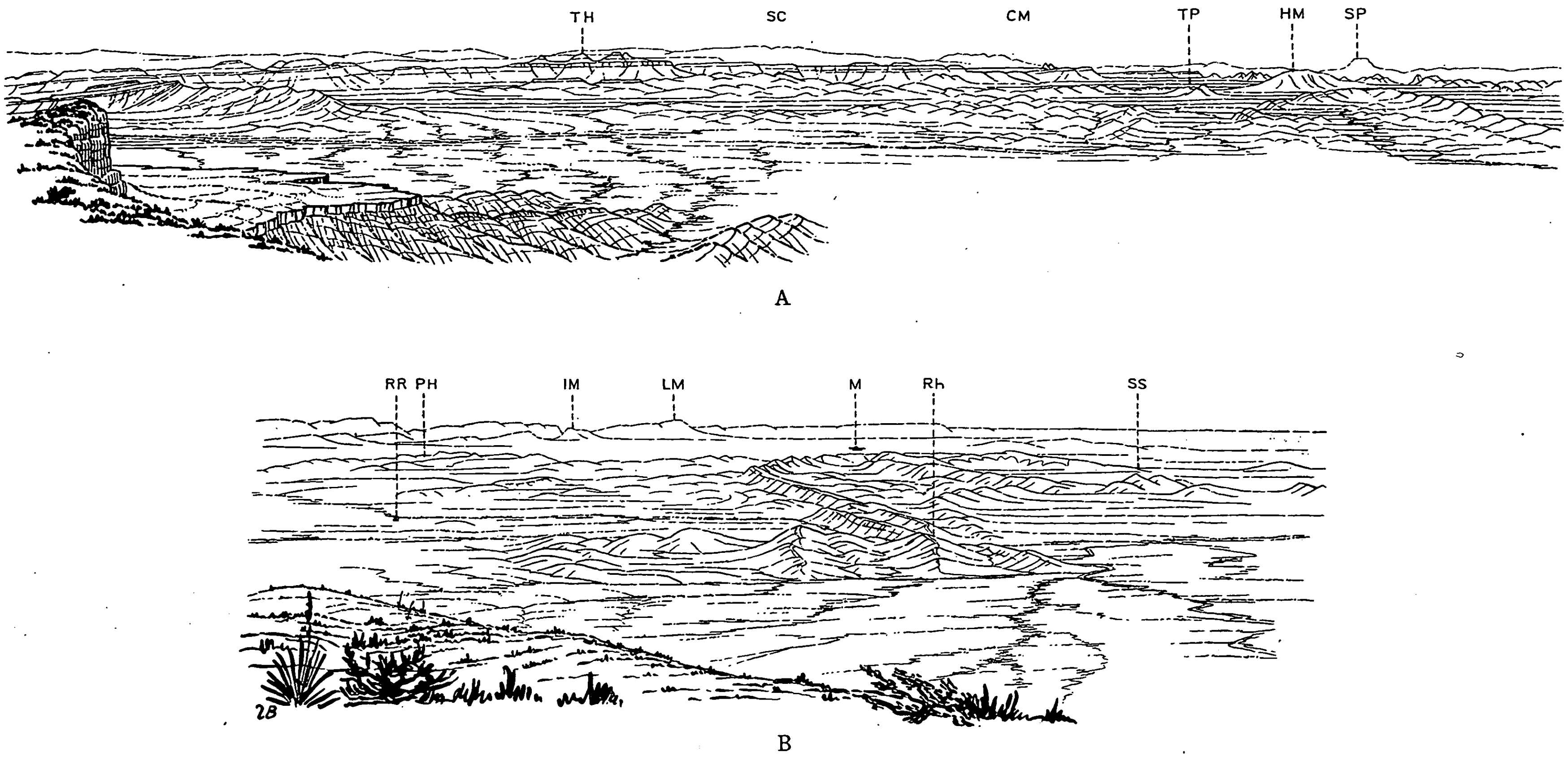


FIGURE 2.—Views of the Marathon Basin from the escarpments on the east and west. (See also pl. 1, *A*, a view of the basin from the top of Horse Mountain.) A, View from summit of Housetop Mountain south and southwest across Marathon Basin. On the left and in the background are the eastern and southern bordering escarpments of Cretaceous limestone. TH, Tres Hermanas Mountain; SC, Sierra del Carmen; CM, Chisos Mountains; TP, Twin Peaks; HM, Horse Mountain; SP, Santiago Peak. (Compare pl. 1, *B*, a view of Housetop Mountain from the plains to the south.) B, View from summit of Del Norte Mountains 2 miles north of Del Norte Gap, looking northwest across Marathon Basin. The Glass Mountains form the sky line on the left. RR, Roberts Ranch; PH, Payne Hills; IM, Iron Mountain; LM, Leonard Mountain; M, Marathon; Rh, Rock House Gap; SS, Sunshine Springs.

A broad valley, followed by the Southern Pacific Railroad, branches from Dry Canyon about 20 miles east of the edge of the Marathon Basin (fig. 9, B, and preliminary topographic map of the Longfellow quadrangle). The upper part of this valley, near the Marathon Basin, drains, not into Dry Canyon, but into Maxon Creek, which leaves the broad valley and flows southward through a narrow gorge into San Francisco Creek. It would seem that Maxon Creek, cutting headward from San Francisco Creek in relatively recent geologic time, captured the headwaters of a stream flowing eastward into Dry Canyon (fig. 9, A).

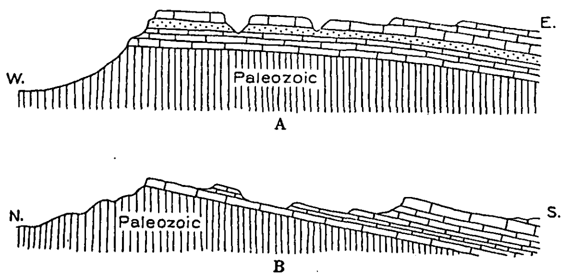


FIGURE 3.—Sections of the Cretaceous escarpments on the east (A) and south (B) sides of the Marathon Basin. The southern scarp has been called the Maravillas scarp.

Most of the upland surfaces of the plateau country stand at accordant levels. These are not ancient uplifted peneplains, but plains that follow the upper surface of some resistant stratum of limestone, from which the overlying softer beds have been removed by erosion.[24] The effect of the resistant, flat-lying beds on the topography is so great that it is difficult to prove the existence of any former levels of erosion higher than the present one in the plateau. In the country southeast of the Marathon Basin, however, are some remnants of old gravel deposits on the divides between the present streams. These have been mapped by N. H. Darton in the region between the lower course of San Francisco Creek and Dryden, 50 miles to the east (fig. 4).

[24] Blackwelder, Eliot, Desert plains: Jour. Geology, vol. 39, pp. 134–135, 1931.

One such deposit was examined by the writer on the highway between Dryden and Sanderson. It consists of well-rounded cobbles, 2 feet in maximum diameter, of chert, novaculite, and sandstone from the Maravillas, Caballos, and Tesnus formations of the Marathon Basin. There are also some cobbles of Cretaceous limestone and of volcanic rock like that now seen only northwest of the Marathon Basin. The eastward trend of the remnant gravel areas diverges at a wide angle from the courses of the present streams and the slope of the country, and none of the streams near the eastern gravel areas now head in the Marathon Basin, from which most of the material was derived. The gravel may have been deposited by one stream or several streams, but in any event it suggests a very different topography at the time of deposition from that of the present.

Escarpments on the north side.—On the northern border of the Marathon Basin are the Glass Mountains, an asymmetric cuestalike upland trending northeast, carved from northwestward tilted limestones, sandstones, and shales of Permian age. The southward-facing front of the range is dissected into cuestas capped by resistant limestone beds, which are separated by lowlands or slopes carved from sandy and shaly beds. In

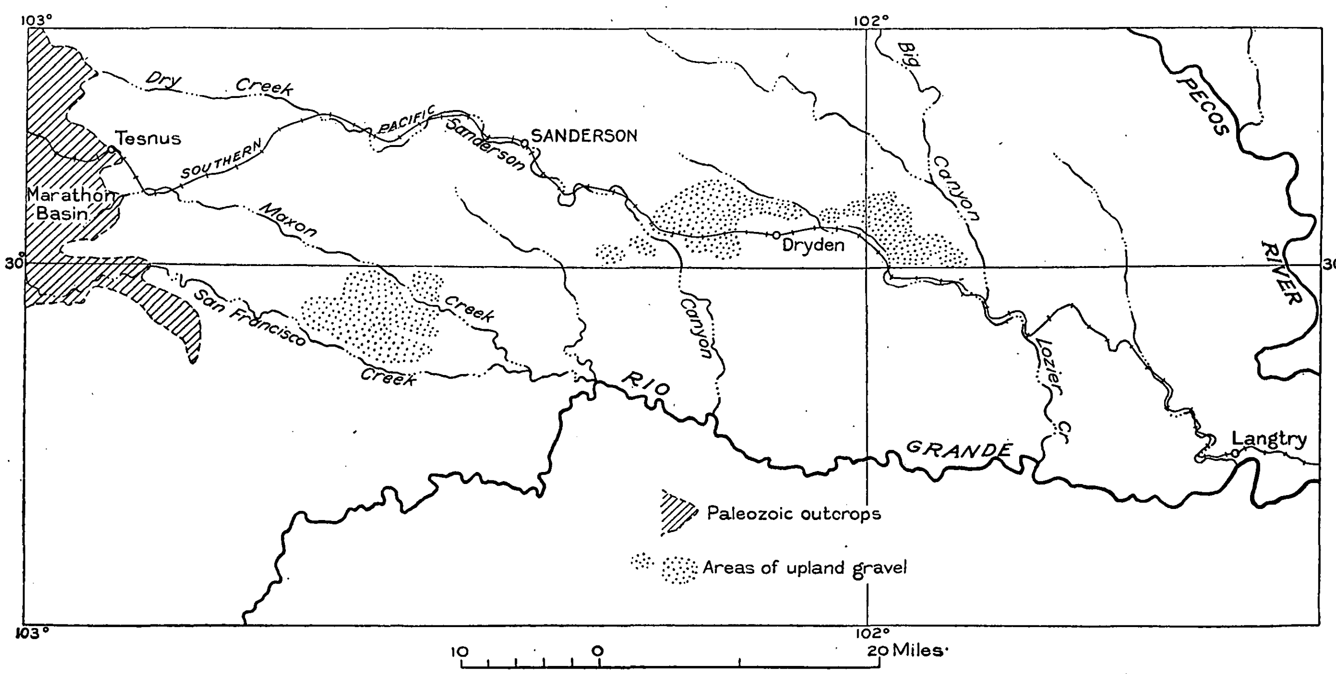


FIGURE 4.—Map showing deposits of gravel on the uplands east of the Marathon region. From data furnished by N. H. Darton.

the northeastern part of the mountains (as shown on the map of the Hess Canyon quadrangle), the face of the escarpment that borders the Marathon Basin is remarkably straight and steep and simulates a fault scarp.

An examination of the structure and stratigraphy proves that there are no faults here. * * * The strike of the strata in the scarps is parallel with the direction of the scarps * * * [and] the dip of the strata is * * * in the opposite direction from that toward which the escarpments face.[25]

The crests and back slopes of the Glass Mountains are composed of massive dolomite. The back slope differs from that of a true cuesta in that it is not controlled by the dip of the beds that underlie it but by the stripped surface of the ancient peneplain on which the overlying Cretaceous strata were deposited. This surface also declines northwestward, but at a slighter angle than the Permian dolomites. From it, in the mountain area, most of the Cretaceous rocks have been carried away by erosion.[26]

Most of the streams that drain the north and northwest slopes of the Glass Mountains are consequent streams that follow low places in the folded surface of the Cretaceous rocks. Most of them do not show a close relation to the numerous northwestward-trending normal faults that disturb the rocks of the mountains; they cross them at right or oblique angles, and although most of them flow from upthrown to downthrown blocks, some flow from the downthrown to the upthrown. There is, however, one conspicuous exception. Hess Canyon, a straight, narrow gorge in the northeastern part of the mountains, follows the northwest trend of the faults and is structurally a narrow graben. "When the long, narrow wedge of Hess Canyon sank to form a deep graben, the previous consequents crossing its site could no longer maintain their flow and were diverted into a new consequent course along the bottom." [27]

Escarpments on the west side.—The escarpments on the western margin of the Marathon Basin are known as the Del Norte Mountains in the north, and the Santiago Mountains in the south (pl. 23). The two ranges are separated near the boundary between the Monument Spring and Santiago Peak quadrangles by Del Norte Gap, but structurally they are a continuous chain. The limestones that compose them are in some places as flat as the strata on the east margin of the basin, but in others they are considerably folded and faulted. The mountains are cut by several gaps. In the north is Doubtful Canyon (pl. 24), followed by a tributary of Maravillas Creek, which flows eastward across the mountains into the Marathon Basin. Next to the south is Del Norte Gap (pl. 13, *B*, and map of Santiago Peak quadrangle), which lies on a divide and is not now followed by any stream. South of the Marathon Basin the Santiago Mountains are also cut by the wind gap of Persimmon Gap and the water gap of Dog Canyon (both in the Bone Spring quadrangle).

The Del Norte Mountains are an upland, several miles broad and about 20 miles long, formed of limestones gently tilted toward the west. Eastward, they face the Marathon Basin in a steep, fairly straight escarpment, indented by few valleys. At the foot of the escarpment is a fault that has raised nonresistant Paleozoic beds on the east against Cretaceous limestones on the west (fig. 5, A). The escarpment has been caused by the wearing away of the nonresistant up-faulted beds, leaving the resistant down-faulted beds relatively undissected (fig. 5, B). It is thus an obsequent fault-line scarp.[28]

The Santiago Mountains are about 40 miles in length and extend for some distance south of the southwest corner of the Marathon Basin. (See maps of Santiago Peak and Bone Spring quadrangles.) For most of their length they are a steep-sided ridge scarcely 2 miles across, carved from a narrow belt of vertical limestones (fig. 5, D). To the north, high mesas of flat-lying limestone, the Cochran Mountains (pl. 23, sec. Q–Q′–Q″; pl. 21; and map of Santiago Peak quadrangle) lie between them and the Marathon Basin. The Santiago Mountains owe their height partly to a large normal fault that has downthrown the Cretaceous beds on the east (fig. 5, C), but erosion has in most places leveled off the up-faulted beds for several miles west of its trace.

The escarpments of the Del Norte, Cochran, and Santiago Mountains are flanked on the east by pediments, or rock-cut plains, which slope down to Maravillas Creek on the east. The plains are covered by a thin layer of limestone gravel washed down from the mountains. In the Del Norte and Cochran Mountains, where the resistant limestone beds lie flat, recession of the cliffs has taken place by sapping of the nonresistant Paleozoic shales beneath. Considerable recession has apparently taken place in fairly recent time, when Maravillas Creek and its tributaries trenched the gravel of the pediments. As a result, the mountains north and south of Del Norte Gap are flanked by a lowland carved from shale, beyond which, at a distance of about a mile, are cuestalike remnants of gravel, sloping to the east and with their steepest

[25] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 160, 1917.
[26] King, P. B., Geology of the Glass Mountains, part 1, Descriptive geology: Texas Univ. Bull. 3038, p. 22, 1931.
[27] Idem, p. 29.
[28] Blackwelder, Eliot, The recognition of fault scarps: Jour. Geology, vol. 36, pp. 305–306, 1928.

inclination near the mountains.[29] The cuestalike areas of gravel probably extended up to the bases of the escarpments when they stood farther forward than now.

Relation of escarpments bordering the Marathon Basin to the later tectonic movements.—The writer believes that most of the physical features to be seen in the escarpments bordering the Marathon Basin have been formed by the stripping of the Cretaceous cover from the crest of the Marathon dome. He therefore considers it probable that they have resulted from the erosion of rocks of different composition and structure and that they are not caused directly by doming, folding, or faulting.

In order that the reader may understand the problem, it seems desirable that the Tertiary structural history of the Marathon region as worked out by the writer and as more fully described on later pages be summarized at this place. Since the withdrawal of the seas, at the end of Cretaceous time, the Marathon region has remained as a land area. After the Cretaceous period two groups of rocks were laid down on parts of the surface in trans-Pecos Texas—the lava flows and associated sediments of the Davis Mountains country and the bolson and lacustrine deposits of the basin and range country. No remnants of these rocks are now found within the Marathon region, and it seems improbable that either of them were ever laid across the region in any great thickness. After the emergence of the Marathon region from the Cretaceous sea, it was subjected to three periods of movement. The movements in the first two periods, one of which was older and the other younger than the lavas to the west, caused the broad doming of the Marathon region and produced local sharp folding and thrust faulting in the Del Norte and Santiago Mountains on the west. The last movement, considerably later than the other two, broke the rocks of the region into fault blocks; its effects are particularly marked in the Glass, Del Norte, and Santiago Mountains.

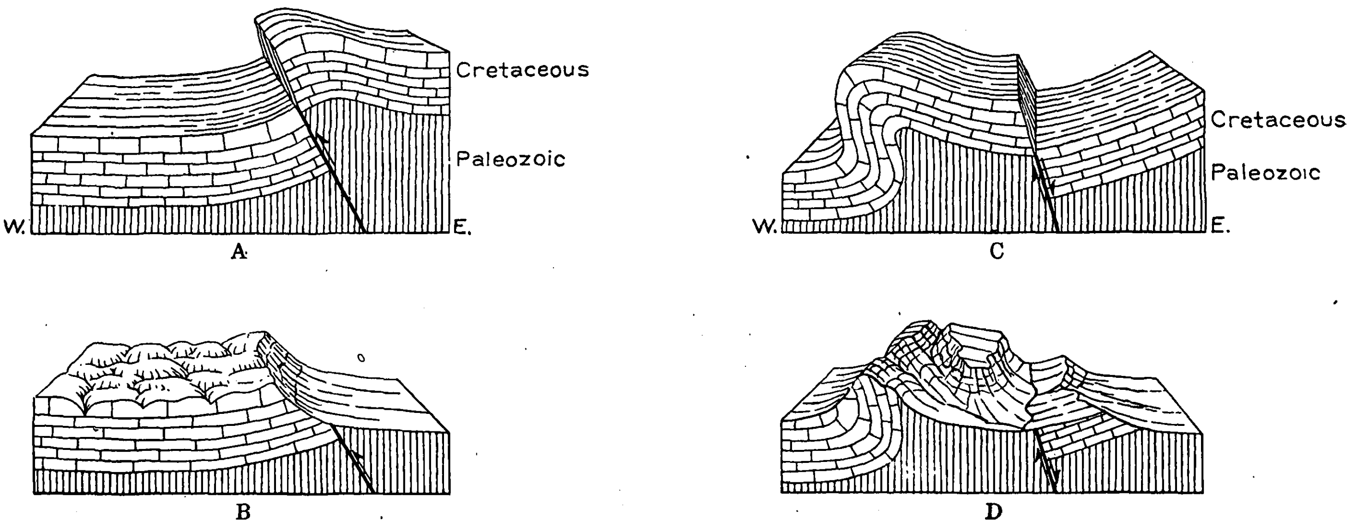


FIGURE 5.—Block diagram of the escarpments on the west side of the Marathon Basin. The upper diagrams (A and C) show the form of the restored structural surface, and the lower diagrams (B and D) show diagrammatically the present surface form. A and B are in the Del Norte Mountains. Here erosion has carved out the weak beds on the upthrown side of the fault so that the resistant beds on the downthrown side stand up in an escarpment (an obsequent fault-line scarp). Compare sections M-M′ and N-N′, plate 21. C and D are in the Santiago Mountains. Here the resistant beds on the west have been raised to their present position by a normal fault. Erosion of the raised beds in places makes an escarpment near the fault line (as toward back of block), but in others has cut back into steeply folded beds to the west (as toward front of block). Compare sections Q-Q′-Q″, R-R′, and S-S′, plate 21.

A somewhat different interpretation, however, has been made by Baker, who believes that "from the standpoint of physiographic development the doming of the Cretaceous rocks rimming the Marathon Basin probably occurred long subsequent to the Laramide movements, and very possibly as late as the Lafayette",[30] an interpretation which implies that the last folding was sufficiently recent to have had a direct influence on the aspect of the present land forms. The surface rocks of the Del Norte and Santiago Mountains are thought by him to be "the surface rocks at the time the latest deformation began",[31] and the streams in the water gaps of Doubtful and Dog Canyons are interpreted as "almost certainly antecedent." [32]

It seems probable that the Marathon region has been more or less actively eroded during the whole time since the last doming and that nearly all the present surface features have resulted from that erosion. The steepness of many of the escarpments, particularly on the west side of the basin, appears to be a normal feature of the desert landscape, even in a region of as

[29] Compare the description of similar features along the base of the Book Cliffs by W. S. Glock (Premonitory planations in western Colorado: Pan-Am. Geologist, vol. 57, pp. 32–33, 1931).

[30] Baker, C. L., Date of the major diastrophism and other problems of the Marathon Basin, trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., vol. 12, p. 1115, 1928.

[31] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 168, 1917.

[32] Idem, p. 148.

mature dissection as this one. In places, it is true, the ridges follow the structure of the rocks within the mountains, but these ridges are composed of resistant Cretaceous limestone. That they have been produced by the stripping of nonresistant beds from their surface seems probable, and a thick sequence of such rocks, of later Cretaceous age, is exposed on the west flanks of the Del Norte and Santiago Mountains.

Moreover, these two mountain ranges, at least in the Marathon region, are not simple anticlines, but are the overturned and much faulted western limb of the Marathon dome (fig. 5 and pl. 21). The Marathon Basin, to the east of them, is structurally much higher than these mountains and has been reduced to its present low altitude by the erosion of the weak rocks that underlie it. In one of the places where the structurally greater altitude of the basin area has been caused by faulting the down-faulted rocks now rise above the up-faulted rocks in an obsequent fault-line scarp. As the region east of the mountains has a greater structural height than its surroundings, it seems rather improbable that such streams as that in Doubtful Canyon, which flow eastward across the mountains and into the basin, could have existed before the doming and maintained their courses in the face of such adverse conditions. On the contrary, it seems probable that the gaps in which these streams flow might at one time have been occupied by streams that drained westward down the structural surface of the dome, and that such streams were afterward captured by subsequent streams actively cutting in the weak rocks of the basin (fig. 9, A and B).

The normal faults of the Glass, Del Norte, and Santiago Mountains are considerably younger than the last time of doming and apparently had a much more direct influence on the topography. Thus in the Glass Mountains most of the streams seem to follow the structural lines produced by the folds but not the faults, as if they had come into existence before the time of faulting. Moreover, in at least one place, Hess Canyon, the faulting seems to have formed a new consequent stream, which cuts across the older drainage lines.

RIDGES OF THE MARATHON BASIN

The strongly folded and faulted Paleozoic rocks of the Marathon Basin have been revealed by the stripping of the cover of Cretaceous limestones from the crest of the Marathon dome. They are a fragment of the denuded roots of a widely extended mountain system, formed in the later part of Paleozoic time. The folds strike northeast, at right angles to the trend of the post-Cretaceous uplifts, and the extensions of the folds on each side are concealed by the cover of younger rocks.

Two rock formations, more resistant than the rest, stand as ridges in the Marathon Basin. The lower of these stratigraphically is the Caballos novaculite, at the top of the pre-Carboniferous succession; the upper is the Dimple limestone, lying within the Carboniferous. As the resistant beds are in all places vertical or steeply tilted, the ridges are narrow and are breached at many places by gaps or sags.

> 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 (compare pl. 24, *D* and *F*) by the fortuitous circumstance of being denuded of the mantle accumulated on them by the sea, which had formerly entirely buried their ancient summits.[33]

Novaculite ridges.—The novaculite rises in white ridges of bare rock, mostly monoclinal, supported on the inner side by beds of chert and limestone (pls. 1, *A;* 7, *B;* fig. 2, B). Soft shales lie on both sides of the resistant beds, and their nonresistance to erosion accentuates the sharpness of the ridges. Novaculite hogbacks enclose the excavated cores of two broad anticlinoria in the western part of the basin (pl. 23). Between the anticlinoria, shorter but no less conspicuous novaculite ridges are carved from lower anticlines and thrust blocks. On the flanks of the anticlinoria the hogbacks run nearly straight and unbroken, save for water gaps of superimposed streams. Where the older rocks pitch beneath the surface on the northeast and southwest ends of the anticlinoria, the novaculite hogbacks pass into convoluted zigzag ridges, which wind across the axes of the plunging folds. The Warwick and Lightning Hills, 8 miles east of Marathon, are a maze of such winding hogbacks (pl. 19, *C*).

The lesser folds, between the anticlinoria and to the south of them, present all stages of degradation, from broad-backed mountains well expressing the doubly plunging anticlinal structure to mere chains of knobs projecting above the plain. The crest of Horse Mountain is still sheeted over by novaculite (fig. 6, A), as this stratum is thicker here than elsewhere. Some other mountains, stripped of this resistant member, still show their anticlinal form in the cherts and limestones beneath. Many more, like East Bourland Mountain (fig. 6, B, and pl. 6, *A*, *B*), are partly breached by axial anticlinal valleys that penetrate weak shales in the core. One of them, the largest of the Woods Hollow Mountains (fig. 6, C), has a wide depression down its center excavated from the shales, from which projects a low ridge of the next resistant member below. This axial depression is drained by a water gap scarcely 100 feet wide in the encircling novaculite ridge.

Dimple limestone ridges.—The limestone ridge maker does not rise as high as the novaculite, and its ridge

[33] Baker, C. L., and Bowman, W. F., op. cit., pp. 162-163.

crests are breached more widely by superimposed streams. Its hogbacks surround synclinal areas and are most extensive in the eastern and northeastern parts of the basin (pl. 23). Those near Haymond, in the eastern part of the basin, extend in great curves around broad synclinal plains. One of these is shown, just below Horse Mountain, in figure 2, A. In the western part of the basin the limestone ridges are less extensive. The most prominent one, West Bourland Mountain, rises out of a synclinal lowland between novaculite ridges. It is a remnant patch of limestone 2 miles long, presenting steep faces outward on all sides but with a synclinal valley hollowed out in the center (pl. 6, *C*). In the southern part of the basin the Carboniferous sandstones also stand at considerable height and are carved into rugged tracts of broken ridges and ledges. These areas are locally known by such descriptive titles as Hells Half Acre and Devils Backbone.

Even summit levels on the ridges.—Many of the hogbacks, of both the limestone and the novaculite, are conspicuously even-crested (fig. 8). Near the center of the basin most of the summits stand at about 4,500 feet, but toward the south, east, and west they gradually decline in height. Two or three ridges, such as Horse Mountain and Simpson Springs Mountain, rise conspicuously above this general level.

Unlike the even summits on the Permian dolomites in the Glass Mountains,[34] the even summit levels in this area probably do not represent the resurrected base of the Cretaceous, for in the surrounding escarpments the base of the overlying Cretaceous beds lies at a higher altitude. There is a possibility that the even summits may represent the last remnants of one or more former high-level surfaces of erosion, now preserved only on the harder rocks of the region; if this is true, too little now remains to tell much about their character.

There is a stronger possibility that the regularity of the summit levels was produced during the last or next to the last cycle of erosion by backward cutting of the ridge slopes from the rock floors on each side. The adjacent rock floors slope in a similar direction to the crests of the ridges and at about the same angle. If the hard rocks were approximately uniformly jointed everywhere, they would tend to produce ridges having nearly the same angle of slope at all places. As the hard rocks are of small but nearly constant thickness, the ridge crests might therefore have a nearly constant height above the rock floors.

LOWLANDS OF THE MARATHON BASIN

Rock floors, their nature and origin.—Under the influence of the semiarid climate erosional agencies have worn down the nonresistant rocks of the Marathon region into rock floors of wide extent. These closely resemble the worn-down surfaces which observers of desert land forms have variously termed "pediments",[35] "graded plains",[36] suballuvial benches" and "subaerial platforms",[37] "rock floors",[38] and "planes of lateral corrasion."[39] The term "pediment", which is most widely used for these features, is not entirely appropriate for the Marathon region, because it implies a sloping rock-cut plain fringing a mountain base, whereas the surfaces in the Marathon region may be unrelated to any mountain area. For them, Davis' term "rock floor" seems preferable, but the term "pediment" will be used for rock floors of steeper inclination near the mountain areas.

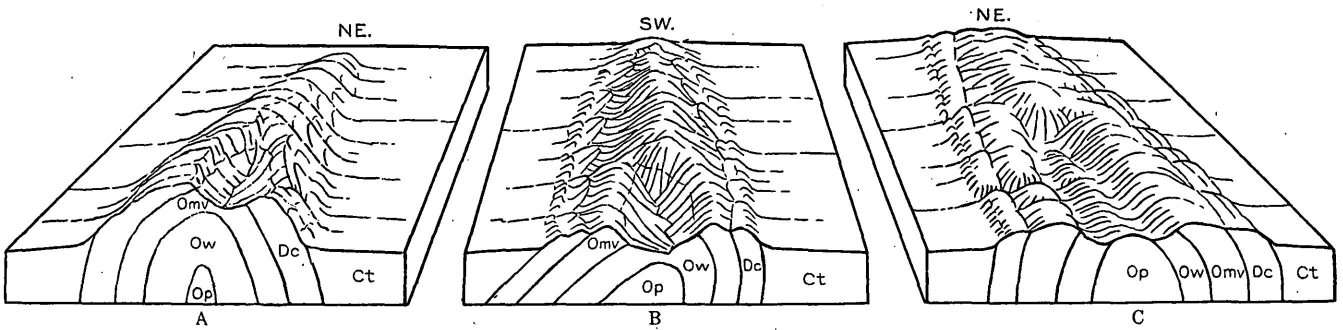


FIGURE 6.—Block diagrams of three anticlinal mountains in the Marathon Basin, arranged in sequence to show forms displayed during the course of their erosion. Op, Fort Peña formation (resistant); Ow, Woods Hollow shale (nonresistant); Omv, Maravillas chert; and Dc, Caballos novaculite (resistant); Ct, Tesnus formation (nonresistant). A, Horse Mountain, which is covered by novaculite; B, East Bourland Mountain, where the novaculite cover is removed and where there is a small axial anticlinal valley cut in the Woods Hollow shale; C, mountain between Woods Hollow and Little Woods Hollow, with an extensive axial anticlinal valley and a low axial ridge on the Fort Peña formation in the center.

[34] King, P. B., The geology of the Glass Mountains, part 1, Descriptive geology: Texas Univ. Bull. 3038, p. 22, 1931.

[35] McGee, W J, Sheetflood erosion: Geol. Soc. America Bull., vol. 8, pp. 92, 110, 1897. Bryan, Kirk, Erosion and sedimentation in the Papago country, Arizona: U. S. Geol. Survey Bull. 730, p. 54, 1922.

[36] Udden, J. A., Sketch of the geology of the Chisos country: Texas Univ. Bull. 93, pp. 10-14, 1907.

[37] Lawson, A. C., The epigene profiles of the desert: California Univ., Dept. Geology, Bull., vol. 9, p. 34, 1915.

[38] Davis, W. M., Granitic domes of the Mohave Desert: San Diego Soc. Nat. History Trans., vol. 7, p. 223, 1933. The term was also used without special definition in a paper published by Davis in 1930.

[39] Johnson, D. W., Planes of lateral corrasion: Science, new ser., vol. 73, pp. 174-177, 1931.

Rock floors and pediments have in the past been widely mistaken for surfaces of deposition, such as bolson plains and bajadas, but as Blackwelder has pointed out, "the pediment, and not the bajada, is the normal and inevitable form developed in arid regions under stable conditions. It is not exceptional * * * but is dominant, widespread, and characteristic." [40] According to this author [41] pediments may be distinguished from bajadas by their low and uniform gradient, by their rambling and braided rather than outward-forking streams, and by the absence of a convex fan form opposite canyon mouths. Some of these criteria have recently been questioned by Johnson,[42] who believes that rock-cut and constructional surfaces in arid regions may be more nearly alike than has been supposed. He brings forth theoretical and field evidence which suggests that "bedrock surfaces near canyon mouths * * * [may] possess the form of alluvial fans." [43]

The manner in which rock floors may be produced has been variously interpreted. Davis [44] has given a useful summary of the theories that were suggested before 1930, many of which need not be repeated here. The first carefully worked out sequence of events was presented by Lawson,[45] following a briefer statement by Paige.[46] Lawson's conclusions have been more or less closely followed by Bryan, and to a certain extent by Davis. The theory is summarized as follows: [47]

> A steep-sloping mountain front is worn back at a constant declivity by the ordinary subaerial processes of mountain recession as controlled by arid weathering and washing. Below the mountain front the worn-down surface of the rock floor—the pediment—is at first narrow, rather steep, and covered with a graded embankment of alluvium. But the embankment gradually rises * * * because its lower end reaches the rising detrital floor of an infilling intermont basin; and as it rises it overlaps farther and farther on the growing pediment, which, as it broadens, becomes less steep and almost bare.

In this theory chief emphasis is placed on the recession of the mountain slopes by weathering, and the pediment is considered to be "a slope of transportation * * * determined by the grade necessary to transport debris away from the mountains." [48]

The problem is approached from a different viewpoint by Johnson and Blackwelder, who attribute the chief work of pediment cutting to the lateral corrasion of streams flowing across it. Johnson [49] calls attention to an early deduction by Gilbert [50]

> that downward wear of streams ceases when the load equals the capacity for transportation. Lateral corrasion then becomes relatively and actually of importance and carves an even surface covered by a thin deposit of alluvium. By cutting laterally into each other's valleys and consuming all remnants of the intervening divides, neighboring streams cooperate to carve a single plain of broad extent.

As noted above, however, Johnson and Blackwelder are not in agreement as to the forms produced. Johnson believes that rock fans, similar to alluvial fans, must be produced by lateral corrasion because the "inclined stream [is] relatively * * * fixed in position at the point of issuance from the canyon mouth and shifts more and more widely below that point." [51] He follows Paige [52] in ascribing the steepness of the mountain front behind the pediments, not to weathering, but to the undercutting of streams swinging laterally on the surface of rock fans.

Most students of desert erosion believe, with Blackwelder, that the rock floor or pediment "is the desert-inhabiting species of the genus peneplain * * * and the higher gradient which distinguishes it is conditioned by aridity." [53] Johnson, however, suggests that this surface is "developed rapidly without any necessary relation to base level and may normally be trenched by streams without any change in the attitude or altitude of the areas affected." [54]

Comparison of rock floors previously described with those in the Marathon Basin.—The rock floors of the Marathon Basin show certain differences from the typical examples farther west that have been described. These differences are more in degree than in kind and are dependent on the local geology, the rainfall, and the disposition of the drainage.

At Marathon the rock floors are carved from steeply tilted sedimentary rocks of varying resistance, rather than from massive rocks such as granites. Most of the rock floors of the region are therefore cut on belts of weak rock. The sedimentary rocks are not as subject to spalling and granular decay as the granites in the pediment areas of southern Arizona and the Mojave Desert. Their weathered fragments are therefore of different size and shape, and this influences the form of the graded slopes that must be carved to transport them.

The base level of the rock floors is controlled by numerous streams which have access to the master

[40] Blackwelder, Eliot, Desert plains: Jour. Geology, vol. 39, p. 138, 1931.
[41] Idem, pp. 136–137.
[42] Johnson, D. W., Rock fans in arid regions: Am. Jour. Sci., 5th ser., vol. 23, pp. 389–420, 1932.
[43] Johnson, D. W., Planes of lateral corrasion: Science, new ser., vol. 73, p. 175, 1931.
[44] Davis, W. M., Rock floors in arid and humid climates: Jour. Geology, vol. 13, pp. 14–19, 1930.
[45] Lawson, A. C., The epigene profiles of the desert: California Univ., Dept. Geology, Bull., vol. 9, pp. 23–48, 1915.
[46] Paige, Sidney, Rock-cut surfaces in the desert ranges: Jour. Geology, vol. 20, pp. 442–450, 1912.
[47] Davis, W. M., Rock floors in arid and in humid climates: Jour. Geology, vol. 38, p. 15, 1931.
[48] Bryan, Kirk, Erosion and sedimentation in the Papago country, Arizona: U. S. Geol. Survey Bull. 730, p. 57, 1922.
[49] Johnson, D. W., Planes of lateral corrasion: Science, new ser., vol. 73, p. 174, 1931.
[50] Gilbert, G. K., Geology of the Henry Mountains, pp. 126–133, U. S. Geol. and Geog. Survey Rocky Mtn. Region, 1877.
[51] Johnson, D. W., Rock fans in arid regions: Am. Jour. Sci., 5th ser., vol. 23, p. 392, 1932.
[52] Paige, Sidney, op. cit., pp. 449–450.
[53] Blackwelder, Eliot, Desert plains: Jour. Geology, vol. 39, p. 138, 1931.
[54] Johnson, D. W., Planes of lateral corrasion: Science, new ser., vol. 73, p. 177, 1931.

drainageways of the Rio Grande and the Pecos, rather than by an interior basin, whose surface is rising slowly by aggradation. This condition favors the development of rock floors of wide extent, as suggested by Bryan [55] and Davis,[56] and the alluvial apron assumed by Lawson and Paige either does not exist or is thin.

The rock floors do not encircle mountain areas but lie in a basin between the highlands. As the resistant rocks of the basin form a relatively small part of the whole, the ridges of unconsumed material are relatively narrow and are penetrated in all directions by arms of the rock floors. The rock floors of the Marathon region thus resemble in many of their features the intramontane canyons and headwater basins in southern Arizona described by Bryan.[57]

Rock floors of the Marathon Basin.—Stratigraphically, there are three groups of weak rocks in the basin. The lowest group, consisting of pre-Carboniferous limestone and shale, lies at the surface in the two anticlinoria in the western part of the basin. The upper two groups, consisting of sandstone and shale of Carboniferous age, lie respectively below and above the ridge-making Dimple limestone and form broad expanses of plain surrounding the anticlinorial areas. Erosion in the Marathon Basin has proceeded with greatest ease along these belts of weak rock, thus favoring the development of subsequent streams, at the expense of consequent streams superimposed on the Paleozoic surface from the former Cretaceous cover. Rock floors have been cut back laterally from the superimposed or subsequent master streams, as far as the limiting belts of hard, ridge-making rocks on both sides.

Along the escarpments bordering the Marathon Basin are pediments with gradients of 200 or 300 feet to the mile, but these flatten outward and have a concave upward profile. Within the basin itself the rock floors have gradients of 75 feet or less to the mile. The rock floors have a general inclination southward toward the Rio Grande, but in detail they are a complex group of sloping surfaces, each drained by an axial stream tributary to one of the master drainage channels. The rock floors in the different drainage basins have an unlike form and gradient because of the varying character of the bedrock, amount of run-off, and relation to each master stream. Some are also controlled by local base levels, determined by sills of hard rock in the stream beds.[58] Though the rock floors of each drainage area are accordant at their lower ends with those along the master stream, they may be discordant at their heads and margins with the floors drained by other streams. The coalescing floors of adjacent drainage areas are thus not likely to meet at the same level, and the junction in some places is marked by a low dissected escarpment that faces the lower rock floor.[59] The discordance is most marked where the coalescing floors drain into far separated master streams. Thus the heads of rock floors drained by tributaries of the Pecos in the northeastern part of the Marathon region stand above W B Flat on the south (pl. 23 and map of Longfellow quadrangle), at the top of an escarpment 500 feet high.

In the Marathon region, so far as the writer's observations go, there are no well-developed rock fans of the type described by Johnson. It is possible, however, that some of the fanlike areas at the bases of the higher mountains, which the writer has interpreted as due to deposition on the pediments, may be underlain by fans carved from bedrock.

Erosion and deposition on the rock floors.—In most places the rock floors of the Marathon Basin are either covered by a thin layer of gravel or dissected to a moderate depth.

Undissected rock floors covered by gravel are most extensive in the north half of the basin (pl. 23). The alluvial deposits here may be of some antiquity, for cobbles of Cretaceous [60] and Dimple limestone occur in some of them where no outcrops of those formations now remain in the drainage area. They may also have been the source of the elephant bone reported to have been found near Marathon in 1930.

Most of the rock floors in the area are covered by 10 to 20 feet of gravel, which effectively masks the bedrock over wide areas, although valleys that incise the surface reveal the small thickness of the deposit. At some places the cover is thicker. Water wells in the northern part of the basin, near the Glass Mountains, penetrate 100 feet or more of gravel, and some of the streams that discharge from these mountains have deposited low alluvial fans on the rock floor.[61] Alluvial fans have been built also along the northeast base of the Del Norte Mountains by Antelope Creek (fig. 7) and the stream in the large canyon 2 miles south of Altuda.[62] Another large fan exists south of the Marathon Basin, in the Hood Spring quadrangle. The outer edges of the two fans in the Del Norte Mountains have been built across the courses of other streams and have ponded some of them (fig. 7), thereby interrupting the normal cycle of down cutting. Clearly these two fans cannot be

[55] Bryan, Kirk, op. cit. (Bull. 730), p. 56.

[56] Davis, W. M., Rock floors in arid and in humid climates: Jour. Geology, vol. 38, p. 18, 1931.

[57] Bryan, Kirk, op. cit., pp. 47–48.

[58] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 164, 1917.

[59] Davis, W. M., Granitic domes of the Mohave Desert: San Diego Soc. Nat. History Trans., vol. 7, pp. 237–239, 1933. King, P. B., Geology of the Glass Mountains, part 1; Texas Univ. Bull. 3038, p. 27, 1930.

[60] King, P. B., op. cit. (Texas Univ. Bull. 3038), p. 20.

[61] Blackwelder, Eliot, Desert plains: Jour. Geology, vol. 39, p. 139, 1931.

[62] King, P. B., op. cit., fig. 9 C.

of the rock-cut type described by Johnson. The outer edges of the fan in the Hood Spring quadrangle are dissected by tributaries of Maravillas Creek, suggesting that the building of this fan antedated the dissection of the rock floors described below.

Deposition of alluvium on the surface of the rock floors indicates that the balance of conditions which permitted their erosion has been modified, either by a change in the base level of the master streams or by a decrease in the amount of rainfall. The widespread occurrence of the deposit in all drainage basins suggests that it was caused by a change in climate toward aridity.

Dissection of the rock floors and pediments and of their alluvial cover is of several sorts. At many places along the bases of the mountains the drainage channels "cut deep, steep-walled 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 * * * materials beyond the foot of the debris slopes." [63] Similar features have been described by Bryan in the Papago country and are explained by him as caused by a relative increase in the amount of rainfall,[64] but Baker has suggested that they may be produced as a normal feature after maturity is reached in the cycle of erosion.[65]

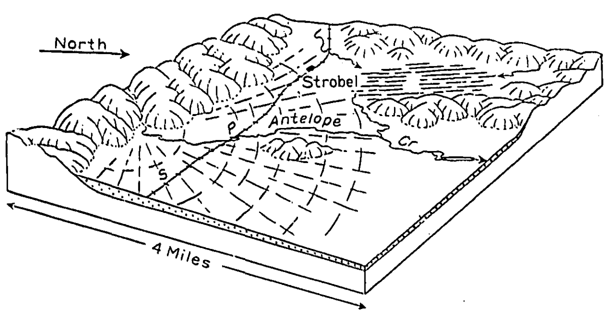


FIGURE 7.—Block diagram of the alluvial fan of Antelope Creek, at the base of the Del Norte Mountains, northwest of Altuda. (See pl. 23.) The building of the alluvial fan has ponded the drainage coming from the back side of the block, producing a patch of swampy land north of Strobel.

In the central and southern parts of the Marathon Basin most of the rock floors are dissected by Maravillas and San Francisco Creeks and their tributaries. Toward the north the streams are cutting headward into the broad area of gravel-covered lowland of the northern part of the basin, and in places the south edge of the undissected area is marked by a low scarp.

Typical dissected country is found along Peña Blanca Creek, in the southeastern part of the Marathon Basin (pl. 24), where the originally smooth rock floor is trenched to a depth of 50 or 100 feet by valleys of trellis pattern, which have been carved along belts of shale of Carboniferous age, leaving the intervening belts of sandstone as low, even-crested ridges. The tops of the ridges are in places covered by patches of gravel, which are remnants of deposits formerly covering the whole of the old rock floor. These patches are accordant with the undissected gravel-covered floors of the northern part of the basin. Similar relations are also found in the lowland of pre-Carboniferous rock in the Dagger Flat area (fig. 8). Here most of the remnants of the old rock floor are preserved on the edges of a resistant limestone bed, the Fort Peña formation, which now crops out in low ridges. Some recession of the Cretaceous escarpments bordering the Marathon Basin has apparently taken place at the same time as the down cutting of the rock floors in the basin.

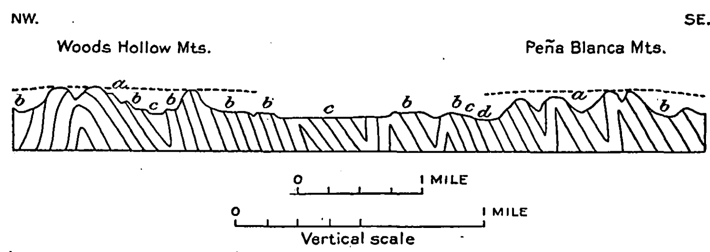


FIGURE 8.—Section across northeastern part of Dagger Flat area, showing the four erosion surfaces typical of the Marathon Basin. Surface *a* is suggested only by the even summit levels of the novaculite ridges. Surfaces *b* and *c* are widely developed rock plains. Surface *d* is the present stream grade.

In the southern part of the Marathon Basin, 25 to 50 feet below the higher rock floor, is another floor of smaller extent (fig. 8). Because of the large contour interval of the topographic maps, it was not possible to map the two surfaces separately. Along the streams a still lower surface has been developed, which is covered by clay and gravel of finer texture than those found on the two older surfaces. This surface has its widest extent along the lower course of Maravillas Creek; elsewhere it fringes the streams in belts rarely more than 2 miles in width and vanishes entirely where the streams cross areas of hard rock.

The dissection of the rock floors apparently resulted from headward cutting of the tributaries that drain by the shortest route to the Rio Grande. The process is therefore probably caused by a lowering of the base level of that stream, which may have resulted either from slight regional uplift or from the lowering of a

[63] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 161, 1917. For a map of one of these features see King, P. B., op. cit., fig. 9 A.

[64] Bryan, Kirk, Erosion and sedimentation in the Papago country, Arizona: U. S. Geol. Survey Bull. 730, pp. 60-65, 1922.

[65] Baker, C. L., Notes on the later Cenozoic history of the Mohave Desert region in southeastern California: California Univ., Dept. Geology, Bull., vol. 6, pp. 374-377, 1911.

temporary base level by the destruction of a rock dam in the river.

There is some suggestion that the dissection of the rock floors may have been aided by slight recurrent uplifts of the Marathon dome. Tilting to the south is suggested on the southeast side of the dome by the anomalous position of upland gravel deposits (fig. 4) and by the capture of an extensive drainage system by lower Maxon Creek (fig. 9). Within the basin also dissection is most active in the central and southern parts, where southward-flowing streams would be accelerated by such an uplift. In the northern undissected part of the basin, which also drains mostly to the south, erosion processes do not seem very active and may have been retarded by an uplift with its center farther south. Most of the features in the basin, however, may be interpreted in other ways.

In many of the valleys the clays of the lowest surface are now in process of dissection by steep-walled arroyos.

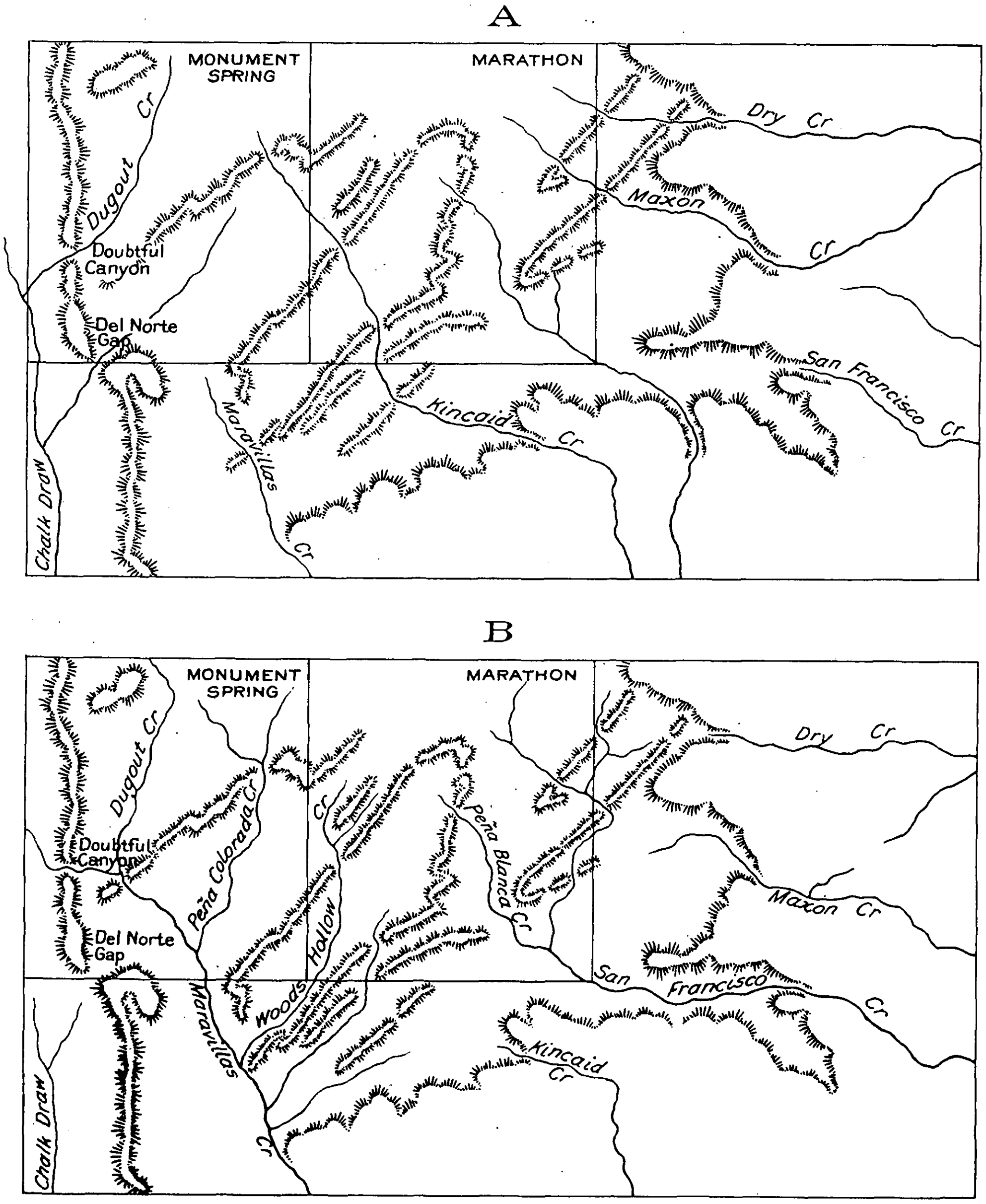


FIGURE 9.—Maps showing possible stream history in south half of the Marathon Basin. A is a hypothetical map at a stage considerably before the present, when the land surface stood several hundred feet above its present position. A consequent drainage radiates from the original center of the Marathon dome and has been superimposed on the hard and soft beds of the Paleozoic rocks which underlie the original cover of the dome. B, map at the present time, showing modification of the original drainage by the cutting of subsequent streams along belts of weak rock in the Paleozoic area.

According to John Bennett, those near his apiary south of Haymond have been cut since about 1920. According to C. L. Baker, those in Green Valley, southwest of the Marathon Basin, have been cut since about 1890. This cutting is similar to that in New Mexico described by Bryan.[66] It may have been brought about by heavy grazing of the country by stock, which has perhaps facilitated run-off and soil erosion.

Streams of the Marathon Basin.—The lowlands of the Marathon Basin are drained by several streams with intermittent flow, the largest of which are Maravillas and San Francisco Creeks. In places these streams pass from one lowland area to another by crossing the ridges of hard rock in narrow water gaps. The broader features of the stream pattern have been acquired from the consequent drainage that was formed on the now removed cover of the Marathon dome and that has been superimposed on the Paleozoic rocks beneath. The pattern has been considerably altered by later cutting along weak rock belts by subsequent streams, as may be seen by comparing on the topographic maps the dendritic stream pattern of the Cretaceous areas surrounding the Marathon Basin with the trellis pattern within the basin. Other modifications of the original pattern have been caused by the advantage possessed by streams flowing southward, off the dome, to the nearby, low-lying Rio Grande over those flowing northward to the higher, more distant Pecos River.

Maravillas Creek is apparently consequent to a post-Cretaceous syncline as far north as the latitude of Del Norte Gap. Subsequent streams, such as Woods Hollow Creek, enter it from the east in this part of its course (fig. 9, B). They are cut in weak-rock belts in the Paleozoic folds of the Marathon Basin. The water gaps by which they cross some of the hard-rock belts may have been inherited from a former southward-flowing consequent drainage system (fig. 9, A). The upper course of Maravillas Creek is apparently subsequent and is cut out along the disturbed zone at the west margin of the Marathon uplift. Its two northeastern tributaries, Peña Colorada and Dugout Creeks, have large headward extensions that drain the southern foothills of the Glass Mountains, where the strata dip north off the Marathon uplift. These creeks may possibly be the dismembered fragments of an original consequent stream that flowed southwestward through gaps in the Del Norte Mountains to join Chalk Draw, which is a consequent stream flowing in a Cretaceous syncline west of the Marathon uplift, in the Santiago Peak quadrangle (fig. 9). One such gap, Doubtful Canyon, is now followed by the eastward-flowing Maravillas Creek. Another, Del Norte Gap, is now a wind gap.

San Francisco Creek is a consequent stream which has acquired the original headwaters of the eastward-flowing Maxon and Dry Creeks by headward cutting along belts of weak rock (fig. 9, B). The two water gaps by which it crosses the limestone hogbacks near Haymond were probably inherited from the consequent headwaters of Maxon Creek. Maxon and Dry Creeks now head near the edge of the Marathon Basin, in broad valleys that are broken off to the west by dissected country draining into San Francisco Creek. The main western tributary of San Francisco Creek, Peña Blanca Creek, is a subsequent stream that flows in a weak-rock belt of northeastward-dipping sandstones and shales, between hogbacks of novaculite and of Carboniferous limestone.

[66] Bryan, Kirk, Date of channel trenching (arroyo cutting) in the arid Southwest: Science, new ser., vol. 62, pp. 338-344, 1925.

STRATIGRAPHY

GENERAL OUTLINE

Most of the bedrock that crops out in the Marathon region consists of consolidated sedimentary rocks. Such rocks also underlie the wide areas of Quaternary gravel and clay in the plains. Intrusive igneous rocks occupy only small areas, and extrusive rocks are found only along the west flank of the Marathon region.

The stratified rocks in the region are of many ages and represent nearly the whole span of geologic time from the Cambrian to the Tertiary. The base of the Paleozoic is not exposed, for the lowest beds raised in the anticlines are a part of the Upper Cambrian. These oldest rocks form the base of a thick Paleozoic succession that includes formations of Ordovician, Devonian (?), and Carboniferous age. The Carboniferous strata attain a great thickness and include in the Marathon Basin thick formations of Pennsylvanian age and in the Glass Mountains a series of Permian strata. Above the Paleozoic on the flanks of the Marathon uplift are rocks of Lower and Upper Cretaceous age. Above them on the west are Tertiary lavas and tuffs.

Nearly all the strata contain fossils, and in some places the fossils are very abundant. Marine invertebrate fossils are found in the rocks of Cambrian, Ordovician, upper Pennsylvanian, Permian, and Cretaceous age. In the lower part of the Pennsylvanian and in the Tertiary tuffs west of the Marathon region some of the strata contain plant remains.

The stratified rocks of the region were laid down under progressively changing geographic conditions. The Paleozoic rocks below the Permian were laid down in a subsiding area, the Llanoria geosyncline [67] (fig. 16 and pl. 20). The geosyncline did not have the same form as the modern, nearly circular Marathon Basin. At the edges of the basin the rocks of geosynclinal facies strike northeast beneath the Cretaceous cover and are encountered again to the east in deep wells and to the southwest in the small uplift of the Solitario.

[67] Sellards, E. H., Pre-Paleozoic and Paleozoic systems, in The geology of Texas, vol. 1, Stratigraphy: Texas Univ. Bull. 3232, p. 23, 1933.

The geosyncline did not extend as far to the northwest or southeast. To the northwest the Paleozoic rocks in the nearest exposures are thinner and more calcareous and were laid down on a sea bottom that did not either rise or subside greatly. To the southeast the sediments in the geosyncline suggest that there was a land area, Llanoria, which at times rose to a considerable height. In Mesozoic times the Paleozoic geographic features had disappeared. The Cretaceous rocks were laid down on the surface of an extensive peneplain carved from the older rocks, and the greatest area of subsidence was southwest of the Marathon region.

The rocks of the region stand in a variety of structural attitudes, and some of them have been greatly deformed. The earlier Paleozoic rocks of the Llanoria geosyncline were folded and faulted before Permian time, and the Permian rocks lie unconformably upon them along the south side of the Glass Mountains. The Cretaceous rocks in turn truncate both the folds of the Marathon Basin and the tilted rocks of the Glass Mountains. The Cretaceous rocks have themselves been deformed, both before and after the early Tertiary volcanic eruptions.

The total thickness of the Paleozoic rocks is about 21,000 feet, of which the pre-Carboniferous strata comprise 2,500 feet; the Pennsylvanian, 12,000 feet; and the Permian, 6,500 feet. The Cretaceous rocks in the area have a maximum thickness of about 1,200 feet. The following table summarizes the formations exposed in the Marathon region:

Geologic formations in Marathon region

Age	Group and formation		Thickness (feet)	Character
Recent.	Alluvium.		----------	Unconsolidated silt and gravel in valley bottoms.
Pleistocene (?).	Terrace gravel.		10–100	Limestone and chert gravel on older pediment surfaces.
Tertiary (Eocene).	Lava and tuff.		----------	Lava and tuff of Elephant Mountain.
	–Unconformity.			
Upper Cretaceous.	Eagle Ford formation.		200+	Flaggy limestone and shale.
Lower Cretaceous.	Washita group.	Buda limestone.	60	White massive limestone.
		Del Rio shale.	20	Drab shale with thin beds of brown sandy limestone.
		Georgetown limestone.	175	Massive limestone and thin-bedded marly limestone.
	Fredericksburg group.	Edwards limestone.	150	Massive cherty limestone.
		Comanche Peak and Walnut formations.	50	Buff marl and soft nodular limestone.
	Trinity group.	Maxon sandstone.	0–100	Massive brown cross-bedded sandstone; prominent in eastern part of Marathon Basin.
		Glen Rose formation.	0–500	Alternating beds of massive limestone and soft marl, with some sandy beds in places.
	–Unconformity.			
Triassic (?).	Bissett conglomerate.		700	Conglomerate of limestone pebbles; some beds of limestone and red shale.
	–Unconformity.			
Permian.	Tessey limestone.		1, 000	Massive dolomitic limestone.
	Capitan limestone.		1, 800	Massive dolomitic limestone.
	Word formation.		1, 500	Siliceous shale, thin layers of fossiliferous limestone, and fine conglomerate.
	Leonard formation.		1, 800	Shale and sandstone, passing down into massive limestone, siliceous shale and fine conglomerate, with a coarse basal conglomerate.
	–Unconformity.			
	Wolfcamp formation.		500	Coarse massive conglomerate, overlain by shale.
	–Unconformity.			

Geologic formations in Marathon region—Continued

Age	Group and formation	Thickness (feet)	Character
Pennsylvanian.	Gaptank formation.	1, 800	Clay shale, sandstone, coarse conglomerate, and fossiliferous limestone. *Uddenites* zone at top.
	Haymond formation.	3, 000	Thin-bedded sandstone and shale, with thick beds of arkose and boulder-bearing mudstone in upper part.
	Dimple limestone	300–1, 000	Thick-bedded gray cherty limestone, with some shale and chert.
	Tesnus formation.	300–7, 000	Divided in eastern part of area into an upper sandstone member 5,000 feet thick and a basal shale member 2,000 feet thick. Sandstones and shales not subdivided elsewhere.
	-Unconformity.		
Devonian (?).	Caballos novaculite.	250–600	Massive white novaculite and bedded varicolored chert.
	-Unconformity.		
Upper Ordovician.	Maravillas chert.	100–400	Bedded black chert and dark limestone.
Middle Ordovician.	Woods Hollow shale.	180–500	Drab shale and thin flaggy limestone and sandstone.
	Fort Peña formation.	175	Massive limestone, bedded chert, and basal conglomerate.
Lower Ordovician.	Alsate shale.	25–100	Hard green shale and thin limestone beds.
	Marathon limestone.	350-900	Thin flaggy limestone, with shale partings and intraformational conglomerate. Near middle is Monument Spring dolomite member.
Upper Cambrian.	Dagger Flat sandstone (base concealed).	300+	Massive saccharoidal sandstone, shale, and thin limestones.

Possible lower beds of the Cambrian and the probable floor of pre-Cambrian crystalline rocks are not exposed in the area.

PRE-CAMBRIAN ROCKS

No rocks of pre-Cambrian age crop out in the Marathon Basin.[68] The floor of basement rocks in the region has been deeply buried by Paleozoic strata of the Llanoria geosyncline. To the north and south of the geosynclinal area pre-Cambrian rocks lie nearer to the surface and have been discovered in a few exposures and a few deep wells.

Pre-Cambrian rocks north and south of Marathon.—About 50 miles northeast of Marathon, near Fort Stockton, a well drilled by the Shell-Humphreys Companies on university land penetrated old rocks below the Permian at a depth of 4,750 feet. The basement rocks are considered to be granites by J. T. Lonsdale, who found that the abundant minerals in the cuttings are quartz, microcline, albite, hornblende, and biotite. Accessory minerals include magnetite, zircon, apatite, and calcite.[69] This is probably a part of the foreland area north of the Llanoria geosyncline. The granite probably has the same relation as the pre-Cambrian rocks that crop out at the surface near Van Horn, 100 miles northwest of Marathon. At that place strata of Permian age overlap across the older Paleozoic rocks and rest locally on the pre-Cambrian on the crests of pre-Permian uplifts.

About 80 miles south of Marathon C. L. Baker [70] has found schists beneath the Cretaceous on the crest of an anticline in the Sierra del Carmen, east of the village of Boquillas. This exposure is probably a part of the land that bordered the geosyncline on the southeast.

Fragments of crystalline rocks in the Paleozoic sediments at Marathon.—The land area of Llanoria, southeast of the geosyncline, appears to have been composed largely of crystalline rocks and probably stood as a highland or mountain area during a large part of Paleozoic time (fig. 16 and pl. 20 *A*). For the most part the former highland is now buried beneath Cretaceous and younger strata, and the hypothesis of its former existence is based largely on evidence supplied by the composition of the Paleozoic sediments in the geosyncline.

[68] Van der Gracht (The Permo-Carboniferous orogeny in the south-central United States: K. Akad. Wetensch. Amsterdam Verh., Afd. Natuurk., deel 27, no. 3, table Va and elsewhere, 1931) notes a reported discovery of pre-Cambrian rocks in the similar district of the Solitario uplift, southwest of Marathon. This report has proved to be erroneous, according to a letter from E. H. Sellards, June 1932.

[69] Sellards, E. H., op. cit. (Texas Univ. Bull. 3232), p. 52. The well has also been noted by E. L. Jones and R. C. Conkling (Basement rocks in the Shell-Humphreys well, Pecos County, Tex: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 314–316, 1930) and by P. B. King (Geology of the Glass Mountains, part 1: Texas Univ. Bull. 3038, p. 117, 1930). Jones and Conkling regarded the rocks as metamorphosed sandstones, penetrated by igneous dikes.

[70] Quoted by Böse, Emil, Vestiges of an ancient continent in northeastern Mexico: Am. Jour. Sci., 5th ser., vol. 6, p. 133, 1923. See also Kellum, L. B., Imlay, R. W., and Kane, W. G., Evolution of the Coahuila Peninsula, Mexico; Part 1, Relation of structure, stratigraphy, and igneous activity to an early continental margin: Geol. Soc. America Bull., vol. 47, pp. 972–977, 1936.

Many of the Paleozoic strata contain fine fragmental material derived from crystalline rocks. Conglomerate beds in various parts of the Ordovician section, but particularly in the Maravillas chert, contain fragments of vein quartz. The Tesnus and Haymond formations (Pennsylvanian) contain beds of arkose, which increase in number and thickness toward the south. Their source perhaps lies in highlands in that direction. The arkose contains grains of microcline and other minerals, probably derived from the break up of granite, as well as small chips of slate and phyllite.

In the boulder-bed member of the Haymond formation near Haymond station there are fragments of ancient rocks of larger size. Most of these are well-rounded cobbles, some of which reach a foot in diameter. They consist of granite, aplite, pegmatite, vein quartz, rhyolite, quartz conglomerate, and possibly of schist. Several thin sections of the rocks have been examined. Some of the specimens consist of fine-grained granite and some of porphyritic granite. Others consist of rhyolites of various types that contain large phenocrysts of quartz and plagioclase, whose edges are rounded by resorption. The groundmass of the rhyolites is a finely crystalline aggregate, probably a devitrified glass. In some specimens it shows a well-developed sinuous flow structure. In the exposures of the boulder-bed member north of Haymond station cobbles of the igneous rocks are few, a fact which suggests that they came from a southern and probably distant source.

Depth of the pre-Cambrian floor in the Marathon Basin.—There is no clear evidence to show at what depth the pre-Cambrian floor lies beneath the Marathon Basin. The oldest exposed parts of the Paleozoic section are of Upper Cambrian age. The character of the structural features of these and the overlying Ordovician rocks suggests that they are underlain by a considerable body of strata that is probably of incompetent character. Unfortunately, paleogeographic evidence furnishes no good clues to the age of these oldest members of the Paleozoic. They may be Middle or Lower Cambrian. The writer considers it possible that the thrust sheets in the Marathon Basin originated in wedges of crystalline rocks that lie at an unknown depth beneath (pl. 20, *B*, *C*, and *D*).

CAMBRIAN SYSTEM

DAGGER FLAT SANDSTONE

GENERAL FEATURES

The Dagger Flat sandstone was named by the writer [71] in 1931 for exposures in Dagger Flat, 13 miles south of Marathon. The sandstones were first described by Baker and Bowman [72] in their section on Threemile Hill, 3 miles northeast of Maravillas Gap, and were designated, without age assignment, as member 2 of their †Marathon series.[73]

The formation is the oldest rock found in place in the Marathon region, and its base is nowhere exposed. Its strata are in all places so intricately contorted that the exposed thickness is not exactly known, but a probable maximum of 300 feet is found on the south side of Dagger Flat. It is exposed in long, narrow belts in the center of the anticlines in both the Marathon and Dagger Flat anticlinoria, with the most extensive exposures in the south, on the Buttrill ranch and near Threemile Hill.

The Dagger Flat sandstone consists of thick ledges of saccharoidal buff sandstone interbedded with shale. These pass toward the top into shales and thin flaggy sandstones, with some calcareous beds that contain a few Upper Cambrian fossils. The formation is overlain without apparent break by thin flaggy graptolite-bearing limestones of the Marathon formation (Lower Ordovician).

LOCAL FEATURES

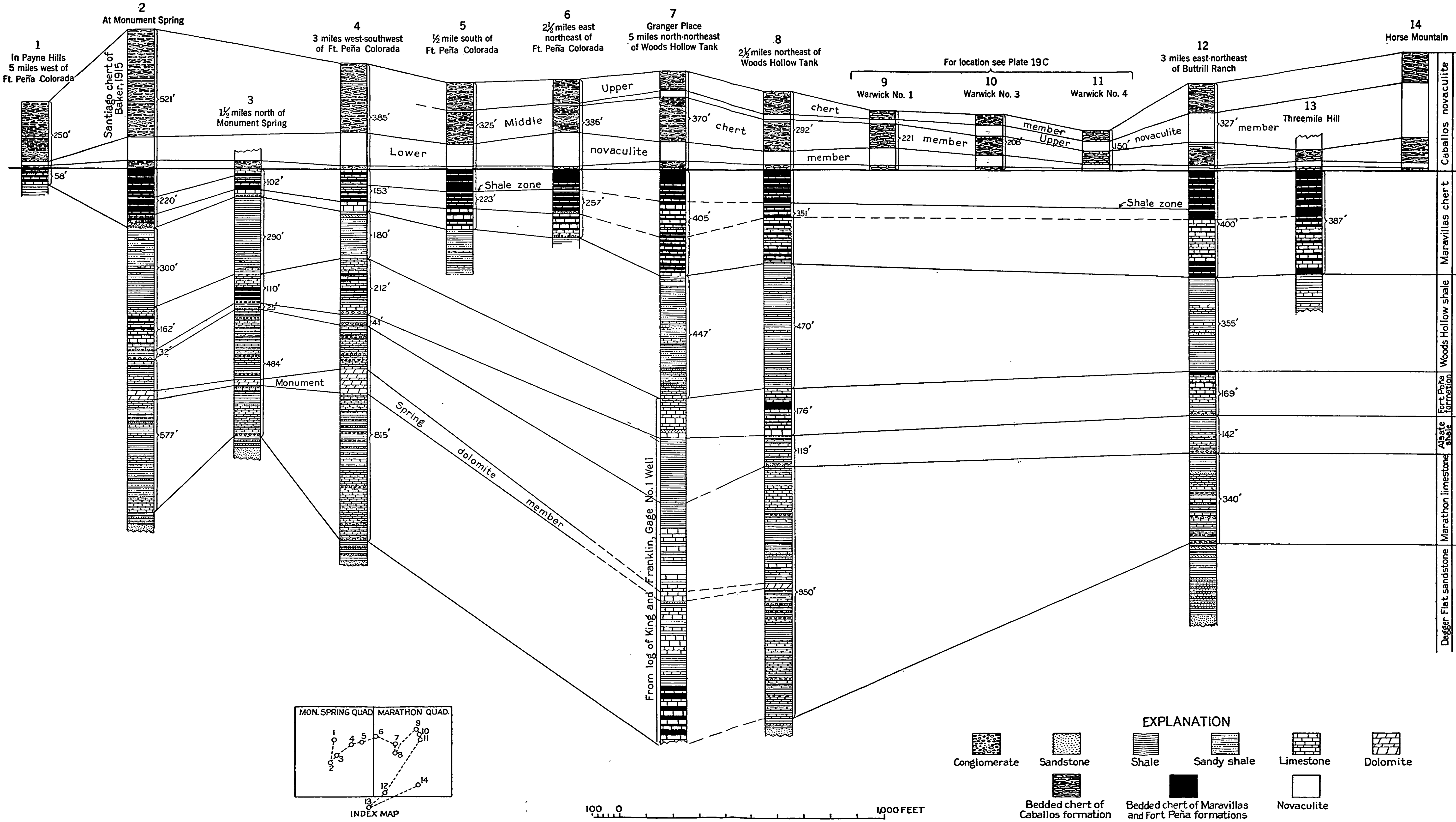
Dagger Flat area.—The Dagger Flat sandstone is well displayed for a distance of 4 miles northeast from the Buttrill ranch [74] (pl. 23) in a series of narrow belts on the crests of anticlines. The southeasternmost of these belts is the broadest and has a width of 1,500 feet. The lowest beds are conspicuous ledges, each 3 or 5 feet thick, of white to buff sugary, moderately coarse-grained sandstone, weathering pale brown (sec. 12, pl. 2). In places these beds pass into a fine conglomerate of rounded pebbles of vein quartz, some of which show a notable secondary regrowth of quartz crystals. The massive sandstones are overlain by flaggy and thinly laminated brown and greenish micaceous sandstones weathering to angular blocks and flags, with much interbedded shale, particularly toward the top. In the upper part there are also several layers of laminated brown calcareous sandstone. Their bedding surfaces are strewn with fragmental fossils, including the cephalons of various trilobites, such as *Agnostus* and many shells of *Lingula* and *Obolus*. There are also several layers of conglomerate composed of small black chert, gray limestone, and clear quartz pebbles in a matrix of brown sandy limestone. The formation is

[71] King, P. B., Pre-Carboniferous stratigraphy of the Marathon uplift: Am. Assoc. Petroleum Geologists Bull., vol. 15, pp. 1064–1065, 1931.

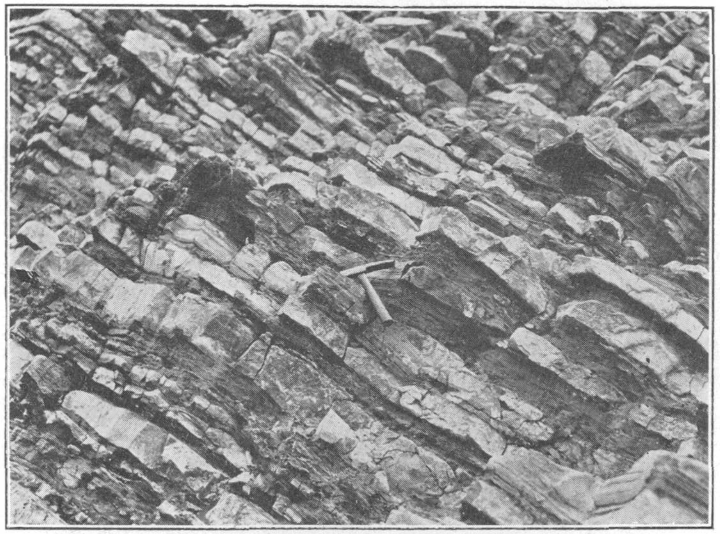
[72] Baker, C. L. and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 83, 1917.

[73] A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the U. S. Geological Survey. Quotation marks, formerly used to indicate abandoned or rejected names, are now used only in the ordinary sense.

[74] The Buttrill ranch referred to in this report is the unnamed house east of the Marathon road in the northeast corner of the Santiago Peak quadrangle. Dagger Flat is in the southwest corner of the Marathon quadrangle. These two places should not be confused with the Buttrill ranch and Dagger Flat farther south, shown on the map of the Bone Spring quadrangle.

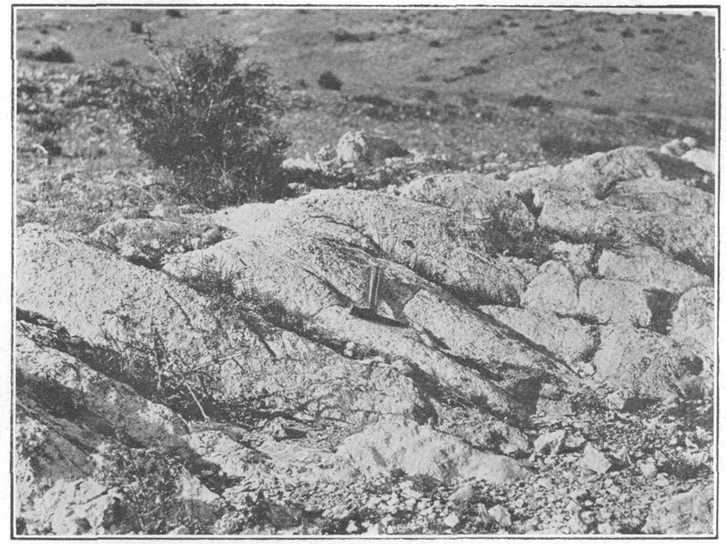


CORRELATED STRATIGRAPHIC SECTIONS OF PRE-CARBONIFEROUS ROCKS OF THE MARATHON BASIN.



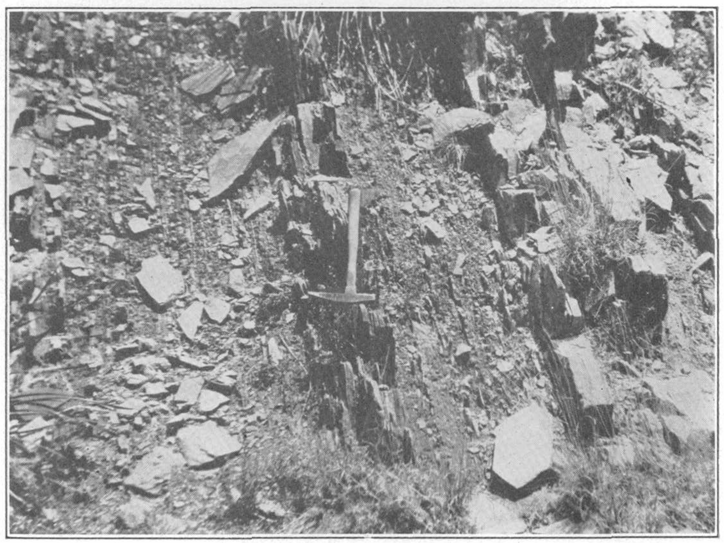
A. UPPER MEMBER OF MARATHON LIMESTONE.

Exposed in bed of Alsate Creek 3 miles west-southwest of old Fort Peña Colorada. Shows alternation of flaggy limestones and shales.



B. MONUMENT SPRING DOLOMITE MEMBER OF MARATHON LIMESTONE.

North of old Fort Peña Colorada. Shows characteristic weathering of member.

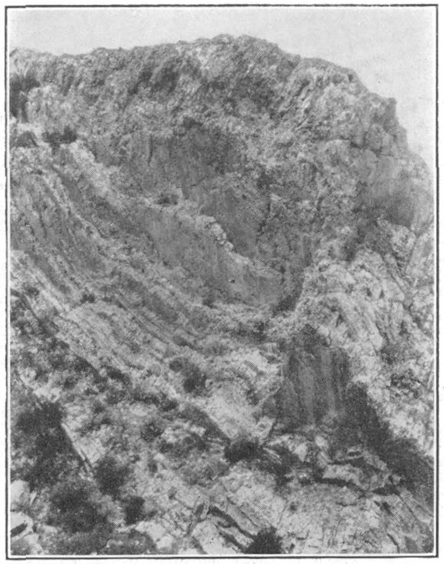


C. WOODS HOLLOW SHALE.

Near old Louis Granger place, 6 miles southeast of Marathon. Shows alternation of shales and thin flaggy sandstones and limestones.

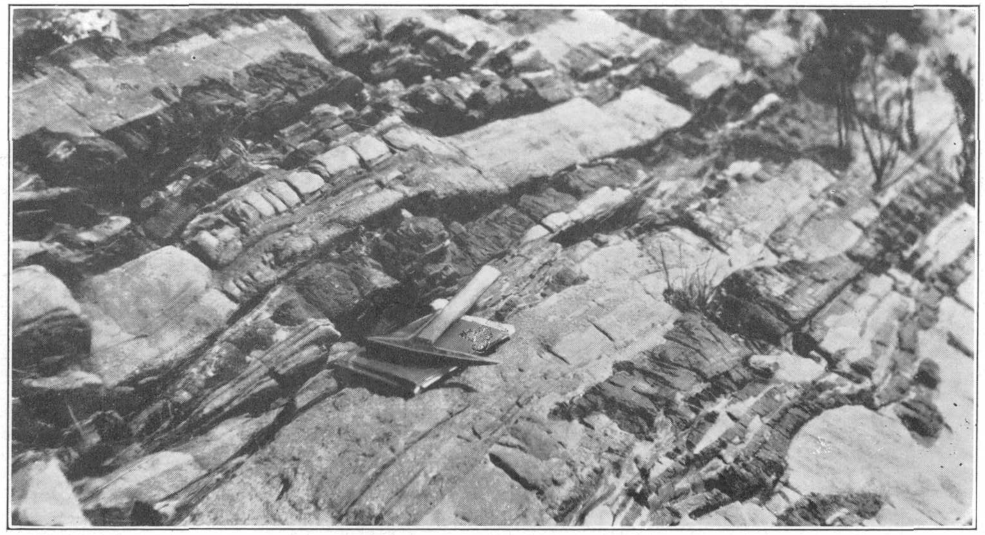
D. UPPER CHERTS, LIMESTONES, AND SHALES OF FORT PEÑA FORMATION.

In bed of Alsate Creek 3 miles west-southwest of old Fort Peña Colorada.



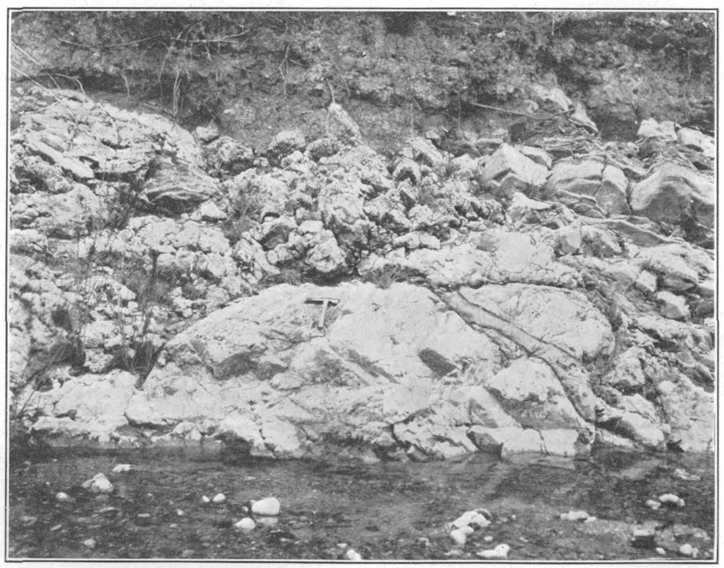
A. VERTICAL LAYERS OF CABALLOS NOVACULITE.

Near old Louis Granger place, 6 miles southeast of Marathon. Photograph by C. L. Baker.



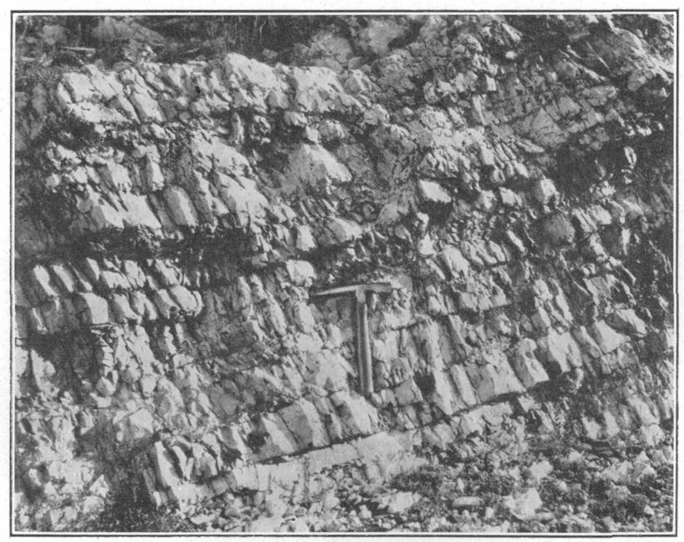
C. MARAVILLAS CHERT AT ROCK HOUSE GAP.

Shows alternation of limestone and black bedded chert.



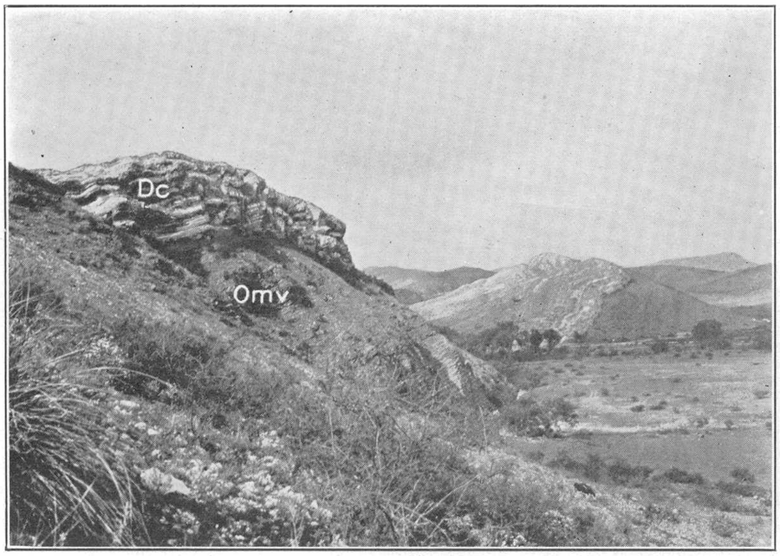
B. BASAL CONGLOMERATE OF MARAVILLAS CHERT AT ROCK HOUSE GAP.

Hammer rests on a 5-foot boulder of calcareous sandstone.



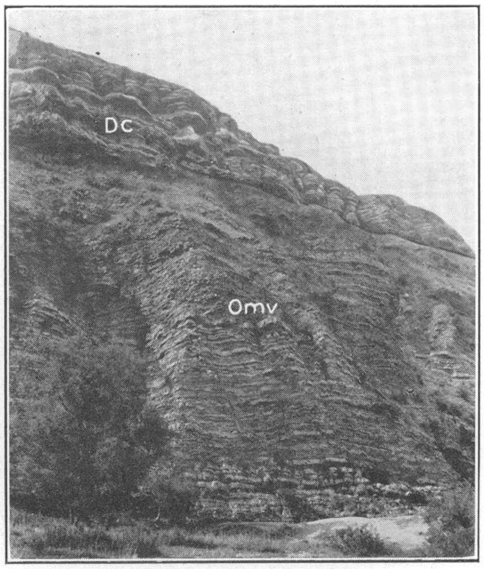
D. DETAIL OF LOWER NOVACULITE MEMBER OF CABALLOS NOVACULITE.

At gap south of old Fort Peña Colorada.



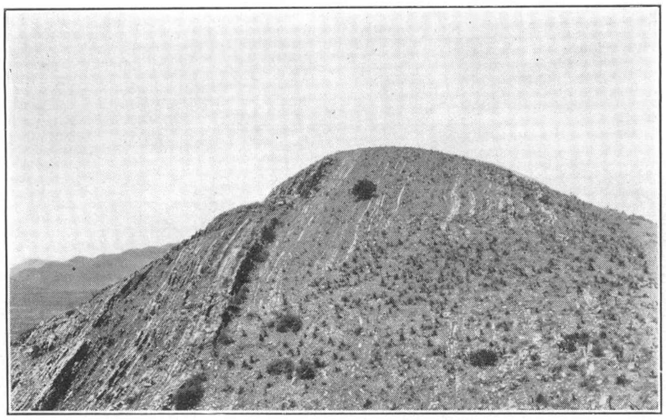
A. GAP IN NOVACULITE RIDGE SOUTH OF OLD FORT PEÑA COLORADA.

White ledges are novaculite, and darker slopes to right are Maravillas chert. Looking southwest.



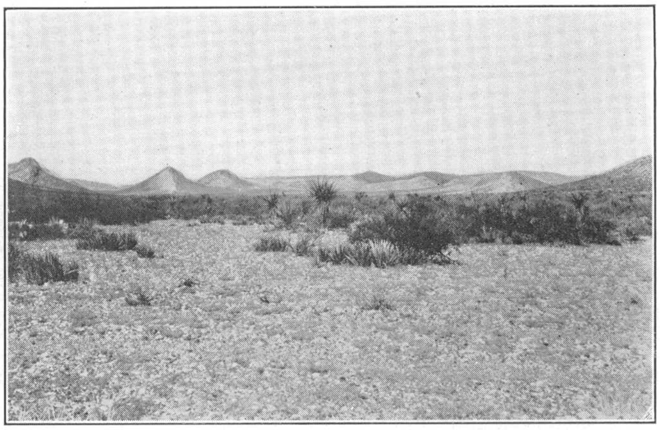
B. MARAVILLAS CHERT NORTHEAST OF GAP SHOWN IN *A*.

Woods Hollow shale crops out in creek bed at base of cliff, and Caballos novaculite forms ledges at top.



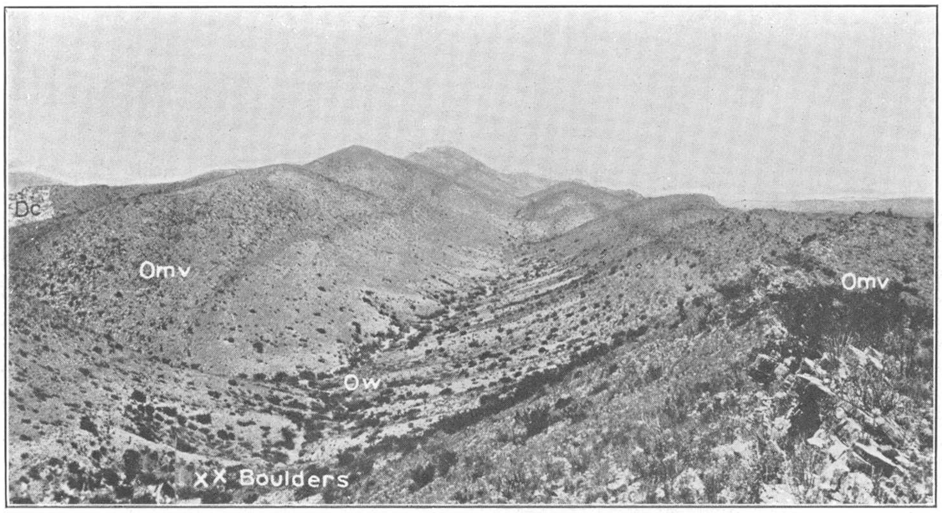
C. NOVACULITE RIDGE SOUTHEAST OF HACKBERRY TANK.

About 3 miles southwest of summit of Horse Mountain, looking southwest. Shows characteristic weathering of upper chert layers of Caballos novaculite.



D. VIEW SOUTHWEST FROM HACKBERRY TANK.

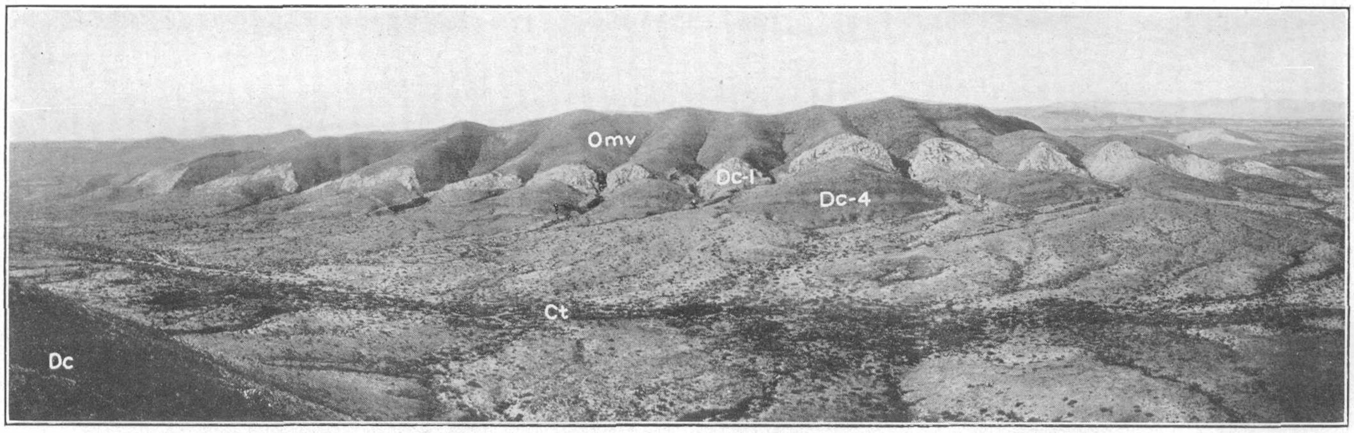
Shows novaculite ridges in southern part of Marathon Basin. In the foreground is white novaculite gravel, washed down from the ridges.



E. AXIAL ANTICLINAL VALLEY IN WOODS HOLLOW SHALE AT SOUTHWEST END OF SIMPSON SPRINGS MOUNTAIN.

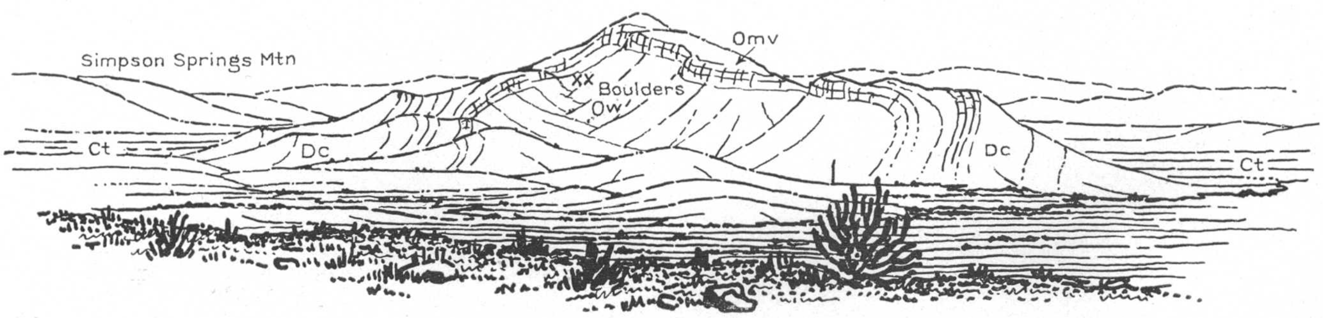
Cambrian and early Ordovician fossils were collected in boulders embedded in Woods Hollow shale in this valley. Looking northeast.

Dc, Caballos novaculite; Omv, Maravillas chert; Ow, Woods Hollow shale.
Photographs *A*, *B*, *C*, and *D* by C. L. Baker.



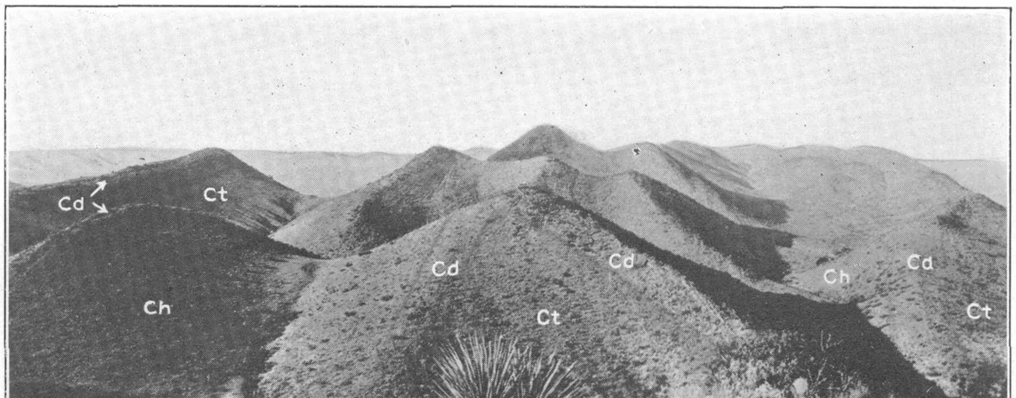
A. EAST BOURLAND MOUNTAIN FROM SOUTHEAST, FROM NORTHEAST END OF SIMPSON SPRINGS MOUNTAIN.

Shows flanking hogbacks of Caballos novaculite. Maravillas chert forms a high ridge along the axis.



B. EAST BOURLAND MOUNTAIN FROM NORTHEAST.

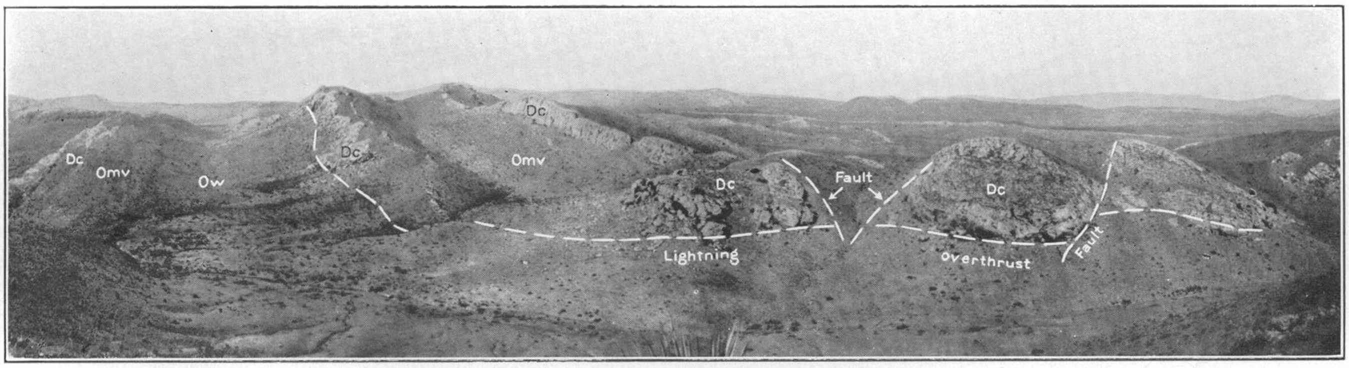
View along axis showing axial anticlinal valley carved from Woods Hollow shale, flanked by ridges of Maravillas chert and Caballos novaculite. From a field sketch.



C. WEST BOURLAND MOUNTAIN, LOOKING NORTHEAST.

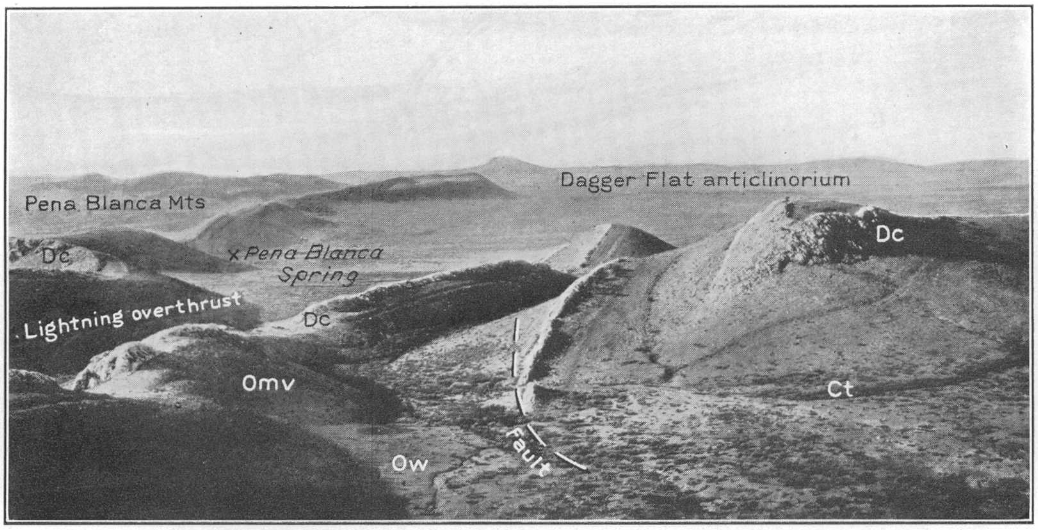
Shows folding of Dimple limestone and of Tesnus and Haymond formations.

Ow, Woods Hollow shale; Omv, Maravillas chert; Dc, Caballos novaculite (1, lower chert member and lower novaculite member; 4, upper chert member); Ct, Tesnus formation; Cd, Dimple limestone; Ch, Haymond formation.



A. NOVACULITE RIDGES IN LIGHTNING HILLS, LOOKING NORTHWEST FROM ELEVATION POINT 4,450.

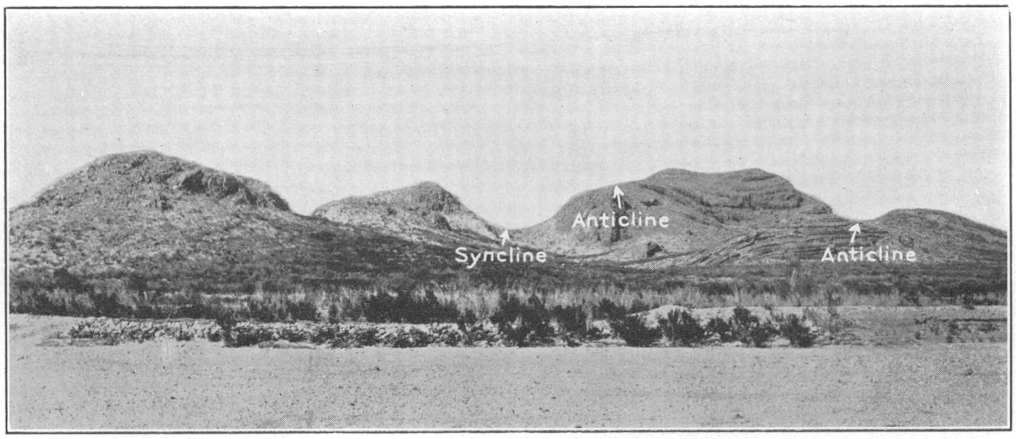
Lightning overthrust crops out in valley in foreground. Convoluted ridges of folded and faulted novaculite in middle distance.



B. NOVACULITE RIDGES IN LIGHTNING HILLS, LOOKING SOUTHWEST FROM ELEVATION POINT 4,462.

Lowlands in distance carved from Ordovician strata on crest of Dagger Flat anticlinorium.

Ow, Woods Hollow shale; Omv, Maravillas chert; Dc, Caballos novaculite; Ct, Tesnus formation.



C. FOLDING IN NOVACULITE ON EAST SIDE OF MARAVILLAS CREEK AT MARAVILLAS GAP.

overlain by flaggy limestones, shales, and flagstone conglomerates of the Marathon formation. The greatest thickness measured is about 300 feet, but no base is exposed. Estimates of thickness of the formation are difficult to make because of the complexity of the structure.

Threemile Hill.—A short distance to the southwest of the exposures on the Buttrill ranch are the original outcrops described by Baker and Bowman, on Threemile Hill (pl. 23). Here the rocks are of similar character but are so intensely contorted that the massive sandstones have been sliced into lenses or rolled into boulderlike masses, around which the shales have been squeezed and indurated nearly to slates. At this locality the Dagger Flat sandstone is overlain in places by a thin layer of Marathon limestone, followed by little-deformed Woods Hollow shales and earthy limestones and by the Maravillas chert (fig. 10). Similar intense contortion is found at Maravillas Gap, where the Dagger Flat sandstones are overlain, locally with a marked difference in dip, by the Maravillas chert (sec. J–J′, pl. 21). The writer considers these relations to be tectonic rather than stratigraphic. It is thought that the Dagger Flat is separated from the rocks above it by an overthrust, whose trace extends along the northwest slope of the hills in which the exposures lie (fig. 10). Several large areas of overthrust rocks 2 miles northwest of Threemile Hill, now isolated from their roots by erosion, are probably the northern extension of the upper strata on Threemile Hill (sec. I–I′–I″ and J–J′, pl. 21).

Woods Hollow Tank.—In the northeast end of the Dagger Flat anticlinorium, 1½ to 5 miles northeast of Woods Hollow Tank, the Dagger Flat sandstone lies at the surface in two long anticlinal belts (pl. 24). The highest beds of the formation are the only part exposed here. The outcrops consist largely of shale and sandy shale, with 6-inch to 1-foot beds of medium-grained calcareous brown sandstone, ripple-marked in places. There are also some brown limestone nodules which contain *Agnostus* and other trilobites. Some of the sandy beds weather to a peculiar chocolate-brown velvety surface, apparently from the leaching of the calcareous constituents, so as to leave a mat of fine quartz grains on the surface.

Marathon anticlinorium.—The Dagger Flat sandstone is found in small outcrops along narrow anticlinal belts southwest of Marathon, between Fort Peña Colorada and Monument Spring, as well as 2 miles northwest of the fort, on the south side of the road to the Roberts ranch (pl. 24). The formation here consists of much crumpled and indurated greenish shale with several layers of fine- to coarse-grained sandstone, in part calcareous. There are some arkosic pebbly layers and a few nodular layers of very fine grained dark-gray or black limestone, weathering chocolate brown. These beds contain scattered fragments of brachiopods and trilobites.

MICROSCOPIC CHARACTER

Thin sections of sandstones from the Dagger Flat formation of Threemile Hill and the region northeast of the Buttrill ranch show that the rock consists mostly of well-rounded large quartz grains in a matrix of finely crystalline calcite. Many of the quartz grains show regrowth of the crystal faces by the addition of secondary quartz. There are also a few grains of calcite and chert. Much of the quartz shows strain shadows, and some of the specimens are traversed by irregular veinlets of coarsely crystalline calcite. A thin section of a more pebbly phase from the Buttrill ranch consisted of large, well-rounded grains of sandy limestone and chert in a calcareous matrix, with a few grains of feldspar, calcite, and quartz.

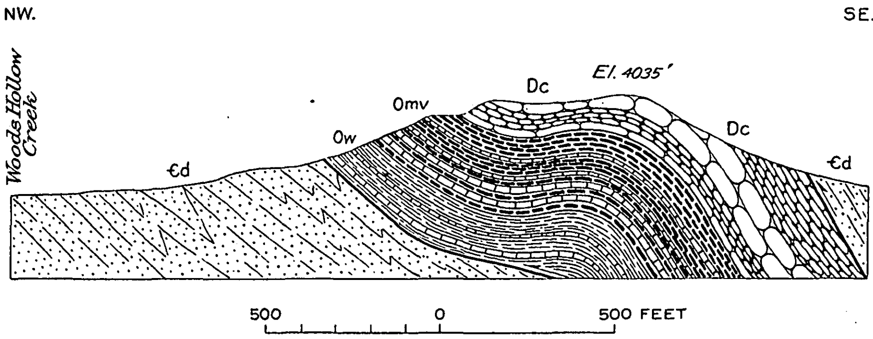


FIGURE 10.—Section through Threemile Hill showing relation of Dagger Flat sandstone (Єd) to Woods Hollow shale (Ow), Maravillas chert (Omv), and Caballos novaculite (Dc). Small wedges of Marathon limestone, not shown in the section, are present along the plane of the overthrust along the northwest slope of hill. For general relations, see section I–I′–I″, plate 21.

FOSSILS AND AGE

The fossils of the Dagger Flat sandstone are poorly preserved and difficult to collect. The largest collections were made in the Dagger Flat anticlinorium, and nearly all are characterized by *Agnostus*, *Lingula*, and *Obolus*. They have been studied briefly by Edwin Kirk and C. E. Resser, who consider the material to be of Upper Cambrian age. The formation is probably almost equivalent to the Bliss sandstone of the El Paso region.

STRATIGRAPHIC RELATIONS

The base of the Dagger Flat sandstone is not exposed, and its possible relation to older Cambrian or pre-

Cambrian formations beneath is not known. The contact between the formation and the overlying Marathon limestone is not a sharp one and is further complicated by local folding. In some places a thin conglomerate appears to form the base of the overlying formation and rests on shales assigned to the Cambrian. Elsewhere the basal beds of the Marathon formation are thin limestone flags containing *Dictyonema.*

PROBLEM OF THE †BREWSTER FORMATION

In 1915 Baker and Bowman collected fossils from two anticlinal mountains 8 to 12 miles southwest of the town of Marathon—one locality 6 miles northeast of the junction of Peña Colorada and Maravillas Creeks, on East Bourland Mountain (pl. 6, *B*), and the other 1½ miles northeast of the creek junction, on Simpson Springs Mountain (pl. 5, *E*). The higher fossil collections from both places came from the Maravillas chert, but below this fossils were found in nodular masses of dense or crystalline gray limestone, in part glauconitic, embedded in clay shales and brown sandy flagstones. The base of the lower series was not exposed. In collections from both localities Ulrich distinguished an Upper Cambrian fauna "like * * * that found in the Dunderberg shale of the Nevada * * * section", and in addition, at the second place, a fauna characterized by *Symphysurina,* to be correlated with "a well-marked zone in the lower part of the Pogonip of Nevada" of which "the evidence permits of only one conclusion * * * namely, that it is Ozarkian, and most probably Upper Ozarkian."[75] On the basis of these determinations, Baker and Bowman set off the lowest beds at the Simpson Springs Mountain locality as the †Brewster formation, of Upper Cambrian age, named for Brewster County. The similar clays and flagstones lying above them, containing the so-called "Ozarkian" fossils, they considered to be member 1 of their †Marathon series. The direct superposition of Maravillas (Upper Ordovician) on supposed Ozarkian of Ulrich at this place and the absence of the intervening Ordovician zones of other localities were explained by a marked erosional unconformity at the base of the upper formation.

Recent collecting at these localities has disclosed some puzzling anomalies not explained by the first interpretations. The sandy flagstones and the matrix of many of the thin layers of conglomerate are profusely fossiliferous at different levels below, between, and above the limestone "nodules." The flagstone fossils are largely species of *Diplograptus, Climacograptus,* and *Glossograptus,* and the conglomerate fossils are various bryozoans, brachiopods, trilobites, and crinoids. In the surrounding region these fossils characterize the Woods Hollow shale, of Middle Ordovician age. In addition, from the shales F. A. Bush and B. H. Harlton[76] have obtained a microfauna which they state is of Black River age. Furthermore, southwest of Garden Springs the Woods Hollow shale, here plainly overlying the earlier Ordovician, also contains large "nodules" of the mottled and glauconitic limestone. Additional collecting from the "nodules" of Simpson Springs and East Bourland Mountains has given plentiful evidence that the fossils are of Cambrian and early Ordovician age.

It is here suggested that the "nodules" are in fact large erratic boulders of Cambrian and Ordovician limestones embedded in the shaly and flaggy strata of the Middle Ordovician Woods Hollow shale. As it is clear that the type locality of the †Brewster formation is a part of the Woods Hollow shale, it has been recommended[77] that the name "†Brewster" should be abandoned. The name "Dagger Flat sandstone" is used here for the indigenous Cambrian strata.

Two faunas appear to be represented in the boulders of the Woods Hollow shale. The oldest of these is of Upper Cambrian age. In a collection made by C. L. Baker on East Bourland Mountain E. O. Ulrich has identified the following species:

Lingulella manticula (White).
Lingulella desiderata (Walcott).
Acrotreta idahoensis (Walcott).
Acrotreta sp.
Alokistocra aff. *A. aoris* (Walcott).

In a collection by the writer on Simpson Springs Mountain Ulrich has recognized *Agnostus* and several new species of Upper Cambrian trilobites. Ulrich notes that the first three species in the list from East Bourland Mountain are typical Upper Cambrian fossils which have been found in Nevada and elsewhere, and that the fauna is decidedly like that found in the Dunderberg shale of the Nevada Upper Cambrian section.

[75] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), p. 83.

[76] Communication to the writer, 1931. Van der Gracht, in referring to the Dagger Flat sandstone (op. cit., table Vb), makes the following comment: "There is controversy whether the Cambrian is represented at Marathon. The above version is contested by B. H. Harlton and F. A. Bush, who advised the writer that the type locality yielded a profusive microfauna of Black River age." The collections of Bush and Harlton came from the type locality of the †Brewster and not of the Dagger Flat formation.

[77] King, P. B., Pre-Carboniferous stratigraphy of the Marathon uplift: Am. Assoc. Petroleum Geologists Bull., vol. 15, p. 1064, 1931.

A younger fauna is of early Ordovician age. In a collection made by C. L. Baker on Simpson Springs Mountain Ulrich has identified the following species:

Obolus rotundatus (Walcott).
Lingulella pogonipensis (Walcott).
Schizambon typicalis (Walcott).
Eoorthis desmopleura (Meek).
Symphysurina spicata n. var. (Ulrich).
Symphysurina 2 n. sp.
Conokephalina inexpectans (Walcott).
Apatokephalus finalis (Walcott).
Hungaia? sp.

From East Bourland Mountain Josiah Bridge has obtained various species of *Symphysurina* and other fossils similar to those in the preceding list. Ulrich notes that the fauna is like that in a well-marked zone of the lower part of the Pogonip limestone of Nevada. The Pogonip limestone is classified by the Geological Survey as of Lower Ordovician age, but this part of the formation is assigned by Ulrich to the upper part of his Ozarkian system.

It is probable that the erratic blocks in the Woods Hollow shale are of a facies foreign to the Marathon geosyncline. Their lithology is quite unlike that of indigenous rocks of the same age, and their faunas have not been revealed by the most diligent collecting from ledges in place. Massive limestones of Upper Cambrian and early Ordovician age are not known to crop out at any place in trans-Pecos Texas. They are found farther east, in the Llano-Burnet uplift (Central Mineral Region).[78] Probably a western extension of these limestones lies beneath the surface not far north of the Marathon folded belt.

ORDOVICIAN SYSTEM

HISTORICAL SUMMARY

Rocks of Ordovician age were reported to occur in the Marathon Basin by J. A. Udden,[79] who collected a few fossils, considered to be of Trenton age by Schuchert, during the course of his journey to the Chisos country, "along the wagon road near Ridge Spring and at different points south from this place for a distance of 10 miles."

Important stratigraphic work in the area was done by Baker and Bowman [80] in 1915. They collected fossils and made brief studies of the Cambrian and Ordovician succession, and their fossil collections were studied by E. O. Ulrich. During field work in 1929 and 1930 the writer [81] restudied the Ordovician rocks of the Marathon Basin and divided the section into five formations.

GENERAL FEATURES

The Ordovician system in the Marathon Basin, with a maximum thickness of about 2,000 feet, is brought to the surface in the Marathon and Dagger Flat anticlinoria (pl. 23). The higher members also appear in anticlines of less height between the anticlinoria and to the south of them. The system is now divided, in ascending order, into the Marathon limestone, the Alsate shale, the Fort Peña formation, the Woods Hollow shale, and the Maravillas chert. The Lower, Middle, and Upper Ordovician are all represented. All the formations contain fossils in greater or less quantity, but collecting is nearly always difficult, as it entails the splitting of great quantities of slaty shales and thin-bedded limestones that bear little or no surface indication of the presence of organic remains. The best fossils are obtainable in finely granular limestone, where there has been little compression of the shells.

The Ordovician section at Marathon is composed of relatively thick beds of shale, muddy limestone, and chert. These beds are intercalated with thinner layers of conglomerate, boulder beds, and sandstone. The faunas are mostly of a specialized facies, with plentiful floating and attached graptolites, associated with linguloid and oboloid brachiopods, pteropods, and trilobites. A very different contemporaneous facies is found in exposures 100 miles to the northwest, where the rocks are nearly all dolomitic limestones (fig. 16) and contain faunas characterized by orthoid brachiopods, cephalopods, corals, and sponges. The differences between the two sections are, however, more apparent than real, for several fossils and a few faunal groups are found in both regions. There is no suggestion that the strata were deposited in separated seaways. It is probable that the more or less clastic Ordovician strata at Marathon were deposited on or near muddy shores, in agitated water, and that the limestones with the gastropod-cephalopod assemblages were deposited farther from shore, in clean and quiet water.

During the course of the present field work 10 stratigraphic sections of Ordovician rocks were measured, of which only 5 extend entirely from the Cambrian to the probable Devonian (pl. 2). At four places in the area the stratigraphic sequence is particularly well exposed and is relatively free from structural complications: (1) On the south side of the road to the Roberts ranch, 3 miles west-southwest of old Fort Peña Colorada; (2) between Woods Hollow and Little Woods Hollow, on the old Louis Granger place, 6 miles southeast of Marathon; (3) on the south side of the Woods Hollow Mountains, 3 miles northeast of

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78 Bridge, Josiah and Dake, C. L., Faunal correlation of Ellenburger limestone of Texas: Geol. Soc. America Bull., vol. 43, pp. 725–748, 1932.

79 Udden, J. A., Sketch of the geology of the Chisos country: Texas Univ. Bull. 93, pp. 18–20, 1907.

80 Baker, C. L., and Bowman, W. F., Exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, pp. 79–101, 1917. A preliminary statement, containing the first published descriptions of their formations, is given in Review of the geology of Texas: Texas Univ. Bull. 44, 1st ed., 1916.

81 King, P. B., Pre-Carboniferous stratigraphy of the Marathon uplift: Am. Assoc. Petroleum Geologists Bull., vol. 15, pp. 1066–1076, 1931.

Woods Hollow Tank; and (4) on the south side of Dagger Flat, 4 miles northeast of the Buttrill ranch. These localities were studied with the greatest care, and at each place a detailed section was measured.

MARATHON LIMESTONE

GENERAL FEATURES

The term "Marathon limestone", as here used, is a restriction of the term "†Marathon series" of Baker and Bowman to the limestones and associated rocks that crop out within the town of Marathon. These strata, which are a well-marked unit of Deepkill (Beekmantown) age, are exposed in the streets and vacant lots of the town. The basal beds, resting on the Dagger Flat sandstone, crop out a mile southwest of the railway station, on the north side of the old road to Alpine, and the highest layers, dipping beneath the Alsate shale, occupy a northeastward-trending belt of outcrop that crosses the Boquillas road 1¼ miles south of the town.

Other good exposures are found on the south side of the road to the Roberts ranch, 3 miles west-southwest of old Fort Peña Colorada. Part of the formation is also beautifully revealed in the bed of Alsate Creek, on the opposite side of the road (fig. 12). There are extensive exposures of the formation in the northeast end of the Dagger Flat anticlinorium, northeast of Woods Hollow Tank.

In aerial photographs the outcrops of Marathon limestone are lighter-colored than those of adjacent formations but are streaked with faint light and dark bands that mark the outcrops of individual beds (pl. 17).

The Marathon limestone generally ranges between 500 and 1,000 feet in thickness but thins to only 350 feet in the southernmost exposures (pl. 2). The most conspicuous parts of the formation are beds of flaggy limestone that weather to an ashen-gray or bluish color, some of which contain graptolites. Partings of shale separate most of the limestone layers (pl. 3, *A*), and there are a few thick members of greenish clay shale. The argillaceous parts of the formation probably make up one-third or one-half its total thickness. Between the limestones are a few layers of sandstone and many beds of intraformational conglomerate. Near the middle of the formation is the Monument Spring dolomite member, which reaches 90 feet in thickness in the Marathon anticlinorium, where it has a wide and persistent development, but it thins and disappears southeastward in the Dagger Flat anticlinorium. The member is a massive mottled dolomitic limestone that contains fossils like those of the El Paso limestone in the region to the northwest.

LOCAL FEATURES

Marathon anticlinorium.—The Marathon limestone has a wide exposure between the town of Marathon and the Roberts ranch along the crest of the Marathon anticlinorium, where it crops out in nearly level plains or in rolling hills covered with ashen-gray outcrops of its limestone flags. The formation is intricately folded and crumpled, and in places the weaker beds are cut out by squeezing or faulting, so that measurements of thickness are not altogether trustworthy, and thicknesses of individual members are quite different in closely adjacent sections. The competent Monument Spring dolomite member near the middle of the formation is broken and shattered, so that its outcrop is characteristically a chain of disconnected boulders. As a result of deformation the layer has been repeated in a most bewildering manner, and only careful field mapping does away with the impression that there are many beds of this sort in the section instead of one. The limestone flags of the formation in many places are traversed by veins of granular calcite and are cut at oblique angles to the bedding by cleavage planes that are strongly slickensided and coated with small calcite crystals. The interbedded shales are somewhat indurated but are not otherwise altered.

The Monument Spring dolomite member, near the middle of the formation, is named for its exposure half a mile west of Monument Spring, 12 miles southwest of Marathon. Its maximum thickness in the area near Fort Peña Colorada and Alsate Creek is 94 feet, but it thins to 25 feet 8 miles to the southwest, near Monument Spring. It consists of dense mottled dolomitic limestone, breaking with conchoidal fracture, and is constructed of small nodular masses of blue-gray dolomite, closely packed in a yellowish dolomitic matrix.[81a] In places it contains small angular calcareous fragments of similar appearance to the matrix. It weathers to light-colored, rounded boulders or disconnected ledges, which appear white from a distance (pl. 3, *B*). In places the rock is strongly silicified; the yellowish matrix is changed to brown chert, and the bluish nodules are relatively unaltered, so that the rock takes on a ribbed or spongy appearance. In other places the yellowish matrix has yielded more readily to decay, and the nodular portions remain as hard lumps. The exposures then resemble the nodular marls of the Comanche Peak and Georgetown formations in the Cretaceous. Near the top and base of the member the beds are less mottled and thick-bedded and are intercalated with thin layers of compact dark-gray or brown limestone. Fossils are common in parts of the dolo-

[81a] For a discussion and interpretation of limestones of this type see Twenhofel, W. H., Treatise on sedimentation, 2d ed., pp. 334–335, 1932.

mite, and there are many obscure reef-like structures, in which heads of *Cryptozoon* and various cuplike sponges such as *Calathium* are embedded.

The beds above and below the Monument Spring dolomite member are identical in appearance and cannot be distinguished in the field. They consist of flaggy limestones with much interbedded shale (pl. 3, *A*) and scattered layers of conglomerate and sandstone. The flaggy limestones are dense, are gray or black, and weather to ashen-gray or bluish surfaces. They break with calcite, probably the traces of algae, and some are penetrated by small tubes and pockets of comminuted organic material (fig. 11, B), perhaps the excrement of some burrowing animal. The limestone bedding surfaces show channel markings and small pockets filled by cross-bedded sand. In the upper part, on Alsate Creek, thin argillaceous limestones have well-developed mud cracks (fig. 11, C). Near Monument Spring some of the lower limestones contain nodules of black chert and reddish silicified seams.

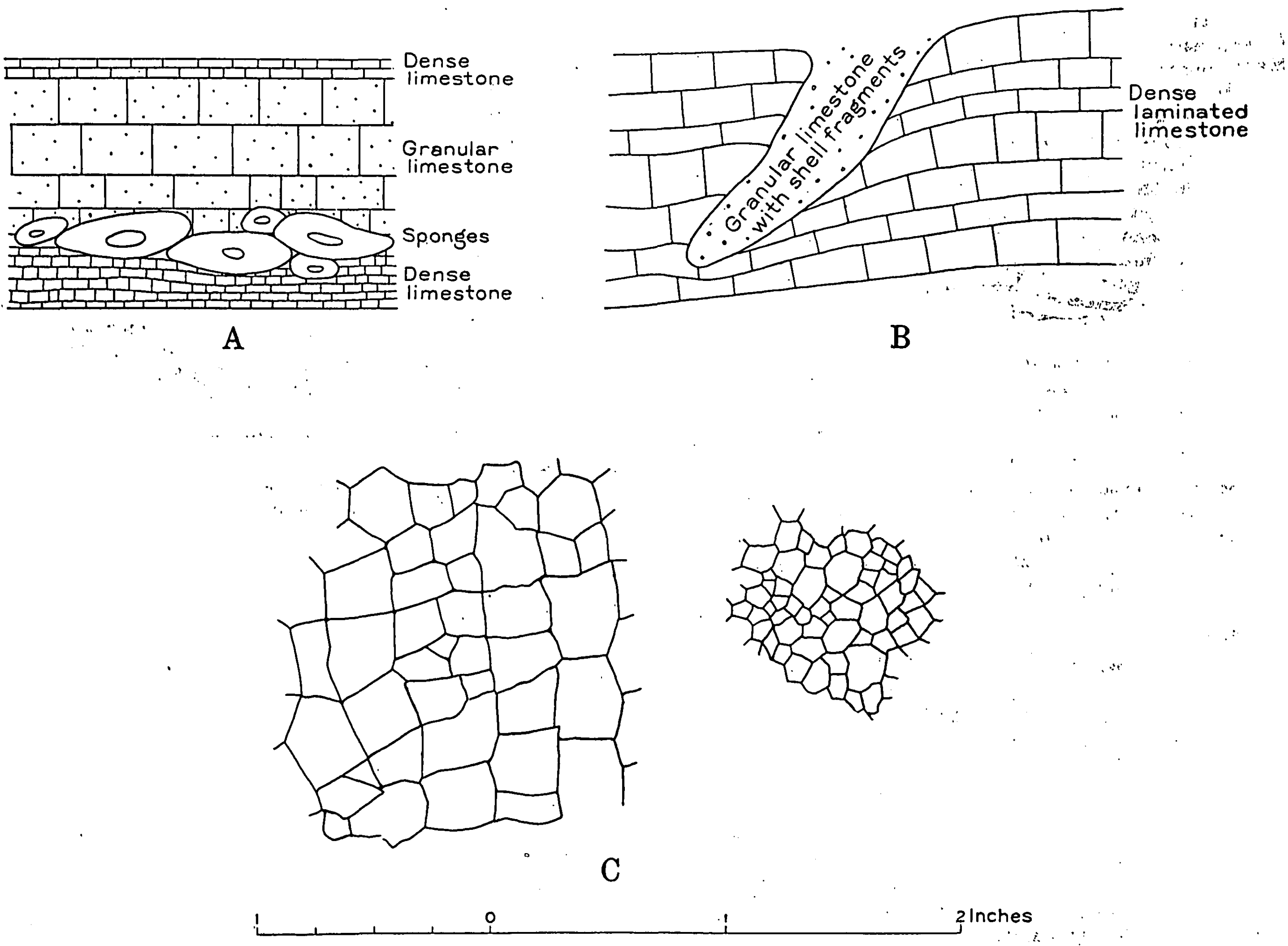


FIGURE 11.—Sketches showing structural features in the Marathon limestone. A, Sponge bed and other features near Alsate Creek; B, animal burrow near Monument Spring; C, mud cracks in calcareous shale near top of formation, Alsate Creek.

with conchoidal fracture. Shale partings occur between most of the layers. Some of the dense limestones contain seams or lenses which are spotted with bituminous matter and which consist of mats of tangled graptolite stipes and crushed linguloid and pteropod shells. There are a few thin layers of globular silicified sponges (fig. 11, A), and the weathered surfaces of some of the beds are thickly strewn with the separated spicules of hexactinellids. Some of the dense limestones are traversed by vertical cylindrical tubules filled

Each section of the formation contains five or six layers of intraformational conglomerate 1 to 5 feet thick. Locally these beds reach 8 or 10 feet in thickness but thin out along the strike. They are composed of shattered limestone flags, turned this way and that and cemented by granular limestone. The flags resemble the limestones that lie beneath the conglomerate layers and were probably derived from them. Some of the conglomerate layers also contain more distantly derived, well-rounded pebbles of chert, limestone, and vein quartz.

The best section in the area is that on the south side of the road to the Roberts ranch, 6 miles southwest of Marathon, where the formation dips to the southeast with only minor duplications by folding. The following section (sec. 4, pl. 2) is a composite of several closely adjacent measurements on the hills south of the road, in which thicknesses have been averaged so as to give as nearly an accurate view of the sequence as possible. The areal relations of the locality are shown on plate 16.

Section on south side of road 6 miles southwest of Marathon

	Feet
Alsate shale, with thick basal conglomerate.	
Marathon limestone:	
Upper member:	
22. Dense gray limestone, interbedded with calcareous shale	32
21. Conglomerate similar to beds below	2
20. Dense gray limestone in beds a few inches thick, weathering nodular, with shale partings	32
19. Conglomerate	1
18. Thin-bedded limestone, banded yellow and gray, interbedded with granular brown limestone, in part sandy	15
17. Conglomerate of rounded limestone and chert pebbles	2
16. Dense brown or gray limestone, in part marked by dark laminae, containing graptolites in lower part	15
Monument Spring dolomite member:	
15. Dense dolomitic mottled gray limestone in 1- to 4-foot ledges. Some of the less coherent layers have weathered to a lumpy marl. Poorly preserved sponges, gastropods, and a cephalopod noted	94
Lower member:	
14. Flaggy limestone	31
13. Conglomerate	2
12. Mostly covered; some limestone exposed	120
11. Conglomerate of limestone pebbles as much as 1 inch across and of chert pebbles 2 inches across in a gray-brown sandy limestone matrix	4
10. Granular gray limestone, in part sandy, in beds a few inches thick, with some shale partings as much as 1 foot thick	26
9. Conglomerate of limestone flags which reach 6 inches across, with some more rounded pebbles of limestone and chert in a brown sandy limestone matrix	6
8. Covered; probably mostly shale	118
7. Flaggy limestone	80
6. Conglomerate of limestone flags, with a few chert fragments	2
5. Gray limestone in 2-foot beds, with thin chert seams; some interbedded thin-bedded limestone	92
4. Dark-gray dense limestone in beds as much as 1 foot thick	77
3. Dense dark-gray limestone in beds a few inches thick, with much interbedded shale. Some of the limestone is laminated by dark bands	35

Section on south side of road 6 miles southwest of Marathon—Con.

	Feet
Marathon limestone—Continued.	
Lower member—Continued.	
2. Green shale, with thin limestone flags	27
1. Conglomerate of fine chert and limestone fragments	2
Total thickness of Marathon limestone	815
Dagger Flat sandstone.	

Nearby, on the east side of the road, the upper part of the same sequence is clearly exposed in the bed of Alsate Creek (fig. 12 and pl. 3, *A*; for location see pl. 16). The following section was measured at this place by Josiah Bridge and C. L. Dake and is reproduced from their field notes. It illustrates the complexity of the structure revealed by good exposures of the formation.

Section on east side of road 6 miles southwest of Marathon

	Feet
Alsate shale, with basal conglomerate.	
Marathon limestone:	
Upper member:	
17. Thin-bedded limestone with thin shale partings, containing graptolites 15 feet below top. Calcareous shales a few feet from top contain well-developed mud cracks	30
16. Shale	14
15. Limestone with large *Didymograptus*	1
14. Shale	13
13. Fine-grained dark thin-bedded limestone, much crushed and brecciated	13
Fault.	
12. Badly shattered thin-bedded limestone with shale partings	24
11. Badly crushed indurated green shale, resembling Alsate	10
10. Conglomerate	1
9. Thin-bedded limestone, with much shale	12
Fault.	
8. Thin-bedded limestone	25
7. Dominantly green shale; thin-bedded limestone in a 10-foot zone near middle contains large *Didymograptus*, and near base are thin limestones with large *Phyllograptus*	35
6. Conglomerate	3
5. Thin-bedded limestone with thin beds of shale	25
4. Conglomerate	3
Monument Spring dolomite member:	
3. Partly covered and badly shattered, with large silicified boulders on hillside above. Coiled cephalopod collected	70
Lower member:	
2. Covered; possible fault	10
1. Thin-bedded dense limestone, with thin shale partings	35
Base of section not exposed.	
Total thickness of exposed section	324

A well drilled in 1935 by King & Franklin near the old Louis Granger place, on the anticline between Woods Hollow and Little Woods Hollow, penetrated over 1,000 feet of Marathon limestone (pl. 2). The following is a condensed record of the boring, based on a study of samples by C. L. Baker and Mrs. D. O. Carsey. The correlations are by Mr. Baker:

Abstract of log of King & Franklin Gage no. 1 well

	Feet
Fort Peña formation:	
1. No record; this formation crops out near the well	0–67
2. Thinly laminated, brown and gray, finely crystalline limestone. Some chert; sandstone and green shale at 90–98 feet	67–114
Alsate shale:	
3. Hard dark-gray shale, a little gray limestone in lower part	114–465
Marathon limestone:	
4. Gray limestone, in part siliceous and dolomitic, with gritty gray shale	465–516
5. Dark-gray gritty shale and some banded siliceous dolomite	516–604
6. No record	604–647
7. Gray-brown and dark-gray limestone, black and blue-gray shale, and some sandstone, which contains water at 741 and 794 feet. Some cream-colored dolomite and white chert at 723 feet (Monument Spring member?)	647–942
8. Black shale and some limestone	942–1, 066
9. Dull-black chert and milky-gray translucent chert. The latter resembles that in the Ellenburger limestone of central Texas. The cherts are associated with gray limestone, in part dolomitic. Light-green hard bentonite at 1,169, 1,221, and 1,231 feet	1, 066–1, 262
At this depth the well is reported to be still in chert, although the percentage of dolomitic limestone has increased. Heavy gas pressure	1, 613

limestone range between 950 feet in the northeast and 350 feet near the Buttrill ranch, in the south (pl. 2). The Monument Spring dolomite member is only a few feet thick in the northern part of the area and is absent on the Buttrill ranch. Its exposures are broken and not persistent, as a result of shattering during deformation. Along the south side of the Woods Hollow Mountains, where the formation is 950 feet thick, the member is 450 feet below the top. Higher up, 350 feet below the top, is a 6-foot bed of black or purple granular thin-bedded chert. Between this and the dolomite member are numerous layers of brown sandstone and several beds of indurated greenish siliceous shale. Near Garden Springs the formation contains a few ledges of light-gray limestone 2 or 3 feet thick.

On the south side of Dagger Flat, near the Buttrill ranch, the Marathon limestone is intensely folded and occupies a narrower belt of outcrop than elsewhere. This may be due to a thinning out of the sediments but possibly also results from squeezing during deformation. Most of the formation here is indurated shale, and there are only a few thin flags of limestone. The limestone increases in prominence in successive strips of outcrop to the north. In the basal part there is much dull-lustered splintery black chert in thin layers. There are also three or four massive conglomerate beds 1 to 2 feet thick.

The following section illustrates the character of the formation in this region (sec. 12, pl. 17). The intense folding of the rocks at the locality may have sheared out some of the beds and makes the determined thickness approximate at best.

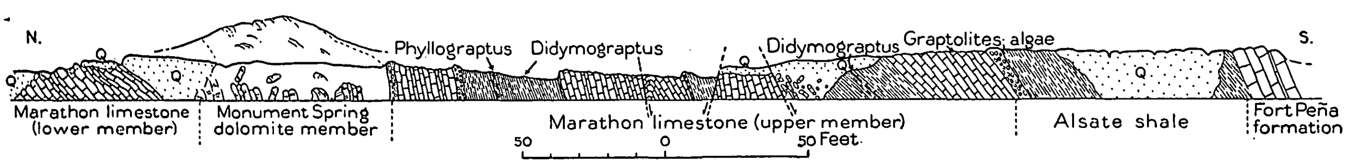


FIGURE 12.—Section in the bed of Alsate Creek, 3 miles west-southwest of old Fort Peña Colorada, showing sequence and structure of part of the Ordovician rocks. Q, Alluvial deposits. From observations by Josiah Bridge and C. L. Dake.

The log thus indicates a thickness of 1,148 feet of beds below the assumed top of the Marathon limestone, which is a greater figure than any measured thickness of the formation in the area. No strata of Dagger Flat type were encountered, and it is quite probable that the lower beds in the boring are either greatly thickened by squeezing of shales from the flanks into the crest of the anticline, or that their apparent thickness is caused by their steep dip.

Dagger Flat anticlinorium.—In the Dagger Flat anticlinorium measured sections of the Marathon

Section 4 miles northeast of Buttrill ranch

	Feet
Alsate shale.	
Marathon limestone:	
17. Shale	73
16. Brown gritty sandstone	6
15. Flaggy limestone, in beds a few inches thick, with brown siliceous material on the bedding planes	56
14. Shale	11
13. Gray limestone	1
12. Shale, with some thin-bedded sandstone	22
11. Flaggy gray limestone in beds a few inches thick, with shale partings	15

Section 4 miles northeast of Buttrill ranch—Continued

	Feet
Marathon limestone—Continued.	
10. Shale and siliceous shale, the shale weathering to yellow plates	9
9. Conglomerate	2
8. Flaggy limestone, with thick beds of shale	36
7. Conglomerate	3
6. Shale, with two beds of limestone	36
5. Shale	14
4. Limestone	8
3. Conglomerate	3
2. Shale	42
1. Conglomerate	3
Total	340
Dagger Flat sandstone.	

The first reported discovery of the fauna of the Marathon limestone was made at Threemile Hill by Baker and Bowman.[82] This collection appears to have come from thin slices along a thrust plane between the Woods Hollow shale and the Dagger Flat sandstone (fig. 10). Except for a few loose blocks, no typical limestones of the Marathon formation were found at the locality by the writer, and the Fort Peña and Alsate formations are wanting entirely. Most of the limestone assigned to the Lower Ordovician in Baker and Bowman's original section is earthy limestone intercalated in the lower part of the Woods Hollow shale. *Dicellograptus* has been collected from it by the writer.

FOSSILS AND AGE

The faunas of the upper and lower members of the Marathon limestone are similar in character, although they represent distinct zones in the Deep Kill section of New York. The most common graptolite genera are *Tetragraptus*, *Phyllograptus*, and *Didymograptus*, but at some localities *Goniograptus* and *Loganograptus* are also found. Various dendroid graptolites, including *Dictyonema*, are found throughout both the lower and upper members. Associated with the graptolites are many linguloid and oboloid brachiopods, a few pteropods and trilobites, and in some zones many sponges. As these faunas are to be correlated with part at least of graptolite beds 1 to 5 of the section at Deep Kill, they belong to the Beekmantown.

Large collections of graptolites have been made by the writer from the lower and upper members of the Marathon limestone, but so far only a few of these have received detailed study. The following are lists of graptolites and associated fossils from the region that have been specifically identified:[83]

[82] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), p. 89.

[83] Many of the identified species from the Marathon limestone and higher formations of the Ordovician are figured in Sellards, E. H., Pre-Paleozoic and Paleozoic systems, in The geology of Texas, vol. 1, Stratigraphy: Texas Univ. Bull. 3232, pl. 4 and pp. 235–236, 1933.

1. About 8 miles southwest of Marathon on road to Roberts ranch, below Monument Spring dolomite member, Monument Spring quadrangle; R. E. King, collector; identified by Rudolf Ruedemann:
   - *Didymograptus nitidus* (Hall). U.S.N.M. 85363.
   - *Didymograptus patulus* (Hall).
2. Thrust slice on north slope of Threemile Hill, Santiago Peak quadrangle; C. L. Baker, collector; identified by E. O. Ulrich:
   - *Didymograptus* cf. *D. extensus* (Hall).
   - *Tetragraptus* aff. *T. fruticosus* (Hall).
   - *Phyllograptus* cf. *P. ilicifolius* Hall.
   - *Phyllograptus* cf. *P. angustifolius* Hall.
   - *Paterula* sp.
   - *Acrotreta* sp.
3. Three-fourths mile northwest of hill 4360 of Peña Blanca Mountains, apparently below Monument Spring dolomite member, near axis of small anticline, Marathon quadrangle; C. L. Baker and J. Hosterman, collectors; identified by Rudolf Ruedemann.
   - *Didymograptus* cf. *D. extensus* Hall (fragment).
   - *Loganograptus logani* (Hall) (fragment).
   - *Phyllograptus typus* Hall.
   - *Phyllograptus anna* Hall.
   - *Diplograptus* (*Glyptograptus*) *dentatus* (Brongniart).
4. Same horizon and locality as 3; P. B. King, collector; identified by Edwin Kirk: (U. S. Geological Survey locality 2411):
   - *Phyllograptus* cf. *P. ilicifolius* Hall.
   - *Didymograptus* cf. *D. nicholsoni* var. *planus* Elles and Wood.
   - *Tetragraptus* sp.
5. Three-fourths mile northwest of bench mark 4015 on Terlingua road, 50 feet above Monument Spring dolomite member, Monument Spring quadrangle; P. B. King, collector; identified by Edwin Kirk (U. S. Geological Survey locality 2412):
   - *Acrotreta* sp.
   - *Didymograptus bifidus* (Hall).

The fauna of the Monument Spring dolomite member is of a distinct facies. It contains plentiful masses of *Cryptozoon*, at least three species of sponges, including *Calathium* cf. *C. formosum*, undetermined orthoid brachiopods, and various poorly preserved gastropods. A single cystoid calyx was found, but stem segments occur in the rock in great numbers. Cephalopods are plentiful and well preserved; the most characteristic are *Piloceras* and the endoceratoid *Colpoceras*. According to Edwin Kirk, this fauna is nearly identical with that in the lower half of the El Paso limestone at El Paso, but particularly in the beds several hundred feet above its base.

STRATIGRAPHIC RELATIONS

The top of the Marathon limestone in the Marathon anticlinorium is sharply separated from the Alsate shale by coarse conglomerate. In the bed of Alsate Creek the limestone below the conglomerate is channeled and broken, and the conglomerate is deposited in cavities and interstices. In the Dagger Flat anticlinorium the contact is also drawn at conglomerate, but the intercalated limestones above and below it are only slightly different in character.

ALSATE SHALE

GENERAL FEATURES

The Alsate shale was named for Alsate Creek,[84] which joins Peña Colorada Creek from the west at old Fort Peña Colorada. The shale is well exposed in a cut in the creek 2½ miles west-southwest of the fort (for location, see pl. 16), and it is widely distributed in narrow convoluted belts of outcrop in both the Marathon and Dagger Flat anticlinoria. In most places the shale occupies a covered interval between the ledges of Marathon and Fort Peña limestones. The Alsate shale is a thin but distinctive formation overlying the normal Deepkill zones of the Marathon formation, set off below and above by conglomerates and characterized by the exotic graptolite genus *Oncograptus*. The formation consists of two facies. In the northern exposures it is mostly shale, but in the south there are many limestone ledges (pl. 2). The faunas in both areas are similar, and the two facies probably intergrade.

LOCAL FEATURES

Marathon anticlinorium.—Near the type locality the formation consists of 5 to 18 feet of conglomerate, overlain by 20 to 40 feet of shale (fig. 12 and sec. 4, pl. 2). Elsewhere in the Marathon anticlinorium the shales are much thinner, but on the hills north of the road to the Roberts ranch and west of Alsate Creek they are 100 feet or more in thickness. As this area is intensely folded and is broken by many small thrust faults (sec. C-C; pl. 16), some of the thickening may be of tectonic origin. The formation here appears to be thickest along anticlinal and synclinal axes, and the folding in the competent Fort Peña formation above is more open than in the Marathon limestone below. This difference suggests that the shales acted as a plastic cushion between the two more competent members, in much the same manner as the Woods Hollow shale, higher in the section.

The conglomerate at the base of the formation is massive and lenticular. It is made up of rounded or subrounded fragments of limestone and chert in a matrix of buff sandy limestone. In the bed of Alsate Creek the conglomerate rests on a channeled surface of flaggy limestone of the Marathon formation. The overlying shale is indurated and greenish and breaks into small hard chips. It contains some lenses of black chert. In many places there are thin nodular beds of dense gray or greenish limestone, weathering yellow and locally containing fossils. The northern exposures include also lenses of gray or buff saccharoidal to quartzitic quartz sandstone. In some exposures are iron-stone nodules that weather to brown limonite but on fresh surfaces consist of radiating marcasite crystals.

Along several of the narrow anticlinal axes 1 to 1½ miles southeast of Marathon there are, in the lower part of the shales, several ledges of granular laminated limestone with brown siliceous seams. These contain *Oncograptus* and resemble lithologically the limestones of the Alsate formation in the Dagger Flat anticlinorium.

A thickness of 351 feet of hard dark-gray shale was penetrated below the Fort Peña formation by the King & Franklin well in the Woods Hollow Mountains, and part or all of it may belong to the Alsate shale.

Dagger Flat anticlinorium.—In the Dagger Flat anticlinorium the formation is from 100 to 145 feet thick (sec. 8, pl. 2). Here ledges of limestone like those in the Fort Peña formation are a conspicuous part of the formation, but each is separated from the next by 3 to 8 feet of poorly exposed shale. Most of the limestones form 6-inch to 1½-foot beds, are gray, and are finely granular or sandy. In part they are thinly laminated and are seamed by brown siliceous matter. Some are cross-bedded. Some of the granular layers contain abundant graptolites, including *Oncograptus*, and oboloid and linguloid brachiopods. There are also thinner layers of dense gray limestone, in part laminated, weathering pale buff and yellow. The formation is locally separated from the underlying Marathon limestone by thin layers of conglomerate.

Relation of the Marathon and Dagger Flat areas.—The rocks of the Alsate formation in the Marathon anticlinorium are of somewhat different character from those in the Dagger Flat anticlinorium. Most of the Marathon area has none of the finely granular laminated limestones that are conspicuous in the Dagger Flat area, and no specimens of *Oncograptus* have been collected there. However, in both areas the rocks contain graptolites and other fossils of late Deepkill age. Moreover, in the eastern part of the Marathon anticlinorium, southeast of Marathon, a few ledges of granular limestone with *Oncograptus* have been found near the base of the Alsate shale, so that it is probable that the sets of strata in the two areas are the lateral facies of a single formation.

MICROSCOPIC CHARACTER

A thin section of saccharoidal sandstone from a lens in the Alsate shale north of the road to the Roberts ranch southwest of Alsate Creek consisted of rounded to angular quartz grains of medium size with a few small grains of feldspar, calcite, and chlorite, in a matrix of crystalline calcite. The rock contains a few

[84] Alsate Creek is named for Alsate, chief of the Chisos Apache Indians, who once occupied this territory. Kokernot Spring, near Alpine, was once called Charco de Alsate. See Raht, C. G., The romance of Davis Mountains and Big Bend country, pp. 166-170, 273-279, El Paso, Rahtbooks Co., 1919. According to M. B. Arick (Early Paleozoic unconformities in trans-Pecos Texas: Texas Univ. Bull. 3501, p. 119, 1930) the name is more properly spelled Alcate, but the writer has not been able to verify this spelling in any reference works at his disposal.

curved fragments of shells. The quartz grains show strain shadows and some shattering.

FOSSILS AND AGE

The limestones of the Alsate formation in the Dagger Flat anticlinorium contain graptolites in thin zones, nearly everywhere including the remarkable genus *Oncograptus*, hitherto known only in Australia, British Columbia, and Idaho. Ruedemann [85] interprets the genus as an aberrant offshoot of *Didymograptus* in the Pacific realm at a horizon probably corresponding to graptolite beds 3 to 7 of the Deep Kill section. Four collections from outcrops lying between Woods Hollow Tank and a point 3 miles to the northeast are typical of the formation in this region; the *Oncograptus* was identified by Ruedemann, and the remaining fossils by Kirk:

Oncograptus upsilon T. S. Hall.
Didymograptus cf. *D. extensus* (Hall).
Didymograptus sp. (with large stipes).
Tetragraptus sp.
Various dictyonemids.

In the Alsate Creek area fossils are found in some of the limestone nodules. A collection from a locality northwest of the road to the Roberts ranch and 1 mile west-southwest of point 4240, identified by Kirk, is typical of the fossils in this region:

Tetragraptus sp.
Didymograptus sp.
Phyllograptus sp.
Orthis (small brachiopod probably referable to this genus in a restricted sense).
Maclurites sp. (apparently identical with a new species occurring high in the Beekmantown member of the Pogonip limestone in Nevada).
Seleneceme sp. (small trilobite).
Large trilobites (fragments).

The Alsate graptolites are of late Deepkill age, and the *Maclurites* indicates that the formation is also to be correlated with some part of the latest Beekmantown.

STRATIGRAPHIC RELATIONS

The Alsate shale is everywhere separated from the overlying Fort Peña formation by layers of conglomerate, which are particularly prominent in the Marathon anticlinorium. In this area also the change in lithology from the shales of the Alsate to massive sandy limestones and intercalated conglomerates of the Fort Peña is very striking. From this evidence it is supposed that the two formations are separated by a considerable unconformity, which probably represents the later part of Lower Ordovician time.

[85] Ruedemann, Rudolf, Fossil evidence of the existence of a Pacific Ocean in early Ordovician time [abstract]: Geol. Soc. America Bull., vol. 39, pp. 299–300, 1928. For a valuable discussion of the anatomy and phylogeny of this genus, based on specimens from the Marathon region, see Bulman, O. M. B., The structure of *Oncograptus* T. S. Hall: Geol. Mag., vol. 73, pp. 271–278, 1936. The specimens certainly did not come from the El Paso limestone, as stated by this author, and are probably from the Alsate shale.

FORT PEÑA FORMATION

GENERAL FEATURES

The Fort Peña formation is the chief ridge maker in the Paleozoic succession below the novaculite and rises in low hogbacks out of the generally level country of the Marathon and Dagger Flat anticlinoria. The type locality is on one of the hogbacks directly north of old Fort Peña Colorada (pl. 24). On aerial photographs the outcrops of the Fort Peña formation stand out as a narrow band that is darker than the outcrops of adjacent formations (pl. 17).

Superficially the formation somewhat resembles the Dimple limestone, of Pennsylvanian age, for which in some places it has been mistaken. The formation ranges from 125 to 200 feet in thickness and consists mostly of alternations of thick-bedded limestone, in part sandy, with bedded bluish and purplish chert (pl. 2). There are some thin partings of shale, and near the base one or more beds of coarse conglomerate. The limestones contain a few fossils.

LOCAL FEATURES

Marathon anticlinorium.—The Fort Peña formation in the Marathon anticlinorium between Marathon and the Roberts ranch stands in low but prominent ridges. One of these parallels the novaculite hogback on the southeast flank of the anticlinorium for long distances (pl. 24) and stands but prominently north of old Fort Peña Colorada, the type locality. Farther north the formation crops out in hills of synclinal structure. In the Marathon anticlinorium the base of the formation is marked by a layer of coarse conglomerate 5 to 15 feet thick, of subrounded pebbles and cobbles of chert, limestone, and sandstone, a quarter of an inch to 6 inches in diameter, in a matrix of gray sandy limestone. Above are gray granular sandy limestones. In places there are fine pebbly seams and some partings of indurated drab shale. The shales increase in prominence toward the top. In the upper part are many thin beds of reddish or bluish granular chert. The uppermost limestones change gradually to a drab color, and the shale beds increase in thickness near the contact with the overlying Woods Hollow shale. Graptolites and oboloid brachiopods are found in some of the granular limestone layers, and some graptolites have been collected from the uppermost interbedded shales on Alsate Creek (pl. 3, *D*).

At a locality "1½ miles south of Marathon, where the dip is about 75° S. 55° E.," Baker and Bowman[86] found an exposure of Dimple limestone containing Pennsylvanian fossils. Their description corresponds to exposures of the Fort Peña formation which cross the road at this point and which contain Ordovician graptolites and brachiopods. The Pennsylvanian fossils

[86] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), p. 106.

reported from this place may have come from a loose block on the surface.

The following section (sec. 4, pl. 2) was measured 3 miles west-southwest of Fort Peña Colorada on the south side of the road to the Roberts ranch (see pl. 16 for location):

Section 3 miles west-southwest of Fort Peña Colorada

Woods Hollow shale; not well exposed.	
Fort Peña formation:	*Feet*
17. Scattered outcrops of finely granular, thinly laminated limestone, containing graptolites and brachiopods	54
16. Gray limestone in 1-foot beds, with some interbedded chert	62
15. Granular chert, laminated in reddish and purplish bands	1
14. Gray granular limestone in 1-foot beds, with some pebbly layers and some chert beds an inch thick	26
13. Granular chert	2
12. Gray granular sandy limestone in 1-foot beds, with 1-inch bands of bluish or reddish granular chert and a few thin partings of indurated shale. The limestone contains linguloid and oboloid brachiopods	13
11. Hard greenish-drab shale, with two or three beds of black dull-lustered chert an inch thick	2
10. Covered	3
9. Granular purplish chert in 1-inch beds, with thin limestone layers between	1
8. Granular sandy light-gray limestone, weathering somewhat crumbly, with pebbly seams	2
7. Covered	15
6. Gray granular sandy limestone, grading up from conglomerate. The limestone is in 1-foot beds and contains some pebbly seams	12
5. Conglomerate	8
4. Gray granular sandy limestone, in part pebbly and cross-bedded	1
3. Conglomerate	2
2. Gray granular sandy limestone	1
1. Conglomerate of subrounded to rounded fragments of gray and brown chert as much as 2 inches in diameter, of sandstone as much as 1 inch in diameter, and of gray limestone as much as 6 inches in diameter. The matrix is a gray sandy limestone	7
Total	212
Alsate shale.	

Dagger Flat anticlinorium.—In the Dagger Flat anticlinorium the Fort Peña formation is divisible into several members, which are well developed near Garden Springs and Woods Hollow Tank. At the base is a thin conglomerate, not everywhere present, of large and small limestone and chert pebbles, with some angular flags closely set in a granular sandy gray-brown limestone matrix (member *A* of sec. 8, pl. 2). These are followed by (*B*) about 75 feet of thick-bedded gray-brown granular limestone, with some thin-bedded chert. The succeeding beds (*C*), about 15 feet thick, consist mainly of shales and occupy a sag in the hogback ridge. Some dense, thinly laminated limestone, weathering yellow, is interbedded in the shale, as well as a few layers of gray granular fossiliferous limestone. The upper member (*D*) consists of bluish-gray to reddish, very massive chert in several 3- to 4-foot ledges, weathering into sharp splinters. It is succeeded by thin limestones and interbedded shales that grade into the Woods Hollow shale.

The following section (sec. 8, pl. 2) is typical of the sequence in the Dagger Flat anticlinorium:

Section 3½ miles northeast of Woods Hollow Tank

Woods Hollow shale.	
Fort Peña formation:	
Member *D* of sec. 8, pl. 2:	*Feet*
7. Yellow-brown flaggy laminated limestone, grading into overlying shale	16
6. Limestone and granular chert	45
5. Massive purple and granular chert in beds as much as 4 feet thick, with thin layers of granular limestone	24
4. Limestone and chert	4
Member *C*:	
3. Shale with thin beds of granular limestone and some beds of dense, yellow-weathering limestone	10
Member *B*:	
2. Limestone with granular purple chert beds a few inches thick. The limestones are thinly laminated and in 1- to 2-foot beds	71
Member *A*:	
1. Conglomerate of large and small chert and limestone pebbles, both angular flags and rounded fragments, closely set in a granular gray-brown limestone matrix	6
Total	176
Alsate shale.	

Jones ranch area.—In the southeastern part of the Marathon Paleozoic area, southeast of the Jones ranch, in the Dove Mountain quadrangle (pl. 23), are strata that are tentatively correlated with the Fort Peña and Woods Hollow formations. They crop out to the south of and apparently up the dip from exposures of Maravillas and Caballos. The lower rocks consist of fine-grained pink quartzite and brown limestone with embedded grits of chert and quartz. There is also some flaggy dark-gray granular limestone in beds a few inches thick, interbedded with indurated green shale. These strata are overlain by the equivalent of the Woods Hollow shale, which here consists of greenish shale and sandy shale, with some indurated sandy flagstones.

MICROSCOPIC CHARACTER

Two thin sections of cherts from the Fort Peña formation in the Marathon anticlinorium show similar characteristics (fig. 15, C). The rocks are laminated and consist of a fine-textured mat of radiating fibers of chalcedony. Embedded in the matrix are large and small rhombic crystals of calcite and scattered rounded grains of quartz. There are also numerous hollow spicules, probably of sponges. Most of these are composed of crystalline calcite, but a few have been wholly or partly altered to chalcedony. In places the fibers of the chalcedonic matrix radiate from the embedded grains. A few minute veins of calcite traverse the rocks.

FOSSILS AND AGE

With the exception of fossils in a few thin seams in the limestones, the Fort Peña formation contains little evidence of life. From limestone beds beneath the upper chert member near Garden Springs were collected *Diplograptus*, *Ceraurus*, *Bucania*, and a rafinesquinoid probably allied to *Ptychoglyptus*. Southwest of Marathon, in the Marathon anticlinorium, *Diplograptus* and *Climacograptus* are plentiful. In some of the more coarsely granular limestones they are not compressed, and all the minute structures of the stipes are beautifully preserved. Associated with them are oboloid and linguloid brachiopods and a small *Orthis* of the type *O. tricenaria*. In several of the collections southwest of Marathon there are also large stipes, seemingly of *Didymograptus*, and specimens of a recurved *Tetragraptus*.

Most of this fauna is suggestive of the Black River, but the occurrence here and there of the two primitive genera last named, reminiscent of the fossils collected by Ruedemann at the Ashill quarry, near Mount Moreno, N. Y.,[87] suggests that the formation is older and possibly Chazyan. The field relations of the Fort Peña formation suggest that it is of Middle rather than Lower Ordovician age, as its massive sandy limestones rest with coarse basal conglomerate on dissimilar Lower Ordovician strata and appear to grade up into the Woods Hollow shale.

STRATIGRAPHIC RELATIONS

The Fort Peña formation apparently passes conformably upward into the Woods Hollow shale. The massive cherty gray limestones of the formation change near the top into drab, thinly laminated limestones, with much interbedded shale, and near the top into shales with a few flaggy limestone layers. The fossils also suggest that the rocks are not greatly different in age.

WOODS HOLLOW SHALE

GENERAL FEATURES

The Woods Hollow shale is best exposed between Woods Hollow and Little Woods Hollow, where it crops out in an anticlinal valley on the former Louis Granger ranch (fig. 6, C). The formation nearly everywhere is worn down to a valley between the hogbacks of the Fort Peña formation and the higher ridges of the Maravillas chert and Caballos novaculite. In most places it is covered by soil and crops out only in gullies and creek banks. The formation is the same as Baker and Bowman's members 4 and 5 of their Marathon series. The strata at Garden Springs, Horse Mountain, and Fort Peña Colorada mentioned by them are also a part of the formation. The differences in lithology noted by them at these localities are at most the local facies of a single stratigraphic unit.

[87] Ruedemann, Rudolf, Graptolites of New York, part 1: New York State Mus. Mem. 7, pp. 499–500, 1907.

The Woods Hollow shale consists of greenish clay shales, with interbedded thinly laminated gray or yellowish sandy limestone and limy sandstone (pl. 3, *C*). There are also some beds of nodular coarsely granular conglomeratic limestone, crowded with fragmental fossils. In several localities in the southwestern part of the Marathon Basin the shales include large embedded boulders that contain Cambrian and Lower Ordovician fossils (p. 24). The formation has a thickness of 300 or 400 feet (pl. 2).

The Woods Hollow shale has a variable width of outcrop (pl. 24). In places it forms a narrow strip, but elsewhere it crops out over wide areas. In the northeastern part of the Dagger Flat anticlinorium it occupies an area of several square miles, but the strata here have probably been piled up and repeated by the squeezing out of beds on the nearby flanks of the fold. The strong differences in structure between the Fort Peña and Marathon formations below and the Caballos and Maravillas formations above suggest that the incompetent shales of the Woods Hollow formation have had a cushioning effect, which has allowed the two groups of strata to be deformed in a different manner. The complexity of these larger structural features is reflected by the intense contortion of the shales in all the local exposures of the formation. North of Peña Blanca Spring a cut in a creek bed shows shales and flagstones dipping steeply southward but standing in isoclinal folds. Exposures in a small arroyo near Monument Spring contain limestone beds that have been broken and rolled and their ends rounded. The limestone fragments are embedded in shales, which have been kneaded and contorted around them. In spite of this deformation, the shales are only slightly indurated and the formation is not metamorphosed.

LOCAL FEATURES

Woods Hollow Mountains.—At the type locality the Woods Hollow shale, 470 feet thick, is clearly revealed in an anticlinal basin and dips in regular order off the highest Fort Peña limestones, which crop out in the center (sec. D–D′–D″, pl. 21). The lower part of the formation consists of flaggy, thinly laminated gray or yellowish sandy limestone or calcareous sandstone, with shale partings. This grades up into greenish clay shale with a few interbedded flaggy limestone layers (pl. 3, *C*). Some of the sandy beds are rill-marked on bedding surfaces, and some of the lower flaggy layers contain graptolites. There are five or six nodular beds of coarsely granular and conglomeratic limestone, weathering yellowish, which are crowded with comminuted remains of bryozoans, trilobites, brachiopods, and crinoids. There are a few beds of black shale near the top of the formation.

The following section (sec. 7, pl. 2) was measured by the writer. Some additional notes by C. L. Baker have been incorporated in the section.

Section in the Woods Hollow region

	Feet
Maravillas chert.	
Woods Hollow shale:	
14. Drab shale, with a few sandy beds, and thin limestone layers	161
13. Fine-grained, thinly laminated sandy brown limestone	1
12. Drab shale, in part sandy	74
11. Gray sandy limestone, weathering brown	1
10. Thin-bedded fine-grained brown sandstone, with some granular sandy limestone containing bryozoans and crinoid stems	24
9. Interbedded shale and fine-grained sandstone	85
8. Finely crystalline dark-gray laminated limestone, with some beds of sandstone	8
7. Finely crystalline dark-gray limestone, with granular seams full of bryozoans and crinoid stems	1
6. Calcareous brown sandstone with some fossiliferous layers, interbedded with shale	26
5. Granular gray sandy limestone	3
4. Greenish-drab shale, with some sandstone beds	31
3. Ledge of finely crystalline dark-gray limestone	4
2. Thin-bedded calcareous brown sandstone, interbedded with 1-foot beds of dark-gray laminated limestone	28
Total	447
Fort Peña formation:	
1. Dark-gray, finely granular, thinly laminated limestone, in beds a few inches to several feet thick, interbedded with some shale and fine sandstone. The flaggy layers contain *Diplograptus*. Forms low anticlinal ridge in middle of basin	30
Base of section not exposed. Lower beds have been penetrated in King & Franklin well. (See p. 29.)	

Simpson Springs and East Bourland Mountains.—The shales, sandy and limy flagstones, and conglomeratic limestones that lie beneath the Maravillas chert on Simpson Springs and East Bourland Mountains are of Woods Hollow age, but at these places, as well as near Garden Springs, they contain rounded masses of hard gray limestone as much as 3 feet in diameter, in part mottled and in part glauconitic (pls. 5, *E*, and 6, *B*). The limestone masses lie in soft clay shales and flaggy sandstones in the upper part of the formation. Cambrian and early Ordovician fossils have been collected from the limestones by both C. L. Baker and the writer, and the interbedded strata contain Middle Ordovician fossils. There is thus no doubt that the limestone masses are boulders which have been transported to the positions they now occupy. The lower part of the exposures on Simpson Springs Mountain was named the †"Brewster formation" by Baker and Bowman and considered to be of Cambrian age, but this interpretation is now discarded.

Other localities.—A few miles southeast of Marathon, near the junction of the Boquillas and Terlingua roads, and also near Peña Blanca Spring, a 30-foot member of sandstone crops out prominently in the lower part of the formation. The sandstone is in 1- to 2-inch layers, with a few thicker beds and is mostly thinly laminated, ferruginous, and quartzitic. It weathers to small angular iron-stained chips and blocks. On the south side of Dagger Flat, in the upper part of the formation, many layers of dense gray laminated limestones are interbedded in the shale. They weather to pale-buff earthy surfaces and form rounded ledges. In Baker and Bowman's section on Threemile Hill these beds were apparently grouped with rocks containing Deepkill graptolites. However, the writer has collected *Dicellograptus* from them at this locality.

MICROSCOPIC CHARACTER

A thin section of sandstone from the lower part of the Woods Hollow shale in the Marathon anticlinorium southeast of Marathon was examined. The sand grains are arranged in laminae a few millimeters thick, which stand out as dark and light bands in the hand specimen. The light layers are composed almost entirely of quartz, most of whose subangular grains are interlocked, though there are small amounts of interstitial crystalline calcite. Some of the quartz grains show strain shadows. There are a few minute grains of minerals with a high refractive index. In the dark layers the quartz grains are more dispersed and are set in an opaque argillaceous and ferruginous matrix.

FOSSILS AND AGE

Fossils are plentiful in the Woods Hollow shale but are nearly all comminuted and poorly preserved. *Diplograptus* is common in the lower flags at the type locality. Higher up, in the more granular limestones, are ramose and massive bryozoans, including *Phaenopora*, *Nicholsonella*, *Rhinidictya*, and *Anolotichia;* the trilobites *Illaenus* and *Asaphus;* the mollusks *Modiolopsis* and *Holopea;* and the brachiopod *Orthis* near *O. tricenaria*. Along the road between Ridge Spring and Garden Springs were collected *Dicellograptus*, *Diplograptus*, *Glossograptus*, *Ceraurus*, and a large *Hormotoma*. Collections on East Bourland Mountain, not far from limestone boulders of Cambrian and early Ordovician age, contain *Diplograptus* and numerous *Glossograptus*. F. H. Bush and B. H. Harlton have informed the writer that microfossils obtained by them from this same locality are like those of Black River age in Oklahoma. At a locality 3¾ miles northeast of the Roberts ranch, about 100 feet below the Maravillas chert, Sidney Powers collected a graptolite identified by Ruedemann as *Glossograptus echinatus* Ruedemann (U.S.N.M. 85371).

Two miles southwest of the Lightning ranch, Böse collected the following fossils, which were identified by E. O. Ulrich:[88]

Anolotichia aff. *A. revalensis* Bassler.
Nicholsonella sp. (ramose, branches slender).
Phaenopora cf. *P. incipiens* Ulrich.
Stichtoporella cf. *S. exigua* Ulrich.
Rhinidictya sp.
Sowerbyella ("*Plectambonites*") aff. *S. quinquecostata* (McCoy).
Eurychlinia sp.
Aparchites sp.

Most of the fossils in the Woods Hollow shale seem clearly to be of Middle Ordovician age and suggest that it is to be correlated with the Trenton. Some of the graptolites, however, such as *Glossograptus echinatus*, suggest a correlation with the Normanskill (Chazy), so that there is a possibility that the formation is older than Trenton. For the present the formation is classified as of Middle Ordovician age.

STRATIGRAPHIC RELATIONS

The Woods Hollow shale is separated from the overlying Maravillas chert by a sharp lithologic break, which represents a change from shale and sandy limestone deposition to the deposition of chert and massive limestone. At some localities, as near the junction of the Boquillas and Terlingua roads south of Marathon, the shales and cherts are interbedded for a few inches below the contact. At some other places, particularly at Monument Spring and Rock House Gap, at the southwest end of the Marathon anticlinorium, there is at the base of the Maravillas a coarse conglomerate containing fragments of Woods Hollow limestones and older rocks, which indicates at least a local uplift and time of erosion between the Woods Hollow and Maravillas epochs of deposition.

Such a break, however, is not as great as has previously been supposed. At no place is the Woods Hollow formation truncated by the Maravillas or even markedly reduced in thickness. The previous supposition that the Maravillas rests on the Cambrian in Simpson Springs and East Bourland Mountains has been shown to be erroneous, for the Cambrian fossils at these localities are in transported fragments of limestone. The only locality where the Maravillas chert lies in contact with rocks older than the Woods Hollow shale is at Maravillas Gap, in the Santiago Peak quadrangle, where it rests on the Dagger Flat sandstone. This relation is thought to have resulted from tectonic action. Differences in dip between the Maravillas and Woods Hollow formations are likewise probably of tectonic origin and result from the gliding of competent over incompetent beds during deformation. At Peña Blanca Spring and the picnic grounds at Fort Peña Colorada the competent Maravillas chert lies on much crumpled soft Woods Hollow shale. At these places the shale is traversed by large veins of fibrous calcite. which probably have filled tension fissures.

MARAVILLAS CHERT

GENERAL FEATURES

The Maravillas chert was named by Baker and Bowman [89] for exposures at Maravillas Gap, 20 miles south of Marathon, in the Santiago Peak quadrangle. Excellent exposures are also found on the northwest slope of Threemile Hill, 3¼ miles northeast of Maravillas Gap, and near Fort Peña Colorada, east of the picnic grounds (pl. 5, *A* and *B*). As originally described, the formation was said by Baker and Bowman to reach 800 feet in thickness and to contain rocks of both Trenton and Richmond ages. However, on a reexamination of the exposures by the writer in company with Baker, it was concluded that the measurements of thickness were not corrected for local duplication, and Edwin Kirk believes, after a new study of the faunas, that the formation is entirely of Upper Ordovician age. The name "Maravillas" is therefore applied here, with a different age interpretation, to the same strata for which it was used by Baker and Bowman.

The Maravillas chert ranges from 100 to 200 feet in thickness in the Marathon anticlinorium but thickens southward to 400 feet (pl. 2). It crops out on the inner slopes of the novaculite hogbacks and consists of interbedded limestone and black bedded chert (pl. 4, *C*), the chert predominating toward the top. In the northwestern part of the area it has a thick coarse basal conglomerate, and there are other conglomerate beds higher in the section. Along the southeast flank of the Dagger Flat anticlinorium, limestones near the middle of the formation contain reef-like aggregates of bryozoans.

[88] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), p. 85.

[89] Baker, C. L., and Bowman, W. F., op. cit., p. 87.

LOCAL FEATURES

Marathon anticlinorium.—In the northeastern part of the Marathon anticlinorium the lower or calcareous part of the formation is sharply set off from the upper or cherty part. In the region south of the town of Marathon, near the junction of the Boquillas and Terlingua roads, the lower division is 90 feet thick. In this region it consists of thick ledges of finely granular dark-gray limestone with thin interbedded layers of brown and gray chert. These are interbedded with thin-bedded dense bituminous limestones, which give off a fetid odor when struck. Graptolites are very plentiful on the bedding surfaces of the denser limestones. The granular limestones contain brachiopods and trilobites. In the exposures near Marathon there are, in the lower beds, three or four lenticular conglomerate layers, 4 feet or less in thickness, of limestone and chert pebbles in a granular-limestone matrix. Rarely also the conglomerates contain well-rounded pebbles and grits of translucent quartz. Most of them contain brachiopods, cup corals, and colonial corals bearing marks of attrition, but of approximately the same age as the fossils in the associated beds.

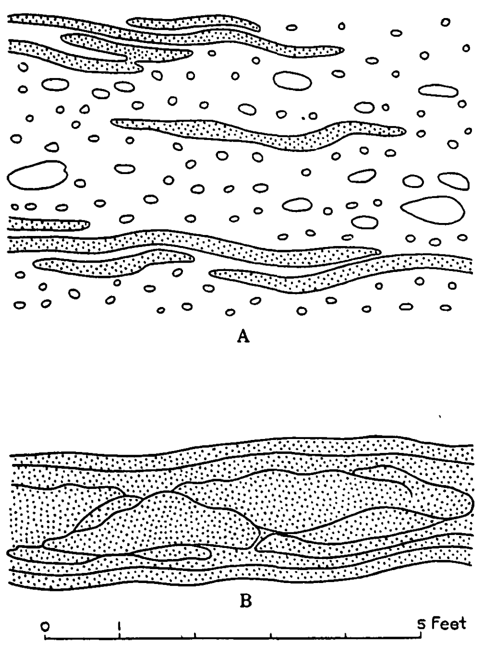


FIGURE 13.—Sketches showing structural features in the Maravillas chert. A, Conglomerate interbedded with lenses of primary chert, near base, Monument Spring; B, beds and ellipsoidal masses of chert near top, Monument Spring. Chert is indicated by shading.

The upper part of the formation south of Marathon is about 170 feet thick. It consists of little else than black, dull-lustered, bedded chert. This is mostly in thin beds, but there are some massive layers 3 or 4 feet thick which are aggregates of pillowlike nodules (fig. 13, B). On weathered surfaces the chert breaks into small blocks, similar to lumps of coal. There are a few thin interbedded layers of bituminous limestone, and many of the chert layers are separated by shale partings. About two-thirds of the way up in the formation is a persistent layer of buff siliceous shale 5 feet thick, which makes a narrow bench on the hillsides that can be followed for long distances by the eye.

The sequence described above is well exposed east of the picnic grounds in the gap south of Fort Peña Colorada. The Maravillas chert here stands in a cliff as a result of the undercutting of Peña Colorada Creek, so that nearly every bed in the formation is exposed (pl. 5, *A* and *B*, and fig. 14). The following section (sec. 5, pl. 17) was measured at this place:

Section in gap south of Fort Peña Colorada

	Feet
Caballos novaculite.	
Maravillas chert:	
Upper member:	
40. Massive black chert	23
39. Thinly laminated pale-gray chert, with two thin limestone beds, one of which contains brachiopods	13
38. Massive, subvitreous chert, weathering brown	3
37. Pale-gray chert in beds a few inches to a foot thick, standing in prominent ledges	13
36. Black and brown, dull-lustered chert in 6-inch to 1-foot beds, with two beds of finely crystalline black limestone near base	9
35. Chert-pebble conglomerate; the pebbles are black and brown chert, angular to subrounded, reach 2 inches in diameter, and lie in a limestone matrix	1
34. Covered	7
33. Dull-lustered black chert, banded gray, with shale partings	16
32. Fine-grained conglomerate of limestone and chert fragments	½
31. Massive dull-lustered chert, banded black, gray, and brown, in 6-inch to 1-foot beds, with thin shale partings	10
30. Shale zone: Siliceous black shale, weathering buff, containing graptolites on bedding planes	2
29. Shaly bituminous limestone, weathering pale gray	6
28. Massive black chert, with some shale partings	8
27. Conglomerate of chert and limestone fragments as much as a quarter of an inch in diameter, with a few clear quartz grains in a limestone matrix. The layer is lenticular	2
26. Black chert, with some brown chert, in layers a few inches thick, with thin beds of dense bituminous limestone containing graptolites	17

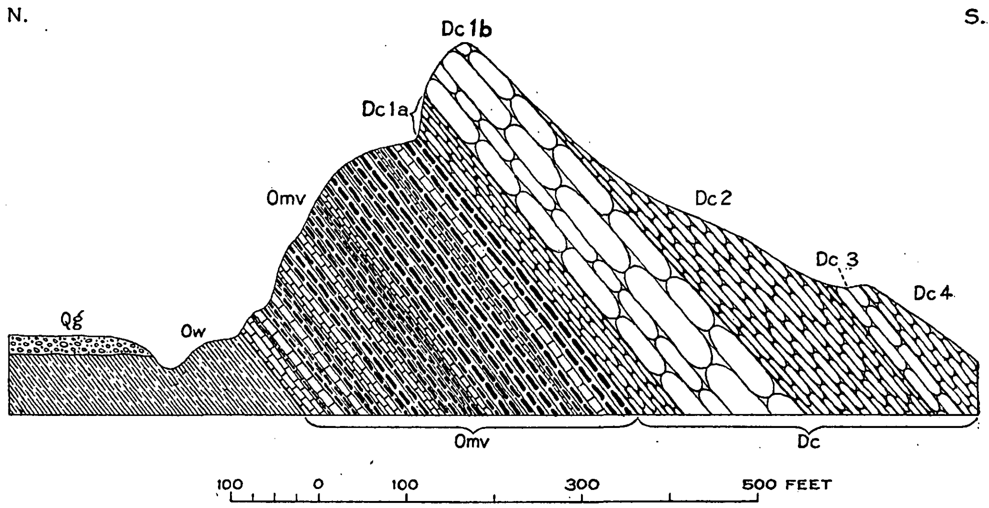


FIGURE 14.—Section across novaculite ridge at picnic grounds south of old Fort Peña Colorada, showing sequence and structure of the Ordovician and Devonian (?) rocks. Ow, Woods Hollow shale. Omv, Maravillas chert. Dc, Caballos novaculite, divided into 1a, lower chert member; 1b, lower novaculite member; 2, middle chert member; 3, upper novaculite member; 4, upper chert member. Og, gravel deposits. Compare plate 5, *A* and *B*.

Section in gap south of Fort Peña Colorada—Continued

	Feet
Maravillas chert—Continued.	
Upper member—Continued.	
25. Prominent layer of dense dark-gray limestone	1
24. Black chert in beds a few inches thick, with a few thin beds of limestone	8
23. Ledge of conglomerate of small chert and limestone pebbles in a granular limestone matrix	3
22. Dense bituminous limestone in beds several feet thick, with interbedded siliceous shale and black chert	8
21. Black chert in beds a few inches thick, with partings of siliceous shale	6
20. Thin-bedded dense bituminous limestone in beds a few feet thick, with thin lenses of brown chert	9
19. Lenticular layer of conglomerate of black chert pebbles as much as 4 inches across, of smaller limetsone pebbles, and a few small well-rounded pebbles of translucent quartz. In the upper part are some cup and colonial corals and crinoid stems	6
Lower member:	
18. Massive, finely granular limestone, with thin chert lenses	3
17. Siliceous shale	1
16. Thin-bedded chert and granular limestone, containing *Cryptolithus* and various graptolites	11
15. Brown chert, with some limestone beds	11
14. Ledge of limestone	1
13. Brown chert, spotted with black, in beds a few inches thick, with thin lenses of granular limestone	3
12. Limestone	4
11. Conglomerate	1
10. Finely granular thinly laminated limestone, with thin lenses of brown and black chert	4
9. Bedded chert	1

Section in gap south of Fort Peña Colorada—Continued

	Feet
Maravillas chert—Continued.	
Lower member—Continued.	
8. Conglomerate of rounded limestone and black chert pebbles 1 inch in diameter in a limestone matrix	4
7. Thin-bedded black chert	1
6. Granular gray limestone, in part bituminous	4
5. Thin-bedded black chert, with some limestone beds	4
4. Finely granular gray limestone, containing coarsely granular seams, and some knots of siliceous material	2
3. Black chert in beds a few inches thick	2
2. Finely granular light-gray limestone in beds several feet thick, with some thin lenses of brown chert	7
1. Black bedded chert, in beds a few inches thick	1
Total	236

Woods Hollow shale at base of section; exposed in creek bank.

Monument Spring and Rock House Gap.—In the southwestern part of the Marathon anticlinorium, near Monument Spring and Rock House Gap, the lower calcareous beds that are well developed to the northeast are nearly all replaced by conglomerate (secs. 2 to 6, pl. 2). At the base of the section is 25 feet of conglomerate, composed of rounded to subangular fragments as much as 3 feet across in a matrix of gray sandy limestone. The fragments consist of various older rocks of the region. They include buff laminated limestone from the Woods Hollow shale, red granular chert from the Fort Peña formation, obscurely mottled limestone similar to the Monument Spring member of the Marathon limestone, and quartzitic sandstone with angular quartz fragments from the Dagger Flat sandstone. The conglomerate also contains small angular pebbles of black chert, like that in the Maravillas itself, and blocks of fine-grained calcareous gray sandstone of an unknown horizon. Near Rock House Gap a boulder of the calcareous sandstone 5 feet long is embedded in the conglomerate (pl. 5, *B*). At both localities the basal conglomerate contains abundant abraded corals and brachiopods. At Monument Spring fine conglomerates in the upper part of the lower member are interbedded with lenses and layers of black chert a few inches thick, which are clearly not transported and are probably not due to replacement of some previous rock (fig. 13, A). It is likely that they are chert deposits of primary origin.

The limestone layers above the conglomerates at Rock House Gap are very fossiliferous (pl. 5, *A*). The dense platy limestones contain oboloid brachiopods and graptolites, and the more granular layers, which form lenses, contain orthoid brachiopods and such trilobites as *Cryptolithus*. The shale zone near Monument Spring is an ashen-gray soft shale on which the dark-colored imprints of graptolites stand out with sharp contrast. A few feet from the top of the Maravillas at Monument Spring, in hard black shale partings between nodular cherts, a large graptolite fauna was collected.

Dagger Flat anticlinorium.—In the Dagger Flat anticlinorium the conglomerate beds of the Maravillas chert are fewer and thinner, and the differentiation between the lower calcareous and the upper cherty parts of the formation is not sharply marked. Near the middle of the formation along the southeast flank of the anticlinorium there are reef-like aggregates of bryozoans, some of which form massive beds with a maximum thickness of 10 feet. These are absent in the northwest flank of the anticlinorium and farther to the northwest. There are also some massive limestones with very irregular bedding, evidently having a channel structure. They contain a few comminuted fossils. The following section (sec. 13, pl. 2) of the Maravillas chert is characteristic of the southeastern exposures of the formation:

Section on northwest slope of Threemile Hill

	Feet
Caballos novaculite.	
Maravillas chert:	
26. Massive black chert, with three thin beds of limestone	50
25. Limestone, with siliceous bands	4
24. Black chert in beds several feet thick, with two thin beds of limestone	42
23. Laminated gray limestone, with thin conglomerate lenses	3
22. Very massive black chert in 2- to 3-foot beds, with much interbedded dense limestone near middle	77
Maravillas chert—Continued.	
21. Massive limestone, with fragmental silicified fossils	4
20. Massive black chert	2
19. Reef-like mass of irregularly bedded limestone, packed with silicified bryozoans	4
18. Limestone in 6-inch beds alternating with black chert and grading down into massive limestone crowded with fossils	21
17. Massive black or bluish chert	4
16. Massive limestone, with fine fossil debris and lenses crowded with bryozoans, interbedded with finely laminated limestone and with beds of chert a few inches thick	40
15. Massive chert	2
14. Thick-bedded limestone, with lenticular chert beds and near the middle a layer of bryozoan limestone	32
13. Very massive, highly silicified limestone, containing long chert lenses and having cross-bedded and channeled structure. It is packed with comminuted bryozoans, most of which are found in the channel fillings	5
12. Massive limestone, with bryozoans in lower part	6
11. Massive black chert	2
10. Thin-bedded limestone, interbedded with black chert	9
9. Massive limestone, with lenses crowded with bryozoans	2
8. Thin-bedded gray finely crystalline to dense limestone	9
7. Thin-bedded black chert	2
6. Limestone, crowded with silicified bryozoans	½
5. Massive black chert	1
4. Finely granular thin-bedded dark-gray limestone in beds a few feet thick, with some black chert lenses	42
3. Brown chert and some black chert, in regular 1-foot beds, with some thin interbedded layers of limestone	18
2. Finely granular gray limestone	1
1. Brown chert in beds a few inches thick	8
Total	390½
Woods Hollow shale; not well exposed near contact with Maravillas.	

Southeastern exposures.—In the southeasternmost exposures of the formation chert greatly predominates over limestone. In the Santiago Mountains, 8 miles south of Maravillas Gap (Santiago Peak quadrangle), it is nearly all black chert with a few thin lenticular limestone beds. On Rough Creek, in the Dove Mountain quadrangle, it consists of black chert with bands of gray chert in 3-inch to 1-foot beds and with two or three layers of black limestone. In this region there is a few feet of dark-green shale between the uppermost cherts and the base of the Caballos.

MICROSCOPIC AND CHEMICAL CHARACTER

Thin sections of the cherts from the Maravillas formation show them to consist of a fine-textured mass of cryptocrystalline quartz. In the more compact types there is no very notable structure. Some of the cherts which in hand specimen show a spotted texture, contain fine fragments of bryozoans, brachiopod shells, and a laminated granular chert, is seen in thin section to contain much quartz sand (fig. 15, A). The sand grains are fine and well rounded and are widely scattered. They are arranged in laminae, separated

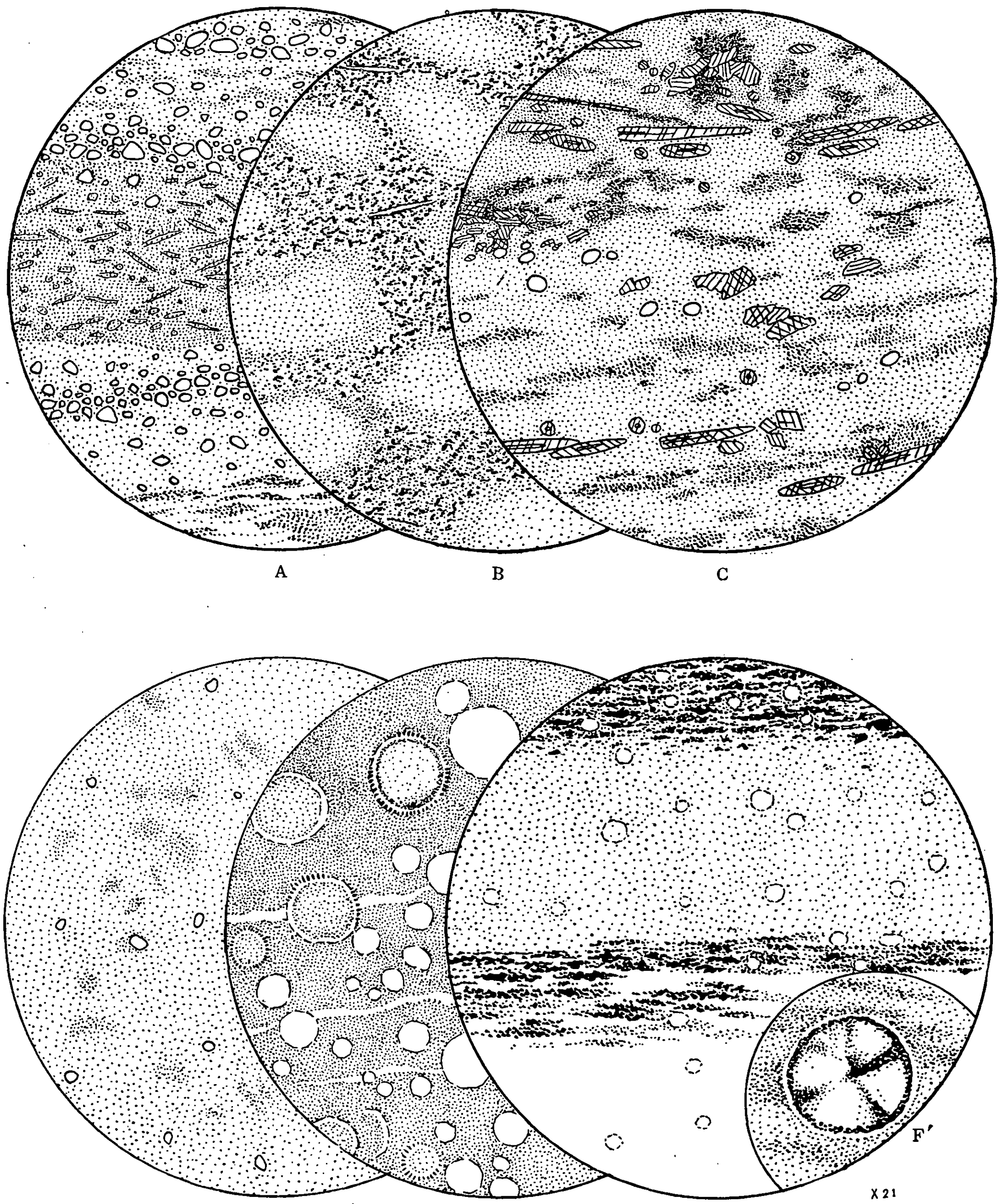


FIGURE 15.—Thin sections of pre-Carboniferous cherts and novaculites; based on camera lucida drawings in plain light, magnified 21 diameters. A, Granular laminated chert, Maravillas formation, Buttrill ranch; note scattered quartz grains. B, Spotted chert, Maravillas formation; 3 miles southwest of Fort Peña Colorada. C, Finely granular chert, Fort Peña formation, near Fort Peña Colorada. Note sponge spicules, calcite crystals (cross-ruled), and quartz grains (unshaded). D, Porcelainlike novaculite, lower novaculite member of Caballos formation; gap south of Fort Peña Colorada; note scattered quartz grains (unshaded). E, Brown chert, Caballos formation, Payne Hills, in northwestern part of Marathon Basin. Note the numerous spherical tests, probably of Radiolaria. F, Banded green and white chert, middle chert member of Caballos formation, gap south of Fort Peña Colorada. Note bands of clay particles and tests of Radiolaria. F', Test of radiolarian from slide. considerably enlarged.

spicules (fig. 15, B). Many of these are composed of crystalline calcite, but some of them have been partly or wholly altered to chalcedony. One rock from the Buttrill ranch, which in hand specimen is by layers of chalcedony, in some of which are embedded calcareous spicules. Some of the limestones in the Maravillas chert are phosphatic. No tests were made during the present investigation, but two samples collected by Udden[90] near Ridge Spring "were analyzed and one yielded 6.03 and the other 1.70 percent of phosphorus pentoxide. This is clearly in excess of the usual phosphatic content of limestones."

FOSSILS AND AGE

Fossils are plentiful at various levels in the Maravillas chert, but particularly in its lower limestone beds. A few graptolites were obtained in the interbedded limestones of the chert series and in some of the shale partings a few feet from the top of the formation.

The conglomerates at and near the base of the Maravillas contain many abraded fossils, which include *Columnaria*, *Halysites*, *Paleofavosites*, and *Streptelasma* among the corals and *Platystrophia* and *Hebertella* among the brachiopods (U. S. Geological Survey localities 2417 and 2395). According to Kirk, this fauna is like that in the basal part of the Montoya limestone at El Paso and is of nearly the same age as that in the overlying interbedded limestones.

The limestones, between the conglomerates and overlying them, contain *Cryptolithus*, *Harpes*, *Strophomena*, and various graptolites, including *Dicellograptus nicholsoni*, *Climacograptus antiquus*, and *Diplograptus amplexicaulis*. The most extensive collection from these beds is that of Baker and Bowman at Rock House Gap,[91] in which the following species have been determined by E. O. Ulrich:

Diplograptus cf. *D. amplexicaulis* (Hall).
Lingula sp.
Leptobolus sp.
Scenidium cf. *S. anthonense* Sardeson.
Strophomena? (two species).
Sowerbyella ("*Plectambonites*") aff. *S. sericeus* (Sowerby).
Platystrophia n. sp.
Bythocypris sp.
Krausella arcuata Ulrich.
Aparchites sp.
Eurychilina aff. *E. ventrosa* Ulrich.
Dicranella cf. *D. spinosa* Ulrich and *D. simplex* Ulrich.
Cryptolithus sp.

According to Kirk the genus *Cryptolithus* occurs in Nevada in beds overlying beds containing a coral fauna like that in the basal Maravillas and is also found in the Viola limestone of Oklahoma.

Several collections of graptolites from the Maravillas chert have been studied by Ruedemann. One of these, obtained by R. E. King three-quarters of a mile east-southeast of bench mark 4361, in the southwestern part of the Hess Canyon quadrangle, contains the following species:

Glyptograptus amplexicaulis (Hall). (U.S.N.M. 85358.)
Glyptograptus amplexicaulis var. *pertenuis* Ruedemann. (U.S.N.M. 85361.)
Glossograptus quadrimucronatus (Hall).
Dicellograptus nicholsoni Hopkinson (fragment).
Climacograptus sp.

At a locality 2 miles to the southeast, about 4 miles northeast of Marathon, R. E. King collected *Glossograptus quadrimucronatus* var. *angustus* Ruedemann (U.S.N.M. 85365). A locality about 2 miles south of this one and 2½ miles northeast of Marathon yielded

Climacograptus antiquus Lapworth. (U.S.N.M. 85364.)
Leptobolus cf. *L. walcotti* Ruedemann.

The faunas of the first two localities are considered by Ruedemann to be of Trenton or Utica age, but the *Climacograptus antiquus* is found in New York only in older beds.

The middle part of the Maravillas in the southern part of the Marathon Basin contains lenticular bryozoan reefs, built of such genera as *Constellaria* and *Pachydictya*, in which are embedded a few shells of *Platystrophia*, *Rafinesquina*, and *Hebertella*. Kirk has also collected *Cryptolithus* in the reef beds on Threemile Hill. The following collection by Baker and Bowman[92] from the reef beds at Maravillas Gap was identified by E. O. Ulrich:

Hallopora aff. *H. elegantula* (Hall).
Anaphragma mirabile Ulrich and Bassler?
Hemiphragma imperfectum (Ulrich).
Bythopora cf. *B. delicatula* (Nicholson).
Crepipora hemispherica Ulrich?
Rhombotrypa subquadrata (Ulrich).
Lioclema wilmingtonense Ulrich.
Constellaria n. sp.
Favositella cf. *F. epidermata* (Ulrich).
Pachydictya sp.
Rhinidictya sp.
Eurydictya cf. *E. sterlingensis* Ulrich.
Phaenopora wilmingtonensis Ulrich.
Helopora sp.
Arthroclema angulare Ulrich.
Sceptropora facula Ulrich.
"*Dalmanella*" aff. *D. testudinaria* (Dalman).
Dinorthis cf. *D. subquadrata* (Hall).
Glyptorthis insculpta (Hall).
Platystrophia sp.
"*Plectambonites*" *elegantula* Foerste.
Sowerbyella ("*Plectambonites*") cf. *S. saxeus* (Sardeson).
Rhynchotrema manniense Foerste.
Rhynchotrema cf. *R. anticostiense* (Billings).

The higher beds of the Maravillas chert contain little else than undetermined species of *Climacograptus* and *Diplograptus* and a few linguloid shells.

The Maravillas faunas, when studied by Ulrich in 1916, were divided, like those of many other western formations (such as the Montoya limestone and Bighorn dolomite), into a lower group, correlated with the

[90] Udden, J. A., Sketch of the geology of the Chisos country, Brewster County, Tex.: Texas Univ. Bull. 93, p. 100, 1907.

[91] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), p. 91. The locality as given by them is "one-half mile north of Payne's ranch on the east side of Maravillas (Dugout) Creek, 300 yards from the creek." According to Baker (letter, November 1929), the Payne ranch referred to is the locality marked "Rock House" on the Monument Spring topographic map.

[92] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), pp. 89-90.

Trenton, and an upper group, correlated with the Richmond. The corals and bryozoans from each locality were considered to be the younger fauna, and the trilobite *Cryptolithus* and its associated diplograptids were called Trenton. Further field work has shown that the coral-bearing beds are interbedded with and in many places lie beneath those containing the *Cryptolithus* fauna and that the *Cryptolithus* fauna in turn extends upward and mingles with the bryozoan fauna. It is therefore clear that the formation is a faunal as well as a lithologic unit.

Kirk [93] has stated his views on the Trenton-Richmond problem in the West in a discussion of the problematical lower Bighorn, as follows:

> [The lower Bighorn] has been variously correlated with the * * * Trenton and Richmondian. Equivalent beds in Manitoba and the far north have been correlated by Foerste * * * with the Richmond. Several years ago * * * I suggested that this horizon was probably of Cincinnatian age (used in the sense of being pre-Richmondian and post-Trenton), and * * * a considerable amount of corroborative evidence has since come to hand. One of the most striking pieces of evidence has been the finding of *Cryptolithus* sp. in abundance in the Eureka district, Nevada, and the Marathon Basin, Texas. In the Marathon Basin * * * [the *Cryptolithus* zone] occurs in a series of limestone carrying a fauna of post-lower Bighorn age * * * Foerste's objections to the assignment of * * * [the lower Bighorn horizon] to the Trenton appear valid to me. I do not see the necessity, however, of skipping the lower Cincinnatian, as he does, and correlating with the Richmond.

Kirk therefore believes that the Maravillas chert is of Upper Ordovician age, probably to be correlated with a part of the Montoya limestone of the El Paso section. There is a strong lithologic resemblance between the cherts and limestones of the Maravillas and the cherty limestones of the Montoya, but the Montoya lacks thick members of bedded chert in which limestone is absent. Like the Montoya, the Maravillas consists of thick-bedded, sparingly cherty limestone in the lower half and very cherty beds above.

STRATIGRAPHIC RELATIONS

The contact between the Maravillas and Caballos formations was carefully studied at many places. At one or two places it is marked by conglomerate, but as a rule the vitreous buff, brown, or gray chert of the lower member of the Caballos novaculite overlies the dull coaly-black chert of the Maravillas with sharp contact. Some evidence of post-Maravillas erosion is afforded by the irregular thickness of beds between the base of the Caballos and the "shale zone" of the Maravillas, a circumstance which is further emphasized by the greater constancy in thickness of members below the shale zone.

In 1917 Baker and Bowman [94] noted "a small amount of light-brown arenaceous shale, weathering pinkish", at a locality 8 miles northeast of the junction of Peña Colorada and Maravillas Creeks. Shale of this description, about 5 feet thick, was seen by Baker and the writer at a place near Maravillas Gap. From similar pinkish shale at the top of the Maravillas at Fort Peña Colorada, Josiah Bridge has collected Ordovician graptolites. At the crest of the anticline on lower Rough Creek and at several other places south of Horse Mountain, the writer has seen thin layers of green slaty shale between the two formations. Sellards [95] has recently observed a similar shale, 25 to 50 feet thick, in the Solitario uplift, southwest of the Marathon region.

These shales may be an argillaceous phase of the Maravillas chert or are perhaps the remnants of a distinct formation laid down in the post-Maravillas and pre-Caballos time interval. If the latter alternative is true, it is possible that formerly they had a wider extent and have since been removed by pre-Caballos erosion or by tectonic squeezing.

GENERAL PROBLEMS OF ORDOVICIAN STRATIGRAPHY

CORRELATIONS AND REGIONAL RELATIONS

General correlations.—The 2,000 feet of Ordovician rocks of the Marathon region are of Lower, Middle, and Upper Ordovician age. Strata representing the Beekmantown (Deepkill), Black River (?), Trenton, and Cincinnatian of the New York section are found in the region. It is also suggested that the Fort Peña may be as old as the beds at Mount Moreno, N. Y., which Ruedemann considers to be Chazy. Field evidence seems to show, however, that there is a considerable hiatus between the Fort Peña and the Alsate, so that the Fort Peña is more probably Middle Ordovician. Further collecting at this horizon is desirable.

In addition to this probable hiatus, there is evidence of marked uplift and diastrophism in the region near the Middle and Upper Ordovician boundary. There are no observable overlaps, discordances, or channeled contacts, but the Middle Ordovician flagstones, in which are embedded Cambrian and Ordovician exotic limestone blocks, are succeeded by Upper Ordovician conglomerates that are peculiar aggregates of boulders, cobbles, and abraded fossils, in which some of the fragments are derived from beds as old as the Cambrian. This disturbance is similar to the Taconian movements of Schuchert in the eastern United States and to that represented by a widespread pre-Cincinnatian unconformity studied by Kirk in the Great Basin.

[93] Kirk, Edwin, Harding sandstone of Colorado: Am. Jour. Sci., 5th ser., vol. 20, pp. 464–465, 1930.

[94] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), p. 89. Baker in a letter to E. O. Ulrich, Oct. 23, 1916, gives the shale locality as Maravillas Gap, the place where it was seen by the writer later.

[95] Sellards, E. H., op. cit. (Texas Univ. Bull. 3232), p. 79.

Correlations in trans-Pecos Texas.—The Marathon Basin section of Ordovician rocks is duplicated in the exposures of the smaller uplift of the Solitario, to the southwest. These have recently been studied by Sellards,[96] and fossil collections from them have been identified by Edwin Kirk and Rudolf Ruedemann. Representatives of the Dagger Flat sandstone, Marathon formation, Woods Hollow shale, and Maravillas chert are recognizable from similarities of lithology and fossils, but the Marathon formation of the Solitario area is more shaly and the Maravillas more cherty than in the Marathon Basin. The Alsate and Fort Peña formations have not been recognized in the Solitario area but probably are present. A layer of shale 25 to 50 feet thick lies between the cherts of the Maravillas and the Caballos novaculite.

The sections at Marathon and in the Solitario area are very different from those exposed farther northwest in trans-Pecos Texas, in the El Paso and Van Horn quadrangles (fig. 16).[97] Here the rocks are nearly all dolomitic limestones which contain orthoid brachiopods, cephalopods, gastropods, corals, and sponges. There is, however, sufficient evidence to indicate general relations. The Dagger Flat sandstone is probably to be correlated with the Bliss sandstone of the El Paso district. The Marathon limestone is correlative with the El Paso limestone, and the Maravillas chert with the Montoya limestone. The Monument Spring dolomite member is the exact replica in lithology and fauna of the middle part of the El Paso limestone, and the Maravillas chert is lithologically similar to the Montoya limestone. The beds intervening between the Marathon and Maravillas are not represented at Van Horn or El Paso.

Correlations with central Texas.—In central Texas no formations of a geosynclinal facies like that at Marathon are exposed or have been penetrated in wells. In the Llano area there is an extensive exposure of Ordovician rocks, the upper part of the Ellenburger limestone,[98] which shows a facies similar to that of the El Paso limestone farther west and like it is of Beekmantown age. Rocks equivalent to the Marathon limestone, but of different facies, are probably to be found in the 2,000 feet of thickness of these rocks. The Ellenburger limestone has been penetrated by numerous borings in central Texas and has been found in deep wells as far west as Irion, Reagan, and Crockett Counties, within less than 100 miles of the Marathon Basin.[99] Overlying it, in Reagan County, are sandy and shaly strata of Chazy age,[1] which may be correlative with some of the beds above the Marathon limestone in the Marathon Basin.

Correlations with Oklahoma and Arkansas.—The Ordovician formations in the Marathon Basin exhibit some interesting resemblances to Ordovician rocks in various parts of Oklahoma and Arkansas. The rocks of the Ouachita Mountains, which were also deposited in the Llanoria geosyncline, contain similar graptolite faunas, but they are largely slates and sandstones and lack the limestone beds found at Marathon. According to Miser,[2] "the Marathon section represents deposits that were formed somewhat nearer the inner or northwest border of the geosyncline than the Ouachita facies, [which] * * * seems to have been formed closer to the old Paleozoic land of Llanoria." The Deepkill graptolites of the Mazarn shale are almost certainly of the same age as those of the Marathon limestone. The fauna of the Blakely sandstone that resembles that at Mount Moreno, N. Y., is perhaps comparable to the Fort Peña fauna, and there is a suggestion that the Normanskill graptolites of the Womble shale will be found in the Woods Hollow shale. Overlying the Womble formation is the black bedded Bigfork chert, which closely resembles the upper or predominantly cherty part of the Maravillas formation.[3]

There is also some resemblance between the Marathon section and that in the Arbuckle Mountains, although the general facies of the two are different. The Beekmantown portion of the Arbuckle limestone contains mottled dolomitic beds and masses of cryptozoans like those in trans-Pecos Texas in the El Paso limestone and in the thin layer of the Monument Spring dolomite at Marathon. The strata of the Woods Hollow shale have a slight resemblance to some of the shales, sandstones, and limestones of the Middle Ordovician part of the Simpson formation in the Arbuckle Mountains. The platy bituminous limestones in the lower part of the Maravillas chert closely resemble graptolite-bearing limestones in the lower part of the Viola limestone in this same region.[4]

CONDITIONS OF DEPOSITION

Faunal facies of the Marathon Ordovician.—The Ordovician rocks at Marathon are not highly fossiliferous. In the fossiliferous layers the variety of species

[96] Sellards, E. H., op. cit., pp. 76–79, fig. 9, p. 119.

[97] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, El Paso folio (no. 166), pp. 3–4, 1909; Van Horn folio (no. 194), pp. 4–5, 1914. Further descriptions of these formations, based on recent observations by P. B. King, are given by E. H. Sellards (op. cit., pp. 74–75).

[98] Dake, C. L., and Bridge, Josiah, Faunal correlation of the Ellenburger limestone of Texas: Geol. Soc. America Bull., vol. 43, pp. 725–748, 1932.

[99] Sellards, E. H., op. cit. (Texas Univ. Bull. 3232), pp. 80–81.

[1] Sellards, E. H., Bybee, H. P., and Hemphill, H. A., Producing horizons in the Big Lake oil field, Reagan County, Tex.: Texas Univ. Bull. 3001, pp. 149–203, 1930.

[2] Miser, H. D., in discussion of King, P. B., Pre-Carboniferous stratigraphy of Marathon uplift: Am. Assoc. Petroleum Geologists Bull., vol. 15, p. 1083, 1931.

[3] Miser, H. D., and Purdue, A. H., Geology of the De Queen and Caddo Gap quadrangles, Arkansas: U. S. Geol. Survey Bull. 808, pp. 24–42, 1929.

[4] The literature on the Ordovician stratigraphy of the Arbuckle Mountains is extensive. Among recent papers see Decker, C. E., and Merritt, C. A., Physical characteristics of the Arbuckle limestone: Oklahoma Geol. Survey Circ. 15, 1928; The stratigraphy and physical characteristics of the Simpson group: Oklahoma Geol. Survey Bull. 55, 1931. Decker, C. E., Viola limestone, primarily of Arbuckle and Wichita Mountain regions, Oklahoma: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 1405–1435, 1933.

is not large, and there is a constant association of certain groups in such a manner as to produce two well-marked faunal facies.

From the base to the top of the Ordovician section at Marathon there are numerous layers that contain floating and attached graptolites. Associated with the graptolites are linguloid and oboloid brachiopods, pteropods, and certain specialized types of trilobites (*Cryptolithus* and others). Fossils of this sort are found in shales and in dense, thinly laminated bituminous limestones. The graptolite beds at Marathon are more calcareous than those of other regions, but their persistence through the whole of the system confirms Ruedemann's axiom that "graptolite shales, as a rule, are deposited in the same region for longer intervals than most other fossiliferous rocks." [5]

Associated with the layers containing graptolites are a lesser number that contain corals, sponges, bryozoans, orthoid brachiopods, cephalopods, and gastropods. Some of the layers with these fossils, such as the Monument Spring dolomite and the bryozoan beds in the Maravillas chert, are thick and persistent and are sharply set off from the graptolite beds above and below. Other layers are thinner. In the Maravillas and Woods Hollow formations the fossils of this facies occur in lenses and thin beds of granular and even pebbly light-colored limestone. These are interbedded with thinly laminated bituminous graptolite-bearing limestone, but the fossils of the two facies seldom occur in the same beds.

Conditions during the time of deposition of the graptolite beds do not appear to have been very favorable to life, for the fossils consist only of a few specialized groups. Some, such as the graptolites and pteropods, appear to have been adapted to a planktonic habitat. Others, such as the linguloid brachiopods and the trilobites, appear to have been adapted to life on muddy bottoms. The bituminous and argillaceous character of the graptolite beds suggests that the unfavorable environment was caused by a muddy sea bottom and by the rarity of bacteria so that organic matter accumulated on it faster than it could be decayed. The alternation between the two facies implies considerable fluctuations in the character of the sea bottom and circulation of the water. These were probably brought about by changes in the character of sediments brought from nearby lands and by changes in currents rather than by an oscillation in the depth of the sea.

The fossils of the coral-bryozoan-cephalopod facies are found throughout the Ordovician limestones of the El Paso and Van Horn districts, where graptolites are entirely absent. The layers at Marathon containing these fossils are probably tongues extending from the northwest. In other parts of North America such fossils are not commonly found in the same region as rocks that contain graptolites, and in some places the rocks of the two facies are supposed to have been laid down in different troughs, separated by land barriers.[6] The close association between fossils of the two types at Marathon and the obvious similarity between some of the fossil zones at Marathon and those in the Van Horn and El Paso districts, to the northwest, make it unlikely that such a barrier ever existed in trans-Pecos Texas.

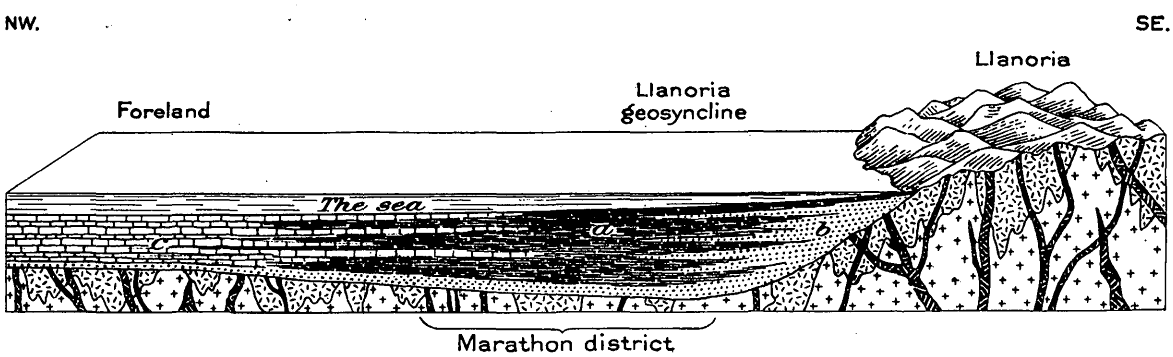


FIGURE 16.—Hypothetical block diagram showing probable geography of the Marathon region in Ordovician time. Length of section, several hundred miles. *a*, Interbedded limestone, shale, and sandstone facies as found in the Marathon region, which probably passes southeastward into a more clastic facies, *b*, and northwestward into a more calcareous facies, *c*, such as is found near Van Horn and El Paso. For later appearance of the region (in Carboniferous time), see plate 20.

Source of the sediments.—The greater part of the sediments of the Ordovician system in the Marathon region were apparently derived from the southeast, presumably from the land mass of Llanoria (fig. 16), for the formations change in character in that direction.

In the northwestern exposures of the Marathon formation limestones are very prominent. Most of these are thin-bedded and flaggy, but in the middle is a

[5] Ruedemann, Rudolf, Graptolites of New York, part 2: New York State Mus. Mem. 11, p. 61, 1908.

[6] See, for example, Ruedemann, Rudolf, Alternating oscillatory movement in the Chazy and Levis troughs of the Appalachian geosynclines: Geol. Soc. America Bull., vol. 40, pp. 409–416, 1929.

member of dolomitic limestone that resembles rocks of Beekmantown age extensively developed in the foreland to the northwest. The sporadic but wide distribution of sponges in all parts of the formation in this area also suggests a northwestward approach to a clear-water environment. In the Dagger Flat anticlinorium limestone flags decrease in number and the dolomitic limestone bed thins and disappears. Most of the formation in the southeastern part of the anticlinorium is shale. In the upper part of the formation in the northeastern part of the anticlinorium are thin beds of gritty sandstone.

Similar but less pronounced stratigraphic changes can be observed in the Fort Peña and Woods Hollow formations. The granular bedded cherts of the Fort Peña, which are in part fine, well-cemented sandstones, increase in thickness in a southeastward direction. Similarly, sandstone members are more prominent in the exposures of the Woods Hollow shale on the southeast flank of the Dagger Flat anticlinorium than they are in the exposures farther northwest. In the little-known outcrops on the Jones ranch (Dove Mountain quadrangle), in the extreme southeastern part of the Paleozoic area, the beds below the Maravillas, correlated with the Woods Hollow and Fort Peña formations, consist of fine-grained quartzite, gritty and pebbly limestone, and micaceous flaggy limy sandstones.

Toward the southeast the Maravillas formation thickens and changes from predominant limestone to predominant chert. The origin of the chert is uncertain, but it may have had its source in that direction.

By contrast to the great bulk of the strata, a few layers in the Ordovician system appear to have had a northwestern source. The Alsate formation appears to change from a shale and limestone succession in the southeast to a shale with few limestone beds toward the northwest. In its northwesternmost exposures, toward Dugout Creek, it contains lenses of coarse sugary sandstone. The conglomerates at the base of the Maravillas and the boulders in the upper part of the Woods Hollow shale also appear to have come from the northwest. Their occurrence is confined to a triangular area between Garden Springs, Del Norte Gap, and Monument Spring, suggesting a nearby local uplift to the west. The fragments in the Maravillas all resemble those in the underlying formations, but those in the Woods Hollow are of a limestone facies foreign to the geosyncline and may therefore have come from farther away, from some part of the foreland area.

Depth of water during deposition.—The character of the Ordovician strata in the Marathon region suggests that they were nearly all laid down in relatively shallow water above the level of wave base, with some parts subjected to intermittent subaerial exposure.

The flaggy limestones of the Marathon formation are interbedded with numerous conglomerate layers, made up of shattered limestone flags, mostly derived from the beds next beneath. The conglomerates were apparently produced by wave action, which shattered and heaped up fragments of the flaggy limestones shortly after their deposition. The limestones themselves in places contain small pockets cut out by wave current action and filled by cross-bedded sand and also tubes and cavities excavated by burrowing animals (fig. 11, B), which are comparable to features seen in the littoral zone today. Limy shales in the formation at one place show well-developed mud cracks (fig. 11, C). Graptolites occur in close association with the beds that show evidence of shallow-water origin. Some were collected a few feet below the layers that contain the mud cracks.

The Woods Hollow shale contains layers of coarse pebbly limestone in which numerous fossil fragments are embedded. These are suggestive of agitated waters and of shallow sea bottoms rich in life.

The Maravillas chert is mostly free from clastic admixtures. However, in the basal part of the formation at Monument Spring and some other places coarse conglomerates are intercalated with and are overlain by bedded chert (fig. 13, A). Lenses of chert fill pockets in the upper part of the conglomerate beds. There are also fine conglomerate layers interbedded in the higher parts of the chert succession. The abraded fossils in the conglomerates, of about the same age as those in the undisturbed layers between, and the numerous pebbles of black chert like that indigenous in the formation indicate approximately contemporaneous destruction of the Maravillas deposits by the waves and their immediate incorporation into new sedimentary rocks. The bryozoan reefs and irregularly bedded, channeled limestones of the southern exposures were probably laid down near a shore line.

These evidences for a shallow-water origin of the Ordovician deposits at Marathon are in agreement with the interpretation of Grabau and O'Connell[7] for the graptolite beds of southern Scotland, which they consider to be "mud deposits on the flood plain and the lagoons of a large delta or series of deltas, where periodic high tides washed in the planktonic graptolites and stranded them on the flats." It is also comparable to the occurrence of recently deposited black muds in bays and lagoons where tide and storm

[7] Grabau, A. W., and O'Connell, M., Were the graptolite shales, as a rule, deep- or shallow-water deposits?: Geol. Soc. America Bull., vol. 28, pp. 959-964, 1917.

action is weak, on the east shore of the Baltic and the north shore of the Black Sea.[8]

Origin of the chert beds.—The Ordovician rocks at Marathon contain a large amount of cherty material. This is particularly true of the Maravillas formation in which a large proportion of the strata consist of bedded chert. Lower down in the section considerable amounts of bedded chert are found in the Fort Peña formation, and locally there are also some chert beds in the Marathon limestone. It is noteworthy that other systems of the Paleozoic at Marathon also include layers of chert and siliceous shale, which suggest that conditions favorable for the accumulation of siliceous deposits were remarkably persistent in the area.

Part of the chert in the Ordovician of the Marathon region is of secondary origin. The original calcareous shells of fossils in some of the limestones of the Maravillas chert have been silicified, and some of the thicker limestone ledges have been replaced along the bedding planes by seams and irregular knots of siliceous material. Some of the thinner limestones can be traced along the outcrop into chert beds. It is probable that these features of obvious secondary origin are a minor part of the whole mass of siliceous deposits. Their formation must have been materially aided by the large amount of silica available in the primary chert deposits.

That a considerable part of the chert is of primary origin is indicated by much evidence. The intraformational conglomerates in the Maravillas formation contain pebbles of both chert and limestone. The cherts are identical with those in place in the formation—a fact which indicates that they assumed their present character at least shortly after deposition. Moreover, thin limestone beds in the chert and thin chert beds in the limestone are sharply set off from the enclosing strata, without gradation between them. The stratification of the cherts is quite different from that of the limestones. Most of them are more thinly bedded, some are nodular, and a few of the thicker beds are aggregates of large pillowlike masses. These features have not been seen in the associated limestone deposits.

Some of the chert layers are laminated and even cross-bedded. These parts are seen under the microscope to contain seams of fine embedded sand grains and various fossil fragments. Some of the cherts also contain siliceous and calcareous spicules.

The source of the material for the cherts lay to the southeast. Those in the Maravillas formation thicken markedly in that direction at the expense of the limestone beds, even within the 40-mile breadth of the Marathon Basin. To the northwest the equivalent of the Maravillas chert is a limestone, the Montoya formation. However, the Montoya contains a great deal more chert than the limestone beds that underlie and overlie it.

The silica that formed the cherts was derived from a land area that was able to supply a large quantity of material through a long period of geologic time. This may have been due to some peculiarity of the rocks of which the land was composed, or it may have resulted from volcanic activity, although direct evidence for such activity in Ordovician time is lacking. That the land from which the siliceous materials was derived was not far distant is suggested both by the rapid increase in volume of cherty material to the southeast and by changes in character in the associated sediments in a similar direction. The thickening of the chert beds to the southeast suggests that whatever process carried the silica into the sea was incapable of transporting it for any great distance.

It is possible that the cherts were derived from colloidal silica that was flocculated directly on the sea bottom. Most of the material thus flocculated was deposited in regular strata, but the nodular parts (fig. 13, B) may have been original gel masses of silica.[9] Organisms with siliceous skeletons, such as sponges, must have found encouragement in this environment, as their spicules are found in the rock, but it is unlikely that they played more than an incidental part in the formation of the chert. The fine clastic materials present in parts of the chert represent an occasional deposition of sediments by mechanical processes but do not show that the chert as a whole had this origin.[9a]

Origin of the boulder beds.—Boulders as much as 5 feet across are embedded in the upper part of the Woods Hollow shale and the basal part of the Maravillas chert. The origin, mode of transportation, and deposition of these masses present many puzzling features.

The boulders of the Maravillas formation are associated with coarse, poorly sorted cobbles in its basal conglomerate. The intercalation of thin layers of chert and limestone in the conglomerate and the water-rounded character of many of the fragments indicate that the rock is a marine rather than a terrestrial deposit and that it is not a breccia of tectonic origin. As the boulders and cobbles include rocks from nearly every older formation in the region down to the Cambrian, they must have been derived from an uplift several thousand feet in height. As the rocks are like those indigenous to the region, the uplift was probably within the Llanoria geosyncline, although

[8] Twenhofel, W. H., Treatise on sedimentation, 2d ed., pp. 262–263, 1932. Trask, P. D., Origin and environment of source sediments of petroleum, pp. 149–150, 1932.

[9] Twenhofel, W. H., op. cit., pp. 541–542.

[9a] For a description and interpretation of the very similar cherts in the Bigfork formation see Hendricks, T. A., Knechtel, M. M., and Bridge, Josiah, Geology of Black Knob Ridge, Okla.: Am. Assoc. Petroleum Geologists Bull., vol. 21, pp. 6–7, 1937.

no evidence of it has been found in the outcrops in the region.

The transportation of blocks as much as 5 feet across from such an uplift to their present position is difficult to explain. It is true that streams at times carry boulders 10 feet in diameter, and streams may have carried the fragments now embedded in the Maravillas to the edge of the sea. However, the deposit itself seems to be far from any shore existing at that time. Large blocks might have been rafted from the shore by floating ice, although their association with corals and similar fossils would seem to argue against a climate sufficiently cold for this.

The boulders in the Woods Hollow shale are stratigraphically not far beneath those in the Maravillas chert, but they do not occur at the same localities and are of somewhat different character. They consist of limestone blocks of Cambrian and early Ordovician age, which are not like indigenous rocks of the same age in the Marathon region. They are not embedded in conglomerates but lie, with no associated smaller fragments, in shales and flaggy sandstones. As their source is obviously foreign and probably lay to the northwest of the Llanoria geosyncline, they must have been transported for longer distances than those of the Maravillas chert. Like those in the Maravillas, they might have been transported by floating ice.

Unlike the Maravillas boulders, however, they fulfill many of the conditions postulated by Van der Gracht [10] for a tectonic origin. They occur in much crumpled and contorted shales. The shales lie between two competent series of beds and are known to have acted as a gliding plane during the folding and thrusting of the region. The boulders are derived from rocks of foreland facies, over which, at least in part, the Marathon geosynclinal rocks have probably been thrust. The boulders are found in the shale not far south of the outcrop of the Dugout Creek overthrust, which is perhaps the frontal thrust of the Marathon folded belt.

If the boulders are of tectonic origin they have been derived from Cambrian and Ordovician limestones of foreland facies, which lie beneath the thrust sheets of the region. Blocks of such underlying rocks may have been plucked off during Pennsylvanian time by thrust sheets advancing over them from the south and thus incorporated in incompetent layers in the overriding mass by intraformational shearing.

[10] Van der Gracht, W. A. J. M. van Waterschoot, Permo-Carboniferous orogeny in the south-central United States: K. Akad. Wetensch. Amsterdam Verh., Afd. Natuurk., deel 27, no. 3, pp. 58-61, 1931.

There is some evidence, though not proof, that the boulders are of true sedimentary origin rather than of tectonic origin. They are closely associated stratigraphically with the boulders of obvious sedimentary origin in the Maravillas chert. The blocks are all of rocks older than the strata of the Woods Hollow formation, although if their origin were tectonic, they might be of much later age. Moreover, other incompetent layers in the section in this part of the Marathon Basin contain no boulders, though some of them are almost as well adapted for such a process of tectonic intercalation as the Woods Hollow shale.

DEVONIAN (?) SYSTEM

CABALLOS NOVACULITE

GENERAL FEATURES

The Caballos novaculite was named by Baker and Bowman [11] for exposures on Horse Mountain, sometimes called Caballos Mountain, the highest summit of the folded beds of the Marathon Basin. The resistant white novaculites of the formation are the chief ridge makers in the area, and the structure of their outcrops is clearly revealed in the desert environment of sparse vegetation (pls. 1, *A;* 5, *C, D;* 6, *A*; 7). They also stand out conspicuously on aerial photographs.

The Caballos formation reaches a maximum measured thickness of 600 feet in the southern part of the area and is only 200 feet thick in the extreme northwestern part (pl. 2). The novaculite beds, which constitute a prominent part of the formation in the south, give place in the northwest to bedded chert, which has many shale partings and a few limestone intercalations in the Dugout Creek area. In the north a lower novaculite member is very prominent but southward this is subordinated to an upper novaculite. The chert and novaculite beds are divisible into five members—a lower chert member at the base, a lower novaculite member, a middle chert member, an upper novaculite member, and an upper chert member at the top. The members change in thickness from northwest to southeast across the area, so that various facies of the formation can be distinguished. These characterize northeastward-trending belts. The stratigraphy and facies of the formation are summarized in the following table:

[11] Baker, C. L. and Bowman, W. F., Geologic exploration of the southeastern Front Range in trans-Pecos Texas: Texas Univ. Bull. 1753, p. 93, 1917.

Stratigraphy of Caballos novaculite

<table>
<tr><th colspan="2">Facies</th><th>1</th><th colspan="2">2</th><th>3</th><th colspan="2">4</th><th>5</th></tr>
<tr><td colspan="2">Locality.</td><td>Dugout Creek area.</td><td colspan="2">Marathon anticlinorium (southeast flank): Monument Spring, Fort Peña.</td><td>Dagger Flat anticlinorium (northwest flank): Warwick to Ridge Spring.</td><td colspan="2">Dagger Flat anticlinorium (southeast flank): Lightning Hills, Horse Mountain, Threemile Hill.</td><td>Ridges southeast of Dagger Flat anticlinorium.</td></tr>
<tr><td colspan="2">Character.</td><td>Nearly all bedded chert; many shale partings, some limestone.</td><td colspan="2">Lower novaculite prominent; succeeded by a thick member of bedded chert.</td><td>Lower novaculite prominent; upper novaculite thin but prominent.</td><td colspan="2">Upper novaculite very prominent; lower novaculite subordinate.</td><td rowspan="6">Like facies 4, except that the upper chert member is changing over into novaculite. The lower 3 members are thin and insignificant.</td></tr>
<tr><td rowspan="5">Average thickness (feet)</td><td>Upper chert member.</td><td rowspan="3">125</td><td rowspan="3">†Santiago chert</td><td>150</td><td>100</td><td colspan="2">125</td></tr>
<tr><td>Upper novaculite member.</td><td>0–5</td><td>25</td><td rowspan="4">Caballos novaculite of Texas Univ. Bull. 44, 1916</td><td>150</td></tr>
<tr><td>Middle chert member.</td><td>125</td><td>135</td><td>80</td></tr>
<tr><td>Lower novaculite member.</td><td>15</td><td colspan="2">115</td><td>60</td><td>15</td></tr>
<tr><td>Lower chert member.</td><td>10</td><td colspan="2">0–15</td><td>20</td><td>15</td></tr>
</table>

The marked changes in facies led in the earlier studies of the area to some confusion in the interpretation of the stratigraphy. In the preliminary announcement of their work, [12] Baker and Bowman proposed the Caballos novaculite, with limits not clearly defined, and the overlying †Santiago chert, from 20 to 450 feet thick. The chert was said to have been named "from a locality at the east base of the Santiago Range, east of the range's summit." [13] The †Santiago was rejected as a formation unit by them in 1917, because "later work by the senior author appears to indicate that they [Caballos and Santiago] are really one formation, two members of both the original Caballos and Santiago being included in the section at some localities." [14] The writer's work has afforded complete confirmation of this later interpretation. (See foregoing table.)

The typical Caballos of 1916 (on Horse Mountain) apparently comprised the lower chert member, the lower novaculite member, the middle chert member, and the upper novaculite member of the present paper. On the other hand, the type †Santiago of 1916 (facies 2 of the northwestern Marathon Basin) consisted of the middle and upper chert members. As shown in the table, the upper novaculite member between the two chert members is thin or absent in this area and is not easily recognized. The type section of the †Santiago thus includes part of the type Caballos and suggests that the two formations should be included in one unit, as stated by Baker and Bowman in their final report. For this reason, in the present report only one formation, the Caballos novaculite, is recognized.

[12] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, 1st ed., p. 41, 1916.

[13] Baker, C. L., and Bowman, W. F., op. cit., (Texas Univ. Bull. 1753) p. 100.

[14] Idem. p. 94.

LOCAL FEATURES

Northwestern exposures (facies 1).—In the northwesternmost exposures of the Caballos formation, in the Dugout Creek area (pl. 16), the formation is about 250 feet thick. Near the base is 10 or 20 feet of white vitreous novaculite, which is probably the equivalent of the lower novaculite member farther southeast. The remainder of the formation consists of layers of chert 1 to 8 inches thick, of dull to vitreous luster, banded by various dull colors, such as white, black, brown, green, and pale blue. Near the top are some dull-black cherts. The banded cherts in some exposures are crumpled, broken, and contorted by deformation. Most of the bedding surfaces of the cherts are smooth and regular, but some are wavy or hummocky. Many of the layers are separated by thin partings of hard greenish siliceous shale. At several localities thin lenticular layers of coarsely crystalline buff or gray siliceous limestone and dense laminated limestone are interbedded with the chert. Some of these contain angular chert fragments. A mile west of the Roberts ranch one of the limestone beds contains plentiful linguloid shells.

The following section, measured in the ridges in the southern part of the Payne Hills, 5 miles north-northeast of the Roberts ranch, shows the general character of the formation in this region (sec. 1, pl. 2; fig. 21).

Section in southern part of Payne Hills

	Feet
Tesnus formation.	
Caballos novaculite:	
Middle and upper chert members:	
9. Black or drab subvitreous chert in 3-inch beds	61
8. Chert in layers several inches thick, banded gray and buff, cropping out in prominent ledges	11
7. Subvitreous chert, banded in pale green, brown, or black; the black bands as much as an inch thick. There are also some opaline bands. The bedding surfaces are mostly faintly wavy, but in some of the beds are large rounded nodules as much as 3 inches across	58
6. Limestone layer between beds of banded chert. The lower part is a sandy siliceous pale-brown laminated limestone. The upper part is a granular gray limestone containing fine chert pebbles. The layer is traceable for about 800 feet along the strike and apparently grades into reddish granular chert	7
5. Siliceous green indurated shale	10
4. Banded chert in 3- to 8-inch ledges, with pale-green and brown bands, the former predominating	18
3. Vitreous dark-gray chert	60
Lower novaculite member:	
2. White subvitreous novaculite, with indistinct bedding planes	15
Lower chert member:	
1. Massive brown and dark-gray chert, with some light-brown laminae	10
Total	250
Maravillas chert.	

Marathon anticlinorium (facies 2).—On the southeast flank of the Marathon anticlinorium, at such localities as Monument Spring and Fort Peña Colorada, and on Simpson Springs and East Bourland Mountains, the lower novaculite is very prominent and is succeeded by a thick member of bedded chert. The formation in this region is in general 300 to 400 feet thick but reaches a maximum of 520 feet at Monument Spring.

The lower chert member, which rests on the Maravillas chert and underlies the lower novaculite, is thin and discontinuous. It is a brown, vitreous, splintery, thick-bedded chert. The lower novaculite, averaging about 125 feet in thickness, forms the crests of the Caballos hogbacks. Its lower and upper parts are white and vitreous and stand out in ledges or bouldery outcrops with indistinct bedding. The middle or main mass of the member is dull-lustered, white or cream-colored, and of porcelainlike texture and forms well-marked layers several inches thick (pl. 4, *D*). These are split by innumerable little vertical joints which cause the rock to break into small flat-faced, sharp-angled fragments few of which are more than 4 inches across. These fragments were utilized by the Indians in the manufacture of arrowheads at the gap south of Fort Peña Colorada. Partly trimmed fragments of novaculite are found at numerous places in this vicinity. On the novaculite ridge 7 miles southwest of Marathon and on the southeast side of Simpson Springs Mountain some of the bedding surfaces in the lower novaculite are marked by closely set ripple marks (fig. 17).

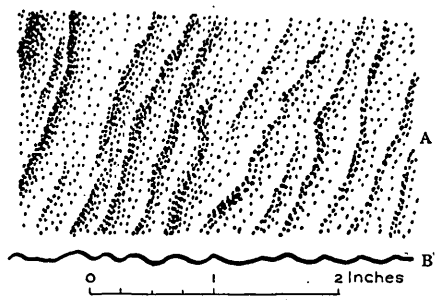


FIGURE 17.—Sketch of ripple marks in Caballos novaculite; B is a cross section across the lower edge of A. From a specimen from the lower novaculite member in the Woods Hollow Mountains.

The upper part of the formation consists mostly of banded cherts and is the original †Santiago chert of Baker and Bowman. At the base, directly on the lower novaculite, are some thin local quartzitic sandy beds and in places fine conglomerate. The cherts crop out in several low cuestas, separated by saddles occupied by thinner-bedded or shaly members. They form beds a few inches to more than a foot thick. The chert is vitreous to dull-lustered and is banded by laminae of various colors a fraction of an inch thick. The predominant color is green, but there are also gray, black, and brown bands and some of bright jasper red. A 15-foot layer of siliceous green shale 180 feet above the lower novaculite is found at many places near Monument Spring. In the upper part of the formation on East Bourland Mountain there is considerable interbedded red and green siliceous shale, from which H. D. Miser has collected conodonts. The joint surfaces of the cherts are much stained by iron and manganese at several places, as at the Clark manganese prospect, on the east side of the Boquillas road 2 miles south of Marathon. In the northeastern part of the Marathon anticlinorium there is a 5-foot member of white massive vitreous novaculite about 100 feet above the base of the formation; this disappears to the southwest near Fort Peña Colorada (secs. 4, 5, and 6, pl. 2).

The following section, typical of this phase of the formation, was measured at the Clark manganese prospect (sec. 6, pl. 2).

Section at Clark manganese prospect, 2 miles south of Marathon

	Feet
Tesnus formation.	
Caballos novaculite:	
Upper chert member:	
6. Dull-lustered chert and siliceous shale in various colors, such as bright green, black, and dull brown. Many of the layers are banded. Beds are several inches thick and mostly straight and even, though some have knobby or knotted bedding surfaces	100
Upper novaculite member:	
5. White chert or novaculite of vitreous texture in a massive ledge	5
Middle chert member:	38
4. Bedded chert of subvitreous to dull luster, in 1- to 6-inch beds. Between are more vitreous layers, banded in various dull colors. Just above the lower novaculite member are several 3-inch layers of fine sandstone, containing minute fragments of chert	106
Lower novaculite member:	
3. White vitreous poorly bedded novaculite in prominent bouldery outcrops	38
2. Dull-lustered, porcelainlike white to creamy novaculite in well-bedded layers. Is less resistant than top and base of member	84
1. Vitreous white novaculite	3
Lower chert member:	
Not present where section was measured. A mile to the northwest it is 17 feet thick and consists of hackly vitreous brown chert in beds several feet thick.	
Total	336
Maravillas chert.	

Dagger Flat anticlinorium (facies 3 and 4).—Along the northwest flank of the Dagger Flat anticlinorium the lower novaculite member is prominent and is about 60 feet thick (pl. 3, *C*), but the upper novaculite thickens from 5 feet in the northwest to about 25 feet in the Woods Hollow Mountains. The novaculite members have a similar thickness along the northwest flank of the anticlinorium from Ridge Spring northeastward to the Warwick Hills.

Farther southeast, on the southeast flank of the Dagger Flat anticlinorium, the relative thicknesses of the two novaculite members are reversed, the lower member being about 15 feet thick and the upper about 100 feet (fig. 32; secs. 9, 10, and 11, pl. 2). The change in thickness takes place on the crest of the anticlinorium and may be traced out in the convoluted novaculite outcrops in the Warwick Hills. In the central part of the hills the thickness of the two members is approximately equal. The formation in these hills is only 150 to 200 feet thick, as compared with 300 or 400 feet to the northwest and southeast. This thinning is shared by all members equally and is probably original in the deposit. Perhaps it was caused by slight positive movements along the anticlinorium during Caballos time.

Both the upper and lower novaculites in the Dagger Flat anticlinorium are white and vitreous. The lower member near Woods Hollow Tank is ripple-marked. Directly above the lower novaculite at several places is an angular chert conglomerate in a siliceous matrix. Just under the upper novaculite in the Woods Hollow Mountains, on Horse Mountain, and elsewhere is a 15-foot bed of green siliceous shale, and in places there is some red shale. At the top of the upper novaculite some 1-foot beds of white chert are interbedded with those of darker color.

The following section (sec. 12, pl. 2) was measured 4 miles northeast of the Buttrill ranch:

Section 4 miles northeast of Buttrill ranch

	Feet
Tesnus formation:	
Caballos novaculite:	
Upper chert member:	
11. Dull-lustered brown or green chert and siliceous shale in 2- to 4-inch beds	50
10. Dull-lustered to vitreous thick-bedded chert	50
9. Massive white chert, weathering brown	3
8. Moderately thick-bedded white or gray banded chert	10
Upper novaculite member:	
7. Massive white novaculite	117
Middle chert member:	
6. Green and maroon shale, widely developed in this district	12
5. Vitreous dark-gray, creamy, or green banded chert in 6-inch beds	31
4. Poorly exposed; mostly thin-bedded dull-lustered chert with some chert-cemented fine sandstone at base	31
Lower novaculite member:	
3. Vitreous white or buff novaculite in 3-inch to 1-foot beds, cut by numerous vertical fractures	10
Lower chert member:	
2. Dull-lustered green or brown chert in 1-foot beds	10
1. Coarse chert conglomerate, not everywhere present, of black and gray chert and of pisolites 1 inch across	3
Total	327
Maravillas chert.	

At Maravillas Gap and Horse Mountain the formation attains a thickness of 500 or 600 feet but with the same members as to the northwest. The novaculite on Horse Mountain is more brecciated and veined than in other places and the joint surfaces are in many places coated with red hematite. The upper novaculite member forms the surface and slopes of Horse Mountain (pl. 24). The upper cherts on the mountain are light-colored, thick-bedded, and vitreous below and pass upward into dull black, brown, and green argillaceous cherts in beds a few inches thick. Near Maravillas Gap the upper cherts have undulatory or hummocky bedding surfaces. In the ridges southeast of the Dagger Flat anticlinorium the cherts of this member are thick-bedded and light-colored and are similar in aspect to novaculite, into which they appear to be changing (pl. 5, *C*).

Southeastern exposures.—In the southeastern part of the Marathon Basin the novaculite is exposed at several places. On Rough Creek (Dove Mountain quadrangle) about 200 feet of beds are exposed in the center of an anticline, surrounded by basal Tesnus shales, which appear to overlap the formation unconformably. At the base is 25 feet of bluish or white novaculite in 1-foot beds, much shattered and brecciated. Above is 175 feet of bluish, black, or greenish dull-lustered chert in 2- to 6-inch beds with thin partings of siliceous shale, which are most abundant toward the top. There is also a small exposure of novaculite 1½ miles south of the Jones ranch, in the same quadrangle.

MICROSCOPIC AND CHEMICAL CHARACTER

Novaculite.—A thin section of cream-colored porcelainlike novaculite from the lower novaculite member of the formation at Fort Peña Colorada is of uniformly fine-grained siliceous material, with no stratification (fig. 15, D). The rock shows a few round or irregular spots, which appear dark under crossed nicols. They consist of siliceous material like that surrounding them but of very fine texture. There are a few widely dispersed minute, well-rounded quartz grains. Chips of the novaculite have a more porous texture than those of chert. This is probably the cause of the dull luster of the novaculite when compared with the chert in hand specimens. The specimen from Fort Peña Colorada is of finer grain than the typical novaculite of Arkansas. Baker and Bowman[15] have studied some specimens of Caballos novaculite that are coarser and consist of a holocrystalline aggregate of fine interlocking granules of quartz.

A specimen of thinly laminated or banded novaculite from the base of the upper novaculite member of Threemile Hill showed in thin section fine-grained siliceous material, interbedded with bands of coarse fibrous chalcedony.

Baker and Bowman[16] have studied some thin sections of Caballos novaculite which have a very uneven texture, with knots of coarse chalcedonic fibers, of undulatory extinction. They interpret the knots as altered tests of Radiolaria. Similar features have been noted by the writer in the banded cherts associated with the novaculite but have not been seen in the novaculite itself.

Specimens of novaculite collected by Baker and Bowman from the hills south of Warwick siding were analyzed by J. E. Stullken in the laboratory of the Texas Bureau of Economic Geology. The specimens are probably from the lower novaculite member of the formation. The following analyses are given by Baker and Bowman:[17]

Analyses of novaculite

	1	2751	2752	2753	2754
Silica	99. 45	97. 32	97. 80	97. 00	96. 80
Alumina	. 26	. 90	1. 07	1. 18	1. 18
Oxide of iron	-------	1. 70	. 53	1. 02	1. 02
Lime	. 12	1. 19	. 83	. 71	. 71
Soda	. 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

1. White novaculite, Hot Springs, Ark. Griswold, L. S., Whetstones and the novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, p. 1892.
2751. Pure snow-white novaculite from Caballos formation, of rather coarse-grained, porous texture, with small quartz crystals lining cavities. Resembles "soft Arkansas" grade.
2752. Fine-grained semitranslucent novaculite from Caballos formation. Resembles "hard Arkansas" grade.
2753. Fine-grained translucent novaculite from Caballos formation. Contains small brown spots, perhaps manganese dioxide; resembles "hard Arkansas" grade.
2754. Snow-white semitranslucent fine-grained novaculite from Caballos formation. Resembles especially the "hard Arkansas" grade, although somewhat similar to the "soft Arkansas."

Tests made by Stullken show that Caballos novaculites contain from 5.2 to 7.0 percent of soluble silica by digestion in sodium hydroxide for 30 minutes, as compared with 3.5 percent for the Arkansas novaculites, and 2.0 to 2.5 percent by digestion in potassium carbonate for 6 hours, as compared with 0.3 to 1.1 percent for the Arkansas novaculite.

Banded chert.—The banded cherts are of various textures and colors and are arranged in laminae from a few millimeters to 1 centimeter in thickness. In thin section the lighter bands are seen to be massive and of a fine, even texture, not unlike some of the finer-grained varieties of novaculite. The darker bands are fine- to moderately coarse-grained and are mostly well stratified (fig. 15, F). They contain small angular to well-rounded detrital grains of quartz, a few grains of minerals of high refractive index, and some small blades of mica. Some of the dark bands have a faint uniform extinction in one direction, produced by minute blades of clay minerals oriented parallel to the stratification. The clay minerals also probably cause the varying colors of the cherts in different bands. Thin sections of some of the chert contain minute opaque crystals of pyrite, and these have also been seen on the surfaces of polished specimens.

Some of the layers, particularly those of coarser texture, contain round bodies, with some evidence of an original outer test wall and with an interior filled by

[15] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), pp. 99–100.
[16] Idem, p. 100 and pl. 2.
[17] Idem, p. 96.

radiating chalcedonic fibers (fig. 15, F and F′). According to L. G. Henbest, these are probably the outer capsules of Spumellaria, a group of Radiolaria. One of the capsules he found to bear uncertain traces of porous structure. There are also some rodlike bodies which Henbest says resemble sponge spicules. One specimen of chert from the Payne Hills contained numerous round tests of varying size, a millimeter in maximum diameter, filled with radiating chalcedonic fibers (fig. 15, E).

Remains of Radiolaria have been reported by other investigators from cherts similar to those examined by the author. Baker and Bowman [18] report that in some thin sections examined by them Radiolaria make up as much as 50 percent of the rock. Specimens collected by H. D. Miser have been examined by Henbest,[19] who reports as follows:

> Radiolarian skeletons are very numerous in this collection but belong to only a few species. * * * The skeletons are symmetrical, radially spinose, and have an outer and a single inner capsule. The outer capsule appears to have a honeycomb structure. They belong therefore to the Spumellaria. * * * The skeletons are in part concentrated in association with the varves, and a large number show varying degrees of flattening, but a few of the better-preserved individuals appear to have a distribution that is not so closely associated with the varves, a condition that turned out to be more apparent than real. The larger part of the organic detritus is zoned, however, and is probably the chief cause for the varved appearance of the rock from a macroscopic viewpoint.

Sandstone.—The granular and sandy cherts that overlie the lower novaculite member are fine sandstones composed of chert and quartz grains with a considerable cherty matrix. A specimen from the old Clark prospect, 2 miles south of Marathon, contained rounded quartz grains and large angular chert and novaculite fragments. Some of the quartz grains in this specimen have been enlarged by secondary growth to form an interlocking mass of crystals.

FOSSILS AND AGE

The Caballos novaculite contains a few fossils, but none have so far given very definite indications as to the age of the formation. Edwin Kirk and the writer have collected abundant linguloid brachiopods from a thin limestone lens in the formation 1 mile west of the Roberts ranch. H. D. Miser collected conodonts from siliceous shales in the upper part of the formation on East Bourland Mountain. Baker and Bowman, Henbest, and the writer have seen Radiolaria in thin sections of the cherts. The linguloids are not sufficiently diagnostic to furnish precise evidence for the age of the formation. Conodonts have given valuable evidence on the age of the cherts and novaculites of the Woodford and Arkansas formations in Oklahoma and Arkansas. Those collected in western Texas have, however, not yet been studied. According to Henbest, the Radiolaria are similar to those in the Arkansas novaculite, but they have not been specifically identified.

The Caballos novaculite is so strikingly similar to the Arkansas novaculite of Oklahoma and Arkansas, not only in lithology but in the character of the members and their stratigraphic behavior, that there is a strong presumption that the two are of the same age. The Arkansas novaculite has yielded fossils of Middle Devonian and Upper Devonian age.[20] Until further evidence is obtained, the Caballos novaculite may best be classified as Devonian (?).

STRATIGRAPHIC RELATIONS

The Caballos novaculite is overlain by the Tesnus formation with considerable unconformity, and the break probably represents most if not all of Mississippian time. On Rough Creek, in the southeastern part of the Marathon Basin, the Tesnus formation overlaps the whole thickness of the Caballos, which is here folded into a steep anticline (fig. 18, B). Elsewhere such sharp overlaps and differences in folding are not evident. The slightly variable thickness of the upper cherts of the Caballos novaculite and also the thin chert conglomerates found nearly everywhere at the base of the Tesnus formation are indicative of an erosional break between the two. In some places, however, the boundary between the two formations is not easy to draw, because the uppermost dull cherts and siliceous shales of the Caballos closely resemble the basal indurated shales of the Tesnus. The Tesnus formation thins greatly to the northwest across the Marathon Basin, as explained beyond. This may be the result of a gradual northwestward overlap of its strata against the unconformable upper surface of the Caballos novaculite. Such an overlap is suggested by the appearance of thick and coarse conglomerates in the Tesnus formation of the northwestern exposures.

There is also a suggestion of an unconformity within the Caballos novaculite. At many places in the region a layer of conglomerate and sandstone occurs at the top of the lower novaculite member. The fragments consist of chert and novaculite derived from the underlying beds. This conglomerate occupies a similar position to the conglomerate beds at the base of the middle member of the Arkansas novaculite in Arkansas,[21] and the two occurrences may represent the same depositional break.

[18] Baker, C. L., and Bowman, F. W., op. cit., p. 101.

[19] Henbest, L. G., Radiolaria in the Arkansas novaculite, Caballos novaculite, and Bigfork chert: Jour. Paleontology, vol. 10, p. 77, 1936.

[20] Miser, H. D., and Purdue, A. H., Geology of the DeQueen and Caddo Gap quadrangles, Ark.: U. S. Geol. Survey Bull. 808, pp. 58–59, 1929.

[21] Idem, p. 52.

GENERAL PROBLEMS OF DEVONIAN (?) STRATIGRAPHY

CORRELATIONS AND REGIONAL RELATIONS

Correlations in trans-Pecos Texas.—The Caballos novaculite is exposed at one place in trans-Pecos Texas outside the Marathon Basin. This is in the Solitario uplift, southwest of Marathon, where the strata are very much like those described above. It is reported [22] that they consist of a prominent lower novaculite member, overlain by bedded cherts. The sequence is thus of the same facies (facies 2, p. 48) as that in the northwestern part of the Marathon Basin.

Northwest of the Marathon and Solitario uplifts, in the Van Horn and El Paso districts, strata that may be equivalent to the Caballos novaculite are exposed. In the Sierra Diablo, north of Van Horn, platy bituminous shales, shaly limestones, and white, buff, and green cherts lie between the Fusselman limestone (Silurian) and strata of Mississippian age.[23] In the Hueco Mountains, east of El Paso, the Fusselman limestone is overlain by cherts, which are succeeded by strata containing Mississippian fossils.[24] In the Franklin Mountains, north of El Paso, shales overlying similar cherts contain Devonian fossils and are correlated by Darton [25] with the Percha shale of New Mexico.

Correlations with Oklahoma and Arkansas.—There are many similarities between the Caballos novaculite and the Arkansas novaculite of the Ouachita Mountains in Oklahoma and Arkansas. The thicknesses of the two formations are similar. It is true that the Arkansas novaculite attains a maximum thickness of 900 feet, which is greater than any observed thickness of the Caballos. This is in its southernmost exposures, however; in most of the Ouachita Mountains the thickness does not exceed 600 feet, and in the northern part of the mountains it is only 250 feet.[26] The members are also similar in the two regions. The lower member of the Arkansas novaculite is a massive white novaculite. It is overlain by a middle member of bedded chert with much shale. At the top of the formation is another member of massive novaculite. The massive novaculites may be equivalent to the two novaculite members of the Caballos. They thin out to the north, so that the northern exposures consist mostly of shales and bedded cherts.[27] The upper member disappears before the northern edge of the Ouachita Mountains is reached.[28] On top of the lower member of the Arkansas novaculite there is a layer of conglomerate that occupies a similar position to the conglomerate bed at the top of the lower novaculite member in western Texas.

The upper member of the Arkansas novaculite differs from the novaculite of the Caballos in several of its features but particularly in that it contains crystals of calcite and other carbonates. The novaculites and cherts of the other members of the Arkansas are very similar to those in the Caballos, both in hand specimen and in thin section.

The lower member of the Arkansas novaculite contains *Leptocoelia flabellites* and is of Middle Devonian age.[29] Conodonts found in the middle member are the same as those found in the Chattanooga shale.[30] This member and the unfossiliferous upper member are therefore to be correlated with the Chattanooga formation, which the United States Geological Survey classifies as of Devonian (?) age.[31]

In the Arbuckle Mountains, west of the Ouachita Mountains, is the Woodford chert, composed of siliceous shale, chert, and thin limestone. This formation occupies a position similar to that of the Arkansas novaculite and also contains conodonts of Chattanooga age. It is correlated by Ulrich [32] with the middle member of the Arkansas novaculite. There is thus a northwestward change in the character of the strata in Oklahoma, like that in trans-Pecos Texas.

ORIGIN OF THE CABALLOS NOVACULITE

Definition of novaculite.—The term "novaculite" has long been used for a fine quality of whetstone or razor hone, and in 1890 it was applied by Griswold [33] to rocks of that type in Arkansas. According to Griswold,[34] the novaculites of Arkansas are composed almost entirely of silica, contain little or no soluble silica (chalcedony), tend to be translucent, and have a gritty rather than a glassy texture. Novaculite appears to be a variety of chert, for chert has been defined [35] as including "all forms of finely crystalline, nonfragmental silica, including opaline, semicrystalline, and completely crystalline varieties." Moreover,

[22] Sellards, E. H., personal communication.

[23] King, P. B., Possible Silurian and Devonian strata in the Van Horn region: Am. Assoc. Petroleum Geologists Bull., vol. 16, p. 96, 1932.

[24] King, P. B. and R. E., Stratigraphy of outcropping Carboniferous and Permian rocks in trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 910, 1929.

[25] Darton, N. H., Devonian strata in western Texas [abstract]: Geol. Soc. America Bull., vol. 40, p. 116, 1929.

[26] Miser, H. D., and Purdue, A. H., Geology of the De Queen and Caddo Gap quadrangles, Ark.: U. S. Geol. Survey Bull. 808, p. 50, 1929.

[27] Griswold, L. S., Whetstones and the novaculites of Arkansas: Arkansas Geol. Survey Ann. Rept. for 1890, vol. 3, pp. 193–194, 1892.

[28] Miser, H. D., and Purdue A. H., op. cit., p. 52.

[29] Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, p. 117, 1923.

[30] Cooper, C. L., Conodonts from the Arkansas novaculite, Woodford formation, Ohio shale, and Sunbury shale: Jour. Paleontology, vol. 5, p. 145, 1931.

[31] Miser, H. D., and Purdue, A. H., op. cit., p. 58. In this paper the occurrence of Genesee fossils is reported from the middle member. Ulrich (Fossiliferous boulders in the Ouachita "Caney" shale and the age of the rocks containing them: Oklahoma Geol. Survey Bull. 45, p. 33, 1927, and other papers) correlates the unfossiliferous upper member with the Boone formation, of Mississippian age.

[32] Ulrich, E. O., op. cit., p. 33.

[33] Griswold, L. S., op. cit., p. 2.

[34] Idem, p. 187.

[35] Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, p. 816, 1904.

Ross [36] states that there is no essential microscopic difference between novaculite and more normal varieties of chert.

In the Caballos formation of the Marathon Basin, two beds are set off as novaculite members, which are considered to be separated, as well as underlain and overlain, by chert members. The novaculites are distinguished by their white color from the cherts, which exhibit a variety of colors, mostly darker. The novaculites are massively bedded and crop out in ledges as much as several feet thick, whereas the layers of chert are rarely more than several inches thick. The massive quality of the novaculite may also be observed in thin section, for the rock is uniformly fine grained, with no evidence of lamination, whereas the banded cherts are marked by laminae of different colors and textures. The novaculite appears to be of a somewhat porous texture, whereas the fracture surfaces of the cherts are smooth and glassy.

Theories of origin.—The novaculite of Arkansas has been interpreted as a replacement product of limestone or dolomite [37] and as a metamorphosed chert,[38] but neither of these suggestions seems adequate to explain the observed features of the rock. It has also been considered to be a fine siliceous clastic sediment [39] and a colloidal precipitate.[40] A possible relation to volcanic activity [41] and to the growth of Radiolaria [42] is suggested by the observations of some geologists. The literature on the origin of novaculite has been summarized by Griswold,[43] Derby,[44] and Miser and Purdue.[45]

Studies of the Caballos novaculite by the writer have failed to establish definitely the validity of any of these interpretations, but they have furnished some new evidence bearing on the origin of the rock. This evidence is discussed below.

Stratigraphic arrangement of the chert and novaculite members.—The two novaculite members of the Caballos formation are most prominent in the southeastern exposures, whereas in the northwestern exposures banded cherts predominate. This change is accomplished by a northwestward thinning of the novaculite members. The upper novaculite member extends no more than halfway across the Marathon Basin and pinches out. The lower novaculite extends farther, but in the northwesternmost exposures it is thin and has assumed more the character of chert than of novaculite. This member also thins, however, to the southeast, from a maximum near the center of the area. The conglomerates immediately above it suggest that the southeastward thinning is possibly caused by an erosional break.

The banded cherts contain a few partings, as well as thicker layers, of siliceous shale, even in the southeasternmost exposures, but in the northwestern exposures such shaly layers are very prominent. In the northwestern part of the area, but nowhere else in the region, they also contain thin lenses of limestone. Moreover, in the Van Horn and El Paso districts, to the northwest, the possible equivalents of the Caballos are shales and limestones, with a subordinate number of chert beds.

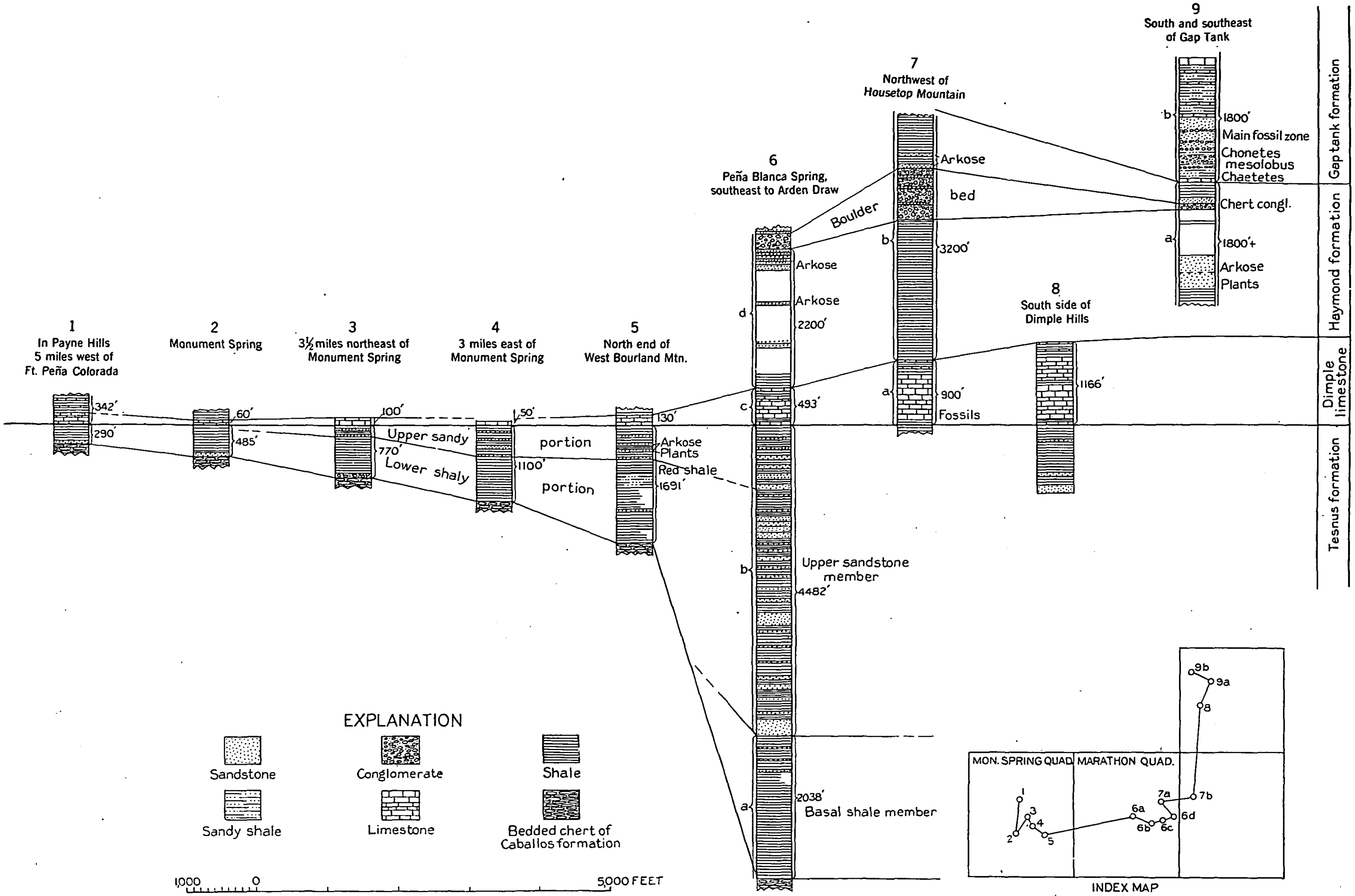
These stratigraphic changes appear to be related to the position of the shore lines and land areas during Devonian (?) time. Clastic rocks, both overlying and underlying the Caballos novaculite, show clear evidence of being derived from a land area to the southeast, and it is therefore probable that the changes in the Caballos in the same direction are related to the same cause. If this is so, the novaculites may have been deposited nearest the shore, the cherts farther out, and the shales and limestones farthest of all. A similar explanation has been offered by Griswold [46] for the novaculites of Arkansas.

Significant features in the novaculite.—As noted in the local descriptions, at several places in the region the bedding surfaces of the novaculites are covered by fine corrugations that have all the appearance of ripple marks (fig. 17). The ridges are spaced about a quarter of an inch apart but may be as far apart as half an inch. They are sharp-crested, and the troughs between are broad and rounded. In places the ridges bifurcate. Ripple marks have also been noted by Miser and Purdue [47] in the Arkansas novaculite. They are described as large and uneven and are therefore probably different in character from those in trans-Pecos Texas.

The form of the marks suggests that they were oscillation ripples, produced "by the to-and-fro motion of the water, occasioned by the passage of wind waves." [48] They suggest that the novaculite was laid down in shallow water and also imply that the sediments which were afterward consolidated into novaculites were deposited in finely granular rather than gelatinous or colloidal form.

The scattered rounded and angular quartz grains and the tests of Radiolaria seen under the microscope in the novaculites of the Caballos formation indicate

[36] Ross, C. S., personal communication, 1932.
[37] Rutley, Frank, On the origin of certain novaculites and quartzites: Geol. Soc. London Quart. Jour., vol. 50, pp. 377-392, 1894. Derby, O. A., Notes on the Arkansas novaculite: Jour. Geology, vol. 6, pp. 366-368, 1898.
[38] Branner, J. C., Arkansas Geol. Survey Ann. Rept. for 1888, vol. 1, p. 49 (footnote), 1888.
[39] Griswold, L. S., op. cit., pp. 191-192.
[40] Honess, C. W., op. cit., p. 138. Miser, H. D., and Purdue, A. H., op. cit., p. 57.
[41] Honess, C. W., op. cit., pp. 121-128.
[42] Baker, C. L., and Bowman, W. F., op. cit., p. 100. Henbest, L. G., op. cit., pp 76-78.
[43] Griswold, L. S., op. cit., pp. 169-187.
[44] Derby, O. A., op. cit., pp. 366-368.
[45] Miser, H. D., and Purdue, A. H., op. cit., pp. 55-57.
[46] Griswold, L. S., op. cit., pp. 192-194.
[47] Miser, H. D., and Purdue, A. H., op. cit., p. 51.
[48] Grabau, A. W., Principles of stratigraphy, p. 713, 1924.



CORRELATED STRATIGRAPHIC SECTIONS OF PENNSYLVANIAN ROCKS OF THE MARATHON BASIN.

that a small part of the rock is of detrital and organic origin. Most of the rock, however, is fine and structureless, and if it were originally either detrital or organic, it must have been very different from the sand grains or the tests. Moreover, the content of silica in the novaculite is much greater than that of any tuff, which would seem to show that the rock is not directly of volcanic origin.

Significant features in the banded cherts.—The banded cherts contain more undoubted clastic and organic material than the novaculites. The rock is divisible into alternating bands and laminae of different textures, which apparently represent the original stratification of the deposit. Some bands consist of fine structureless silica very similar to novaculite. Other bands contain a large percentage of sand and clay particles, and tests of Radiolaria and other organisms. These bands appear to grade into siliceous shales by a slight increase in the clastic components. The different colors in the bands may have been caused by variations in the organic and ferruginous material associated with the clays, and the bands may have been caused by periodic fluctuations in conditions of sedimentation in a region of relatively quiet water.

Conclusions.—With this inconclusive evidence, no definite interpretations can be made as to the origin of the novaculite. A relation between novaculite deposition and the secretion of silica by such organisms as Radiolaria, with volcanic activity, is possible but remains to be proved. To the writer the northwestward thinning of the novaculite members, their relation to the banded chert members, and the ripple-marked bedding surfaces suggest that the novaculite of the Caballos formation may have been laid down as a fine clastic sediment, rather than as a precipitate.

CARBONIFEROUS SYSTEM

PENNSYLVANIAN SERIES

The Pennsylvanian strata of the Marathon region were first studied by Baker and Bowman[49] in 1915 and divided in ascending order into the Tesnus, Dimple, Haymond, and Gaptank formations. Later work has not modified this classification, though it has furnished more information on the ages of the different parts of the succession and has altered the interpretation of some of the exposures.

The formations are predominantly clastic, made up of sandstone and shale, with some beds of limestone and conglomerate. They reach a thickness of at least 12,000 feet in the southeastern part of the area but are much thinner to the northwest (pl. 8). The lowest formation, the Tesnus, is a mass of shales and fine sandstones 6,500 feet or more thick; the Dimple formation is a limestone as much as 1,000 feet thick; the Haymond formation, 3,000 feet thick, is again sandstone and shale, with a remarkable boulder bed in the upper part. The upper 1,800 feet of the succession, the Gaptank formation, is an alternation of limestones and conglomerates, with sandy and shaly beds. Marine fossils are found sparingly in the Dimple limestone and parts of the Haymond formation but are most abundant at numerous horizons in the Gaptank formation. Fossil plants, mostly abraded and poorly preserved, have been found at several places in the Tesnus and Haymond sandstones.

The folded and faulted lower formations crop out in rugged hills and ridges over wide tracts in the Marathon Basin. The higher parts of the succession are found only on the north side of the folded belt, where they have been partly overridden by thrust sheets that advanced from the south. The succeeding Permian strata to the north of them, in the Glass Mountains, are tilted away from the uplift and overlap across the folded and eroded edges of the Pennsylvanian.

TESNUS FORMATION

GENERAL FEATURES

The Tesnus formation was named by Baker and Bowman[50] for exposures near Tesnus station, on the Southern Pacific Railroad east of Haymond, in the eastern part of the Marathon Basin. The Tesnus is the oldest Carboniferous formation in the Marathon region and is extensively exposed around the southeast, east, and northeast edges of the basin, where it flanks the central area of pre-Carboniferous rocks. It also crops out in narrow synclines between the anticlinoria of older strata. Because of the generally nonresistant character of its sandstones and shales, it occupies low places on the plains. In the northern part of the basin it is widely mantled by wash, but toward the south recent dissection has broken the old surface into an intricate topography of cockscomb sandstone ridges and shale valleys.

The Tesnus formation is a great mass of interbedded sandstone and shale, in thin and thick beds, nearly barren of fossils except for a few plant remains in the upper part. In most places it attains a thickness of several thousand feet, but its thickness is variable (pl. 8). In the northwestern part of the basin it is about 300 feet thick and is nearly all black shale, with few sandstone beds. In the southeastern part it exceeds 6,500 feet in thickness and is predominantly sandstone, with many arkose layers and several prominent massive layers of white quartzite. In this part of the area the basal part of the formation is predominantly shaly and

[49] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern Front Range of trans-Pecos Texas: Texas Univ. Bull. 1753, pp. 101-112, 1917. Preliminary descriptions of the formations are found in Review of the geology of Texas: Texas Univ. Bull. 44, 1916.

[50] Baker, C. L., and Bowman, W. F., op. cit., p. 101.

has been called †"Rough Creek shale member" by Baker and Bowman, but that name is preoccupied in the Pennsylvanian of central Texas.

LOCAL FEATURES

Tesnus and Haymond area.—Along the east side of the Marathon Basin, east of the novaculite ridges that bound the Dagger Flat anticlinorium on the southeast, the Tesnus and other strata of Carboniferous age are folded into broad open anticlines and synclines (secs. B–B′, C–C′, and D–D′–D′′, pl. 21). In this region the formation is about 6,500 feet thick. Only the upper part is exposed near Tesnus station, the type locality.

The basal shale member, the lower fourth of the formation, is clearly separable from the upper three-fourths, in which sandstone predominates. The basal member crops out in rolling hills along the flanks of the novaculite ridges and appears on aerial photographs as a dark-colored, featureless surface (pl. 18). It is mostly a soft greenish shale, with interbedded layers and lenses of pale-green argillaceous sandstone. There are also some thin beds of hard platy dark-blue or black shale. The shales are less competent than the sandstones above and the novaculite below and are irregularly folded and crumpled. In places they are sheared and macerated by faulting. The interbedded sandstones are most prominent near the top of the member, and it grades into the main body of the Tesnus formation above. In view of the lenticular character of the sandstone beds, it is doubtful whether the boundary as drawn is at the same level at all places.

The upper part of the formation is predominantly sandstone in massive ledges that stand in low parallel ridges, separated by shallow valleys carved from the interbedded shales. In aerial photographs the outcrops of the sandstones and shales stand out in a striking manner as alternating narrow light and dark bands, which clearly reveal the structure of the formation (pl. 18). The sandstone beds are mostly buff or green and are friable and somewhat arkosic. Some of the members are thick-bedded, and there are a few massive layers as much as 50 feet thick (pl. 9, *A*). Other sandstone beds, mostly fine-grained, are thinly laminated and flaggy, with numerous shale partings. Some of the layers near the middle of the upper member southwest of Haymond station are coarsely ripple-marked. Near Tesnus station sandstones in the upper part contain the pinnules of ferns. At several places there are layers of thin-bedded black, dull-lustered chert. The upper 300 or 400 feet of the Tesnus is predominantly black indurated splintery shale, with subordinate sandstone layers. The contact with the overlying Dimple formation is drawn at the lowest limestone layer interbedded in the shale.

The following section of the Tesnus formation, 6,520 feet in thickness, was measured between Peña Blanca Spring and the Haymond Mountains (sec. 6, pl. 8). The structure of the region is simple and is made plainly evident by excellent exposures, so that there is little chance for duplication by folding and faulting. The writer was aided in the instrument work on this section by A. G. Nance and John Bean.

Section of Tesnus formation between Peña Blanca Spring and the Haymond Mountains

Dimple limestone.	
Tesnus formation:	
Upper sandstone member:	*Feet*
41. Mostly shale, with many thin sandstone beds, some of which are arkosic	460
40. Compact green quartzitic sandstone in 1-foot beds, interbedded with platy sandstone and with shale, which is not exposed	490
39. Mostly black indurated shale, weathering to splinters and small cubes, with some interbedded sandstone near the base and top	345
38. Massive buff friable medium-grained sandstone in 3-foot beds, with a few shale partings near the top. Some of the sandstone is ripple-marked	355
37. Shale, with much interbedded sandstone	485
36. Sandstone	50
35. Soft shale, with much interbedded sandstone	290
34. Buff friable sandstone	40
33. Shale, with thin interbedded layers of compact green quartzite. There are some beds of black coaly chert	135
32. Massive buff coarse-grained friable sandstone in thick ledges, with no shale partings	185
31. Shale	70
30. Compact pale-green or buff platy sandstone in thin ledges, with some arkosic layers and a few shale partings	65
29. Green shale and indurated dark-blue shale, with some thin layers of green compact quartzitic sandstone	590
28. Massive buff friable medium-grained sandstone without bedding planes	40
27. Shale	60
26. Compact sandstone and coarse-grained arkosic pale-brown sandstone, with a few shale partings	50
25. Green shale and thin beds of black indurated shale, with some sandstone ledges	160
24. Friable pale-brown sandstone in 3-foot ledges, with many shale partings	50
23. Soft green shale with thin beds of argillaceous sandstone	225
22. Massive friable buff sandstone	62
21. Soft green shale	25
20. Compact green sandstone and some friable buff sandstone in 3-foot ledges	250
Total	4,482

Section of Tesnus formation between Peña Blanca Spring and the Haymond Mountains—Continued

Tesnus formation—Continued.

Basal shale member:

	Feet
19. Green shale and thin beds of argillaceous sandstone	97
18. Argillaceous sandstone, with some shale beds	10
17. Shale, with some sandstone	66
16. Argillaceous sandstone	10
15. Green shale with thin sandstone beds	60
14. Argillaceous sandstone	5
13. Green shale, with some sandstone in upper part	135
12. Argillaceous pale-green sandstone	10
11. Green shale, with thin sandstone beds	54
10. Massive argillaceous pale-green sandstone in beds as much as 10 feet thick, with interbedded shale	48
9. Covered	180
8. Green and blue shale, with some thin sandstone beds; not well exposed	276
7. Soft green shale, with several 5-foot beds of indurated platy blue-black shale	123
6. Sandstone	4
5. Green shale, with thin beds of argillaceous arkosic sandstone	113
4. Argillaceous arkosic pale-green massive sandstone	4
3. Soft green shale with thin lenses of argillaceous sandstone and a few layers of blue-black shale	273
2. Covered	385
1. Olive-green sandy indurated shale	185
	2, 038
Total	6, 520

Caballos novaculite; base of section.

Southeastern part of Marathon Basin.—Along lower San Francisco Creek, south of the great fault that bounds Hells Half Acre on the north, the folds of the Tesnus formation are obscure and closely packed and, except near the northern border, the succeeding Dimple limestone is wanting (sec. D-D′-D″, pl. 21). In places the strata have been so much crumpled and broken that there are no continuous ledges. Many of the massive sandstones are traversed by lines of shear and fracture and are veined by quartz and calcite. The thinner beds show a large development of secondary mica and other evidences of incipient metamorphism.

The lowest beds are exposed along Rough Creek for several miles above its entrance into San Francisco Creek in the Dove Mountain quadrangle (fig. 18, A, and pl. 23). The Caballos novaculite crops out on the crest of an anticline a mile above the mouth of the creek and is overlain uncomformably by green indurated clay shales, forming a basal shale member of the Tesnus. These constitute the type †Rough Creek shale of Baker and Bowman. The banded cherts included in this member by Baker and Bowman [51] appear to belong to the upper part of the Caballos formation and are exposed only below the unconformity on the north flank of the anticline (fig. 18, B). Interbedded sandstones are abundant in the upper part of the shale member of the Tesnus on Rough Creek, and it grades into the main body of the Tesnus formation above. The basal shale member on Rough Creek has a similar stratigraphic position and thickness to that in the Tesnus and Haymond area to the north, and it is likely that the two are of the same age.

Farther west, near the Indian Creek ranch, in the Hood Spring quadrangle (pl. 23), the Caballos novaculite is overlain by thin-bedded argillaceous sandstone and the basal shale member is not recognizable as such.

The upper part of the Tesnus formation, which crops out in rugged ridges in the region of Hells Half Acre and Devils Backbone, consists of compact greenish quartzitic sandstone and coarse-grained friable buff arkose, with small amounts of interbedded shale. There are several massive members of white or cream-colored quartzitic sandstone in beds 25 to 50 feet thick, which stand in jagged hogbacks. These sandstones resemble the Jackfork sandstone of the Ouachita Mountains. On Devils Backbone there are two such white members, separated by several hundred feet of shales and sandstones (fig. 19), but the stratigraphic relations of the quartzites are not everywhere evident, and their outcrops are broken by obscure faults and folds.

Peña Colorada synclinorium.—On the opposite or northwest side of the Dagger Flat anticlinorium the Tesnus formation consists predominantly of shale and is scarcely more than 2,000 feet thick. These strata probably represent only the upper part of the succession exposed in the Tesnus and Haymond area, and it is believed that the lower part, including the basal shale member, has passed out by overlap against the Caballos novaculite.

Several layers of conglomerate a few feet thick occur near the base, composed of angular chert and novaculite fragments in a siliceous matrix. The conglomerates 3 miles south of Marathon also contain spherical calcareous pisolites as much as an inch across. The conglomerate beds increase in number and thickness toward the northwest. At several places, as near Sunshine Springs and in the Woods Hollow Mountains, there are beds of maroon-red shale near the base of the formation.

The greater part of the formation is composed of olive-green clay shales, in part sandy, and of blue-black indurated slaty shales, which weather to gray chips and splinters. There are some interbedded layers and

[51] Baker, C. L., and Bowman, W. F., op. cit., p. 103, pl. 1 b.

lenses of argillaceous green sandstone, much sheared and fractured, which in places have a cone-in-cone structure. Near West Bourland Mountain the argillaceous sandstones weather to spherical cannon-ball concretions (fig. 20, B). At wide intervals in the succession are ledges of compact dark-green quartzitic sandstone, and in the upper 500 feet several thick layers of arkose. These arkose layers are conspicuously developed around the flanks of West Bourland Mountain, where they are separated from the Dimple limestone, which caps the mountain, by several hundred feet of indurated shale and bedded chert (fig. 20, A). Each arkose layer at this locality rests on a channeled surface of the bed beneath, with the pockets in the channels filled by coarse sandstone crowded with water-worn plant fragments: Several casts of large logs of *Calamites* were also noted.

The following section was measured across the valley of Peña Colorada Creek between the novaculite outcrops of East Bourland Mountain and the Dimple limestone in the syncline of West Bourland Mountain (fig. 20, A; sec. 5, pl. 8). Baker and Bowman [52] report a thickness of 3,370 feet at the same place but probably did not correct their measurements for minor structural features. The beds change from an overturned position below to a gentle inclination above, with several local folds and reversals of dip between (fig. 20, B). The thicknesses given here for the lower part of the section are scarcely more than approxima-

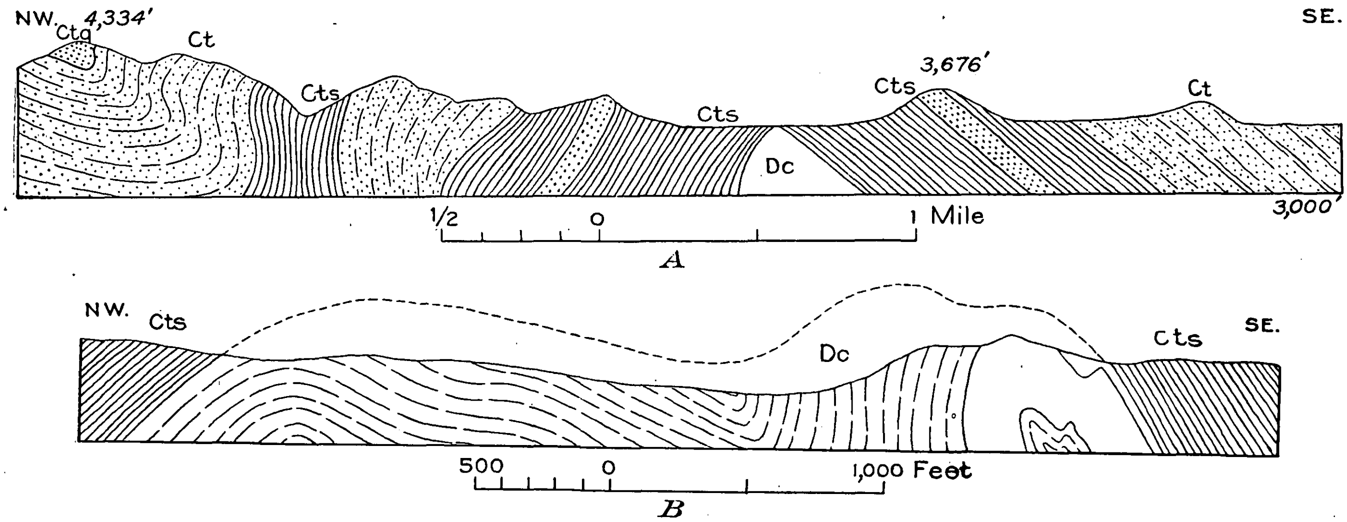


FIGURE 18.—Sections of lower part of Tesnus formation along Rough Creek, in southeastern part of Marathon Basin (Dove Mountain quadrangle; see pl. 23 for location). A, General section. (See sec. D–D′–D″, pl. 21, for general relations.) Dc, Caballos novaculite; Cts, basal shale member of Tesnus formation; Ct, upper part of Tesnus formation with white quartzite member (Ctq). B, Detailed section on Rough Creek, a mile above its mouth, showing apparent overlap of basal shale member of Tesnus formation onto Caballos novaculite. Novaculite unshaded; thin-bedded chert and siliceous shale, probably a part of Caballos formation, shaded. Cts, dark clay shale of basal member of Tesnus formation.

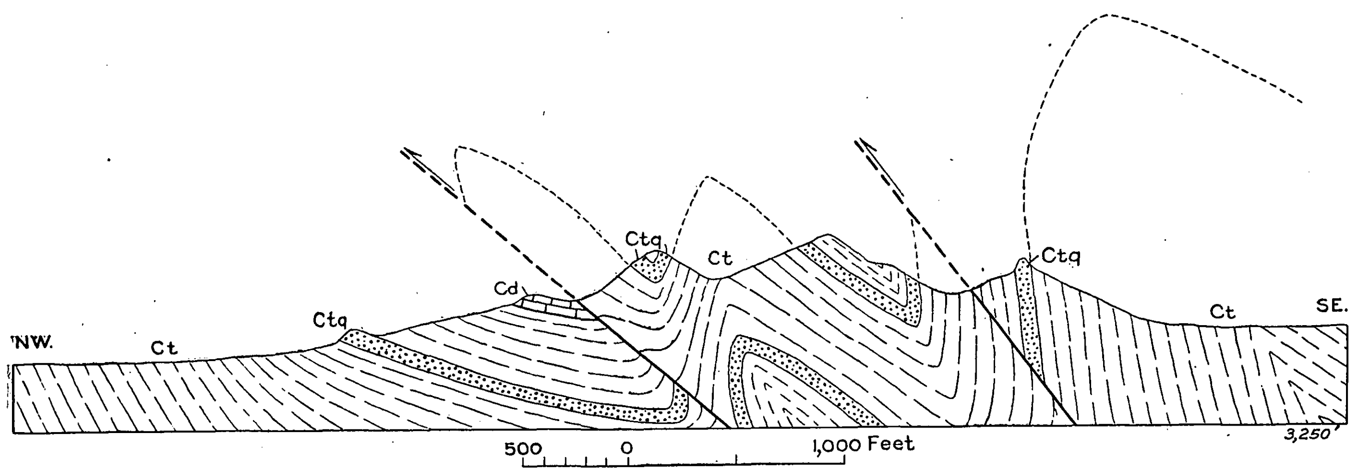


FIGURE 19.—Section across middle part of Devils Backbone showing structure and relations of white quartzite beds (Ctq) in Tesnus formation. The remainder of the formation in the section is sandstone and shale (Ct). In the northern fault block the upper quartzite appears to lie a short distance stratigraphically below the Dimple limestone (Cd). (For general relations of Devils Backbone, see sec. E–E′–E″, pl. 21.)

[52] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), pp. 101–102.

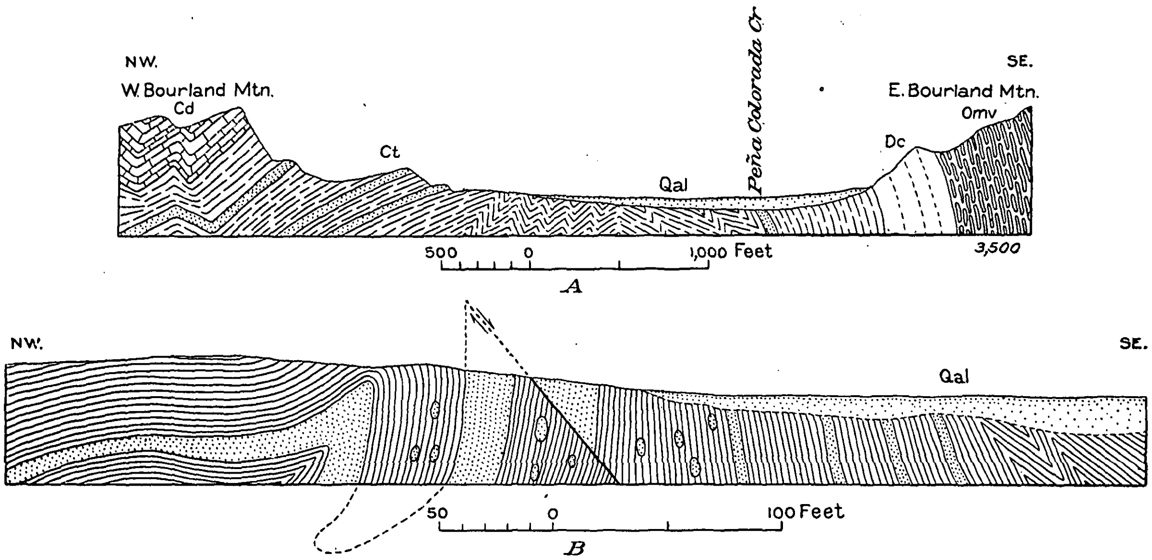


FIGURE 20.—Sections between East and West Bourland Mountains showing structural features in Tesnus formation along line of stratigraphic section described in the text. A, General section between the two mountains. (For general relations, see sec. H–H′–H″, pl. 21.) Omv, Maravillas chert; Dc, Caballos novaculite; Ct, Tesnus formation; Cd, Dimple limestone; Qal, alluvium. B, Detailed section on bank of Peña Colorada Creek near middle of A, showing complex folding of middle of Tesnus formation; note sandy concretionary masses in the shales.

tions. The lower shaly portion is believed not to be of the same age as the basal shale member of the Tesnus and Haymond area.

Section of Tesnus formation between East and West Bourland Mountains

Dimple limestone.
Tesnus formation:

Upper sandy portion:	Feet
30. Blue-black platy shale, with some lenses of finely granular sandstone	168
29. Soft argillaceous arkosic sandstone, weathering to rounded surfaces	26
28. Soft green sandy shale, with some sandstone lenses	51
27. Arkose, passing up into compact ferruginous sandstone; numerous plant remains in lower part	4
26. Shale, not well exposed	32
25. Dense platy green sandstone, with some gritty layers, which contain clay pebbles and plant stems	4
24. Blue-black indurated shale, weathering gray, with some thin beds of sandstone	45
23. Dull-lustered black chert and indurated shale, with some finely conglomeratic beds	10
22. Arkosic greenish sandstone	4
21. Conglomerate of angular chert fragments in a siliceous matrix	2
20. Shale	16
19. Arkosic green sandstone, weathering pale greenish brown and in part quartzitic. Weathers in part to square blocks and in part to friable rounded surfaces	6
18. Soft blue-green shale	14

Section of Tesnus formation between East and West Bourland Mountains—Continued

Tesnus formation—Continued.

Upper sandy portion—Continued.	Feet
17. Arkosic green sandstone in thin and thick beds. The lower surface of some of the beds is coarse-grained and undulatory and full of plant remains. There are also some sandstone casts of large logs of *Cordaites*	20
16. Indurated dark-green or blue shale, with minute white flecks on some of the beds. The rock weathers gray and is stained red or brown along joints	94
15. Fine-grained greenish quartzite, with conchoidal fracture, relatively nonarkosic	6
	502

Lower shaly portion:	
14. Soft green sandy shale, with some sandstone beds and some indurated bluish shale	205
13. Green sandy shale, with beds of maroon shale near top. The green shales contain cannon-ball sandstone concretions	10
12. Argillaceous green sandstone	8
11. Sandy green shale, with thin beds of argillaceous sandstone	55
10. Dense platy fine-grained argillaceous sandstone	1
9. Blue-black indurated shale, breaking into plates and chips	17
8. Argillaceous arkosic sandstone, with some thin beds of blue shale	5
7. Green shale, in part somewhat sandy	23
6. Greenish-gray argillaceous sandstone containing clay pebbles	3

Section of Tesnus formation between East and West Bourland Mountains—Continued

	Feet
Tesnus formation—Continued.	
Lower shaly portion—Continued.	
5. Green sandy shale	30
4. Blue-black slaty shale, breaking into chips; a few sandy seams an inch or less in thickness	12
3. Not exposed; thickness estimated	300
2. Massive green quartzite, with some interbedded shale. At the base at one place is a fine chert conglomerate	20
1. Not well exposed; mostly green hard thin-bedded argillaceous sandstone or sandy shale	500
Total	1, 189
	1, 691

Caballos novaculite.

Northwest of this section the formation thins out rapidly and near Monument Spring is only 500 feet thick (secs. 2–5, pl. 8). The plant-bearing arkoses of West Bourland Mountain disappear along the outcrop, and the whole formation to the northwest consists of bluish indurated shale with several interbedded layers of conglomerate. This northwestward thinning is probably chiefly the result of overlap of the Tesnus strata on the surface of the Caballos novaculite beneath.

Dugout Creek area.—Exposures of the Tesnus formation are nearly continuous from Monument Spring around the southwest end of the Marathon anticlinorium to the Dugout Creek area, on its northwest flank. The formation here is nowhere more than 300 feet thick and consists of greenish clay shales and indurated blue-black shales, with interbedded conglomerate and some beds of dull-lustered chert. In places the Dimple limestone lies directly on cherts of the Caballos formation, but whether from the actual disappearance of the Tesnus formation by overlap or from later tectonic squeezing cannot be said. The following section was measured in the southern part of the Payne Hills, 5 miles north-northeast of the Roberts ranch (sec. 1, pl. 8, and fig. 21).

Section of Tesnus formation in Payne Hills

	Feet
Dimple limestone.	
Tesnus formation:	
10. Hard stony dark-blue siliceous shale and subvitreous faintly banded blue-gray chert	16
9. Conglomerate of angular pebbles one-fourth to 3 inches in diameter of Caballos chert in a siliceous or chalcedonic matrix	2
8. Dark-blue stony indurated shale, weathering to flags	56
7. Soft drab clay shale with large brown siliceous concretionary masses near top	18
6. Bluish indurated shale, with some green shale	30

Section of Tesnus formation in Payne Hills—Continued

	Fee
Tesnus formation—Continued.	
5. Chert conglomerate of rounded to subangular fragments 3 inches to 1 foot in diameter in a brown sandy matrix	1
4. Brown indurated shale, whose harder layers crop out in ledges	106
3. Covered	46
2. Dense green indurated shale, breaking into conchoidal chips	13
1. Conglomerate	2
Total	290

Caballos novaculite.

MICROSCOPIC CHARACTER

Thin sections of the Tesnus sandstones show that most of them are made up of fine, subangular to subrounded quartz fragments in a chloritic matrix. The matrix imparts the characteristic greenish color to the fresh exposures of the rock, and its decomposition gives rise to the characteristic brown weathered surfaces.

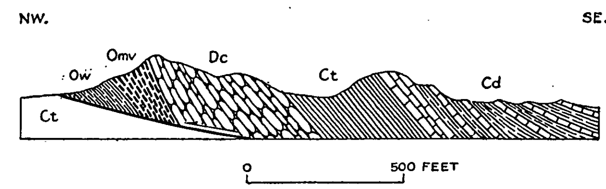


FIGURE 21.—Structure section across southern part of Payne Hills, 5 miles northwest of Roberts ranch, where a stratigraphic section was measured. Note small thickness of Tesnus formation, a characteristic feature of this part of the region. Ow, Woods Hollow shale; Omv, Maravillas chert; Dc, Caballos novaculite; Ct, Tesnus formation; Cd, Dimple limestone. See middle part of section D-D′, plate 16, for location and relations of this section.

Arkosic sandstones are fairly common in the formation. Megascopically they are greenish, of dull earthy appearance, and spotted by small light and dark grains. Such rocks are most common in the southeastern exposures of the formation. Three thin sections of arkose were examined, one from Devils Backbone, one from West Bourland Mountain, and one from a layer 1,000 feet below the top of the formation southeast of the Dimple Hills, in the northeastern part of the Marathon Basin. The three are of similar character. Quartz grains, somewhat shattered and nearly all showing strain shadows, make up 75 percent of the rock. Most of them are angular, but a few are well rounded. Most of the other grains are angular chips of sericitic slate and quartz-chlorite phyllite. There are also a few grains of potash feldspar, sodic plagioclase, chert, biotite in bleached twisted. plates, and muscovite. A few small grains of high refractive index may be seen. The arkoses from West Bourland Mountain, in the northwestern part of the area, are of finer grain than the other two and contain more quartz, but fragments of slaty and cherty rocks are present, as well as feldspar and mica.

Other sandstones in the formation contain more quartz and approach quartz sandstones and quartzites. Nearly all, however, contain a few grains of metamorphic rocks. The matrix of most of the Tesnus sandstones, including the arkoses, is an iron-rich chlorite, possibly chamosite. Honess [53] suggests that the chlorite matrix in similar sandstones of the Stanley shale is derived from the alteration of an original ferruginous and argillaceous cement. Of all the sections of sandstone and arkose examined, including those from the strongly deformed southeastern part of the area, none could be classified as a truly metamorphosed rock. However, all the quartz grains show strain shadows, and many are crushed, granulated, and sheared.

The layers of white quartzite in the southeastern part of the area are quite different from the other sandstones of the Tesnus formation. They consist almost entirely of quartz, and there is no chloritic or argillaceous matrix. Some of the quartz grains are rounded and others angular. There is some variation in the size of the fragments, so that the smaller grains fill the interstices between the larger ones. There has also been some secondary regrowth of crystals. The whole rock is therefore an interlocking mass of quartz grains with very little matrix.

FOSSILS AND AGE

The Tesnus formation contains a few plant remains and Foraminifera in the upper part, but otherwise no fossils have been found in it. The largest collections have been obtained from the north end of West Bourland Mountain, 10 miles southwest of Marathon, from arkosic sandstones 400 feet below the top of the formation (bed 17 of section on p. 59; U. S. Geol. Survey localities 7937 and 8093). Material was gathered here by Sidney Powers in 1929 and by David White and the writer in 1930. Dr. White examined both collections and reported as follows:

All specimens are badly water-worn, fragmentary, and even abraded. The identifications are therefore largely tentative.

1. *Neuropteris gigantea?* Nearly complete pinnule, certainly belonging to the *Neuropteris gigantea* type. In the Appalachian trough this is mainly confined to the middle Pottsville.
2. *Neuropteris* sp. Tip of a narrow pinnule with extremely oblique nervation, suggesting *N. obliqua*.
3. *Alethopteris*. Indeterminate fragment of very narrow compact form close to a species in the middle Pottsville of the Appalachian trough.
4. Numerous fragments of fern petioles, very badly abraded. One specimen strongly suggests *Heterangium*.
5. *Calamites* node and portion of two internodes tentatively referred to *Calamites ramifer*.
6. *Calamites* cf. *C. cistii*.
7. *Asterophyllites* stems.
8. Leaves probably belonging to an *Asterophyllites*, like *Asterophyllites gracilis*.
9. *Lepidodendron clypeatum?* A few detached and deformed bolsters probably belonging to this species or included under the comprehensive name *Lepidodendron obovatum*.
10. *Lepidostrobus* sp. Fragment of axis from which bracts and sporangia have been stripped. It suggests *Lepidostrobus variabilis*, though the axis is rather thick for that species.
11. *Stigmaria* sp. Scattered cicatrices left by rootlets.
12. *Cordaites* sp. Fragment of narrow leaf not specifically determnable.
13. *Artisia* sp. Pith of *Cordaites* stem.
14. *Cardicocarpon* sp. Nucleus indeterminable.
15. *Trigonocarpum* cf. *T. ampulliforme*.
16. *Trigonocarpum*. Very small ovate form, possibly undescribed.

In discussing the age of this flora, Dr. White stated that

> The characters exhibited by the calamarian forms, the pteridosperms, and the *Lepidodendron* show that the beds from which the plants were obtained are undoubtedly Pennsylvanian. The *gigantea* type of *Neuropteris*, the *Alethopteris*, and to some extent the *Lepidodendron* point toward a middle Pottsville age, though the evidence is not absolutely conclusive. Viewed broadly, the flora is Westphalian; certainly it cannot be older than Namurian.

He also stated that the flora is clearly younger than that of the Jackfork sandstone of Oklahoma but probably older than that of the Atoka formation.

Plants have also been collected by Sidney Powers from the upper part of the Tesnus formation south of Tesnus station. From his collection at this place, Dr. White identified the tips of some leaflets as either *Neuropteris* or an elongated *Cardiopteris*. "I think it is *Neuropteris* and referable either to *Neuropteris gigantea* of the middle Pottsville or to *Neuropteris capitata* of the upper Pottsville." [54]

Foraminifera have been obtained by Bruce Harlton from shale samples collected near the top of the Tesnus formation 18 miles east of Marathon. They are said to be of "lowermost Pennsylvanian age" and to be identical with "microfossils from the Caney shale in Oklahoma." [55]

In a calcareous sandstone on the north slope of West Bourland Mountain below the plant horizon were collected what appear to be sponge spicules. According to G. H. Girty, they "consist of slender rods, circular in section and showing no appreciable taper. They have all the characters of a not uncommon type of sponge spicule except that they are black and shining, as if the material of which they are composed was phosphatic instead of siliceous." These fossils afford no evidence as to the age of the sandstone.

[53] Honess, C. W., Geology of the southern Ouachita Mountains of Oklahoma: Oklahoma Geol. Survey Bull. 32, p. 189, 1923.

[54] Letter from David White to Sidney Powers, July 1930.

[55] Powers, Sidney, Age of the folding in the Oklahoma Mountains: Geol. Soc. America Bull., vol. 39, p. 1066, 1928.

STRATIGRAPHIC RELATIONS

The Tesnus formation is probably conformable with the Dimple limestone, which overlies it. In nearly every locality the two formations are separated by a transition zone of interbedded limestone and shale. In the northwestern part of the area the lower beds of the Dimple are conglomeratic and the Tesnus is only a few hundred feet thick. This is probably not the result of a break between the two formations and appears to be caused by a northwestward overlap of the Tesnus formation on the Caballos novaculite. The shales at these northwestern localities are not the basal shale member as recognized in the southeastern part of the basin, for they can be traced from section to section till they interfinger with the plant-bearing sandstones of the upper Tesnus along Peña Colorada Creek. They do not resemble the basal shales in lithology.

DIMPLE LIMESTONE

GENERAL FEATURES

The Dimple limestone was named by J. A. Udden [56] for exposures in the Dimple Hills, in the northeastern part of the Marathon Basin, 20 miles northeast of Marathon. The massive and resistant limestones of the formation rise as low monoclinal ridges above the waste-mantled plains of the basin. The formation is widely exposed in narrow sinuous belts of outcrop in the eastern part of the area and extends from the Dimple Hills southward beyond Haymond station. It is also found in scattered synclinal areas along Dugout and Peña Colorada Creeks, in the western part of the Marathon Basin. The southeasternmost exposures are small patches surrounded by outcrops of the Tesnus formation in the faulted complex of Hells Half Acre and Devils Backbone.

The formation is composed of limestone in moderately thick beds. Most of the limestone beds are gray, granular, and somewhat sandy, with scattered seams of chert pebbles. Other beds are dense and very bituminous. The limestone contains a sparse fauna of marine invertebrates. In the eastern part of the Marathon Basin there is much shale in the upper and lower parts of the formation, so that it grades by transition zones into the clastic rocks of the Tesnus and Haymond below and above. The boundaries of the formation are drawn at the highest and lowest limestone beds.

LOCAL FEATURES

Eastern part of Marathon Basin.—At the type locality, in the synclinal area of the Dimple Hills, the Dimple limestone is over 1,000 feet thick (sec. 8, pl. 8). The top is not exposed here, though the highest beds evidently belong to the upper transition zone.[57]

The formation is thinner toward the south (sec. 6–8, pl. 8). Baker and Bowman [58] report 925 feet in the water gap traversed by the Southern Pacific Railroad 1½ miles west of Haymond station, and the writer measured only 497 feet at the water gap in the Haymond Mountains 4 miles south of the station. The lower 50 feet and the upper 150 feet in this region consist mostly of dark indurated shales, with a few thin beds of limestone. The main mass of the formation consists of dark-gray, finely granular limestone, weathering gray or yellow, in beds 1 to 4 feet thick, with many partings of dark indurated shale. Some of the limestones are banded by seams of brown chert, part of which are arranged in domelike concentric structures, possibly of organic origin.[59] There are some layers of thinly laminated flaggy gray or bluish dense limestone and many thin interbedded layers of gray dull chert. In the lower part some of the yellow-weathering limestones contain granular seams crowded with fragments of brachiopods and bryozoans. A few crushed and flattened shells of ammonoids were collected from the flaggy layers. Many of the limestone beds contain fine sand, but there is very little chert conglomerate in the southern part of the area. In the excellent exposure on the Sanderson road, 15 miles east of Marathon, there are four or five thin beds of gray clay between the limestone layers.

The following section was measured in the water gap 4 miles south of Haymond station (sec. 6, pl. 8).

Section of Dimple limestone 4 miles south of Haymond

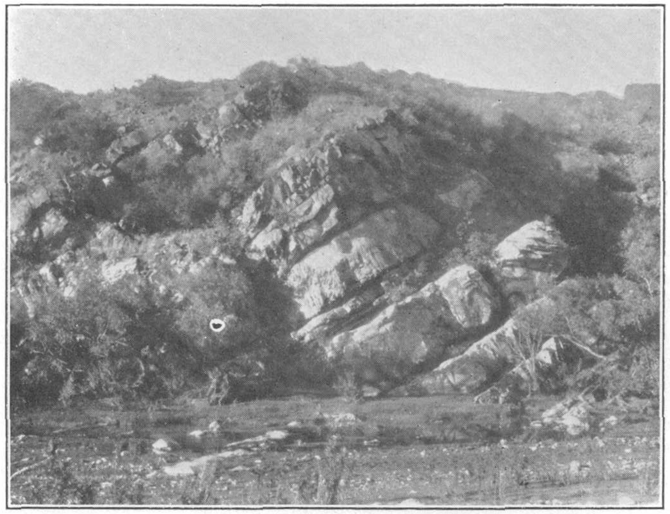
	Feet
Haymond shales.	
Dimple limestone:	
Upper transition beds:	
32. Shale and chert with a few thin limestone beds	82
31. Brown sandy limestone interbedded with shale	65
30. Massive limestone with undulatory siliceous bands	2
29. Shale	8
Main body of Dimple limestone:	
28. Thin-bedded finely granular gray limestone	30
27. Flaggy brown sandy limestone with much interbedded shale	30
26. Granular limestone in 2-foot beds interbedded with shale	11
25. Indurated shale and some sandy limestone	9
24. Flaggy bluish limestone, which contains ammonoids	11

[56] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, 1st ed., p. 46, 1916.

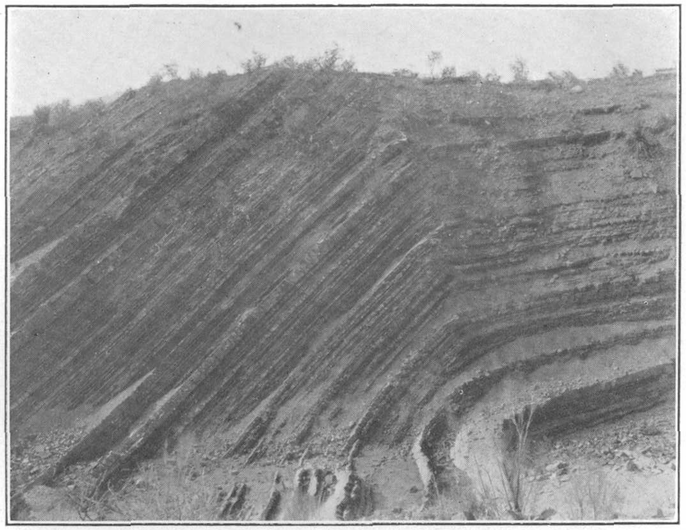
[57] King, P. B., Geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, pp. 36–38, 1930.

[58] Baker, C. L., and Bowman, W. F., op. cit. (Texas Univ. Bull. 1753), p. 105.

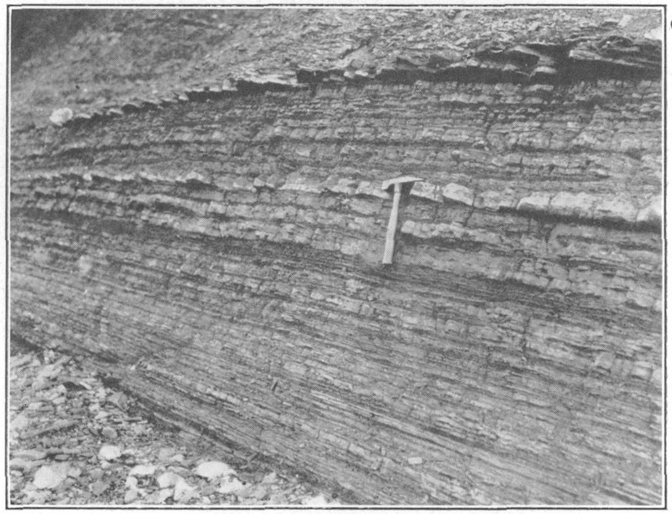
[59] King, P. B., op. cit., pl. 2, *A*.



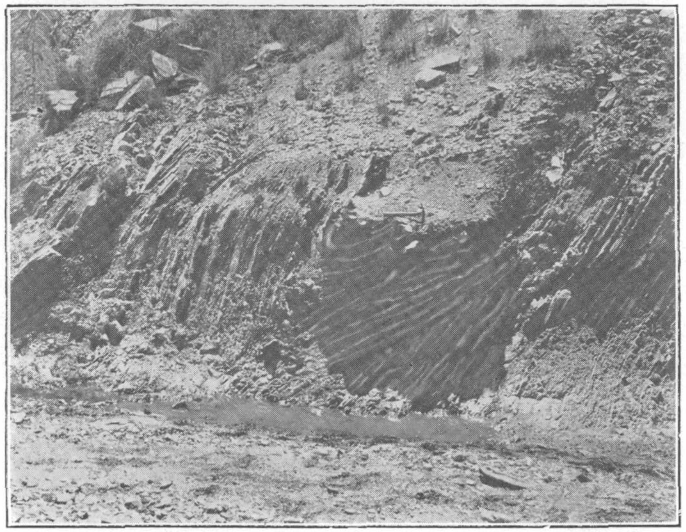
A. MASSIVE SANDSTONE OF UPPER PART OF TESNUS FORMATION.
On San Francisco Creek north of Devils Backbone.



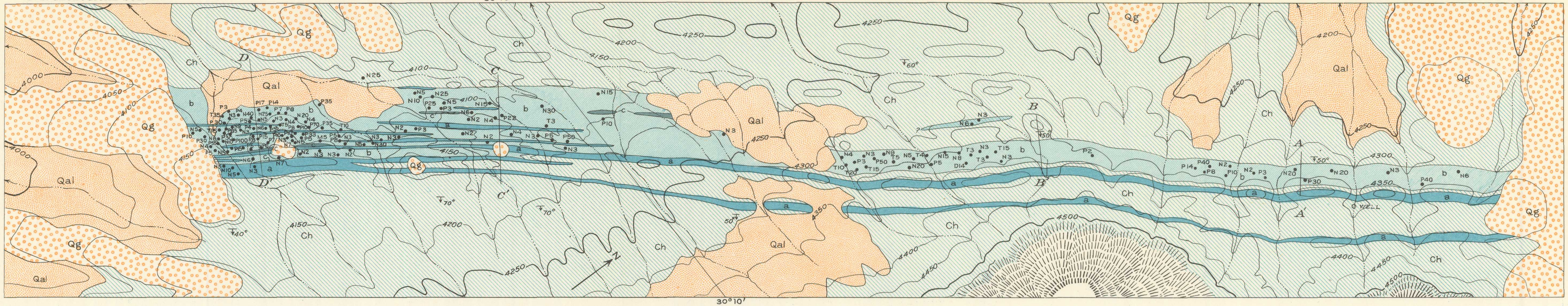
B. SANDSTONES AND SHALES OF LOWER PART OF HAYMOND FORMATION.
In cut of San Francisco Creek 3 miles south of Haymond station.
Photograph by C. L. Baker.

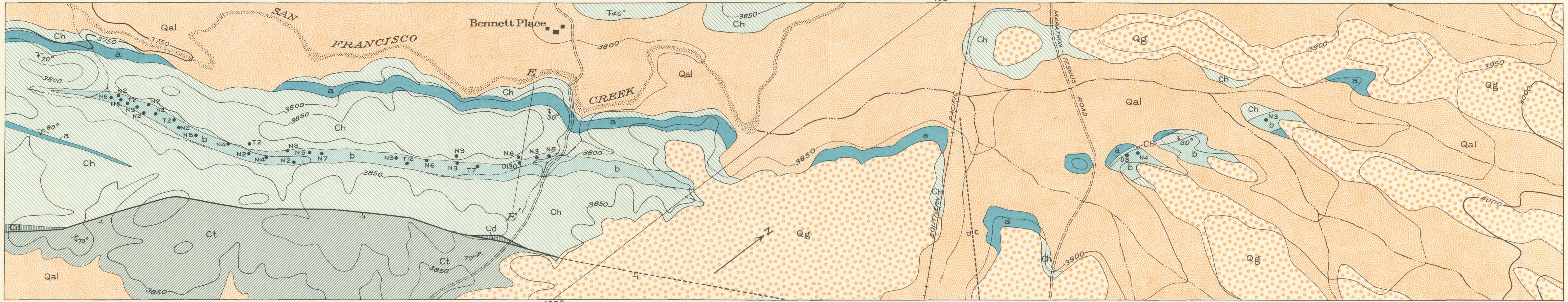


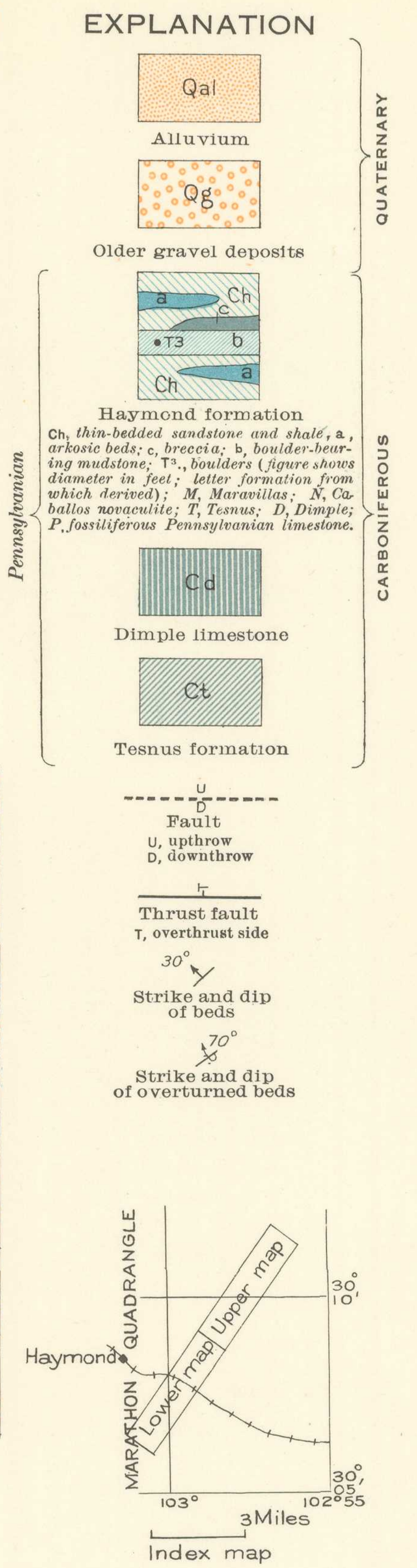
C. SHALES AND SANDY SHALES OF UPPER PART OF HAYMOND FORMATION.
In cut on Dugout Creek 2½ miles south of Dugout Mountain.



D. FOLDING AND THRUSTING OF THIN-BEDDED SHALES AND SANDY SHALES OF UPPER PART OF HAYMOND FORMATION.
In cut on Dugout Creek 1½ miles southeast of Dugout Mountain.
Photograph by C. R. Longwell.







Topography west of 103° from U. S. Geol. Survey map of Marathon quadrangle; east of 103°, reconnaissance by P. B. King.

Lith. A. Hoen & Co., Inc.

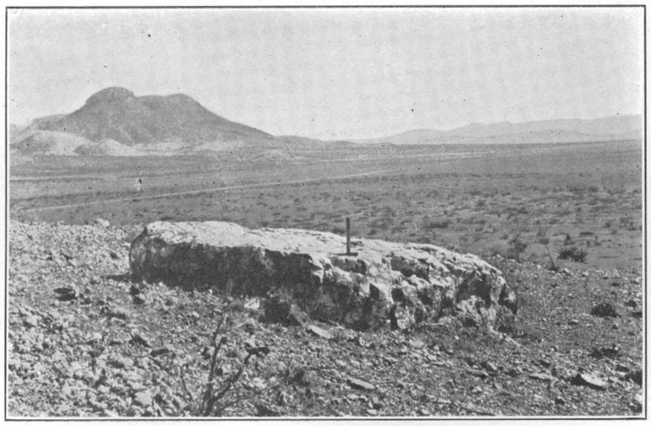
Geology by P. B. King
Surveyed in 1930 and 1931

GEOLOGIC MAP OF BOULDER BEDS OF THE HAYMOND FORMATION IN THE EASTERN PART OF THE MARATHON REGION

0 — 1/4 — 1/2 — 1 Mile

1,000 — 0 — 2,000 Feet

1938

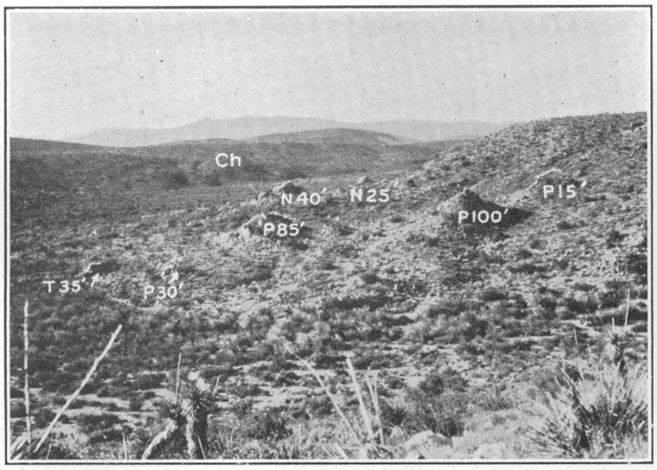


A. BLOCK OF NOVACULITE IN BOULDER-BED MEMBER OF HAYMOND FORMATION.

Five miles southeast of Gap Tank. Photograph by C. L. Baker.

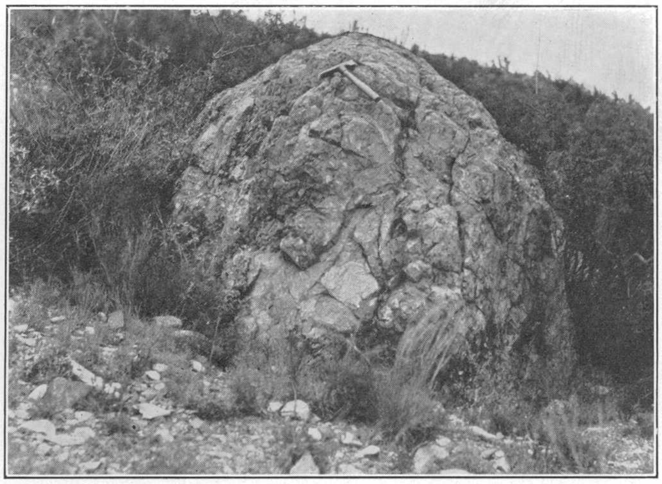
B. WATER-WORN COBBLES OF DIMPLE AND GAPTANK LIMESTONES IN FIRST CONGLOMERATE MEMBER OF GAPTANK FORMATION.

A mile and a half south of Gap Tank.



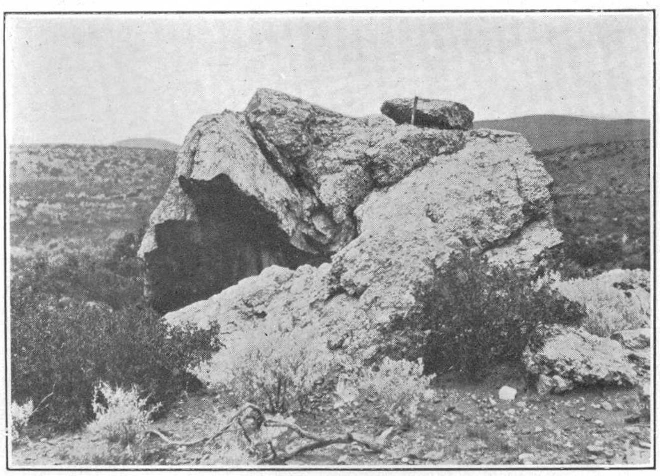
C. EXPOSURES OF BOULDER-BED MEMBER.

A mile west of Housetop Mountain (locality of sec. D–D′, fig. 23). Knobs on hillside in middle distance are boulders of novaculite and of Pennsylvanian limestone. Letters refer to boulders: N, Caballos novaculite; T, Tesnus formation; P, Pennsylvanian limestone. Diameter of each boulder given in feet. Ch, Sandstones and shales of Haymond formation underlying boulder-bed member.



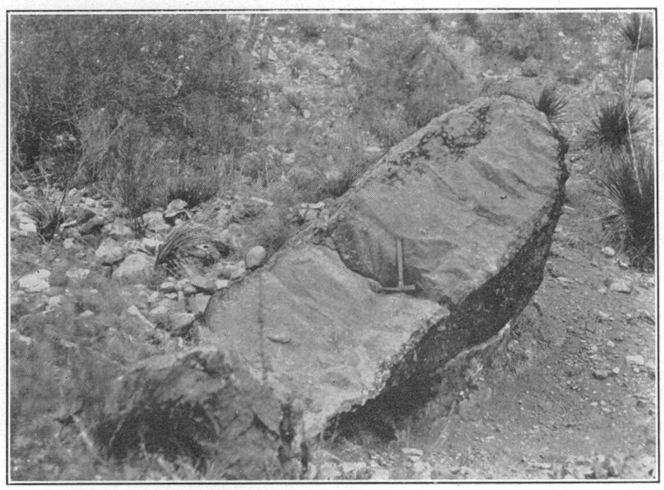
D. ROUNDED BOULDER OF BRECCIATED CHERT FROM CABALLOS FORMATION IN BOULDER-BED MEMBER.

A mile and a half north of summit of Housetop Mountain.



E. BOULDER OF NOVACULITE IN BOULDER-BED MEMBER.

About 2½ miles north of summit of housetop Mountain. The boulder has been shattered by later deformation and by weathering.



F. BOULDER OF PENNSYLVANIAN LIMESTONE.

Projecting from the mudstone matrix of the boulder-bed member 1 mile west of summit of Housetop Mountain.

Section of Dimple limestone 4 miles south of Haymond—Con.

		Feet
Dimple limestone—Continued.		
Main body of Dimple limestone—Continued.		
23.	Indurated blue shale and flaggy limestone	9
22.	Massive granular gray limestone	3
21.	Shale and chert	5
20.	Massive gray finely granular limestone, some of which contains undulatory or concentric siliceous bands	14
19.	Brown sandy limestone, in part cross-bedded, interbedded with shale	13
18.	Finely granular dark-gray limestone	3
17.	Shale and granular chert	4
16.	Massive limestone with undulatory siliceous bands	4
15.	Brown sandy limestone interbedded with shale	8
14.	Massive limestone with undulatory siliceous bands	3
13.	Thin ledges of gray granular limestone interbedded with shale and granular chert	15
12.	Massive granular gray limestone	3
11.	Thinly laminated blue-gray dense limestone with shale partings	11
10.	Massive limestone with undulatory siliceous bands, in 3-foot ledges, interbedded with flaggy bluish limestone	14
9.	Flaggy bluish limestone and brown sandy limestone interbedded with shale and chert	15
8.	Massive limestone with undulatory siliceous bands	2
7.	Shale and thin-bedded brown sandy limestone	11
6.	Massive limestone with siliceous bands of undulatory or concentric structure, possibly of organic origin, in 2-foot ledges, interbedded with indurated shale	10
5.	Indurated bluish shale with some blue-gray flaggy limestone	8
4.	Granular dark-gray limestone in a massive ledge with some fine conglomerate in lower part	3
3.	Indurated blue shale and dull chert with thin layers of limestone	19
2.	Massive gray-brown sandy limestone, altered on upper bedding surface to granular chert	4
Lower transition beds:		
1.	Thin to thick beds of brown laminated sandy limestone interbedded with much indurated bluish shale and some laminated dull chert	64
	Total	493
Tesnus formation.		

Western part of Marathon Basin.—In the western part of the Marathon Basin the Dimple limestone is only about 100 feet thick (secs. 1–5, pl. 8), but it is similar to the beds exposed farther east. It consists mainly of dark-gray granular limestones, which crop out in ledges several feet thick (pl. 6, *C*) and contain seams of fine chert pebbles and crinoidal fragments. There are many layers of thin-bedded or flaggy sandy brown limestone and siliceous limestone, and some beds of indurated greenish shale. Some of the bedding surfaces of the flaggy limestones are marked by a net of winding trails or fucoidlike markings.

Along Peña Colorada Creek the limestones are succeeded by shales belonging to the Haymond formation, but farther northwest, along Dugout Creek, they are overlain by about 200 feet of indurated greenish shales and thin beds of green compact sandstone in which there are half a dozen ledges of brown sandy and pebbly limestone (fig. 21). Although these beds are classed with the Dimple limestone, they may well be equivalent to the lower part of the Haymond formation farther south.

A short distance north of the Roberts ranch there is at the base of the Dimple limestone a lenticular layer of conglomerate as much as 10 feet thick, composed of subangular cobbles and pebbles of Caballos chert and novaculite and of Maravillas limestone and chert in a siliceous matrix. About 3 miles north of the Roberts ranch two other thinner conglomerate beds are found higher in the formation. The fact that the Tesnus formation beneath is almost cut out by overlap suggests that these conglomerates were derived from an exposed surface of the pre-Carboniferous rocks farther north, on which the Tesnus formation was never deposited. In the outliers of the Dugout Creek overthrust sheet northeast of Lenox the Dimple contains thick beds of angular chert breccia cemented by silica, and nearly all the limestones are conglomeratic.

The following section was measured in the southern part of the Payne Hills, 5 miles north-northeast of the Roberts ranch (sec. 1, pl. 8, and fig. 21).

Section of Dimple limestone in southern part of Payne Hills

		Feet
Haymond formation.		
Dimple limestone:		
11.	Indurated greenish shale and thin flaggy fine-grained greenish sandstone, interbedded with ledges of brown granular limestone, containing chert pebbles	227
10.	Thin ledges of dark-gray granular limestone, interbedded with clay shale	15
9.	Gray sandy limestone, with brown chert bands and some interbedded shale	13
8.	Shale and dull dark-gray bedded chert	20
7.	Coarse-grained gray limestone, containing fine chert fragments, with some dense limestone at top; crops out in a massive ledge	4
6.	Indurated green shale, with thin beds of gray granular limestone	26
5.	Granular gray limestone containing fine chert fragments	3
4.	Conglomerate like bed 1	3
3.	Limestone interbedded with black dull chert	8
2.	Gray granular limestone, in massive ledges, crowded with pebbles; some partings of green shale	18
1.	Conglomerate of chert and limestone pebbles and cobbles in a sandy siliceous matrix	5
	Total	342
Tesnus formation.		

FOSSILS AND AGE

Fossils are not abundant in the Dimple limestone. Many of the layers appear to be composed of the fragments of shells, but these are so finely comminuted that no identifiable material is preserved. Thin sections of the limestone show many such shell fragments.

Foraminifera (other than fusulinids) are reported by Harlton from shales interbedded with the limestone layers of the Dimple Hills and of the exposures 18 miles east of Marathon. They were also noted in a thin section from the basal layers south of Iron Mountain.[60] Harlton correlates the microfauna studied by him with that of the Marble Falls and Wapanucka limestones.[61]

Megafossils have been found at several localities in the formation, but only a few specimens have been found at each place, and none of these are well preserved. The largest collection was obtained by G. H. Girty and the writer in 1929 from the lower part of the formation, 1½ miles west-northwest of Haymond station, to the north of the Southern Pacific Railroad (U. S. Geological Survey locality 6707). From this collection Mr. Girty has identified the following fossils:

Orbiculoidea sp.
Chonetes aff. *C. arkansanus* Girty.
Chonetes n. sp.
Productus aff. *P. cora* D'Orbigny.
Pustula n. sp.
Pustula aff. *P. globosa* Mather.
Pustula sp.
Hustedia multicostata Girty?.

In commenting on this collection, he states:

> It is not reminiscent of the more common Pennsylvanian faunas and is almost equally lacking in definite alliance to the more common Mississippian faunas. Very tentatively I am considering it as of Pottsville age, although one of the Producti is almost identical with a Mississippian species. The new species of *Pustula* is very close to an undescribed but distinctive productid that occurs in the earlier Mississippian faunas of Oklahoma and Arkansas. The remainder of the fauna does not very well bear out the relation suggested by that resemblance but appears to be more closely affiliated with Pottsville faunas.

From the southwest side of the Dimple Hills, 1 mile east of the Arnold ranch (U. S. Geological Survey locality 7084), the following fossils have been collected:

Clisiophyllum sp.	*Cystodictya* sp.
Crinoid stem.	Minute gastropods.
Coeloconus sp.	

At three localities poorly preserved ammonoids have been found in the Dimple limestone. A collection from the basal layers of the formation on West Bourland Mountain (U. S. Geological Survey locality 6919) and one from a similar horizon 6 miles south of Haymond station (U. S. Geological Survey locality 6918) each contain large crushed shells which not improbably belong to the same species. According to Mr. Girty, "they have a rather wide umbilicus, suggesting *Gastrioceras*, but the form of the suture cannot be determined." A collection from bed 24 of the section 4 miles south of Haymond station (U. S. Geological Survey locality 6917) (p. 62) contains two specimens of a much smaller ammonoid, which is completely flattened in stiff shale. These specimens "show the sculpture but afford no evidence that the shell was originally chambered. The sculpture, which consists of strong, rather coarse revolving costae, together with such other characters as are preserved, recalls *Gastrioceras caneyanum* (Girty)." This same collection also contains small three-rayed sponge spicules.

The other fossil collections each contain only a few poorly preserved specimens. One from exposures west of Iron Mountain contains sponge spicules, crinoid stems, and a species of *Spirifer*. Another, 2½ miles north-northeast of the Roberts ranch, contains a zaphrentoid coral, crinoid stems, *Streblotrypa* sp., and *Productus* sp. A collection from the lower part of the formation 15 miles east of Marathon on the Sanderson road contains *Rhombopora*? sp., and one from a similar horizon 5 miles southwest of Haymond station contains *Amplexus*? sp.

In summarizing the collections from the Dimple limestone, Mr. Girty writes:

> The fossils in the Dimple suggest a Pottsville age. At all events, they apparently must represent an unusual facies if the horizon from which they came is regarded as post-Pottsville.

STRATIGRAPHIC RELATIONS

The contact between the Dimple and Haymond formations, as exposed north and south of Haymond station and near Peña Colorada Creek southwest of Marathon, is apparently gradational, and the Dimple limestone is separated from the shales and sandstones of the Haymond formation by several hundred feet of transition beds.

HAYMOND FORMATION

HISTORICAL SUMMARY

The name "Haymond formation" was applied by Baker [62] in 1916 to exposures in the synclines near Haymond station, in the eastern part of the Marathon Basin, but there has been considerable doubt as to the status of the unit, because Baker [63] later suggested that it might be a part of the Tesnus formation that

[60] King, P. B., Geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, p. 38, fig. 13 (middle left), 1930.

[61] Powers, Sidney, Age of the folding in the Oklahoma Mountains: Geol. Soc. America Bull., vol. 39, p. 1066, 1928.

[62] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, 1st ed., p. 46, 1916.

[63] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 107, 1917. Baker, C. L., Date of major diastrophism and other problems of the Marathon Basin: Am. Assoc. Petroleum Geologists Bull., vol. 12, p. 1114, 1928.

had been overthrust across the Dimple. Field work by R. E. King and the writer in 1927 [64] indicated that the Haymond formation overlay the Dimple without such a structural break, and its validity was demonstrated beyond question in 1930 with the discovery of boulders of Tesnus and Dimple rocks in the boulder-bed member of the younger formation. In the last few years there has been much interest in the formation on account of the large boulders which are found in it.[65]

GENERAL FEATURES

The Haymond formation is a mass of shales and sandstones whose thickness locally exceeds 3,000 feet. Although sections have been found which extend through part of the Haymond up to the Gaptank formation, or down through part of it to the Dimple limestone, no exposure is known where there is a complete and uninterrupted sequence from the base to the top of the formation (pl. 8). The Haymond beds crop out in disconnected synclinal areas in various parts of the Marathon Basin but are most extensively exposed between Haymond station and Gap Tank. Because of their generally nonresistant character, they form low rolling hills or plains and are extensively mantled by gravel and wash.

Most of the formation consists of layers of sandstone and carbonaceous shale a fraction of an inch to several inches in thickness, in regular, rhythmic alternation (pl. 9, *B*, *C*, *D*). There are a few thicker sandstone beds at long intervals, and near the base some thick bodies of shale. The peculiar stratification of the Haymond formation is quite unlike anything seen in the Tesnus, with which it has previously been confused. At a few places in the region the Haymond sandstones and shales have thin intercalations of sandy limestone, some of which contain marine invertebrate fossils.

The upper part of the formation contains thick layers of massive arkose, and in the syncline east of Haymond station there are several members of boulder-bearing mudstone as much as 150 feet thick. The boulders in the mudstone beds include erratic blocks of the older formations as much as 130 feet across (pl. 11, *C–F*). Southeast of Gap Tank a thinner boulder bed lies at about the same stratigraphic position.

[64] King, P. B., and King, R. E., The Pennsylvanian and Permian stratigraphy of the Glass Mountains: Texas Univ. Bull. 2801, p. 113, 1928.

[65] King, P. B., Baker, C. L., and Sellards, E. H., Erratic boulders of large size in the west Texas Carboniferous [abstract]: Geol. Soc. America Bull., vol. 42, p. 200, 1931. Sellards, E. H., Erratics in the Pennsylvanian of Texas: Texas Univ. Bull. 3101, pp. 1–17, 1931. King, P. B., Large boulders in the Haymond formation of west Texas [abstract]: Geol. Soc. America Bull., vol. 43, p. 148, 1932. Baker, C. L., Erratics and arkoses in the middle Pennsylvanian Haymond formation of the Marathon area, trans-Pecos Texas: Jour. Geology, vol. 40, pp. 577–607, 1932. Carney, Frank, Glacial beds of Pennsylvanian age in Texas [abstract]: Geol. Soc. America Proc., 1934, p. 70, 1935.

HAYMOND AREA

General relations.—The Haymond formation is exposed in the two synclines northwest and southeast of Haymond station. Both synclines are broad and open but are overturned and faulted on the southeast. In the southeastern syncline the Haymond formation crops out in a belt 1½ miles in width, which is terminated on the southwest up the pitch of the fold by outcrops of the Dimple limestone. These curve around the axis and are cut off by a fault on the southeast. The strata on the northwest flank of the syncline dip southeastward in regular order at angles of 30° to 45° in the south (sec. A–A′; pl. 21), but with the inclination increasing gradually northward to about 70° near the Sanderson road. The strata on the southeast flank of the syncline have steep or overturned dips and are cut off a short distance southeast of the synclinal axis by a steep thrust fault that raises Tesnus sandstones against those of the Haymond. Southeast of Haymond station the outcrops of the boulder-bed member of the formation appear to lie along the trace of the synclinal axis, but farther north, near Housetop Mountain, the axis is in strata overlying the boulder bed to the east. Here the boulder bed and the rocks that enclose it are a part of a steeply tilted normal sedimentary sequence, without duplication by folding or faulting.

In the syncline east of Haymond station the sequence is roughly as follows (sec. 6–7, pl. 8):

Section of Haymond formation east of Haymond

Axis of syncline; top of formation not exposed.	
Haymond formation:	*Feet*
6. Interbedded carbonaceous shales and green sandy shales or sandstones, in layers a fraction of an inch to several inches in thickness	1,000
5. Boulder-bed member: Layers of massive arkosic mudstone in two to five members 25 to 150 feet thick, containing pebbles and large boulders. Between the mudstone members are layers of massive arkose and some of thin-bedded sandstone and shale	300–900
4. Thin alternations of sandstone and shale	500
3. Massive arkose, absent north of railway	0–6
2. Thin alternations of sandstone and shale	1,000
1. Dark shale	200
Total	3,600
Dimple limestone.	

Lower members of formation.—The lower four members of the Haymond formation crop out in a belt of low rolling hills about a mile wide east of Haymond station (pl. 24), where there are several excellent exposures in railroad excavations and in the cut banks of San Francisco Creek. This part of the formation is also exposed in the narrower syncline northwest of Haymond station.

In the large cut on San Francisco Creek 3 miles south of Haymond station the rocks dip steeply eastward with some local folding (fig. 22). They consist of a rhythmic alternation of thin beds of shale and sandstone (pl. 9, *B*). The arenaceous beds are flaggy fine-grained, greenish sandstones or hard pale-greenish sandy shales, in ¼-inch to 2-inch beds. The argillaceous beds are black or dark-blue carbonaceous shales in layers of similar thickness. At intervals of 5 to 15 feet are beds of compact sandstone as much as a foot thick, some of which are current-marked and cross-bedded on a small scale. In other exposures the light-colored layers are sandy shales rather than sandstones. The sandstone beds break down into thin brown plates and flags, which cover the hillsides. The rhythmically bedded nature of the formation is not well revealed except on fresh exposures.

Boulder-bed member.—The term "boulder-bed member of the Haymond formation" is applied to a complex group of interstratified, thin-bedded sandstones and shales, massive arkose, and boulder-bearing mudstone, lying in the upper part of the formation east of the Marathon quadrangle. The southwesternmost exposures of the member are 3 miles southeast of Haymond station, and the northeasternmost are west of the summit of Gap Peak and about half a mile south of the Sanderson road (pl. 10). Between these points, a distance of 8 miles, the boulder-bed member crops out in a linear belt, interrupted only by strips of surficial deposits. The arkose layers in the member rise in low knobs and hogbacks, but the boulder-bearing mudstones are mostly worn down to valleys and lowlands. At one locality, due west of the summit of Housetop Mountain, large erratic blocks are so numerous in the boulder bed that the member stands up in a group of rugged hills (pl. 11, *C;* sec. D–D′, fig. 23).

The boulder-bed member is about 900 feet thick west of the summit of Housetop Mountain, where it consists of five mudstone layers, from 25 to 150 feet thick, interbedded with thin-bedded sandstones and shales and ledges of massive arkose. Farther north two boulder beds at the base and one at the top merge into sandstones and shales along the strike of the rocks, and only the two middle layers persist to the northernmost exposures (sec. A–A′, fig. 23). There are two layers of massive arkose at the top of the member in this region, and it is underlain by thinly bedded sandstones and shales. South of the latitude of Housetop Mountain the boulder-bed member is not well exposed for a distance of 3 miles, and the next continuous outcrop is south of the railroad. Here the main arkose layers underlie the boulder bed and there is only one mudstone layer, which pinches out between sandstones and shales 2 miles south of the railroad. This layer is probably on the axis of the syncline, and whatever higher beds once existed have been removed by erosion. Probably the mudstone of the southwestern exposures, like that of the northeasternmost, is correlative with the middle part of the boulder-bed member near Housetop Mountain, and the lower arkoses connect with the thin arkose layers between the lower mudstone members farther north.

The fragments in the boulder-bed member include a great variety of rocks. Among them are pre-Cambrian crystalline rocks, such as granite, aplite, pegmatite, vein quartz, rhyolite porphyry, quartz conglomerate, and possibly schist. No recognizable masses from the Cambrian or early Ordovician have been found, but there are a few blocks from the Maravillas chert. Numerous fragments from the Caballos formation include massive white novaculite, thinly laminated novaculite, varicolored banded cherts, in part contorted, and coarse chert breccias cemented by silica (pl. 11, *C, E*). The breccias resemble those seen along some of the thrust faults in the novaculite area. There are many fragments of dense, fine-grained greenish quartzitic sandstone from the Tesnus formation, as well as one or two blocks of its characteristic indurated green shale. Boulders from the Dimple limestone are rare except for a single large slab near the Bennett place, a thick-bedded, compact dark-gray limestone, with seams of chert conglomerate and thick shale partings. There are also boulders of black, yellow-weathering dense limestone, containing chert in irregular knotty masses (pl. 11, *F*). These boulders contain Pennsylvanian fossils, but the rock and its fauna are quite unlike any found in place in the Pennsylvanian succession of the Marathon Basin.

The most striking feature of the boulder-bed member is the large size of some of these embedded rock fragments. Some of the novaculite blocks are 50 feet across, and those of the fossiliferous Pennsylvanian limestone reach 100 feet in longer dimension. The largest block is the mass of Dimple limestone east of the Bennett place, which is 130 feet across (sec. E–E′, fig. 23). The novaculite blocks are mostly angular, but some are spherical (pl. 11, *D*); all are nearly equidimensional. Most of the limestone blocks are angular, and many of them are slablike (pl. 11, *F*), being two or three times wider than thick. Nearly all the slabs lie parallel to the bedding of the matrix. Associated with the large blocks are innumerable smaller well-rounded to subangular pebbles and cobbles. Baker [66] has found striations on a number of the smaller stones, particularly on the dense quartzites. One boulder of Maravillas black chert 18 inches long, which had numerous intercrossing striae on a flattened surface, was found by him near the Bennett place. The pre-Cambrian

[66] Baker, C. L., letter, February 1931.

stones have smoothed and rounded surfaces, but a large number have one or more flattened faces, and a few are striated. Many of the cobbles are broken and shattered by subsequent deformation of the rocks (pl. 11, *E*), and some of the larger novaculite blocks are slickensided.

The smaller fragments are evenly distributed along the outcrop of the boulder-bed member, but the larger masses are found only in groups and clusters (pl. 10). The clusters are separated by a mile or more of outcrop without any large masses. The largest cluster of boulders is west of the summit of Housetop Mountain,

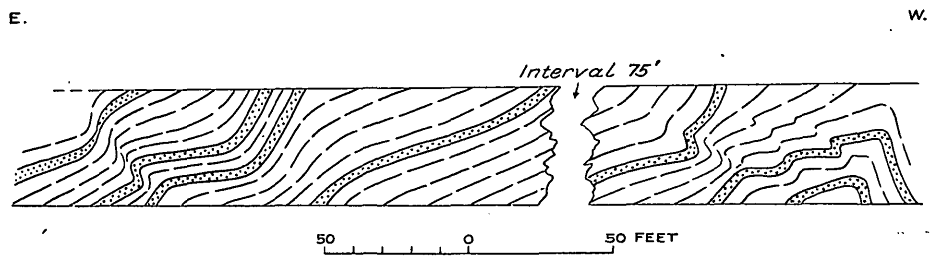


FIGURE 22.—Sketch showing structural features of the Haymond beds in the bank of San Francisco Creek 3 miles south of Haymond. The rocks consist of thin alternations of sandstone and shale, with a few thicker beds of sandstone, represented by stipple pattern. Compare plate 9, *B*, a photograph of the left end of the section.

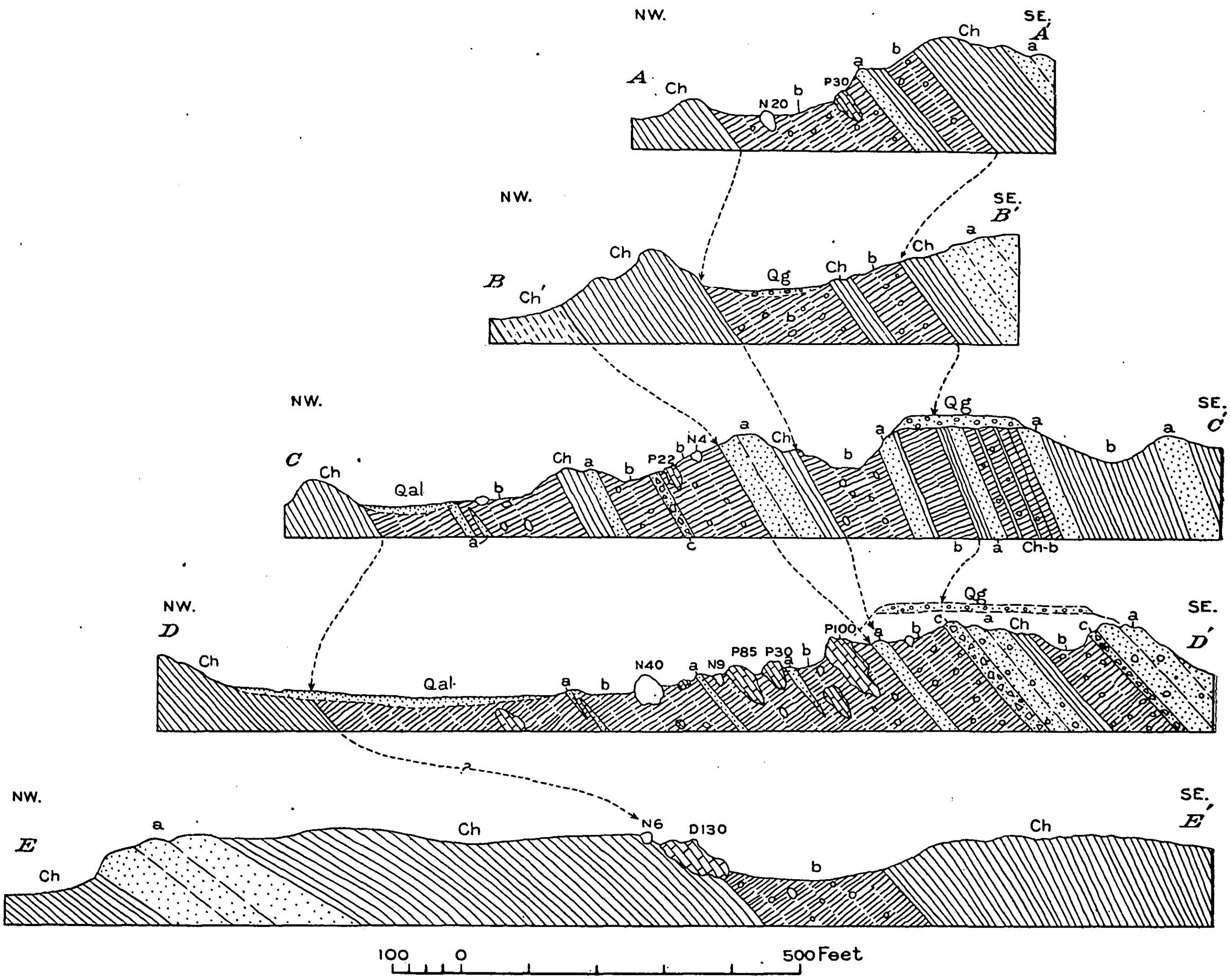


FIGURE 23.—Schematic structure sections of boulder-bed member of Haymond formation. Qal, alluvium; Qg, gravel deposits; Haymond formation: Ch, thin-bedded sandstone and shale; Ch′, a more shaly phase; a, arkose beds; b, boulder-bearing mudstone; c, breccia. Boulders in the mudstone consist of N, Caballos novaculite; D, Dimple limestone; P, fossiliferous Pennsylvanian limestone. Diameters of boulders in feet shown by figures following the letters. For location of sections see plate 10.

where the boulder-bed member reaches its greatest thickness and has the greatest number of mudstone members (pl. 11, *C*). The large blocks at this and other places are found in all the mudstone layers but are slightly more abundant in the middle ones.

Except for a few small blocks embedded in the arkose layers, all the boulders lie in a matrix of massive dark greenish-gray mudstone, containing fine flakes of mica, grains of rotten feldspar, and a few wood fragments. The pebbles and boulders are sparsely set in the matrix, like plums in a pudding. Bedding planes are obscure or lacking in the mudstone, but in places lenses of well-bedded sandstone and arkose as much as several feet in thickness are enclosed. Some of these lenses show irregular dips, which may be original in the deposit.

In sharp contrast to the mudstone layers are the beds of stratified clastic rocks intercalated with them. There are several layers of thin-bedded sandstones and shales as much as 15 feet thick and many thin to thick ledges of coarse friable arkose. In places the arkose is pebbly, and rarely small boulders are embedded in it. The arkose contains a few imprints of *Cordaites* stems. In places the arkose layers merge into lenses of chert and limestone breccia 5 to 10 feet thick, consisting of closely packed angular fragments 6 inches or less across with a small amount of interstitial arkosic matrix.

Upper member of formation.—The strata above the boulder-bed member are exposed only on the west side of Housetop Mountain. They show the rhythmic bedding characteristic of the lower part, but most of the light-colored beds are sandy shales, with sandstone layers only at considerable intervals. They extend up to the axis of the syncline west of Housetop Mountain and are the highest Paleozoic strata exposed in the region. By what interval their highest parts are separated from the Gaptank formation, if this was ever laid down over them, is not known.

OTHER AREAS OF HAYMOND FORMATION

Gap Tank area.—In the vicinity of the old Clark ranch, 4½ miles southeast of Gap Tank (pl. 23), there are 1,800 feet of Haymond beds in a downward succession below the Gaptank formation, with the base of the formation not exposed (sec. 9, pl. 8). The lower part consists of flaggy sandstone and shale, with two thick members of massive arkose, of which the lower contains fossil plants.

In the upper part of the exposure, 400 feet below the basal beds of the Gaptank, is a boulder bed 10 to 25 feet thick which extends for 4 miles along the outcrop. It rests on a bed of coarse arkose and fine chert conglomerate. The fragments in the boulder bed are closely packed, and the interstices are filled by coarse arkosic grit. Most of the fragments consist of Caballos novaculite and bedded chert, some of which are contorted and brecciated. One slab of novaculite near the southeast end of the exposure measures 10 by 6 by 2½ feet (pl. 11, *A*), and angular masses as much as 3 feet across are common. There are also fragments of fossiliferous limestone from the Maravillas formation, some of which contain reef-like masses of bryozoans like those seen on the outcrop only in the southern part of the Marathon Basin. The bed also contains a few cobbles of Tesnus quartzite, rhyolite porphyry, and blocks of limestone with Pennsylvanian fossils. The boulder bed at this locality is notable for its isolation in a succession of finer-grained deposits. The fragments are somewhat different from those in the boulder bed near Haymond. It is true that novaculites and cherts are abundant in both, but this locality has only a few fragments of pre-Cambrian and fossiliferous Pennsylvanian limestone, whereas they are abundant in the southern exposure, which has only a few fragments of Maravillas limestone.

About 8 miles south of Gap Tank, in the syncline south of the Dimple Hills anticlinorium, there are extensive exposures of the lower part of the Haymond formation, but no outcrops of boulder beds. Near the anticlinal axis, on the Pecos-Brewster County line 3 miles southeast of the Dimple Hills, the thin-bedded sandstones and shales contain two intercalated layers of brown sandy and pebbly limestone from which E. H. Sellards and C. L. Baker have collected a few specimens of *Fusulina*.

Exposures west of Marathon.—Thin-bedded shales and sandstones belonging to the lower part of the Haymond formation are exposed in several synclinal areas southwest of Marathon and south of the Dugout Creek overthrust. These grade up from the Dimple limestone below, with thick beds of dark shale near the base. At the foot of the escarpment of the Cochran Mountains, 3 miles east of Del Norte Gap, are thick ledges of arkosic sandstone, with obscure plant remains.

Beneath the Dugout Creek overthrust, near Dugout Creek (locality A, pl. 16), are scattered exposures of the upper part of the Haymond formation, surrounded by the basal beds of the Gaptank formation (pl. 9, *C*, *D*). The rocks of this region are much folded and contorted, so that the detailed relations cannot everywhere be made out. At the best-known locality, on Dugout Creek 2½ miles south of the summit of Dugout Mountain, 250 feet of beds are exposed below the plane of the Dugout Creek overthrust. Most of the succession consists of dark carbonaceous shale and greenish sandy shale in alternating layers a fraction of an inch thick, with thin sandstone beds at intervals of 3 or 4 feet (fig. 24, B). Careful measurements of part of the exposure show an average of 185 alternations for each

10 feet of section (fig. 24, C). Near the top of the exposure are two thin layers of granular limestone containing fragments of brachiopods and crinoid stems, and lower down is a limestone lens that contains fusulinids. In the lower part, on the banks of Dugout Creek, are several thick beds of sandstone, some of which contain plant remains. The fossil evidence from this locality, some of which is conflicting, is considered on pages 71–72.

MICROSCOPIC CHARACTER

Arkosic sandstones.—Three thin sections of the coarse arkosic sandstones of the Haymond formation were examined. One of these was from the arkose beds below the boulder-bearing mudstone southeast of Haymond station. The other two were from layers southeast of Gap Tank, one from immediately below the boulder-bed member and the other from a horizon 1,000 feet lower in the section. These sections are all of similar character. They consist of about 60 percent of quartz grains; the remaining constituents are mostly small chert fragments and granitic detritus. The quartz grains in the thin section from the Haymond station locality are shattered and show strain shadows, but those in the sections from localities farther north where the rocks are not so greatly folded show less of the effects of deformation.

The section from the beds southeast of Haymond and the one from the lower horizon southeast of Gap Tank both show moderately coarse-grained sandstones, made up of subangular grains of various minerals, with a few well-rounded grains. Many of the quartz grains show small included blades of apatite. Biotite and muscovite plates are abundant and are in places bent and twisted about the other grains. Feldspar grains are common and are fresh and unaltered except for a small amount of sericite along the cleavage planes. A few rectangular cleavage fragments were noted. The most abundant feldspar mineral is plagioclase, but the section from the northern locality contains several grains of microcline. There are a few fragments of slaty rock and of chert and a few grains of unaltered hornblende and minerals of high refractive index. The matrix makes up only a small part of the rock and is chloritic and argillaceous.

The rock from the higher horizon southeast of Gap Tank is of coarser grain and contains many large angular fragments of cryptocrystalline chert. Otherwise its constituents are much the same as those of the other two rocks; it consists predominantly of quartz, with lesser amounts of biotite, muscovite, microcline, and sodic plagioclase. A few minute grains of colorless garnet and a single larger fragment of hornblende were noted.

The constituents of these sandstones suggest that they were derived from the weathering of granitic

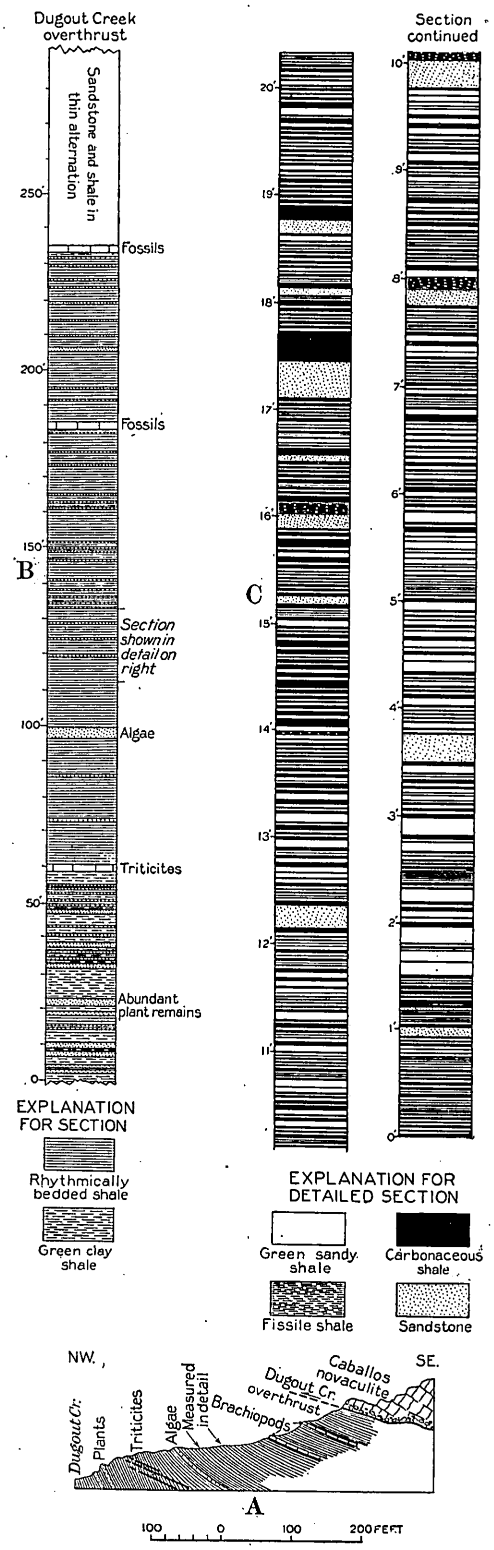


FIGURE 24.—Sections showing stratigraphy and structure of the Haymond beds at the fossil-plant locality on Dugout Creek, 3 miles south of Dugout Mountain (locality *A*, pl. 16). Compare pl. 9, *C*, a photograph of part of the beds at this locality. A, Structure section across locality; B, columnar section of the beds exposed; C, section of 20 feet of the shaly strata near the middle of section B, based on careful field measurements, to show rhythmic alternation of green sandy shale (in white) and carbonaceous shale (in black). There are also some beds of sandstone (stippled) and fissile shale (dashed).

rocks. The apatite-bearing quartz and the microcline are characteristic of granites, and the occurrence of sodic plagioclase, biotite, and muscovite tend to sustain this conclusion, though they may also occur in metamorphic rocks. These characteristic constituents are somewhat different from those of the Tesnus sandstones, in which fragments derived from metamorphic rocks predominate over those of igneous rocks.

Thin-bedded sandstone and shale.—A thin section several inches square was cut from a specimen of thin-bedded sandstone and shale collected in the cut on Dugout Creek 2½ miles south of Dugout Mountain. As seen in the section, the rock is composed of alternating layers of dark shaly and light sandy material from an eighth to half an inch in thickness. Most of these layers are continuous across the slide and through the hand specimen from which it was cut, but in detail there is considerable variation in their form and thickness.

Several dark argillaceous bands 4 millimeters or less in thickness cross the slide. These consist largely of argillaceous material, but there are a few embedded quartz silt particles as much as 0.015 millimeter in diameter. The argillaceous bands grade through a small thickness into the sandy beds at the top and base.

The lighter sandy bands contain a large number of subangular quartz particles. These range from 0.045 to 0.120 millimeter in diameter, or from "coarse silt" to "fine sand" in Udden and Wentworth's classification.[67] Most of the fragments are nearer the minimum than the maximum, but there are a few larger grains. The quartz grains are embedded in a small amount of argillaceous matrix.

Within the sandy layers there are many thin bands and streaks of argillaceous material, some of which are no thicker than the diameter of the larger quartz grains. In parts of the slide they form sharply marked, regular layers, which alternate with sandy beds several millimeters thick. A larger number are not at all regular but form streaks and shreds, embedded in sandy material, and are in part considerably contorted. The irregularity of these parts may have resulted from secondary disturbance of an original laminated deposit, perhaps by gliding or compaction shortly after deposition.

It is perhaps desirable at this place to summarize the character of the thin-bedded sandstones and shales as seen on the outcrop, in hand specimen, and in thin section. Rocks of this type showing great thicknesses occupy wide areas in the Haymond formation in the Marathon Basin. The specimen studied in thin section has many of the characters of the strata found elsewhere in the region but differs somewhat from most of them in that the sandy beds are finer-grained and more argillaceous.

On the outcrop rocks of this type are found to consist of layers, several inches in maximum thickness, of sandy and shaly material in repeated rhythmic alternation. Each layer persists through the whole length of the exposures that have been studied. Measurements at the locality 2½ miles south of Dugout Mountain show an average of 185 alternations in each 10 feet of section, or an average thickness of 0.27 inch for each sandy or shaly layer. The thickness of the individual beds, however, is far from regular. In parts of each exposure there may be groups of four or more thick shaly beds, separated by thin sandy beds, and in other parts there may be similar groups of thick sandy beds. At intervals of 5 to 20 feet in each exposure there are also sandstone beds as much as a foot thick, which stand out prominently as ledges.

In the hand specimens and under the microscope the thin sandy beds seen on the outcrop contain shaly laminae only a fraction of a millimeter in thickness. So far as these could be observed, they are rarely continuous, and many of them appear to be contorted and broken.

The sandy layers in the rock are noncarbonaceous and consist of fine sand or coarse silt, composed of quartz fragments, with a small amount of argillaceous material. The texture varies in different parts of the section and different parts of the region, so that in some places the beds are fine sandstones, and in others sandy shales. The grain size appears to be somewhat greater in the thicker sandstone beds, for even where the thin sandy layers are argillaceous, the thicker layers are true sandstones. None of the sandstones, however, attain a noticeably coarse or gritty texture. The shaly layers consist chiefly of argillaceous material, though under the microscope a few grains of quartz silt can be seen. They are prevailingly dark-colored and apparently contain a certain amount of carbonaceous material.

Boulder-bearing mudstone.—Thin sections of the mudstones of the boulder-bed member were cut from fresh specimens collected on the dump of a water well half a mile south of the Sanderson road, near the north end of the exposures of the member (fig. 25). Specimens of the mudstone were also collected by C. L. Baker from a locality several miles farther south and were studied by F. J. Pettijohn of the University of Chicago.[68]

The greater part of the rock consists of fine angular mineral and rock particles, which are evenly dispersed in an opaque argillaceous matrix. The matrix makes up about 30 percent of the rock. Most of the frag-

[67] Twenhofel, W. H., Treatise on sedimentation, 2d ed., p. 202, 1933.

[68] Baker, C. L., op. cit. (Jour. Geology, vol. 40), p. 585.

ments have right- or acute-angled corners. There are a few rounded grains, which contrast strongly with the angularity of the rest. The fragments are poorly sorted. Most of them range from 0.075 to 0.225 millimeter in diameter, or from "very fine sand" to "fine sand" in Udden and Wentworth's classification. Other fragments are larger. There are a great many as much as 1 millimeter in diameter, and one slide also contains four subangular pebbles 5 to 10 millimeters across.

About half of the grains in the rock are quartz, a few of which contain apatite inclusions. Most of the quartz shows faint strain shadows, but none of the grains have been shattered by deformation. About a quarter of the grains are feldspar, most of which is plagioclase. The feldspar is very little altered, except for some sericite along the cleavage planes. There are a few chips of slaty and schistose rock and of chert. The larger pebbles consist of finely crystalline fossiliferous limestone. There are also a few grains of muscovite, biotite, garnet, and calcite.

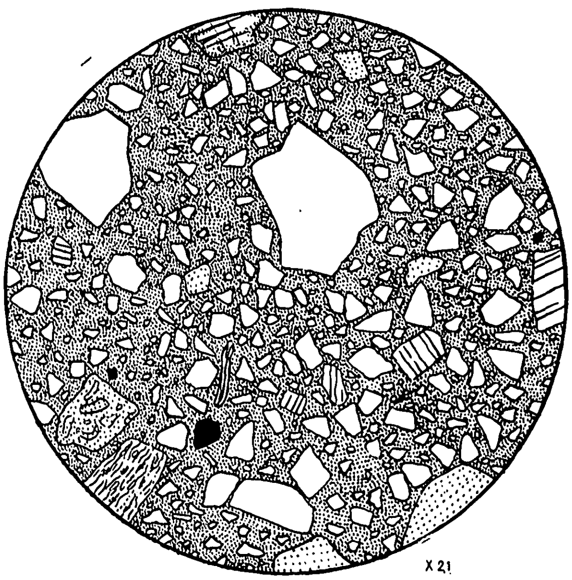


FIGURE 25.—Thin section of the mudstone matrix of the boulder bed, from a specimen collected on the dump of a well near the north end of the exposure. Based on camera lucida drawing in plain light. Note angular fragments of quartz (unshaded), limestone (stippled), and feldspar (ruled).

At one place in the slide is a lens or streak of argillaceous material about an inch in length, which tapers at the ends into a thin seam that passes between the granular parts of the rock. The lens contains only a few fine quartz grains and shows a faint extinction in one direction as a result of the parallel orientation of its clay particles. Aside from this argillaceous lens, there is no evidence of stratification in the mudstone.

FOSSILS AND AGE

Indigenous fossils.—The Haymond formation contains few indigenous fossils. At some localities fossil plants have been collected, though so far only two places have afforded much material.

In the middle part of the formation, about 1,200 feet below the boulder-bed member, 3 miles southeast of Gap Tank, near the old Clark ranch, David White and the writer collected plants from ledges of arkosic sandstone (U. S. Geological Survey locality 8089). Dr. White reported as follows on this collection:

> The fossil-plant fragments were very badly ground up before indiscriminate mixture in sand. No fragments of ferns or fernlike leaves are present. All plant debris is decorticated. The examination of the material permits the recognition of the following forms:
>
> A fragment of a calamarian stem with open nodes, alternating ribs, and well-developed leaf scars. It is possibly referable to *Calamites suckowii.*
>
> Another incomplete internode of a calamarian stem is comparable to *Calamites cistii.*
>
> Also there is present a slender stem apparently belonging to a defoliated *Annularia.*
>
> Two seeds, one without envelope and one lacking an apex, represent the nuclei of *Cardiocarpon.* These nuclei agree in size and shape with a type common in the Pennsylvanian and especially in the Pottsville. They are rather nearly comparable to the nuclei of *Cardiocarpon fluitans.*
>
> The alternate arrangement of the costae at the nodes in the calamarian and annularian fragments leaves no doubt as to the Pennsylvanian age of the formation. The aspect of the *Cardiocarpon* remains strongly suggests a stage somewhere in the Pottsville.

At a locality about a mile farther east and at about the same stratigraphic level Sidney Powers collected *Artisia* sp., *Cardiocarpus* sp., *Lepidodendron* sp., and *Calamites* sp., which were identified by C. B. Read.

From arkoses near the top of the boulder-bed member west of Housetop Mountain Sidney Powers collected *Calamites* sp., *Artisia* sp., *Lepidodendron* sp., *Trigonocarpus* sp., and *Cordaites* sp., which were also identified by Mr. Read.

From a layer in the bed of Dugout Creek, 2½ miles south of the summit of Dugout Mountain, David White and the writer made a rather extensive collection of plants (U. S. Geological Survey locality 8094). Dr. White reported as follows on this material:

> The material is extremely fragmentary. It is comminuted in current-bedded sand. Following is a preliminary list of the species in hand:
>
> *Neuropteris*, part of a broad pinnule.
> *Neuropteris*, point of a narrow pinnule.
> *Dictyoxylon* stem.
> *Stigmaria* scars.
> *Cordaites*, fragment of leaf; probably new species.
> *Carpolithus transsectus?*
> *Cardiocarpon* seeds, including a remnant belonging probably to *Cardiocarpon elongatum.*
> *Trigonocarpum*, slender triangular form; deformed.
> *Lepidostrobus*, part of slender axis.
>
> The fragments are for the most part too incomplete for specific determination, and the collection therefore has little

diagnostic value. It is fairly evident, however, that the collection is of Pottsville age, and probably it belongs in the upper Pottsville.

In a limestone bed 30 feet higher the writer collected a fossil identified by C. O. Dunbar as a small species of *Triticites*, whose "age should be younger than the oldest Gaptank and younger than the Strawn."[69] This fossil suggests that a part of the exposure at this place is of Gaptank rather than Haymond age. As shown in figure 24, A, the structure is complex, and the limestone with *Triticites* may somehow have been included tectonically in older rocks. A few fragmentary remains of *Productus* and *Spirifer* have been found in thin limestones several hundred feet above the plant horizon on Dugout Creek, but these layers have yielded no specifically identifiable material.

Marine invertebrate fossils are rare in the Haymond formation. Fusulinids were collected by E. H. Sellards and C. L. Baker from a thin bed of brown sandy limestone in the middle part of the formation 3 miles southeast of the Dimple Hills, on the Pecos-Brewster County line. These have been determined by C. O. Dunbar as a *Fusulina*, probably belonging to a new species. The genus *Fusulina* ranges no higher than the Strawn group of central Texas and the upper part of the Des Moines group of the northern midcontinent area, and its occurrence in the Haymond indicates an early Pennsylvanian age for that formation.

Fossils of the exotic blocks.—The exotic blocks in the boulder-bed member of the Haymond formation east of Haymond station consist of rocks of a great variety of ages and lithologic types. Most of these are easily identified with formations that crop out in the Marathon Basin, but the numerous masses of limestone that contain Pennsylvanian fossils are unlike anything seen in place in the region.

The collections from the exotic blocks were made by J. Brookes Knight and the writer and were identified by G. H. Girty. The largest collection was obtained from a limestone block 50 feet long about 1 mile northwest of the summit of Housetop Mountain (U. S. Geological Survey locality 6999) and included the following fossils:

Cristellaria sp.
Foraminifera undet.
Sponge spicules.
Sponge?
Productus coloradoensis Girty.
Productus aff. *P. pertenuis* Meek.
Spirifer aff. *S. opimus* Hall.
Nucula anodontoides Meek?
Leda bellistriata Stevens?
Parallelodon sp.
Aviculopecten, 2 sp. undet.
Myalina swallowi McChesney.
Astartella sp.
Bellerophon aff. *B. incomptus* Gurley.
Worthenia aff. *W. speciosa* (Meek and Worthen).
Pleurotomaria aff. *P. fisheri* Sayre.
Pleurotomaria aff. *P. ornatiformis* Morningstar.
Pleurotomaria, 2 sp. undet.
Goniasma aff. *G. lasallensis* Worthen.
Goniasma n. sp.
Aclisina aff. *A. swallowana* (Geinitz).
Naticopsis aff. *N. nana* (Meek and Worthen).
Trachydomia n. sp.
Orthonema aff. *O. carbonarium* (Worthen).
Holopea? n. sp.
Euomphalus sp.
Flemingia? n. sp.
Cyclonema sp.
Meekospira aff. *M. peracuta* (Meek and Worthen).
Pseudozygopleura? aff. *P. peorense* (Worthen).
Rotalina? n. sp.
Zygopleura aff. *Z. parva* (Cox).
Griffithides sp.
Ostracoda undet.

The following collection was obtained from a block about 1 mile west of the summit of Housetop Mountain (U. S. Geological Survey locality 6909):

Lithostrotion? sp.
Fenestella sp.
Cystodictya? sp.
Productus coloradoensis Girty?
Productus sp.
Euomphalus sp.
Trachydomia n. sp.

The following collection was obtained not far from the last, from an exotic block 70 feet in length (U. S Geological Survey locality 7073):

Chaetetes milleporaceus Milne-Edwards and Haime.
Triplophyllum sp.
Glyptopora sp.
Productus aff. *P. altoensis* Norwood and Pratten.
Pustula aff. *P. wallaciana* (Derby).
Edmondia sp.

Mr. Girty makes the following comments on these collections:

These three collections rather clearly represent two different faunal facies, the first two belonging together and the last containing a different fauna. Although different in facies, the two faunas are not necessarily widely different in geologic age, and, so far as the facts are known to me, both faunas find their nearest allies in the Pottsville. It should be understood that neither of them is an exact duplicate of any Pottsville fauna that I have seen; instead, they merely contain a few of the same or comparable species.

The first fauna is by far the most extensive and consists largely of gastropod shells. Brachiopods, which in most faunas of Pennsylvanian age excel in abundance most other classes, are rare, and pelecypods scarcely less so. The gastropods, on the other hand, are abundant, and by a somewhat arduous process a large number of individuals have been recovered. They are also richly varied, though mostly ranging in size from small to minute. Certain collections from the Marble Falls limestone resemble this fauna in general makeup and also in a community of similar or identical species. How many species are identical

[69] Dunbar, C. O., letter, August 1934.

or merely similar I am not prepared to say, for the material from the Marble Falls limestone is not well preserved, and the specimens fail to show clearly the sculpture, which, in its scale, corresponds to the diminutive size of the specimens themselves.

Such comparisons as are suggested by the faunas of these three collections reach out, not to the fauna of any one Pottsville formation, but now to the fauna of the Marble Falls, now to that of the Smithwick shale, now to that of the Wapanucka limestone, or more remotely to that of the Morrow formation. Thus the most abundant gastropod in the first collection is a small *Trachydomia*, which has not been observed in the other Pottsville formations mentioned but which may be represented by a few specimens from the Morrow formation. The fact that the gastropods of all the Pottsville faunas are as yet largely unstudied makes this evidence difficult to evaluate. On the other hand, the richly varied brachiopods of these Pottsville formations, which are fairly well known, do not appear in the collections under consideration in sufficient variety to afford much evidence in correlation.

A smaller collection, made by C. L. Baker and E. H. Sellards, has been examined by F. B. Plummer, of the Bureau of Economic Geology, University of Texas.[70] Plummer notes its resemblance to a collection obtained from cores in the Big Lake oil field, northeast of the Marathon Basin. Baker,[71] on seemingly meager evidence, states that the fauna "is definitely middle Pennsylvanian" and suggests its correlation with some part of the Strawn or Canyon groups of central Texas. There is thus a possibility that rocks of more than one age are represented in the limestone blocks. The writer has the impression, however, that most of the collections made by Baker and Sellards came from the same fossiliferous blocks as those that yielded his own collections; and until more definite evidence is obtained, it is thought more likely that all the collections are of early Pennsylvanian age, as suggested by Mr. Girty.

STRATIGRAPHIC RELATIONS

The contact of the Haymond with the Gaptank formation is evidently conformable. The *Chaetetes*-bearing limestone at the base of the Gaptank contains no basal conglomerate. The contact between the two formations is best exposed along the road between Marathon and Fort Stockton, 2 miles south-southwest of Gap Tank. A slight divergence in dip between the thin-bedded sandstones and shales of the Haymond and the *Chaetetes*-bearing limestone of the Gaptank can be seen here, but this appears to be the result of slipping of competent limestone over incompetent sandstones and shales during deformation. The conglomerate beds that are a conspicuous part of the middle layers of the Gaptank formation nowhere extend to its base. The first appearance of conglomerates in the Gaptank is several hundred feet above the base.

[70] Sellards, E. H., Erratics in the Pennsylvanian of Texas: Texas Univ. Bull. 3101, pp. 15-16, 1931. See also Baker, C. L., Erratics and arkoses of the middle Pennsylvanian Haymond formation: Jour. Geology, vol. 40, p. 590, 1932.

[71] Baker, C. L., op. cit., p. 590.

GAPTANK FORMATION

HISTORICAL SUMMARY

The name "Gaptank formation" was applied by Udden [72] in 1916 to exposures of upper Pennsylvanian strata at Gap Tank, in Stockton Gap, 23 miles northeast of Marathon (pl. 14). The original definition evidently included the strata now known as the Wolfcamp formation, which were separated in the following year [73] as a result of studies by Böse [74] of the fauna of the *Uddenites* zone and higher beds at Wolf Camp, in the Glass Mountains, which he considered to be of Permian age. Further knowledge of the fossils near the Pennsylvanian-Permian boundary obtained in recent years has led to the conclusion that the *Uddenites* zone is of Pennsylvanian age, as first suggested by Keyte, Blanchard, and Baldwin,[75] and the top of the Gaptank formation is now placed above this zone.[76]

West of Marathon are exposures of strata, here considered to be a part of the Gaptank formation, which were variously placed in the Tesnus,[77] Haymond,[78] and Gaptank [79] formations by Baker, Böse, and Udden. A separate formation name ("Dugout beds") has also been proposed for them.[80] In 1927 Schuchert [81] expressed the opinion that these beds were "unmistakably lower Gaptank", an interpretation for which much confirmatory evidence has been gained by the writer and others.[82]

GENERAL FEATURES

The Gaptank formation crops out only in the northern part of the Marathon Basin. In the area to the south only the older formations remain, and if the Gaptank formation was ever laid down there it has since been removed by erosion. The type area of the Gaptank lies north of the region described in this report, but the problematic strata exposed on Dugout Creek

[72] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, 1st ed., p. 47, 1916.

[73] Udden, J. A., Notes on the geology of the Glass Mountains: Texas Univ. Bull. 1753, pp. 38-43, 1917.

[74] Böse, Emil, Permo-Carboniferous ammonoids of the Glass Mountains: Texas Univ. Bull. 1762, p. 16, 1917.

[75] Keyte, I. A., Blanchard, W. G., and Baldwin, H. L., Gaptank-Wolfcamp problem of the Glass Mountains, Texas: Jour. Paleontology, vol. 1, pp. 175-178, 1927.

[76] Sellards, E. H., Pre-Paleozoic and Paleozoic systems, in Geology of Texas, pt. 1, Stratigraphy: Texas Univ. Bull. 3232, p. 148, 1933. King, P. B., Permian stratigraphy of trans-Pecos Texas: Geol. Soc. America Bull., vol. 45, pp. 727-729, 1934.

[77] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 104, 1917.

[78] Böse, Emil, op. cit., p. 17.

[79] Udden, J. A., op. cit., p. 17.

[80] Baker, C. L., Date of the major diastrophism and other problems of the Marathon Basin, trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., vol. 12, p. 1114, 1928.

[81] Schuchert, Charles, Pennsylvanian-Permian systems of western Texas: Am. Jour. Sci., 5th ser., vol. 14, p. 386, 1927.

[82] King, P. B., and King, R. E., The Pennsylvanian and Permian stratigraphy of the Glass Mountains: Texas Univ. Bull. 2801, pp. 117-119, 1928. King, P. B., The geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, pp. 45-48, 1930. Miller, A. K., A new ammonoid fauna of late Paleozoic age from western Texas: Jour. Paleontology, vol. 4, pp. 383-386, 1930.

and here considered to be a part of the Gaptank formation crop out over a wide area in the northwestern part of the Monument Spring quadrangle. These exposures are bounded on the south by early Paleozoic strata along the trace of the Dugout Creek overthrust and on the north by Permian rocks in the foothills of the Glass Mountains. The best-exposed section is in the vicinity of the type locality.

The Gaptank is the youngest Pennsylvanian formation in the area and the last to be involved in the Marathon disturbance. It is the only member of the series that contains fossils in any abundance. It is somewhat more variable in lithology than the formations below and consists of sandstones and shales, with interbedded conglomerates and limestones. The conglomerate fragments are derived from the Maravillas chert, the Caballos novaculite, and the Dimple limestone, which are thousands of feet lower in the section than the base of the Gaptank. They indicate the rise of local folds in the Marathon geosyncline in the middle part of Gaptank time.

LOCAL FEATURES

Exposures near Gap Tank.—The type locality of the Gaptank formation, in the region near and to the south of Gap Tank (pl. 23), has been described in detail in a previous publication.[83] At that locality there is exposed a section about 1,800 feet thick, considerably folded in the south but passing conformably, with a dip of about 30°, beneath the Wolfcamp beds on the north. Along the crest of the broad anticline south of Gap Tank the basal limestones of the formation, which contain large masses of *Chaetetes milleporaceus*, rest on thin-bedded sandstones and shales of the Haymond formation. The basal limestone is succeeded by 900 feet of sandstone and shale, with five interbedded layers of coarse conglomerate, of which the lower ones reach 50 feet in thickness and contain rounded limestone cobbles as much as 2 feet in diameter (pl. 11, *B*). Within the small area of exposure near Gap Tank all the conglomerate beds thin out to the north. This suggests a nearby southern source for the material. The upper 800 feet of the formation has no conglomerate and consists of thick layers of limestone, interbedded with sandstone and shale. Fossils have been collected at various horizons in the section at Gap Tank but particularly in the lower part. These make possible a correlation of the formation with the Pennsylvanian sections of central Texas and the northern midcontinent area.

The following section of the Gaptank and Wolfcamp formations (sec. 9, pl. 8) is a composite of various short sections measured near Gap Tank and is presented for reference, so that the exposures west of Marathon in the Monument Spring quadrangle may be compared with it.

[83] King, P. B., op. cit. (Texas Univ. Bull. 3038), pp. 44–45.

Section of Wolfcamp and Gaptank formations near Gap Tank

	Feet
Basal conglomerate of Leonard formation, with an angular unconformity of 5° or 10° with the Wolfcamp formation.	
Wolfcamp formation:	
2. Mostly covered; a few exposures of sandy shale	0–53
1. Dense to medium-grained light-gray or gray-brown limestone, containing large crinoid stems and a few well-rounded limestone pebbles. A few hundred yards east of Gap Tank brown limestones in this member contain *Pseudoschwagerina*	35–50
Gaptank formation (upper portion):	
22. Brown sandy shale and sandy limestone. East of the tank a thin brown sandy limestone near the base contains abundant angular chert pebbles. West of the tank a *Schistoceras* was collected from the shale	40–100
21. Fifth limestone member: Dense to coarsely crystalline light-gray limestone, in thick massive beds; crops out just below the tank	75
20. Blue shale, with thin beds of brown sandstone and sandy limestone, containing crinoid stems	60
19. Fourth limestone member: Light-gray dense, somewhat nodular limestone, which breaks west of the tank into thin-bedded gray-brown limestones, interbedded with thin layers of nodular fossiliferous marl	40
18. Mostly covered; a few exposures of soft brown sandstone	124
17. Third limestone member: Light-gray dense limestone in 1-foot beds, which weather nodular; abundant fossils in cross section	40
16. Covered below; in upper part are 1-foot beds of calcareous cross-bedded brown sandstones, with seams of chert pebbles	230
15. Second limestone member: Light-gray massive limestone	55
14. Sandstone and shale	124
13. First limestone member: Light-gray massive limestone, in moderately thick beds, with some crinoid stems and *Triticites cullomensis* var. *pygmaeus*	40
12. (*b*) Soft buff sandstone, with two beds of sandy gray-brown limestone, containing scattered chert pebbles	127
12. (*a*) Fine-grained brown calcareous sandstone in 1-foot beds, in part cross-bedded on a small scale and containing crinoid stems and seams of grit	66

Sections of Wolfcamp and Gaptank formations near Gap Tank—Continued

	Feet
Gaptank formation (lower portion):	
11. Fifth conglomerate member: Cobbles and pebbles of limestone and chert in a sandy limestone matrix, with a bed of shale in the middle	27
10. Covered on north side of Gap Tank anticline. On the south it consists of brown sandstone with richly fossiliferous calcareous layers, and some thick beds of soft blue shale. The abundant fauna of the calcareous layers includes *Triticites*	140
9. Fourth conglomerate member, similar to those below	15
8. Thin-bedded fine-grained buff sandstone, in part cross-bedded, with some calcareous layers and some thin layers of limestone pebbles	97
7. Third conglomerate member, similar to those below but lenticular	25
6. Fine-grained buff sandstone, passing southward into a greater thickness of shale, which contains a nodular ferruginous limestone with *Pugnax rockymontanus*	80–290
5. Second conglomerate member: Rounded to subangular pebbles, cobbles, and a few boulders of limestone and some chert, in a calcareous sandstone matrix. Thin interbedded layers of sandy limestone in the upper part	40
4. Sandstone and shale; sandstone layers chiefly thin-bedded, fine-grained, and in places channel-marked	80
3. First conglomerate member: Subangular to rounded cobbles and boulders of limestone, chert, and sandstone. Most of the limestone is dark gray, sandy, and pebbly and has the aspect of the Dimple limestone. There are some cobbles of coarsely crystalline light-gray fossiliferous limestone. Thin limestone and calcareous sandstone beds appear at the base in the north, with *Chonetes mesolobus*. In the north the conglomerate is nearly absent	40
2. Shale and sandstone; not well exposed	150
1. *Chaetetes*-bearing limestone: Gray crystalline limestone, in part cherty, with large masses of *Chaetetes milleporaceus* and a few specimens of *Fusulina haworthi* and *Wedekindellina euthysepta*	50
Total	1, 725–1, 935

Haymond thin-bedded sandstones and shales.

Exposures east of Gap Tank.—The Gaptank formation is also exposed at a locality 7 miles east of Gap Tank (pl. 23), where it lies between steeply inclined flaggy sandstones of the Haymond formation and gently tilted thin-bedded limestones of the Hess member of the Leonard formation. The Gaptank exposures at this place were mapped with the Hess in the previous work on the Glass Mountains,[84] but since that time abundant *Triticites irregularis* (identified by C. O. Dunbar) and various brachiopods of Pennsylvanian aspect have been collected from the limestones. The formation here consists of thick-bedded gray limestones and sandy marls, with subordinate conglomerate beds, made up of rounded pebbles and cobbles of Dimple limestone. This exposure, with its predominance of calcareous beds, illustrates the variability of the strata of the Gaptank formation and confirms the suggestion that the thick conglomerate beds of the type locality are derived from a nearby local source.

Area west of Marathon.—The area of Gaptank formation west of Marathon has been overridden by a great mass of pre-Carboniferous rocks along the Dugout Creek overthrust, and the formation is now exposed by the erosion of the overthrust sheet (pl. 16). Here and there small hills of novaculite overlie the formation, and in places blocks several feet to 10 feet across of novaculite, bedded chert, and chert breccia are scattered over the surface or partly embedded in the incompetent sandy or shaly beds of the formation. The structural complexity produced by the overthrusting, coupled with the scattered nature of the exposures, makes it impossible to obtain a complete section of the formation, but about 1,500 feet of beds are probably present.

In some of the closely folded anticlines and anticlinoria are exposures of the upper part of the Haymond formation, with its characteristic thin alternating beds of carbonaceous shale and greenish sandy shale or sandstone. The Haymond age of strata of this sort is indicated by the fossil plants collected on Dugout Creek 2½ miles south of Dugout Mountain (pl. 16). Similar beds, much crumpled and broken by small thrusts (pl. 9, *D*), were seen farther north along Dugout Creek and in the anticlinorial area on the south side of Dugout Mountain. These beds are not mapped separately from the overlying Gaptank formation in detail, on account of the complexity of the structure, The Gaptank strata lack the peculiar thin-bedded alternation of the lower formation, their sandstones are coarser-grained and of buff or rusty-brown color, and they include numerous limestone and conglomerate beds.

The lowest Gaptank strata are exposed in the region south of Dugout Mountain and consist of soft drab shales with scattered ledges and ridges of fine- to medium-grained rusty-brown sandstone, in part calcareous, and several layers of gray limestone from a few feet to 15 feet in thickness. The limestone layers

[84] King, P. B., Geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, geologic map, 1930.

are remarkably folded and broken and do not form continuous ledges for any great distance. Each one is more coarsely granular toward the base and in places even conglomeratic. Toward the top each is fine-grained or compact. The lowest limestone bed contains a few fossils, which include *Chaetetes milleporaceus* and *Fusulina meeki*. These suggest a correlation with the *Chaetetes*-bearing limestone at the base of the formation in the type section. Near the Wilcox & Anderson well, at the foot of Dugout Mountain, there are in the lower part of the formation some layers of conglomerate, which contains well-rounded chert pebbles.

Farther south, at the northeast end of the novaculite ridges of the Payne Hills and 4 miles south-southeast of Lenox, are other exposures, evidently of younger beds (pl. 16). These are overlain by overthrust masses of older strata, which form the capping of the Payne Hills. At the northeast corner of the hills dark-blue shale has been cut into by several ravines and contains thin ledges of granular fossiliferous gray-brown limestone and limy sandstone. In a small gully southeast of the Payne Hills, 4½ miles south-southeast of Lenox and 1¾ miles south of the Arnold ranch, is a great block of limestone, lying in shale and seemingly a part of an indistinct steeply tilted limestone ledge, striking east (pl. 16). The dense gray limestone of the block is packed with ammonoid shells, from which a large fauna has been collected.

Farther east, on the Decie and Hargus ranches, are other exposures of the high part of the Gaptank formation, here much obscured by wash and terrace gravel (pl. 24). Near milepost 580, 4 miles west of Marathon on the Southern Pacific Railroad and along the highway to the north of it, 400 or 500 feet of the formation is exposed. There are 8 or 10 ledges, each as much as 3 feet thick, of hard, finely granular limestone, weathering rusty brown and containing angular fragments of green chert, rounded limestone pebbles, and a few small chips of green shale. All the calcareous layers are more or less fossiliferous. They are separated by beds of olive-green clay shale and sandy shale, with some interbedded slabby rusty-brown sandstones. Similar beds are exposed near the old Wedin oil boring, north of the highway on the Decie ranch. South of the old well are some ledges of coarse conglomerate, with subrounded limestone and chert fragments.

Black Peak.—At Black Peak, north of Doubtful Canyon, in the Del Norte Mountains, are rocks that are tentatively mapped as part of the Gaptank formation (pl. 24). The exposures are isolated from the other areas of Paleozoic rock to the east and northeast, and the rocks of the peak are thrust to the west against the Cretaceous limestones of the Del Norte Mountains (sec. M–M′, pl. 21). A much sheared gray crystalline limestone, several hundred feet thick, forms the main mass of the peak and dips steeply to the east (pl. 13, *C*). It is overlain by thin-bedded limestone, shale, and some sandstone. The highest beds exposed are dark-gray limestones, from which Pennsylvanian fossils have been collected by R. E. King.

FOSSILS AND AGE

FAUNAS OF THE GAP TANK AND WOLF CAMP AREA

The Gaptank formation at the type locality contains fossils in various beds of the stratigraphic section. They show a progressive change in character from the base to the top. The faunas are described below in ascending order.

Bed 1.—The basal layer of the formation at Gap Tank is known as the *Chaetetes*-bearing limestone. From the collections of R. E. King and the writer at several localities 2 miles south of Gap Tank (U. S. Geological Survey locality 6703), G. H. Girty has identified the following fossils:

Chaetetes milleporaceus Milne-Edwards and Haime.
Campophyllum torquium Meek?
Clisiophyllum n. sp.
Fistulipora sp.
Productus n. sp.
Productus boonensis Swallow var.
Pustula semipunctata (Shepard)?
Squamularia perplexa (McChesney) var.
Streblopteria sp.

From the same collections C. O. Dunbar has identified *Fusulina haworthi* (Beede) and *Wedekindellina euthysepta* (Henbest).

According to Mr. Girty:

> The most distinctive form in bed 1 is *Chaetetes milleporaceus*. * * * As this genus of corals is especially abundant in the lower part of the Pennsylvanian sections of Kansas and Missouri, if indeed it is not restricted in its upward range to the Des Moines group,[85] and as the fauna, so far as it is known, contains nothing that would indicate a Pottsville age, the tentative conclusion seems to be warranted that the first Gaptank deposits were laid down in early post-Pottsville time.

According to Dunbar and Condra, *Fusulina haworthi* ranges from the Fort Scott limestone to the Altamont limestone of the northern midcontinent area,[86] and *Wedekindellina euthysepta* is widely distributed in the Cherokee shale of the northern midcontinent area and its equivalents in Illinois and Ohio. The latter species is also found in association with *Fusulina meeki* in the lower part of the Strawn group in the section on the Brazos River in central Texas.[87]

Bed 3.—Thin limestone layers at the base of the first conglomerate member (bed 3) on the north flank of the

[85] Cf. Moore, R. C., Correlation of Pennsylvanian formations of Texas and Oklahoma: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 896, 1929.
[86] Dunbar, C. O., and Condra, G. E., The Fusulinidae of the Pennsylvanian system of Nebraska: Nebraska Geol. Survey, 2d ser., Bull. 2, p. 84, 1927.
[87] White, M. P., Some Texas Fusulinidae: Texas Univ. Bull. 3211, p. 21, 1932.

Gap Tank anticline, 1 mile southwest of the tank, have yielded a small fauna, of which the following have been identified by Charles Schuchert:[88]

Chaetetes milleporaceus Milne-Edwards and Haime.
Campophyllum torquium Meek.
Chonetes mesolobus Norwood and Pratten.
Productus gratiosus var. *occidentalis* Schellwien.
Productus cora D'Orbigny.
Spirifer cameratus Morton.
Composita subtilita (Hall).

The most distinctive fossil in the fauna is *Chonetes mesolobus*, which is found in the Mineral Wells formation of the Strawn group in central Texas and the upper part of the Des Moines group in the northern midcontinent area. It is a characteristic zone fossil of the lower Pennsylvanian.[89]

Most of the cobbles in the conglomerate members of the Gaptank formation are derived from the erosion of the Dimple limestone and older formations. In the lower members, however, there are some fragments of coarsely crystalline light-gray crinoidal limestone. From such cobbles in the first conglomerate member the following fossils, which have been identified by C. O. Dunbar, have been collected:

Large cup corals.
Crinoid stems.
Platyceras sp.
Derbya crassa (Meek and Hayden).
Productus (fragment).
Pugnax cf. *P. osagensis* (Swallow).
Squamularia perplexa (McChesney) (small type).

Schuchert collected a fragment of *Chaetetes* from this conglomerate. The fauna of the fossiliferous cobbles is decidedly of lower Pennsylvanian aspect. This fact and the lithology of the rock make it probable that the cobbles were derived from the erosion of the *Chaetetes*-bearing limestone, at the base of the formation.

Bed 6.—In the shale between the second and third conglomerate members (bed 6), there is locally a nodular ferruginous limestone that contains various pyritized fossils. From collections at several localities 2 miles southeast of Gap Tank (U. S. Geological Survey localities 6691 and 7095) G. H. Girty has identified the following fossils:

Enchostoma sp.
Lophophyllum profundum (Milne-Edwards and Haime).
Orbiculoidea sp.
Productus aff. *P. insinuatus* Girty.
Productus cora D'Orbigny var.
Pustula sp.
Marginifera muricata (Norwood and Pratten).
Pugnax rockymontana (Marcou).
Composita subtilita (Hall).
Allerisma sp.
Edmondia sp.
Nuculopsis ventricosa (Hall).
Leda bellistriata Stevens.
Bellerophon crassus var. *wewokanus* (Girty).
Euphemites carbonarius (Cox).
Bucanopsis sp.
Worthenia tabulata (Conrad).
Trepospira depressa (Cox).
Phanerotrema grayvillense (Norwood and Pratten) var.
Phanerotrema sp.
Meekospira? sp.
Sphaerodoma sp.
Orthoceras sp.
Nautilus? sp.
Various species of goniatites.

Mr. Girty remarks that this fauna "rather pointedly resembles the fauna of the Wewoka formation of Oklahoma." The most characteristic shell of the collection, *Pugnax rockymontana*, is abundant in the upper part of the Des Moines group of the northern midcontinent area and is found very rarely in the Kansas City group. In the central Texas section it is found only in the Graford formation (lower Canyon).

Bed 10.—From calcareous sandstones between the fourth and fifth conglomerate members (bed 10) a large fauna has been collected. From this horizon, at several localities 2 miles southeast of Gap Tank (U. S. Geological Survey localities 6705, 7085, and 7088), Mr. Girty has identified the following species:

Textularia sp.
Wewokella aff. *W. solida* Girty.
Mesandrostria n. sp.
Coelocladia n. sp.
Amblysiphonella prosseri Clarke?
Lophophyllum profundum (Milne-Edwards and Haime).
Axophyllum sp.
Delocrinus sp.
Fistulipora sp.
Stenopora sp.
Fenestella sp.
Polypora sp.
Rhombopora sp.
Rhipidomella carbonaria (Swallow).
Meekella striaticostata (Cox).
Derbya aff. *D. bennetti* Hall and Clarke.
Chonetes verneuilianus Norwood and Pratten.
Productus cora D'Orbigny.
Productus calhounianus Swallow.
Productus pertenuis Meek.
Productus portlockianus Norwood and Pratten.
Marginifera wabashensis Norwood and Pratten.
Teguliferina armata (Girty).
Rhynchopora illinoisensis (Worthen).
Dielasma bovidens (Morton).
Spirifer triplicatus (Hall).
Spiriferina kentuckyensis (Shumard).
Squamularia perplexa (McChesney).
Composita subtilita (Hall).
Cleiothyridina orbicularis (McChesney).
Edmondia? sp.
Parallelodon carbonarius (Cox).
Parallelodon aff. *P. sangamonense* (Worthen).
Schizodus? sp.

[88] Schuchert, Charles, The Pennsylvanian-Permian systems of western Texas: Am. Jour. Sci., 5th ser., vol. 14, p. 386, 1927.
[89] Moore, R. C., op. cit., p. 896.

Aviculopecten interlineatus (Meek and Worthen).
Streblopteria sp.
Lima retifera Shumard.
Aviculipinna peracuta (Shumard).
Astartella varica McChesney.
Bellerophon stevensianus McChesney.
Pleurotomaria n. sp.
Pleurotomaria aff. *P. subcalaris* (Meek and Worthen).
Yvonia aff. *Y. subconstricta* (Meek and Worthen).
Worthenia perizomata White?
Porcellia peorensis Worthen.
Murchisonia aff. *M. copei* White?
Anomphalus? sp.
Trachydomia wheeleri (Swallow)?
Trepospira depressa (Cox).
Platyceras parvum (Swallow).
Diaphorostoma peoriense (McChesney)?
Naticopsis aff. *N. nana* (Meek and Worthen).
Zygopleura aff. *Z. plebeia* (Herrick).
Bulimorpha sp.
Orthoceras sp.
Metacoceras aff. *M. perelegans* Girty.
Gastrioceras sp.
Griffithides? sp.
Ostracoda undet.

From this same horizon *Parenteletes cooperi* King has been identified by R. E. King, *Schistoceras smithi* Böse by Emil Böse, and a new species of *Shumardites* by F. B. Plummer. The beds also contain great numbers of small *Triticites*, which at one time were considered by Dunbar to be *T. irregularis* (Schellwien and Staff), but which he "now regards as a new species of about the same age." [90]

Mr. Girty says:

This extensive fauna contains many novel features and to that extent is not comparable to any of the Pennsylvanian faunas already known. It is related to certain faunas of the Cisco, but especially those that occur in the lower part of the formation. Insofar as there exist grounds for comparison, there seems to be no reason why this fauna might not represent a horizon well up in the Pennsylvanian of Kansas, without, on the other hand, the existence of much reason why it should represent a horizon so late.

The fusulinid in this fauna is found in the lower Canyon and upper Strawn groups of central Texas and the Kansas City group of Kansas. According to F. B. Plummer, the ammonoid *Schistoceras smithi* is found in the Palo Pinto limestone at the base of the Canyon group in central Texas.

Bed 13.—From the first limestone member (bed 13) specimens of a small, poorly preserved, silicified fusulinid have been collected. C. O. Dunbar states that it resembles *Triticites cullomensis* var. *pygmaeus* Dunbar and Condra, which is found in the Shawnee formation of the northern midcontinent area.

Bed 19.—Nodular limestones in the lower part of the fourth limestone member (bed 19) a quarter of a mile west of Gap Tank contain a small fauna, from which the following fossils have been identified by R. E. King:

Heterocoelia beedei Girty.
Spirifer triplicatus (Hall).
Composita subtilita (Hall).
Rhipidomella carbonaria (Swallow).

Beds beneath the Uddenites zone.—Farther west, a mile northeast of Wolf Camp, the strata immediately beneath the *Uddenites* zone of the Gaptank formation contain a few fossils. These beds may be in about the same part of the formation as bed 19. The following fossils have been identified from the locality near Wolf Camp by R. E. King:

Cladopora sp.
Echinocrinus spines and plates.
Platyceras sp.
Derbya bennetti Hall and Clarke.

From limestones directly beneath the *Uddenites* zone at this locality C. O. Dunbar has identified *Triticites cullomensis* Dunbar and Condra, a fusulinid that characterizes the Jacksboro limestone member of the Graham formation (upper Canyon) of central Texas [91] and the Shawnee and lower part of the Wabaunsee groups of the northern midcontinent area.[92]

Uddenites zone.—The *Uddenites* zone at Wolf Camp and between this place and Gap Tank (pl. 23) contains a large and abundant fauna. Immediately north of Wolf Camp, in the saddle between an outlying butte and the main escarpment capped by the overlying Wolfcamp formation (R. E. King locality 88), the fossils listed below have been identified.[93] The fossils occur in shale beds, or loosely embedded in thin brown limestone layers.

Triticites ventricosus (Meek and Hayden).
Rhipidomella carbonaria (Swallow).
Orthotichia kozlowskii King.
Orthotetella wolfcampensis King.
Parenteletes cooperi King.
Streptorhynchus pyramidale King.
Meekella irregularis var. *texana* King.
Chonetes granulifer Owen (small type).
Chonetes verneuilianus Norwood and Pratten.
Productus semireticulatus var. *hermosanus* Girty.
Productus semistriatus Meek.
Linoproductus cora (D'Orbigny).
Linoproductus villiersi (D'Orbigny).
Pustula semipunctata (Shepard).
Waagenoconcha montpelierensis (Girty).
Overtonia cristato-tuberculata (Kozlowski).
Marginifera capaci (D'Orbigny).
Marginifera lasallensis (Worthen).

[90] Dunbar, C. O., letter, August 1934.

[91] White, M. P., op. cit., p. 19.
[92] Dunbar, C. O., and Condra, G. E., op. cit., p. 95.
[93] Fusulinid identified by C. O. Dunbar (King, P. B., Geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, p. 55, 1931); brachiopods by R. E. King (Geology of the Glass Mountains, pt. 2; Texas Univ. Bull. 3042, 1931); ammonoids by Emil Böse (Permo-Carboniferous ammonoids of the Glass Mountains: Texas Univ. Bull. 1762, pp. 17-18, 1917) and J. P. Smith (Transitional Permian ammonoid fauna of Texas: Am. Jour. Sci., 5th ser., vol. 17, p. 67, 1929).

Marginifera wabashensis (Norwood and Pratten).
Aulosteges wolfcampensis King.
Teguliferina bösei King.
Rhynchopora illinoisensis (Worthen).
Spirifer condor D'Orbigny.
Spirifer texanus Meek.
Spirifer triplicatus Hall.
Squamularia perplexa (McChesney).
Ambocoelia planoconvexa (Shumard).
Martinia wolfcampensis (King).
Hustedia mormoni (Marcou).
Composita subtilita (Hall).
Punctospirifer kentuckyensis (Shumard).
Daraelites texanus Böse.
Uddenites schucherti Böse.
Gastrioceras modestum Böse.
Schistoceras diversicostatum Böse.
Paralegoceras incertum Böse.
Agathiceras frechi Böse.
Marathonites vidriensis Böse.
Marathonites sulcatus Böse.
Marathonites smithi Böse.
Shumardites (Vidrioceras) uddeni Böse.
Shumardites (Vidrioceras) irregulare Böse.

In addition, the zone at this place contains corals (including abundant *Cladopora*), a few crinoids, and numerous gastropods and pelecypods, none of which have been studied in detail. A mile to the northeast *Scacchinella gigantea* Schellwien has been collected from the layer.

Five miles northeast of Wolf Camp, near the base of some outlying buttes of the Glass Mountains, are other exposures of the *Uddenites* zone in which fossils were first discovered by I. A. Keyte. The following fossils collected from various beds in the zone at this place have been identified by R. E. King and J. P. Smith (R. E. King localities 94 and 95).

Crania sp.
Parenteletes cooperi King.
Orthotetella wolfcampensis King.
Meekella irregularis var. *texana* King.
Chonetes verneuilianus Norwood and Pratten.
Productus semireticulatus var. *hermosanus* Girty.
Productus semistriatus Meek.
Linoproductus cora (D'Orbigny).
Overtonia cristato-tuberculata (Kozlowskii).
Marginifera wabashensis (Norwood and Pratten).
Marginifera dugoutensis King.
Teguliferina bösei King.
Camarophoria venusta Girty.
Spirifer triplicatus Hall.
Squamularia perplexa (McChesney).
Ambocoelia planoconvexa (Shumard).
Martinia wolfcampensis King.
Composita subtilita (Hall).
Composita subtilita var. *angusta* King.
Hustedia mormoni (Marcou).
Dielasma bovidens (Morton).
Daraelites texanus Böse.
Parapronorites bösei Smith.
Uddenites schucherti Böse.
Prothalassoceras keytei Smith.
Marathonites smithi Böse.
Schistoceras diversicostatum Böse.
Shumardites sp.
Gastrioceras sp.
Phillipsia sp.

In addition, the layer contains sponges; various corals, including *Cladopora;* several species of pelecypods, gastropods, and nautiloids; and fragments of carbonized wood.

The fusulinid *Triticites ventricosus*, which characterizes the *Uddenites* zone, is found in the Thrifty and Harpersville formations of the middle of the Cisco group in central Texas [94] and in the Wabaunsee, Council Grove, and Chase groups of the northern midcontinent area.[95]

The brachiopods of the *Uddenites* zone consist predominantly of species common in the upper part of the Pennsylvanian, but, as pointed out by R. E. King,[96] they also include "other species that are definite heralders of the Permian and some that are unlike American Pennsylvanian forms but have foreign affinities." The species of Permian type include *Meekella irregularis* var. *texana*, *Waagenoconcha montpelierensis*, *Avonia boulei*, *Scacchinella gigantea*, *Aulosteges wolfcampensis*, *Spirifer condor*, and *Martinia wolfcampensis*. Two foreign faunas are suggested—that of the Bolivian upper Carboniferous by such species as *Waagenoconcha montpelierensis*, *Avonia boulei*, *Marginifera capaci*, and *Spirifer condor;* and that of the Trogkofel limestone of the Karnic Alps by such species as *Meekella irregularis* var. *texana*, *Scacchinella gigantea*, *Parenteletes cooperi*, and *Teguliferina bösei*.

Recent work by F. B. Plummer and Gayle Scott has shown that "every single ammonoid described by Böse from Wolf Camp has been found by us in the Wayland", [97] which is a member of the Graham formation, in the lower part of the Cisco group of central Texas. Smith's analysis of the ammonoid fauna [98] shows that it includes several species of *Schistoceras* and *Gastrioceras* which range up unchanged from the typical Pennsylvanian; other Pennsylvanian genera, such as *Shumardites*, *Agathiceras*, and *Daraelites*, which are represented by new species; and some Permian genera, such as *Parapronorites* and *Prothalassoceras*. He interprets the genus *Uddenites* as "the most primitive medlicottoid known, clearly related to and possibly

[94] White, M. P., op. cit., p. 71.
[95] Dunbar, C. O., and Condra, G. E., op. cit., p. 91.
[96] King, R. E., op. cit., p. 7.
[97] Plummer, F. B., letter, June 1931. See also Sellards, E. H., Pre-Paleozoic and Paleozoic systems: Geology of Texas, vol. 1, Texas Univ. Bull. 3232, p. 114, 1933. For further information on this fauna, and on the ammonoids from other Pennsylvanian and Permian horizons in Texas, see Plummer, F. B., and Scott, Gayle, Mississippian, Pennsylvanian, and Permian ammonites: Geology of Texas, vol. 3, Texas Univ. Bull. 3701, 1937.
[98] Smith, J. P., Transitional Permian ammonoid fauna of Texas, Am. Jour. Sci., 5th ser., vol. 17, p. 65, 1929.

ancestral to the Medlicottinae that mark the Permian everywhere."

CORRELATION OF THE GAPTANK STRATA AT GAP TANK AND WOLF CAMP

Most of the fossils in the section at Gap Tank are also found in the areas of Pennsylvanian exposure in central Texas and the northern midcontinent area. Nearly all these fossils have a long range, although the fusulinids and ammonoids and a few of the brachiopods occupy well-marked zones in the sections farther east. The fossils in the various layers in the section at Gap Tank show a gradual change in character from base to top, which corresponds in a broad way with changes in faunas in sections to the east. These changes in different parts of the section are such as to indicate that the Gaptank formation represents a large span of later Pennsylvanian time.

The lower zones lie well down in the series. *Chaetetes milleporaceus*, the two species of *Fusulina*, and *Chonetes mesolobus* have never been found in the higher parts of the Pennsylvanian farther east. They strongly suggest that the lower members of the section at Gap Tank are to be correlated with some part of the Strawn and Des Moines groups. *Pugnax rockymontana*, which occurs above them in the section at Gap Tank, is also found at a somewhat higher level in the sections to the east.

The large fauna of bed 10 contains little except long-ranging Pennsylvanian fossils, which are similar to those found in the Canyon and Cisco groups of central Texas and to those in the Wewoka formation of Oklahoma. With these is a species of *Triticites* and the ammonoid *Schistoceras smithi*, whose stratigraphic range is more limited and which occur in the lower part of the Canyon group of central Texas. The strata lying between bed 10 and the *Uddenites* zone at the top of the formation contain few fossils, and most of these are long-ranging species. *Triticites cullomensis*, found immediately below the *Uddenites* zone, suggests that this part of the formation corresponds to the upper part of the Canyon group.

As the fusulinid and the ammonoids of the *Uddenites* zone occur in the lower formations of the Cisco group, it is probable that the zone is to be correlated with this part of the central Texas section. The fossils occur near or below various unconformities in the middle of the Cisco group, including that beneath the basal sandstone member of the Thrifty formation. As they are found in central Texas in unquestioned Pennsylvanian strata, which were apparently laid down prior to the greatest crustal disturbance in the region, the *Uddenites* zone of the Marathon region may also most properly be considered of Pennsylvanian age. The zone is therefore placed in the Gaptank formation, whose top is here assumed to be at the base of a gray limestone member that overlies the *Uddenites* zone. The fossil evidence afforded by this bed, however, is indefinite. Sellards [99] places the top of the formation at the top of the gray limestone.

FAUNAS OF THE AREA WEST OF MARATHON

Fossils are found at numerous localities in the area west of Marathon, but on account of the complexity of the structure it is not possible to fit them to any stratigraphic section. The fossils of the largest collections are listed below in rough chronologic order.

Basal beds.—From the lower limestones a few miles south of Dugout Mountain (U. S. Geological Survey locality 7093), G. H. Girty has identified *Chaetetes milleporaceus* Milne-Edwards and Haime, and C. O. Dunbar has identified *Fusulina meeki* (Dunbar and Condra). The fusulinid is characteristic of a limestone immediately below the Thurber coal in the Millsap Lake formation of Sellards (Strawn group) of central Texas,[1] and of the Cherokee shale of the northern midcontinent area.[2] The occurrence of these fossils strongly suggests a correlation with the *Chaetetes*-bearing limestone of the type locality.

The ammonoid fauna.—Southeast of the Payne Hills, 4½ miles south-southeast of Lenox and 1¾ miles south of the Arnold ranch (locality B, pl. 16) (U. S. Geological Survey locality 6698), is the limestone mass that contains an ammonoid fauna. From this place A. K. Miller [3] has identified the following cephalopods:

Orthoceras longissimicameratum Miller.
Bactrites postremus Miller.
Daraelites texanus Böse.
Pronorites pseudotimorensis Miller.
Prouddenites primus Miller.
Uddenites schucherti Böse?
Gastrioceras gaptankense Miller.
Paralegoceras reticulaterale Miller.
Schistoceras reticulatum Miller.
Schistoceras smithi Böse.
Prothalassoceras kingorum Miller.
Marathonites hargisi Böse.

From the same locality Mr. Girty has identified the following other fossils:

Triticites sp.
Derbya? sp.
Chonetes aff. *C. granulifer* Owen.
Productus semireticulatus var. Martin.
Productus aff. *P. pertenuis* Meek.
Productus cora D'Orbigny.
Pustula nebrascensis (Owen).
Pustula semipunctata (Shepard).
Marginifera wabashensis Norwood and Pratten.
Dielasma sp.
Ambocoelia sp.

[99] Sellards, E. H., op. cit., p. 148.
[1] White, M. P., op. cit., pp. 20-21.
[2] Dunbar, C. O. and Condra, G. E., op. cit., p. 80.
[3] Miller, A. K., A new ammonoid fauna of late Paleozoic age from western Texas Jour. Paleontology, vol. 4, pp. 383-411, 1930.

Cleiothyridina orbicularis (McChesney).
Schizodus sp.
Myalina aff. *M. swallowi* McChesney.
Myalina? sp.
Pteria ohioensis (Herrick).
Pleurotomaria sp.

In regard to this fauna, Mr. Girty writes:

> It is unique among all the Gaptank collections by reason of the abundance of ammonitic forms, and especially of forms having a highly developed sutural pattern. Deprived of this ammonitic element, however, the fauna would be without distinctive characters in its relation to other faunas of the Gaptank.

F. B. Plummer, who has compared the ammonoids from this place with those collected by Gayle Scott and himself, states [4] that "every single ammonoid and fossil" from this locality is found in shale layers in the Palo Pinto limestone (lower Canyon), in Jack and Wise Counties, central Texas.

The fusulinids from the bed were examined by C. O. Dunbar, but they are too much silicified and too fragmentary for identification.

Northeastern part of Payne Hills.—At the northeast corner of the Payne Hills (locality C, pl. 16) (U. S. Geological Survey locality 6908), thin limestones in the shale directly beneath the Dugout Creek overthrust contain the following fossils, which have been identified by Mr. Girty:

Triticites sp.
Heliophyllum? sp.
Syringopora multattenuata McChesney?
Lophophyllum? sp.
Eupachycrinus sp.
Rhipidomella carbonaria (Swallow).
Derbya sp.
Productus pertenuis Meek.
Productus semireticulatus Martin.
Productus hermosanus Girty.
Productus cora D'Orbigny.
Pustula nebrascensis (Owen).
Pustula semipunctata (Shepard).
Marginifera splendens (Norwood and Pratten).
Marginifera wabashensis Norwood and Pratten.
Spirifer triplicatus (Hall).
Squamularia perplexa (McChesney).
Composita subtilita (Hall).
Sphaerodoma sp.

According to C. O. Dunbar, the *Triticites* is the same small species that is found abundantly in bed 10 of the section near Gap Tank. From ledges nearby to the east C. L. Baker collected a large shark tooth.

Several closely adjacent ledges about a quarter of a mile to the south (U. S. Geological Survey locality 7016) and also immediately beneath the Dugout Creek overthrust contain the following fossils, identified by Mr. Girty:

Amblysiphonella? sp.
Wewokella sp.
Chainodictyon? sp.
Sponge undet.
Triplophyllum sp.
Michelinia eugeneae White.
Crinoidal fragments.
Fistulipora nodulifera Meek.
Stenopora sp.
Rhombopora lepidendroides Meek.
Chonetes flemingi Norwood and Pratten.
Productus semireticulatus Martin.
Productus aff. *P. portlockianus* Norwood and Pratten.
Productus cora D'Orbigny.
Pustula nebrascensis? (Owen).
Pustula semipunctata (Shepard).
Marginifera splendens (Norwood and Pratten).
Marginifera wabashensis Norwood and Pratten.
Spirifer cameratus Morton?
Composita subtilita (Hall).
Bellerophon sp.
Platyceras sp.
Euconispira? sp.

From these same layers A. K. Miller has identified *Marathonites hargisi* Böse and *Schistoceras smithi* Böse, which suggest that the strata are of nearly the same age as those not far to the south, which contain the larger ammonoid fauna.

In occurrence and general character this fauna is similar to that of bed 10 of the type section. There are many identical species, but most of these are so long-ranging that no safe correlation can be made. The occurrence in both faunas of *Schistoceras smithi* is suggestive of similar age. The general aspect of the faunas in these collections is middle Pennsylvanian.

Milepost 580 area.—Between the Payne Hills and Marathon, north and south of milepost 580 on the Southern Pacific Railroad, are extensive exposures of the Gaptank formation, but these have not yielded extensive faunas. A few fossils have been collected in a limestone lens in conglomerate beds half a mile south of the milepost (U. S. Geological Survey locality 6922), from which Mr. Girty has identified *Lophophyllum?* sp., and *Stenopora* sp., and Mr. Dunbar a small *Triticites* of the same species as that found abundantly in bed 10 of the section near Gap Tank.

Half a mile west of the milepost and not far south of the railroad, Schuchert collected *Schistoceras smithi* Böse and from his collection C. O. Dunbar identified *Triticites secalicus* (Say), a fusulinid which is found in the Gunsight limestone member of the Graham formation (lower Cisco)[5] and which ranges from the lower part of the Kansas City group to the upper part of the Douglas group in the northern midcontinent area.[6] The fusulinid of the fauna suggests that it is slightly younger than the beds in the northeastern part of the Payne Hills.

Localities southeast of the Payne Hills.—Several collections that may be younger than those just

[4] Letter, June 1931. See also Sellards, E. H., op. cit., p. 112.

[5] White, M. P., op. cit., p. 21.

[6] Dunbar, C. O., and Condra, G. E., op. cit., pp. 107-108.

described have been obtained southeast of the Payne Hills. A mile southeast of the ammonoid locality, on the east side of Alsate Creek, is a hill capped by overthrust masses of Ordovician limestone (locality D, pl. 16). On the lower slopes are exposures of shales and limestones from which two collections have been made, one on the north side of the hill and the other on the south side (U. S. Geological Survey localities 6923 and 7022). From these collections Mr. Girty has identified the following fossils:

Wewokella? sp.
Coelocladia spinosa Girty?
Lophophyllum profundum var. *sauridens* White?
Campophyllum? sp.
Crinoid stems (abundant).
Rhombopora aff. *R. lepidendroides* Meek.
Fenestella (fragments).
Meekella striaticostata (Cox).
Productus sp.
Teguliferina sp.
Spirifer triplicatus Hall.
Squamularia sp.
Composita subtilita (Hall).
Naticopsis? sp.
Schizostoma catilloides (Conrad)?
Orthoceras sp.

From a layer on the north side of the hill C. O. Dunbar has identified *Triticites cullomensis* Dunbar and Condra, the same fusulinid that is found directly beneath the *Uddenites* zone at Wolf Camp.

RELATION OF THE STRATA WEST OF MARATHON TO THOSE OF THE TYPE SECTION

The fossiliferous Pennsylvanian strata west of Marathon are considered by C. L. Baker to be older than the typical Gaptank formation and therefore to merit a separate formation name, and he has called them the "Dugout beds." On the other hand, the writer has correlated most of these strata with the Gaptank formation of the type section.

Correlation between the two areas is made difficult by the lack of identical faunas and lithologic facies. This may be due to an actual difference in age between the two sections, or it may result from the lenticular nature of the Gaptank deposits and from the local sources of much of their clastic material. The conditions of sedimentation probably influenced the faunas. Moreover, the two districts, now 30 miles apart, have been brought closer together than they were originally by the strong folding of the region. The strata west of Marathon lie beneath and northwest of the Dugout Creek overthrust, and the strata near Gap Tank may have lain southeast of it.

The two areas have many fossils in common, but most of these are of long-ranging types. The area west of Marathon contains some fossils that have a restricted range in the better-known sections of central Texas and the northern midcontinent area, but some of these fossils are not found in the section at Gap Tank. Direct comparisons cannot therefore be made with most of the beds in the type section. West of Marathon, however, there appears to be a progressive upward change in the faunas, like that in the type section, which corresponds roughly to that in the regions farther east.

The lowest limestones west of Marathon contain *Chaetetes milleporaceus* and a species of *Fusulina*. The *Fusulina*, though not the same as either of the two species found at Gap Tank, occurs in association with them in the Des Moines group of the northern midcontinent area. The distinctive character of both the coral and the fusulinid suggests a correlation with the *Chaetetes*-bearing limestone at the base of the type section.

The various faunas in the northeastern part of the Payne Hills appear to be younger. Most of their fossils are long-ranging upper Pennsylvanian types, but the occurrence in some of the collections of ammonoids that can be matched with those of the lower part of the Canyon group suggests that the faunas are of this age. They may also be approximately equivalent to the similar fauna of probable Canyon age in bed 10 of the type section. *Schistoceras smithi*, one of the less striking species of ammonoids, occurs in both localities.

The correlation of the higher strata west of Marathon is rather uncertain on account of the lack of distinctive fossils. The fusulinid *Triticites cullomensis*, which occurs at one locality, is also found directly beneath the *Uddenites* zone in the upper part of the typical section. It is therefore probable that the youngest strata west of Marathon extend as high as the upper part of the section near Gap Tank.

STRATIGRAPHIC RELATIONS

In places the Gaptank formation is separated from the Wolfcamp formation by a strong angular unconformity. The unconformable relations are clearly shown at many places in the southwestern part of the Glass Mountains. On the south side of Dugout Mountain, in the northwestern part of the Monument Spring quadrangle (pl. 24), the Wolfcamp formation, with 350 feet of basal conglomerate, rests in a nearly horizontal position on strata of the Gaptank formation, which are overturned and now dip 35° S. (sec. G–G′–G″, pl. 21). Beds in the Wolfcamp formation immediately above its basal conglomerate contain *Pseudoschwagerina* and other fossils that indicate a correlation with the upper part of the formation farther northeast. Limestones in the folded strata on the south side of Dugout Mountain contain *Fusulina* and *Chaetetes*, but younger strata were also involved in the movement, because not far to the south, beneath the Dugout Creek overthrust, are found the *Prouddenites* ammonoid fauna, *Triticites cullomensis*, and other middle to upper Pennsylvanian fossils.

In the northeastern part of the Glass Mountains this marked discordance and hiatus disappear, and the Wolfcamp formation rests on the Gaptank formation with nearly equal dip and strike. At Wolf Camp there is apparently a nearly complete sequence of strata from the zone of *Triticites cullomensis* to the zone of *Pseudoschwagerina*, and the intervening beds contain the *Uddenites* ammonoid fauna and *Triticites ventricosus*, whose position relative to the unconformity in the southwestern part of the mountains is not certainly known. At the eastern base of Leonard Mountain fossils apparently of the *Uddenites* fauna were collected from a shale that seemingly rests directly on the Tesnus formation, but the relations here are much obscured by talus, and the two sets of beds may be separated by faults. The occurrence of the *Uddenites* fauna in central Texas is such as to suggest that it existed prior to the greatest crustal disturbances in that region.

East of Gap Tank the Gaptank and Wolfcamp formations are apparently overlapped by the basal conglomerates of the succeeding Leonard formation. At a locality 3½ miles southeast of the tank the Leonard formation, with possibly some older Permian beds beneath, rests directly on the Haymond formation, but farther east, as shown by the fossils collected 7 miles east of the tank, the Gaptank formation comes in again beneath the unconformity.

South of Gap Tank the folds of the Gaptank formation increase in complexity and pass without apparent structural break into the steeper folds of the Haymond formation to the southeast. It is possible that the northward dying out of the strong folding may have been due to a northward progression of the deformation. Folding in the area south of Gap Tank had begun by middle Gaptank time, as shown by the conglomerates in that formation. The Gap Tank area itself appears to have been involved only in the final stages of the deformation.

GENERAL PROBLEMS OF PENNSYLVANIAN STRATIGRAPHY

STRATIGRAPHIC SEQUENCE

The subdivision of the Pennsylvanian series in the Marathon Basin into the Tesnus, Dimple, Haymond, and Gaptank formations depends on the correlation of exposures that are separated by anticlinoria of the older rocks or by alluvial deposits (pl. 23). There are four main areas in which rocks of Pennsylvanian age are exposed.

1. Near Tesnus and Haymond stations there is a continuous sequence some 10,000 feet in thickness which extends from the Caballos novaculite into the upper part of the Haymond formation (secs. 6 and 7, pl. 8).

2. To the northwest, near Peña Colorada Creek, on the opposite side of the Dagger Flat anticlinorium, is a similar but much thinner sequence which also extends from the Caballos novaculite into the Haymond formation (secs. 2, 3, 4, and 5, pl. 8).

3. Near Gap Tank, at the east end of the Glass Mountains, a sequence with its base not exposed extends through a thickness of 3,600 feet from the middle of the Haymond formation to the top of the Gaptank formation (sec. 9, pl. 8). This sequence is overlain at the top by strata of early Permian age.

4. West of Marathon, separated from the other sequences by the Dugout Creek overthrust, are exposures of strongly deformed sandstones and shales. The stratigraphy of this area is not like that of the other three, but correlations by means of fossils suggest that the beds are equivalent to parts of the Gaptank and Haymond formations.

In the first two sequences fossils are so few that correlations must be made very largely on lithologic grounds. In this region the most persistent and characteristic layer is the Dimple limestone. This formation makes possible a separation of the Tesnus sandy and shaly beds from those of the Haymond, and its constant position at the top of the Tesnus formation demonstrates the great northwestward thinning of the Tesnus—from 6,500 feet in the first area to as little as 300 feet in the second—with a change from predominant sandstone to predominant shale. In both areas, however, the Tesnus is overlain by the Dimple limestone, of constant lithologic character.

The Haymond formation, which succeeds the Dimple limestone in normal stratigraphic order, is composed of sandstones and shales. These strata are so nearly like the Tesnus formation that without careful work they might be confused. Baker at one time suggested that a part of them might be Tesnus overthrust across Dimple. Not only is evidence for overthrusting wholly lacking, however, but the contact of the Haymond with the underlying Dimple limestone is gradational. The Haymond sandstones and shales are distinguished from those of the Tesnus by their thin-bedded character, and in the boulder-bed member of the formation there are transported fragments of Tesnus and Dimple rocks.

Northwest of Peña Colorada Creek there is a suggestion that the lower part of the Haymond formation interfingers northward with limestones like those of the Dimple formation. There is no evidence, however, of any similar interfingering at the upper contact. The main exposures of the Haymond formation lie south of those of the Gaptank formation, but the one is not the lateral facies of the other. The few plant remains and invertebrate fossils found in the Haymond formation and the abundant fauna in the transported blocks of the boulder-bed member are definitely older than anything found in the Gaptank formation. Moreover, the Haymond formation possesses constant lithologic characters over the entire Marathon Basin, including those places where it underlies the Gaptank, and these characters are unlike those of the later formation.

A gap of unknown extent lies within the Haymond formation, for at no place is there a continuous succession from its base to its top. However, the boulder-bed member east of Haymond station, which lies near the top of the first of the four sequences mentioned above, may be the same as that southeast of Gap Tank, which lies near the base of the third sequence. This boulder bed probably provides a link between the two areas.

The Gaptank formation in the third sequence contains many fossil zones, by means of which it can be correlated approximately with formations in the upper part of the central Texas and northern midcontinent sections. The fossil zones in the formation show that it embraces equivalents of several formations, and even groups, of the sections farther east. Under more favorable circumstances the formation would be broken into many subdivisions. Such a division could not, however, be attempted here because the formation is exposed over too small an area and its structure is too complex.

Pennsylvanian marine fossils are found in the disturbed strata of the fourth sequence west of Marathon. They indicate an age no greater than that of the Gaptank in the third sequence, and a few of them appear to be equivalent to those in its upper part. Baker's conception of the beds in the fourth sequence as a separate entity thus has little justification in fact, although they show some differences in lithology from the type Gaptank.

CORRELATIONS AND REGIONAL RELATIONS

General relations.—The sequence of Pennsylvanian rocks at Marathon presents many problems of correlation. Its great thickness and the predominance of clastic material make it unique among the sections in trans-Pecos Texas, and the scarcity of fossils in most parts of it makes a comparison with regions of similar stratigraphy difficult.

The fossils that have been found indicate that the section at Marathon represents the greater part of Pennsylvanian time. Its lower parts probably extend into the early Pottsville, and its upper parts are equivalent to the higher members of the succession in the better-known sections farther east. Both plant and invertebrate fossils indicate that the three lower formations, comprising by far the greater part of the whole section, are of Pottsville age. The upper divisions of the Pennsylvanian, comprising equivalents of the greater part of the northern midcontinent section, all appear to lie within the relatively small thickness of the Gaptank formation. The Pottsville equivalents are thus greatly expanded, whereas the post-Pottsville equivalents have a normal or even a reduced thickness.

Correlations in trans-Pecos Texas.—Pennsylvanian rocks of the same facies as those in the Marathon Basin are exposed at only one other locality in trans-Pecos Texas, the Solitario uplift. Here only the Tesnus formation is found.[7] East of the Marathon Basin, however, such rocks have been penetrated by wells. Water wells a few hundred feet in depth not far east of the Marathon Basin encounter such rocks below the Cretaceous,[8] and deep wells in the southeastern part of Terrell County and in Val Verde County, to the east, have entered sheared and talcose shales, probably also of Pennsylvanian age, after passing through a thick Cretaceous section.[9]

In the northwestern part of trans-Pecos Texas, 100 miles or more from the Marathon Basin, the Pennsylvanian is exposed, but it is here of very different facies. In the Hueco and Franklin Mountains the Magdalena limestone, 1,500 feet thick, lies between rocks of Mississippian and Permian (?) age.[10] This formation is the southward extension of the group of that name in New Mexico. Field observations by J. Brookes Knight indicate that there is an upward progression of faunas in the formation. The lower part in the Hueco Mountains is characterized by the primitive fusulinid genera *Wedekindellina*, *Fusulinella*, and *Fusulina*, which are replaced upward by the more advanced genus *Triticites*.[11] In the lower part there are abundant *Chaetetes milleporaceus* Milne-Edwards and Haime and *Spirifer rockymontanus* Marcou. The zone of *Chonetes mesolobus* Norwood and Pratten occurs near the middle of the section, and the upper part includes abundant fossils of upper Pennsylvanian aspect, including *Enteletes* near the top. The faunal succession in the Magdalena limestone of the Hueco Mountains is thus comparable to that in the Gaptank formation, and whether it includes equivalents to any of the older beds of the Marathon Basin section is doubtful.

Nearer to Marathon, in the Sierra Diablo, north of Van Horn, there are less continuous exposures of Penn-

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7 Sellards, E. H., Pre-Paleozoic and Paleozoic systems, in The geology of Texas, vol. 1, Stratigraphy: Texas Univ. Bull. 3232, p. 118, 1933.

8 Christner, D. D., and Wheeler, O. C., The geology of Terrell County: Texas Univ. Bull. 1819, pp. 11–12, 1918.

9 Sellards, E. H., op. cit., fig. 10, p. 128, and pp. 190–191.

10 King, P. B., and King, R. E., Stratigraphy of outcropping Carboniferous and Permian rocks of trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 910–911, 1929. Most of the information in this paragraph is derived from field observations made later by J. Brookes Knight and the writer.

11 Identifications by C. O. Dunbar.

sylvanian rocks. The youngest beds exposed belong to the lower part of the Magdalena limestone, but beneath them are shales and limestones from which a fauna of Smithwick (early Pennsylvanian) age has been collected.[12] The limestones associated with the shales have a close resemblance to those of the transported blocks of early Pennsylvanian age in the boulder-bed member of the Haymond formation. The fauna of the transported blocks suggests also that they are of about the same age.

East of these localities there are no other outcrops of Pennsylvanian rocks until central Texas is reached, but a few hundred feet of limestones of middle Pennsylvanian age have been encountered by deep borings in the Big Lake oil field, in Reagan County, northeast of the Marathon Basin.[13]

Correlations with central Texas, southern Oklahoma, and Arkansas.—The Pennsylvanian section at Marathon, although unlike most of the sections nearby in trans-Pecos Texas, is similar to more distant sections to the east and northeast, which also lie in or near the site of the Llanoria geosyncline. In these regions, as in the Marathon district, there were disturbances and mountain-making movements at several times in the Pennsylvanian epoch, and the deposition of clastic sediments was closely related to this orogeny.

In parts of central Texas, southern Oklahoma, and western Arkansas, where the stratigraphic sequence resembles that in the Marathon region, there are three main masses of clastic rocks. One, represented by the Stanley shale, Jackfork sandstone, and Springer formation, of early Pennsylvanian age, is found only in the Ouachita Mountains and Ardmore Basin. Another is represented by the Strawn group of Texas and the Atoka and overlying formations north of the Ouachita Mountains. The third is represented by the Cisco group in Texas and by the Pontotoc group and some underlying beds in Oklahoma. In central Texas the clastic rocks are separated, as well as overlain and underlain, by more calcareous strata. Beneath the Strawn group are the Smithwick shale and Marble Falls limestone. In parts of southern Oklahoma their equivalent, the Wapanucka limestone, separates the Springer and Jackfork clastic rocks from the clastic rocks of the Atoka. Between the Strawn and Cisco groups in central Texas is the Canyon group, which contains abundant and conspicuous beds of limestone. In the southern part of the central Texas area the Cisco group is overlain by the predominantly calcareous beds of the Wichita group.

Times of movement in these regions are suggested by several unconformities. Between the Smithwick shale and the Strawn group in central Texas there is a well-marked break, and the Strawn overlaps westward on the older beds.[14] A similar break has been recognized in Oklahoma between the Wapanucka limestone and the Atoka formation.[15] Miser suggests that nearly contemporaneous movements gave rise to the uplifts that furnished the source for the boulders in the Johns Valley shale (between the Jackfork and Atoka formations in the Ouachita Mountains). Less conspicuous unconformities are reported to occur higher in the section in Texas and Oklahoma,[16] but the next pronounced break in the Arbuckle Mountain area is at the base of the Vamoosa formation, high in the Pennsylvania section. This and the succeeding formations, including the Pontotoc group, overlap all the older formations of the Arbuckle Mountains. In central Texas these later Pennsylvanian unconformities are not so marked, but Plummer and Moore report several breaks in the Cisco group.

It has been the writer's opinion for many years that the Tesnus formation of the Marathon Basin is correlative with some part of the lowest mass of clastic deposits in Oklahoma and Arkansas (Stanley, Jackfork, and Springer formations). The fossil evidence is meager, and the fossils are poorly preserved. The plants of the Stanley and Jackfork formations are now considered [17] to be of very early Pennsylvanian age, but White believed the plants collected near the top of the Tesnus formation to be slightly younger. No fossils have been found in the lower part of the Tesnus. The stratigraphic position of the Tesnus is similar to that of the Stanley and Jackfork, as it lies between novaculites of Devonian (?) age and limestones considered to be of Marble Falls and Wapanucka age. It also resembles the Stanley and Jackfork formations in lithology: all three consist of chloritic sandstone, dark slaty shale, and white quartzite.

The character of the Dimple limestone, a calcareous layer in a predominantly clastic succession, and its widespread occurrence within the area of exposure suggest that it may be of the same age as the Marble Falls and Wapanucka limestones, which occupy a similar position and cover wide areas in central Texas and southern Oklahoma. The few fossils in the Dimple limestone are of a somewhat different facies from those in the two formations to the east, but this difference may have been brought about by conditions

[12] Arick, M. B., Occurrence of strata of Bend age in Sierra Diablo, Culberson County, Tex.: Am. Assoc. Petroleum Geologists Bull., vol. 16, pp. 484–486, 1932.

[13] Sellards, E. H., Bybee, H. P., and Hemphill, H. A., Producing horizons in the Big Lake oil field, Reagan County: Texas Univ. Bull. 3001, pp. 149–203, 1930.

[14] Plummer, F. B., and Moore, R. C., Stratigraphy of the Pennsylvanian formations of north-central Texas: Texas Univ. Bull. 2132, p. 60, 1921.

[15] Miser, H. D., Carboniferous rocks of Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 1008–1009, 1934.

[16] See references in Plummer, F. B., and Moore, R. C., op. cit.; Morgan, G. D., Geology of the Stonewall quadrangle, Okla.; Oklahoma Geol. Survey Bull. 2, pp. 19–20, 1924; and Dott, R. H., Overthrusting in Arbuckle Mountains, Okla.: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 583–588, 1934.

[17] White, David, Age of Jackfork and Stanley formations of Ouachita geosyncline, Arkansas and Oklahoma, as indicated by plants: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 1010–1017, 1934.

unfavorable to abundant marine life in the Marathon region. The faunas of the exotic blocks in the Haymond formation have a much more direct relation to those of the Marble Falls and Wapanucka limestone and contain many identical or comparable species.

The Haymond formation probably corresponds to part of the second of the three main groups of clastic rocks in central Texas, southern Oklahoma, and western Arkansas (p. 85). The occurrence of fossiliferous blocks in the formation indicates clearly that it is younger than the Marble Falls limestone. The plants and fusulinid indigenous to the formation show, however, that it is still of lower Pennsylvanian age. As such, it may be correlative with the clastic rocks in the lower part of the Strawn group of central Texas and with the Atoka formation of Oklahoma and Arkansas. The occurrence of large boulders in part of the Haymond formation suggests the possibility that this part may be of the same age as the boulder-bearing beds in the Johns Valley shale of the Ouachita Mountains. Miser now considers these beds to be a little younger than the Wapanucka limestone,[18] which would make them approximately correlative with the Haymond boulder-bearing beds.

The overlying Gaptank formation occupies a considerable span of later Pennsylvanian time and its numerous fossils permit approximate correlations with formations of other regions. The Gaptank contains many of the fossils cited by Moore [19] as characteristic zone fossils of the upper part of the Pennsylvanian. The fossils indicate that the formation contains equivalents of the upper part of the Strawn group, the Canyon group, and perhaps a part of the Cisco group of central Texas. It is also equivalent to a considerable part of the Des Moines and Missouri groups of the northern midcontinent area. The conglomeratic lower part of the Gaptank formation may be related to the clastic rocks of the upper Strawn, which also contain a conglomerate, the Brazos River member. The more calcareous upper part of the Gaptank formation is similar to the Canyon group, in which there are many thick limestone beds.

Pennsylvanian-Permian boundary.—The boundary between the Pennsylvanian and Permian series in the south-central United States has been subject to much difference of opinion. The eventual solution of the problem will probably be made by a regional study of all the areas of exposure in this part of the country. Such a study, or even a review of the existing evidence, is outside the scope of this paper.

In the Marathon region the boundary is assumed to lie at the horizon of the great unconformity that separates tilted Carboniferous rocks of the Glass Mountains from greatly disturbed older Carboniferous rocks of the Marathon Basin. Paleontologically, this unconformity is supposed to lie between the *Uddenites* zone in the upper part of the Gaptank formation and the *Pseudoschwagerina* zone [19a] in the lower part of the Wolfcamp formation. An unconformity is also found below the Hueco limestone, which contains the *Pseudoschwagerina* zone in northwestern trans-Pecos Texas. In the Hueco Mountains the upper part of the Magdalena limestone, which underlies the Hueco, contains fossils of approximately the same age as those in the upper part of the Gaptank formation.

In the beds immediately below and above the boundary as now drawn in the Marathon region there is a gradual replacement of fossils of Pennsylvanian character by those of Permian character. Permian elements first appear in the brachiopods of the *Uddenites* zone. In the overlying Wolfcamp formation, where there are still many species of upper Pennsylvanian type, there are also some species that continue unchanged into higher beds of the Permian and other genera and species that appear to be ancestral to the characteristic Permian forms above. The faunas of the Leonard formation above the Wolfcamp are definitely of Guadalupian character, and only a few Pennsylvanian species persist. The faunal changes encountered on ascending the section in the Glass Mountains are probably in large part the result of progressive evolution. Whether they are related to changes in environment caused by the late Pennsylvanian and early Permian diastrophism has not been proved.

Marked diastrophism took place in late Pennsylvanian time in the Arbuckle Mountains and the Wichita Mountain system of central Texas and southern Oklahoma. The Ouachita Mountains may also have been disturbed at the same time, but as no sedimentary rocks of this age are found near them it is not possible to date the later part of their movements. The late Pennsylvanian movements caused the deposition of the third group of clastic sediments found in that series. The disturbances in central Texas and southern Oklahoma probably correspond roughly with the great disturbance at the end of Gaptank time in the Marathon region. In those areas, however, instead of a single great unconformity, there are several lesser ones, and in some places where the unconformities are not large, strong movement in nearby areas is indicated by the character of the sedimentary rocks. This is particularly true in the Cisco group of central Texas. Recently Sellards [20] has reported the occurrence of

[18] Miser, H. D., op. cit., p. 1007.

[19] Moore, R. C., Correlation of Pennsylvanian formations of Texas and Oklahoma: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 896-900, 1929.

[19a] The characteristic fossil of this zone has been generally known as *Schwagerina*, but as a result of recent taxonomic revisions by C. O. Dunbar that name is now applied to another genus, and the names *Pseudoschwagerina* and *Paraschwagerina* substituted for it. See Dunbar, C. O., and Skinner, J. W., *Schwagerina* versus *Pseudoschwagerina* and *Paraschwagerina*: Jour. Paleontology, vol. 10, pp. 83-91, 1936.

[20] Sellards, E. H., op. cit., p. 172.

Pseudoschwagerina in the Moran formation, in the upper part of the Cisco group, and the base of that formation is now regarded as the base of the Permian by the U. S. Geological Survey.

Another interpretation of the Pennsylvanian-Permian boundary has recently been offered by Romer,[21] based partly on his work on the vertebrates and partly on a review of the plant and invertebrate evidence. He states that a horizon higher in the section than that used by the writer, Sellards, and others corresponds more closely to the base of the Permian in the type area in Russia, and he advocates its adoption in this country. In trans-Pecos Texas the boundary proposed by Romer would lie between the Wolfcamp and Leonard formations and between the Hueco and Bone Spring formations. In support of this view it is worth noting that, although the time of greatest disturbance in trans-Pecos Texas was earlier than the Wolfcamp and Hueco, the fossils of these formations are partly of Pennsylvanian and partly of primitive Permian character. Fossils of unmistakable Permian (Guadalupian) character appear for the first time in the Leonard and Bone Spring formations.

CONDITIONS OF DEPOSITION OF THE PENNSYLVANIAN STRATA

Older formations.—That the Pennsylvanian rocks of the Marathon region were laid down in a geosyncline is evident from their great thickness and predominantly clastic character, as compared with the small thickness and predominance of limestone in the equivalent strata to the northwest. The older formations of the Marathon section appear to have been restricted to this basin. The Tesnus formation overlaps and thins out toward the northwest, within the limits of the Marathon region, and neither it nor the Haymond formation is clearly represented in the region northwest of the geosyncline.

In the northwestern part of the Marathon region both the Tesnus and Dimple formations contain layers of chert conglomerate, probably derived from the erosion of land areas of older rock along the northwestern margin of the Llanoria geosyncline. However, most of the clastic rocks in the Tesnus and Haymond formations appear to have come from the southeast.

The sedimentary rocks of northwestward source consist of nothing but chert fragments, and apparently no strata older than the Caballos novaculite or the Maravillas chert were laid bare in this direction. On the other hand, the sandstones and arkoses of the Tesnus and Haymond formations contain fragments of igneous and metamorphic rocks. In the Tesnus formation these layers replace shales to the southeast, and in the same direction the formation itself thickens from a few hundred to thousands of feet. In the Haymond formation the relations are less conclusive, for the formation is not as widely exposed as the Tesnus, and its thin-bedded sandstones and shales are uniform over wide areas. However, the section near Haymond station appears to be several thousand feet thicker than that in the synclines to the southeast and south of Gap Tank, and arkose beds are more numerous in the Haymond exposure than in the Gap Tank area.

The land from which the sediments of the Tesnus and Haymond formations were derived was evidently a highland of crystalline rocks (A, pl. 20). The great thickness of the two clastic formations suggests that the land was strongly uplifted and vigorously eroded. This uplift took place some time after the deposition of the Caballos novaculite, for that formation, most of whose sediments also came from the same direction, contains only cherts, novaculites, and fine clastic rocks. Apparently the uplift marks the first phase of the late Paleozoic orogenic epoch in the Marathon region. The character of the Tesnus and Haymond sedimentary rocks and their relation to the diastrophic history is comparable to that of the Flysch of Alpine chains in Europe. Van der Gracht,[22] following European authors, defines the Flysch as

> a sequence of sediments deposited during the later stages of the geosyncline, directly previous to the major paroxysm, when initial diastrophism has already developed interior ridges exposed to erosion. In the * * * troughs of this early structure a * * * marine sequence of poorly fossiliferous clayey muds, with more or less sandy beds intercalated in the shales, was laid down to a great thickness.

Both the Tesnus and the Haymond formations appear to have been laid down under shallow water, for the bedding surfaces of many of the sandstones are channeled and ripple-marked, and thin layers persist for long distances in the exposures, as if the sediments had been well sorted and distributed by waves and currents before they were deposited. Whether the water in which the sediments were laid down was marine is uncertain, for great thicknesses of strata are quite barren of fossils, which if present would give some clue to the nature of their environment. The Dimple limestone, which lies between the two formations, contains marine invertebrate fossils, and some have also been found in thin limestone layers in the Haymond formation. Some other beds in the Tesnus and Haymond also contain land plants, but these are fragmentary and water-worn, showing that they had been washed for considerable distances from their place of growth. The plant remains might therefore have been laid down in a shallow sea. The strati-

[21] Romer, A. S., Early history of Texas redbeds vertebrates: Geol. Soc. America Bull., vol 46, pp. 1642-1657, 1935.

[22] Van der Gracht, W. A. J. M. van Waterschoot, The Permo-Carboniferous orogeny in the south-central United States: K. Akad. Wetensch. Amsterdam Verh., Afd. Natuurk., deel 27, no. 3, p. 9, 1931. See also Bailey, E. B., Tectonic essays, mainly alpine, pp. 37-38, Oxford, 1935.

graphic relations of the Tesnus formation suggest that its basin of deposition was enclosed by land areas to the northwest and southeast, so that a connection with the sea, in those directions at least, was unlikely. The formation may therefore have been laid down in fresh water. In Dimple time this area of deposition was widely covered by the sea, and limestones were laid down. In Haymond time there was probably a return to brackish- or fresh-water conditions, but a sea may have existed to the northwest and must have extended into the region during the few times when marine fossils were laid down.

Younger formations.—Beginning with the upper part of the Haymond formation there was a great change in sedimentation. Most of the older clastic rocks were derived from the erosion of crystalline rocks beyond the limits of the Llanoria geosyncline. From this time onward the greater part of the fragments consisted of older Paleozoic rocks of the Llanoria geosyncline itself (*B* and *C*, pl. 20).

The boulder-bed member of the Haymond formation contains large blocks of the older rocks, which could not have been transported for great distances. These appear to have come from the southeast, for in the Gap Tank area the boulder-bed member is thin, and in the Haymond area it is hundreds of feet thick and contains numerous large blocks. The overlying Gaptank formation, at its type locality, contains many beds of conglomerate of rounded cobbles from the Dimple limestone and Caballos novaculite, as well as a few cobbles apparently derived from the *Chaetetes*-bearing limestone at the base of the Gaptank formation itself. West of Marathon the Gaptank contains conglomerate beds made up of chert fragments from the Caballos novaculite. The source of these fragments was close at hand and of local extent, for the deposits are variable from place to place. Even within the relatively small exposures of the Gap Tank area the conglomerate beds thin out to the north, and in exposures of the formation several miles to the east they are nearly all replaced by beds of limestone. In the area west of Marathon the conglomerates are of finer grain than those of the type locality and contain relatively few limestone cobbles.

The conglomerates in the upper part of the Pennsylvanian section indicate nearby contemporaneous uplifts of considerable magnitude, although no unconformities have been found in the areas of sedimentation. The beds from which the conglomerate fragments were derived should normally lie buried beneath thousands of feet of Pennsylvanian strata. At the top of the Pennsylvanian section is a great unconformity by which it is separated from the Permian rocks that overlie it on the northwest. This unconformity marks the culmination of the orogeny, but the record of the sedimentary beds beneath it suggests that a considerable part of the folding and faulting in the Marathon Basin had taken place earlier, while deposition was still going on in the region.

The younger Pennsylvanian strata are comparable to the Molasse of the Alpine ranges, which Van der Gracht [23] has defined as

> a generally much more clastic, very thick sequence, succeeding the Flysch; partly marine, partly deltaic, often containing enormous masses of conglomerate. It is the detritus worn down from the elevated ranges during and immediately succeeding the major diastrophism.

As a result of the orogenic movements, the depositional basin assumed in later Pennsylvanian time a very different form from that which it had in the earlier part of the epoch. The strata of the Gaptank formation are found only on the northwest side of the Marathon region, and it is questionable whether they were ever laid down much farther southeast (C, pl. 20). It is probable that the former area of the Llanoria geosyncline had been raised into land during this time. The Gaptank formation contains marine invertebrate fossils at numerous horizons, which indicate that the greater part of the formation was laid down beneath the sea. The close relation of these faunas to those in the Hueco Mountains, on the northwest, and in central Texas, on the east, shows that this sea was in free communication with the Pennsylvanian seas in the interior of the continent. The Gaptank deposits were probably laid down as a clastic facies along the southeast shore of the sea. The conglomerates of the formation faded out northwestward away from the folds of the Marathon region.

PROBLEMS OF THE HAYMOND FORMATION

General features.—The Haymond formation is a remarkable deposit. Not only does it contain boulder beds in which there are fragments of gigantic size, whose mode of origin and deposition are difficult to explain, but there are also many thick layers of arkose derived from the break-up of crystalline rocks and thousands of feet of strata in which there is a rhythmic alternation of thin sandy and thin shaly layers. The peculiar character and great thickness of all these deposits point to an epoch of sedimentation under unusual geographic conditions and perhaps under an unusual climate.

Origin of the thin-bedded sandstones and shales.—The thin-bedded sandstones and shales in the Haymond formation occupy wide areas and are of great thickness. In the section east of Haymond station they begin several hundred feet above the top of the Dimple limestone and continue up to, are partly interbedded with, and overlie the arkoses and mudstones of the boulder-

[23] Van der Gracht, W. A. J. M. van Waterschoot, op. cit., p. 10.

bed member. In the section near Gap Tank and in the region west of Marathon the thin-bedded sandstones and shales extend to the basal limestones of the Gaptank formation, but above this they are displaced by the nonlaminated shales and coarse lenticular sandstones of the Gaptank. These peculiar strata were thus laid down during a long and uniform period during which a specialized sort of sedimentation took place.

The persistence of each layer through the whole dimension of the exposures studied and the small thickness of some of them indicate deposition in quiet water, in which thin accretions of sediment were widely distributed and not subsequently disturbed by waves and currents. The general relations of the Haymond formation suggest that the water in which its sandstones and shales were laid down was brackish or fresh, rather than marine.

The lamination of the beds results from the alternate deposition of fine sand and of clay and silt. Slight variations in the deposition are indicated by variations in thickness of the dark and light layers, and by the occurrence at long intervals of thicker sandstone beds. That the deposition of each layer occupied approximately the same length of time is suggested by the slightly coarser texture of the thicker sandstone beds. The alternation resulted from a periodic change in the type of material supplied to the area of deposition. Such changes most probably resulted from seasonal variations in climate, for they recur with great regularity through great thicknesses of beds. If the thin-bedded sandstones and shales of the Haymond formation are of this origin, they may well be classed as varves, which have been defined [24] as distinct annual deposits of any origin, each usually consisting of two different layers representing summer and winter conditions.

The thickness of the layers in the Haymond formation is about the same as that of similar beds of shale and fine sandstone in the lower part of the Cambridge slate of the Boston area, Mass. Those beds lie directly on the Squantum tillite and have been interpreted as varves by Sayles.[25] The layers in the Haymond formation do not, however, show a diminution in thickness upward, such as may be seen in the Cambridge slate. The thin-bedded sandstones and shales of the Haymond also closely resemble the laminated siltstones in the Cretaceous of California, described and figured by Reed,[26] and like them are associated with beds of arkose. Baker [27] has also noted the resemblance of the deposits to parts of the Imperial formation, of lower Miocene age, west of the Salton Sea in California.

Origin of the arkoses.—The arkose deposits of the Haymond formation were probably derived from the erosion of lands to the southeast, for they thicken and increase in number in that direction across the Marathon Basin. That the land was probably granitic is indicated by the mineral content of the rocks. They contain microcline and apatite-bearing quartz, which are characteristic minerals of granites. Sodic plagioclase, biotite, and muscovite, which are also present in the arkoses, might well have come from granites, although they are found in metamorphic rocks as well. It is probable, in view of the bedded nature of the arkose and suggestion of rude sorting in the grains, that these rocks, like the other clastic deposits of the Haymond formation, were laid down under water.

The arkoses contain many quartz grains, but they also contain a great variety of minerals that are less resistant to decay. The micas, the sodic plagioclase, and the microcline are moderately resistant and might have weathered from a granitic terrane under conditions of several sorts. However, the occurrence of unaltered hornblende and of rectangular cleavage fragments of fresh feldspar strongly suggests that the weathering took place under rigorous climatic conditions, where granular disintegration prevailed over decomposition. The slight amount of argillaceous material in the arkoses also suggests that the land from which they were derived was not deeply covered by soil and that there was little decomposition of the fragments during transportation.

It is most probable that these rigorous conditions were the result of arid rather than cold climate, because granular disintegration is not known to be pronounced in cold regions,[28] and large deposits of arkose are not known to be associated with modern glacial deposits.[29] The plant remains found in the arkoses would also seem to argue against a cold climate. After the arkosic debris was weathered from its granitic terrane, it was apparently washed for a comparatively short distance into the marine or lacustrine environment in which the sediments of the Haymond formation were being deposited.

Origin of the boulder-bed member.—One of the most striking features of the Haymond formation is its boulder-bed member, which contains large transported blocks of older rock. The peculiar features of this layer make its origin difficult to explain.

[24] Antevs, Ernst, Retreat of the last ice sheet in Canada: Canada Dept. Mines Mem. 146, p. 1, 1925.

[25] Sayles, R. W., Seasonal deposition in aqueoglacial sediments: Harvard Coll. Mus. Comp. Zoology Mem., vol. 47, no. 1, pp. 43-49, fig. 2, pl. 13, 1919.

[26] Reed, Ralph, The geology of California, pp. 104-106, and figs. 17 and 18, 1933.

[27] Baker, C. L., Erratics and arkoses in the middle Pennsylvanian Haymond formation: Jour. Geology, vol. 40, pp. 580-581, 1932. See also Reed, Ralph, op. cit., pp. 237-238, fig. 45.

[28] Barton, D. C., Geologic significance and genetic classification of arkose deposits Jour. Geology, vol. 24, pp. 438-439, 1916. Special conditions under which arkose may form in humid tropical climates have been set forth by Krynine, P. D., Arkose deposits in the humid Tropics; a study of sedimentation in southern Mexico: Am. Jour. Sci., 5th ser., vol. 29, pp. 358-361, 1935.

[29] Barton, D. C., op. cit., p. 445.

It is at least clear that the boulder-bed member is a true sedimentary deposit and is not of tectonic origin. The boulders lie in a steeply tilted succession, dipping regularly toward the southeast, and the strata are not greatly crumpled and deformed. It is therefore certain that the boulders were not introduced by thrusting, or by the gliding of one part of the formation over another along shear planes. The large boulders are not a part of a single broken ledge or lens. They consist of a great variety of rocks of different ages. It is true that in some places the Pennsylvanian limestone blocks are so crowded together that they have the appearance of nearly continuous ledges (fig. 26), but such large masses are found at almost any position in a section several hundred feet thick, and they are associated with smaller limestone fragments, many of them well rounded, which appear to have been transported.

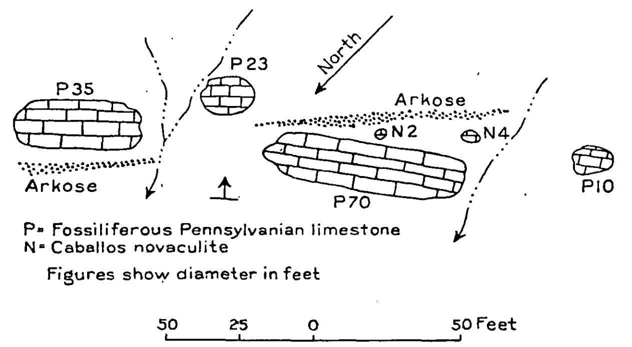


FIGURE 26.—Plan of part of outcrop of boulder bed between sections C-C′ and D-D′ of figure 23, showing how, where the large limestone boulders are very numerous, they might be interpreted as parts of a single stratum of limestone, subsequently broken by faulting. P, Limestone of Pennsylvanian age; N, novaculite. Figures are longer dimensions of boulders in feet.

The boulder-bed member is undoubtedly the product of unusual conditions of sedimentation. Its boulders reach unwieldy proportions and could not easily have been transported far by most of the known processes, yet some of the masses are unlike any now found in place in the region. Moreover, the boulder beds are not basal conglomerates but are intraformational conglomerates in an apparently conformable sequence. The boulder-bed member is not a subordinate layer in the geologic section. East of Haymond station boulder-bearing mudstones extend through a thickness of 900 feet of strata. Moreover, they appear to represent the culmination of a long epoch of unusual sedimentation, for they are overlain and underlain by arkose beds, and these in turn by thin-bedded sandstones and shales in rhythmic alternation. The conditions of sedimentation during this epoch are rendered difficult of interpretation by the strong deformation and deep erosion of the region, which have obliterated most features of the geography of Haymond time.

The differences between the exposures of the boulder-bed member southeast of Gap Tank and those near Haymond station indicate that the source of most of the material in the member lay to the southeast. At the Gap Tank locality the member is thin and the fragments are relatively small; at the Haymond locality the member is thick and the fragments are large. Moreover, the fragments of pre-Cambrian rock and those of fossiliferous Pennsylvanian limestone are very abundant in the southern locality and are very scarce in the northern.

The character of most of the fragments also suggests that they came from the southeast. The pre-Cambrian stones, as well as the arkose with which the boulder bed is associated, appear to have come from highlands of crystalline rock southeast of the Marathon region. The limestone fragments of Maravillas age at the northern locality contain reef-like masses of bryozoans, such as are found only in outcrops along the southeast flank of the Dagger Flat anticlinorium. The chert and novaculite of Caballos age are also like those seen in outcrops in the southeastern rather than the northwestern part of the Marathon Basin.

Some of the blocks, however, have a possible northwestern source. The large block of Dimple limestone southeast of Haymond station contains numerous chert pebbles and thus resembles the formation as it is exposed in the northwestern part of the Marathon Basin. Outcrops of the Dimple formation near the boulder contain few or no pebbles. The fossiliferous Pennsylvanian limestones, which are unlike any strata found in place in the region, are similar to rocks found north of the Marathon geosyncline, such as the limestones near Van Horn, those penetrated in deep wells near Big Lake, and those of the Marble Falls limestone of central Texas.

The center of maximum accumulation of the boulder-bearing mudstones appears to have been west of the summit of Housetop Mountain. The mudstones have the form of long lenses that die out northeastward along the outcrop from this place (pl. 10). Less complete evidence suggests that the mudstones also die out southwestward. The large blocks nowhere occur singly but are everywhere in clusters, the largest of which is also at the Housetop Mountain locality. The clustered nature of the boulders and the lenticular form of the mudstone layers suggest that the deposit had a lobate form, with a boulder cluster in the center of each lobe.

The boulder-bed member appears to have a close relation to orogenic movements. The great variety of rocks in the bed implies a great uplift, and the embedded fragments of Caballos novaculite and Maravillas chert now lie about 10,000 feet above their original positions. Moreover, in both the Haymond and the Gap Tank areas many of the fragments of chert and novaculite are brecciated and crumpled in the same manner that they are in regions of unusually great deformation (as near overthrust faults) in other parts of the Marathon Basin. In most of the outcrops of chert and novaculite there is very little crumpling or brecciation.

The probable southeasterly source of the boulders and their evident relation to orogenic movements make it possible that they were derived from the erosion of thrust sheets advancing from the southeast (B, pl. 20). That thrusting took place during Haymond time is suggested by the occurrence of folded overthrusts in the southeastern part of the Marathon Basin. These must have been formed early in the Marathon orogenic epoch and may be of Haymond age. A fault that may have supplied the sediments of the boulder-bed member is that which extends through Hells Half Acre, south and southeast of the Haymond area. There is some evidence that this fault, although now dipping steeply southward, is an old overthrust fault which may at one time have had a much greater extension toward the northwest (fig. 27). Along most of its trace the fault extends through the Tesnus formation, but along its plane are slices of Maravillas chert, Caballos novaculite, and Dimple limestone, of tectonic origin. These reach several hundred feet in length. Such slices, discharged at the front of the overthrust, are a plausible source for the large blocks found in the boulder-bed member.

The manner in which the boulders were transported from their original to their present positions cannot definitely be proved. It is clear that they were not caused by landslides, ice rafting, or solifluction, because the boulder beds are not like deposits formed by these processes. The boulders strongly resemble both deposits left by glaciers and those caused by mud flows.

Baker [30] has concluded that the exposures of the boulder-bed member near Haymond station are probably of glacial origin. A similar conclusion has also been announced by Carney,[31] but because of his untimely death before his observations could be presented, the evidence on which the conclusion is based is not known. Baker has suggested [32] that the following features are more easily explainable by this process than by any other: (1) The association of the boulder-bed with varved sediments; (2) the interbedding of fine-grained and thinly laminated deposits with the boulder beds; (3) the abrupt beginning and ending of the boulder-bed deposit, without a grading off into finer fragmental material; (4) the sparse distribution of boulders in the matrix and its lack of bedding; (5) the large size of some of the boulders; and (6) the soled or flattened faces of some of the smaller fragments. The mudstone matrix of the boulder bed has a close resemblance to some published photomicrographs of other deposits that have been interpreted as tillites.[33]

The writer feels that many of these features may equally well be interpreted as the work of mud flows. He has the impression that rounded fragments are much more common than soled or flattened ones among the smaller stones; and that a large number of the fragments with flattened faces owe their shape to joints within the rock. Striated stones are by no means common in the deposit, and Blackwelder [34] has found striated fragments in Death Valley and other places, in deposits which he considers most likely to be of mud-flow rather than of glacial origin. Large boulders may occur in glacial deposits, but they are not usually a common feature, whereas large unwieldy blocks are said [35] to be transported for many miles by mud streams, and several Tertiary formations in the western United States interpreted as mud-flow deposits are reported [36] to contain numerous blocks as large as most of those in the Haymond formation.

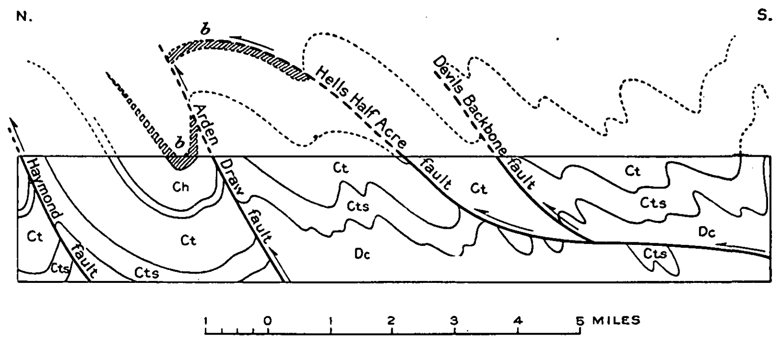


FIGURE 27.—Hypothetical section between exposures of boulder-bed member of Haymond formation and Hells Half Acre fault, showing a reconstruction of structural features now removed by erosion. The boulder bed (*b*) is represented as having been derived from the erosion of material raised up on the overriding block of the Hells Half Acre fault. (Compare pl. 20, *B*.) Dc, Caballos novaculite; Cts, basal shale member of Tesnus formation; Ct, upper part of Tesnus formation; Ch, Haymond formation.

[30] Baker, C. L., op. cit. (Jour. Geology, vol. 40), pp. 602-603.
[31] Carney, Frank, Glacial beds of Pennsylvanian age in Texas: Geol. Soc. America Proc. for 1934, p. 70, 1935.
[32] Baker, C. L., op. cit., pp. 599, 602.

[33] Blackwelder, Eliot, An ancient glacial formation of Utah: Jour. Geology, vol. 40, p. 294, 1932. Sayles, R. W., op. cit. (Harvard Coll. Mus. Comp. Zoology Mem., vol. 47, no. 1), fig. 1, pl. 16.
[34] Blackwelder, Eliot, Striated boulders as evidence of glacial action [abstract]: Geol. Soc. America Bull., vol. 41, p. 154, 1930.
[35] Blackwelder, Eliot, Mud flow as a geologic agent in semiarid mountains: Geol. Soc. America Bull., vol. 39, pp. 470-471, 1928.
[36] Woodford, A. O., The San Onofre breccia: California Univ., Dept. Geology, Bull., vol. 15, pp. 159-280, 1925. Longwell, C. R., The Geology of the Muddy Mountains, Nev.: U. S. Geol. Survey Bull. 798, pp. 68-74, 1928.

Very little evidence for a glacially cold climate is furnished by Pennsylvanian strata in or near the Marathon region. Plant remains are found in beds closely adjacent to the boulder-bearing mudstones. Widespread limestones of the Dimple formation underlie them and are probably equivalent to an even more extensive deposit, the Marble Falls limestone. In northwestern trans-Pecos Texas there are thick limestone deposits with abundant corals which are only slightly younger. As the solubility of calcium carbonate increases in cold water, the continuous deposition of limestone appears to be more characteristic of warm than of cold climates.

According to Blackwelder,[37] mud flows are most likely to form where there is "a mass of earthy material permeated with water somewhat to excess, situated on an oversteepened slope that is not well protected by forest cover. * * * Mud flows are the dominant components of the steepest fans of semiarid mountains." The strong relief suggested by evidence of contemporaneous diastrophism and the dry climate of Haymond time would create conditions favorable for the formation of mud flows. The boulder beds near Haymond station may therefore have been caused by a series of mud flows which spread out along the northwest base of advancing overthrust blocks. The mudflow deposits probably had the form of a series of alluvial fans, with a boulder train in the central part of each fan. At their outer edges the fans merged into the subaqueous sandstone and shale deposits which make up the greater part of the Haymond formation. The boulder bed near Gap Tank was probably an outwash of the smaller and more resistant blocks spread in front of the main deposit.

[37] Blackwelder, Eliot, op. cit. (1928), p. 479.

This interpretation of the boulder beds is suggested tentatively. It is recognized that most of the various features of these beds may be interpreted equally well by glacial processes, and the occurrence in the Gap Tank area of a novaculite block 10 feet across can be readily accounted for at present only by ice rafting. Still other features, such as the occurrence of blocks in the boulder bed which seem to have come from the north, cannot be explained by any of the processes here suggested. It is possible that further evidence will be found in the future that will furnish more clues to the origin of the bed, but at present this does not seem likely, because the possible undiscovered outcrops cannot be of large extent, profound erosion has taken place in the region, and wide areas are covered by Cretaceous rocks.

PERMIAN SERIES

HISTORICAL SUMMARY

The Permian rocks of the Glass Mountains were first studied by Udden[38] in 1915 and 1916, and the ammonoids collected by him were described by Böse.[39] The section was divided by them into formations which are the chief basis for the present classification of the series. In 1925–28 R. E. King and the writer made a geologic map of the mountains and studied the stratigraphy of the Permian rocks.[40] R. E. King[41] described

[38] Udden, J. A., Notes on the geology of the Glass Mountains: Texas Univ. Bull. 1753, pp. 5-59, 1917.

[39] Böse, Emil, The Permo-Carboniferous ammonoids of the Glass Mountains and their stratigraphical significance: Texas Univ. Bull. 1762, 1918.

[40] King, P. B., The geology of the Glass Mountains, pt. 1, Descriptive geology: Texas Univ. Bull. 3038, 1931.

[41] King, R. E., The geology of the Glass Mountains, pt. 2, Faunal summary and description of the Brachiopoda: Texas Univ. Bull. 3042, 1931.

Classifications of Permian rocks in the Glass Mountains

<table>
<tr><th>Udden, 1916</th><th>Udden, 1917</th><th>King and King, 1930</th><th>This report</th></tr>
<tr><td colspan="4">Cretaceous rocks at top of section</td></tr>
<tr><td></td><td></td><td>Bissett formation.</td><td>Bissett conglomerate (Triassic?).</td></tr>
<tr><td rowspan="2">Gilliam formation.</td><td>Tessey formation.</td><td rowspan="3">Capitan formation (containing Tessey, Gilliam, Vidrio, and Altuda members).</td><td>Tessey limestone.</td></tr>
<tr><td>Gilliam formation.</td><td rowspan="2">Capitan limestone (containing Gilliam, Vidrio, and Altuda members).</td></tr>
<tr><td>Vidrio formation.</td><td>Vidrio formation.</td></tr>
<tr><td>Word formation.</td><td>Word formation.</td><td>Word formation (divided locally into members).</td><td>Word formation (divided locally into members).</td></tr>
<tr><td rowspan="2">Leonard formation.</td><td>Leonard formation.</td><td>Leonard formation.</td><td rowspan="2">Leonard formation (divided locally into members, including Hess thin-bedded limestone member).</td></tr>
<tr><td>Hess formation.</td><td>Hess formation.</td></tr>
<tr><td rowspan="2">Gaptank formation.</td><td>Wolfcamp formation.</td><td>Wolfcamp formation.</td><td>Wolfcamp formation.</td></tr>
<tr><td colspan="3">Gaptank formation (Pennsylvanian) at base.</td></tr>
</table>

the brachiopods collected during the course of the field work. Some changes were made in the previous classification of the strata, and one new formation was added to the section. In the present paper further modifications are made in the nomenclature, and the section is divided into five formations. The table on page 92 shows the present classification of the rocks in the Glass Mountains and its relation to the terminology of the previous reports.

GENERAL FEATURES

Rocks of Permian age crop out in the Glass Mountains along the northern flank of the Marathon uplift (pl. 23). They are tilted gently toward the north and northwest, away from the greatly disturbed older rocks of the Marathon Basin, on which they rest unconformably. The limestones of the series rise in cuestas, whose cliffs and escarpments face toward the south and southeast. They are separated by valleys and lowlands carved from the interbedded sandy and shaly strata.

which the *Productus* group greatly predominates. The brachiopods also include several strange types, such as *Leptodus*, *Scacchinella*, *Teguliferina*, and *Prorichthofenia*. The last three are so greatly modified from the typical brachiopod form that they resemble corals or rudistids. In the higher part of the Glass Mountains section the more massive limestones appear to have been constructed by reef-making algae, whose remains are numerous in the rock. The fossils in many of the layers have been very perfectly replaced by silica, so that their delicate internal structures can be revealed by dissolving the matrix in acid.

The relations of the various types of rock in the Permian series of the Glass Mountains are exceedingly complex, and there are great variations in thickness and lithology along the strike of the mountains (fig. 28). As a result of lateral changes, the rocks in the northeast are mostly bedded limestones, whereas in the southwest shales and sandstones predominate. These two facies persist through nearly the entire section, indicating the continuance for a long period of time of two

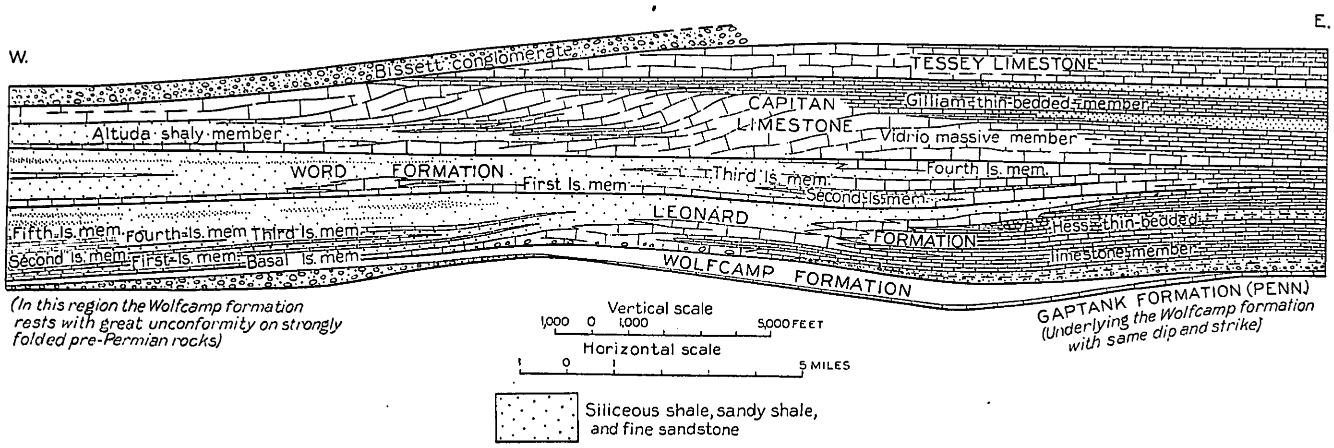


FIGURE 28.—Stratigraphic diagram of Permian rocks in the Glass Mountains. The diagram extends from the southwest to the northeast end of the mountains. Based on field work by P. B. and R. E. King.

The Permian rocks attain a thickness of 5,000 to 7,000 feet and are all of marine origin. Their upturned edges are exposed in continuous succession across the mountains, almost uninterrupted by faults and other structural complications. They consist of limestones, in part dolomitic, siliceous shales, clay shales, and sandstones. In the lower part are many beds of conglomerate whose fragments were derived from the erosion of older Paleozoic rocks raised by the Marathon disturbance.

The fossils in the Permian rocks of the Glass Mountains are mostly marine invertebrates, which are in large part of Guadalupian type. They include many Foraminifera (especially fusulinids of large size), sponges, corals, echinoids, crinoids; a fine assemblage of ammonoids; some nautiloids, pelecypods, and gastropods; profuse bryozoans; and a whole host of brachiopods, in

facies of deposition. Between the area of bedded limestone and the area of clastic deposits there are in many places thick beds of crystalline, noncherty limestone with indistinct, irregular bedding planes. These are interpreted as limestone reefs, and the growth of such reef masses is believed to have influenced the development of the lithologic facies.

As shown in the preceding table, the Glass Mountains section is now divided into five formations. The lower formation, the Wolfcamp, is set off from the beds above by an unconformity. That part of the section above the unconformity comprises by far the greater thickness of the series, and here the lateral changes in the strata are most striking. In places tongues of the limestone facies of the northeastern part of the mountains extend southwestward into the shale and sandstone facies. Two of these tongues are more persistent than the rest, are readily traceable in the field, and mark times of maximum limestone deposition. In addition, they apparently separate faunas of slightly different character. On the basis of the persistent limestone beds and other criteria, the main part of the Glass Mountains section is divided into four formations—the Leonard, Word, Capitan, and Tessey.

WOLFCAMP FORMATION

GENERAL FEATURES

The Wolfcamp is the oldest formation of the Glass Mountains section and crops out in scattered exposures in the southern foothills of the mountains. In the western part of the mountains it rests with strong unconformity on the older Paleozoic rocks of the Marathon Basin. To the east this unconformity is no longer evident, and the formation rests with no marked difference in dip or strike upon the higher members of the Pennsylvanian. The top of the formation is everywhere a well-marked plane of unconformity, by which it is separated from the succeeding Leonard formation.

In the western part of the mountains, where the formation encroaches on the strongly folded older rocks, there are several hundred feet of coarse conglomerate at the base, succeeded by shales and sandstones. In the eastern part of the mountains the formation contains no coarse clastic materials and consists of green or blue clay shales, with many thin fossiliferous limestone beds. The maximum thickness of the formation is about 600 feet.

LOCAL FEATURES

Wolf Camp area.—The Wolfcamp formation was set off in 1917 by Udden [42] and Böse,[43] with its type locality in the hills north of Wolf Camp (pl. 23). Wolf Camp is in the present Taylor or White ranch, 12 miles northeast of Marathon, and is "the site of an old dwelling place, just to the south of two buttes, * * * and is marked by an old open well some hundred feet deep." [44] The formation was separated from the uppermost Pennsylvanian (Gaptank) formation on the basis of fossils of Permian aspect collected at this locality.

The section at Wolf Camp, as shown by Udden, includes at the base shales and limestones of Pennsylvanian age, succeeded by 100 feet of shale containing the ammonoids described by Böse as the *Uddenites* fauna. These are in turn succeeded by a thick-bedded limestone, which is here considered to be the basal bed of the Wolfcamp formation. Above this are several hundred feet of shales and thin limestones, which extend up to the basal conglomerate of the overlying Leonard formation.

Since the original work in the area the Wolfcamp formation and its fossils have been studied by various geologists. The upper part of the formation has been generally considered to be of Permian age, but the shale containing the *Uddenites* fauna has been interpreted as uppermost Pennsylvanian by some paleontologists and as lowermost Permian by others. The writer here includes it in the Gaptank formation, and considers it to be Pennsylvanian.

The following section was measured at the west end of the hills north of Wolf Camp. The section begins on the north side of an outlying butte capped by the gray limestone member of the formation and continues north along the west side of a small canyon that drains through the hills from the main escarpment of the mountains.

Section of Wolfcamp formation north of Wolf Camp

	Feet
Basal conglomerate of Leonard formation.	
Wolfcamp formation:	
Upper shale member:	
21. Greenish-drab shale	57
20. Granular brown limestone	1
19. Mostly covered with some greenish shale	56
18. Finely granular brown limestone containing crinoid stems and limestone pebbles	2
17. Mostly covered, with a few thin ledges of brown limestone	105
16. Finely granular brown limestone	2
15. Covered	38
14. Granular brown limestone, with some limestone pebbles and crinoid stems	3
13. Covered, with an indistinct limestone ledge near the middle	38
12. Granular gray limestone, with limestone pebbles in upper part. Forms a ledge of considerable prominence and contains numerous fossils	10
11. Covered	35
10. Granular brown limestone, with scattered fossils	2
9. Covered where section was measured. Farther east, from limestones and shales at this horizon, numerous fossils were collected	19
8. Dark-gray limestone, sparingly fossiliferous	3
7. Shale, mostly covered	103
6. Granular brown limestone, crowded with crinoid stems and brachiopod fragments	2
5. Soft blue or black shale	58
Gray limestone member:	
4. Brown, irregularly crystalline limestone, containing crinoid stems, rounded pebbles, and some fossils	4
3. Limestone, poorly exposed	8
2. Massive gray limestone, containing some fossil fragments. Thickness variable	37
Total thickness of Wolfcamp formation	583

[42] Udden, J. A., Notes on the geology of the Glass Mountains: Texas Univ. Bull. 1753, pp. 41-43, 1917.

[43] Böse, Emil, The Permo-Carboniferous ammonoids of the Glass Mountains and their stratigraphical significance: Texas Univ. Bull. 1762, p. 16, 1917.

[44] Udden, J. A., op. cit., p. 42.

Section of Wolfcamp formation north of Wolf Camp—Continued

Gaptank formation:

1. *Uddenites* zone: Greenish-drab clay shale, in part calcareous, with two thin layers of brown granular limestone in the upper part, and some beds of shaly limestone. The thickness varies within short distances from a few feet to 113 feet.

Limestone ledge.

Exposures in Monument Spring quadrangle.—In the Monument Spring quadrangle the Wolfcamp formation crops out along the northwest edge of the Marathon Basin, on the face of the Permian escarpments (pl. 24). Its most prominent exposures are on the south slope of Dugout Mountain, southwest of Lenox. In this region the base of the formation is a thick coarse conglomerate which rests on the upturned edges of the Gaptank formation and various older members of the Paleozoic. The basal conglomerate reaches a maximum thickness of 450 feet near Lenox. It thins out to a few feet to the northeast and also thins westward along the face of Dugout Mountain. The conglomerate is overlain by shales and sandstones, with a few thin fossiliferous limestone beds.

The following section was measured on the face of Dugout Mountain, immediately to the south of its highest summit:

Section of Wolfcamp formation on Dugout Mountain

Conglomeratic limestone of Leonard formation.

Wolfcamp formation:

	Feet
Upper shale member:	
4. Greenish sandy shale, containing a few fossils	30
3. Hard, coarsely crystalline dark-gray limestone, weathering brown. Contains ammonoids and brachiopods	3
2. Greenish sandy shale. These three upper layers are cut out to the east by the unconformity at the base of the Leonard formation, so that the Leonard rests directly on the basal conglomerate of the Wolfcamp formation at the east end of the mountain	30
Conglomerate member:	
1. Massive brown calcareous conglomerate in rounded ledges. The fragments consist of pebbles, cobbles, and boulders of white limestone, gray sandy limestone, chert, and novaculite. They are closely set in a matrix of gray limestone	330
Total	393

Shales and sandstones of lower part of Gaptank formation, tilted at high angles.

FOSSILS AND AGE

FOSSILS OF THE TYPE SECTION

The Wolfcamp formation at Wolf Camp contains numerous fossils at various horizons. Brachiopods collected from the formation have been identified by R. E. King [45] and fusulinids by J. W. Beede,[46] C. O. Dunbar,[47] and M. P. White.[48] The lists given below are compiled from their papers. The other groups of fossils have not yet received detailed study. Fossils from the *Uddenites* zone and other beds underlying the Wolfcamp formation at Wolf Camp are listed under the Gaptank formation.

Gray limestone member.—The member of gray limestone which lies above the *Uddenites* zone of the Gaptank formation does not contain many recognizable fossils. However, a few brachiopods from the limestone in the hills north of Wolf Camp have been identified. Bed 2 of the section has yielded the following species (R. E. King localities 168 and 200 [48a]):

Triticites, sp.
Meekella irregularis var. *texanus* King.
Pustula semipunctata (Shepard).
Composita subtilita var. *angusta* King.

Sellards [49] reports that Plummer has collected *Schistoceras hyatti* Smith from this bed.

From bed 4 of the section, a brown crystalline limestone regarded as the top of the gray limestone member, the following fossils have been identified (R. E. King locality 89):

Triticites pinguis Dunbar and Skinner.
Triticites uddeni Dunbar and Skinner.
Triticites subventricosus Dunbar and Skinner.
Paraschwagerina kansasensis (Beede).
Parenteletes cooperi King.
Orthotetella wolfcampensis King?
Chonetes granulifer Owen (small type).
Productus semireticulatus var. *hermosanus* Girty.
Marginifera wabashensis Norwood and Pratten.
Spirifer triplicatus Hall.
Punctospirifer kentuckyensis (Shumard).
Hustedia mormoni (Marcou).
Composita subtilita (Hall).

Paraschwagerina kansasensis has also been found in the Neva limestone of Kansas, which is a member of the Wabaunsee group, at the top of the Pennsylvanian series.

Bed 8.—Bed 8 of the section is a thin layer of granular limestone. It contains the following fossils (R. E. King locality 90):

[45] King, R. E., The geology of the Glass Mountains, pt. 2: Texas Univ. Bull. 3042, 1931.

[46] Beede, J. W., and Knicker, H. T., Species of the genus *Schwagerina* and their stratigraphic significance: Texas Univ. Bull. 2433, 1924.

[47] Dunbar, C. O., and Condra, G. E., The Fusulinidae of the Pennsylvanian system in Nebraska: Nebraska Geol. Survey, 2d ser., Bull. 2, 1927. Dunbar, C. O., and Skinner, J. W., New fusulinid genera from the Permian of west Texas: Am. Jour. Sci., 5th ser., vol. 22, pp. 252–268, 1930. For this formation and higher formations of the Permian, complete information on the fusulinids is given in Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas: Geology of Texas, vol. 3, Texas Univ. Bull. 3701, 1937.

[48] White, M. P., Some Texas Fusulinidae: Texas Univ. Bull. 3211, 1932.

[48a] Fossils of the R. E. King collection are deposited in the Peabody Museum of Yale University and the museum of the Bureau of Economic Geology, University of Texas.

[49] Sellards, E. H., Geology of Texas, vol. 1, Stratigraphy: Texas Univ. Bull. 3232, p. 148, 1933.

Rhipidomella carbonaria (Swallow).
Orthotichia kozlowskii King.
Orthotetella wolfcampensis King.
Meekella irregularis var. *texana* King?
Productus semistriatus Meek.
Linoproductus cora (D'Orbigny).
Rhynchopora illinoisensis (Worthen).
Squamularia perplexa (McChesney).
Hustedia mormoni (Marcou).
Composita subtilita (Hall).

Bed 9.—The succeeding shales and thin limestones in bed 9 of the section are not everywhere well exposed. However, on the banks of a small canyon that drains through the hills north of Wolf Camp, a few hundred yards east of the slope where the section was measured, the following fossils were collected from loose blocks derived from this bed and the immediately succeeding layer (R. E. King locality 93):

Neofusulinella kingi Dunbar and Skinner.
Triticites subventricosus Dunbar and Skinner.
Triticites uddeni Dunbar and Skinner.
Paraschwagerina kansasensis (Beede).
Schwagerina diversiformis Dunbar and Skinner.
Schwagerina franklinensis Dunbar and Skinner.
Schwagerina compacta Dunbar and Skinner.
Rhipidomella carbonaria (Swallow).
Streptorhynchus pyramidale King.
Orthotetella wolfcampensis King.
Meekella irregularis var. *texana* King?
Meekella striaticostata (Cox).
Derbya buchi (D'Orbigny).
Productus gratiosus var. *occidentalis* Schellwien.
Productus semireticulatus var. *hermosanus* Girty.
Linoproductus cora (D'Orbigny).
Pustula semipunctata (Shepard).
Buxtonia occidentalis King.
Avonia boulei (Kozlowski).
Marginifera capaci (D'Orbigny).
Aulosteges wolfcampensis King.
Strophalosia hystricula Girty.
Parakeyserlingina fredericksi King.
Camarophoria thevinini Kozlowski.
Spirifer condor D'Orbigny.
Spirifer triplicatus Hall.
Squamularia guadalupensis Shumard.
Martinia wolfcampensis King.
Hustedia mormoni (Marcou).
Composita subtilita (Hall).

Bed 12.—From a thick bed of gray limestone, bed 12 of the section, and from the layers immediately above it the following fossils were collected north of Wolf Camp and in the hills to the west (R. E. King localities 87 and 91):[50]

Schwagerina longissimoidea (Beede).
Schwagerina huecoensis (Dunbar and Skinner).
Pseudoschwagerina fusulinoides (Schellwien).
Pseudoschwagerina gigantea (White).
Pseudoschwagerina uddeni (Beede).
Rhipidomella carbonaria (Swallow).
Orthothetina cf. O. mutabilis (Girty).
Orthotetella wolfcampensis King.
Derbya buchi (D'Orbigny)?
Meekella striaticostata (Cox)?
Chonetes spinoliratus King.
Chonetes verneuilianus Norwood and Pratten?
Productus gratiosus var. *occidentalis* Schellwien.
Productus semireticulatus var. *hermosanus* Girty.
Buxtonia occidentalis King.
Aulosteges wolfcampensis King?
Marginifera capaci (D'Orbigny).
Strophalosia hystricula Girty.
Parakeyserlingina fredericksi King.
Spirifer texanus Meek.
Spirifer triplicatus Hall.
Martinia wolfcampensis King.
Hustedia mormoni (Marcou).
Dielasma bovidens (Morton).

Three of the fusulinids in this collection—*Schwagerina huecoensis*, *Pseudoschwagerina fusulinoides*, and *P. uddeni*—are also found in the basal part of the Hueco limestone in the Hueco Mountains.[51] One of the other fusulinids, *Schwagerina longissimoidea*, is found in the Harpersville and Putnam formations of central Texas and in the Elmdale shale of the Wabaunsee group in Kansas.[52]

Bed 14.—The highest fossiliferous layer in the section at Wolf Camp is bed 14, a thin limestone in the upper shales of the Wolfcamp formation, from which the following fossils were collected (R. E. King locality 92):

Pseudoschwagerina uddeni (Beede).
Pseudoschwagerina texana Dunbar and Skinner.
Schwagerina diversiformis Dunbar and Skinner.
Schwagerina franklinensis Dunbar and Skinner.
Orthotichia kozlowskii King.
Orthotetella wolfcampensis King.
Meekella irregularis var. *texana* King.
Chonetes spinoliratus King.
Productus semireticulatus var. *hermosanus* Girty.
Productus semistriatus Meek.
Linoproductus cora (D'Orbigny).
Marginifera capaci (D'Orbigny).
Aulosteges wolfcampensis King.
Spirifer texanus Meek.
Composita subtilita (Hall).
Hustedia mormoni (Marcou).

AGE OF THE WOLFCAMP FORMATION IN THE TYPE SECTION

The fusulinid genus *Pseudoschwagerina*, which occurs in bed 12 and elsewhere in the Wolfcamp formation, also occupies a well-marked zone in northwestern trans-Pecos Texas, in central Texas, and in the northern

[50] Some of the fusulinids in this layer have been reported from lower horizons. Beede and Knicker (op. cit., pp. 52–55) reported *Pseudoschwagerina uddeni* from a bed below the *Uddenites* zone at Wolf Camp, and M. P. White reported *P. fusulinoides* from the upper part of the Gaptank formation at Gap Tank, and *P. uddeni* and *Schwagerina longissimoidea* from the lower part of the Wolfcamp formation at Wolf Camp. All these authors are apparently in error, and as the material studied was not collected by them, it was probably incorrectly labeled in the field. According to Sellards (op. cit., p. 149), White's second collection came from "the basal 5 feet of bed 13"; his first collection was probably obtained from the outcrop of Wolfcamp mapped by the writer at Gap Tank (pl. 23).

[51] Dunbar, C. O., and Skinner, J. W., op. cit., p. 258.

[52] White, M. P., op. cit., p. 23. Dunbar, C. O., and Condra, G. E., op. cit., p. 116.

midcontinent area. It is found in the lower part of the Hueco limestone in the Hueco Mountains, in the Moran formation (upper Cisco) in central Texas, and in the Neva limestone and higher beds (Wabaunsee group) in Kansas. The associated genus *Schwagerina* has a similar but somewhat more extended range. The Hueco formation as now restricted is classified by the United States Geological Survey as Permian (?), the Moran as Permian, and the Neva as Pennsylvanian. R. E. King [53] notes that in the Wolfcamp formation "many interesting brachiopod types make their first appearance, * * * heralding the developments of the succeeding faunas. Ancestors of *Prorichthofenia* and *Leptodus* are present, and the productids show a great expansion."

FOSSILS AND AGE OF THE WOLFCAMP FORMATION IN THE MONUMENT SPRING QUADRANGLE

Northeast of Lenox the following fossils have been collected from the Wolfcamp formation at various places between the railway and the road to the Sullivan ranch (Altuda quadrangle) (R. E. King localities 70–74). The brachiopods, as in the preceding lists, were identified by R. E. King.

Pseudoschwagerina sp.
Schwagerina linearis Dunbar and Skinner.
Orthothetina cf. *O. mutabilis* (Girty)?
Meekella irregularis var. *texana* King.
Aulosteges medlicottianus Waagen?
Aulosteges wolfcampensis King.
Teguliferina bösei King.
Parakeyserlingina fredericksi King.

In this same region ammonoids have been collected in 1917 by Böse [53a] and in 1931 by C. L. Baker. From Baker's collection, which was made at a point "2 miles northwest of Poplar Tank on Decie's ranch" and from "fossiliferous limestone 20 to 30 feet above the base of the formation", Plummer and Scott [54] have identified the following species:

Artinskia adkinsi Plummer and Scott.
Metalegoceras aricki Plummer and Scott.
Paragastrioceras deciense Plummer and Scott.
Vicrioceras subquadratum Plummer and Scott.
Perrinites bakeri Plummer and Scott.
Prothalassoceras welleri Böse.

From bed 3 of the section on Dugout Mountain (R. E. King locality 193) the following fossils have been identified:

Pseudoschwagerina sp.
Chonetes biplicatus King.
Productus huecoensis King.
Linoproductus villiersi (D'Orbigny)?
Avonia boulei (Kozlowski).
Marginifera dugoutensis King.
Aulosteges wolfcampensis King.
Teguliferina bösei King.
Camarophoria venusta Girty?
Spirifer triplicatus Hall.
Hustedia mormoni (Marcou).
Composita subtilita var. *angusta* King.

In addition, numerous ammonoids have been found in the bed, which according to Plummer [55] are of the same genera and probably of the same species as those listed above from the Decie ranch. From float in bed 4 of the same section *Parakeyserlingina fredericksi* King and *Spirifer condor* have been collected.

All the brachiopods from the Wolfcamp formation in the Monument Spring quadrangle are characteristic of the formation at the type locality, and the fusulinid also occurs there abundantly. These fossils have not been found in higher parts of the Permian section, and only a few have been found as low as the *Uddenites* zone beneath. No ammonoids, however, have been found in the type section. According to Plummer and Scott,[55a] the ammonoids collected in the Monument Spring quadrangle are very similar to those in the Indian Creek shale member of the Admiral formation, about 50 feet above the Coleman limestone, in the Wichita group of central Texas. They state

> The two localities do not represent exactly the same stratigraphic zone, and the ammonites from the two localities are not identical; however, they are so closely related and have sutures so nearly in the same stage of development that they are not separated by many feet of beds. * * * Two representatives of the group occur in the Florena shale of the Big Blue group in southern Cawley County, Kans. * * * Similar forms are described from the lower Artinskian of Russia.

STRATIGRAPHIC RELATIONS

There is a well-marked unconformity between the Wolfcamp formation and the overlying Leonard formation. Sufficient erosion took place before Leonard time to remove considerable thicknesses of Wolfcamp beds in places. At many localities there is also a divergence in dip of 5° or 10° between the two formations.[56] The base of the Leonard along the whole mountain front is marked by beds of conglomerate. There is also clear evidence of marked overlap at the base of the Leonard, as on the horst north of the Hess ranch, where 300 feet of basal Leonard strata pass out by overlap in a distance of 2 miles.

[53] King, R. E., op. cit., p. 7.
[53a] Böse, Emil, Permo-Carboniferous ammonoids of the Glass Mountains and their stratigraphical significance: Texas Univ. Bull. 1762, p. 106, 1917. The ammonoid identified by Böse, *Prothalassoceras welleri* Böse, was assigned by him to the Hess formation.
[54] Plummer, F. B., and Scott, Gayle, Upper Paleozoic ammonites in Texas: Texas Univ. Bull. 3701, p. 22, 1937.
[55] Letter, July 1932.
[55a] Plummer and Scott, op. cit., p. 391.
[56] King, P. B., The geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, p. 57, fig. 20 (upper), 1931.

LEONARD FORMATION

HISTORICAL SUMMARY

The Leonard formation was named by Udden [57] in 1916 from exposures on and north of Leonard Mountain, which is 10 miles north of Marathon. In 1917 the limestones northeast of the Hess ranch were taken out of the formation and called the "Hess formation",[58] because they were thought to be separated by an unconformity [59] from the beds above. Later work has shown that this unconformity does not exist, and in 1932 the writer [60] presented evidence which indicated that the limestones typical of the Hess formation were largely equivalent to the shales and thin limestones typical of the Leonard formation. The two facies were interpreted as being separated by limestone reefs. In the present paper the two units are brought together in a single formation, the Leonard, in accordance with Udden's original definition, and the Hess is designated the "Hess thin-bedded limestone member."

GENERAL FEATURES

The Leonard formation crops out in a belt 2 or 3 miles wide for 40 miles along the front of the Glass Mountains. Its aggregate thickness is nowhere less than 2,000 feet.

In the southwestern part of the mountains the strata of the formation are a prevailingly clastic series of interbedded siliceous shale (with Radiolaria), clay shale, and sandstone, with thin interbedded layers of limestone and conglomerate. Many of the limestones are coarsely clastic and are composed of abraded shells, crinoid columns, and other fragments. Pebbles of limestone and chert are embedded in many of the limestone layers. In places in the western part of the mountains there are several limestone members as much as 100 feet thick.

In the northeastern part of the mountains beds of this sort occupy only the uppermost several hundred feet of the formation (fig. 28). Beneath is a mass of thin-bedded dirty-gray dolomitic limestone, with few fossils other than fusulinids. This is the Hess thin-bedded limestone member of the Leonard formation.

Between the northeastern and southwestern areas there is a region of much faulted and disturbed strata, without any complete sections of the lower Permian formations. In this region there are bold but disconnected hills, made up for the most part of massive gray and white limestone. This limestone intergrades with the thin-bedded limestones of the Hess member northeast of the Hess ranch (fig. 28). On Leonard Mountain (pl. 23), one of the disconnected hills, the massive limestones also intergrade westward with siliceous shales and thin limestones like those that form the predominant part of the formation in the southwestern part of the mountains. The form of the massive limestone beds on Leonard Mountain suggests that they stood at some height above the sea bottom on which the shaly strata to the west were laid down, and the fossils found in them suggest adaptation to a reef environment.

The base of the Leonard formation is drawn at the unconformity that separates it from the Wolfcamp formation. The top is drawn at the base of a persistent limestone bed that is considered to be the lowest member of the Word formation. Paleontologically the top of the Leonard marks the highest occurrence of *Perrinites vidriensis* and associated fossils. In the overlying Word formation, *Waagenoceras* and associated ammonoids extend down into the lowest limestones.

EXPOSURES IN THE MONUMENT SPRING QUADRANGLE

The Leonard formation crops out over a wide area in the northwestern part of the Monument Spring quadrangle (pl. 24). It forms the greater part of the mass of Dugout Mountain and of the hills northeast of Lenox. It consists mostly of siliceous shales and fine sandstones, such as characterize the formation at other places in the western part of the mountains. In the lower part are six prominent limestone members, which crop out in prominent cliffs and cuestas. The following section was measured on Dugout Mountain, from its highest summit northwestward down the back slope to the old Payne ranch:

Section of Leonard formation on Dugout Mountain

Word formation.	
Leonard formation:	*Feet*
22. Drab clay shale, with some thin sandy beds and two dense brown limestone layers, weathering orange, which contain *Perrinites vidriensis* Böse, *Meekella attenuata* Girty, *Marginifera reticulata* King, *Aulosteges medlicottianus* Waagen, *Prorichthofenia likharewi* King, and *Camarophoria venusta* Girty (R. E. King locality 226)	127
21. Fine-grained shaly sandstone, in flaggy beds a few inches thick	105
20. Pink and purplish massive quartzitic sandstone, containing layers crowded with rounded pebbles of chert and quartz	40
19. Covered across valley	525
18. Fifth limestone member: Coarsely crystalline gray limestone, full of fossil fragments	12
17. Siliceous shale	128
16. Fourth limestone member: Dark-gray finely crystalline limestone, with interbedded siliceous shale. The limestone contains *Derbya nasuta* Girty?, *Marginifera cristobalensis* Girty, *Marginifera? whitei* King, and *Hustedia mormoni* var. *papillata* (Shumard) (R. E. King locality T 226)	12

[57] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, 1st ed., pp. 51-52, 1916 (changed in later editions).

[58] Udden, J. A., Notes on the geology of the Glass Mountains: Texas Univ. Bull. 1753, pp. 43-48, 1917.

[59] Idem, p. 45. Beede, J. W., Notes on the geology of the northern Diablo Plateau in Texas: Texas Univ. Bull. 1852, pp. 29-30, 1920.

[60] King, P. B., Limestone reefs in the Leonard and Hess formations of trans-Pecos Texas: Am. Jour. Sci., 5th ser., vol. 34, pp. 338-354, 1932.

Section of Leonard formation on Dugout Mountain—Continued

	Feet
Leonard formation—Continued.	
15. Siliceous shale with an 8-foot bed of friable sandstone in the upper part	126
14. Brown limestone, containing abundant quartz pebbles	8
13. Siliceous shale, with thin sandstone beds and two intercalated layers of fossiliferous limestone	242
12. Third limestone member: Light-gray irregularly crystalline limestone, full of silicified fossils. There are a few pebbles of chert in the limestone	21
11. Brown siliceous shale, with some sandy beds, and a few layers of limestone	54
10. Second limestone member: Gray sandy limestone, with abundant chert pebbles and *Chonetes subliratus* Girty, *Marginifera reticulata* King, and *Camarophoria venusta* Girty (R. E. King locality 227)	15
9. Coarse-grained calcareous sandstone	10
8. Siliceous shale	26
7. First limestone member: Light-gray irregularly crystalline limestone, in thick, massive ledges. Chert pebbles are rather common in the lower part, and near the top are abundant fossils, which include *Schwagerina hessensis* Dunbar and Skinner, *Schwagerina hawkinsi* Dunbar and Skinner, *Streptorhynchus lamellatum* King, *Marginifera cristobalensis* Girty, *Marginifera reticulata* King, *Aulosteges magnicostatus* Girty, *Prorichthofenia likharewi* King, and *Spiriferina hilli* Girty (R. E. King locality 228)	153
6. Covered	21
5. Siliceous shale, with several 2-foot ledges of finely crystalline limestone, containing chert pebbles and fossils	74
4. Gray crystalline limestone, containing some pebbles and fossils	10
3. Siliceous shale	13
2. Basal limestone member: Gray coarsely crystalline limestone in 2-foot ledges, containing scattered pebbles and various fossils, including *Enteletes plummeri* King, *Productus schucherti* King, *Linoproductus waagenianus* (Girty), *Squamularia guadalupensis* (Shumard), *Spiriferina hilli* Girty?, and *Composita subtilita* (Hall) (R. E. King locality 205)	47
1. Coarse gray calcareous conglomerate, made up of boulders reaching 3 feet across, of limestone, and of conglomerate like the Wolfcamp conglomerates below. The matrix is a gray limestone. This bed is massive and breaks along smooth vertical joints	25
Total	1, 844
Erosional unconformity.	
Wolfcamp formation.	

FOSSILS AND AGE

General features.—The fossils of the Leonard formation are characteristically Permian, for they include such brachiopod genera as *Prorichthofenia* and *Leptodus*, as well as large fusulinids and ammonoids of complex suture. They lack, however, some elements of the more highly developed faunas above, in the typical Guadalupian, and several brachiopod species are reported by R. E. King to continue unchanged into the formation from the Pennsylvanian. The statements on the brachiopods of the Leonard formation given below are compiled from King's paper,[61] and those on the ammonoids from Böse's work.[62] C. O. Dunbar has kindly furnished some unpublished information on the fusulinids.

The fossils of the formation are most abundant in thin limestones interbedded with the siliceous shales of the southwestern part of the Glass Mountains. They are also found in the massive limestones of the central part of the mountains, and a sparse fauna has been obtained from a few layers in the thin-bedded limestones on the northeastern part. The changes in lithology of the formation along the strike of the mountains have given rise to considerable differences in the faunal facies, but some characteristic lower Permian fossils are found in both the eastern and the western exposures of the formation.

Long-ranging fossils in the formation.—Some of the fossils of the Leonard formation have long ranges and extend up unchanged from the Pennsylvanian or are found throughout the Permian. *Composita subtilita* (Hall), a common Pennsylvanian brachiopod, is present at many places in the formation but does not continue into the higher strata. *Linoproductus cora* var. *angustus* King, a variety of the well-known Pennsylvanian species, is found in the northeastern exposures of the formation. *Camarophoria venusta* Girty, *Hustedia meekana* (Shumard), and *Squamularia guadalupensis* (Shumard) are common brachiopods in the Leonard formation but are also found in the Wolfcamp formation, and occur abundantly in strata above the Leonard.

Characteristic lower Permian fossils of the formation.—Some of the fossils of the Leonard formation are unlike those found in the higher strata or in the underlying Wolfcamp formation. Some of the other fossils are unlike those found in the Wolfcamp formation and mark the first appearance of genera or species that reach a more advanced development in strata above the Leonard.

The Leonard formation marks the first appearance of the fusulinid genus *Parafusulina*, which is also found in the succeeding Word formation. Some members of the genus attain considerable size in the Leonard, but none are as large as the largest in the succeeding beds. The genus *Schwagerina* also extends from the underlying Wolfcamp into the lower part of the formation, where the species *Schwagerina hessensis* Dunbar and

[61] King, R. E., The geology of the Glass Mountains, pt. 2: Texas Univ. Bull. 3042, 1931.

[62] Böse, Emil, Permo-Carboniferous ammonoids of the Glass Mountains and their stratigraphical significance: Texas Univ. Bull. 1762, 1919.

Skinner and *S. crassitectoria* are found. Fusulinids of these genera are abundant in the Hess thin-bedded limestone member of the formation and are found only sparingly in the rocks of the southwestern part of the mountains.[63]

The Leonard formation contains several species of the ammonoid *Perrinites*, a genus which makes its first appearance in the upper part of the Wolfcamp formation and which is not found in the Word formation. *Perrinites vidriensis* Böse is the most abundant Leonard species. A closely related form, *Perrinites compressus* Böse, is found in the upper part of the Hess thin-bedded limestone member in the northeastern part of the Glass Mountains. With *Perrinites vidriensis* is commonly found *Medlicottia whitneyi* Böse, a member of a characteristic Permian genus which, as Smith [64] has suggested, may be descended from the genus *Uddenites* of the upper part of the Gaptank formation. According to F. B. Plummer [65] *Perrinites vidriensis* is more nearly similar in development to two undescribed species of *Perrinites* in the Clear Fork group than it is like ammonoids from any other zone in the central Texas Permian. Sellards [66] states, however, that a new species of *Perrinites* which occurs in the Blaine formation "is very close to *P. vidriensis*."

The Leonard formation is characterized throughout its extent by *Productus ivesi* Newberry, a brachiopod which, in the Glass Mountains, is restricted to this formation. With it are commonly associated *Productus occidentalis* Newberry, *Marginifera manzanica* (Girty), and *Marginifera cristobalensis* (Girty), of which only the first ranges into higher formations. These species are common fossils in the upper part (San Andres limestone member), of the Chupadera formation of New Mexico, and *Productus ivesi* is also one of the most abundant brachiopods of the Kaibab limestone in the Grand Canyon region.

The Leonard formation contains three species of the highly specialized brachiopod genus *Prorichthofenia*. One of these, *Prorichthofenia teguliferoides* King, is found at three localities in the lower part of the formation and represents a stage "intermediate in structure between *Teguliferina* and the more specialized forms of *Prorichthofenia*." [67] At higher levels in the formation two more advanced species, *Prorichthofenia likharewi* King and *Prorichthofenia uddeni* (Böse) are abundant, but they do not continue into the Word formation.

The Leonard formation also contains *Leptodus nobilis* var. *americanus* Girty. The genus *Leptodus* is probably in the line of descent from *Parakeyserlingina*, which is found in the Wolfcamp formation. The species continues above the Leonard formation into the higher strata of the Permian.

A possible lower Leonard faunule.—In the lower part of the Leonard formation in the western part of the mountains there is apparently a distinct brachiopod faunule which does not extend into higher beds. The group includes the primitive richthofenid *Prorichthofenia teguliferoides* King, and in addition *Spiriferina angulata* King, *Hustedia hessensis* King, *Streptorhynchus* (?) *undulatum* King, and *Enteletes plummeri* King. All these species are found in massive limestones in the lower part of the formation, and *Enteletes plummeri* ranges several hundred feet higher into the interbedded thin limestones and siliceous shales.

Faunal facies of the Leonard formation.—The fossils described above appear to have a more or less well-marked vertical range. In addition to the vertical changes in faunas there is also a marked lateral change, which, together with the marked lateral changes in lithology, has been brought about by the sharply contrasted environments of deposition that existed in the Glass Mountains area in Leonard time.

The most individualized fossil assemblage is found in the massive limestone reefs that lie between the Hess thin-bedded limestone member on the northeast and the interbedded siliceous shales and thin limestones on the southwest. The fossils of this facies appear to have been adapted to a reef environment. They include massive calcareous algae, massive sponges, colonial corals, crinoids with massive columns, massive bryozoans, and large thick-shelled brachiopods.

In some layers large-sized species of the sponge *Heterocoelia* have been found. Four characteristic brachiopods, *Scacchinella gigantea* Schellwien, *Meekella hessensis* King, *Geyerella americana* Girty, and *Streptorhynchus undulatum* King, appear to be confined to this facies. All four are characterized by high and deformed cardinal areas. In addition, the genera *Enteletes* and *Rhipidomella* are more common in the massive limestones than in any other part of the formation. *Enteletes dumblei* Girty and *Rhipidomella hessensis* King are found only in the massive limestones. The first shell reappears in the massive limestones of the Word formation.

The interbedded thin limestones and siliceous shales that lie to the west of the massive limestones contain a different assemblage of fossils. Radiolaria and sponge spicules are found in the siliceous shales. Fusulinids are relatively uncommon. The limestones contain cup

[63] For more complete information see Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas: Geology of Texas, vol. 3, Texas Univ. Bull. 3701, 1937.

[64] Smith, J. P., The transitional Permian ammonoid fauna of Texas: Am. Jour. Sci., 5th ser., vol. 17, p. 72, 1929.

[65] Letter, July 1932.

[66] Sellards, E. H., op. cit., p. 181.

[67] King, R. E., op. cit., p. 100.

corals, crinoids with small columns, echinoids, ramose bryozoans (such as *Fenestella* and *Polypora*), and numerous spinose and thin-shelled brachiopods. Ammonoids are very abundant locally in nodular limestones. According to R. E. King,[68] the following brachiopods are characteristic of this part of the formation:

Meekella difficilis Girty.
Chonetes subliratus Girty.
Productus ivesi Newberry.
Productus leonardensis King.
Productus occidentalis Newberry.
Productus schucherti King.
Linoproductus waagenianus Girty.
Marginifera cristobalensis Girty.
Marginifera manzanica Girty.
Marginifera reticulata King.
Marginifera sublaevis King.
Aulosteges magnicostatus Girty.
Aulosteges medlicottianus Waagen.
Prorichthofenia likharewi King.
Prorichthofenia uddeni (Böse).
Leptodus nobilis var. *americanus* Girty.
Camarophoria venusta Girty.
Spirifer pseudocameratus Girty.
Squamularia guadalupensis (Shumard).
Martinia rhomboidalis Girty.
Spiriferina hilli Girty.
Hustedia meekana (Shumard).
Composita mira (Girty).
Composita subtilita (Hall).

The thin-bedded limestones of the Hess member of the Leonard formation, which lie northeast of the massive limestones, are characterized by an abundance of fusulinids, most of which belong to the genus *Schwagerina*. Gastropods are found at many places, and in one layer near the top are large specimens of *Omphalotrochus*. Near this same horizon are also found *Productus hessensis* King and *Spirifer huecoensis* King, which are not known to occur in other parts of the formation in the Glass Mountains. They are common in the Hueco limestone of the Hueco Mountains. Near the top of the member at some localities *Composita mexicana* (Hall) and *Pugnoides texanus* (Shumard) occur together in great abundance. The two species are similarly associated in the upper part of the Hueco limestone of the Hueco Mountains and at other localities in the Diablo Plateau.

Correlation of the Leonard formation.—According to R. E. King,[69] the fauna of the Leonard formation is similar to that of the Bone Spring limestone of the Guadalupe Mountains and the Sierra Diablo. The occurrence of *Productus ivesi* and its associated brachiopods in the Leonard formation suggests a correlation with the upper part (San Andres limestone member) of the Chupadera formation of New Mexico and with the Kaibab limestone of the Grand Canyon region. Correlations with central Texas are uncertain, and the chief evidence existing lies in the ammonoids. Species of *Perrinites* found in both the Clear Fork and Double Mountain groups resemble *P. vidriensis* of the Leonard, so that the formation is probably to be correlated with parts of those groups.

STRATIGRAPHIC RELATIONS

The contact between the Leonard and Word formations is well exposed northeast of the Word ranch, in the Glass Mountains, and is apparently conformable, showing no evidence of erosion. West of Leonard Mountain the contact is not continuously exposed for distances great enough to furnish definite evidence as to the nature of the contact.

WORD FORMATION

GENERAL FEATURES

The Word formation was named by Udden [70] from exposures on the Word ranch, in the northeastern part of the Glass Mountains (p. 23). The formation crops out in a belt that extends northeastward across the mountains. In the western part of the area it forms smooth shaly slopes below the cliffs of dolomite of the overlying Capitan limestone. Toward the east, where all the formations are calcareous, it has no distinctive topographic expression.

The formation reaches a thickness of 1,500 feet in the southwestern part of the mountains, where it consists of siliceous shale, some clay shale, and beds of sandstone. The only limestone bed of any importance, which is also the only abundantly fossiliferous layer, is at the base. Throughout most of its extent in this part of the region the formation may be distinguished from the underlying Leonard in that it contains no pebbles of quartz, chert, or limestone. On the east side of Gilliland Canyon (pl. 23) wedges of limestone appear in the middle and upper parts of the section, which thicken northeastward. These are referred to, from below upward, as the first, second, third, and fourth limestone members (fig. 28). The third limestone member in the hills east of Gilliland Canyon is oolitic. Near the Word ranch the shales that intervene between the limestone layers disappear, and in the northeastern part of the mountains the formation is a cherty fossiliferous dolomite about 500 feet thick.

There is little evidence to suggest that the massive limestones of the Word formation were reef deposits. They have a much greater lateral extent than those of the underlying and overlying formations and are, in part, well bedded. A reef-like mass that rests on the basal limestone member south of Cathedral Mountain (pl. 23) is shown in figure 28, but this appears to be an exceptional feature.

[68] King, R. E., op. cit., p. 9.
[69] Idem, pp. 11, 14.
[70] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, 1st ed., p. 52, 1916.

EXPOSURES IN THE MONUMENT SPRING QUADRANGLE

The Word formation crops out in the northwest corner of the Monument Spring quadrangle, northwest of Lenox section house (pl. 24). The section resembles that seen elsewhere in the southwestern Glass Mountains, but there are more beds of sandstone and a few beds of chert conglomerate, which suggest that these southwesternmost exposures were nearest to the source of the clastic sediments. The following section was measured between the old Payne ranch and the high spur of the Del Norte Mountains, 2 miles to the northwest:

Section of Word formation near old Payne ranch

	Feet
Capitan limestone: Gray massive dolomitic limestone, which forms an isolated remnant at top of ridge.	
Word formation:	
25. Dense light-gray, somewhat dolomitic limestone, in thin beds; contains small rounded chert nodules	95
24. Fine-grained shaly sandstone	53
23. Brown platy siliceous shale, with small limestone nodules	81
22. Fine-grained pale-pink or brown sandstone, interbedded with siliceous shale. The sandstone weathers either into flags or rounded blocks	96
21. Coarse-grained pale-brown sandstone, weathering reddish, cropping out in a prominent ledge	40
20. Coarse-grained sandstone, interbedded with considerable sandy shale	49
19. Coarse-grained brown sandstone, weathering into rounded blocks	16
18. Fine-grained brown friable sandstone, interbedded with much siliceous shale. The member contains two thin beds of nodular bituminous limestone	81
17. Platy siliceous shale, with some sandy beds and a few thin layers of limestone	197
16. Gray finely crystalline limestone in 1-foot beds (R. E. King locality 170); contains abundant *Parafusulina* and also *Meekella attenuata* Girty and *Squamularia guadalupensis* (Shumard). Two miles to the south, in the Del Norte Mountains (R. E. King locality 238), the same bed contains *Meekella attenuata* Girty, *Chonetes subliratus* Girty, *Prorichthofenia permiana* (Shumard), *Leptodus nobilis americanus* Girty, and *Hustedia mormoni papillata* (Shumard)	10
15. Brown platy siliceous shale	12
14. Finely crystalline limestone, with indistinct bedding planes, containing much chert	45
13. Poorly exposed; mostly soft pale-buff fine-grained sandstone	42
12. Conglomerate of quartz and chert pebbles, closely packed in sandstone matrix, separated by thin sandstone layers. The pebbles are well rounded, some are polished, and they do not exceed 2 inches in diameter. This conglomerate is very persistent and has been traced for 4 miles to the south	14
11. Dense gray limestone	4
10. Coarse- to medium-grained brown sandstone	42

Section of Word formation near old Payne ranch—Continued

	Feet
Word formation—Continued.	
9. Platy siliceous shale, with a few thin layers of bituminous limestone in the upper part	88
8. Coarse-grained sandstone, cropping out in a prominent ledge, which locally caps small buttes. The sandstone contains small fossil fragments	42
7. Poorly exposed. A few outcrops of friable fine-grained sandstone and interbedded siliceous shale	272
6. Siliceous platy shale, with some large limestone nodules	117
5. Coarsely crystalline gray limestone, crowded with fossil fragments	8
4. Siliceous shale	38
3. White coarsely crystalline cherty limestone	13
2. Siliceous shale	16
1. Dense dark-gray finely crystalline limestone, with some interbedded dense bituminous layers. Crops out in 2-foot ledges. Fossils are very abundant in the crystalline layers (R. E. King locality 171) and include *Prorichthofenia perminana* (Shumard), *Leptodus nobilis americanus* Girty, *Camarophoria venusta* Girty, and *Dielasma spatulatum* Girty	100
Total	1, 571
Leonard formation.	

Southwest of this section the Word formation is exposed along the eastern slopes of the Del Norte Mountains to a point 3 miles south of the latitude of Marathon (pl. 24). At the base of the mountains the strata are vertical or overturned along a steep monocline, which is the northward continuation of the Black Peak thrust fault (sec. K–K′, pl. 21). At its southernmost exposure the basal beds of the Word are in contact with fossiliferous sandstones of the Gaptank formation (sec. L–L′, pl. 21), but this relation is probably the result of movements along this fault. In the Del Norte Mountains the uppermost beds, equivalent to the strata above bed 18 of the foregoing section, are all changed to a massive fine-grained brown sandstone. Below are three layers of rather coarse conglomerate, probably equivalent to beds 1, 8, and 12 of the section, which contain chert and limestone pebbles and cobbles.

FOSSILS AND AGE

General character of the fauna.—The fossils of the Word formation are similar to those of the Leonard formation. There are, however, many innovations, and the fauna differs from the Pennsylvanian faunas even more markedly than those beneath. It has the same character as the Guadalupian fauna described by Girty.[71]

The fauna is characterized by large-sized members of the fusulinid genus *Parafusulina*. Some specimens of this shell in the Word formation reach 2 inches

[71] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, 1908.

in length. *Parafusulina wordensis* Dunbar and Skinner [72] has been described from specimens collected in the third limestone member of the formation near the junction of Road and Gilliland Canyons. The genus ranges up into the Word from the Leonard formation, where it makes its first appearance, but does not extend into the overlying Capitan limestone.

The Word formation is characterized by an ammonoid fauna, of which the most diagnostic genus is *Waagenoceras*.[73] This fauna is most abundant in the third limestone member of the formation near the junction of Road and Gilliland Canyons but has been found by R. E. King at some other places in this member and also in the basal limestone member of the formation.

Among the brachiopods of the Word formation, R. E. King [74] has described 33 species that are not found in the lower formations of the Glass Mountains. The most abundant of these are the following:

Enteletes wordensis King.
Meekella skenoides Girty.
Chonetes quadratus King.
Productus arcticus Whitfield.
Productus guadalupensis Girty.
Productus multistriatus Meek.
Avonia signata (Girty).
Avonia walcottiana (Girty).
Marginifera opima (Girty).
Marginifera? texana (Girty).
Marginifera? wordensis King.
Aulosteges guadalupensis Shumard.
Aulosteges tuberculatus King.
Prorichthofenia permiana (Shumard).
Leiorhynchus weeksi var. *nobilis* (Girty).
Pugnoides swallowianus (Shumard).
Rhynchopora taylori Girty.
Spirifer sulcifer (Shumard).
Spiriferina laxa Girty.
Punctospirifer billingsi (Shumard).
Composita emarginata var. *affinis* Girty.
Dielasma schucherti var. *minor* King.

The brachiopods of the Word formation include many species found also in the dark limestone member of the Delaware Mountain formation and in the Capitan limestone of the Guadalupe Mountains. Among these are *Chonetes hillanus* Girty, *Marginifera popei* (Shumard), *Aulosteges guadalupensis* Shumard, *Pugnoides swallowianus* (Shumard), *Spiriferina laxa* Girty, and *Punctospirifer billingsi* (Shumard). They also include several species from the Phosphoria formation of the northern Cordilleran province.[75] These brachiopods are listed below, and those that are restricted to the Word formation in trans-Pecos Texas are marked with a star.

**Productus multistriatus* Meek.
Linoproductus waagenianus (Girty).
Linoproductus phosphaticus (Girty).
**Avonia subhorrida* (Meek).
Waagenoconcha montpelierensis (Girty).
**Composita persinuata* (Meek).
**Leiorhynchus weeksi* var. *nobilis* (Girty).
**Pugnoides swallowianus* (Shumard).
Spirifer pseudocameratus Girty.
Ambocoelia guadalupensis Girty.
Composita mira Girty.

The fauna of the Word formation includes another brachiopod species of northern origin, *Productus arcticus* Whitfield, which has hitherto been described only from the Permian of the Ellesmere Islands, and *Horridonia texana* King, the only species of this characteristic Permian genus which has been found in North America.

Faunas of different parts of the formation.—Each of the four limestone members of the Word formation contains a characteristic fauna. The first or basal limestone member is most abundantly fossiliferous in the southern foothills of Cathedral Mountain, in the southwestern part of the Glass Mountains, in the Altuda quadrangle (pl. 23). Ammonoids are rare at this horizon, but a few specimens of *Waagenoceras* have been collected. The following are the most abundant brachiopods [76] and fusulinids:

Parafusulina splendens Dunbar and Skinner.
Parafusulina bösei Dunbar and Skinner.
Parafusulina bösei var. *attenuata* Dunbar and Skinner.
Chonetes subliratus Girty.
Productus indicus Waagen.
Linoproductus waagenianus (Girty).
Avonia subhorrida var. *rugulata* (Girty).
Camarophoria venusta Girty.
Hustedia meekana (Shumard).
Composita mira (Girty).

The second limestone member is not well developed more than a few miles southwest of Hess Canyon, and most of its fossils are similar to those of the third limestone member. The third limestone member is very fossiliferous on the south side of Road Canyon and the west side of Hess Canyon, in the Hess Canyon quadrangle (pl. 23). On the south side of Road Canyon occur the following ammonoids, identified by Böse:[77]

Medlicottia burckhardti Böse.
Gastrioceras roadense Böse.
Agathiceras girtyi Böse.
Waagenoceras dieneri Böse.
Adrianites marathonensis Böse.
Stacheoceras bowmani Böse.
Stacheoceras gilliamense Böse.

[72] Dunbar, C. O., and Skinner, J. W., New fusulinid genera from the Permian of west Texas: Am. Jour. Sci., 5th ser., vol. 22, pp. 261-263, 1931. For other fusulinid species found in the formation see Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas: Geology of Texas, vol. 3, Texas Univ. Bull. 3701, 1937.

[73] Böse, Emil, Ammonoids of the Glass Mountains: Texas Univ. Bull. 1763, p. 18, 1917.

[74] King, R. E., op. cit., pp. 147-150.

[75] Idem, p. 32.

[76] Idem, p. 10.

[77] Böse, Emil, op. cit., p. 18.

From the same horizon on the west side of Hess Canyon have been collected *Paraceltites multicostatus* Böse and *Paraceltites* aff. *P. elegans* Girty. In this same district *Parafusulina wordensis* Dunbar and Skinner and *P. sellardsi* Dunbar and Skinner have been found.

The following brachiopods are considered by R. E. King to be most characteristic of the third limestone and the underlying second limestone member. The collections were made chiefly in the hills west of Hess Canyon and those south of Road Canyon.

Enteletes dumblei Girty.
Meekella attenuata Girty.
Meekella skenoides Girty.
Productus multistriatus Meek.
Avonia signata (Girty).
Avonia walcottiana (Girty).
Marginifera opima (Shumard).
Marginifera popei (Shumard).
Marginifera? wordensis King.
Aulosteges guadalupensis Shumard.
Aulosteges tuberculatus King.
Prorichthofenia permiana (Shumard).
Leptodus nobilis var. *americanus* Girty.
Pugnoides swallowianus (Shumard).
Rhynchopora taylori Girty.
Camarophoria venusta Girty.
Spirifer pseudocameratus Girty.
Spirifer sulcifer Shumard.
Squamularia guadalupensis (Shumard).
Punctospirifer billingsi (Shumard).
Spiriferina laxa Girty.
Hustedia meekana (Shumard).
Composita emarginata var. *affinis* Girty.
Composita mira Girty.
Dielasma spatulatum Girty.
Dielasma schucherti var. *minor* King.

The fourth limestone member, which does not occur in its normal development west of Gilliland Canyon, is very fossiliferous in the hills east and west of Hess Canyon. It contains *Parafusulina kingorum* Dunbar and Skinner and a few *P. rothi* Dunbar and Skinner. The latter is common in parts of the Delaware Mountain formation beneath the Capitan limestone in the Guadalupe Mountains. Some species of productids are especially abundant. Many of the brachiopod species of this member are found also in the dark limestone member of the Delaware Mountain formation in the Guadalupe Mountains and in the Phosphoria formation. The following are considered by R. E. King to be especially characteristic:

Meekella attenuata Girty.
Derbya? crenulata Girty.
Chonetes quadratus King.
Productus arcticus Whitfield.
Productus guadalupensis Girty.
Linoproductus nasutus King.
Linoproductus phosphaticus (Girty).
Waagenoconcha montpelierensis (Girty).
Composita emarginata var. *affinis* (Girty).
Avonia signata (Girty).
Marginifera opima (Girty).
Marginifera popei (Girty).
Marginifera texana (Girty).
Spirifer sulcifer Shumard.
Spiriferina laxa Girty.
Punctospirifer billingsi (Shumard).
Hustedia meekana (Shumard).

The brachiopods of the Word formation suggest that it is to be correlated with the main part of the Delaware Mountain formation in the Delaware and Guadalupe Mountains of northern trans-Pecos Texas. There is also a possibility that the Phosphoria formation of the northern Cordilleran province is of the same age, as the Word contains many of its brachiopod species. The equivalent beds in the central Texas section are not known, but it is possible that they are to be found in strata above the Blaine formation.

STRATIGRAPHIC RELATIONS

The Word formation is apparently overlain conformably by the Capitan limestone. Where the rock facies of the two formations are the same the contact appears to be gradational. This is true in the dolomitic rocks northeast of the Word ranch and in the siliceous shales and thin limestones of the Del Norte Mountains.

CAPITAN LIMESTONE

ORIGIN OF NAME

The Word formation is overlain by a thick and complex mass of dolomitic limestone, with some interbedded sandy and shaly strata, for which the name "Capitan limestone" is used. The beds included in the formation have been divided into several local lithologic units, such as the Vidrio and Gilliam formations of Udden [78] and the Altuda member of the writer.[79] In 1929 these units were grouped by R. E. King and the writer under the name "Capitan formation."[80] The unit appears to be of the same general age as the typical Capitan limestone of the Guadalupe Mountains, as suggested by the fossils in the formation in the two areas and by those in the underlying Delaware Mountain and Word formations. Moreover, in both areas it has about the same thickness and its rocks express the same physical history—the culmination of reef development in later Permian time.

[78] Udden, J. A., Baker, C. L., and Böse, Emil, Review of the geology of Texas: Texas Univ. Bull. 44, 1st ed., p. 52, 1916. Udden, J. A., Notes on the geology of the Glass Mountains: Texas Univ. Bull. 1753, pp. 50–54, 1917.

[79] King, P. B., The Bissett formation, a new stratigraphic unit in the Permian of west Texas: Am. Jour. Sci., 5th ser., vol. 14, p. 217, 1927.

[80] King, P. B., and King, R. E., Stratigraphy of outcropping Carboniferous and Permian rocks of trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 920, 1929.

GENERAL FEATURES

In the northeastern part of the Glass Mountains the Capitan limestone is about 1,800 feet thick and is divided into two members. At the base is the Vidrio massive member (a limestone reef), which is followed by the Gilliam thin-bedded member. The Gilliam member is a tongue of bedded limestone, similar to the Hess thin-bedded limestone member of the Leonard formation, and contains interbedded layers of sandstone and red beds. It changes southwestward into massive limestones of the Vidrio member, but its upper contact appears to be everywhere marked by a persistent bed of sandstone (fig. 28).

In the southwestern part of the Glass Mountains the Vidrio member is divided into two parts by a tongue of siliceous shale and thin-bedded limestone, which forms the Altuda shaly member. The massive dolomitic limestones below the Altuda extend southwestward as a tapering wedge and serve to divide the shaly strata of the Altuda member from those in the upper part of the Word formation (fig. 28). The massive dolomitic limestones above the Altuda form a prominent limestone reef and contain thick, irregular beds, inclined at an angle of about 10° more steeply than the beds above or below. They extend through 200 or 300 feet and interfinger at their bases with more clastic beds of the Altuda member. The limestone reefs of this part of the Vidrio member extend north-northeastward along the high ridges on the west side of Gilliland Canyon, in the central part of the Glass Mountains (pl. 23). They are flexed down steeply toward the northwest.

EXPOSURES IN THE MONUMENT SPRING QUADRANGLE

The Capitan limestone is not widely exposed in the Monument Spring quadrangle. A small thickness of its lower beds is exposed in the Del Norte Mountains between the Word formation and the unconformably overlying strata of Lower Cretaceous age (pl. 24). These rocks are massive limestones that belong to the lower tongue of the Vidrio massive member (fig. 28). The Altuda shaly member and the higher strata are not exposed in the quadrangle, although they crop out in extensive areas in the Altuda quadrangle, to the north.

FOSSILS AND AGE

The Capitan limestone is not abundantly fossiliferous in the Glass Mountains. No ammonoids have been found in it. The brachiopods, though very abundant in places, are of few species, and none of them are restricted to the formation.

Fossils of the Altuda shaly member.—The most abundant fossils have been found in the Altuda shaly member, which contains a fairly abundant brachiopod fauna, as well as some bryozoans and other fossils. In the northeastern part of the Del Norte Mountains, southwest of Altuda section house (pl. 23) (R. E. King locality 50), the following brachiopods were identified:

Avonia subhorrida var. *rugulata* Girty.
Marginifera opima (Girty).
Punctospirifer billingsi (Shumard).
Hustedia meekana (Shumard).
Composita emarginata var. *affinis* Girty?

About 1½ miles northeast of Altuda section house (R. E. King locality 51) the following fossils were collected from this member:

Leptodus nobilis var. *americanus* Girty.
Camarophoria? indentata (Shumard).
Composita emarginata var. *affinis* Girty?
Squamularia guadalupensis (Shumard) (abundant).
Martinia rhomboidalis Girty (abundant).

At the top of the east end of Cathedral Mountain (R. E. King locality 43) the basal beds of the Altuda shaly member contain the following species:

Marginifera popei (Shumard).
Squamularia guadalupensis (Shumard).
Martinia rhomboidalis Girty.
Spiriferina laxa Girty.
Punctospirifer billingsi Shumard.
Hustedia meekana (Shumard).
Composita emarginata var. *affinis* Girty.

From collections near the base of the member at the northeast corner of Altuda Mountain Dunbar and Skinner have identified the following fusulinids:

Leella bellula Dunbar and Skinner.
Codonofusiella paradoxica Dunbar and Skinner.
Polydiexodina shumardi Dunbar and Skinner.

Fossils of the Vidrio massive member.—The massive dolomitic limestones, presumably of reef origin, that make up the Vidrio member contain few recognizable fossils. Most of the abundant remains of life that once existed in the rock have been more or less thoroughly destroyed by diagenesis. Where this process is less nearly complete, the rock contains the remains of lime-secreting algae, of both massive and scale-forming types, as well as cup corals, crinoid stems, fusulinids, echinoid spines, and a few brachiopod shells. These fossils are set in a matrix of obscure structure, which is probably composed of fine calcareous debris.

Fossils of the Gilliam thin-bedded member.—The Gilliam thin-bedded member contains a great abundance of fusulinids. These belong to the long, slender, highly specialized genus *Polydiexodina*,[81] which is not known in the Word formation and which characterizes the upper Permian strata of the Guadalupe and Delaware Mountains. Two species, *Polydiexodina capitanensis* Dunbar and Skinner and *P. shumardi* Dunbar and Skinner, are present. Southwest of the mouth of

[81] Dunbar, C. O., personal communication, September 1932.

Gilliland Canyon a fragmentary specimen of *Productus capitanensis* (Girty) was also collected.

Correlation of the Capitan limestone.—The Capitan limestone is of about the same age as the upper part of the Permian section in the Guadalupe and Delaware Mountains. It is believed to be approximately equivalent to the Capitan limestone as exposed on El Capitan, in the Guadalupe Mountains. The fossils of the uppermost Word limestones along Hess Canyon, in the Glass Mountains, indicate a correlation with the dark limestone member of the Delaware Mountain formation, which lies beneath the Capitan at this place. Moreover, the thickness of dolomitic limestone above this horizon is about the same at the two places. The few brachiopods found in the Capitan limestone, although long-ranging, are all identical with species found in the more abundant faunas of the Guadalupe Mountains. The fusulinid *Polydiexodina*, which is found in the Gilliam and Altuda members of the Capitan limestone in the Glass Mountains, also occurs in that formation in the Guadalupe Mountains and in the upper part of the Delaware Mountain formation in the Delaware Mountains.[82]

STRATIGRAPHIC RELATIONS

In the northeastern part of the Glass Mountains the Capitan limestone is overlain by the Tessey limestone, whose lower part, according to the suggestion of Adams,[83] is of the same age as the Salado halite farther north. If this is correct, there is a hiatus between the Capitan and the Tessey representing the time of deposition of the Castile anhydrite that lies between them elsewhere in trans-Pecos Texas. No erosion has been observed at the contact, and the uppermost sandstone beds of the Gilliam member may be traced for long distances beneath the Tessey limestone.

In the southwestern part of the Glass Mountains the Tessey limestone has been removed by erosion, and the Capitan limestone is overlain unconformably by the Bissett conglomerate, of Triassic (?) age (fig. 28). Near Bissett Mountain and farther southwest the Bissett conglomerate overlies either thin-bedded dolomite that is a southwestern tongue of the Gilliam member or massive dolomite that is a southwestern tongue of the Vidrio member. At a locality 4 miles west of Bissett Mountain the conglomerate overlies only 215 feet of the southwestern upper tongue of the Vidrio member, which in turn overlies the Altuda shaly member.

[82] Dunbar, C. O., and Skinner, John, New fusulinid genera from the Permian of west Texas: Am. Jour. Sci., 5th ser., vol. 22, pp. 263-264, 1931.

[83] Adams, J. E., Upper Permian stratigraphy of west Texas Permian basin: Am. Assoc. Petroleum Geologists Bull., vol. 19, p. 1019, 1935.

TESSEY LIMESTONE

The Tessey limestone was named by Udden [84] for "a post office now defunct but once located about 2 miles north from the mouth of Gilliam Canyon." It has been classed as a member of the Capitan in some previous reports, but recent work strongly suggests that it is younger than the typical Capitan limestone of the Guadalupe Mountains, so that it is here considered to be a separate formation.

The Tessey limestone is a massive or indistinctly bedded deposit about 1,000 feet thick that crops out on the northern foothills of the northeastern Glass Mountains. Most of its limestones contain few or no fossils, but at one locality near the middle of the member there are many specimens of *Pleurophorus*. Toward the northeast, as indicated by the correlation of the section on the outcrop with that penetrated in the Vacuum Oil Co.'s Elsinore No. 1 well,[85] the lower three-fourths of the formation changes into anhydrite with thin beds of dolomitic limestone. The upper fourth, as penetrated in the well, is dolomitic and in part sandy limestone.

Evidence obtained from drilling north of the Glass Mountains suggests that the Tessey limestone is equivalent to the Salado halite and Rustler formation. According to Adams: [86]

> On the southwest the salt of the Upper Castile [Salado] is replaced by anhydrite. This is effected by the thickening and coalescing of the anhydrite stringers of the salt series at the north. Associated with this gradation, tongues of dolomite appear in the section. This change is progressive, and in the Glass Mountains the Upper Castile [Salado] appears to be equivalent to the limestones and dolomites of the lower Tessey.

The "lower Tessey" of Adams is probably the lower three-fourths of the formation that changes from limestone to anhydrite between the Glass Mountains and the Elsinore well. The upper fourth as penetrated in the well has been correlated by the subsurface geologists with the Rustler formation, which overlies the Salado farther north in trans-Pecos Texas.

The Tessey limestone is missing by pre-Bissett erosion in the southwestern Glass Mountains, beyond the mouth of Gilliland Canyon.

GENERAL PROBLEMS OF PERMIAN STRATIGRAPHY

REGIONAL RELATIONS OF THE GLASS MOUNTAINS SECTION

Rocks similar to those in the Glass Mountains are exposed in northern trans-Pecos Texas, in the Guadalupe, Delaware, and Apache Mountains and the Sierra

[84] Udden, J. A., Notes on the geology of the Glass Mountains: Texas Univ. Bull. 1753, p. 53, 1917.

[85] King, P. B., Geology of the Glass Mountains, part 1: Texas Univ. Bull. 3038, p. 78 and pl. 14, 1931.

[86] Adams, J. E., op. cit., p. 1019.

Diablo. In most of these mountain areas, however, only parts of the series are exposed, and in some of them only rocks of one facies. The most closely comparable section is that at the southwest end of the Guadalupe Mountains, where the lowest formation exposed is the Bone Spring limestone, which is probably of Leonard age. This is succeeded by the sandstones, shales, and thin limestones of the Delaware Mountain formation, here largely of Word age, and by the reef mass of the Capitan limestone. To the east are three younger formations, the Castile anhydrite, Salado halite, and Rustler limestone, which are in part equivalent to the Tessey limestone of the Glass Mountains. The fossils in the strata at the southwest end of the Guadalupe Mountains are of the same general character as those in the Glass Mountains and form the Guadalupian fauna as described by Girty.[87]

The Permian strata exposed in northern trans-Pecos Texas exhibit the same peculiar changes in facies as those in the Glass Mountains. In both areas there are thick deposits of siliceous shale, but in the north these are associated with black shaly limestones and fine-grained sandstones. The three rock types are apparently closely related; the siliceous shale appears to differ from the sandstone chiefly in its much finer grain, and the limestone differs chiefly by its greater content of calcareous and bituminous matter. These deposits hold a constant relation to limestone reefs, so that here, as in the Glass Mountains, there was a tendency for rocks of one facies to be deposited in the same general region throughout Permian time.

The direction of change in facies, characteristic of all parts of the section, varies from one mountain area to another. In the Glass Mountains a change from clastic to calcareous rocks in a northeasterly direction has been described. In the Sierra Diablo the change is southwestward, in the Guadalupe Mountains northwestward (section A–B, fig. 29), and in the Apache Mountains southward. East of the mountain areas, in the plains near the Pecos River, drilling discloses similar changes.[88] Here drill holes have penetrated a broad uplift of north-northwesterly trend, not exposed at the surface, which has been called the Pecos uplift, or "central basin platform" (fig. 29). This is capped by massive limestone deposits similar to those in the mountain areas, which are shown by drilling to be joined on the south to the upper limestones in the Glass Mountains and on the north to those in the Guadalupe Mountains. They are flanked on the west by sandy and shaly deposits.[89]

[87] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, 1908.

[88] See especially Cartwright, L. D., Transverse section of Permian basin, west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 969–981, 1930.

[89] Willis, Robin, Structural development and oil accumulation in the Texas Permian: Am. Assoc. Petroleum Geologists Bull., vol. 13, figs. 2, 3, 1929.

A study of the exposures and of drill records thus suggests that the black limestones, siliceous shales, and sandstones were laid down in a relatively restricted depression, nearly surrounded by limestone reefs; the depression has been called the "Delaware Basin" (fig. 29). The Permian rocks now exposed in the Glass Mountains were apparently laid down on the southeast side of this basin, where it impinged on the late Pennsylvanian folds of the Marathon region.

East of the Delaware Basin and east of the Pecos uplift, another depression, the Midland Basin, received marine deposits in early Permian time but was shut off from the sea in the middle part of that epoch. West of the Delaware Basin, in the region south of the Sierra Diablo and west of the Glass Mountains, there appears to have been another depression, which has been called the "Marfa Basin"[90] (fig. 29), but this feature is relatively little known.

SEDIMENTATION OF THE PERMIAN SERIES IN THE GLASS MOUNTAINS

The deposition of the Wolfcamp formation, at the base of the Permian section, was apparently very similar to that of the underlying Gaptank formation. Coarse conglomerates were spread out near the scene of orogenic movements in the Marathon Basin, and shales and thin limestone beds farther away; no limestone reefs existed in Wolfcamp time.

With the beginning of Leonard time and continuing through the Capitan, conditions of sedimentation were very different, being marked by the development of limestone reefs and other massive limestone deposits. These deposits separated bedded limestones in the northeastern part of the area from siliceous shales and other clastic deposits in the southwestern part. The reefs of the Leonard formation were small and probably rose to a height of no more than 100 feet. Their greatest basinward growth occurred in earlier Leonard time, when they extended along the present strike of the rocks to the southwest end of the mountains. In later Leonard time the reef deposits gradually retreated northeastward. In the overlying Word formation there is little evidence for the existence of true limestone reefs, but massive limestone deposits without reef form were laid down. Like those in the Leonard, they had their greatest basinward extent at the base of the formation, followed by a retreat northeastward along the present strike (fig. 28).

In the overlying Capitan limestone reefs had a great development. The inclined bedding planes in the Vidrio member suggest that the reefs were built up as high as 200 or 300 feet above the sea bottom on the southwest. There were two times of advance of reef deposits during the Capitan epoch, separated by a time

[90] Lahee, F. H., Contributions of petroleum geology to pure geology in the southern midcontinent area: Geol. Soc. America Bull., vol. 43, fig. 2, 1932.

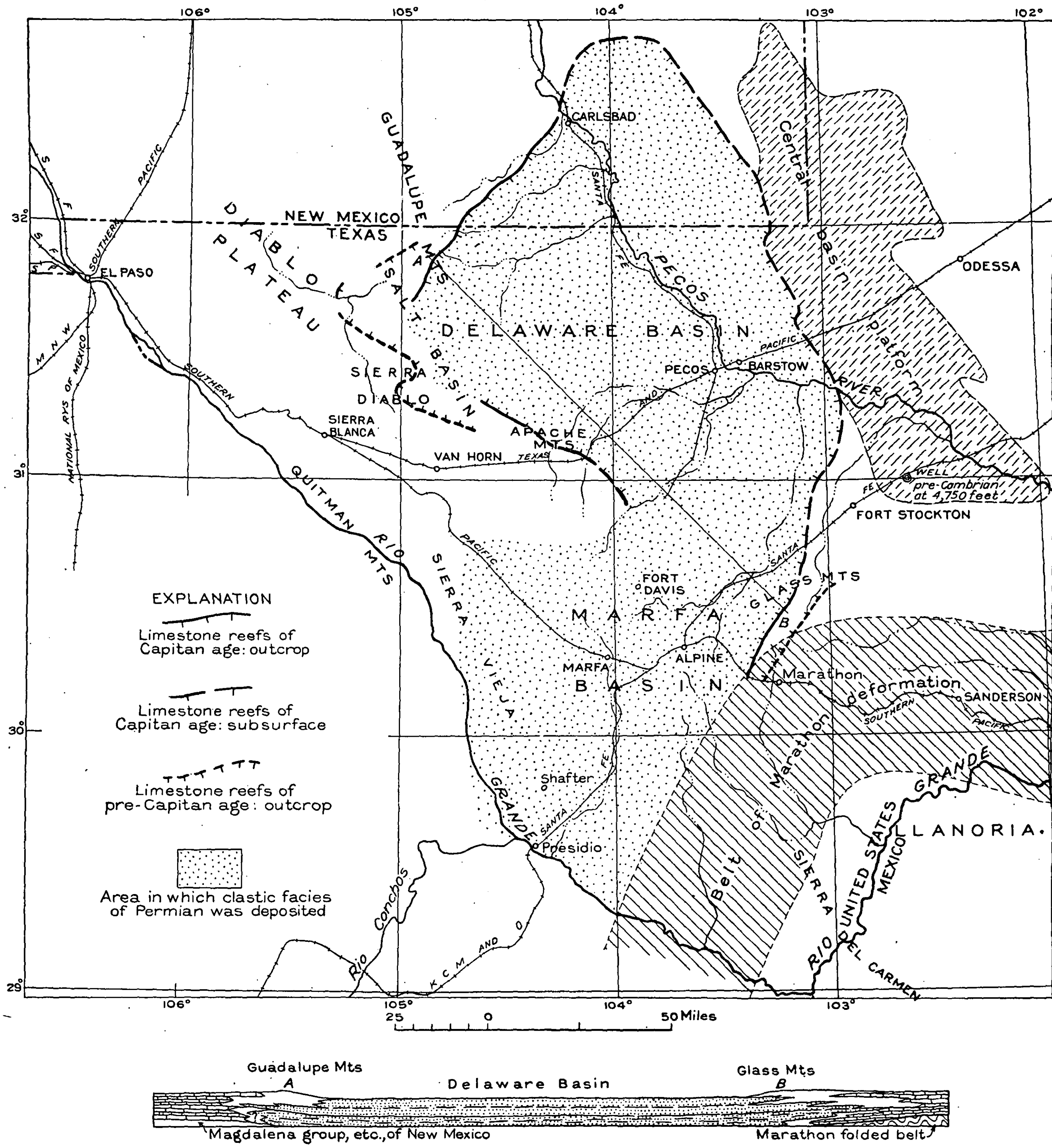


FIGURE 29.—Map of trans-Pecos Texas showing structural features of Permian time. Below is a stratigraphic diagram extending across the area, showing the relation of the Permian strata to the Delaware Basin.

when the Altuda shaly deposits were spread widely across the southwestern part of the area. During the later time of advance thick reefs were built forward on the surface of the preceding deposits. The overlying Tessey limestone is possibly a limestone reef similar to the Vidrio, but it has an almost complete lack of evident organic remains, so that it may instead be of inorganic origin.

The moderate flexing and faulting and the northwestward tilting of the Permian rocks of the Glass Mountains in Mesozoic and Cenozoic time make it difficult to obtain a three-dimensional picture of the limestone reefs of the region. They appear, however, to be related to some of the structural features of the mountains. In the vicinity of Leonard Mountain the limestone reefs of the Leonard formation appear to have a northeasterly trend. It is possible that farther northeast, where they lie beneath the surface, they are related to a prominent monoclinal flexure that extends northeastward from the Word ranch to the northeast end of the mountains.[91] Those of the Capitan limestone, as observed in the ridges on the west side of Gilliland Canyon, have a north-northeast trend, which is parallel to a monoclinal flexure, bent down to the west-northwest. This flexure, as expressed in the Cretaceous rocks, is shown on plate 15, but it is much more pronounced in the Permian strata. It is possible that these flexures came into existence at the time of deposition of the Permian strata, for they are apparently in considerable part of pre-Cretaceous age.[92]

SOURCE OF THE CLASTIC SEDIMENTS IN THE PERMIAN

The clastic sediments in the Leonard and Word formations of the southwestern part of the Glass Mountains were apparently derived in part from the erosion of the folded rocks of the Marathon area, to the south. The clastic materials include pebbles of chert and limestone that can be matched with rocks in the older Paleozoic formations, and some of the sandstones contain fine grains of chert.[93] In most of the area of outcrop in the southwestern part of the mountains conglomeratic rocks extend only to the top of the Leonard, and in the upper part of the formation the pebbles are of small size. In the southwesternmost exposures, however, at the base of the Del Norte Mountains, several beds of conglomerate also appear in the Word formation and increase in prominence toward the south. In this region, also, sandstone beds in both the Leonard and Word formations are more prominent than elsewhere, and those in the Word thicken southward along the Del Norte Mountains.

The source of the siliceous shales of the Leonard and Word formations is not known. They are apparently fine siliceous sedimentary rocks, possibly of clastic character, in which the tests of Radiolaria and spicules of sponges are a prominent but not dominant component. They may have had some relation to the volcanic activity known to exist at the same time in Mexico (Las Delicias area), to the south.[94]

[91] King, P. B., The geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, pl. 10, 1931.
[92] Idem, p. 21 and pl. 12.
[93] Idem, pp. 67–68.
[94] Idem, p. 69.

TRIASSIC (?) SYSTEM

BISSETT CONGLOMERATE

GENERAL FEATURES

The Bissett conglomerate was named by the writer in 1927.[95] Its type locality is Bissett Mountain, 6 miles north of Altuda section house (pl. 23), on whose north slopes the formation is well exposed. The formation crops out in a belt along the northwest flank of the Glass Mountains, but the exposures are in many places separated by strips of alluvium.

The Bissett conglomerate is for the most part a conglomerate of rounded dolomite fragments derived from the erosion of the beds beneath. These are set in a calcareous matrix. There are also some interbedded layers of sandstone and limestone and lenticular layers of red shale. The maximum observed thickness of the formation is 740 feet. It rests with erosional unconformity but with nearly equal dip and strike on the underlying Tessey and Capitan limestones and is overlain with angular unconformity by the Comanche series.

On the west side of Hess Canyon 3 miles north of the Warren ranch (pl. 23), in the north-central part of the Glass Mountains, thin limestone layers in the upper part of the Bissett conglomerate contain fossils. The following section was measured in this area:

Section of Bissett conglomerate 3 miles north of Warren ranch

Basement sands of the Comanche series.	
Bissett conglomerate:	*Feet*
6. Calcareous conglomerate of limestone and dolomite pebbles, with a few fragments of quartz, quartzite, and chert	100
5. Gray and brown dense to finely crystalline dolomitic limestone, with platy or splintery fracture, in beds a few inches or a few feet thick, interbedded with buff shale. The limestones are fossiliferous	50
4. Calcareous conglomerate	10
3. Covered, probably conglomerate	100
2. Similar to bed 1, but with a sandy matrix and a few lenticular layers of sandstone	240
1. Calcareous conglomerate composed of rounded dolomite pebbles in a calcareous matrix. There are also abundant well-rounded pebbles of quartz and chert, some of which reach 2 inches in diameter	240
Total	740
Tessey limestone.	

[95] King, P. B., The Bissett formation, a new stratigraphic unit in the Permian of west Texas: Am. Jour. Sci., 5th ser., vol. 14, pp. 212–221, 1927.

FOSSILS AND AGE

The limestones of bed 5 of the foregoing section contain abundant poorly preserved fossils, including numerous ostracodes of the genus *Bairdia*. Bruce Harlton, who has examined specimens from the locality, states that although this genus is long ranging, the species represented appears to be a Permian type. The layer also contains numerous gastropods and pelecypods, but these are probably not specifically determinable.

The limestones also contain fragments of vertebrates. A specimen of these collected by Sidney Powers was examined by E. C. Case, of the University of Michigan, who reports as follows:

> The specimen looks amazingly like the horn of my *Desmatosuchus*, and the size is appropriate for this genus. I know of no Permian form which could have this form of bone. It cannot be a tibia. I suggest that your specimen is a washed specimen from some perhaps distant locality. If it is a *Desmatosuchus*, it is closely related to the Phytosaurs and was a swamp or river animal. The Bissett formation is apparently in about the position of the La Plata [96] of southwestern Colorado, which is not far from the Shinarump.

A fairly abundant though poorly preserved flora was collected in the limestones in 1930 and 1931 by E. H. Sellards. The collections have been studied by David White [97] and C. B. Read.[98] White, on the basis of the material first sent in, tentatively concluded that the flora was of Permian age. Read, who has studied this and the later material, considers the flora to be of early Triassic age. He writes:

> The genera are *Pelourdea* (was called *Cordaites*), *Zamites Brachyphyllum*, *Voltzia*, and several fern fragments of obvious Mesozoic types. I prefer to make no more than generic assignments at this time, owing to the fact that most of the species are new. The plants are all early Mesozoic types, although some of them have been noted in the literature as occurring sporadically in the Permian. However, in such cases they are associated with clear Permian types, and there are no elements of any Permian flora in the Bissett collections. Furthermore, the cycad (*Zamites*) is particularly Mesozoic in its appearance. I feel that the Permian possibility can be definitely ruled out.
>
> Furthermore, from what I have seen of the Dockum flora at localities farther north, it is quite unlike that of the Bissett and certainly younger. In fact, the flora of the Bissett reminds me very much of a flora of Middle Triassic age described by Wills several years ago from a locality in England.

Read's recent conclusions would seem to bring the plant and vertebrate evidence into close agreement, and the writer now believes that the Bissett is of pre-Dockum Triassic age.

[96] Dolores; certainly not La Plata.—J. B. Reeside, Jr.

[97] Sellards, E. H., Pre-Paleozoic and Paleozoic systems, in The geology of Texas, vol. 1, Stratigraphy: Texas Univ. Bull. 3232, p. 155, 1933. King, P. B., Permian stratigraphy of trans-Pecos Texas: Geol. Soc. America Bull., vol. 45, pp. 738-739, 1934.

[98] King, P. B., Age of Bissett conglomerate: Am. Assoc. Petroleum Geologists Bull., vol. 19, p. 1545, 1935.

STRATIGRAPHIC RELATIONS

The Bissett conglomerate appears to have shared the post-Permian and pre-Cretaceous folding of the region equally with the beds beneath. At nearly every locality the Bissett is separated from the overlying Comanche series by a perceptible angular unconformity, and this series overlaps southward across the Bissett conglomerate to rest on all the older rocks of the region.

POST-BISSETT AND PRE-CRETACEOUS TIME INTERVAL

Between the time of deposition of the Bissett conglomerate and that of the oldest rocks of the Cretaceous, no strata seem to have been laid down in the Marathon region. Upper (?) Triassic rocks of the Dockum group probably occur beneath the surface north and east of Fort Stockton, 50 miles northeast of Marathon.[99] The nearest exposures of Jurassic rocks are to the west of the Marathon region, at Malone Mountain, in northwestern trans-Pecos Texas, 150 miles northwest of Marathon,[1] and near the Rio Conchos in Mexico, 100 miles southwest of Marathon.[2] In these localities marine deposits of Upper Jurassic age are found. The sea in which these deposits were laid down did not extend as far east as the Marathon region (fig. 30).

CRETACEOUS SYSTEM

GENERAL FEATURES

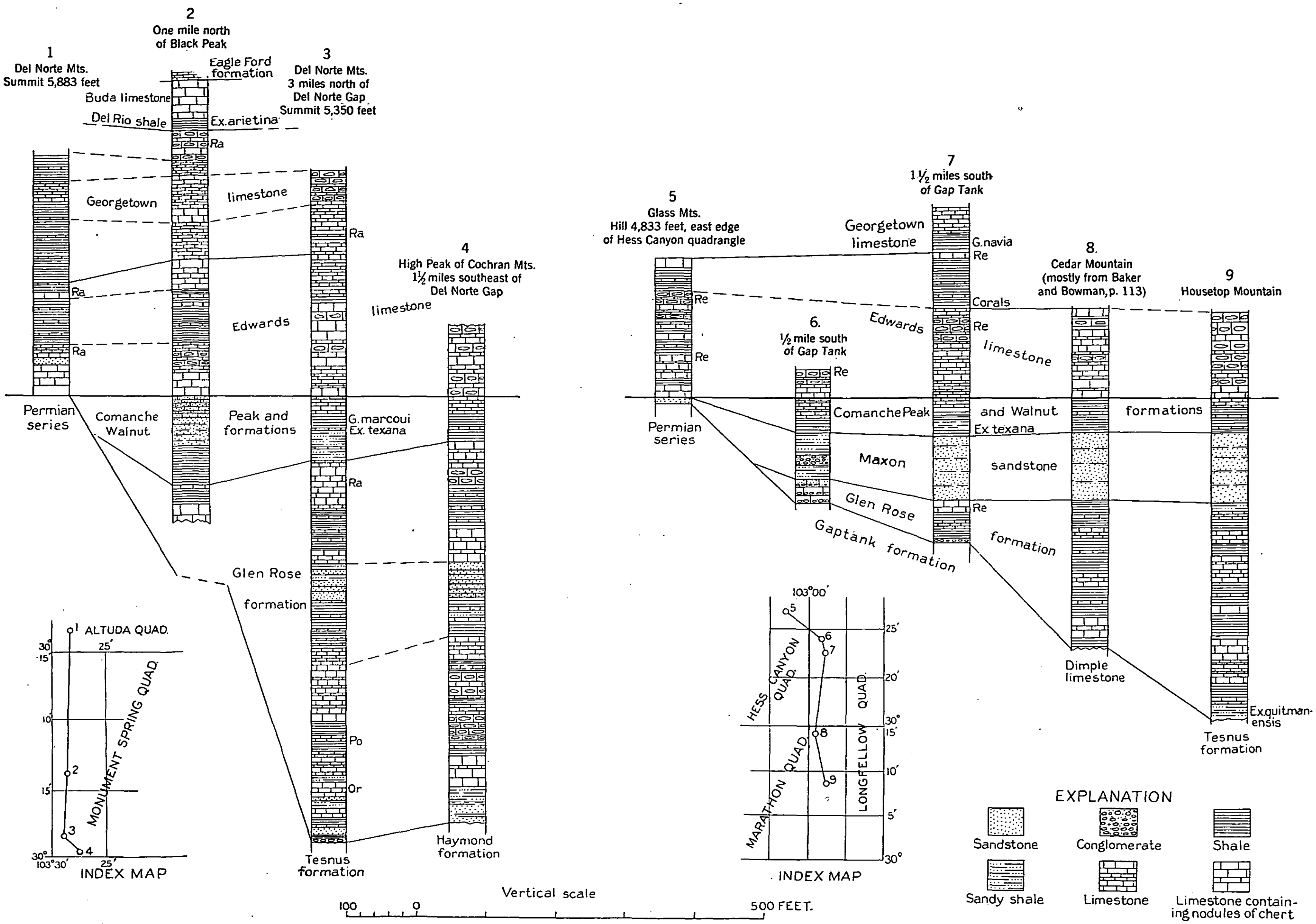
Cretaceous rocks that belong chiefly to the Comanche or Lower Cretaceous series are exposed along the east and west margins of the Monument Spring and Marathon quadrangles (pl. 24) and completely encircle the older strata of the region (pl. 23). They were deposited in a gradually overlapping sea (fig. 30), which advanced upon a land surface worn down nearly to a peneplain. The Cretaceous rocks are relatively thin in comparison with those of the older systems in the area; scarcely more than 1,000 feet is exposed near the Marathon uplift. They consist very largely of limestone. Cretaceous rocks were probably once deposited over the entire Marathon region, but on the crests of the uplift, in the present Marathon Basin, they have been stripped away, and the remnants now surround the area in steep-walled escarpments produced by erosion.

The overlap relations of the Cretaceous rocks serve to explain the distribution of the basal formations. The region did not have abrupt hills and valleys at the time of the advance of the Cretaceous seas, but the area of the Glass Mountains rose as a low asymmetric ridge, with its steeper face on the south. South of

[99] Adkins, W. S., Geology and mineral resources of the Fort Stockton quadrangle: Texas Univ. Bull. 2738, p. 27, 1927.

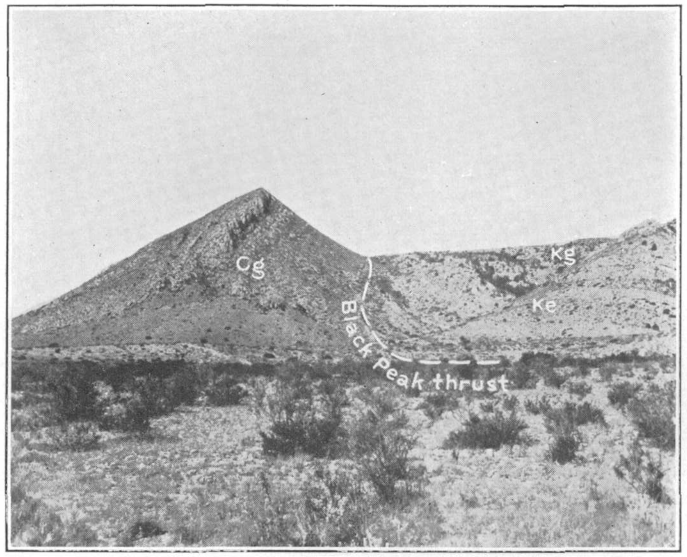
[1] Adkins, W. S., Mesozoic systems: The geology of Texas, vol. 1, Stratigraphy, Texas Univ. Bull. 3232, pp. 254-256, 1933. Cragin, F. W., Paleontology of the Malone Jurassic formation of Texas: U. S. Geol. Survey Bull. 266, 1905.

[2] Idem, p. 256. King, R. E., letter, July 1933.



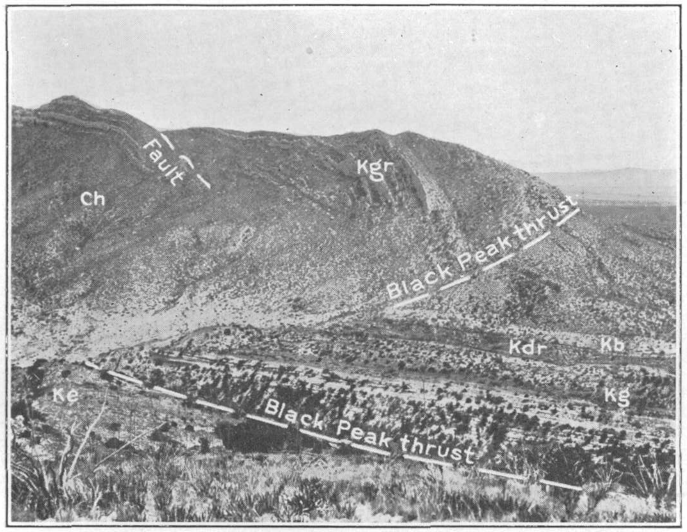
CORRELATED STRATIGRAPHIC SECTIONS OF COMANCHE SERIES ON THE EAST AND WEST SIDES OF THE MARATHON BASIN.

Ra, Radiolights; Po, Porocystis; Or, Orbitolina; Re, Requienia; Ex, Exogyra; G, Gryphaea.



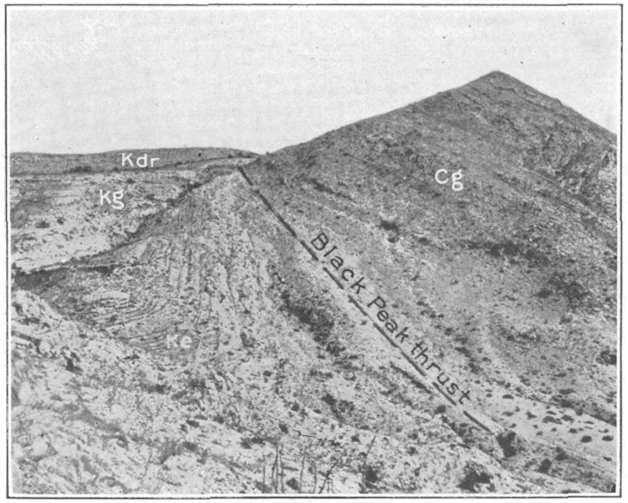
A. BLACK PEAK, IN THE DEL NORTE MOUNTAINS, FROM NORTHEAST.

The peak is a mass of limestone of the Gaptank formation (Cg) thrust against the limestones (Kg, Ke) of the Comanche series, which crop out in the background.



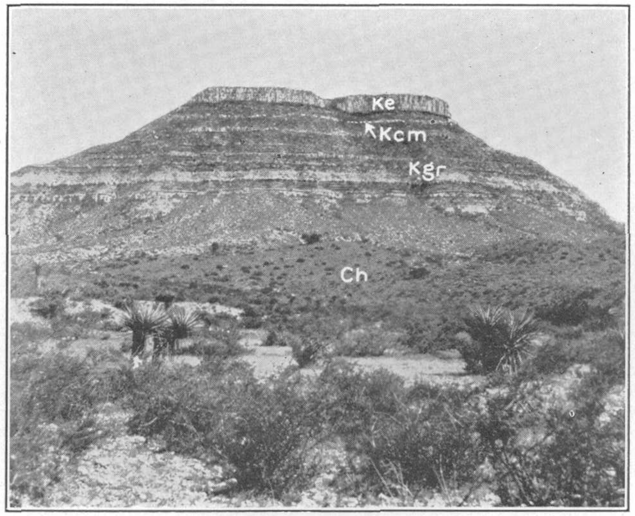
B. DEL NORTE GAP FROM SUMMIT OF DEL NORTE MOUNTAINS, TO THE NORTH.

In the distance vertical strata of Glen Rose formation (Kgr) are thrust over flaggy limestones of Eagle Ford formation.



C. BLACK PEAK FROM SOUTH.

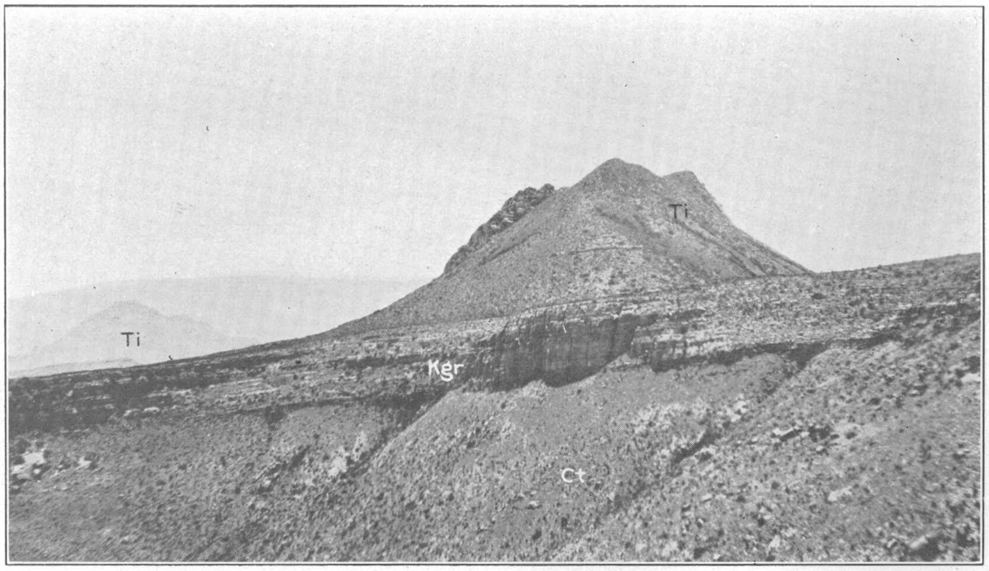
Shows exposure of Black Peak thrust. Upthrown block consists of limestones of Gaptank formation (Cg) dipping to the east. On downthrown block, limestones of Edwards formation (Ke) are dragged to a vertical position near the fault.



D. NORTH END OF HOUSETOP MOUNTAIN.

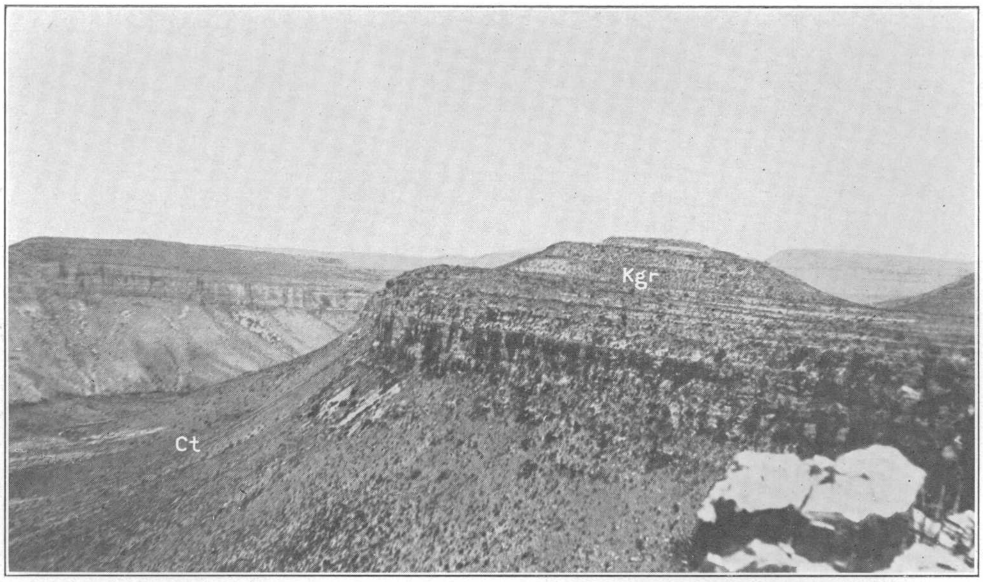
Limestones, marls, and sandstones of Comanche series are exposed in peak. Strata of Haymond formation exposed in foreground.

Kb, Buda limestone; Kdr, Del Rio shale; Kg, Georgetown limestone; Ke, Edwards limestone; Kcm, Comanche Peak limestone, Walnut clay, and Maxon sandstone; Kgr, Glen Rose formation; Ch, Haymond formation.



A. LIMESTONES OF GLEN ROSE FORMATION (Kgr) INTRUDED BY IGNEOUS ROCK (Ti).

On south margin of Marathon Basin. The sharp peak, which is composed of igneous rock, is elevation point 4,748. Looking southwest. Ct, Tesnus formation.



B. LIMESTONES OF GLEN ROSE FORMATION (Kgr) OF THE MARAVILLAS SCARP, DIPPING SOUTH OFF MARATHON UPLIFT.

Sandstones of Tesnus formation (Ct) crop out on lower part of canyon walls. View looking southward from point at which view shown in *A* was taken.

the Glass Mountains the basal beds are the marl and limestone of the Glen Rose formation. This ends abruptly northward against the Permian. The next higher formation is the Maxon sandstone, which to the south lies between the Glen Rose and the Edwards limestone, but which on the flanks of the Glass Mountains north of the Glen Rose outcrop forms the basement sands of the Cretaceous. On the crests of the range, however, the sands are absent, and the Edwards limestone rests directly on the Permian, suggesting that the area of the present mountains stood as an island in the older Lower Cretaceous sea. The succeeding formations of the Comanche series and the Upper Cretaceous were laid down continuously across the present Marathon region.

In the present investigation the Cretaceous rocks of the Monument Spring and Marathon quadrangles were studied only in reconnaissance, and no attempt was made to work out the details of the faunal and lithologic sequence. Further observations of the writer on the north flank of the Marathon uplift were published in 1931,[3] and much information on the fossil zones and distribution of lithologic facies in this part of trans-Pecos Texas has been presented by Adkins.[4]

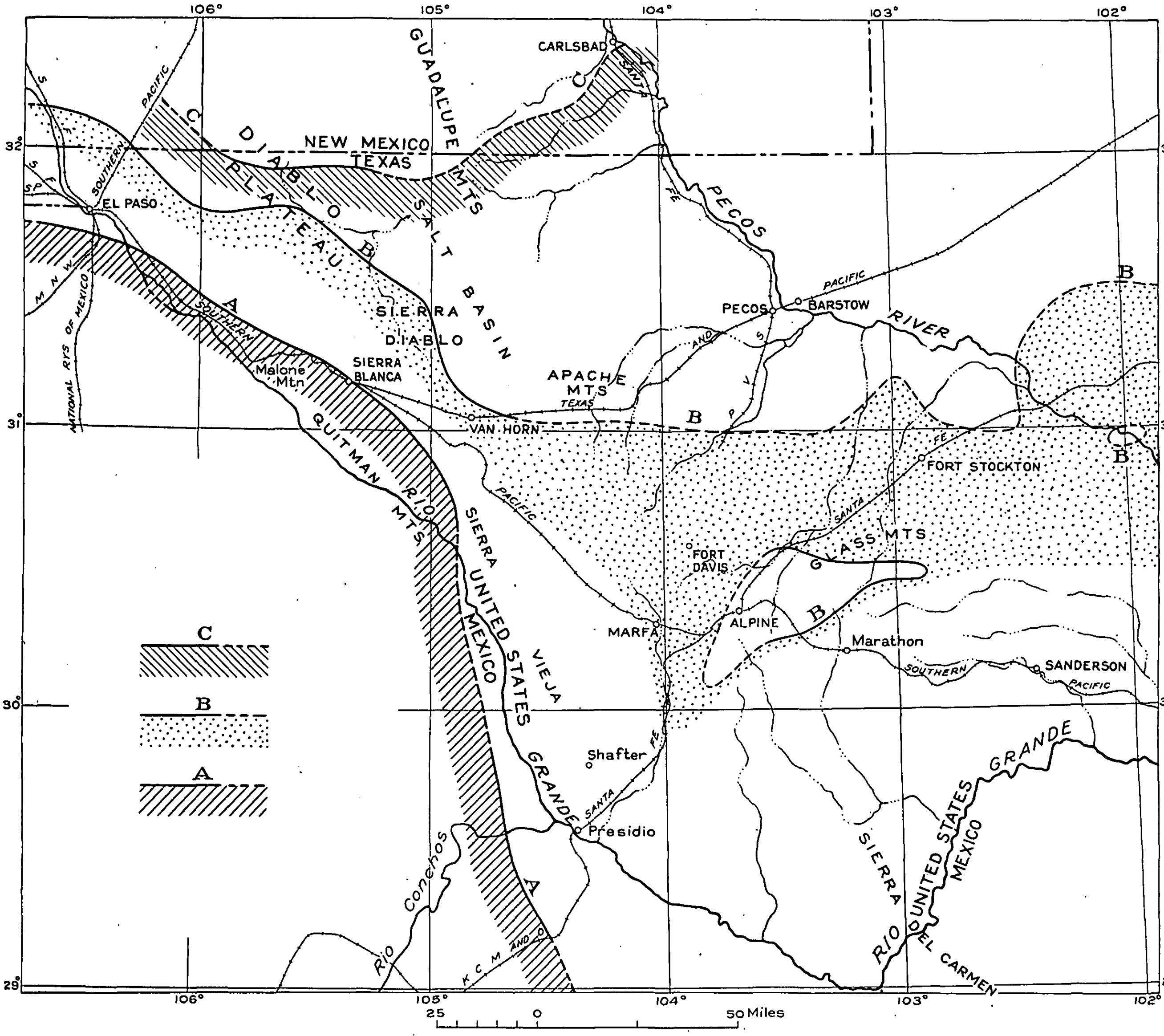


FIGURE 30.—Map of trans-Pecos Texas showing progressive northeastward overlap of Comanche series and shore lines at successive stages during the epoch. A, Shore line in late Jurassic and early Cretaceous time; B, shore line at end of Trinity time (stippled area shows extent of marginal sandstone facies of Trinity group); C, shore line at end of Fredericksburg time. Based chiefly on observations of W. S. Adkins, C. L. Baker, and P. B. King.

[3] King, P. B., The geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, pp. 90-97, 1931.

[4] Adkins, W. S., Geology and mineral resources of the Fort Stockton quadrangle: Texas Univ. Bull. 2738, pp. 31-72, 1927; Mesozoic systems: The geology of Texas, pt. 1, Stratigraphy, Texas Univ. Bull. 3232, numerous references in the section between pp. 259-400, 1933.

LOWER CRETACEOUS (COMANCHE) SERIES

TRINITY GROUP

GLEN ROSE FORMATION

GENERAL FEATURES

The Glen Rose formation crops out along the bounding scarps of the Marathon Basin on both the east and west sides as far north as the Glass Mountains, where it ends abruptly by overlap (pl. 12). On the east side it extends as far north as Gap Tank, and on the west, in the Del Norte Mountains, nearly to the latitude of Marathon. As here mapped the formation includes all the beds between the base of the Comanche series and the base of the Maxon sandstone. These are believed to be very nearly the equivalent of the Glen Rose at its type locality in central Texas. The term has been given the same scope in this region by Stanton.[5]

For the most part the Glen Rose rests on an even surface of strongly folded Carboniferous strata, which is well exposed along the bare escarpments surrounding the basin (pl. 1, *B*). Even the Dimple limestone, a ridge-maker of some prominence under present conditions, does not break the regularity of the contact.

LOCAL FEATURES

East side of Marathon Basin.—Along the east side of the Marathon Basin the Glen Rose first appears in the region of Gap Tank. Near the tank and in the mesas not far to the south it has a thickness of 50 feet or less, and its beds contain cobbles of limestone derived from the erosion of the nearby Permian rocks (sec. 6, pl. 12). A short distance north of the tank the formation disappears abruptly by overlap against the Permian limestone. About 1½ miles south of the tank the formation is made up of buff marls, in part sandy, interbedded with thin ledges of white marly limestone (sec. 7, pl. 12). The limestone beds contain oysters and rudistids. There is a few feet of conglomerate at the base, made up of limestone pebbles.

In the mesas 8 or 10 miles south of Gap Tank the Glen Rose formation is 200 to 300 feet thick and consists of alternating beds of buff marl and thin limestone, with some sandstone interbedded toward the top (pl. 13, *D*). According to T. W. Stanton, the zone of *Orbitolina texana* (Roemer), with an abundant and characteristic fauna, is well developed at many localities near Maxon and Tesnus stations and to the north. At the railroad the zone of abundance of *Orbitolina* is about 100 feet below the top, but to the north the interval becomes somewhat less. On Housetop Mountain and in the mesas near Tesnus the basal ledges contain a great abundance of an oyster, which is probably *Exogyra quitmanensis* Cragin.

[5] Stanton, T. W., The Lower Cretaceous or Comanche series: Am. Jour. Sci., 5th ser., vol. 16, p. 404, 1928.

On Housetop Mountain the formation is 312 feet thick. The following section (sec. 9, pl. 12) was measured at the south end of the mountain:

Section of Maxon sandstone and Glen Rose formation on Housetop Mountain

	Feet
Maxon sandstone: Pale-brown or buff medium-grained sugary sandstone, weathering dark brown, in thin to thick beds, in part cross-bedded at various angles. In places the formation stands in a sheer cliff, but at all places it is much jointed, and breaks off in great angular blocks	102
Glen Rose formation:	
19. Sandy marl, with some nodular limestone layers	16
18. Ledge of calcareous sandstone	5
17. Buff sandy marl and thin nodular limestone	8
16. Cross-bedded sugary sandstone	4
15. Brown sandy marl	16
14. Massive gray-brown limestone	19
13. Marls, not well exposed	21
12. Gray limestone, in 3-foot to 8-foot ledges	38
11. White and buff marl and white thin-bedded nodular limestone	32
10. Massive limestone in a single ledge, with abundant oysters at the top	16
9. Brown and buff marl and marly limestone	37
8. Massive gray limestone in 3-foot to 4-foot ledges	32
7. White limestone in 1-foot beds, with marls between	24
6. White to pale-buff limestone in thick ledges	13
5. White and buff marl	4
4. Massive white limestone	2
3. Soft white platy limestone	5
2. Buff mottled nodular limestone, forming a ledge and containing fragments of oysters	7
1. Brown nodular sandy marl, resting on the upturned edges of the Tesnus formation. Contains *Exogyra quitmanensis* Cragin?	13
Total thickness of Glen Rose formation	312
Tesnus formation.	

South side of Marathon Basin.—Along the south edge of the Marathon Basin the Glen Rose formation is 500 feet thick. At the base, resting on the eroded surface of the Tesnus formation, is a few feet of red-brown coarse-grained sandstone, with angular to subrounded pebbles of chert, passing locally into a coarse massive chert conglomerate. This is overlain by 100 to 150 feet of very massive light-gray limestone that stands in vertical cliffs and forms the cap rock of the escarpments (pl. 14, *B*). A short distance east of the Boquillas road abundant specimens of *Orbitolina* were noted in this bed.

Above the massive basal limestone of the Glen Rose on the south side of the Marathon Basin are 300 or 400 feet of interbedded thin limestones and buff marls, which have been worn down into a strike valley between the scarp of the basal beds and the cuestas of the Edwards limestone farther south. The beds also remain in residual patches on the dip slope of the lower limestones, where they rise as low knolls of tawny-yellow color. Near the 4,748-foot igneous peak in the northern part of the Hood Spring quadrangle the marls are metamorphosed to a gray marble for 5 or 10 feet away from the igneous body (pl. 14, *A*). Part of the highest marls immediately beneath the Edwards limestone on the slopes of the next escarpment to the south are doubtless of Walnut and Comanche Peak age, but their exposures were not studied.

West side of Marathon Basin.—In the northern part of the Del Norte Mountains, on the west side of the Marathon Basin, the Edwards limestone directly overlies the Permian (sec. 1, pl. 12). The Glen Rose formation first appears farther south, almost due west of Marathon, and thickens from this point to 250 feet in a distance of 1½ miles along the face of the escarpment. Near the north edge of the Glen Rose the basal layer is a conspicuous ledge of conglomeratic limestone containing fragments of oyster shells, which follows the rise in surface of the Permian rocks northward. To the south, for a distance of 8 miles, only the uppermost beds of the Glen Rose are exposed in the Del Norte Mountains (sec. 2, pl. 12). Pennsylvanian and Devonian(?) rocks are in contact with the formation along the front of the range, but these have attained their position by faulting (secs. M–M′ and N–N′, pl. 21). The fault relation is well shown at Black Peak, west of the Roberts ranch.

The full sequence of the Glen Rose formation is again exposed 2 or 3 miles north of Del Norte Gap, in the high mesa that forms the southern end of the Del Norte Mountains. The formation here and in adjacent parts of the Cochran and Santiago Mountains is 550 feet thick (secs. 3 and 4, pl. 12). The basal beds, which rest on the upturned edges of the Tesnus formation, are sandstones and sandy marls, with beds of conglomerate. The higher part of the formation consists of two members of thick-bedded or massive limestone, which contain rudistids in places. Between them is a member of sandy marl and calcareous sandstone. The two limestone members stand in prominent cliffs and ledges, and the sandy beds between are eroded to a slope.

The following section (sec. 3, pl. 12) was measured 3 miles north of Del Norte Gap:

Section on east face of Del Norte Mountains 3 miles north of Del Norte Gap

	Feet
Edwards limestone.	
Walnut and Comanche Peak formations:	
22. White nodular limestone	28
21. Gray marl, containing *Gryphaea marcoui*	21
20. Gray limestone	4
19. Buff sandy marl, with a thin limestone ledge near the middle	35
18. Light-gray nodular marly limestone	16

Section on east face of Del Norte Mountains 3 miles north of Del Norte Gap—Continued

	Feet
Glen Rose formation:	
17. Rudistid limestone in ledges as much as 3 feet thick	55
16. White nodular marly limestone, with some 3-foot ledges of limestone containing *Requienia*	70
15. Gray limestone in 5-foot beds, forming a massive ledge	20
14. Poorly resistant buff marly sandstone, with some sandy limestones that contain oysters	42
13. Brown medium-grained calcareous sandstone in ledges as much as 5 feet thick, in part cross-bedded. Some layers contain angular limestone pebbles	11
12. Sandy marl, with some thin limestone layers	65
11. Nodular gray marly limestone, with a ledge at top	26
10. Limestone in 2-foot ledges, with marly partings	60
9. Finely crystalline or marly gray limestone in thin nodular layers; contains *Protocardia* and *Porocystis* in lower part	58
8. Marl and nodular limestone, containing *Caprina*, oysters, and gastropods. There are three ledges of massive limestone	44
7. Fine sandy buff marl, with thin limestone beds	12
6. Gray limestone in 3-foot beds, which stand in cliffs, containing oysters and *Orbitolina*	24
5. Buff marly fine-grained sandstone, with angular fragments of chert and limestone in the lower part	8
4. Poorly exposed marl, with some indistinct ledges of light-gray limestone	42
3. Buff calcareous sandstone, containing small pebbles; forms a ledge	10
2. Buff sandy marl	4
1. Conglomerate of angular chert pebbles 2 inches or less in diameter, closely packed in a sandstone matrix. The pebbles can be matched with Paleozoic cherts that crop out nearby	8
Total thickness of Glen Rose formation	559
Tesnus formation.	

South of Del Norte Gap the Glen Rose formation is steeply tilted or overturned, and its limestones make part of the sharp ridges in the narrow folded belt of the Santiago Mountains (pl. 13, *B*).

MAXON SANDSTONE

GENERAL FEATURES

The Maxon sandstone crops out in a prominent ledge midway up the scarps along the east side of the Marathon Basin (pl. 13, *D*). It extends southward from the vicinity of Gap Tank at least as far as the southeast corner of the basin; its southernmost outcrop is 1 mile north of the Jones ranch house in the Dove Mountain quadrangle. It was first described by Baker and Bowman,[6] though its age was not discussed, and was later mentioned by Stanton,[7] who noted that

[6] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 114, 1917.

[7] Stanton, T. W., The Lower Cretaceous or Comanche series: Am. Jour. Sci., 5th ser., vol. 16, p. 404, 1928.

it has much the same age and relations as the Paluxy sand of north-central Texas. The name was given by the writer in 1930 [8] because the exposures of the sandstone are now widely separated from those of the Paluxy, and the two formations may never have been connected. The type locality of the formation is at Maxon station, near the point where the Southern Pacific Railroad leaves the Marathon Basin on the east. It crops out in prominent ledges 100 feet above the valley level east of the station and caps several buttes of Glen Rose formation to the west of it. In the mesas 5 or 8 miles east of Gap Tank the sandstone may be traced northward beyond the point where the Glen Rose formation disappears by overlap (pl. 12).

LOCAL FEATURES

The sandstone crops out in one or more conspicuous massive ledges, cut by vertical joints that run through 25 feet or more of strata and cause the rock to break off in great cubical blocks. It is a brown, well-indurated coarse- to medium-grained sandstone, with prominent cross-bedding. In some places there are one or more thin shaly layers. Near Gap Tank it loses its massive character and is interbedded with sandy marl and conglomerate. It passes out by overlap about a mile north of this place. The formation thickens gradually southward from Gap Tank. A mile and a half to the south it is 90 feet thick (sec. 7, pl. 12), and on Housetop Mountain 102 feet (sec. 9, pl. 12). At the southeasternmost exposures, along San Francisco Creek north of the Jones ranch, in the Dove Mountain quadrangle, it consists of brown or buff fine-grained calcareous sandstone. It is absent a short distance to the south and southwest of the Jones ranch, where its position is occupied by sandy shales and marly limestones.

In the northern part of the Del Norte Mountains, on the west side of the Marathon Basin, the Edwards limestone rests directly on strata of Permian age. West of the summit of Dugout Mountain, however, the Edwards is underlain by 50 feet of limestone crowded with angular fragments of sandstone and limestone, interbedded with calcareous pink sandstone. A few miles to the south the Glen Rose formation appears beneath these sandy beds. Near Black Peak the strata beneath the Edwards limestone are brown calcareous friable sandstones, in part cross-bedded, in 1-foot to 4-foot ledges, with some conglomeratic layers and beds of sandy limestone (sec. 2, pl. 12). Farther south, near Del Norte Gap, the same beds are marls and marly limestones containing Walnut and Comanche Peak fossils (sec. 3 and 4, pl. 12). Evidently the sandstone beds in this region are replaced southward by marls of the Walnut and Comanche Peak formations.

AGE OF THE FORMATION

No fossils have been found in the Maxon sandstone. Regarding its age Stanton [9] writes:

> Whether it should be classified as Trinity or Fredericksburg is largely a matter of personal preference. Following the precedent established in classifying the Paluxy sand of north-central Texas, which is in approximately the same stratigraphic position, it would be placed in the Trinity, but it may well be in part of Fredericksburg age.

FREDERICKSBURG GROUP

WALNUT AND COMANCHE PEAK FORMATIONS

GENERAL FEATURES

At the typical sections of the Comanche series in central Texas the Edwards limestone is separated from the Trinity group beneath by the Walnut clay and Comanche Peak limestone, a thin group of marls and soft limestones characterized by *Oxytropidoceras*, *Gryphaea marcoui* Hill and Vaughan, *Exogyra texana* Roemer, and other fossils. The abrupt change from the marly strata of these formations to the rudistid reefs and thick limestones of the Edwards makes it easy to recognize the boundary between them at the type sections, but elsewhere, where the rudistid facies is lacking, ammonoids and oysters of the Walnut and Comanche Peak formations are found to range through the whole of the Fredericksburg group. Adkins [10] and Thompson [11] have suggested that the lithologic units of the Fredericksburg are facies that are in part lateral equivalents of each other. They consider that the Walnut and Comanche Peak formations were deposited nearer to the shore than the thick-bedded limestones of the Edwards. They present evidence which suggests that, in central Texas at least, they replace the Edwards limestone northward along the outcrop.

For this reason, in outlying areas, such as the Marathon region, the precise time equivalents of the Walnut and Comanche Peak formations of the type localities are not easy to establish. The equivalents of the formations are with little doubt represented in the Comanche succession south of the Glass Mountains, for the section here extends from undoubted Trinity below to undoubted upper Fredericksburg above, but the boundary lines drawn in this region are based on local lithologic differences.

LOCAL FEATURES

Along the east side of the Marathon Basin 50 feet or more of marls and thin limestones intervene between

[8] King, P. B., Geology of the Glass Mountains, pt. 1, Descriptive geology: Texas Univ. Bull. 3038, pp. 92–93, 1930.

[9] Stanton, T. W., op. cit., p. 404.

[10] Adkins, W. S., op. cit. (Bull. 3232), pp. 323, 325, fig. 19.

[11] Thompson, S. A., Fredericksburg group of Lower Cretaceous, with special reference to north-central Texas: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 1508–1537, 1935.

the Maxon sandstone and the Edwards limestone and are tentatively correlated with the Comanche Peak and Walnut formations (secs. 6–9, pl. 12). In the Del Norte Mountains most of the beds between the Glen Rose and the Edwards limestone are sandstones and sandy marls, but these give place, near Del Norte Gap and in the Santiago Mountains, to the south, to buff marls, in part sandy, with interbedded light-gray or white nodular limestones that contain *Gryphaea marcoui* Hill and Vaughan (secs. 3 and 4, pl. 12). These are mapped as the Comanche Peak and Walnut formations. In the Cochran Mountains, east of Del Norte Gap, at the south edge of the Monument Spring quadrangle, the Cretaceous rocks are nearly flat-lying, and the marly beds of these formations stand in residual knolls on the summit (pl. 24), on top of benches of the resistant limestones of the upper part of the Glen Rose formation.

EDWARDS LIMESTONE

The Edwards limestone, with a maximum thickness of 200 feet, is one of the most prominently exposed formations in the area. Its resistant massive limestones stand in ledges and cliffs that cap most of the escarpments surrounding the Marathon Basin.

In the vicinity of the Glass Mountains north of the Marathon Basin, the Edwards is predominantly a light-gray finely crystalline or dense limestone, in layers from a few feet to 10 feet or more in thickness. These beds everywhere contain considerable quantities of nodular and concretionary brown chert, and the more massive ledges contain various types of rudistids and chamids. Between the more massive strata, particularly in the upper part of the formation, are members of marly limestone and soft argillaceous marl of varying thickness, which increase in prominence toward the north.

Farther south, along the east and west sides of the Marathon Basin, the marly strata are mostly absent except for some thin members near the top, and the formation is nearly all massive light-gray limestone in 5- or 10-foot ledges that contain sparse chert concretions. These weather blue gray or dirty gray. On the steeper escarpments the whole formation stands in a single cliff, as on Housetop Mountain, on the east side of the basin (pl. 13, *D*), and on the high mesa north of Del Norte Gap, where it is 200 feet thick. The formation makes the conical cap of each of the three peaks of the Tres Hermanas, in the southeastern part of the basin (fig. 2, A). On the south side of the Marathon Basin the Edwards limestone stands in a cuesta to the south of and parallel to the cuesta of the Glen Rose formation, from which it is separated by a strike valley carved from the marls and thin limestones of the upper part of the Glen Rose and the Walnut and Comanche Peak formations.

WASHITA GROUP

GEORGETOWN LIMESTONE

On the west side of the Marathon Basin the Edwards limestone is succeeded by about 200 feet of thin- to thick-bedded limestone, which belongs to the Georgetown formation. Beds of the same age have been subdivided in some detail by Adkins in the Fort Stockton district, farther north, and correlated with the zones of similar formations in north-central Texas. At Fort Stockton they consist of alternations of shaly and marly layers with ledges of rudistid-bearing limestone. South of that place the soft beds change into limestone ledges, and the subdivisions prominent to the north become indistinct, although some of the zone fossils persist.[12] This situation exists in the vicinity of the Marathon Basin, but in the present work no subdivision of the Georgetown limestone or correlation of its members was attempted.

Near Del Norte Gap and Black Peak, in the Del Norte Mountains (pl. 24), the formation consists of buff or gray nodular limestone and marly limestone in beds a few inches to a few feet thick. There are two members of massive limestone, one near the middle and one near the top (sec. 2, pl. 12). The uppermost ledges are full of ovoid brown chert concretions, and some of the layers are crowded with various rudistids and Gryphaeas. It is suggested that the two ledge-making members are to be correlated with the "middle cap rock" and the "upper cap rock" of the Fort Stockton district. In comparing the Fort Stockton section with that in north-central Texas Adkins suggests that the first of these is "of approximately Denton age" and the age of the second should be "provisionally put as Mainstreet." [13]

DEL RIO SHALE AND BUDA LIMESTONE

On the west slope of the Del Norte Mountains the Georgetown limestone is capped by 15 or 20 feet of drab shale (pl. 13, *B*, *C*; sec. 2, pl. 12), with some layers of brown, thinly laminated sandy limestone that contains *Haplostiche* ("*Nodosaria*") *texana* (Conrad). In places the shales contain abundant *Exogyra arietina* Roemer. The lithology and fossils of the shale are characteristic of the Del Rio shale at its type locality. Much information on the formation, its facies and fossils, in trans-Pecos Texas is given by Adkins.[14]

Overlying the shale and forming a low hogback that fringes the west flank of the Del Norte Mountains is about 60 feet of thick-bedded light-gray or white limestone, which belongs to the Buda limestone. Most

[12] Adkins, W. S., The geology and mineral resources of the Fort Stockton quadrangle: Texas Univ. Bull. 2738, pp. 57–58, 1927.

[13] Idem, pp. 46, 48.

[14] Adkins, W. S., Mesozoic systems, in Geology of Texas, vol. 1, Stratigraphy: Texas Univ. Bull. 3232, pp. 386–396, 1933.

of the limestone is regularly bedded, but there are some nodular layers.

UPPER CRETACEOUS (GULF) SERIES

EAGLE FORD FORMATION

In the western foothills of the Del Norte Mountains and in the valley between them and the lava escarpments of the Davis Mountains (pl. 24), the Buda limestone is overlain by thinly laminated flaggy argillaceous limestones of buff or gray color. These beds split characteristically into slabs and flags a few inches to a fraction of an inch in thickness, and the bedding surfaces show imprints of *Inoceramus* and small ammonoids. The contact between the Buda limestone and these beds is well exposed along the roadside at the west end of Del Norte Gap, in the northern part of the Santiago Peak quadrangle (pl. 23).

The strata above the Buda limestone are considered to be the same as the Eagle Ford formation of central Texas. They closely resemble strata that lie above the Buda east and southeast of the Marathon uplift, which may be correlated from one closely spaced outlier to another with the main outcrop of Eagle Ford to the east. They also closely resemble the Boquillas flags of Udden of the Chisos and Terlingua districts, to the south.[15] The thickness of the Eagle Ford formation was not determined in the Monument Spring quadrangle, but Udden gives the thickness of his Boquillas flags in the Chisos district as about 600 feet.

POSSIBLE HIGHER BEDS

The upper part of the Eagle Ford formation was not studied during the present work, and the nature of the beds that overlie it is unknown. A considerable thickness of Upper Cretaceous strata crops out between the Del Norte Mountains and the escarpments of Tertiary lava to the west, and these beds may include equivalents of the Austin chalk of central Texas, or possibly even of higher beds. They were not differentiated from the Eagle Ford formation on the geologic map.

QUATERNARY SYSTEM

GENERAL FEATURES

Deposits of Quaternary age occupy wide areas in the Marathon region. They consist chiefly of stream deposits that were laid down on the lowland areas of the Marathon Basin during times when wide areas of plains had been worn down near baselevel. Some of these deposits now form terraces that stand above the present stream grade; others have been laid down in recent time in the valleys and flats formed during the present cycle of erosion.[15a]

[15] Udden, J. A., Sketch of the geology of the Chisos country: Texas Univ. Bull. 93, p. 29, 1907.

GRAVEL DEPOSITS

In the northern part of the Marathon Basin there are wide areas of gravel-covered rock floors, as yet untouched by down-cutting streams. Near the mountain bases these deposits merge into low broad alluvial fans (fig. 7). In the southern Marathon Basin, along Peña Blanca Creek, in Dagger Flat and other places, the lowland areas have been trenched by streams to a depth of 50 or 100 feet (fig. 8). Between the streams are low ridges underlain by the more resistant beds, which are capped in places by small patches of gravel. These stand at a common level, which is about the same as that of the gravel-covered plain to the north.

In the southern part of the Marathon Basin there is also a gravel-covered terrace of smaller extent which lies 25 or 50 feet below the higher surface. This has been grouped with the higher gravel-covered rock floor on the geologic map (pl. 24) because the two surfaces cannot everywhere be distinguished and because the large contour interval of the topographic maps makes it impossible to correlate isolated remnants of terraces with either one or the other of the two levels.

The thickness of the gravel deposits, as shown in areas where erosion has cut through them, is rarely greater than 25 feet. Along the south base of the Glass Mountains, in the northern part of the Marathon Basin, records of water wells suggest that the cover is thicker and may reach 100 feet.

The gravel cover consists of pebbles and cobbles of limestone, chert, and novaculite of local origin, set in a matrix of clay and fine fragmental material. Near the Dimple Hills the higher deposits contain cobbles of Cretaceous limestone where no rocks of that age now remain within the drainage area. At the northeast end of East Bourland Mountain they contain numerous cobbles of the Dimple limestone, though the deposit is now separated by several miles of lower ground from any exposures of this formation.

The higher gravel cover may be as old as the Pleistocene. The occurrence in the deposit of some boulders derived from rocks that now lie outside the drainage area implies either a change in drainage, or else a change in the extent of the formations from which the boulders were derived. It is probable that the higher gravel cover was the source of an elephant bone reported to have been found near Marathon in 1930.

[15a] For a description of the types of soil found in the Mε rathon region and a map showing their distribution see Carter, W. T., and others, Soil survey (reconnaissance) of the trans-Pecos area, Texas: U. S. Dept. Agr., Bur. Chemistry and Soils, ser. 1928, no. 35, 1928.

ALLUVIUM

Alluvial deposits are found on the flood plains of the present streams of the Marathon Basin. They consist of clay and gravel of a finer texture than those found on the terraces. The deposits are most widespread along the lower course of Maravillas Creek. Elsewhere they fringe the present streams in belts generally not more than 2 miles in width, which are entirely lacking where the streams cross areas of hard rock. The alluvial deposits probably in few places reach a thickness of more than 25 feet, but they may be thicker on the lower course of Maravillas Creek.

IGNEOUS ROCKS

VOLCANIC ROCKS

West of the Del Norte Mountains, on the west side of the Marathon region, are plateaus made up of lava flows and tuffs that form a part of the Davis Mountains area (pl. 23). These break off to the east in prominent escarpments. Part of the lavas that are isolated from the main mass to the west form the broad mesa of Elephant Mountain, which extends into the southwest corner of the Monument Spring quadrangle. According to Baker and Bowman [16] the Elephant Mountain flows are of soda trachyte. In the escarpments to the west there are trachytes, phonolites, and some rhyolites.[17] These escarpments

consist of interbedded flows, tuffs, tuff-breccias, mud flows, lacustrine limestones, and conglomerates. The whole is cut by dikes and sills. The more resistant flows and tuff breccias and the sills form east-facing rim-rock scarps, which have gradually receded through sapping brought about by the more rapid removal of the underlying tuffs and mud flows. The dikes usually form narrow cockscomb ridges. Some porphyritic plugs occur, a good example of which is the low, small Straddlebug Mountain, just east of Terlingua Creek (Buck Hill quadrangle), which has domed up the Eagle Ford and Buda formations.[18]

Few fossils have been found in the volcanic rocks of trans-Pecos Texas, and the precise age of most of them remains to be established. Northwest of Marathon, in the basal rhyolitic tuffs of the Barilla Mountains, Baker collected fossil plants determined by E. W. Berry as of Eocene age.[19] A little farther northwest, near Gomez Peak, Baker has collected mammalian bones, such as *Hipparion*, in the basal tuffs, and these have been determined to be of Oligocene age.[20] In the Chisos country, southwest of the Marathon region, Udden [21] found that the Upper Cretaceous marine strata passed with apparent conformity upward into continental tuffaceous rocks, and finally into lava flows and agglomerates, so that no great time interval may here have separated the laying down of the latest Cretaceous and the first beds of the volcanic succession. Away from the Chisos area, however, Ross [22] reports that the break between the two increases in magnitude, so that the overlying volcanic series rests on the eroded surface of a variety of the older rocks.

The volcanic rocks on the west side of the Marathon region overlie the Cretaceous strata with a considerable erosional break. On Elephant Mountain and near Strobel siding, at the north and south ends of the Del Norte Mountains, they lie on high Upper Cretaceous beds. At Mount Ord, about halfway between, they overlap the higher part of the Cretaceous succession and rest on strata that are probably of Georgetown age. Farther northwest, at a small exposure near Kokernot Spring, near the edge of the town of Alpine, Darton [23] has also found Lower Cretaceous strata directly beneath the lavas.

At a few places there is evidence of recent volcanism in the region. Southeast of the Marathon uplift, 1½ miles southeast of the summit of Dove Mountain, in the Maravillas Canyon quadrangle, is a small deep crater rimmed by porphyritic intrusive rocks and surrounded by tilted Georgetown limestone. The central basin is masked by alluvium. This is probably a recent explosion crater.[24]

INTRUSIVE ROCKS

Intrusive igneous rocks occupy small areas in the Marathon region and invade all the sedimentary rocks from the oldest to the youngest. The largest masses are on the north and west and include the plugs of Iron Mountain, the Altuda Mountain uplift, and Santiago Peak. Along the south rim of the Marathon Basin smaller plugs cut the Paleozoic and Cretaceous rocks. A few plugs and dikes intrude the Paleozoic strata within the basin itself. The intrusions on the north, in the Glass Mountains region, are closely related to structural trends in the Permian and Cretaceous strata and generally lie near the crests of uplifts or anticlinal axes. Those farther south do not have this close relation, but some of those in the Marathon Basin appear to have come up along the planes of thrust faults of Paleozoic age. All the intrusive igneous rocks are porphyritic, and most of them appear to be of intermediate composition. Some of them are markedly alkalic, a feature which they share with many of the igneous rocks elsewhere in trans-Pecos Texas.

[16] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 129, 1917.

[17] Idem, p. 120.

[18] Baker, C. L., letter, January 1931.

[19] Baker, C. L., and Bowman, W. F., op. cit., p. 123. Berry, E. W., An Eocene flora from trans-Pecos Texas: U. S. Geol. Survey Prof. Paper 125-A, 1919.

[20] Plummer, F. B., Cenozoic system: The geology of Texas, vol. 1, Stratigraphy, Texas Univ. Bull. 3232, p. 805, 1933.

[21] Udden, J. A., Sketch of the geology of the Chisos country: Texas Univ. Bull. 93, pp. 41-56, 1907.

[22] Ross, C. P., personal communication, August 1934.

[23] Darton, N. H., Guidebook of the western United States, part F, The Southern Pacific lines: U. S. Geol. Survey Bull. 845, p. 96, 1933.

[24] From notes by E. H. Sellards and C. L. Baker, January 1931.

The plugs of Altuda Mountain and Iron Mountain are each about 1 mile in diameter and consist of syenite and syenite porphyry. They are associated with smaller dikes and sills of trachyte. The rocks in the vicinity of Altuda Mountain are sodic.[25]

Two miles north of Black Peak, on the crest of the Del Norte Mountains, a large igneous mass intrudes the Comanche series. The intrusion appears to be a laccolith, which has divided the strata at about the horizon of the Walnut clay. The mass has been split by a later east-west fault, downthrown to the south, and the igneous rock and its domed cover are exposed on a southward-facing escarpment several miles in length. Hand specimens of the rock are finely crystalline and dark gray, with numerous feldspar and other phenocrysts as much as one-sixteenth of an inch in length in an aphanitic groundmass. According to C. S. Ross, the rock is a basalt with analcite, olivine completely altered to iddingsite, and very sodic plagioclase.

Within the Marathon Basin are other basaltic masses, mostly plugs, none of which are more than a few hundred yards in diameter. Most of these intrude the Cambrian and older Ordovician rocks, but one mass southeast of Simpson Springs Mountain and 2½ miles west of Garden Springs invades the Tesnus formation. All these masses are fresh and undeformed and do not share the intense folding of the sedimentary rocks that they invade. A specimen of the rock from the largest of the plugs, which lies in Dagger Flat, 1½ miles east of Garden Springs, is aphanitic and black, with numerous phenocrysts one-sixteenth of an inch in maximum diameter. According to C. S. Ross, it is a fine-grained olivine basalt. Other plugs to the south and east in Dagger Flat appear to be of similar composition.

East of Horse Mountain and about 7 miles southwest of Haymond station are two parallel dikelike masses about a mile in length, which form the Twin Peaks. The igneous rock of the dikes invades the basal shale member of the Tesnus formation. The two dikes follow approximately the strike of the rocks of the region, but dip 70° SE., whereas the strata dip in the same direction at a much lower angle. The northwestern intrusion lies only a few hundred yards southeast of the trace of the southeastward-dipping Arden Draw fault, and the igneous rock may have risen along this old break, or lines of fracture parallel to it. Specimens from the southeastern intrusion consist of blue-gray porphyritic rock, with feldspar phenocrysts as much as a quarter of an inch in diameter, set in a finely crystalline matrix. According to C. S. Ross, the rock is a porphyritic quartz diorite. The feldspars are very alkalic, and the ferromagnesian minerals are aegirite-augite and riebeckite, which are also alkalic minerals.

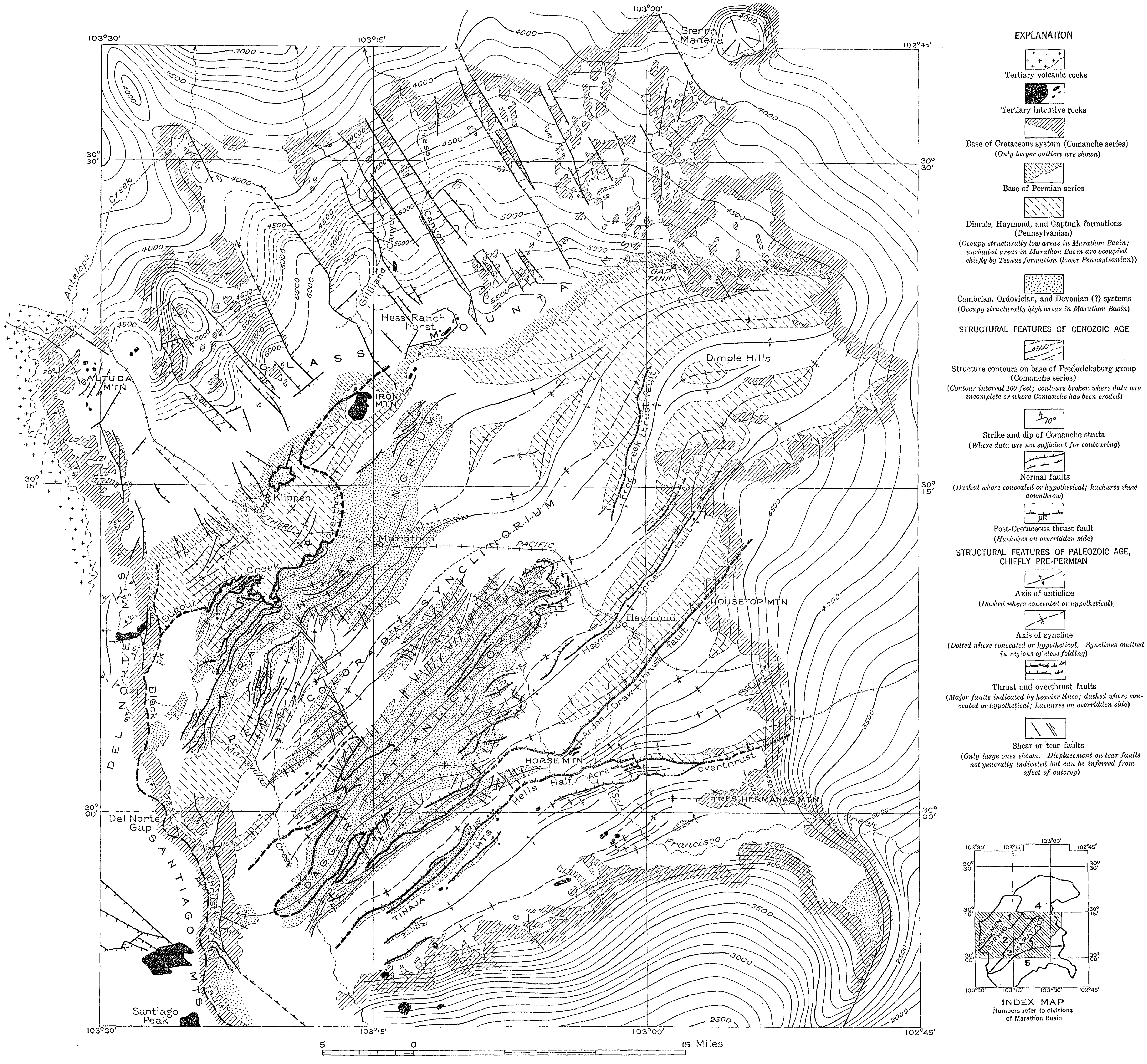
One mile south of Twin Peaks is a series of dikes that extend irregularly east and west along the trace of the Hells Half Acre fault for a distance of about 2 miles. Megascopically, they are similar to the rock at Twin Peaks. Farther southwest, in the Tinaja Mountains, in the Hood Spring quadrangle, there are several plugs in the Caballos novaculite and immediately overlying Tesnus formation near the trace of the same fault. The largest of the masses, 2 miles west of the Gage Indian Creek ranch, is a porphyritic rock, weathering to a buff color, with small sparse phenocrysts of feldspar set in a dense groundmass. According to C. S. Ross, this rock is a soda rhyolite, with a small amount of aegirite-augite. Several other masses southeast of the same ranch, which invade the Tesnus formation or the Comanche series, appear to be of similar composition.

STRUCTURAL GEOLOGY

GENERAL FEATURES

The rocks of the Marathon stand in a variety of structural attitudes, and many of them are complexly deformed. The structural features have been produced by several periods of orogeny, which are shown in the table below. The Pennsylvanian and older strata in the Marathon Basin were folded and faulted before Permian time, and rocks of the Permian series lie unconformably on the underlying beds along the south face of the Glass Mountains. The Cretaceous system in turn truncates both the structural features of the Marathon Basin and the younger ones in the Glass Mountains but has itself been deformed, both before and after the volcanic eruptions in the early part of the Tertiary period. For purposes of description, the structural features of the area will be considered in chronological order.

[25] King, P. B., Geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, pp. 100-102, 1930.



STRUCTURAL MAP OF MARATHON BASIN REGION.

Shows structural features of Paleozoic and of post-Cretaceous age.

AERIAL PHOTOGRAPH OF NORTHEASTERN PART OF DAGGER FLAT ANTICLINORIUM.

Center of area shown is about 2½ miles southwest of Lightning ranch. Shows isoclinal northeastward-pitching folds of Marathon (Om), Alsate (Oa), Fort Peña (Op), and Woods Hollow (Ow) formations and some outcrops of Maravillas chert (Omv). Scale, about 1,500 feet to the inch. Photograph by Edgar Tobin Aerial Surveys.

AERIAL PHOTOGRAPH OF AREA OF CARBONIFEROUS ROCKS SOUTH OF HAYMOND STATION.

Center of area about 3 miles northeast of summit of Horse Mountain. Shows basal shale member (Cts) and upper sandstone member (Ct) of Tesnus formation, Dimple limestone (Cd), and Haymond formation (Ch) folded into a broad syncline. Note that folds are more open here than in area shown on plate 17. Scale, about 1,500 feet to the inch. Photograph by Edgar Tobin Aerial Surveys.

Structural history of Marathon region

Era	Age	Character		Record in sedimentary rocks	Where found	
Cenozoic	Late Tertiary.	Normal faulting and uplift (?).			Glass and Del Norte Mountains.	
	Mid-Tertiary (post-Oligocene).	Gentle folding.	Igneous intrusion.		Davis Mountains.	Not separable in the Glass Mountains.
	Post-Cretaceous.	Folding, increasing in intensity to west.		Lavas rest on eroded edges of various Cretaceous formations.	Del Norte Mountains.	
Mesozoic	Later Mesozoic.	Quiescence, peneplanation, followed by submergence.		Cretaceous rocks, with little or no basal clastic material, resting on an even floor of greatly up-tilted Paleozoic.	Glass Mountains.	
	Middle Mesozoic.	Tilting and warping.				
	Post-Permian (pre-Bissett).	Uplift and erosion.		Coarse conglomerate from subjacent rocks; slight unconformity.		
Paleozoic	Permian.	Quiescence.		Reef deposition.		
	Early Permian (pre-Leonard, post-Wolfcamp).	Marathon orogenic epoch	6. Tilting and folding.	Thin persistent conglomerate; slight unconformity.		
	End of Pennsylvanian (post-Gaptank, pre-Wolfcamp).		Erosion. 5. Warping. 4. Strong folding and overthrusting.	Coarse thick conglomerate at base of the Wolfcamp locally.	Marathon Basin.	
	Mid-Gaptank.		3. Beginning of folding, including folding of first overthrusts.	Deposition of a "Molasse" facies, with conglomerate beds near middle of Gaptank.		
	Late Haymond.		2. Overthrusting in southeastern part of area.	Exotic blocks. Deposition of a "Flysch facies" of enormous thickness.		
	Haymond to Tesnus.		1. Strong uplift of the hinterland.			
	Mid-Paleozoic (pre-Tesnus, post-Caballos).	Broad uplift and retreat of the sea.		Thin basal conglomerate of Tesnus formation, resting unconformably on Caballos.		
	Earlier Paleozoic (Caballos to Cambrain).	Mid-Ordovician uplift.		Periodic submergence and deposition of peculiarly geosynclinal rocks. Conglomerates at base of the Maravillas indicate mid-Ordovician uplift.		

MARATHON BASIN

GENERAL FEATURES

The Marathon Basin exposes a system of ancient structural features of Appalachian type, produced toward the end of Pennsylvanian time by the Marathon disturbance. The disturbance acted on geosynclinal strata, consisting of shaly limestone and bedded chert in the lower part and a vast succession of sandstones and shales above. Folded rocks of geosynclinal facies also appear in the Solitario, 35 miles southwest of the Marathon Basin, and they resemble those in the Ouachita Mountains of Oklahoma and Arkansas. In the Hueco and Diablo Mountains of northwestern trans-Pecos Texas are broad folds of the same age in what was apparently a foreland area. The movements that produced the structural features were pulsatory and extended through a considerable span of Pennsylvanian time. Deposition was nearly continuous in the area during the Pennsylvanian, so that many of the movements are recorded in the sedimentary rocks. Strata of early Permian age lie unconformably on the folds along the north side of the Marathon Basin.

The major features of the Marathon Basin are plainly revealed by the hogbacks of the pre-Carbonif-

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erous Caballos novaculite and the mid-Carboniferous Dimple limestone, which now rise as a skeleton of the greatly denuded mountain structure. The minor features, on the other hand, are in many places complex and obscure and are further complicated by the extensive mantling of the lowlands by mountain waste.

The rocks of the Marathon Basin are thrown into northeastward-trending folds (pl. 15), overturned toward the northwest (secs. A–A′, B–B′, and C–C′, pl. 23). Many of these are broken by thrust faults. The faulting culminated on the northwest in the nearly flat-lying Dugout Creek overthrust, with a known displacement of more than 6 miles. Farther southeast are other great thrusts, also with miles of displacement, some of which are folded and therefore older than the frontal overthrust. The folds are shattered by transverse flaws and tear faults, some of which have a large component of horizontal displacement. The folds and faults have a slightly arcuate form, which is most pronounced in the northwestern part of the area (pl. 15). The folds are crossed in a north-northwesterly direction by cross warps; in the west half of the basin the folds are arched up to reveal Cambrian and Ordovician strata; in the east half there is a complementary depressed area of Carboniferous rocks whose axis extends northward roughly from Tesnus to Gap Tank. Two large doubly plunging anticlinoria lie athwart the arch; these are the Dagger Flat and Marathon anticlinoria (pls. 15, 23, and 24).

Estimates of the amount of crustal shortening were made in various parts of the area, allowing faults their minimum possible throw and folds their minimum possible height. These estimates show a shortening to 1 mile across the strike from an original distance of 1½ to 3 miles (fig. 33). The strata of the Marathon Basin are nearly unmetamorphosed, though the sandstones and shales are somewhat indurated, and the shales approach slates to the southeast. The harder layers in the succession, such as the sandstones and limestones, are much shattered, jointed, and slickensided and are traversed by innumerable small veins of calcite. Some of the pebbles of the conglomerate beds have been broken and sheared out. The shale beds have been tremendously crumpled and squeezed. The brittle cherts and novaculites have fractured and glided and have piled up in places like shingles along numerous small thrusts. Most of the folds are closely compressed. Only the competent sandstones of the Tesnus and Haymond formations in the Carboniferous lie in folds of any great breadth.

The known structural features in the Marathon Basin are illustrated by the accompanying tectonic map (pl. 15), which shows anticlinal and synclinal axes, the traces of thrust and overthrust faults, and the position of the transverse tear faults. The structural features of the Marathon Basin are described below under several divisions, which are shown on the index map on plate 15.

MARATHON ANTICLINORIUM (INCLUDING DUGOUT CREEK AREA)

General features.—The Marathon anticlinorium embraces the northwestern part of the Marathon Basin and lies across the belt of upwarping. The folds of the anticlinorium pitch both to the northeast and southwest. In the northwestern part of the area the Dugout Creek overthrust comes to the surface, evidently as a result of the upwarping of this part of the district; here pre-Carboniferous rocks overlie the higher Pennsylvanian. The area may be divided into the outcrops of the overriding mass of the thrust and the exposed parts of the block overridden by it.

Exposures of the Dugout Creek overthrust.—The Dugout Creek overthrust is best exposed about 7 miles west of Marathon, in the Payne Hills, which flank Dugout Creek on the south (pls. 16 and 24). The fault plane here is nearly flat, as revealed by the position of the dissected trace. Cherts of the Caballos and Maravillas formations cap the hills, and upper Pennsylvanian shales and thin sandstones crop out on the slopes, in reentrant valleys, and in rare small windows. At the east end of the hills the trace of the fault turns southward for 2 miles down the valley of Alsate Creek, in which Pennsylvanian rocks are exposed. To the southeast the fault dips at a low angle beneath the surface. Toward the east the outcrop is masked by deposits of wash in most places, but the fault is exposed in a small area on the Hargus ranch, 3 miles west of Marathon (pl. 24).

Near the railroad north of the Hargus ranch and at several places 2 miles northwest of the Decie ranch, farther north, there are small klippen, or outliers of the overthrust, consisting mostly of novaculite; these rest on the Gaptank formation. North of the Decie ranch, at the base of the Permian escarpment, is an area of about 1 square-mile much obscured by alluvium, in which cherts, novaculites, and limestones of the Dimple formation crop out, surrounded and apparently underlain by Pennsylvanian sandstones and shales (pl. 24). This area, without doubt a larger outlier of the thrust sheet, is 4 miles from the present main front of the fault and gives it a known displacement of about 6 miles. Another exposure, possibly related to the overthrust, is that of the Gaptank formation, which underlies the Permian northwest of Iron Mountain (pl. 23). Exposures of Dimple limestone are found not far to the south, probably separated by a fault. This fault lies along the northeastern projection of the overthrust trace.

Where the Dugout Creek overthurst and the thrusts immediately behind it moved across such competent rocks as limestone or chert, they produced a considerable amount of brecciation. The breccias reach 5 or 10 feet in thickness but are lenticular. They consist of angular fragments of chert and novaculite in a chalcedonic matrix; and some of them consist of jumbled flags and plates of bedded chert. Along the present margins of the thrust sheets the breccias, released by erosion, are strewn over the surface of the overridden rocks in great blocks, which resemble the boulders in the boulder-bed member of the Haymond formation. Where the thrusts moved across shale there is rarely any breccia, and the chert beds rest directly on the Pennsylvanian. There is no evidence at any place of mylonitization or cataclastic metamorphism.

Structure of the overridden rocks.—The Gaptank and Haymond shales and sandstones beneath the overthrust are mostly incompetent and have been minutely deformed by small folds and thrusts (pl. 9, *D*). However, in spite of the intense deformation, metamorphic effects are negligible, and the shaly beds are only slightly indurated. The thin incompetent limestone beds intercalated in the series are bent about, broken, and repeated in a most complicated manner. At a locality 4 miles south-southwest of Lenox a limestone layer is thus duplicated 12 times in one-third of a mile (pl. 24). The complexity appears to be greatest in the lower part of the series; higher up there are more numerous beds of competent limestone and limestone conglomerate, so that the folding is more open, as at milepost 580, 4 miles west of Marathon (pl. 21). The planes of the thrusts and the axial planes of the folds dip to the southeast.

The highest part of the area structurally is in the northwest, near the base of the Permian escarpment (sec. G–G′–G″, pl. 21). Here beds correlated with the Haymond formation are brought up in two anticlinoria, one on the Decie ranch, the other south of Dugout Mountain. These anticlinoria have a complicated minor structure and are bounded by a thin limestone with a basal Gaptank fauna. The north flank of the anticlinorium south of Dugout Mountain is overturned and dips 35° S. The higher Gaptank beds are exposed to the southeast in a synclinorial area. It is likely that this major structure is the reflection of broad open folds in the competent Dimple and older formations beneath.

Permian rocks with coarse thick basal conglomerate lie with great unconformity on the overturned beds on the face of Dugout Mountain (sec. G–G′–G″, pl. 21). North of the Decie ranch the Permian conglomerates rest in places on the Caballos novaculite and Dimple limestone of the thrust sheet, and at other places nearby they rest on the Pennsylvanian sandstones of the overridden mass (pl. 24). The lower parts of the Haymond and Gaptank exposed below the thrust consist of an alternation of sandstone, shale, and thin limestone. Layers of chert conglomerate appear higher up, as in the exposures near milepost 580, and elsewhere there are layers of limestone and chert cobbles in the higher beds. These may have come from the first erosion of the upraised mass, which later moved forward by overthrusting.

Faults of the overriding block.—The overriding block of the Dugout Creek overthrust is a part of the Marathon anticlinorium, in which early Paleozoic strata are exposed. For a few miles behind the fault these overlying rocks have been broken into an imbricate structure as a result of friction developed on the sole of the thrust, and farther back there are several secondary overthrusts of considerable displacement. In addition, a system of pronounced en échelon tear faults extends back from the front of the thrust at Alsate Creek for a distance of nearly 10 miles to the southeast (pl. 15) and appears to have resulted from differential movement between two parts of the overriding mass.

The tear faults that extend southeastward from the head of Alsate Creek have an en échelon pattern and are downthrown on their northeast side. The en échelon arrangement and the offset of folds and faults by the tear faults suggest a greater northwestward movement on the northeast than on the southwest side. Farther east, near the gap in the novaculite ridge south of Fort Peña Colorada, are other vertical or steeply inclined faults on which there also have been greater northwestward movements on the northeast sides. The rocks of the Marathon anticlinorium on the northeast side of the en échelon system of fractures are strongly folded but not greatly faulted, but on the southwest side the strata are broken into numerous thrust faults.

On the southwest side of the en échelon system of tear faults there are four main thrust blocks in the overriding mass of the Dugout Creek overthrust (pl. 16). The frontal block, which crops out in the Payne Hills, consists of Maravillas and Caballos cherts and Carboniferous strata as high as the Haymond formation. At the north edge of the hills the cherts are piled up in imbricated slices, with very little folding (sec. C–C′, pl. 16). There are several windows of Gaptank formation in the hills caused by erosion through the plane of the Dugout Creek overthrust. Two of the windows are bounded on the northwest side by steep faults that appear to be later than the overthrusting (sec. B–B′, pl. 16). In the southern part of the Payne Hills Dimple and Tesnus strata overlie the older rocks, first in sharp folds and then, near the boundary of the next sheet to the south, in a broad syncline (sec. D–D′, pl. 16). About 3 miles north-northeast of the Roberts ranch these strata are nearly flat over an area of about one square mile (southwest corner of area shown on pl. 16).

In the southern part of the Payne Hills, near their east end, a mass of Maravillas and Caballos strata has been thrust forward for more than half a mile over the rocks of the northern part of the hills and forms the second thrust block (sec. C–C′, pl. 16). The thrust dies out in a faulted fold to the southwest (sec. D–D′, pl. 16). Masses of chert breccia and of novaculite are strewn in front of it and show a former greater extension of the sheet. Toward its east end the rocks above this overthrust are broken by two thrust faults, which, in contrast to the other faults of the area, have moved backward (southeast) (sec. B–B′, pl. 16).

The third block to the southeast brings up Caballos and older strata (secs. C–C′ and D–D′, pl. 16) and, like the thrust just described, has its greatest throw at the northeast. To the southwest it is traceable as far as Rock House Gap on the Roberts ranch, where it splits into several southwestward-pitching faulted folds (pls. 15 and 24). The plane on which this sheet moved has an inclination ranging between 30° and 45°, and the thrust carried Ordovician rocks over the Dimple and Haymond formations. The Ordovician strata for a mile to the southeast of the fault are folded into isoclinal, closely packed, faulted anticlines (secs. C–C′ and D–D′, pl. 16). Beyond, Cambrian strata come up in several narrow folds near the road to the Roberts ranch and are on the highest part of the Marathon anticlinorium. Immediately southeast of the fault there are in places as many as 12 anticlines or thrust blocks in a distance of a mile across the strike. Southeast of the outcrops of Cambrian rocks at the crest of the anticlinorium the Ordovician and Devonian (?) strata dip in regular order at angles of 40° or less to the southeast, beneath the Tesnus formation in the valley of Monument Creek (secs. B–B′ and C–C′, pl. 16).

On the southeast side of Monument Creek is a fourth fault block, which has moved along the Sunshine Springs overthrust. This fault dips 30° SE., and carries Woods Hollow, Maravillas, and Caballos strata in a recumbent fold over the Tesnus formation (sec. C–C′, pl. 16). To the southwest the overthrust splits into several irregularly branching faults, which extend into and die out in a synclinal area of Dimple and Haymond strata (pls. 15 and 24).

East of the system of en échelon faults there is very little thrusting southeast of the main overthrust (pl. 24), but the frontal fault, as exposed at the Hargus ranch and some other places, consists of several separate slices. The main mass of overriding strata is made up of pre-Carboniferous rocks, but in places a narrow wedge of Dimple limestone intervenes between this mass and the underlying Gaptank formation (sec. A–A′, pl. 16).

Folds of the overriding block.—In addition to the many faults into which the Marathon anticlinorium has been broken, all parts of it have been strongly folded. The folds in the beds below the Maravillas chert are isoclinal and are overturned toward the northwest. Dips on the southeast flanks of the anticlines range from 30° to 45° SE.; the northwest limbs either dip steeply northwest or are overturned. There are about four anticlines in each mile across the strike in these rocks. The Marathon limestone has been crumpled and repeated many times, as is shown by the complicated, broken outcrop of the Monument Spring dolomite member near the middle (pl. 24).

On the northwest flank of the anticlinorium west of Alsate Creek, where the Alsate shale is unusually thick, this incompetent layer appears to have acted as a gliding plane so that the Marathon beds are more intricately deformed than the massive limestones of the Fort Peña above. In a similar manner but on a larger scale the Fort Peña and older beds are more complexly deformed than the Maravillas and Caballos strata, as a result of the gliding of the Woods Hollow shale, which served as a cushion between two series that were deformed in a different manner. The shales are now greatly squeezed and crumpled.

South of Marathon, between the Boquillas road and Fort Peña Colorada, the Maravillas chert and Caballos novaculite lie in open folds quite unlike the isoclinal structure of the older rocks (sec. E–E′–E″, pl. 21). In this district there are four anticlines in a distance of 3 miles across the strike. The strata on the northwest limb have steep or vertical dips, but they arch gently over the crest to join the gently dipping beds on the southeast limb. The folds have no great height or depth. They are considerably broken by tear faults, some of which have offset anticlinal and synclinal axes. They resemble the folds in the Jura Mountains and like them appear to result from the gliding of competent beds over an incompetent substratum.

PEÑA COLORADA SYNCLINORIUM

General features.—The synclinorial area 5 or 6 miles in width that separates the Marathon from the Dagger Flat anticlinorium (pl. 15) is here called the Peña Colorada synclinorium. Its northwest flank is bounded by Caballos strata dipping gently to the southeast off the marginal folds of the Marathon anticlinorium. Its southeast flank is bounded by a straight outcrop of strongly overturned Caballos strata on the northwest flank of the Dagger Flat anticlinorium. It consists of broad areas of Tesnus formation, with anticlines of Caballos and older rocks rising through it, and of a few synclinal areas that preserve rocks younger than the Tesnus formation (pl. 24).

The rocks of the area are openly folded and are not greatly faulted. Most of the folds in the synclinorium are nearly symmetrical and show little overturning of the strata. The folds pitch southwest at the southwest end and northeast at the northeast end, like those in the anticlinoria to the northwest and southeast. Near the middle of the area, however, near Woods Hollow Tank and about due south of Marathon, is a central depressed area, much obscured by terrace gravel but apparently exposing little except Tesnus strata. A part of this depression resulted from a sinking of the folds on the northeast side of the belt of en échelon tear faults that extends southeastward across the synclinorium from the Dugout Creek overthrust. The high anticlinal folds of novaculite on East Bourland and Simpson Springs Mountains are cut off sharply at their northeast ends by these faults (pl. 24).

Synclinal area south of Monument Spring.—At the southwest end of the synclinorium, between Monument Spring and the Bourland ranch, are broad synclinal areas of Dimple and Haymond strata (pl. 24). Apparently this is not the region of greatest depression in the Caballos formation, for the overlying Tesnus formation in this part of the synclinorium has thinned from several thousand feet to 500 feet, thus allowing higher strata to be preserved (secs. H–H′–H″ and I–I′–I″, pl. 21).

The Carboniferous rocks in the synclines, as shown by the outcrops of the Dimple limestone, are much more sharply folded than the underlying Caballos and are broken by small thrust faults. This results from the incompetent character of the predominantly shaly Tesnus formation between the Dimple limestone and the Caballos novaculite and the small thickness of the limestone formation. A bundle of sharp synclinal folds of Dimple limestone form the crest of West Bourland Mountain (pl. 6, *C*, and sec. H–H′–H″, pl. 21).

Simpson Springs and East Bourland Mountains.—Southeast of the exposures of Dimple limestone in these synclines are two anticlinal ridges, East Bourland and Simpson Springs Mountains, composed of Caballos novaculite and Maravillas chert. Woods Hollow shale is exposed in narrow axial basins along their crests (pls. 5, *E*, and 6, *B*). East Bourland Mountain is a simple fold, somewhat overturned toward the northwest (pl. 6). Its northeast end has been downthrown several hundred feet by one of the en échelon tear faults noted above (pl. 24). Simpson Springs Mountain is more complicated and is composed of three closely compressed en échelon anticlines (pl. 24). These are likewise broken off on the northeast by a fault. The Woods Hollow shale revealed along the axes of these two anticlinal ridges is intricately folded and contorted and contains large erratic boulders of Cambrian and Ordovician limestone, which may have a tectonic origin.

Woods Hollow Mountains.—Farther northeast the Woods Hollow Mountains rise from the synclinorium and also consist of anticlinal ridges of chert and novaculite. They are separated by narrow synclinal valleys, such as Woods Hollow and Little Woods Hollow, carved from Tesnus shales (sec. D–D′–D″, pl. 21). The folds have a peculiar pattern of branching and joining axes. Some of the anticlines split into two folds when traced along their crests, and an anticline is implanted in the middle of the narrow Little Woods Hollow syncline at its southwest end (pl. 24). Dips are steep on both flanks of the anticlines, though they are greater on the northwest side. The beds are overarched gently on the crests. The rocks are cut by numerous tear faults, which trend mostly north-northwest at the northeast end of the hills and west-northwest at the southwest end. Most of the faults have a considerable component of horizontal displacement; the rocks at the northeast and southwest ends of the hills appear to have been pushed farther northwest than those in the center, as if this part had offered an obstacle to the deformation. The regularity of the folding in the Woods Hollow Mountains is not confined to the Caballos and Maravillas formations, for in the Woods Hollow shale, beautifully revealed on the crest of the anticline on the Granger place (fig. 6, *C*), the strata are arched concentrically to the beds above. The folding of the Woods Hollow formation was not accompanied by the intricate minor deformation which occurred in the Marathon and Dagger Flat anticlinoria. However, the thickness of the Alsate shale and Marathon limestone penetrated by the King & Franklin well, on the crest of the anticline, is greater than in any sections measured on the outcrop, and either these formations may be steeply tilted, or considerable amounts of their shaly members may have been squeezed into the crest of the fold from the flanks.

DAGGER FLAT ANTICLINORIUM

General features.—The great Dagger Flat anticlinorium is the highest uplift in the Marathon Basin (secs. B–B′ and C–C′, pl. 23) and has large tracts of Cambrian strata exposed in the center. It extends for 25 miles in a northeasterly direction across the center of the Marathon Basin and has a maximum width of about 6 miles (pl. 15). Its broader features are simple. It is bounded by outcrops of Caballos novaculite, which extend in long, straight ridges on the flanks but which pass into convoluted and zigzag outcrops to the northeast and southwest, where the pitch of the folds carries that formation beneath the Carboniferous. The Caballos formation on the northwest flank is strongly overturned. On the southeast it dips steeply southeastward in most places, but locally there is some southeastward overturning.

In detail the structure of the anticlinorium is exceedingly complex, for it is a bundle of tightly compressed folds. The deformation was not the same in different parts of the succession, on account of the alternation of competent and incompetent members. The Caballos and Maravillas formations over the anticlinorium were broken into flat slices which have slid forward, one over the other, and have since been folded. The strata beneath stand in narrow, sharp isoclinal folds.

The anticlinorium appears to have had its origin far back in the depositional history. The Caballos novaculite is much thinner on the crest of the fold than on the flanks, and the Tesnus formation on the northwest flank is about 2,000 feet thick, as compared with 6,500 feet on the southeast flank. These differences in thickness of strata in the area may have played a part in the location of the fold, or they may be an expression of some older line of weakness in the basement on which the strata were laid down.

Structural features of the older rocks.—The rocks below the Maravillas chert, which occupy the great central lowland of the anticlinorium, are folded into innumerable sharp, narrow anticlines and synclines (pl. 17). Most of these are isoclinal, with dips on both flanks of 70°–80° SE. (secs. G–G′–G″ and H–H′–H″, pl. 21). In the southeasternmost folds, however, on the Buttrill ranch, there is some backward overturning, and the strata dip away from the Caballos ridge to the southeast at an angle of 70° NW. The pitch of the folds in these older rocks is in general the same as that of the anticlinorium as a whole, but in the central part there are some local irregularities and downwarps (pl. 24). Some of the anticlines northeast of Woods Hollow Tank, in the northeastern part of the anticlinorium, are broken by thrust faults on their northwest flanks. In this area there are as many as four anticlinal folds in a distance of 1 mile across the strike of the rocks. The synclines contain Woods Hollow and Fort Peña formations, and the anticlines reveal Marathon limestone and Dagger Flat sandstone. The most elevated area of older rocks is northeast of the Buttrill ranch, where the Cambrian lies at the surface in several broad anticlines (pl. 24).

The Woods Hollow shale in the anticlinorium has been greatly contorted and squeezed. Nearly every exposure of the formation shows intricate crumpling and contortion. The shales have an outcrop several miles in width in the northeast end of the anticlinorium, west of the Lightning ranch, inasmuch as this area is on the crest of the pitching anticlinorium, and the beds have an isoclinal structure. In addition, the thickness of the shales here may have been augmented by a squeezing of material from the flanks into the crest of the anticlinorium. Near Woods Hollow Tank and at some other places on the flanks the outcrop of the Woods Hollow shale is only a few hundred feet wide, and its thickness is probably less than normal.

Folding in the younger rocks.—The structural features in the Maravillas and Caballos formations are unlike those of the strata that underlie them. Their folding is open but with steep or overturned dips on the northwest flanks of the anticlines. In the Warwick and Lightning Hills there are five anticlines in 3 miles across the strike; in the Peña Blanca Mountains, six or seven anticlines in 3 miles. The folds in these formations may best be observed along the northeastern and eastern sides of the anticlinorium, in the Warwick and Lightning Hills and Peña Blanca Mountains (pl. 24), and toward its southwest end, between Garden Springs and Maravillas Gap (in the Santiago Peak quadrangle) (pl. 23), where the two formations crop out along pitching folds in zigzag ridges.

The outcrops of Caballos and Maravillas formations along the northwest flank of the anticlinorium run nearly straight for almost its entire length. Along this belt they are strongly overturned and commonly dip at angles of 45°–60° SE. (sec. E–E′–E″, pl. 21). The outcrops on the southeast flank are more sinuous, and there are a few minor folds. In the Peña Blanca Mountains, on the southwest flank of the anticlinorium, there is some backward folding, with the anticlines somewhat overturned toward the southeast and in places broken on their southeast sides by steep thrust faults that dip northwest (sec. E–E′–E″, pl. 21). Elsewhere dips on this flank are steeply southeast.

In view of the close folding and great crustal shortening in the older rocks, the open folding in the Caballos and Maravillas formations of the anticlinorium appears to be anomalous until a further group of structural features in these formations is considered—the remarkable system of folded overthrusts that characterize nearly all their outcrops near the crest of the anticlinorium.

Folded overthrusts in the younger rocks.—This peculiar system of structural features brings about a remarkable overfolding and repetition of the Caballos and Maravillas formations along the crest of the Dagger Flat anticlinorium and is found where the folds pitch down at both its northeast and southwest ends. The most complex system is in the Warwick and Lightning Hills, on the northeast. Other folded thrusts are found in the Peña Blanca Mountains, to the south, and near Garden Springs and Threemile Hill (in the Santiago Peak quadrangle), to the southwest. The pitch of the folds aids greatly in the interpretation of these structural features. Their ground plan is roughly similar to their probable cross section, and the higher and lower parts of the features may be pieced together by observations at different places along the strike.

An understanding of the character of these structural features may be obtained by a study of some of the minor folds and faults associated with them. One such small feature, a part of the larger system that embraces all of the Lightning and Warwick Hills, is found on the northwest flank of a northeastward pitching anticline three-quarters of a mile north-northeast of the Lightning ranch (at point c on fig. *C*, pl. 19, shown on a larger scale in fig. *A* of the same plate). The Caballos and Maravillas formations here form a northeastward-trending ridge and in general dip steeply northwest. To the northeast they flatten out over the crest of the anticline (sec. 4, fig. *C*, pl. 19), and to the southwest they flatten across the axis of the next syncline to the northwest (sec. 3, fig. *C*). When the strata are traced from the synclinal toward the anticlinal axis, they are found to be offset near the middle of the northeastward-trending ridge by a sharp zigzag fold which is faulted in the middle. Dips on the fold are inverted, as shown in figure *A*, plate 19. The normal northwest dip changes to an overturned southeast dip by which the Tesnus passes under the Caballos at an angle of 15° (sec. 2, fig. *A*), and this in turn under the Maravillas and Woods Hollow (sec. 3, fig. *A*). The fault that breaks the middle of the fold dips northwest and has moved the overturned strata down on the northwest relative to those on the southeast. The fault might be interpreted as a normal fault, were it not for its association with overturned strata. The writer is inclined to believe that it is a thrust fault, originally nearly flat, along which a recumbent fold was broken, and that the whole feature was subsequently turned to a new position by later folding.

Between Ridge Spring and Garden Springs on the Boquillas road is a larger and more complicated structural feature of this sort (pl. 24 and fig. *B*, pl. 19). In the center of the area is a southwestward-pitching anticline of Caballos and Maravillas formations, with Woods Hollow and Fort Peña formations along the axis (secs. 2 and 3, fig. *B*). On the southeast flank the beds dip away from the axis at an angle of about 45°; on the crest of the fold they dip 30° SW.; and on the northwest flank they are vertical or overturned. The Caballos and Maravillas outcrop on the northwest flank of the fold connects with the main outcrop of these formations on the northwest flank of the anticlinorium farther northeast (sec. 4, fig. *B*). The anticline is bounded on its southeast and northwest sides by faults, which almost certainly join on the southwest (between secs. 1 and 2, fig. *B*), down the pitch of the fold. The fault on the southeast flank is a steep thrust fault with southeast dip that brings Fort Peña and Marathon limestones against the Maravillas chert (sec. 2, fig. *B*). The Maravillas chert is greatly brecciated along the fault near Garden Springs. The Caballos formation on the downthrown side is dragged up against the fault half a mile southwest of the springs. The fault on the northwest flank of the anticline has either a vertical or a steep southeast dip and brings Tesnus shales on the southeast against Woods Hollow, Maravillas, and Caballos strata on the northwest (pl. 24). There are continuous exposures of Woods Hollow shale from the northwest to the southeast flank of the fold around its southwest end, southwest of the point where the Caballos novaculite pitches beneath the surface. On the hill west of Ridge Spring the Caballos and Maravillas formations northwest of the fault curve about southwestward toward it and are overturned, with a dip of 15° SW. (sec. 4, fig. *B*). Maravillas cherts cap the ridge and overlie the Caballos novaculite, whose higher members crop out near the watering trough at the base of the hill.

It is believed that the faults which surround the anticline at Garden Springs were at one time continuous over its crest (fig. 31, *A*) and that the overturned strata near Ridge Spring have been moved from an original position southeast of the present anticline. It is probable that these movements took place before the anticline was folded and that the thrust plane was originally tilted gently to the southeast. If the fault were rotated back to this position the overturned strata at Ridge Spring would be a recumbent fold of nappe-like form on the overridden block of the thrust sheet (fig. 31, *B*).

The general geologic structure of the Warwick and Lightning Hills is similar to that in the two areas described above but is much more complicated. It is much better illustrated by the accompanying block diagram (fig. *C*, pl. 19) than by any possible written description. There are two major overthrusts—the Warwick thrust (*b*) in the north and the Lightning thrust (*a*) in the south (pl. 7). There are also minor recumbent folds and thrusts. Some of these branch from the main thrusts. Others, like that at locality c, figure *A*, plate 19, are developed in the overridden sheet beneath the Warwick overthrust. The front of each thrust mass of Caballos novaculite shows strong inversion of the strata like that at Ridge Spring (secs. 4 and 5, fig. *C*, pl. 19). Evidence for overthrusting of the various masses of novaculite is afforded by a change in facies in the Caballos formation over the crest of the Dagger Flat anticlinorium. Sections of the formation on the northwest side of the anticlinorium have a thick lower novaculite member and a subordinate upper novaculite member (secs. 1, 2, and 3, fig. 32; for location, see fig. *C*, pl. 19). These relations are reversed along the outcrop of the formation half a mile north of the Lightning ranch (sec. 4), and in all sections on the southeast side of the anticlinorium the upper novaculite member is the thicker (secs. 7 and 8). In addition, the southern facies is also found all along the exposure of Caballos novaculite above the Warwick overthrust to the north side of the Lightning Hills, where it now lies only a few hundred yards from Caballos exposures with a northern facies (secs. 5 and 6). The southeastern facies of Caballos has therefore been moved by the thrust for 2 or 3 miles over the northwestern facies.

in 1915 on Threemile Hill probably came from a slice along the plane of this fault, and practically all the section between the Woods Hollow and Dagger Flat is absent. An outlier, probably of this thrust sheet, is found 2 miles to the northwest, overlying and infolded with a normal synclinal area of novaculite (sec. I–I′–I″, pl. 21). South of Threemile Hill a steep thrust fault brings up Caballos and Maravillas, again resting on the Dagger Flat (pl. 23 and sec. I–I′–I″, pl. 21), so that the overthrust has apparently been faulted as well as folded since its formation.

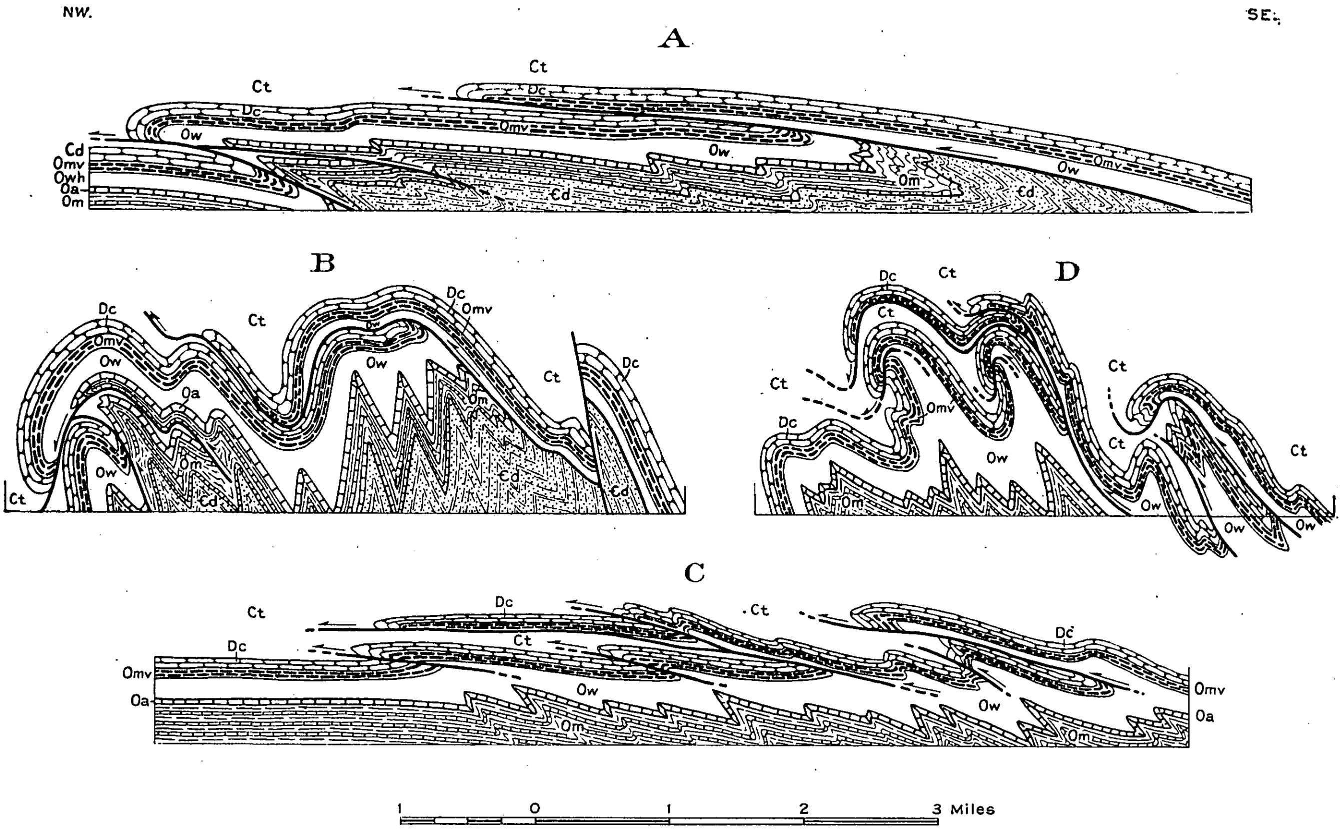
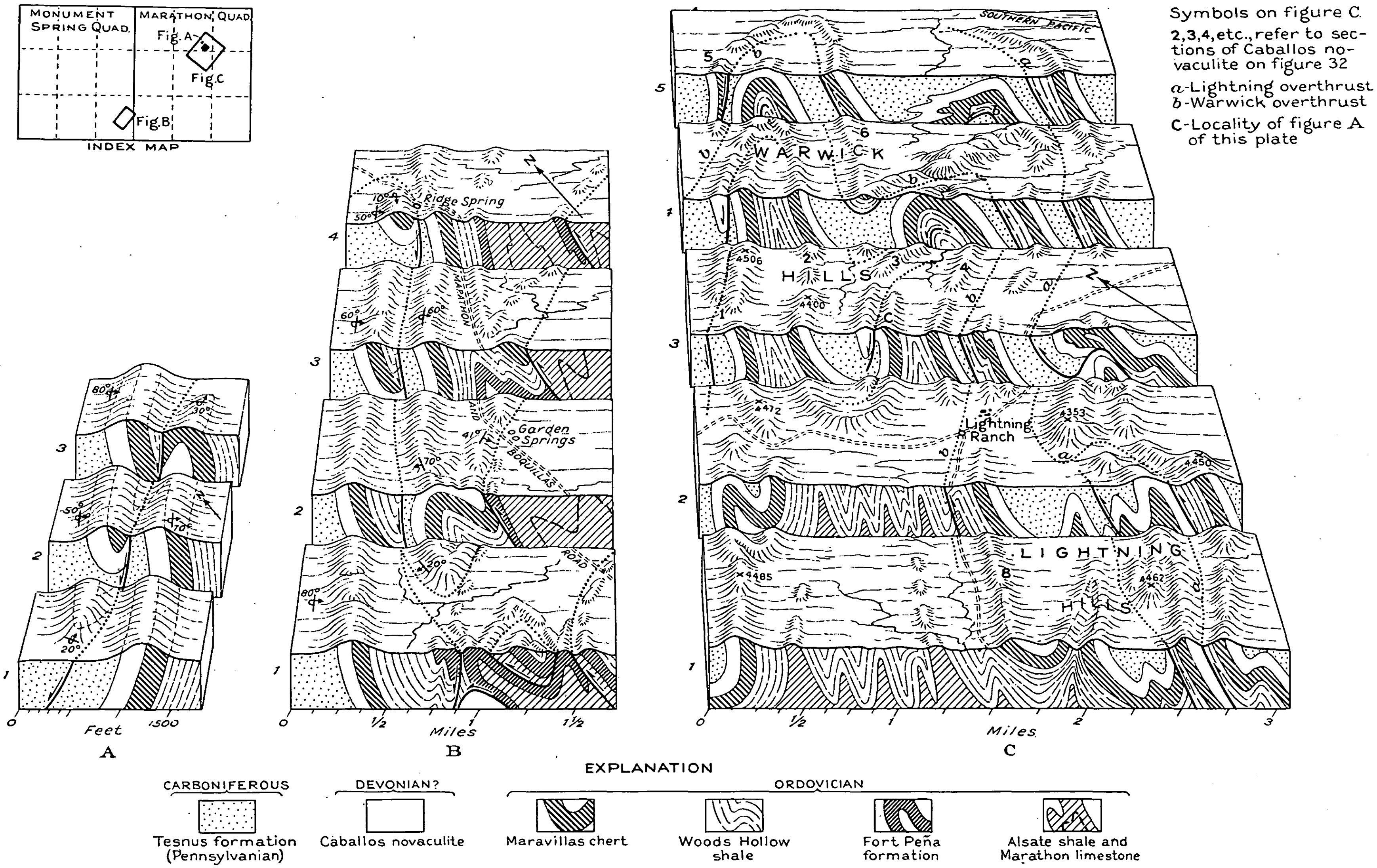


FIGURE 31.—Restoration of structural features in the younger rocks of the Dagger Flat anticlinorium. Figures B and D are pieced together from observations at different places along pitching folds, such as those shown in figures B and C, plate 19. No single section may have contained all the features represented on these restorations, but a complexity of structure of equal degree is probable. Figure A represents the probable structure of section B, and figure C the probable structure of figure D, after the first folding and overthrusting in the region, and before the final folding. A and B are in the southwestern part of the Dagger Flat anticlinorium, between Threemile Hill (on right) and the Garden Springs district (on left). For sections in Garden Springs district, see figure B, plate 19. C and D are in the northeastern part of the Dagger Flat anticlinorium, in the Warwick and Lightning Hills. For sections in this district, see figure C, plate 19. Ct, Tesnus formation; Dc, Caballos novaculite; Omv, Maravillas chert; Ow, Woods Hollow shale; Om, Marathon limestone; Ꞓd, Dagger Flat sandstone.

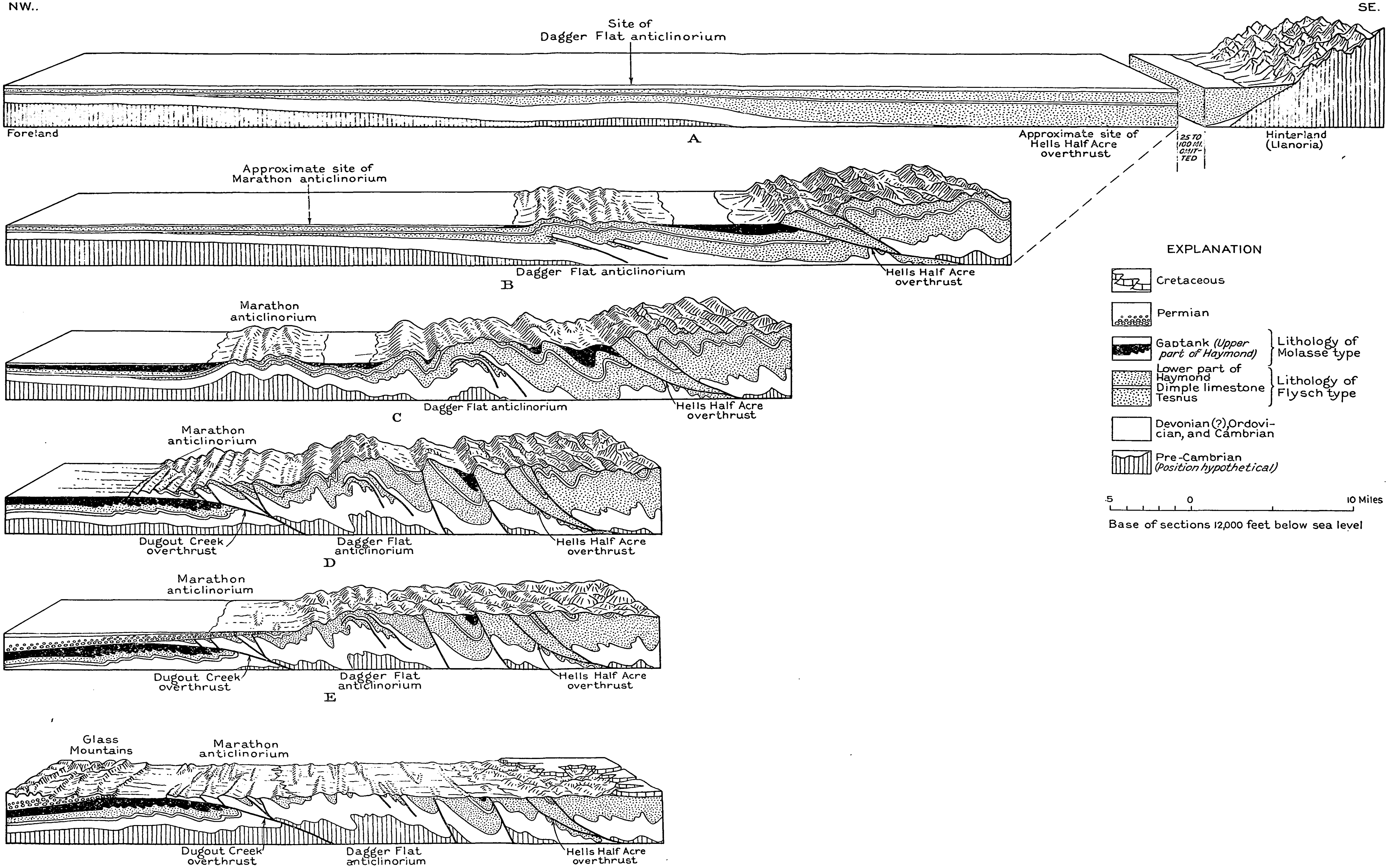
In addition to these areas of overthrusting there is a large folded overthrust east of the old Reed place, in the Peña Blanca Mountains (pl. 24 and sec. D–D′–D″, pl. 21). Another is found between Threemile Hill and Maravillas Gap, in the Santiago Peak quadrangle (pl. 23). Along the ridges between the two latter places Woods Hollow shale and Maravillas chert, only moderately folded, rest on greatly contorted and sheared Dagger Flat sandstone, probably with overthrust contact (fig. 10). A small collection of graptolites of Deepkill (Marathon) age made by Baker and Bowman

It is possible in this area to make a rough estimate of the original inclination of the overthrust plane. On Threemile Hill the fault lies at the base of 500 feet of Woods Hollow shale (right-hand end of fig. 31, *B*). Two miles to the northwest it lies about 100 feet from the top of this formation. On the north side of the same outlier it lies within the succeeding formation, the Maravillas chert (center of fig. 31, *B*). This indicates a stratigraphic rise of about 700 feet between the two farthest points in a distance (allowing for crustal shortening) of 3½ miles, or a southeasterly dip of the plane of 200 feet to the mile.



BLOCK DIAGRAMS SHOWING FOLDED OVERTHRUSTS OF DAGGER FLAT ANTICLINORIUM.

A, Enlarged view of locality C, figure C. B, Region of Ridge and Garden Springs. C, Region of Warwick and Lightning Hills.



HYPOTHETICAL BLOCK DIAGRAMS SHOWING PROGRESSIVE DEVELOPMENT OF STRUCTURAL FEATURES IN MARATHON REGION.

The explanation of these structural features as folded overthrusts is based on a reconstruction of the folds and faults by means of numerous observations along the strike (fig. 31, *A*, *C*). Proof is afforded by the peculiar inversion of the strata at the northwest ends of the Caballos outcrops on the thrust sheets (as in fig. *C*, pl. 19) and by the difference in facies in the Caballos formation in closely adjacent areas of outcrop on different thrust sheets (fig. 32). It is believed that these relations cannot be explained by the hypothetical construction of any other system of thrust or normal faults.

Hollow and Fort Peña formations such as characterizes the higher beds (sec. 1, fig. *B*, pl. 19). The overthrust at Threemile Hill and Maravillas Gap extends into older rocks as low as the Cambrian. At all other places the faults appear to die out in the Woods Hollow shale and cannot be traced into the older beds.

It is therefore concluded that the folded overthrusts represent the response to the earlier compressive forces of brittle competent beds enclosed within incompetent strata (shales of the Woods Hollow and the basal member of the Tesnus). The beds below were evidently folded into isoclines at the same time, as suggested in figure 31, B and D. Some confirmation for this suggestion is given by estimates of crustal shortening in the Dagger Flat anticlinorium. These indicate that both the isoclinal folds of the lower beds and the folded and overthrust younger strata have been shortened by about the same amount, from 3 miles originally to 1 mile (fig. 33). The differences in structure may therefore represent only a different response to the same deformative forces.

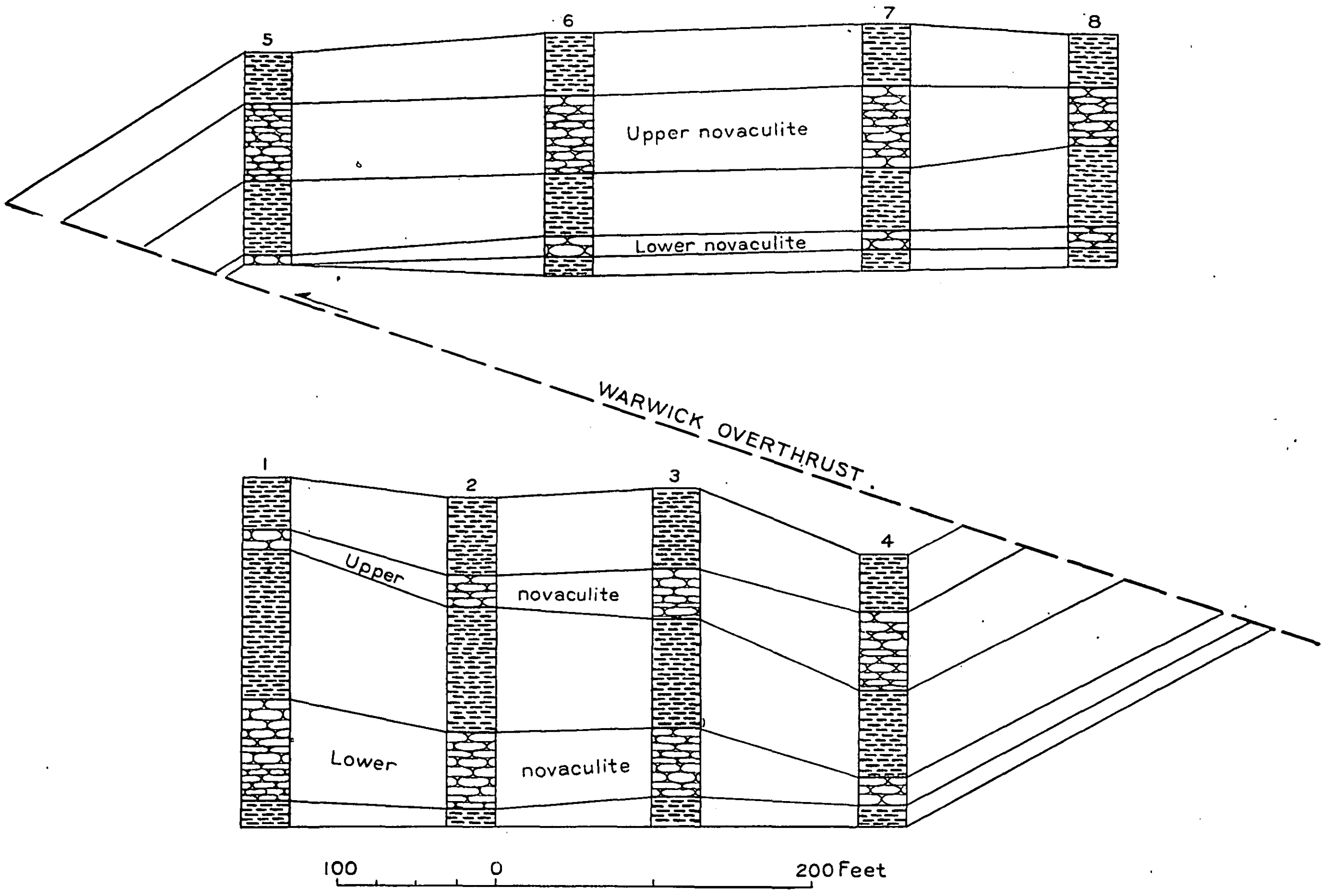


FIGURE 32.—Sections of Caballos novaculite in the Warwick Hills, showing change in thickness of members and its relation to the Warwick overthrust. For location of sections, see block diagram C, plate 19. Note the difference in thickness of the two novaculite members in the overriding and overridden block of the overthrust.

The folded overthrusts appear to be almost wholly confined to the competent Maravillas and Caballos strata. The massive beds of the upper Tesnus and the Dimple higher in the section, which crop out down the pitch of the folds northeast of Warwick, show a certain amount of faulting along steep thrust planes but no inversion of the strata or folding of the faults. The beds below the Maravillas are steeply folded into isoclines, but faulting is a subordinate feature. At only one place, southwest of Garden Springs, is there any of the curious inversion of the strata in the Woods

The evidence seems clear that the thrusts in the Dagger Flat anticlinorium are definitely older than most of the folds in the Caballos and Maravillas formations in that area. It seems difficult if not impossible for the rocks to have moved along the fault planes in the form the planes now possess. In the tables on pages 119 and 135 and in figures *B* and *C*, plate 20, the time of thrusting and the time of folding have been separated into two distinct epochs, but there may not have been a long pause between and the two epochs may have overlapped.

Folded overthrusts are found at both the northeast and southwest ends of the anticlinorium, where the Caballos and Maravillas formations dip beneath the surface on the pitch of the folds. It is therefore probable that they also characterized these formations all along the crest of the anticlinorium, where they have since been removed by erosion.

Tear faults in the younger rocks.—The Caballos and Maravillas formations in the Dagger Flat anticlinorium are traversed by innumerable tear faults, which have a general northwest trend (pl. 24). There are probably more of these faults than have been mapped. It was not feasible to show all the small faults in these formations, and some were probably overlooked in the older rocks, where they stand out less distinctly, and in the shales in the lower part of the Tesnus formation, where there are no key beds. Apparently, tear faults are much less numerous in the older and younger formations, and not many may be seen in them in aerial photographs (pls. 17, 18). In the Warwick and Lightning Hills and other places the faults offset the planes of the folded overthrusts and the axes of the folds (pl. 7, *A*), so that in general they are younger than these features. They have the same general trend as many of the post-Cretaceous normal faults in the region, but they are probably much older and still a part of the features produced by the late Pennsylvanian deformation. Their detailed pattern and their large component of horizontal displacement show clearly that they were produced by compressive forces from the southeast.

The horizontal movement on the faults is shown by their offset of vertical strata and of the axes of anticlines and synclines. Slickensides on the fault surfaces are inclined 20°–40° NW. and are clearly exposed in the novaculite at many places. Movement parallel to the slickensides would produce both vertical and horizontal components, and such components have been observed on the faults. In a few places the vertical component probably exceeds the horizontal, for some of the folds are dropped along the faults with little offset of the axes.

The faults in the Woods Hollow Mountains, the Warwick and Lightning Hills, and the Peña Blanca Mountains have a general northwest trend but appear to belong to two groups lying at about equal distances from the direction of strike. These two groups are separated from each other by angles of 45° to 90°.

Ridges southeast of the anticlinorium.—There are several anticlinal folds southeast of the Dagger Flat anticlinorium in which Maravillas and Caballos strata are exposed, surrounded by areas of the Tesnus formation. The most conspicuous of these is Horse Mountain, a symmetrical eastward-plunging fold whose crest is still covered very largely by novaculite (pl. 24). Dips on the north and south flanks of the mountain are between 60° and 80° (sec. E–E′–E″, pl. 21). Horse Mountain is cut off at its west end by a tear fault, by which the rocks on the mountain are raised higher than those on the west and have been moved a quarter of a mile farther north.

To the southwest the Horse Mountain anticline and adjacent folds are broken by thrust faults on their northwest limbs, but some novaculite and chert are preserved on these limbs in small irregular remnants, perhaps squeezed and crushed out. An outcrop of this sort is found near Hackberry Tank (pl. 24). The next anticline south of the ridges at Threemile Hill is broken by several steep thrusts upthrown on the northwest instead of the southeast side (sec. J–J′, pl. 21).

The last great novaculite ridge to the southeast, the Tinaja Mountains, in the Hood Spring quadrangle, appears to be separated from these ridges by a zone of overthrusting and is therefore discussed in another place (p. 130).

SYNCLINORIAL AREA BETWEEN TESNUS AND GAP TANK

General features.—The area extending from Gap Tank past Tesnus and Haymond stations, as far south as the north edge of Hells Half Acre (see index map on pl. 15), is a down-warped area in which only strata of Carboniferous age are exposed. The west side of the area is bounded by zigzag ridges of northeastward-dipping Caballos novaculite in the Dagger Flat and Marathon anticlinoria. The eastern extension of the synclinorial area is hidden by the overlap of Cretaceous rocks. The youngest rocks in the area, the Gaptank formation, of upper Pennsylvanian age, are exposed along the north side of the area, in the vicinity of Gap Tank (pl. 23). This locality is structurally the lowest point in the Marathon Basin.

Interpretation of the structure in the northern part of the synclinorial area is made difficult by the extensive gravel deposits in the lowlands and by the considerable areas still hidden beneath outliers of Cretaceous rocks. Farther south, where there has been recent downcutting by San Francisco Creek and its tributaries, there are excellent exposures over wide areas, but even here the monotonous character of the sandstones and shales in the succession makes some of the structural features hard to interpret. Fortunately, the folds in the region are broad and open, with regular dips and only a few faults. The Dimple limestone is well exposed throughout the area in sharp hogbacks, and lower in the section, in the southern part of the area, the top of the basal shale member of the Tesnus formation is easily traceable.

The folds have an amplitude of several miles (pl. 18), with dips of 30° to 60° on the southeast flanks of the anticlines but with local overturning on the northwest flanks. In some places, however, the dips on the northwest flanks are as low as 45°, and near the synclinal axes the strata are in places nearly flat (sec. B–B′, C–C′, and D–D′–D″, pl. 21). The anticlines tend to be narrower and sharper than the synclines. Some of them are broken on their northwest limbs by steep thrust faults. The pitch of the folds is 15°–30° NE. over most of the area, but in the eastern part of the Paleozoic exposures (pl. 15), northeast of the Marathon quadrangle, the pitch reverses and is southwestward. The strike of the folds near Haymond and Tesnus is N. 40° E., but in the eastern part of the Paleozoic exposures, farther northwest, the strike changes to N. 60° E. (pl. 15).

Folds.—Three synclinoria (shaded on pl. 15) extend northeastward across the down-warped area and are separated by anticlines and anticlinoria. The northern synclinorium extends northeastward under the Permian and includes the Gap Tank area. It is bounded on the south by the anticlinorium that extends through the Dimple Hills. This is succeeded by a second synclinorium, which extends southwestward to the syncline northwest of Haymond station. Southeast of this is a long, narrow anticline, beyond which is the deep syncline southeast of Haymond station (pl. 18). Southeast of this syncline, in the vicinity of Tesnus station, is a broad anticlinorial area of openly folded Tesnus strata, with a few synclinal remnants of Dimple limestone. Each of the anticlinorial areas is broken on its northwest side by a thrust fault.

The northernmost synclinorium, that in the Gap Tank area, is much more gently folded than those to the south. The folding in this synclinorium appears to die out entirely near the base of the Glass Mountains, where the Gaptank formation passes northwestward beneath the Permian with nearly equal dip and strike.

The southwesterly continuation of the synclines and anticlines into the pre-Carboniferous rocks can be worked out by mapping the top of the shale member at the base of the Tesnus (pl. 24). The syncline northwest of Haymond station extends into the complicated synclinorium in the northern Peña Blanca Mountains (pl. 15). The syncline southeast of Haymond station extends into the synclinorium between the novaculite areas of Horse Mountain and the Peña Blanca Mountains. The relation of the thrust faults in the Tesnus and Dimple formations to those in the Caballos and older rocks cannot, however, be determined.

Faults.—The northwest side of the anticlinorium that extends through the Dimple Hills is bounded by overturned outcrops of Dimple limestone and to the southwest, by a thrust fault known as the Frog Creek fault (pl. 15), which carries the Dimple and Tesnus over the Haymond formation. At a locality about 7 miles north of the Sanderson road (pl. 23), in the Hess Canyon quadrangle, the thrust is exposed in a small arroyo and dips 20° E., with Dimple limestones above resting on steeply tilted Haymond sandstones below. Farther south, near the old Matthews place (pl. 24), where Tesnus is thrust over Dimple, the Dimple limestones on the downthrown block to the west slope up from the fault at an angle of nearly 40°.

The southeast side of the syncline northwest of Haymond station is broken by the Haymond thrust fault (pl. 15). Northeast of Haymond the upper Tesnus, with sharp anticlinal structure, is thrust against the Dimple and Haymond formations (pl. 24). Southwest of Haymond the basal shale member of the Tesnus formation is thrust against the upper part of the formation, and in this region the thrust is paralleled to the northwest by another of smaller displacement. A few poor exposures of the thrust plane north of Haymond show dips of 60°–80° SE.

The southeast side of the syncline southeast of Haymond is broken by the Arden Draw thrust fault, which passes beneath the Cretaceous cover half a mile northwest of the summit of Housetop Mountain (sec. A–A′, pl. 21). North of the Southern Pacific Railroad and for a few miles to the south of it the upper part of the Tesnus formation is thrust against the Haymond formation. To the southwest, as in the vicinity of Twin Peaks, the basal shale member of the Tesnus is thrust against upper Tesnus. The fault is lost in the basal shales several miles west of Twin Peaks and about due north of Horse Mountain, but it may continue into one of the thrusts that break the folds in the novaculite west of the mountain. The dikelike intrusives of Twin Peaks, which lie parallel and close to the fault plane, may have come up along it. The few exposures of the Arden Draw fault that have been found dip, like the Haymond fault, at high angles to the southeast. These faults appear to be simple breaks along the overturned limbs of anticlines and to have had a chiefly vertical movement. They are in no sense overthrust faults. The throw on each fault is several thousand feet or more.

The hogbacks of Dimple limestone northwest and southeast of Haymond station are cut by several small tear faults (pl. 24).

SOUTHEASTERN PART OF MARATHON BASIN

General features.—In the southeastern part of the Marathon Basin the folds are closely compressed, and the crustal shortening is probably much greater than in the region to the northwest. The structure is obscure, partly because of the intense deformation and partly because of the monotonous character of the Tesnus sandstones, which crop out over most of the area. The area is more rugged than most of the Carboniferous areas farther north and includes such rough ground and jagged ridges as Hells Half Acre and Devils Backbone. To the south and east the relations of the strata are hidden by the overlap of the Comanche series.

Hells Half Acre fault.—The northwestern boundary of this area within the Marathon quadrangle is drawn along the Hells Half Acre fault, which extends along the north side of Hells Half Acre and crosses San Francisco Creek near its junction with Nigger Creek (pl. 24). The course of the fault is obscure, because strata of the Tesnus formation crop out on both sides. The rocks to the north are folded into open anticlines and synclines with a northeast strike, which are truncated by the fault (pl. 15). The rocks to the south, with an east-northeast strike, are closely folded. For as much as a mile south of the fault, east of San Francisco Creek, the strata are so disordered that it is impossible to trace any of the sandstone ledges for more than a few hundred yards. The trace of the fault is sinuous but is in general east and west near San Francisco Creek. Along the north side of Hells Half Acre its plane is bounded by long narrow wedges of cherty limestone and interbedded shale belonging to the Dimple formation. A few hundred yards east of San Francisco Creek are wedges of Caballos novaculite as much as 500 feet in length. West of San Francisco Creek are wedges of Maravillas chert (sec. D–D′–D″, pl. 21). South of Twin Peaks and Horse Mountain the fault is followed for a distance of 2 miles by a dike of Tertiary porphyry (pl. 24).

The Hells Half Acre fault apparently continues southwestward into the thrust faults that bound the north flank of the Tinaja Mountains, in the Hood Spring quadrangle (pl. 15). These mountains are ridges of Caballos novaculite, much folded and broken by closely spaced parallel thrust faults (sec. H–H′–H″, pl. 21). Numerous masses of Tertiary porphyry along the north flank of the mountains have evidently ascended along the thrust planes (pl. 23). Apparently there is some difference in facies between the Caballos novaculite in the Tinaja Mountains and that in the next ridges to the northwest.

It is altogether probable that the Hells Half Acre fault marks a line of major overthrusting. Extensive movements along the fault are suggested by crushing and lack of evident structure in the Tesnus formation along its south side and by wedges of Maravillas, Caballos, and Dimple formations included in the fault plane. Overthrusting is also suggested by the truncation by the fault of the open northeastward-trending folds that lie to the north of it (pl. 15).

It is suggested on page 91 that the exotic blocks in the boulder-bed member of the Haymond formation, which crops out a few miles to the north, were derived from the erosion of the northern extension of this thrust sheet (fig. 27 and pl. 20, *B*). This would place its time of movement as contemporaneous with the deposition of the upper part of the Haymond formation. A relation between the fault and the exotic boulders is suggested by the wedges of various sorts of rocks found along the fault plane, but aside from this there is very little definite evidence in the fault itself to indicate its age.

Structural features south of Hells Half Acre fault.—The structure of the rocks south of the fault has not been worked out in detail. The crustal shortening is probably very great, and there is more metamorphism than farther northwest in the basin, with secondary mica developed in the less competent layers and numerous shear zones and veinlets of calcite and quartz in the massive sandstones.

The folding of the Tesnus formation on Devils Backbone is well shown by two layers of white quartzite, which stand in several sharp faulted anticlines and synclines (fig. 19). Wedges of Dimple limestone are found along the largest of the thrust faults, which is named the "Devils Backbone fault." Southeast of Devils Backbone, on the ridges between San Francisco Creek and the Cretaceous outliers on the Tres Hermanas Mountains, several large overturned folds can be seen in the sandstones of the Tesnus formation (sec. D–D′–D″, pl. 21). South of the Tres Hermanas, in the valley of Rough Creek, in the Dove Mountain quadrangle, is a sharp anticline that brings up the basal shale member of the Tesnus and the Caballos novaculite (fig. 18, *A*). The shale overlies the novaculite with erosional unconformity.

Farther west, southeast of the Tinaja Mountains (pl. 23), in the Hood Spring quadrangle, several obscure folds have been noted in the Tesnus formation but have not been worked out in detail. In this region there are several narrow belts of outcrop of Caballos novaculite that have evidently been carried up along faults; they resemble the thrust slices in the Tinaja Mountains. At a distance of about 6 miles south of the edge of the Marathon quadrangle the Paleozoic strata pass unconformably beneath the limestones of the Comanche series, and the character of their structural features beyond this point is unknown.

GENERAL STRUCTURAL PROBLEMS IN THE MARATHON BASIN

Theoretical problems of the overthrust faults.—There have been great movements along the overthrust faults in the Marathon Basin. Along the Dugout Creek overthrust in the northwestern part of the basin the old rocks overlie upper Pennsylvanian strata over the whole area of exposure, so that the original position of the overthrust rocks must have been to the southeast of all outcrops of the thrust plane. If the fault moved in a northwesterly direction, as suggested by the alinement of the tear faults behind it, the amount of overthrusting has been more than 6 miles. The movements on the thrusts behind the main fault probably amount to several miles or more. The amount of overthrusting along the Dugout Creek system appears to have varied from place to place, however, for differential movements in the sheet are suggested by the line of en échelon tear faults that extend back from the front of the fault (pl. 15).

The overthrusts in the Caballos and Maravillas formations in the Dagger Flat anticlinorium probably once extended entirely along the now eroded crest of the fold, as suggested by the restoration of the structure in figure 31. Each of the major thrusts has several miles of displacement. At the southwest end of the anticlinorium the overthrust at Garden Springs has moved at least 1½ miles, and that which crops out near Threemile Hill and Maravillas Gap has moved at least 3 miles. At the northeast end of the anticlinorium the Warwick thrust has moved at least 2 miles, the Lightning thrust 1 mile, and the thrust in the Peña Blanca Mountains near the old Reed place, 1½ miles.

The next great thrust to the southeast, the Hells Half Acre fault, is poorly known, and the amount of movement along it has not been established. East of San Francisco Creek it truncates a belt of northeastward-trending folds 5 miles wide, which may furnish evidence of the minimum amount of overthrusting.

The minimum possible amount of crustal shortening brought about by overthrusting in the Marathon Basin is thus at least 15 miles, and the maximum amount is probably much greater. The thrusts mentioned above extend across any section drawn from northwest to southeast, but continuous exposures of them have not been traced across the entire region, on account of the alluvial cover and overlaps of rocks younger than the deformation. The Dugout Creek overthrust passes beneath Permian and Cretaceous rocks to the northeast and southwest but may bound the whole northwest margin of the Marathon folded belt. The thrusts in the Dagger Flat anticlinorium may have extended entirely along its crest, but they apparently die out in the Carboniferous rocks to the northeast. The Hells Half Acre fault in its typical exposures may be connected with various thrust faults, such as those in the Tinaja Mountains, so as to extend it entirely across the exposed Paleozoic rocks of the Marathon Basin.

The overthrust faults appear to be of different ages, with the youngest toward the northwest. The Dugout Creek overthrust is nearly flat and involves strata of upper Pennsylvanian age; apparently it is a late feature of the deformation. The faults of the Dagger Flat anticlinorium are folded and therefore older than the later part of the deformation of the region. There is a suggestion that the Hells Half Acre fault is related to the deposition of the blocks in the boulder-bed member of the Haymond formation (fig. 31). If these several pieces of evidence are correctly interpreted, the earliest thrusting in the region occurred in late Haymond time, in the southeastern part of the region. Successive thrusts farther to the northwest were formed in later Pennsylvanian time, culminating before the Permian in the farthest one, the Dugout Creek overthrust (figs. *B*, *C*, and *D*, pl. 20).

The overthrust masses above the Dugout Creek fault have the form of broken folds. The outer sheet, in the Payne Hills, now greatly shattered by small thrusts, is structurally higher in its northern part, where Maravillas and Caballos strata crop out, than in its southern part, where Dimple and Haymond strata occupy synclinal areas. The next sheet to the south likewise has an anticlinal structure, which brings up Cambrian strata about a mile behind the fault. The Caballos and Maravillas strata on the third sheet, south of Monument Creek, are folded into a recumbent anticline. Evidently the breaks along which the faults moved were formed along the northwest flanks of anticlines or anticlinoria. Their location was possibly related to the abrupt thinning of the Tesnus formation, from 2,000 to 3,000 feet a few miles to the southeast to only a few hundred feet near the front of the thrust, and possibly also to a thinning of the Caballos formation beneath.

The frontal part of the overriding mass of the Dugout Creek overthrust appears to have been relatively thin, and the rocks now exposed there seem to have moved under a slight overburden of younger strata. The youngest rocks involved are those of the Gaptank formation on the overridden block, which is overlain by Permian strata later than the disturbance. Whatever strata once existed on the overthrust sheets must therefore be Gaptank or older. It is rather unlikely that any great thickness of this formation was laid down on the thrust sheets, however, for chert conglomerates in that formation in the overridden area show that movements had begun to the southeast of it during Gaptank time. In the Payne Hills, near the overthrust front, there were no more than 2,600 feet of pre-Gaptank Carboniferous strata overlying the Caballos novaculite (Tesnus, 300 feet; Dimple, 300 feet; Haymond, 2,000 feet). In the sheets behind, where Ordovician and Cambrian strata are now exposed, the rocks now at the surface were covered by 3,000 or 4,000 feet of pre-Gaptank strata. These thicknesses were probably increased during deformation by the piling up of the beds, but this must in part have been compensated by erosion of the upraised masses. These estimates are confirmed by the lack of metamorphism and cataclastic products and by the geologic structure of the overriding block.

As the youngest Pennsylvanian exposed beneath the thrust is not greatly older than the unconformably overlying Permian rocks, it is probable that these strata were nearly the last to be deposited in the region before the main overthrusting, and that the overthrust sheets rode forward over the depositional surface of the Gaptank formation (fig. *C*, pl. 20).

The means by which the thrust of the Dugout Creek fault was transmitted is not known. The whole section exposed on the overriding sheet over several miles of breadth consists of Paleozoic sedimentary rocks of no great competency. The oldest exposed rocks in the region are of Upper Cambrian age; to what extent they are underlain by older Cambrian rocks cannot be said. It is possible that within the thrust sheet, though not extending to its margin, is a wedge of pre-Cambrian rock by which the thrust was transmitted.

The overthrusts within the Dagger Flat anticlinorium appear to be of only local extent, and evidence has been presented to show that they are almost wholly confined to the competent Maravillas chert and Caballos novaculite. They appear to have been formed as a response of these rocks to the first deformative forces in the region, whereas the strata above and below, separated from them by incompetent beds of shale, were deformed in a different manner. The Hells Half Acre fault, to the southwest, appears to be of greater extent, and may have involved the movement of a large block of the earth's crust, but very little is known of it.

Theoretical problems of the steep thrust faults.—Thrust faults with steep dips are found at many places in the region. Some of these appear to have originally been overthrust faults whose planes have since been deformed. Such faults dip in a variety of directions at different places along their trace. At least a part of the steep thrusts, however, are quite different from the overthrusts.

Some of the steep thrusts cut the overthrust faults. One raises the overthrust of the Threemile Hill area to the surface on the southeast side of the hill. Several small thrusts appear to have displaced the Dugout Creek overthrust in the Payne Hills (pl. 16). The largest of the steep thrust faults are found in the synclinorial Carboniferous area in the eastern part of the Marathon Basin. All these faults follow the northwest limbs of anticlines and separate them from synclinal areas. Evidently they are simple breaks in the overturned limbs of the folds, and there is no great component of horizontal movement. These thrusts are seemingly late features in the deformation. On the southeast flank of the Dagger Flat anticlinorium there has been some backward thrusting in the novaculite along fault planes that dip steeply northwest.

Theoretical problems of the tear faults.—At numerous places in the region, but particularly in the outcrops of novaculite, there are tear faults that extend in directions transverse to the strike. These faults are younger than the folds and the folded overthrusts, which they displace. Those on the northwest seem genetically related to the forces that brought about the Dugout Creek overthrust. The faults are roughly parallel to many of the post-Cretaceous normal faults in the surrounding region, but their large component of horizontal displacement and their close genetic relation to the folding and overthrusting in the Marathon Basin make it very probable that they are of Pennsylvanian age.

In the northwest a conspicuous zone of en échelon tear faults extends southeast from the front of the Dugout Creek overthrust and appears to separate two masses in the thrust sheet that have moved in a different manner (pl. 15). The mass northeast of the fault zone appears to have moved farther forward than that on the southwest. To the southeast, in the Dagger Flat anticlinorium, are numerous transverse faults, which are arranged in two more or less evident systems at about equal angles to the strike. The angle between them may represent the shearing angle for chert and novaculite.

Theoretical problems of the folds.—The crustal shortening resulting from folding in the Marathon Basin is shown in figure 33. Estimates were made along the lines of structure sections drawn at right angles to the strike allowing folds their minimum possible height and faults their minimum possible throw.

In the Marathon anticlinorium the estimates show that each present mile of cross section represents 1.8 to 2 miles originally. In the Dagger Flat anticlinorium both the Maravillas and Caballos with their folded overthrusts and the older rocks with isoclinal structure show a ratio of 1 mile to 3 miles. The crustal shortening in the synclinoria is generally less. In the Peña Colorada synclinorium and in the down-warped area between Tesnus station and Gap Tank there is a ratio of 1 present mile to 1.5 original miles, both in the

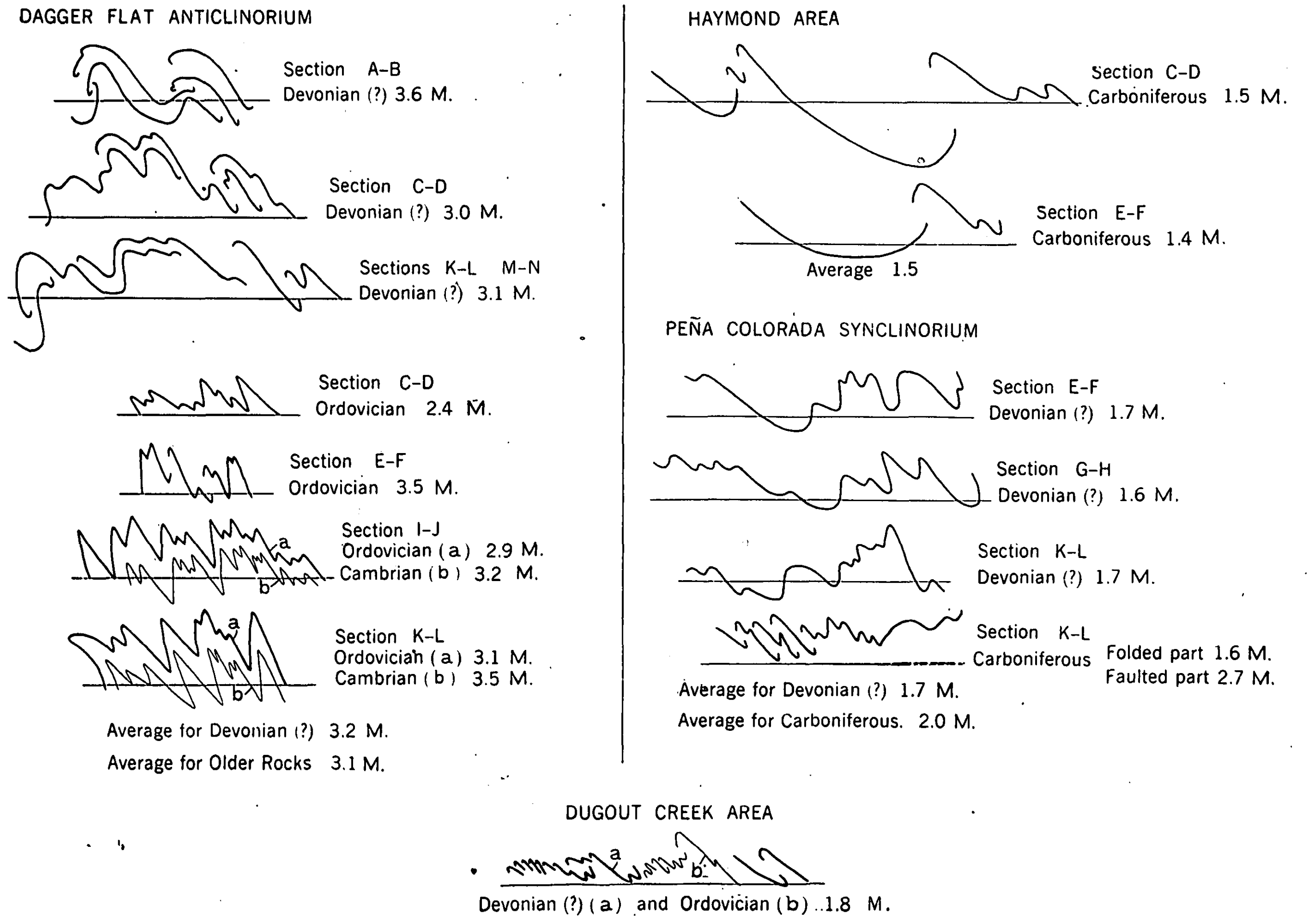


FIGURE 33.—Diagram showing estimates of crustal shortening in different parts of the Marathon Basin. The curved lines show the attitude of the beds from which the estimates were made.

Caballos and in various parts of the Carboniferous. It is possible that not even the older rocks were strongly folded in these areas, for an extensive exposure of Woods Hollow shale in an anticline in the Woods Hollow Mountains is folded into as open an anticline as that in the Maravillas and Caballos formations, which overlie it. Apparently the two anticlinoria were the centers of most active deformation in the area.

The district south of the Hells Half Acre fault probably has crustal shortening equal to that in the Dagger Flat anticlinorium, to judge from the intense deformation at localities where the structure could be made out.

The folds in the Marathon Basin are notably different in different parts of the succession, as a result of the alternation of competent and incompetent layers indicated by the following table:

Section showing competent and incompetent beds in Marathon Basin

Competent	Incompetent
	Gaptank, 2,000 feet.
Haymond, Dimple, Upper Tesnus } 7,500 feet.	
	Basal shale member of Tesnus formation, 1,500 feet.
Caballos, Maravillas } 750 feet.	
	Woods Hollow, 500 feet.
Fort Peña, 200 feet.	
	Alsate, 50 feet.
Marathon, 750 feet.	
Dagger Flat sandstone and various competent and incompetent beds beneath.	

The contrast in structure between two rock groups above and below a shale formation is best displayed by the Ordovician rocks below the Woods Hollow shale and the Caballos and Maravillas formations above it. Both groups have received an approximately equal amount of crustal shortening, but the beds below the shale are folded into isoclines and those above are piled up in thrust sheets, which have since been openly folded. The change in structure is so great in some places as to appear almost like an angular unconformity. In a similar manner, but to a lesser degree, the Alsate shale, where it is thick in the northwest, has allowed differences in folding between the Marathon limestone below and the Fort Peña formation above.

East of the Dagger Flat anticlinorium the massive competent upper Tesnus sandstones, Dimple limestone, and Haymond sandstones, in all 7,500 feet or more in thickness, have been folded into broad, open arches several miles across, in contrast to the smaller and shallower folds in the Caballos formation, to the west. The two competent groups are separated by the incompetent basal shale member of the Tesnus. In the Peña Colorada synclinorium, to the west, the Tesnus formation is thinner and is nearly all shale, so that the thin Dimple limestone above it is much more sharply folded than the Caballos novaculite below. These differences in structure are illustrated by the following table:

Intensity of folding in Marathon Basin

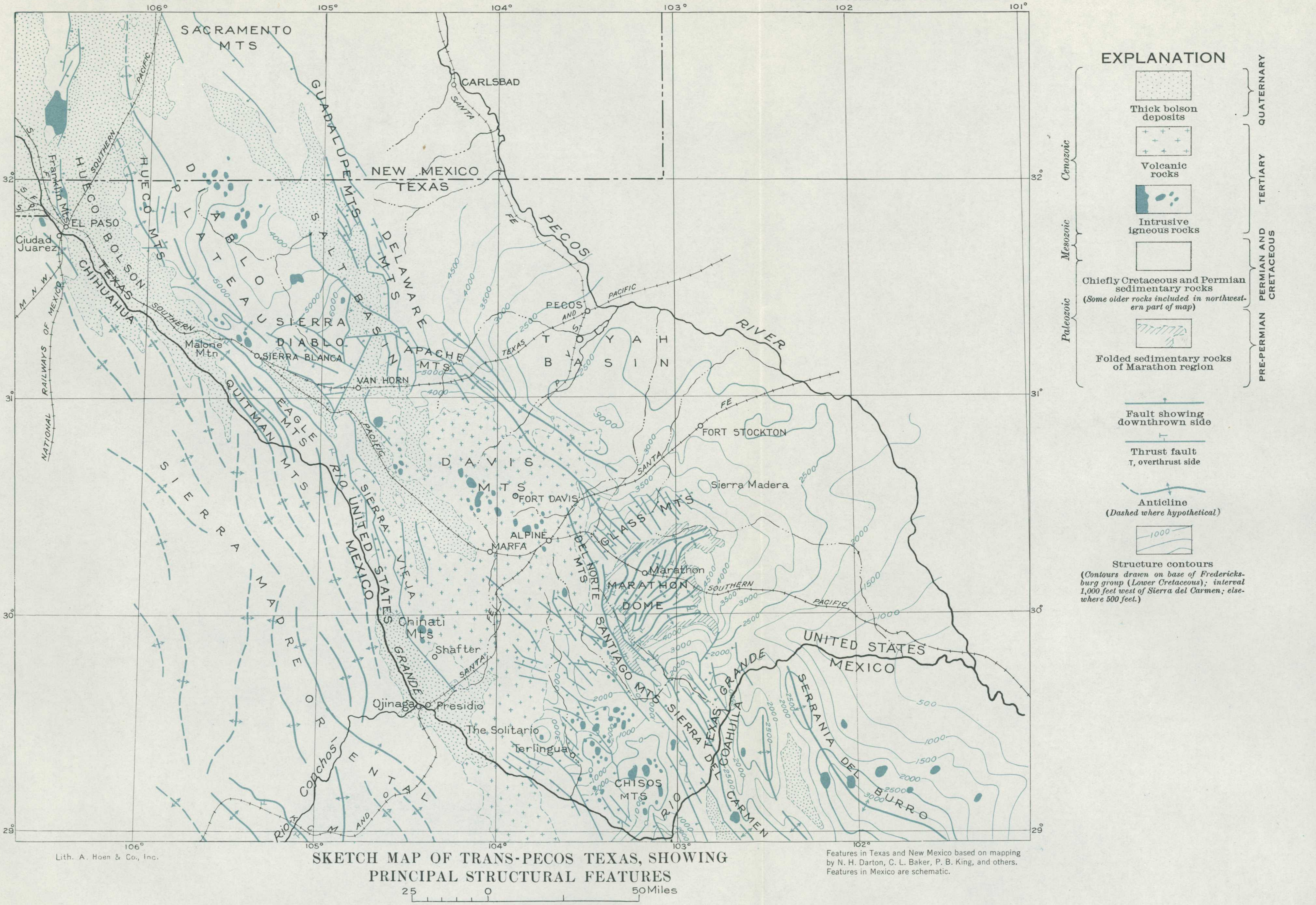
Formations	Area	Anticlines per mile
Dimple	Peña Colorada synclinorium	5
Tesnus and Dimple	Haymond area	⅓
Caballos and Maravillas	Peña Colorada synclinorium	2
	Dagger Flat anticlinorium	1½
	Marathon anticlinorium	2
Pre-Woods Hollow	Dagger Flat anticlinorium	4
	Marathon anticlinorium	4

The structural features of the Marathon Basin are similar to those in the Ouachita Mountains, but there are some significant differences. The folds are generally of much less amplitude than those in the Ouachita Mountains, which are commonly several miles across and in more massive rocks many miles. The strata in the Marathon Basin are generally less competent than those in the Ouachita Mountains, but there is also a more decided contrast between the members, so that differences in folding in different parts of the series are more marked. Besides, the strata in the Marathon Basin were deformed under less cover than those of the Ouachita Mountains. At Marathon the maximum cover above the novaculite was 12,000 feet, and in places is much less; in the Ouachita Mountains the novaculite was deformed under 20,000 feet or more of higher strata. The small amount of overburden above the exposed folds at Marathon at the time of deformation at least partly accounts for the lack of metamorphism in the area.

AGE OF THE DEFORMATION

The writer believes that the movements which produced the Marathon folds were pulsatory and that, although they culminated at the end of the Pennsylvanian epoch, they began earlier. The chief evidence in support of such a belief is that, although the great angular unconformity in the sequence lies between the Gaptank formation and the basal Permian, conglomerates and boulder beds occur lower down in the section, in the Gaptank and Haymond formations. These beds contain fragments of rocks of the geosyncline that would have been deeply buried during later Pennsylvanian time, had not movements brought them to the surface. Fortunately, deposition appears to have been nearly continuous in at least some parts of the area while the diastrophism was taking place, so that the record of the sediments furnishes a valuable clue to the structural history. A sequence of tectonic events can also be worked out from the character of the structural features themselves. The features that were formed earliest were deformed by later movements.

The evidence afforded by the conglomerates and by the character of the structural features has been fitted together into a hypothetical sequence, which is shown in the subjoined table. A generalization of the same events and of those that came before and after is shown in the table on page 119, and the events are shown diagrammatically in plate 20.



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SKETCH MAP OF TRANS-PECOS TEXAS, SHOWING PRINCIPAL STRUCTURAL FEATURES

Features in Texas and New Mexico based on mapping by N. H. Darton, C. L. Baker, P. B. King, and others. Features in Mexico are schematic.

Hypothetical sequence of events during the deformation of the Marathon Basin

Age	Record in sedimentary rocks	Structural features produced	Possible related features
5. Early Permian (pre-Leonard, post-Wolfcamp) (pl. 21, *E*).	Thin persistent conglomerate at base of Leonard; slight unconformity at top of Wolfcamp.	Tilting of beds in Glass Mountains; possibly folding to south.	
Wolfcamp time.	Coarse conglomerates locally at base of Wolfcamp.		
	Hiatus.	Warping of folds.	
4. End of Pennsylvanian (post-Gaptank, pre-Wolfcamp) (pl. 20, *D*).	Conglomerates in higher part of Gaptank formation.	Strong folding followed by overthrusting at Dugout Creek.	Tear faults and steep thrusts.
3. Mid-Gaptank (pl. 20, *C*).	"Molasse facies": Conglomerate beds near middle of Gaptank formation.	Beginning of folding, including folding of first thrusts.	
2. Late Haymond (pl. 20, *B*).	"Molasse facies": Boulder beds in upper part of Haymond formation.	Overthrusting in southeastern part of area, as along Hells Half Acre fault.	Overthrusts in Dagger Flat anticlinorium.
1. Haymond to Tesnus (pl. 20, *A*).	"Flysch facies": Deposition of an enormous thickness of shale and fine sandstone, with one interruption when a small thickness of limestone (Dimple) was laid down.	Strong uplift of hinterland of Llanoria, southeast of geosyncline.	

A strong uplift of the hinterland of Llanoria in Tesnus and lower Haymond time is indicated by the southeastward source of the great mass of clastic sediments in these formations (pl. 20, *A*). They thicken and become coarser in this direction and contain numerous minute fragments of granitic and metamorphic rocks, as if derived from a land area of crystalline rocks. During this time there may have been marked differences in the amount of sedimentation in the later anticlinorial and synclinorial areas, and such a relation is suggested in plate 20, *A*. The Tesnus formation is at least 6,500 feet thick southeast of the Dagger Flat anticlinorium and 2,000 to 3,000 feet thick northwest of it, but toward the Marathon anticlinorium the Tesnus thins from 2,000 feet to a few hundred feet. A complete disappearance of the Tesnus formation not far northwest of the Marathon anticlinorium is suggested by chert conglomerate derived from the erosion of pre-Tesnus rocks in the overlying Dimple formation.

There is a suspected relation between the exotic blocks in the boulder-bed member of the Haymond formation and the first overthrusting in the Marathon Basin. The nature of the deposit suggests a considerable nearby relief. The fragments of Maravillas and Caballos rocks in the bed are like the strata of those ages that crop out in the southeastern part of the basin, where the early thrusts are found, and the fragments of Caballos novaculite are brecciated or contorted in the same manner as that formation has been along known faults in other parts of the region. Elsewhere the Caballos does not show conspicuous minor deformation. The thrusts themselves, folded by later movements, appear to be among the oldest structural features in the area, and as at least a part of the folding took place during Gaptank time, they may be as old as the Haymond.

Conglomerates are found within the Gaptank formation, both at the type locality and west of Marathon. Those at the type locality contain large cobbles of limestone that can be matched with rocks in the Dimple formation and the basal part of the Gaptank (pl. 11, *B*). The northward thinning of these deposits within short distances suggests a nearby source from newly raised folds to the southeast. Those west of Marathon, which consist largely of chert fragments, may have come from rising folds to the south, which later rode forward along the Dugout Creek overthrust. The fossils associated with the conglomerates here are younger than those in the conglomerate beds at the type locality.

That the Dugout Creek overthrust was a late event in the diastrophism is indicated by the late Pennsylvanian fossils in strata beneath the overthrust, some of which are younger than those in the conglomerate beds of the middle Gaptank at its type locality. Moreover, the thrust is nearly flat and undeformed and transects many of the older folds. Coarse conglomerates in the basal Permian immediately to the north show that the masses that had been moved along the overthrust were still being actively eroded. The system of tear faults that extends back from the front of the overthrust appears to be of about the same age as the thrusting and to have resulted from differential movement between two parts of the overriding sheet. The tear faults farther southeast, which transect the folds and folded overthrusts, may also have been formed at the same time.

The Dugout Creek overthrust and the older structural features southeast of it are warped in such a manner that a belt which extends across the western part of the Marathon Basin has been arched up, and the area to the east of it has been depressed. This cross warping of the folds occurred before Permian time, for Permian strata lie unconformably on the overridden rocks of the Dugout Creek overthrust in the highest part of the upraised area west of Marathon and on the Gaptank formation in the deepest part of the depressed area to the east. The warping may have taken place at about the same time as the last overthrusting in the region, or it may have been somewhat later. The manner in which the Permian strata rest on the warps suggests an extensive period of erosion in parts of the area before Permian time.

There were lesser orogenic events after the culmination of the disturbance, for in places a perceptible angular unconformity exists between the Wolfcamp and Leonard formations, and there is a persistent conglomerate bed at the base of the Leonard. The coarse conglomerates in the Triassic (?) Bissett formation along the northwestern edge of the Glass Mountains suggest an uplift of that area, and possibly of the Marathon Basin, toward the end of Permian time. Further movements after Bissett time are indicated by the pronounced angular unconformity that separates the Bissett conglomerate and older formations from the Comanche series.

The history of the Marathon orogeny just outlined is based on the best available evidence, but on account of the gaps that necessarily exist in the record, it hardly represents more than the writer's own opinion. Several other hypotheses have been suggested as to the date of the culmination of the orogeny. Baker [26] has expressed the opinion that this was older than the Gaptank, whereas the writer would place it toward the end of Gaptank time. There is also some doubt as to the relation of the *Uddenites* zone, here placed at the top of the Gaptank, to the orogenic events. The chief difference of opinion between Baker and the writer hinges on the age of the youngest beds involved in the overthrusting west of Marathon, which he considers to be of Strawn age or older. Faunas of Strawn age certainly exist here, but there are also younger faunas, and the writer believes that there is little doubt that the beds are to be correlated with parts of the typical Gaptank and Haymond formations.

[26] Baker, C. L., and Bowman, W. F., Geologic exploration of southeastern front range in trans-Pecos Texas: Texas Univ. Bull. 1753, pp. 107-112, 1917. Baker, C. L., Date of the major diastrophism and other problems of the Marathon Basin, trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., vol. 12, pp. 1111-1114, 1928.

REGIONAL RELATIONS OF THE STRUCTURAL FEATURES AT MARATHON

The Marathon folds, as noted above, were formed from rocks deposited in the Llanoria geosyncline, an area of subsidence which extended for considerable distances northeast and southwest of Marathon. The Llanoria geosyncline was probably bounded on the southeast during Paleozoic time by an area of highlands underlain by crystalline rocks (pl. 20, *A*). This has been called "Llanoria", by analogy with the land mass of that name which is supposed to have lain south of the Ouachita Mountains.[27] The existence of such a land is suggested by the nature of the geosynclinal sediments exposed in the Marathon Basin, and this evidence has been summarized on pages 22, 45, and 87 of this paper. Both clastic and cherty formations thicken southeastward across the basin; limestones are replaced by shales or cherts; and the clastic deposits contain grains of schistose or granitic rocks, pebbles of vein quartz, and cobbles of igneous rocks. The distance at which the land lay during Paleozoic time is unknown, but it may have been 100 miles or more away.

A few exposures of crystalline rocks are found south of the Marathon region, in Mexico, where they are directly overlain by Mesozoic strata. One of these occurs 80 miles south of Marathon, south of the Rio Grande and east of the village of Boquillas, near the axis of the Sierra del Carmen.[28] It is possible that these exposures represent the worn-down surface of the old land area.

There is a considerable tract of country in Mexico south of the Marathon region which apparently stood as a positive area in early Mesozoic time. South and southwest of a line extending westward from Saltillo to Torreon, in southern Coahuila, and thence northwestward through Chihuahua to western trans-Pecos Texas, Jurassic and early Cretaceous rocks are developed to a great thickness. Northeastward from this region these older Mesozoic rocks apparently disappear or are represented by a clastic marginal facies.[29] At Las Delicias, not far northeast of Torreon, Lower Cretaceous rocks, approximately of Glen Rose age, rest directly on the Permian. The strong post-Cretaceous folding of the region follows the edge of the positive area, so that the general northwestward Cordilleran trend changes to an east-west trend west of Saltillo. The writer has suggested that the positive area was a rem-

[27] Miser, H. D., Llanoria, a Paleozoic land in Louisiana and eastern Texas: Am. Jour. Sci., 5th ser., vol. 2, pp. 61-89, 1921.

[28] Böse, Emil, Vestiges of an ancient continent in northern Mexico: Am. Jour. Sci., 5th ser., vol. 6, p. 113, 1923. Also from conversation with C. L. Baker, 1930.

[29] Böse, Emil, op. cit., pp. 130-136. For a more detailed recent statement see Kellum, L. B., Imlay, R. W., and Kane, W. G., Evolution of the Coahuila Peninsula, Mexico; Part 1, Relation of structure, stratigraphy, and igneous activity to an early continental margin: Geol. Soc. America Bull., vol. 47, pp. 969-1007, 1936.

nant in Mesozoic time of the Paleozoic land mass of Llanora.[33]

It is possible that the northwestward margin of the Llanoria geosyncline lay near the present northwest edge of the Marathon Basin, and that the Dugout Creek overthrust is the marginal overthrust of the folded belt, as suggested on plate 20, *D*. The Tesnus formation, a typical geosynclinal deposit, which reaches thousands of feet in thickness in the central and southern parts of the basin, thins out to a few hundred feet near the margin of the Dugout Creek thrust sheet, and the underlying Caballos and Maravillas formations are thinner here. Moreover, Cambrian and Ordovician limestone boulders of foreland facies are found in the Woods Hollow shale a few miles southeast of the outcrops of the thrust, and whether these are of tectonic or sedimentary origin, they indicate the presence of foreland rocks not far to the northwest. Not much is known of the stratigraphy of the rocks overridden by the thrust, as only upper Pennsylvanian rocks are exposed or encountered in wells in the Dugout Creek area. It is to be hoped that later drilling will penetrate the older strata and furnish evidence as to their character.

Whether the Dugout Creek overthrust extends under younger strata for any great distance northeast or southwest from its exposures cannot be said. In the northeastern part of the Marathon Basin the folding of the Pennsylvanian rocks dies out rapidly northward, and the Gaptank formation, which to the west is overridden by the thrusts, passes beneath the Permian strata of the Glass Mountains without evident difference in dip or strike. This may mark the northwestern margin of the Marathon folded belt in this region, but the northeastward projection of the trace of the Dugout Creek overthrust would lie northwest of the Gap Tank area.

At the southwest edge of the Marathon Basin the strike of the folded rocks extends beneath the Cretaceous, but structural features of similar character and age come to the surface again in the small dome of the Solitario, 35 miles southwest of the edge of the basin (locality D 1, pl. 22). Here Sellards [31] reports folded overthrusts like those of the Dagger Flat anticlinorium in the Marathon Basin. The further extension of the folds to the southwest is unknown, as they are covered in this direction by Cretaceous rocks and Tertiary lava flows. Without doubt they extend beneath the post-Cretaceous folds of the Sierra Madre, a few miles southwest of the Solitario.

[30] King, P. B., Outline of the structural geology of the United States: 16th Internat. Geol. Cong. Guidebook 28, p. 41, 1933.

[31] Sellards, E. H., Overthrusting in the Solitario region of Texas [abstract]: Geol. Soc. America Bull., vol. 43, pp. 145–146, 1932. For a geologic map, see Sellards, E. H., Pre-Paleozoic and Paleozoic systems, in Geology of Texas, vol 1, Stratigraphy: Texas Univ. Bull. 3232, fig. 9, p. 119, 1933.

At the east edge of the Marathon Basin the folded rocks also strike beneath the Cretaceous and although they are not seen at the surface again in this direction, they have been encountered by wells. They are found in water wells a few hundred feet deep for several miles east of the basin, and Sellards [32] lists six deeper borings in Terrell and Val Verde Counties that encounter talcose and altered shales, probably belonging to the system of folded Paleozoic rocks. Farther east, in Kinney County, [33] one boring was drilled through several hundred feet of altered rocks and entered unaltered limestone of Ordovician age, possibly of foreland facies. Sellards suggests that the well may have been drilled through an overthrust sheet.[34] The positions of these wells suggests that the strike of the folded belt may change to an east-southeasterly course east of the Marathon Basin, as indicated on a map by Sellards.[35]

East of Kinney County the strike of the folded belt, as indicated by altered rocks encountered in borings, turns northward and the belt joins the Ouachita Mountains in southeastern Oklahoma.[36] Southeast of the folded belt, near Austin, Tex., wells have been drilled into metamorphic rocks, probably of pre-Cambrian age,[37] which may be a part of the hinterland of the geosyncline. The rocks and structural features of the Ouachita Mountains are very similar to those in the Marathon Basin and were probably a part of the same folded system.[38]

Northwest of the folded Paleozoic rocks of trans-Pecos Texas there was apparently a foreland area, but this has been extensively covered by Permian, Cretaceous, and Tertiary rocks. In northwestern trans-Pecos Texas, within 100 miles of the Marathon region, pre-Permian Paleozoic rocks are exposed in the Van Horn and El Paso districts, where they are thin and consist largely of limestone. They were broadly folded and deeply eroded before Permian time, probably during the culmination of the movements at Marathon. Farther east, near Fort Stockton, 60 miles north of the Marathon region, pre-Cambrian granite has been penetrated by the drill below the Permian.

[32] Sellards, E. H., op. cit. (Bull. 3232), pp. 190–191.

[33] Idem, p. 189.

[34] Idem, p. 134.

[35] Idem, fig. 10, p. 128.

[36] Miser, H. D., and Sellards, E. H., Pre-Cretaceous rocks found in wells in Gulf Coastal Plain south of Ouachita Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 15, pp. 801–818, 1931. Sellards, E. H., Rocks underlying Cretaceous in Balcones fault zone of central Texas: Idem, pp. 819–827.

[37] Sellards, E. H., op. cit. (Bull. 3232), 132–133.

[38] For general discussions of the relations of these various areas of folded Paleozoic rocks see Powers, Sidney, Age of the folding of the Oklahoma Mountains: Geol. Soc. America Bull., vol. 39, pp. 1031–1071, 1928. Van der Gracht, W. A. J. M. van Waterschoot, The Permo-Carboniferous orogeny in the south-central United States: K. Akad. Wetensch. Amsterdam Verh., Afd. Natuurk., Deel 27, no. 3, 1931. King, P. B., An outline of the structural geology of the United States: 16th Internat. Geol. Cong. Guidebook 28, pp. 15–20, 1933. Miser, H. D., Relation of Ouachita belt of Paleozoic rocks to oil and gas fields of midcontinent region: Am. Assoc. Petroleum Geologists Bull., vol. 18, pp. 1059–1077, 1934.

In Reagan, Irion, and Crockett Counties (the Crockett County locality less than 100 miles northeast of Marathon) Pennsylvanian and Ordovician limestones have been reached by the drill. The Ordovician at these three localities is evidently a westward extension of the upper part of the Ellenburger limestone, which spreads as a broad sheet across the foreland area of central Texas.

STRUCTURAL FEATURES OF THE GLASS MOUNTAINS

A portion of the Glass Mountains extends into the northwest corner of the Monument Spring quadrangle (pl. 24), but most of the range lies farther to the north, in the Altuda and Hess Canyon quadrangles (pl. 23). The structural features of these mountains were produced by three distinct periods of movement—tilting at the end of the Permian, folding in early Tertiary time, and normal faulting late in the Tertiary. The rocks in the Glass Mountains are all inclined to the north and northwest, away from the Marathon Basin. The Permian strata dip more steeply than those of the Comanche series, because of the unconformity between them. The inclination of the Permian locally exceeds 20° and averages 10°, whereas the Comanche rarely dips more steeply than 5°. There is a general decrease in steepness of dip away from the mountains, so that in areas to the north the Comanche lies nearly flat and the Permian dips at low angles. Superimposed on the major features are domes, low anticlines, and terraces, developed at the time the beds were tilted to the northwest. The range is also transected by a series of northwestward-trending normal faults. Several igneous plugs, the largest of which are Iron Mountain and the mass south of Altuda Mountain, have considerable local influence on the structure.

Many of the local post-Cretaceous structural features are apparently superimposed on similar features in the Permian, which were formed before Cretaceous time, so that the older series has a steeper dip off most of the anticlines, domes, and terraces than the similarly deformed Cretaceous rocks above.[39]

Permian rocks, which form the southwest end of the Glass Mountains, crop out in the northwestern part of the Monument Spring quadrangle (pl. 24). Their dip in this area is 10°–15° NW. (sec. G–G′–G″, pl. 21). Along the Del Norte Mountains they diverge by several degrees from the strata of the Comanche series above. They are cut by many normal faults with a general northwest trend, some of which are downthrown to the northeast and others to the southwest. Dugout Mountain appears to be separated from the ridges north of Lenox by a belt of marked normal faulting that extends along the wide alluvial valley followed by the Southern Pacific Railroad between Lenox and Altuda, in the Altuda quadrangle (pl. 23). The rocks on the southwest are dropped relative to those on the northeast, so that their outcrops lie farther southeast than those in the main area of the Glass Mountains.

[39] King, P. B., Geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, p. 121, 1930.

POST-CRETACEOUS STRUCTURAL FEATURES

Structural features of post-Cretaceous age are revealed in the exposures of the Comanche series surrounding the Marathon Basin (pl. 15). These are the margins of the broad uplift of the Marathon dome, of which the Paleozoic exposures near Marathon are the center. The base of the Fredericksburg group (in the Comanche series) at distances of 40 miles to the north and south of Marathon lies 1,000 feet above sea level. It rises to 6,500 feet on the summits of the Glass Mountains, not far north of the probable crest of the Marathon dome (pl. 22). The dome is broken off on the west by a narrow zone of westward thrusting and overfolding in the Del Norte and Santiago Mountains. To the east the slope of the Cretaceous rocks away from the dome is gradual, and the strata spread out in a broad fold that extends nearly to the Pecos River.

Eastern margin of the Marathon dome.—The post-Cretaceous structural features in the Glass Mountains have been noted above, and have been described in more detail elsewhere.[40] To the east the strata dip away from the dome at an inclination of about 100 feet to the mile and are gently flexed into broad arches, whose general trend is east and west.

On the southeast and south the dips are much steeper. South of the Southern Pacific Railroad there are dips of as much as 10° E. near the Tres Hermanas Mountains and of 5° S. on the escarpments on the south side of the Marathon Basin. At the southeast corner of the uplift is a sharp southeastward-plunging anticline whose axis lies near the Jones ranch, in the Dove Mountain quadrangle (pl. 15). Its crest is eroded into a narrow basin, along which Paleozoic rocks are exposed for 5 or 10 miles southeast of the main Paleozoic outcrops in the Marathon uplift. The Cretaceous rocks flank the anticline in steep escarpments, and dip gently off the southwest flank but at angles as great as 20° off the northeast flank. Southeast of the Jones ranch the anticlinal axis bends about sharply to the southwest, and the beds on the southeast flank of the fold are dropped by a fault.

Western margin of the Marathon dome.—The western margin of the Marathon dome is formed by the Del Norte and Santiago Mountains, which structurally constitute a single unit. The rocks of the mountains are raised into a sharp monocline or anticline, overturned toward the west and broken in most places by an east-

[40] King, P. B., op. cit. (Bull. 3038), pp. 117-120.

ward-dipping thrust fault that has raised Paleozoic and Lower Cretaceous rocks on the east against younger Cretaceous beds on the west (pl. 15). This narrow belt of strong deformation forms the sharply buckled western edge of the Marathon dome.

The north end of the Del Norte Mountains consists of a broad arch that pitches northwestward beneath Tertiary lavas, as shown northwest of Altuda Mountain (pl. 15). In the vicinity of Altuda Mountain, near the north end of the range, is a broad dome, faulted on the south and east, which brings up strata as young as the Leonard near an igneous intrusion in the center. In the northwest corner of the Monument Spring quadrangle (pl. 24) the fold steepens and changes into a monocline, in which the strata are vertical or overturned to the west near the east base of the mountains (sec. K–K′, pl. 21). This feature does not continue far to the north of the latitude of Dugout Mountain.

West of the monocline in the Monument Spring quadrangle the Cretaceous strata dip in general at low angles to the west, toward the escarpments of Tertiary lava. Near the monocline are several broad folds. One of these, west of Dugout Mountain, is a domelike anticline, elongated north and south, with dips of 45° on the west flank (sec. K–K′, pl. 21). Another domelike area 3 miles north ot Black Peak, now much broken by normal faults, has an igneous mass in the center (sec. L–L′, pl. 21).

South of the latitude of Dugout Mountain the sharp monocline is broken by a thrust fault. At its northernmost exposure, 4 miles north of Black Peak, Gaptank sandstones are faulted against rocks belonging to the Word formation (pl. 24). A dike of igneous rock lies along the fault here. The fault is well exposed at Black Peak (pl. 13, *A*, *C*, and sec. M–M′, pl. 21) and is therefore named the "Black Peak fault" in this paper. Black Peak is a much sheared mass of Carboniferous limestone, which dips 45° E. and which is thrust toward the west against Edwards and Georgetown limestones of the Del Norte Mountains. The fault plane dips 60° E., and the Cretaceous limestones are turned up sharply against it near the contact (pl. 13, *C*), although they are nearly horizontal a few hundred yards to the west. At most places in this part of the Del Norte Mountains there is a high escarpment of Cretaceous limestone along the fault; this faces the eastern or upthrown side, where nonresistant Paleozoic rocks have been worn down to a lowland.

South of Black Peak the fault trace follows the base of the Del Norte Mountains for 3 miles, and Caballos, Maravillas, and older formations lie against the upper part of the Glen Rose formation (sec. N–N′, pl. 21). The fault plane, well exposed at several places, dips 60° E. South of these localities the fault crosses the mountains to the west side, and there are high mesas of flat-lying Cretaceous strata on the upthrown block. One of these forms the crest of the Del Norte Mountains just north of Del Norte Gap (sec. O–O′ and P–P′, pl. 21). Another forms the Cochran Mountains, east of the gap (sec. Q–Q′–Q″, pl. 21).

The Santiago Mountains, immediately south of Del Norte Gap, are a narrow ridge of vertical Glen Rose and Edwards limestones, faulted on the west against the Eagle Ford formation, which dips westward from the fault at a low angle (pl. 13, *B*, and sec. Q–Q′–Q″, pl. 21). Immediately south of the gap the fault dips 40° E. Farther along the crest of the Santiago Mountains the Glen Rose limestones are overturned (sec. S–S′, pl. 21). About 2 miles southeast of Del Norte Gap the vertical Cretaceous rocks of the Santiago Mountains arch over and join the flat-lying beds of the same age in the Cochran Mountains, to the east (sec. Q–Q′–Q″, pl. 21). A similar relation probably once existed farther south, but here the flat-lying beds have been removed by erosion except in down-faulted areas, as in section S–S′, and their relation to the vertical beds in the mountains to the west is no longer evident. The folded Paleozoic rocks in the plains east of the Santiago Mountains approach the upturned Cretaceous rocks of the mountains with nearly a 90° difference in strike. Toward the south, for about a mile from the base of the mountains, however, the strike of some of the folds has been deflected to the northwest (pl. 15), probably as a result of the post-Cretaceous movement.

South of the Marathon Basin the Santiago Mountains continue for 20 miles as a sharp, narrow anticline in the Lower Cretaceous and die out near Dog Canyon, against the broad uplift of the Sierra del Carmen (pl. 22). Paleozoic rocks, probably of the Tesnus formation, are exposed by erosion of the crest of the fold at Persimmon Gap, in the Bone Spring quadrangle.

The Del Norte and Santiago Mountains are broken by many normal faults, which are in general parallel to the trend of the ranges. Most of these faults are downthrown toward the east. The largest one extends through the Cochran Mountains along Bear Canyon, in the Santiago Peak quadrangle, and thence southward along the east base of the Santiago Mountains for a distance of 8 miles (pl. 15). Along its east side Cretaceous rocks are downthrown several thousand feet (secs. R–R′ and S–S′, pl. 21).

Age of the Marathon dome.—The Marathon dome is certainly younger than the Lower and Upper Cretaceous rocks found on its flanks, and older than the gravel of possible Pleistocene age that covers the rock floors in the Marathon Basin and stream divides to the southeast of it. Its relation to the Tertiary lavas to the west is uncertain. Near Strobel siding (pl. 23), at the north end of the Del Norte Mountains, and west of Black Peak, near their south end, the lavas overlie various parts of the Upper Cretaceous. In the intervening area, near Mount Ord, in the Alpine quadrangle (pl. 23), they rest directly on the Comanche series. Moreover, the dip of the lavas is not as steep as that of the Cretaceous, thus indicating a time of disturbance and erosion before their eruption. The lavas in the Del Norte Mountains, however, dip away from the Marathon dome at angles of 10° or less, and near Strobel, where the anticline of the north end of the mountains enters the lava area, they are tilted more steeply off the flanks of the fold. Moreover, an anticline that has folded the Permian and Cretaceous rocks in the Glass Mountains extends northwestward into the Davis Mountains (pl. 22), where it also involves the Tertiary lavas. It is probable, therefore, that a considerable part of the uplift of the Marathon dome and the subsidiary folding on its flanks took place after the Tertiary volcanic eruptions. These have been dated as Eocene and Oligocene by fossils in the tuff beds.

The folds appear to be definitely older than the normal faults that break the Permian and Cretaceous rocks in the Glass, Del Norte, and Santiago Mountains, for they are cut across and are displaced by the faults. Both folding and normal faulting appear to have taken place long before the present time and probably before the Pleistocene. Upper Cretaceous rocks now found west of the Del Norte and Santiago Mountains must certainly have extended over the present area of these mountains before the folding and thrust faulting and have since been removed by erosion. The lowlands east of these mountains, underlain by uplifted and nonresistant Paleozoic rocks, owe their present form to the removal of a great thickness of Cretaceous and Paleozoic beds. The mountains themselves are erosion remnants of resistant folded Lower Cretaceous limestone. The normal faults apparently had a more direct influence on the present topography. In the Glass Mountains most of the streams appear to have been in existence before the faulting took place, but the faulting appears to have directly caused the formation of one new stream—that occupying Hess Canyon. The land forms produced by the normal faulting have, however, been greatly eroded and, except where the rocks are resistant to erosion such as the Permian dolomites in the Glass Mountains, their escarpments have been greatly modified.

Baker [41] has maintained that "the doming of the Cretaceous rocks rimming the Marathon Basin occurred long subsequent to the Laramide movements, and very possibly as late as the Lafayette." In this "latest deformation" he apparently groups folding, thrust faulting, and normal faulting. As there were two epochs of movement rather than one and as the land forms have been produced chiefly by differential erosion, it is probable that the greater part of the doming in the Marathon region took place well back in the Tertiary.

Regional relations of the post-Cretaceous structural features.—The post-Cretaceous structural features of southern trans-Pecos Texas form the north end of the Sierra Madre Oriental, typically developed in northeastern Mexico. These features are related to an area of geosynclinal deposition, which appears to be purely Mesozoic. In northeastern Mexico, south of Saltillo, Coahuila, the Sierra Madre is a single bundle of close folds of north-northwesterly trend, which face the Gulf Coastal Plain to the east. In the vicinity of Saltillo the Sierra Madre bifurcates northward.[42] The lower outer folds, composed largely of Lower and Upper Cretaceous rocks, continue north-northwestward through Coahuila into eastern trans-Pecos Texas. The main group of folds bends west as far as Torreon, in southwestern Coahuila, around the south side of the early Mesozoic positive area noted on a preceding page, then turns north-northwestward through Chihuahua, and extends as far as the Quitman and Eagle Mountains, in western trans-Pecos Texas (pl. 22).

The western group of folds arose from an area of thick Mesozoic deposition, whose outline was largely determined in Jurassic time. The intense folds occupy approximately the area of the Jurassic sea, as may be seen by comparing figure 30 and plate 22. In the Quitman and Eagle Mountains the rocks are thrown into long steep folds trending north-northwest and are broken by overthrust faults, which in Texas have carried the thick geosynclinal sequence northeastward over a thinner sequence.[43] The truncated surface of the folds is overlain by gently dipping lavas, presumably of the same early Tertiary age as those farther east, and in the intermontane areas the lavas and older folded rocks are covered by bolson deposits and lake beds, possibly of Miocene or Pliocene age.[44]

The eastern branch of the Sierra Madre enters Texas as the high, broad anticline of the Sierra del Carmen (pl. 22), which dies out south of the Marathon region. It is much broken by normal faults, and Baker [45] reports that in the Mexican part of the range a fault of great

[41] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range in trans-Pecos Texas: Texas Univ. Bull. 1753, p. 168, 1917. Baker, C. L., Date of the major diastrophism and other problems of the Marathon region, trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., vol. 12, p. 1115, 1928.

[42] King, P. B., Outline of the structural geology of the United States: 16th Internat. Geol. Cong. Guidebook 28, pl. 1, 1933. See also Kellum, W. B., Imlay, R. W., and Kane, W. C., op. cit., pp. 992–1001.

[43] Baker, C. L., Overthrusting in trans-Pecos Texas: Pan-Am. Geologist, vol. 53, p. 24, 1929.

[44] Baker, C. L., Exploratory geology of a part of southwestern trans-Pecos Texas: Texas Univ. Bull. 2745, p. 39, 1927.

[45] Baker, C. L., and Bowman, W. F., Geologic exploration of the southeastern front range of trans-Pecos Texas: Texas Univ. Bull. 1753, p. 157, 1917.

displacement drops the beds on the west. North of the Sierra del Carmen is the much smaller and narrower fold of the Santiago and Del Norte Mountains, which continues northward along the west side of the Marathon Basin. This fold, like that of the Sierra del Carmen, is faulted on its west side; the fault (the Black Peak fault) is a thrust which has carried the upthrown strata westward, or the reverse of the direction of thrusting in the western branch of the Sierra Madre. North of the Marathon Basin broad anticlines, which lie somewhat east of the north end of the Del Norte Mountains, continue with the same trend past the northeast end of the Davis Mountains to the Texas & Pacific Railway near Kent. Both the Del Norte Mountains and the folds to the north involve Tertiary lavas and may therefore be in considerable part of post-Oligocene age.

Between the western folds of the Sierra Madre in trans-Pecos Texas and their narrower branch to the east is a structurally lower area. To the north it is occupied by gently dipping lava flows of the Davis Mountain area, which are younger than a part of the strong deformation. South of the Davis Mountains, in the Chisos Mountain area, near the south end of the great bend of the Rio Grande, is a broad synclinal area in which strata of late Upper Cretaceous age are preserved and in which the base of the Cretaceous extends several thousand feet below sea level.

The Marathon dome lies east of the eastern branch of the Sierra Madre and may be considered a broad swell in its foreland. Similar broad domes lie farther southeast [45a]; the nearest one is the Serrania del Burro, on the opposite side of the Rio Grande (pl. 22). This dome has about the same structural height as the Marathon dome, but the Cretaceous cover is complete over its crest; it is elongated from northwest to southeast, parallel to the Sierra del Carmen, which flanks it on the southwest.

There is some evidence in the minor post-Cretaceous structural features that posthumous movements also occurred along Paleozoic trend lines that lay nearly at right angles to those of the Sierra Madre. The Solitario dome (pl. 22), southwest of the Marathon Basin, is known to lie on the southwestern continuation of the belt of strongly folded Paleozoic rocks exposed in the basin. The dome lies at the crest of an irregular uplift, in which Lower Cretaceous limestones are exposed as far southeast as the Terlingua quicksilver district. Between this uplift and the Marathon Basin the Paleozoic rocks are concealed by those of Cretaceous age, but the Cretaceous rocks stand much higher structurally than they do either to the southeast, in the synclinal basin of the Chisos Mountains, or to the northwest, in the lava area. They form a very broad, irregular arch of northeast trend, bounded approximately by the two 1,000-foot contour lines shown on plate 22. In a similar manner the synclinal basin of the Chisos Mountains also appears to have a northeast trend and is alined with several other synclinal basins east and west of the Santiago Mountains and south of the Marathon Basin. Both the arch connecting the Marathon dome with the Solitario dome and the line of basins southeast of it appear to follow the strike of the underlying Paleozoic rocks.

There is a possible similar relation between the arrangement of the normal faults in the area and the Paleozoic trend lines. The Glass Mountains contain many normal faults of northwest trend, which die out to the northwest and southeast and which are distributed along a belt trending east-northeast (pl. 15). They may have been formed in rocks that overlie the northwestern margin of the Marathon folded belt.[46] Similar faults are found on the northwest flank of the arch that connects the Marathon dome with the uplift of the Solitario and Terlingua districts (pl. 22).

On the east slope of the Marathon dome, on the opposite side of the Marathon Basin from the features just described, several broad arches in the Cretaceous rocks extend eastward nearly to the Pecos River. These may also have influenced the strike of the Paleozoic rocks beneath.

ECONOMIC GEOLOGY

ORE DEPOSITS

There appear to be no economically important ore deposits within the Marathon region. The occasional igneous intrusions within the area have only slightly metamorphosed the enclosing sediments. Some small-scale replacement of limestone by ore minerals has been noted in the Glass Mountains area, to the north.[47]

At several places the bedded cherts and the novaculites of the Caballos formation have been impregnated with oxides of iron and manganese along bedding planes and joints, but the amount of such material is nowhere large. At the Clark prospect, 3 miles south of Marathon on the Boquillas road, a deposit of this sort in the middle chert member of the Caballos has been explored by a shaft about 25 feet deep. Similar deposits are found to the southeast, at several places in the Woods Hollow Mountains. Three miles southwest of the Roberts ranch, at the foot of the Del Norte Mountains, the lower novaculite member, here very much jointed, has likewise been coated with iron and manganese minerals. These deposits may have been

[45a] Muir, J. M., Geology of the Tampico region, Mexico, fig. 4, p. 18, Tulsa, 1936.

[46] King, P. B., Geology of the Glass Mountains, pt. 1: Texas Univ. Bull. 3038, p. 119, 1931.

[47] Idem, pp. 127-128.

derived, as those in Arkansas appear to be,[48] by the concentration by percolating ground water of iron and manganese carbonates originally disseminated in the cherts and novaculites.

NOVACULITE

The novaculites of the Caballos formation in the Marathon region are similar to those in the Arkansas novaculite, which have been quarried for whetstones near Hot Springs, Ark. The commercial stones in Arkansas are white, are minutely porous, and have an even texture not unlike unglazed pottery. The beds that are quarried are cut by close joints that may run in as many as five or six directions. The quarried blocks and pieces are free of joints but are bounded by joint faces.[49] Some of the novaculites at Marathon have a similar texture. Most of their exposures appear to be greatly jointed, but exploration would doubtless show places where joint conditions would be favorable for extracting whetstones.

Much of the novaculite and chert of the Caballos formation and some of that from the underlying Maravillas formation is suitable for road metal or railroad ballast. Unimproved roads in the chert country are usually covered with a natural floor of siliceous fragments and remain firm and dry even in wet weather. The more jointed outcrops of these formations would yield much material by blasting and crushing. Still more could be obtained from the terrace deposits near the outcrops of the formations, for here the cherts have already been broken up and roughly sorted.

BUILDING STONE

There are no quarries in the Monument Spring and Marathon quadrangles. In places stone houses have been built from flaggy limestone and sandstone beds in the Cambrian and Ordovician succession. Some of the massive sandstones of the Tesnus formation would also serve this purpose. None of the rocks of the region would be of much value for the commercial production of building stone.

WATER SUPPLY

The Marathon Basin is relatively well watered. Numerous wells 25 to 100 feet deep obtain water from gravel sheets that cover the pediments or from the fractured and jointed bedrock immediately beneath. This underground water flows southward toward the Rio Grande, and where the drainageways cross the chert and limestone ridges in narrow water gaps the ground water rises to the surface in springs that feed short stretches of permanently flowing water. The water remains above ground for the length of the gap and sinks again beneath the surface a few miles farther down. Flowing water is found under these conditions in San Francisco Creek where it crosses the Dimple limestone hogbacks, near Haymond, and at the crossing of the Caballos novaculite hogbacks; in Peña Colorada Creek south of old Fort Peña Colorada; and in Maravillas Creek at Maravillas Gap, in the Santiago Peak quadrangle.

In the Marathon Basin there are numerous springs that are not on large watercourses. Most of these rise along the contact between the Maravillas chert and Caballos novaculite, in valleys that slope down the dip of the strata. Monument Spring, Sunshine Springs, Simpson Springs, and Peña Blanca Spring are of this type. The springs may be fed by water that has seeped into the fractured and broken Maravillas chert and has been brought to the surface in its downhill flow by encountering the more impervious novaculite. Most of the springs are used for watering stock and appear to maintain a fairly constant flow, even in dry years, although the volume of none of them is great.

Two other springs, Ridge Spring and Garden Springs, deserve special notice. They lie a few miles apart near the Boquillas road, on the northwest flank of the Dagger Flat anticlinorium. They rise on or near the trace of the Garden Springs overthrust, which is one of the folded overthrusts that characterize the Dagger Flat anticlinorium. Ridge Spring is near the intersection of this overthrust and a northwestward-trending tear fault. It has a greater discharge than Garden Springs, and flows several hundred gallons a minute. Its water is carried along pipe lines into Dagger Flat, to the south, where troughs and tanks have been set up for watering stock. The two springs appear to be related in some manner to the fracturing of the rocks near and along the overthrust and tear faults.

OIL AND GAS

Several borings have been made for oil and gas in the Monument Spring and Marathon quadrangles, but nothing except small showings have been obtained. The strongly folded strata of the Marathon Basin do not appear to possess structural features favorable for oil accumulation, even though some of the rocks, as noted below, are petroliferous.

In the area of exposure of the pre-Carboniferous rocks most of the anticlines are tightly compressed, overturned, and in part complexly faulted. Open anticlines a mile or more in width are found, however, in the Peña Colorada synclinorium, at such places as the Woods Hollow Mountains and Simpson

[48] Miser, H. D., and Purdue, A. H., Geology of the De Queen and Caddo Gap quadrangles, Ark.: U. S. Geol. Survey Bull. 808, pp. 171–172, 1929.
[49] Miser, H. D., personal communication, 1935.

Springs Mountain. The pre-Carboniferous rocks contain many bituminous layers; they are particularly well-marked in the Maravillas limestones, of Ordovician age, some of which are so impregnated with bitumen that they emit a strong fetid odor when struck. There are, however, few rocks in the section that would be good reservoir beds for oil. The Dagger Flat sandstone lies too deep in the section and is too well indurated to present any possibilities of oil, and most of the sandstone beds in the Ordovician are thin and lenticular.

In the northwestern part of the Marathon Basin some oil has been encountered in wells. A favorable showing of oil has been reported in a well drilled on the Hargus ranch, 4 miles west of Marathon, and shallow water wells in the town of Marathon are said to be contaminated by oil that does not appear to have come from storage tanks or other surface supplies. These oil showings suggest that the Gaptank formation in this district contains oil. The wells near Marathon, where the country rock is of Ordovician age, may receive their oil from the Gaptank formation by migration upward through the plane of the Dugout Creek overthrust. Wells drilled on surface structural features in the Gaptank formation, however, may pass through faults or recumbent folds beneath the surface, so that such locations are unreliable.

In the eastern part of the Marathon quadrangle the older Carboniferous rocks lie in broad, open folds, but in this region the Tesnus and Haymond formations consist predominantly of sandstone, with only minor amounts of shale, and do not offer much promise, either as a source or as a reservoir of petroleum.

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