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GEOLOGY OF THE SOUTHERN GUADALUPE MOUNTAINS TEXAS

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GEOLOGY OF THE SOUTHERN GUADALUPE MOUNTAINS TEXAS

BY

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GEOLOGY OF THE SOUTHERN GUADALUPE MOUNTAINS, TEXAS

By Philip B. King

ABSTRACT

This report deals with an area of 425 square miles in the western part of Texas, immediately south of the New Mexico line. The area comprises the south end of the Guadalupe Mountains and the adjacent part of the Delaware Mountains; it includes the highest peaks in the State of Texas. The area is a segment of a large mountain mass that extends 50 miles or more northward and southward. The report describes the geology of the area, that is, the nature of its rocks, tectonics, and surface features, and the evidence that they give as to the evolution of the area through geologic time. Incidental reference is made to the geology of surrounding regions in order to place the area in its environment.

Stratigraphy of Permian rocks.—The consolidated rocks of the area are all marine sediments of Permian age, whose total exposed thickness is about 4,000 feet. Most of the rocks contain abundant invertebrate fossils, some of which were described by B. F. Shumard in 1858. They were made famous by the classic study of G. H. Girty in 1908. The rocks consist chiefly of sandstones and limestones of various textures and structures, and are notable for their abrupt change from one rock type into another within short distances. This characteristic is believed to have been caused by the rocks being laid down on the margin of the Delaware Basin, a structural feature of Permian time. The margin lay between the more rapidly subsiding basin and a less rapidly subsiding shelf area to the northwest.

The lowest exposed formation is the Bone Spring limestone. Two deep wells indicate that it is underlain by the Hueco limestone (of Carboniferous or Permian age), and this by rocks of Pennsylvanian age. The Bone Spring is predominantly black, thin-bedded limestone to the southeast, in the basin area, but to the northwest this facies changes into gray, thicker-bedded limestone. At the margin of the basin, the formation is raised along the Bone Spring flexure, which was apparently in movement toward the close of Bone Spring time, as the succeeding beds overlap the flexed strata.

Overlying the Bone Spring limestone to the southeast, in the basin area, is the Delaware Mountain group, a mass 2,700 feet thick, consisting largely of sandstone, most of which is fine grained. The group is separable into three formations; in the lower are many beds of coarse-grained sandstone, and in the upper two a number of limestone members.

Northwestward, away from the basin, great changes take place in the rocks of Delaware Mountain age. The lower formation overlaps the older rocks along the Bone Spring flexure and is absent beyond. The lower part of the middle formation persists northwestward as a thin sandstone tongue, but the upper part changes into the Goat Seep limestone. Near its southeast edge this limestone forms a set of massive beds over 1,000 feet thick, whose form suggests that the limestone beds grew as reefs along the edge of the basin area. Farther northwest, the limestone becomes thinner bedded, and contains much interbedded sandstone.

In the same manner, the upper formation of the Delaware Mountain group changes northwestward into the thick mass of the Capitan limestone, which, like the Goat Seep was probably a reef deposit. The Capitan reaches a thickness of nearly 2,000 feet and forms some of the highest peaks and ridges of the Guadalupe Mountains. The formation does not persist far to the northwest, however, and within a few miles is replaced by the thin-bedded Carlsbad limestone. Still farther north, beyond the area studied, these limestones change in turn into the anhydrites, sandstones, and red beds of the Chalk Bluff formation.

The invertebrate fossils of the Delaware Mountain group and its correlatives exhibit considerable variety both laterally and vertically. The lateral changes are interpreted as resulting from differences in environment, and the vertical changes not only to changes in environment, but also to progressive evolution with the passage of time. Differences in environment are suggested by the contrasting nature of contemporaneous deposits; there were probably also differences in the chemistry of the water, its degree of agitation, and its depth. Available evidence indicates that the limestone reefs of the Goat Seep and Capitan formations were laid down in relatively shallow water, and that the equivalent Delaware Mountain deposits to the southeast were laid down in deeper water.

Above the Delaware Mountain group in the basin area are the anhydrites of the Castile formation, also of Permian age, which were laid down after the waters of the region were shut off from free access to the sea. No younger consolidated rocks are exposed in the area. Younger Permian formations are present farther east, however, and a greatly dissected ancient erosion surface on the mountain summits is probably the exhumed surface on which Cretaceous rocks were once deposited.

Tectonic features.—The mountain mass of the Guadalupe and Delaware Mountains is a great uplifted block of the earth's crust. Although some earlier movements took place, the movements that raised the block itself took place entirely in Cenozoic time. The structure of the block resembles that of other mountain blocks of the Basin and Range province. The east flank is a gently tilted surface which descends toward the slightly disturbed area of the Pecos valley and Llano Estacado at the east. The west flank is steep and broken by numerous faults, some of which have displacements of thousands of feet and serve to outline the west side of the mountains. West of the mountains downfaulted rocks are exposed here and there in low foothills, and beyond is a lowland, the Salt Basin, in which the bedrock is greatly depressed and is covered to a thickness of more than 1,000 feet by unconsolidated Cenozoic deposits.

The faults along the west flank of the mountains in general trend parallel to the long axis of the uplift and are either vertical or dip steeply toward the downthrow. The rocks are cut by numerous joints whose dip and trend are similar to those of

the faults. The faults appear to be tensional features, but the uplift itself was caused by vertically acting movements, whose ultimate cause may have been compressional force.

Cenozoic deposits and land forms.—The present land surface of the Guadalupe and Delaware Mountains closely resembles the structural form of the uplift, but there are actually considerable differences. These differences have resulted from degradation of the uplifted parts and deposition of sediments on the depressed parts by subaerial agencies similar to those now at work in the region. The evolution of the Cenozoic deposits and land forms is thus closely related to the upheaval of the mountain area.

The uplift took place in several stages. After the first uplift, consequent streams formed on the sloping surface of the mountain block, and some of their courses are preserved with little modification today. Material washed from the mountains after the first uplift was deposited in the nearby lower areas and is probably represented by the oldest unconsolidated rocks of the Salt Basin and Llano Estacado. These materials are probably of Pliocene age.

A second period of uplift probably took place in late Pliocene or early Pleistocene time and raised the mountains nearly to their present height. This uplift gave rise in places to new consequent streams, which flowed along fault troughs. It also caused renewed degradation in the mountains. The resistant rocks of the Guadalupe Mountains were incised by deep canyons, and the less resistant rocks of the Delaware Mountains were worn down to a plain of about the same altitude as the present canyon bottoms.

In Pleistocene time, perhaps as a result of fluctuation in climate, a part of this lower country was buried under a sheet of gravel. Deposition of coarse-grained deposits took place west of the mountains also, partly as a result of climatic change but mainly in response to the uplift of the adjacent mountains. During this period the Salt Basin was probably covered by standing water, for the upper surface of the fine-grained deposits that form its floor has a conspicuous levelness, such as could not have been caused by streams or subaerial agencies. Faint beach ridges present in the Salt Basin indicate the existence of a lake in late Pleistocene time.

In late Pleistocene time, the area was again disturbed. Renewed movements of small amount took place along some of the faults on the west flank of the mountains, and some of the previously formed unconsolidated deposits were displaced. The disturbance also caused renewed dissection of the land surfaces. Erosion and sedimentation that followed this time of disturbance have shaped the mountains into their present form.

Economic geology.—The main economic interest of the area is indirect. Knowledge of the area is valuable to petroleum geologists because features exposed at the surface here are analogous to features to the east known only from drilling in the oil fields. No oil or gas has been found in the area itself, but the area has not been adequately tested by wells. There is a slight possibility that oil or gas may be discovered in the deeper formations.

The other economic resources of the area are meager. Some building stone, road material, and salt have been produced. In a few places are small mineral deposits, but no ore has been mined from them. The resource most valued by the local residents is ground water, for the region is generally dry and without permanent streams. Here and there ground water issues as springs, whose intakes are the higher parts of the area, where rainfall is greater than in the lower parts.

INTRODUCTION

THE PERMIAN PROBLEM

The Permian system of the southwestern United States has been until recently one of the intriguing but little known subjects of American stratigraphy. In the latter half of the nineteenth century after the western United States was settled, the "red bed" sections of the Permian were studied and reported on by many geologists, but up to 1920 the existence of a contemporaneous marine sequence in western Texas and southeastern New Mexico was little appreciated. Since that year the discovery of extensive oil fields and potash beds in this region gave an impetus to the study of the Permian rocks, and furnished the geologist with records of hundreds of drill holes from which to deduce the nature of the strata not exposed at the surface. At the same time geologists have studied the rocks in the outcropping areas, and have compared them with the strata encountered by drilling.

Much remains to be done in order to understand the history of Permian time in the region. The physical and chemical conditions that caused the deposition of the various and often complexly related deposits need to be better understood. More of the fossils of the rich and interesting marine faunas should be described, and the relations of the fossils to their environments should be determined. Further, a satisfactory scheme of correlation is needed, and also a subdivision into series that will express the contemporaneity of strata in different areas. One useful contribution to the solution of these problems is the detailed study of sequences of rocks exposed at the surface in the different mountain ranges of Texas and New Mexico.

This report deals with one such sequence of rocks in western Texas, the one exposed in the southern Guadalupe Mountains (for location, see fig. 1). Here, the Permian rocks are magnificently exposed, to a thickness of about 4,000 feet (for a typical exposure, see pl. 1). They are all of marine origin, and belong to the middle part of the system, with the base concealed and the top absent. Overlying and underlying beds, however, are found in nearby areas.

PRESENT INVESTIGATION

Field work on which this report is based was carried out mainly during eight months in 1934 and 1935, during which time I was assisted by H. C. Fountain. Expenses for this work were paid by a grant from the Penrose bequest of the Geological Society of America. Some additional field work was done in subsequent years, especially in the spring of 1939. In 1945 and 1946, I studied a series of vertical aerial photographs made by the U. S. Army, covering the southern Guadalupe Mountains and surrounding areas. This study made possible a final revision of the geologic mapping.

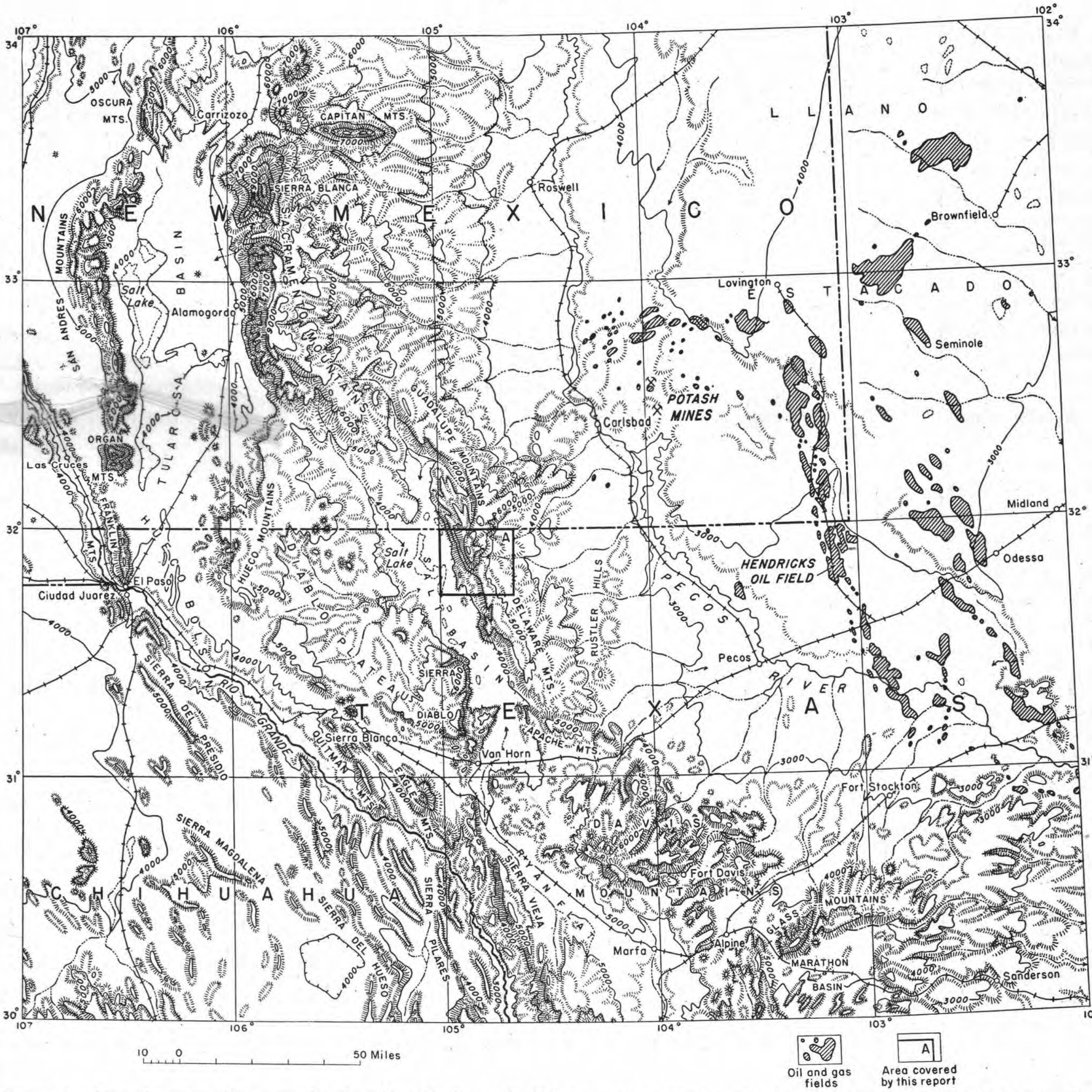

FIGURE 1.—Map of western Texas, southeastern New Mexico, and adjoining area in Mexico, showing topography, political divisions, oil and gas fields, and other features. Compiled from various sources, including U. S. Geological Survey's topographic maps of Texas and New Mexico (1 : 500,000), oil and gas map of Texas (1 : 750,000), and American Geographical Society's Chihuahua sheet, millionth map of Hispanic America (1 : 1,000,000).

As a result of the investigations between 1934 and 1946, an area 25 miles long and 18 miles wide, covering 425 square miles, has been surveyed geologically (pl. 3).

Most of the fossils mentioned in this report were collected by H. C. Fountain in 1934 and 1935, to obtain which he spent many hours of patient labor with the hammer. The excellence of the specimens that he obtained is a testimony of his devotion to the work.

The greater part of the fossils collected were studied by the late G. H. Girty of the Geological Survey, who also visited our party in the field for three weeks. The fusulinids have been studied by C. O. Dunbar of Yale University and J. W. Skinner of the Humble Oil Co., and the cephalopods by A. K. Miller and W. M. Furnish of the State University of Iowa. The results of the work of Dunbar and Skinner,[1] and of Miller and Furnish,[2] have been published; but the information that was supplied by Girty is published for the first time in this report.

Some thin sections of sandstones from the region were studied by Ward Smith, thin sections of volcanic

[1] Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas, in The Geology of Texas, vol. 3, Texas Univ. Bull. 3701, pp. 519–825, 1937.

[2] Miller, A. K., and Furnish, W. M., Permian ammonoids of the Guadalupe Mountain region and adjacent areas: Geol. Soc. America Special Paper 26, 1940.

ash were studied by C. S. Ross, and insoluble residues of limestones by Charles Milton, all of the Geological Survey. Chemical analyses of limestones, of volcanic ash, and of other rocks were made by K. J. Murata and E. T. Erickson in the chemical laboratory of the Geological Survey.

The data in the chapters on tectonics and geomorphology of the southern Guadalupe Mountains are incidental results of the stratigraphic investigation; I believe they comprise information of so much interest, and are so useful a contribution to the knowledge of the Basin Ranges, that I give them in detail. In preparing these chapters, I have been aided by consultation with W. H. Bradley, James Gilluly, and W. W. Rubey of the Geological Survey.

Many of the pictures in the report are based on pencil drawings which I executed as accurately as possible in the field. I believe that these drawings bring out many geological features more accurately than photographs. Some of the views, especially plates 4 and 5, form a series of panoramas around the escarpments of the southern Guadalupe Mountains.

This report was largely written between 1936 and 1938, but was extensively revised in 1940. Publication of the report by the Geological Survey was postponed during the period of World War II. A preliminary description of the stratigraphic results was included in a general summary of the Permian of west Texas and southeastern New Mexico, published in 1942, and a preliminary edition of the geologic map was published in 1944.[3] Because of the fact that a general summary of the Permian was published in 1942, only incidental mention is made of regional matters in this report, and main emphasis is given to descriptions of the local geology.

Since 1940, only minor revisions have been made in the present report, and it may be that some geological publications or discoveries made since that date, which are pertinent to the subject, have been overlooked.

ACKNOWLEDGMENTS

As may be seen from the preceding statement, I have had the aid of many collaborators and advisers through the years in which this report was in preparation. In addition to those mentioned, I have received aid from many others not named, especially on the staff of the Geological Survey and among the petroleum geologists stationed in west Texas and southeastern New Mexico. To all these persons, I wish to extend thanks and appreciation.

During the field work, A. J. Williams, Wallace Pratt, the Grisham-Hunter Corporation, and other landowners allowed access to their properties, and were helpful in many other ways. With J. T. Smith and Walter Glover, both residents of the region for many years, I have had many interesting conversations, during which I learned much regarding the local history and geography.

Thanks are also extended to the Edgar Tobin Aerial Surveys and to the U. S. Army Air Corps for supplying small collections of oblique aerial photographs of the southern Guadalupe Mountains, and for permitting the publication of two of them, which appear as plates 1 and 18 of this report. In the preparation of the topographic base for the eastern part of the area shown on the geologic map (pl. 3) use was made of surveys by the Humble Oil Co., the El Paso Natural Gas Co., and the Pasotex Pipe Line Co. The information supplied by these organizations is gratefully acknowledged.

My list of acknowledgments would not be complete if I failed to mention my wife, Helen Carter King, whose inspiration, both as a field companion and as a critic of this manuscript, has done much to bring it to completion.

PHYSICAL FEATURES OF THE REGION

EL CAPITAN

Bartlett,[4] in 1850, when journeying by wagon from San Antonio to El Paso, wrote:

> Our road led in a direction nearly west, towards the bold head of the great Guadalupe Mountain, which had been before us some eight or ten days. This is a most remarkable landmark, rising as it does far above the surrounding plain. The sierra which ends with it comes from the northeast. It is a dark, gloomy-looking range, with bold and forbidding sides, consisting of huge piles of rocks, their debris heaped far above the surrounding hills. As it approaches its termination the color changes to a pure white, tinted with buff or light orange, presenting a beautiful contrast with the other portions of the range, or with the light blue of the sky beyond, for in this elevated region the heavens have a remarkable brilliancy and depth of color.

(Views of the southeast side of the Guadalupe Mountains, appearing much as Bartlett saw them, are shown on plate 4).

The "head of the great Guadalupe Mountain" is still as impressive an object to the traveler as when Bartlett first saw it. Soon after leaving Carlsbad, Van Horn, or El Paso, the motorist discovers it in view before him, 50 miles or more away. When at length he draws closer, his road, following the course of the old caravan road that came into existence at the close of the Mexican War, winds through the hills and canyons of Guadalupe Pass with the headland rising above it to the north.

[3] King, P. B., The Permian of west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 26, pp. 535–763, 1942. King, P. B., and Fountain, H. C., Geologic map of southern Guadalupe Mountains, Hudspeth and Culberson Counties, Texas: U. S. Geological Survey Oil and Gas Investigations, Preliminary map 18, 1944.

[4] Bartlett, J. R., Personal narrative of explorations and incidents in Texas, New Mexico, California, Sonora, and Chihuahua, connected with the United States and Mexican Boundary Commission, during the years 1850, 1851, 1852, and 1853, vol. 1, pp. 117–118, New York, D. Appleton & Co., 1854.

From the road, tier after tier of flat-lying sandstone beds extend upward on barren slopes. On them, as on a pedestal, reposes a monumental crag of white limestone, forming a sheer cliff a thousand feet high (pl. 1). To the modern traveler, as to the Mexicans of the last century who dug for salt in the flats west of the headland, the crag is truly El Capitan, the leader or landmark.

The high peaks at the south end of the Guadalupe Mountains have been given a number of names at different times, the use of which has been indefinite and conflicting. The terminology followed here, which is that adopted by the U. S. Geographic Board, is to call the headland El Capitan, and the higher peak a short distance to the north Guadalupe Peak. However, Richardson (1904) and Girty (1908), in their geological reports, called the headland Guadalupe Point and used El Capitan for the higher peak to the north. Their terminology has been followed in most subsequent geological writings. In addition, the higher peak is commonly known to the local residents as Signal Peak, a term that appears to be of relatively recent origin. Use of the name El Capitan for the headland rather than for the higher peak seems to agree better with the original Spanish meaning of the term.[5]

GUADALUPE MOUNTAINS

El Capitan lies near the center of the area here described, and is the southern extremity of the Guadalupe Mountains, a limestone upland that expands like a wedge toward the north (fig. 2). The eastern side of the upland is the forbidding escarpment with northeast trend described by Bartlett, and is appropriately termed the Reef Escarpment.[6]

The western side of the wedge, whose trend is somewhat west of north, has an even more impressive face (as shown on plate 5). It is only from this direction, Shumard [7] observed

> that these mountains can be contemplated in all their grandeur. Here extends an unbroken line of vertical precipices from two to three thousand feet in height, the faces of which are so smooth as to be accessible only a few hundred feet above the base. The abrupt faces of these cliffs pursue a general course parallel to the axis of upheaval of the mountains, which present the appearance of having cleft vertically through their centers and the western halves removed.

Between the two escarpments, the interior of the wedge is a pine-covered, rolling upland, divided into many parts by deeply incised canyons. In the southern end of the wedge, the uplands exceed 8,000 feet in altitude above sea level, and culminate in Guadalupe Peak, which rises to 8,751 feet. This is the highest point in the State of Texas. Beyond the Texas-New Mexico boundary, about 7 miles north of Guadalupe Peak, the summits are lower, and at some distance farther north and northeast the range fades out in the Pecos Valley.

The Guadalupe Mountains form the northern half of a great, eastward-tilted block of the earth's crust more than 100 miles long and about half as wide (fig. 2). The southeast-facing Reef Escarpment, which extends diagonally across the tilted surface, follows an ancient tectonic and stratigraphic axis, along which the limestones of the Guadalupe Mountains come to an end. To the southeast, where the limestones are absent, the tilted block forms a lower series of broken sandstone plateaus, known as the Delaware Mountains.

On the west side of the tilted block, the mountains break off in steep escarpments, of which the precipices described by Shumard are a part. The escarpments slope toward the Salt Basin, a depression with no outlet to the sea, whose lower part stands at an altitude a few feet above 3,600 feet, or nearly a mile below the summit of Guadalupe Peak not far away. Extending westward from the lowest benches of the escarpment toward the saline lakes and alkali flats that dot the central floor of the basin, is a great alluvial apron composed of detritus washed down from the mountains. Rising from the alluvium in places are low rock ridges, such as the Patterson Hills southwest of El Capitan (pl. 5, *A*). The rocks in the ridges are the same as those high in the mountains to the east, but instead of dipping gently eastward as in the mountains, they dip more steeply westward beneath the basin.

The main tectonic feature of the Guadalupe and Delaware Mountains is thus a great arch whose steepest dip is on its west flank. The archlike form, however, is greatly complicated by faulting (as may be seen in the structure sections of plate 3). The west base of the mountains is followed in most places by one of several major faults, whose presence is shown in part by outcrops of down-dropped rocks to the west, and in part, where alluvium buries the down-thrown side, by the even base line of the mountains. Between the west-tilted rocks of the Patterson Hills and the east-tilted rocks in the mountains near El Capitan are fault blocks in which the strata are more deeply depressed than in those on either side. The crest of the arch has thus collapsed by the sinking of its keystone. The rocks within the southern Guadalupe Mountains for several miles east of the major faults at the west base of the mountains also are faulted, but still farther eastward, the only sign of disturbance is the gentle tilting of the rocks to the east.

The surface configuration of the region, with its mountains, foothills, and flanking basin on the west, is thus closely related to the tectonic configuration

[5] For a discussion of geographic terminology, see Lang, W. B., The Permian formations of the Pecos Valley of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., vol. 21, pp. 839–844, 1937.

[6] King, P. B., The Permian of west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 26, p. 553, 1942.

[7] Shumard, G. G., Observations on the geological formations of the country between the Rio Pecos and Rio Grande, in New Mexico: St. Louis Acad. Sci. Trans., vol. 1, p. 280, 1858 [1860].

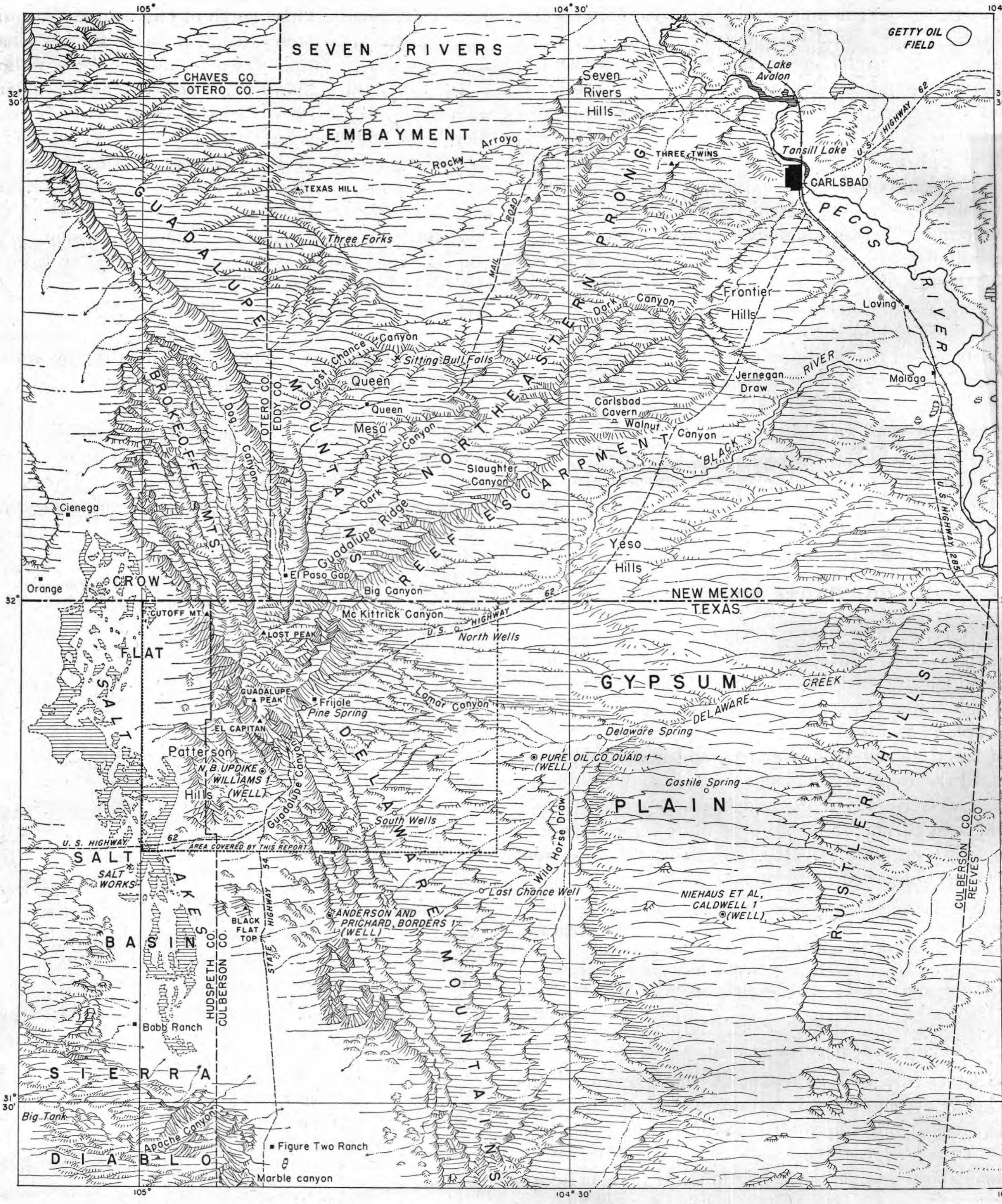

FIGURE 2.—Map of Guadalupe Mountains and vicinity, showing topographic features. Compiled from various sources, including maps by U. S. Geological Survey and U. S. Forest Service.

duced by uplift and faulting. The original tectonic configuration has been somewhat modified by erosion of the higher parts of the area and by deposition in the lower parts, but these modifications have been so small that they suggest the uplifting and faulting are of relatively recent age. Some of the movements are certainly of Quaternary age, for unconsolidated deposits of the alluvial apron are disturbed and faulted near the base of the mountains. However, the alluvial apron is composed of fragments washed from high mountains, and these mountains were formed by movements older than those just noted. How old these earlier movements are is a matter for conjecture; they may be of later Tertiary age.

STRATIGRAPHY OF PERMIAN ROCKS

HISTORICAL SKETCH [8]

SHUMARD'S DISCOVERY

The first observations on the geology of the Guadalupe Mountains were published during the period of exploration that accompanied the opening up of the western country after the Mexican War, and were an outgrowth of surveys by Army engineers to determine a practicable route for a railroad to the Pacific coast. In 1854, the party of Captain John Pope laid out a route through Guadalupe Pass.[9] In the following year, when Pope returned to the region to investigate more fully the prospects for artesian water near the route, his party included Dr. G. G. Shumard,[10] a geologist who had gained experience in western explorations as a member of several previous expeditions.

Like Bartlett's party five years before, that of which Shumard was a member approached the mountains from the east. The foot of the Guadalupe Mountains was reached at "the canyon known as the Pinery" (Pine Spring Canyon). This he explored for about a mile, collecting fossils from the white limestone "remarkably rich in organic remains" that formed its rugged sides. Continuing farther, the party descended into Guadalupe Pass, and Shumard saw that the white limestone reposed in heavy beds upon a great thickness of flat-lying sandstones. He found that the section contained the following members in descending order (pl. 1): [11]

	Feet
1. Upper, or white limestone	1,000
2. Dark-colored thinly laminated and foliated limestone	50–100
3. Yellow quartzose sandstone	1,200–1,500
4. Black thin-bedded limestone	500

Shumard's notes indicate that in the field he regarded the fossils collected from the white limestone and underlying rocks as of Carboniferous (Pennsylvanian) age, but his brother, B. F. Shumard,[12] who later examined the material, was impressed with its dissimilarity to the Carboniferous faunas and observed that many of its brachiopods and other forms closely resembled those of the Permian system that had been established in Europe 17 years before. Moreover, it included the genus *Aulosteges* "that had not been recognized in formations below the Permian."

WORK OF GIRTY AND RICHARDSON

Shumard's interesting discovery received little notice for many years. There were few visitors in this region, which had become isolated in the turbulent days that followed the Civil War. Except for Tarr[13] of the Texas Geological Survey, who made a brief trip to the mountains in 1890, the next geologists to visit and describe the region were G. H. Girty and G. B. Richardson, of the United States Geological Survey, in 1901 and 1903.

Girty's collecting trip to the mountains was brief but wonderfully fruitful. Large amounts of fossil material were obtained from the white limestone that forms the slopes of Guadalupe Peak (member 1 of Shumard's section, pl. 1), which was named the Capitan limestone by Richardson.[14] Numerous fossils were collected also from the underlying dark limestone (member 2). The collections were more meager, however, from the underlying sandstone and basal black limestone (members 3 and 4), which together were named the Delaware Mountain formation by Richardson.[15] In his monumental work on the Guadalupian fauna, Girty[16] described the fossils obtained during this visit and those collected by Richardson and others in nearby areas. By his work he expanded Shumard's original assemblage of 54 species to 326 species without, as he says, doing full justice to the richness of the fauna.

With this more extensive material before him, Girty was able to confirm Shumard's original opinion as to the unusual quality of the fauna. He was impressed

[8] Under this heading, only the main ideas that have been held in the past regarding the rocks of the Guadalupe Mountains can be mentioned, and not all the papers published on the area are cited. A complete list of papers on the area, with a summary of their conclusions, is given in the annotated bibliography at the end of this report.

[9] Pope, John, Report of exploration of route for the Pacific Railroad near the 32nd parallel from the Red River to the Rio Grande: U. S. Pacific Railroad Exploration, 33d Cong., 2d sess., S. Doc. 78, vol. 2, pp. 1–95, 1855.

[10] Shumard, G. G., op. cit., pp. 278–282.

[11] Shumard, G. G., op. cit., p. 280.

[12] Shumard, B. F., Notice of new fossils from the Permian strata of New Mexico and Texas: St. Louis Acad. Sci. Trans., vol. 1, pp. 290–297, 1858 [1860]; Notice of fossils from the Permian strata of Texas and New Mexico: op. cit., pp. 387–403, 1859 [1860].

[13] Tarr, R. S., Reconnaissance in the Guadalupe Mountains: Texas Geol. Survey Bull. 3, 1892.

[14] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, p. 41, 1904.

[15] Idem., p. 38. The Delaware Mountain formation is now classed as a group, but with the basal black limestone separated from it and placed in the Bone Spring limestone.

[16] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, 1908. The term Guadalupian as used by Girty embraces approximately the Leonard and Guadalupe series of present terminology.

with its dissimilarity to any of those in the Carboniferous of the Mid-continent region, or even elsewhere in North America. Although he emphasized the "very individual facies" of the fauna, like Shumard he found the only closely comparable fossils among those described from the Permian of Europe and Asia.[17]

Richardson's reconnaissance of the northern trans-Pecos area furnished some evidence on the relations of the beds containing the Guadalupian fauna. To the east, they were overlain by unfossiliferous gypsum and red beds.[18] To the west, he found an extensive limestone formation, the Hueco,[19] considered by Girty to be of Pennsylvanian age, which apparently passed beneath the base of the Guadalupian succession, although the actual connection was concealed beneath the unconsolidated deposits of the Salt Basin. Some hint of an extension to the southeast of the beds of the Guadalupe Mountains was given by small fossil collections made by R. T. Hill in Glass Mountains, over a hundred miles away (fig. 1).[20] This was confirmed some years later by the important researches of Udden [21] and Böse.[22]

To the east, however, beyond the Llano Estacado, red beds and other strata quite unlike those of the Guadalupe Mountains were being assigned to the Permian by various authors, either on account of scanty marine faunas as in Kansas, or because of vertebrate remains as in central Texas. The manner in which these joined or were overlapped by the beds of the Guadalupe Mountains remained a matter for conjecture. Nearer at hand, in the mountains of New Mexico northwest of the Guadalupes, the higher Paleozoic rocks were found to be the red beds and limestones of the Manzano group.[23] Its fossils, although of later Paleozoic age, did not resemble those of the Guadalupe Mountains, and the physical relations between the two groups of strata were unknown.

The well-marked lithologic units of the section in the southern Guadalupe Mountains seemed to offer no obstacles to the tracing of them into the adjoining, problematical regions, yet many stratigraphic puzzles developed as soon as the beds were followed for any distance away from their type sections. Thus, upon the completion of the Texas work, Richardson [24] attempted to trace them northwestward toward the area of the Manzano group and found that

> the massive Capitan limestone merges along the strike into thin-bedded limestone and sandstone, the limestone element finally disappearing altogether or being represented by thin, local beds. * * * Northward from Guadalupe Point, fossiliferous horizons become rare in the Capitan, and the collections * * * brought in tend to show that with the change in lithology the fauna also changes in character, so that practically nothing of the typical Guadalupian fauna is left.[25]

As a result of these discoveries, Girty concluded in 1909 that "the evidence is such as to demand consideration, if not adoption, of the hypothesis that the facies of the Guadalupian fauna is a regional matter, denoting not time relations, but geographic relations." [26]

SEARCH FOR OIL IN THE LLANO ESTACADO

The puzzles that developed in correlating the Permian rocks of the Guadalupe Mountains, and in explaining their strange variations in facies, arose in part from the impossibility of deducing what lay beneath the surface in the extensive areas covered by younger deposits. Much light was soon shed on this question by drilling. During the second and third decades of the century, there was a tremendous expansion in the development of petroleum resources in the southwestern United States. The Llano Estacado area, east of the Guadalupe Mountains and west of the previously discovered oil fields of central Texas, received its share of wildcat drilling. As exploration continued oil was found at many places in beds of Permian age. At about the same time, beds containing potash minerals were discovered in the higher parts of the wells,[27] and considerable exploration was begun for this important resource.

When the first wells were drilled, the Paleozoic rocks beneath the Mesozoic and Tertiary cover of the plains were assumed to be warped down in a broad, gentle, and relatively simple synclinorium.[28] Thus, east of the plains, the Pennsylvanian and Permian strata were seen to dip westward, and on their western side the Permian strata rose again toward the Guadalupe Mountains and other ranges of the trans-Pecos region. The early drilling in the basin disclosed a sequence of red beds, salt, and anhydrite, which was interbedded below with dolomites. Deeper borings on the east side showed that these beds were underlain by Pennsylvanian rocks.[29] To the west, near the Pecos River, deep wells penetrated sandstones of the Delaware Mountain group beneath the salt and anhydrite beds.[30]

As drilling progressed, it was found that the sequences in different parts of the region were unlike in

[17] Girty, G. H., op. cit., p. 39.
[18] Richardson, G. B., op. cit., pp. 43–45.
[19] Richardson, G. B., op. cit., pp. 32–38.
[20] Girty, G. H., op. cit., pp. 26–27.
[21] Udden, J. A., Notes on the geology of the Glass Mountains: Texas Univ. Bull. 1753, pp. 3–59, 1918.
[22] Böse, Emil, The Permo-Carboniferous ammonoids of the Glass Mountains and their stratigraphical significance: Texas Univ. Bull. 1762, 1919.
[23] Lee, W. T., and Girty, G. H., The Manzano group of the Rio Grande valley, New Mexico: U. S. Geol. Survey Bull. 389, 1909.
[24] Richardson, G. B., Stratigraphy of the upper Carboniferous in west Texas and southeast New Mexico: Am. Jour. Sci., 4th ser., vol. 29, pp. 325–337, 1910. See also, Beede, J. W., The correlation of the Guadalupian and Kansas sections: Am. Jour. Sci., 4th ser., vol. 30, pp. 131–140, 1910.
[25] Girty, G. H., The Guadalupian fauna and new stratigraphic evidence: New York Acad. Sci. Annals, vol. 19, p. 138, 1909.
[26] Girty, G. H., idem., p. 141.
[27] Udden, J. A., Potash in the Texas Permian: Texas Univ. Bull. 17, 1915.
[28] Hoots, W. H., Geology of a part of western Texas and southeastern New Mexico, with special reference to salt and potash: U. S. Geol. Survey Bull. 780, pp. 113–114, pl. 17, 1925.
[29] Udden, J. A., The deep boring at Spur: Texas Univ. Bull. 363, pp. 74–75, 1914.
[30] Hoots, W. H., op. cit., pl. 16.

character, and that the configuration of the synclinorium was far from regular. Thus, in 1926, oil was discovered in the Hendrick field, Winkler County (fig. 1), about 125 miles east of the Guadalupe Mountains, in dolomite that stood high above its anticipated position. It had previously been assumed that this district lay near the axis of downwarping.[31]

A short distance west of the Hendrick oil field, the oil-bearing dolomites were not encountered by the drill. Instead, after passing through salt and anhydrite, the sandstones of the Delaware Mountain group were reached at a much greater depth than the oil-bearing dolomites. East of the field, much anhydrite was interbedded with the dolomites, and no trace of the Delaware Mountain group could be found. Drilling north and south of the new field made it even clearer that the Delaware Mountain sandstones were confined to a relatively restricted area within the major synclinorium, forming a depression now known as the Delaware Basin (fig. 11).[32] The higher-standing zone of dolomites that bounded the formation on the east in Winkler County was found to curve westward toward the limestones of the Guadalupe Mountains on the north and the Glass Mountains on the south.

What was the nature of this zone, and what was its relation to the Delaware Mountain group on the one side and to the interbedded dolomite and anhydrite on the other? For answer, the geologists who had been studying the well records turned to the outcrops in the Guadalupe Mountains, for here, lying at the surface, there seemed to be the stratigraphic analog of the oil-bearing beds in Winkler County and elsewhere.

RECENT WORK IN THE GUADALUPE MOUNTAINS

Richardson's later observations on the changes in lithologic and faunal facies in the Guadalupe Mountains were amplified by the work of Baker[33] in 1918 and of Darton and Reeside[34] in 1925. Baker discovered that the thick succession of sandstones of the Delaware Mountain group (member 3 of Shumard's section, pl. 1), well developed to the south, does not extend far to the north in the Guadalupe Mountains (pl. 7, *A*). Instead, its lower part passes out by overlap against a surface of unconformity that develops abruptly not far north of El Capitan between it and the underlying black limestone (member 4). The upper part "passes to the north into limestone only a little less massive than the overlying Capitan,"[35] the Goat Seep limestone of the present paper. Beyond the point where the sandstone loses both its lower and upper beds, only an inconsequential stratum of sandstone could be found in the middle of a succession of limestones.

The work of the geologists who had sought an answer to subsurface problems by studying the outcrops was directed particularly to the structure of the overlying Capitan limestone (member 1 of Shumard's section, pl. 1) and its relation to adjacent beds. It was found that this formation, like the oil-bearing dolomites to the east, stands at a greater height than do the upper beds of the Delaware Mountain group to the southeast. However, along the Reef Escarpment which bounds the Guadalupe Mountains on the southeast, it was found that the Capitan comes to an abrupt end, with its beds sweeping down in great curves to interfinger with the lower-lying sandstones (as shown in sections on plate 17). Northwestward also, within a few miles, the massive limestones merge with well-bedded limestones, now called the Carlsbad limestone. Farther north, as at Rocky Arroyo in the northeastern Guadalupe Mountains, Baker[36] and Darton and Reeside[37] observed that the well-bedded limestones interfingered in turn with beds of anyhydrite. The Capitan limestone was thus found to occur only in a narrow belt that followed the northeastward trend of the Reef Escarpment, rising above contemporaneous sandstone deposits to the southeast and forming a barrier between them and the thin-bedded limestones and the anhydrites to the northwest.

With these stratigraphic relations in mind, many resemblances became evident between the Capitan limestone and the barrier reefs now being built by corals and other lime-secreting organisms along the coasts of tropical seas. The interpretation of the Capitan limestone as a reef deposit was announced by Lloyd[38] in 1929, and was followed in papers by Crandall,[39] and Blanchard and Davis,[40] later in the same year, as well as by Cartwright[41] in 1930. The reef was assumed to extend as a curving barrier around the Delaware Basin from the Guadalupe Mountains through Winkler County to the Glass Mountains (fig. 14*B*).

It should be noted that these conclusions although now generally accepted, and accepted in this report, were based very largely on the lithologic character of the beds and on their stratigraphic relations to one an-

[31] Willis, Robin, Structural development and oil accumulation in Texas Permian: Am. Assoc Petroleum Geologists Bull., vol. 13, fig. 3, p. 1039, 1929. Ackers, A. L., de Chiccis, R., and Smith, R. H., Hendrick field, Winkler County, Texas: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 923–944, 1930.

[32] Willis, Robin, op. cit., p. 1034. Cartwright, L. D., Transverse section of Permian basin, west Texas and southeast New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 14, fig. 1, p. 971, 1930. Originally called the Delaware Mountain Basin, but the shorter term seems preferable, and has come into general use.

[33] Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, pp. 112–117, 1920.

[34] Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 413–428, 1926.

[35] Baker, C. L., op. cit., p. 114.

[36] Baker, G. L., op. cit., p. 115.

[37] Darton, N. H., and Reeside, J. B., Jr., op. cit., p. 419.

[38] Lloyd, E. R., Capitan limestone and associated formations: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 645–648, 1929.

[39] Crandall, K. H., Permian stratigraphy of southeastern New Mexico and adjacent parts of western Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 936–937, 1929.

[40] Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 980, 1929.

[41] Cartwright, L. D., op. cit., pp. 977–979.

other, and that in the work done by Lloyd and his contemporaries, little study was made of the fossils. The fossils in the Capitan described by Girty included no corals such as are abundant in modern reefs, and the fauna as a whole did not seem to express a particular specialization to a reef environment. Girty, however, had described a number of massive, lime-secreting sponges from the formation, and Ruedemann,[42] during a visit to the region in 1927, had found in it and the associated Carlsbad limestone the remains of calcareous algae. One object of the present investigation was to obtain further information on these unsettled problems.

GENERAL FEATURES OF STRATIGRAPHY

Previous geologic studies in the Guadalupe Mountains, as summarized in the preceding section, have indicated that the strata change greatly in character from southeast to northwest across the region. In the southeast, resting on the basal limestones (member 4 of Shumard's section, pl. 1), that are now called the Bone Spring limestone, is a great thickness of sandstone—the Delaware Mountain group. Northwestward, the sandstone thins nearly to disappearance, partly by overlap of the lower beds on the upraised surface of the Bone Spring limestone, and partly by intergradation of the higher beds with different limestone masses, including those of the Capitan limestone. The Capitan itself has been shown to occupy a zone only a few miles wide, northwest of which it is replaced by thinner-bedded limestone, anhydrite, and other rocks. These relations have suggested that the Capitan limestone is a reef deposit comparable to modern barrier reef deposits.

The present investigation has confirmed and amplified these observations. The complex stratigraphy of the southern Guadalupe Mountains was studied by detailed mapping, by measuring numerous stratigraphic sections, and by making fossil collections. The stratigraphic sections were spaced closely enough to trace the rock units involved through successive sections across the area.

The areal relations are shown on the geologic map, plate 3. The stratigraphic sequences in the northwest and southeast parts of the area are so different that it is necessary to explain them in two separate columns on the map. Basic stratigraphic data are also shown on the sheet of correlated stratigraphic sections, plate 6. Other basic data are presented on the structure sections through the limestone mass of the Guadalupe Mountains (pl. 17). On these structure sections only the rocks that can be seen on escarpments and canyon walls are shown, and their hypothetical underground extensions are omitted.

As shown on section *K–K′*, plate 17, the deepest exposures—which also give the most complete idea of the stratigraphic changes—are those on the escarpments at the western side of the mountains. The other sections shown on plate 17 lie farther northeast and show only parts of the upper beds. The long stratigraphic sections shown on plate 6 were measured on this western escarpment, and the shorter sections elsewhere in the area.

These basic stratigraphic data are assembled, summarized, and interpreted on plate 7. Plate 7, *A* is a stratigraphic diagram extending from northwest to southeast across the area, on which the structure of the rocks of the area is shown as it is assumed to have existed at the close of Permian sedimentation. Plate 7, *B* is a group of similar diagrams, each for a successive stage of the Permian, which show the manner in which the structure of the rocks is assumed to have developed.

The stratigraphic features shown on plate 7, *A* are in a vertical plane, and therefore are two-dimensional. A part of the stratigraphic information on the area must be of this two-dimensional sort, as it is obtainable only on the west-facing escarpment of the mountains. For the higher beds, however, exposures in the canyons east of the escarpment, and in downfaulted areas west of the escarpment, are so numerous that one can express their stratigraphic features in a horizontal, as well as a vertical plane. For them, three-dimensional stratigraphic information is therefore available. This is summarized in three maps, figures 6, 8, and 10, for successive stages of the higher beds. On these maps, the boundaries of the different facies are shown by lines. Note that the information is least complete for the oldest beds (fig. 6) and most complete for the youngest (fig. 10).

TERMINOLOGY

The complex stratigraphic relations of the Permian rocks of the Guadalupe Mountains are difficult to express in a workable scheme of terminology. Such terminology must take into account, not only the rock units, which interfinger with one another in a complex manner and are likely to be of small geographic extent, but also time units, which from place to place include dissimilar rock units of the same age. The terminology as now worked out attempts to make use of both time and rock classifications.

The first subdivision of the section into rock units was made by Richardson in 1904 and although his original names still remain, later authors have redefined them and have introduced many new ones. The newly named units are subdivisions of the original rock units, or are rock units that were not known at the time the original classification was made. Some of the more important changes that have been made since Richard-

[42] Ruedemann, Rudolf, cited in King, P. B., and King, A. E., The Pennsylvanian and Permian stratigraphy of the Glass Mountains: Texas Univ. Bull. 2801, p. 139, 1928. Ruedemann, Rudolf, Coralline algae, Guadalupe Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1079–1080, 1929.

EL CAPITAN FROM SOUTH.

The cliff of El Capitan lies near the center, with Guadalupe Peak concealed behind it. Numbers refer to original section by Shumard. 1, White limestone (Capitan); 2, upper dark limestone (Pinery); 3, yellow sandstone (Delaware Mountain); 4, basal black limestone (Bone Spring). Letters refer to Quaternary deposits. *a*, Older slope deposits; *b*, younger slope deposits. Aerial photograph by U. S. Army Air Corps.

A. McKITTRICK CANYON TO PINE TOP MOUNTAIN.

B. RADER RIDGE TO EL CAPITAN.

PANORAMIC VIEWS OF REEF ESCARPMENT ON SOUTHEAST SIDE OF GUADALUPE MOUNTAINS.

For locations, see plate 2. The escarpment marks the southeastern edge of the Capitan limestone. In front are plains cut on the Cherry Canyon and Bell Canyon formations of the Delaware Mountain group, which are mantled by Quaternary gravels. *Qoa*, Older alluvial deposits; *Pcb*, Carlsbad limestone; *Pc*, Capitan limestone; *Pdb*, Bell Canyon formation (8, Lamar limestone member, 7, flaggy limestone beds, 6, Rader limestone member, 5, Pinery limestone member, 4, Hegler limestone member); *Pdc*, Cherry Canyon formation (3, Manzanita limestone member, 2, South Wells limestone member). *F*, Fault.

A. LOOKING NORTH FROM NEAR THE FORK OF THE VAN HORN AND EL PASO ROADS.

B. VIEW WEST FROM LEWIS WELL.

PANORAMIC VIEWS OF WESTWARD-FACING ESCARPMENT OF GUADALUPE MOUNTAINS.

For locations, see plate 2. The escarpment is related to faults, whose traces extend along its base. On the escarpment nearly the whole Permian succession of the mountains is exposed in horizontal position. To the west the same rocks, tilted and downfaulted, project here and there in foothills but are in part concealed by Quaternary alluvial deposits. *Qya*, Younger alluvial deposits; *Pcb*, Carlsbad limestone; *Pc*, Capitan limestone; *Pdb*, Bell Canyon formation (6, Rader limestone member, 5, Pinery limestone member); *Pg*, Goat Seep limestone; *Pdc*, Cherry Canyon formation (1, Getaway limestone member); *Pd*, Sandstone tongue of Cherry Canyon formation; *Pdy*, Brushy Canyon formation; *Pbc*, Cutoff shaly member of Bone Spring limestone, *Pbv*, Victorio Peak gray member, *Pbl*, black limestone beds. *F*, Fault.

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son's time are indicated in the table below. The publications cited therein are by no means all that have appeared on the area; they are selected because they are representative of a particular stage in the geologic study of the mountains—a task that has been carried on by many geologists. Not all of the new names that appear in each column were proposed by the particular author cited; many have originated in contemporaneous writings of other geologists.

Most of the units listed in the following tables are of lithologic significance, and have only an incidental time value. The west Texas Permian, however, is now divided by Adams and others into the four series shown in column 5. These units are dominantly of time significance, and are applied across the region to beds of the same age, regardless of their local rock or faunal facies.

The writer's terminology in the southern Guadalupe Mountains, shown in column 4 of the table below, is given in greater detail in the table on p. 12, and diagrammatically in plate 7, *A*.

In the descriptions of the stratigraphy that follow, the beds are divided into five local time units. The first of these units corresponds to the Leonard series, the next three to the lower, middle, and upper parts of the Guadalupe series, and the last to the lower part of the Ochoa series. They are treated in turn, from oldest to youngest. The outcrops of each, and the lithologic changes that take place in them, are followed across the area from the southeast to the northwest.

ROCKS NOT EXPOSED

The oldest rocks exposed in the southern Guadalupe Mountains belong to the Bone Spring limestone, of Permian age. The rocks beneath it do not come to view, but they have been penetrated in two wells that have been put down in the region. Some deductions as to the character of the underlying beds can be made from the data of the wells and also from study of pre-Bone Spring rocks exposed in nearby mountain ranges.

The two wells are the N. B. Updike, Williams No. 1, put down with diamond-drill tools in 1921 and 1922 at

History and general classification of the geologic terms used in the Guadalupe Mountains

<table>
<tr><th colspan="2">Richardson, 1904 [1]</th><th colspan="3">King, 1934 [2]</th><th colspan="3">Lang, 1937 [3]</th><th colspan="4">This report</th><th>Adams and others, 1939 [4]</th></tr>
<tr><td colspan="2">Rustler limestone</td><td colspan="3">Rustler limestone</td><td colspan="3">Rustler formation</td><td colspan="4">Rustler formation</td><td rowspan="3">Ochoa series</td></tr>
<tr><td colspan="2" rowspan="2">Castile gypsum</td><td rowspan="2">Castile gypsum</td><td colspan="2">Upper member</td><td colspan="3">Salado halite</td><td colspan="4">Salado formation</td></tr>
<tr><td colspan="2">Lower member</td><td colspan="3">Castile anhydrite</td><td colspan="4">Castile formation</td></tr>
<tr><td colspan="2">Capitan limestone</td><td colspan="2">Capitan limestone</td><td rowspan="4">Delaware Mountain formation</td><td>Carlsbad limestone</td><td>Capitan limestone</td><td rowspan="4">Delaware Mountain formation</td><td>Carlsbad limestone</td><td>Capitan limestone</td><td>Bell Canyon formation</td><td rowspan="4">Delaware Mountain group</td><td rowspan="4">Guadalupe series</td></tr>
<tr><td rowspan="4">Delaware Mountain formation</td><td>Dark limestone member</td><td colspan="2">Dark limestone member</td><td colspan="2" rowspan="3">Dog Canyon limestone</td><td>Goat Seep limestone</td><td colspan="2" rowspan="2">Cherry Canyon formation</td></tr>
<tr><td rowspan="2">Sandstone member</td><td colspan="2" rowspan="2">Sandstone member</td><td>Sandstone tongue of Cherry Canyon formation</td></tr>
<tr><td>Hiatus</td><td colspan="2">Brushy Canyon formation</td></tr>
<tr><td>Black limestone member</td><td colspan="3">Bone Spring limestone</td><td colspan="3">Bone Spring limestone</td><td colspan="4">Bone Spring limestone</td><td>Leonard series</td></tr>
<tr><td colspan="2">Hueco limestone</td><td colspan="3">Hueco limestone</td><td colspan="3">Hueco limestone</td><td colspan="4">Hueco limestone</td><td>Wolfcamp series</td></tr>
</table>

[1] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, pp. 32–45, 1904.
[2] King, P. B., Permian stratigraphy of trans-Pecos Texas: Geol. Soc. America Bull., vol. 45, pp. 763–782, 1934.
[3] Lang, W. B., The Permian formations of the Pecos Valley of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., vol. 21, pp. 857–878, 1937.
[4] Adams, J. E., and others, Standard Permian section of North America: Am. Assoc. Petroleum Geologists Bull., vol. 23, pp. 1673–1681, 1939.

Detailed classification of the formations in the Guadalupe Mountains as used in this report

Northwest part of area	Southeast part of area		Series
Absent	Castile formation		Ochoa
Carlsbad limestone Capitan limestone	Bell Canyon formation: ***** [1] Lamar limestone member. ***** Flaggy limestone bed. ***** Rader limestone member. ***** Pinery limestone member. ***** Hegler limestone member.	Delaware Mountain group	Guadalupe
Goat Seep limestone Sandstone tongue of Cherry Canyon formation	Cherry Canyon formation: ***** Manzanita limestone member. ***** South Wells limestone member. ***** Getaway limestone member. *****		
Hiatus; absent by overlap	Brushy Canyon formation		
Bone Spring limestone: Cutoff shaly member. Victorio Peak gray member. Black limestone beds.	Bone Spring limestone: Cutoff shaly member. Black limestone beds.		Leonard
Base concealed	Base concealed		

[1] Unnamed beds.

a point 3 miles south of El Capitan, and the Anderson and Prichard, Borders No. 1, put down with cable tools in 1934 and 1935 at a point about 14 miles south of El Capitan. The first well started at or a little above the top of the Bone Spring limestone, and was drilled to a depth of 3,400 feet (section 47, pl. 8). The second started 590 feet below the top of the formation, and was drilled to a depth of 4,728 feet (section 48, pl. 8).[43]

ROCKS OF PENNSYLVANIAN AGE

From a depth of 3,183 to 3,400 feet in the Updike well, and a depth of 3,950 to 4,728 feet in the Anderson and Prichard well, there are black shales and dark limestones which are probably of Pennsylvanian age. That they are of this age is suggested by some fragmentary fossil evidence. In the Anderson and Prichard well, between the depths mentioned, Rynicker has identified *Triticites*. In the Updike well, in cores from an unknown depth, Fountain has broken out fossils, including fusulinids on which Dunbar[44] comments as follows:

> Before completing the Texas volume [in 1937] we worked these small pieces of the core for all they were worth and got eleven rather well-oriented sections. * * * The two species of *Triticites* closely resemble two that I have from the Home Creek limestone of central Texas. The single specimen of *Dunbarinella* is probably juvenile. The type species of that genus was described by Thompson from the Deer Creek limestone, which would be up in the middle of the Cisco. It is possible that the large species of *Triticites* is the form described by Needham from the upper part of the Magdalena limestone, as *Triticites ventricosus sacramentoensis.* * * * In short, upon restudying this collection after a lapse of several years, I am still convinced that it presents a horizon in the Pennsylvanian, though possibly it is a little higher than the top of the Canyon.

Brachiopods, pelecypods, and gastropods included in the same lot (No. 7714) were studied by G. H. Girty, who reported that "nothing in the fauna definitely points to a geologic age older than the Bone Spring limestone, and it has no affinities to the Hueco fauna." In view of the fusulinid evidence, this lot evidently contains specimens broken from cores of different depths.

[43] Information on the N. B. Updike well is obtained from the driller's log, from notes taken by J. W. Beede, who visited the well when it was being drilled, and from examination by H. C. Fountain and the writer of the cores themselves, which were lying unmarked on the ground at the head of the well. Information on the Anderson and Prichard well is based on microscopic examination of cuttings by Max Littlefield and Charles Rynicker of the Gypsy Oil Co.

[44] Dunbar, C. O., letter of July 1945. For an earlier statement, see Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas: Texas Univ. Bull. 3701, p. 592, 1937.

The lower strata penetrated by the wells noted are thus probably of upper Pennsylvanian age. They are younger than the lower Pennsylvanian rocks which underlie the Hueco limestone in the northern Sierra Diablo, not far to the southwest.

WOLFCAMP SERIES OF CARBONIFEROUS OR PERMIAN AGE

Above the depth of 3,183 feet in the Updike well and the depth of 3,950 feet in the Anderson and Prichard well, most of the sequence consists of black limestones and shales like those forming a part of the Bone Spring limestone at the surface. However, from a depth of 2,912 to 3,183 feet in the first well, and of 3,660 to 3,950 feet in the second, there are clastic beds. In the Updike well these clastic beds consist of conglomerate composed of rounded limestone pebbles in a limestone matrix, interbedded with layers of gray limestone and black shale. In the Anderson and Prichard well, they consist of dark limestones, in which are embedded clastic fragments of quartz and feldspar. At the base are granite and porphyry pebbles as much as 4 millimeters in diameter. Despite certain dissimilarities, the clastic beds in the two wells are probably of the same age. They are probably correlatives of clastic beds exposed elsewhere in trans-Pecos Texas, which lie at the base of the Wolfcamp series, on a surface of unconformity which cuts across Pennsylvanian and older rocks.[45]

Further evidence that the rocks in this part of the two wells are of Wolfcamp rather than of Leonard (Bone Spring) age is afforded by the occurrence in rocks in the Anderson and Prichard well, as reported by Rynicker, of the fusulinid genus *Pseudoschwagerina*. This is a characteristic fossil of the Wolfcamp series. In the well, it occurs in black shale and dark limestone identical with the Bone Spring beds above and of a facies unlike that seen in rocks containing it in the Sierra Diablo and other ranges to the west. In those ranges it occurs in the gray thick-bedded Hueco limestone, the local representative of the Wolfcamp series. In the Updike well, the limestones for several hundred feet above the conglomerate are gray and thus more like the outcrops of the Hueco limestone, but no diagnostic fossils have been reported from them.

LEONARD SERIES

BONE SPRING LIMESTONE

The Bone Spring limestone is the oldest formation exposed in the Guadalupe and Delaware Mountains. It forms a bench of varying height along the west-facing escarpment of the mountains, which is fringed on the west by alluvial deposits or outcrops of down-faulted rocks. (For views of typical exposures see pl. 5; for map relations, pl. 3.) The formation passes beneath the surface in the southern Delaware Mountains, south of the area described, but across the Salt Basin to the southwest is extensively exposed and forms the upper three-fourths of the east-facing escarpment of the Sierra Diablo.[46]

The formation was named by Blanchard and Davis,[47] but it had previously been recognized by both Shumard [48] and Girty [49] as the "basal black limestone" (member 4 of Shumard's section). The type locality is in the lower course of Bone Canyon below Bone Spring, on the west side of the Guadalupe Mountains 1 mile northwest of El Capitan, where there are characteristic exposures of several hundred feet of its upper beds.

The formation is several thousand feet thick, as shown by the sections on plate 8. On the promontory of the Delaware Mountains 18 miles south of El Capitan, 1,500 feet of beds were measured (section 49), and at a point 2 miles north of Bone Spring 1,700 feet (section 7), but at neither place is the base exposed. In the Sierra Diablo, measured sections show a combined thickness for the Bone Spring and underlying Hueco of about 3,000 feet (section 45). This agrees closely with the 3,123 feet recorded in the Updike well near El Capitan (section 47).

In the Delaware Mountains to the south, which in Permian time were a part of the Delaware Basin, the formation is evidently much thicker, for in the Anderson and Prichard well the combined thickness of Bone Spring and Hueco limestones, including the beds exposed above the top of the well, totals 4,540 feet (section 48). According to Adams,[50] in this part of the section several faults may have been drilled through, as "chunks of rocks showing slickensides were bailed from the hole." Judgment must be reserved as to whether the possible faults have materially altered the amount of thickness, but they should be kept in mind as a possible source of error.

The Bone Spring is composed almost entirely of limestone beds, as contrasted with the dominantly sandy strata of the Delaware Mountain group which overlies it (plate 7, *A*). In the Delaware Mountains, and extending as far north as Bone Canyon, the exposed parts of the formation are black, cherty limestone in thin beds, with partings and a few members of shaly limestone and siliceous shale. North of Bone Canyon in the Guadalupe Mountains, the upper part of the black limestone is replaced by a thick-bedded gray limestone, the Victorio Peak gray member, which also forms the cap-

[45] King, P. B., Permian stratigraphy of trans-Pecos Texas: Geol. Soc. America Bull., vol. 45, pp. 716–717, 1934.

[46] King, P. B., op. cit., pp. 751–755.

[47] Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 961, 1929. Originally called Bone Springs limestone; the singular form is used here to agree with the geographic term.

[48] Shumard, G. G., Observations on the geological formations of the country between the Rio Pecos and Rio Grande, in New Mexico: St. Louis Acad. Sci. Trans., vol. 1, p. 281, 1858 [1860].

[49] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, p. 7, 1908.

[50] Adams, J. E., letter of May 1939.

ping stratum of the Sierra Diablo. Between the main mass of limestones and the sandstones of the Delaware Mountain group is a small thickness of interbedded limestone and shale, which forms the Cutoff shaly member and its probable equivalents.

SEQUENCE IN THE SOUTH

OUTCROP

South of Bone Canyon, the black limestones of the Bone Spring crop out in a bench along the west base of the mountains, forming rounded slopes of a darker color than those carved from the sandstones above. Near United States Highway No. 62 the bench is discontinuous and low, but it rises to the north and south. At the top of the bench in the Delaware Mountains south of the area studied, two cliff-making members of black limestone form steep walls, in places unscalable.

Outcrops of the Bone Spring limestone in the south part of the area are shown on the geologic map, plate 3. A part of the outcrop can be seen in the panorama, plate 5, *A*, fringing the base of the escarpment below El Capitan and Pine Top Mountain. Stratigraphic sections south of Bone Canyon appear on the right halves of plates 6 (numbers 15–44) and 8 (numbers 48 and 49). The two cliffs referred to form the 460-foot interval in the upper part of the formation in section 49.

BLACK LIMESTONES AND ASSOCIATED ROCKS

In the southern part of the area studied no more than the topmost 500 feet of black limestones is exposed, although more beds come to the surface farther south. These topmost beds are fine-textured, dense, black limestones, in beds a few inches to a foot or more thick. They are in part straight-bedded and in part have lumpy or undulatory bedding surfaces. Black, brown-weathering chert occurs in some of the beds as long, knobby lenses, nodules, and flat sheets. Chert is also common in the Anderson and Prichard well for more than 1,000 feet below the surface,[51] suggesting that most of it is original with the deposit. The black limestones are nearly barren of fossils. The known fauna has been collected from discontinuous lenses, generally more granular than the inclosing rock. Ammonoids in some of the lenses not far north of United States Highway No. 62 are filled with free oil, which spills over the rocks when the ammonoids are broken.

The black limestone in most exposures shows no stratification between the bedding planes, but in some exposures it is marked by finer laminations. Limestones marked by closely spaced, light and dark laminae similar to varves are common lower down in the formation (pl. 10, *A*); they have been observed on the promontory of the Delaware Mountains 18 miles south of El Capitan, in the Sierra Diablo, and in the cores from the Updike well. Some of the limestone beds are separated by partings of shaly black limestone. The strata for several hundred feet beneath the two cliff-making members south of the area studied consist of brown, platy siliceous shale and shaly limestone.

The following analyses of black limestone from the Bone Spring limestone were made. These and subsequent analyses of carbonate rocks in this report were determined by methods described by Hillebrand.[52] The only modification was that insoluble residues were caught on Jena glass filtering crucibles, and the organic insoluble determined by the Robinson [53] method.

Analyses, in percent, of black limestone from the Bone Spring limestone

[Analyses by K. J. Murata; notes on insoluble residues by Charles Milton]

Specimen locality	Insoluble		R_2O_3 (mostly Fe_2O_3)	$CaCO_3$	$MgCO_3$	$MnCO_3$	$Ca_3(PO_4)_2$	Total
	Inorganic	Organic						
1. Near top of black limestone, 3 miles south-southeast of El Capitan	6. 11	0. 33	0. 29	91. 19	1. 76	None	0. 06	99. 74
2. Several hundred feet below top of black limestone, at narrows of Bone Canyon below Bone Spring	4. 34	. 36	. 23	91. 52	3. 36	None	. 06	99. 87
3. Middle part of Bone Spring limestone, 3 miles north of Victorio Peak, Sierra Diablo; laminated limestone, a thin section of which is illustrated on pl. 10, A	23. 65	. 73	. 37	72. 00	2. 86	None	. 13	99. 74

Insoluble residues: 1, Dark brownish and carbonaceous, consisting of clay with finely divided quartz particles; 2, similar to No 1; 3, light brown and of fine-grained particles.

At several places, layers as much as 10 feet thick of platy, fine-grained, calcareous sandstone are interbedded with the black limestones. Two specimens of the sandstone, one from a point 2½ miles south-southeast of El Capitan and the other from the mouth of Black Canyon farther south, were studied under the microscope by Ward Smith. The grains have a maximum diameter of 0.2 millimeter and lie in a calcite matrix. They consist chiefly of quartz, with some microcline and plagioclase, and a small but noteworthy

[51] Littlefield, Max, Personal communication, 1936.

[52] Hillebrand, W. F., The analysis of silicate and carbonate rocks: U. S. Geol. Survey Bull. 700, pp. 253–266, 1919.

[53] Robinson, W. O., U. S. Dept. Agr., Jour. Agr. Research, vol. 34, p. 339, 1927.

amount of zircon, tourmaline, and apatite. These are the more stable minerals of igneous and metamorphic rocks.

A mile south of Bone Canyon, several thin conglomerate layers containing black limestone pebbles are interbedded in the black limestone (sec. 17, pl. 13). One of these beds locally attains a thickness of 4 feet and contains boulders several feet across of light-gray, fossiliferous limestone similar to that of the Victorio Peak gray member as developed a few miles to the north. Apparently some erosion of this contemporaneous, light-gray limestone was taking place at the time the black limestones were being deposited.

Near Bone Spring, the upper part of the black limestone contains lenticular masses of poorly bedded, gray, granular limestone as much as 50 feet thick (secs. 15a and 16a, pl. 13). One such mass exposed on the escarpment face not far south of the mouth of Bone Canyon seems to lie in a channel in the underlying black limestone. Other masses have a moundlike upper surface, against which the succeeding beds overlap. They contain the heads of massive bryozoans, and also numerous productids and other brachiopods like those in the Victorio Peak gray member nearby. At least some of these lenticular masses were small reef deposits.

STRUCTURAL FEATURES IN THE BLACK LIMESTONE

The black limestones are thinly and evenly bedded. In the vicinity of Bone Canyon and farther south, however, most of the exposures when viewed as a mass show a great irregularity of stratification, so much so that at nearby points the dip is quite different in direction and amount. This irregularity results from two types of structural features, described below.

The first type is found in the vicinity of Bone Canyon. Here, the black limestone is divided into numerous wedge-shaped and basin-shaped masses as much as 100 feet thick. The strata within each mass are parallel but the masses themselves are separated by sloping planes of contact from other masses of similar lithologic character in which the strata are differently inclined.[54] In some places, gently dipping strata overlie more steeply tilted strata, and in other places the overlying strata have the steeper dips. The upper beds are generally parallel to the plane of contact beneath, and the lower beds are cleanly truncated. None of the limestones near the planes of contact is contorted, and none contains any breccia or conglomerate; the overlying limestones rest directly on the underlying. At one or two places, however, the smoothness of the contact is broken by small pockets in the underlying beds, which are filled by limestone like that above and below.

A typical exposure of such features is shown in plate 11, *A*, in which a pocket like that noted above can be seen on one of the surfaces. The features are shown also on the sections accompanying plate 9, especially in the enlarged sketch on the left, and in figures *A* and *B*, accompanying plate 13. The area in which they occur is shown on plate 7, *A*.

These features are strikingly exposed in Bone Canyon, and in Shumard Canyon,[55] the next valley to the north. They are found also for somewhat more than a mile south of Bone Canyon, but are absent beyond. They are absent also north of Shumard Canyon, where the bedding planes in the black limestone are straight and parallel.

In Shumard Canyon, the lower part of the overlying thicker-bedded Victorio Peak gray member contains a few similar structural features, but the angle of divergence between the overlying and the truncated beds is less than that in the beds beneath. In this canyon, the Victorio Peak itself is truncated and overlain by basin-shaped remnants of the Cutoff shaly member (sec. *C–C′*, pl. 9).

The second type of structural feature, a remarkable contortion of the black limestone beds, is known only in the area south of El Capitan, where it can be seen in the upper layers of the black limestone, the oldest beds exposed in the district. These features have not been described in previous publications, although they may have been seen by geologists, and confused with the features of the other type near Bone Canyon. A typical exposure of this second type of feature is shown in plate 11, *B*, and the area in which they occur on plate 7, *A*.

In many places the canyons that drain across the black limestone bench cut through steep to overturned or recumbent folds, involving 10 to 20 feet of beds. Accompanying the folds are small thrust faults. In places the contorted rocks pass into masses of sheared, wrinkled, and rolled lenses of limestone. The general trend of the folds and thrusts is between east-northeast and west-northwest, but the direction of overturning is either northward or southward. Numerous furrows and slickensides of the same trend as the folds groove the bedding planes, both in the contorted rocks and in rocks not otherwise conspicuously disturbed.

Wherever they are exposed the strata beneath any set of contorted beds are little disturbed. Many of the contorted beds are truncated, and overlain by gently dipping strata. Whether the upper strata lie unconformably on the lower or have been thrust over them cannot be determined with certainty. The contortion

[54] First described by Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, pp. 112–117, 1920. Later described by Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, p. 423 and pl. 14, 1926; Lloyd, E. R., Capitan limestone and associated formations: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 657, 1929; Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 962, 1929; and others.

[55] Name used in this report for the large, hitherto unnamed canyon lying between Bone and Shirttail Canyons on the west side of the Guadalupe Mountains. The canyon and Shumard Peak, on whose slopes it heads, are named in honor of Dr. G. G. Shumard, the first geologist to visit the region.

has not modified the broader features of the strata, for toward the south the contorted beds stand in cliff-making members that can be traced continuously for long distances.

Both sets of structural features are relatively ancient, for the tilted beds, planes of contact, and thrusts are in many places cut cleanly through by vertical joints of probable Tertiary age, some of which are shown on plate 11, *B*. The features near Bone Canyon were interpreted by Baker[56] as thrust slices. Darton and Reeside[57] and later geologists, however, have regarded the truncated surfaces in this neighborhood as local unconformities, and the whole feature as a sort of gigantic cross-bedding[58] formed during the time of deposition. This latter interpretation seems best to fit the facts, as the basinlike form of some of the masses and the pockets along some of the planes of contact more closely resemble sedimentary than tectonic features. Further, similar truncated surfaces higher up, which separate the Victorio Peak from the Cutoff member, seem clearly to be local unconformities. Such unconformities do not necessarily mean emergence of the sea bottom; they may have been caused by submarine currents.

The features farther south are certainly the result of some sort of deformation, but I am inclined to believe that they also were formed during or shortly after the time of Bone Spring deposition. The intensity of the contortion and the small thickness of the beds involved suggests that they were deformed under a relatively thin overburden, and that the beds retained a certain plasticity at the time of deformation. They must have been sufficiently consolidated, however, to have been grooved and slickensided. The deformation might have been caused by a sliding of one part of the newly deposited beds over another, causing the beds between to crumple.[59] Some of the flat-lying beds that truncate contorted beds may have slid in this manner. (See p. 27.)

CUTOFF SHALY MEMBER

South of El Capitan, the black limestone bench is separated from the first sandstone ledges of the Brushy Canyon formation above by a slope 50 to 150 feet high, carved from shales, sandstones, and thin limestones, of which a typical exposure is shown on plate 14, *B*. These beds are classed as an upper member of the Bone Spring limestone, and tentatively correlated with the Cutoff shaly member of the Bone Spring, which is found in the northern part of the area studied. Near El Capitan, however, the beds thin out and disappear, so that the actual connection to the north cannot be traced. The Cutoff member of the southern area is well exposed in Brushy Canyon, not far south of United States Highway No. 62 (sec. 36, pl. 6).

The member consists of black, platy, siliceous shale and shaly sandstone, with a few intercalated sandstone beds in the upper part, and many thin beds of compact gray or black limestone. At some localities, the various constituents are very irregularly interbedded. In Brushy Canyon, one of the limestone beds develops locally into a mass 15 feet thick and contains abundant brachiopods, mollusks, and other fossils. The thinner limestones contain little else than fusulinids, and many are unfossiliferous. In some exposures, the shales contain large, spherical, cannon-ball concretions of limestone.

In the lower 25 feet of the member, and resting in places directly on the black limestones beneath, are lenticular beds of conglomerate a few feet thick, composed of round black limestone pebbles set in a calcareous matrix. The upper surface of the black limestones is not channeled, however, and the limestones interbedded in the shales above the contact are identical in appearance with those below. The top of the member is drawn at the base of the lowest prominent sandstone ledge of the Brushy Canyon formation, but this is not a definite boundary, as some similar sandstone is interbedded in the shales below, and shales and platy sandstones are interbedded in the thicker sandstones above.

SEQUENCE IN THE NORTH

OUTCROP

Near Bone Canyon the bench of Bone Spring limestone rises to a greater height than farther south. To the north it stands in an imposing line of cliffs that rise 1,000 feet or more above the foothill ridges of downfaulted rocks that flank it on the west. About 4 miles north of Bone Canyon, these downfaulted rocks rise so high that they conceal the Bone Spring beds on the main escarpment. Toward the northwest, however, in the lower ridges near Cutoff Mountain, the formation reappears in places. It and the overlying rocks are much faulted, and some of its limestones form dip slopes that are inclined steeply westward toward the Salt Basin.

Outcrops of the Bone Spring limestone in the northern part of the area are shown on the geologic maps, plates 3 and 9. The whole outcrop in the northern part of the area also can be seen on the panorama, plate 5, *B*. The part of the outcrop on the main escarpment extends from below El Capitan to the right, northward past points 5738 and 6402 to below the Blue Ridge on the left, where it comes to an end. The outcrops near Cutoff Mountain appear farther to the left, and form the cuestas below point 5443 and elsewhere. Stratigraphic sections of the formation north of Bone Canyon are shown on the left half of plate 6, numbers 1 to 14.

[56] Baker, C. L., op. cit., p. 113.
[57] Darton, N. H., and Reeside, J. B., Jr., op. cit., p. 423.
[58] Lloyd, E. R., op. cit., p. 657.
[59] Twenhofel, W. H., Treatise on sedimentation, 2d ed., pp. 739–741 (subaqueous gliding), Baltimore, 1932. Jones, O. T., On the sliding or slumping of submarine sediments in Denbighshire, north Wales, during the Ludlow period: Geol. Soc. London, Quart. Jour., vol. 43, pp. 241–283, 1937.

VICTORIO PEAK GRAY MEMBER

The black limestones are exposed for only a few miles north of Bone Canyon and pass from view beyond. Most of the exposed part of the formation in this district belongs to the Victorio Peak gray member, a succession of thick-bedded, gray limestones 800 feet thick, which are the northward equivalent of the upper part of the black limestones.

The member is named for Victorio Peak,[60] a high point on the Sierra Diablo escarpment southwest of the Guadalupe Mountains. A correlation of the rocks assigned to the member in the two areas seems assured, because in addition to a similarity of the faunas, the member at the northwest end of the Sierra Diablo is divisible into three parts that are identical with its three divisions in the Guadalupe Mountains. (Compare secs. 46 and 7, pl. 8.) Here, as in the Guadalupe Mountains, it rests on black limestone and is overlain by the Cutoff shaly member.

On the high ridge between Shumard and Shirttail Canyons,[61] about a mile north of Bone Spring, two well-marked divisions in the member are recognized. (See sec. 10, pl. 6; for structure of the ridge, see sec. *B–B′*, pl. 9.)

The lower division, resting with gradational contact on the black limestone, consists of 350 feet of gray-brown, fine-grained, dolomitic limestone in beds several feet thick. In Shumard Canyon, many layers of thin-bedded, hackly limestone are interbedded. Here erosion has carved the limestone of the division into picturesque, serrated walls and pinnacles, which are shown in the lower left-hand part of plate 12, *B*. The division commonly contains widely spaced, large, subspherical chert nodules, and in many beds fragmental remains of fossils. In Shirttail Canyon, several layers of light-brown, fine-grained sandstone are interbedded in the lower part.

The upper division of the Victorio Peak member on the ridge between Shumard and Shirttail Canyons is a light-gray, nondolomitic, noncherty, thick-bedded calcitic limestone 160 feet thick, which contains various productids and other brachiopods.

The following analyses of limestones from the Victorio Peak gray member were made:

Analyses, in percent, of limestones from the Victorio Peak member

[Analyses by K. J. Murata; notes on insoluble residues by Charles Milton]

Specimen locality	Insoluble		R_2O_3 (mostly Fe_2O_3)	$CaCO_3$	$MgCO_3$	$MnCO_3$	$Ca_3(PO_4)_2$	Total
	Inorganic	Organic						
1. Lower division, first ridge south of Shumard Canyon, at entrance	2. 64	0. 24	0. 25	55. 54	41. 25	0. 07	0. 10	100. 09
2. Upper division, Shumard Canyon ¼ mile north-northeast of Bone Spring	. 74	. 33	. 25	97. 50	. 69	. 02	. 10	99. 63
3. Upper division, 1 mile northwest of Bush Mountain	. 92	. 04	. 20	98. 20	. 60	None	. 10	100. 06

Insoluble residues: 1, Dark brownish, carbonaceous, consisting of clay and finely divided quartz, some of which is perhaps authigenic; 2, dark brown, carbonaceous, with large garnet particles, some of which are well-rounded, and also red tourmaline, quartz, and chalcedony; 3, brown, with quartz, chalcedony, microcline, and coarse garnet.

The two divisions of the Victorio Peak gray member disappear south of Shumard Canyon. The lower division extends as far as a ravine between Shumard and Bone Canyons, where it intergrades abruptly with black limestone, as shown in figure *A*, plate 13. The upper division is cut off southward by pre-Brushy Canyon (Delaware Mountain) erosion. In the northern branches of Shumard Canyon its beds are truncated by a smooth surface, sloping 15° southeast, against which the sandstones of the Brushy Canyon formation overlap (sec. *B–B′*, pl. 9). In the southern branches the upper division extends as a rapidly thinning wedge, which is locally overlain by basin-shaped remnants of the Cutoff shaly member.

The black limestone exposed in Bone Canyon is of the same age as the lower division of the Victorio Peak member a little to the north, and the lenticular masses of gray, granular limestone which it contains are considered as outliers of the Victorio Peak deposits. No equivalent of the upper division is present here. Crude tracing of the ledges suggests, however, that black limestone beds younger than any in Bone Canyon come in beneath the Brushy Canyon formation to the south, as indicated diagrammatically on plate 7, *A*. They are probably equivalent to the upper division of the Victorio Peak member to the north.

[60] 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. 922, 1929. In the Guadalupe Mountains, the name supersedes the term "gray limestone member" of Darton and Reeside (op. cit., p. 421), which has been used for it in many geologic reports.

[61] According to Mr. A. J. Williams, Shirttail Canyon was so named because about 1918 a party of fugitives made the canyon their hiding place and tied a shirt to a bush near its entrance as a signal to their confederates.

North of Shirttail Canyon, the lower division of the Victorio Peak member, which is not widely exposed, is separated from the upper division by a middle division 100 feet thick of slope-making, thin-bedded, light-gray or white limestone, with much buff, fine-grained, calcareous sandstone interbedded. (Shown on secs. 5 and 7, pl. 6.) The upper division is calcitic, light gray, noncherty, and thick-bedded. (See chemical analysis No. 3, above.) Its upper layers contain numerous poorly preserved fusulinids and productid shells.

CUTOFF SHALY MEMBER IN SHUMARD CANYON

In the southern branches of Shumard Canyon, resting unconformably on both the lower and upper divisions of the Victorio Peak member, and overlain unconformably by the Brushy Canyon formation, are small remnants of poorly fossiliferous beds which are probably equivalent to the Cutoff member to the north.

Two divisions are present, separated by an unconformity. The older one, composed of thin-bedded, black, cherty limestone, is exposed at only one place, near the head of the south fork of the canyon. It lies in a steep-sided basin carved in the Victorio Peak limestone, which it fills to a thickness of 90 feet. The younger division crops out somewhat more widely in the branches of the canyon, and consists of thin-bedded black limestone, weathering to ashen-gray, hackly fragments, interbedded with platy siliceous shale. They closely resemble the limestones and shales of the Cutoff member as developed farther north. The younger division is well exposed on the ridge south of the mouth of Shumard Canyon, where it reaches a thickness of 60 feet.[62]

The outcrops of the two divisions of the Cutoff shaly member in Shumard Canyon are shown on the geologic map, plate 9, and their structure on the accompanying section *C–C'*. The basin-shaped remnant of the lower division stands out prominently on the nearest ridge in the center of the panorama, plate 12, *B*. The lower division is included in section 12*a*, and the upper in section 13*a* of plate 6.

CUTOFF SHALY MEMBER IN NORTH PART OF AREA

In the northern part of the area studied, the Victorio Peak gray member is overlain, apparently conformably, by 230 feet of shales and limestones which crop out on slopes above the limestone cliffs. They form the Cutoff member, which is named for exposures on the west slope of Cutoff Mountain about 1,000 feet below its summit (sec. 1, pl. 6).[63]

The member consists of thin-bedded, dense limestone of black, buff, or gray color, weathering to dove-gray or ashen, hackly, conchoidal fragments. Some of the lower beds contain irregular masses of black chert. In the upper part, much platy black siliceous shale, brown sandy shale, and soft sandstone is interbedded. The member contains few fossils; some pelecypod imprints were seen in the upper part west of Cutoff Mountain.

About half a mile north of Shirttail Canyon, the southeastward extending outcrop of the Cutoff member comes to an end. At this place an erosion surface slopes southward across the truncated edges of the Cutoff beds, with sandstones of the Brushy Canyon formation overlapping northward against it, as shown diagrammatically on plate 7, *A*. To the south, the Brushy Canyon beds rest directly on the Victorio Peak member.

Correlation of the typical Cutoff shaly member of the north part of the area with the shales and limestones at the top of the Bone Spring limestone farther south is tentative because only the beds to the south contain fossils in any abundance. The rocks of the different areas are similar lithologically, however, and all are included in the Cutoff shaly member in this report.

STRATIGRAPHIC RELATIONS

BONE SPRING FLEXURE

A study of the region south of El Capitan reveals no unusual features near the Bone Spring-Brushy Canyon contact. The black limestones, which project as a low bench at the base of the mountains, are overlain without apparent break by the interbedded shales, limestones, and sandstones of the Cutoff member. They are followed in turn by the sandstone ledges of the Brushy Canyon formation of the Delaware Mountain group, as in section 36, plate 6. A view to the north along the western side of the mountains, however, shows that the limestone bench rises to a much greater height in this direction, without a similar rise in the overlying sandstone ledges (as shown in pl. 5, *A*).

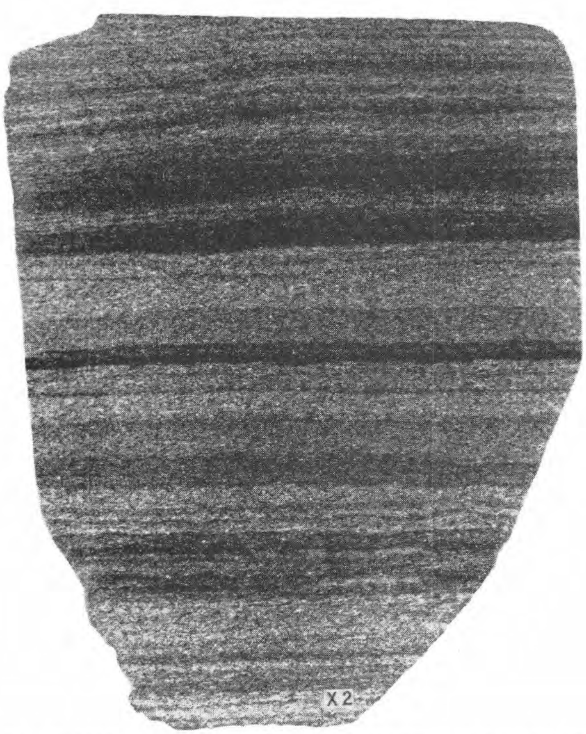
At the Bone Spring-Brushy Canyon contact in Bone Canyon a few miles to the north, in the area of higher-standing limestone, the Cutoff member is not found. Instead, the upper surface of the black limestone is channeled and is overlain by coarse conglomerate, which contains fragments derived from the limestone.[64] Besides these fragments the conglomerate contains cobbles and boulders of gray limestone unlike any rock exposed here or to the south. The conglomerate grades upward into typical sandstones of the Brushy Canyon formation, as shown in section 15, plate 13.

A view of the relations farther north can be had from the crest of the succeeding ridge (pl. 12, *B*). Looking down into Shumard Canyon, the next large drainage beyond Bone Canyon, one can see the contact

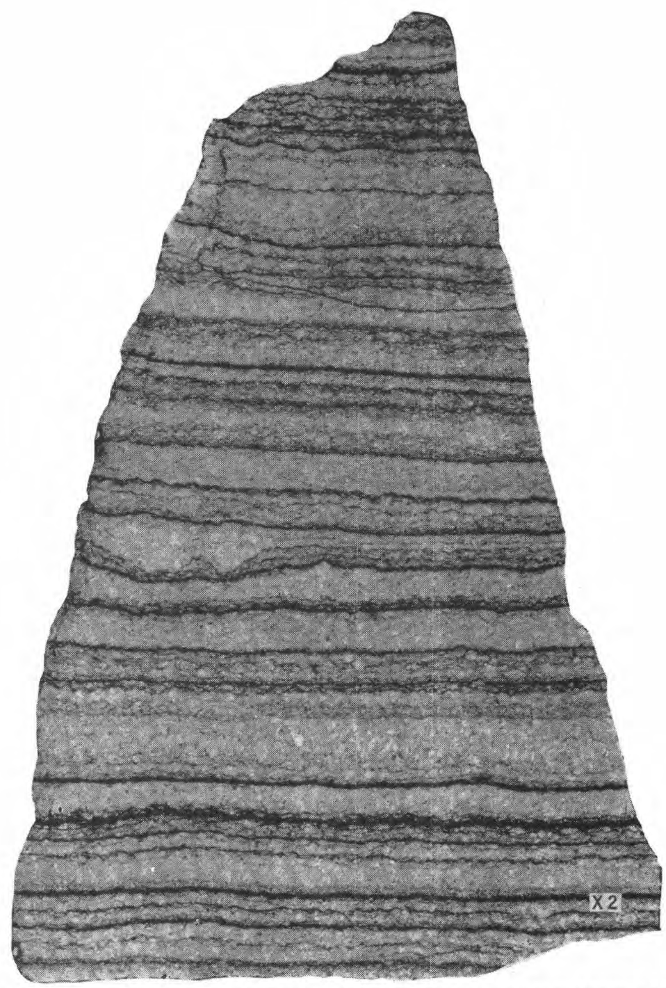
[62] This exposure was first noted by E. R. Lloyd, op. cit., p. 657.

[63] This member seems not to have been recognized as a separate entity in previous reports. Blanchard and Davis (op. cit., pp. 968–970) have described some of its exposures in their measured sections a short distance north of the Texas-New Mexico line. They refer to it as the "top, gray, hackly member" of the Bone Spring limestone.

[64] First described by Baker (Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, p. 114, 1920) and later by Darton and Reeside (Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 421–423, 1926) and others.



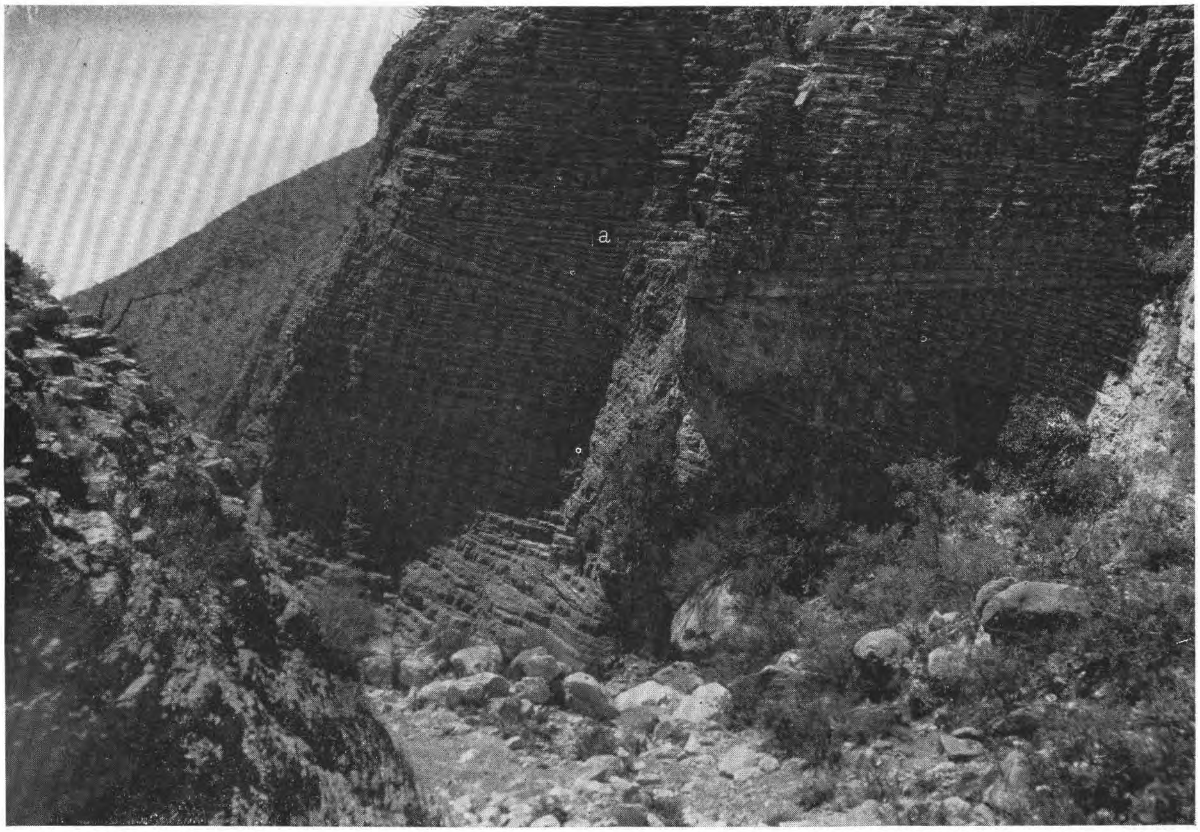
A. BLACK LIMESTONE OF BONE SPRING, SEVERAL HUNDRED FEET ABOVE BASE, FROM SIERRA DIABLO SCARP NORTH OF VICTORIO CANYON.



B. ANHYDRITE OF CASTILE FORMATION, ON ROAD TO 9 K RANCH, 4 MILES SOUTH OF U. S. HIGHWAY NO. 62.

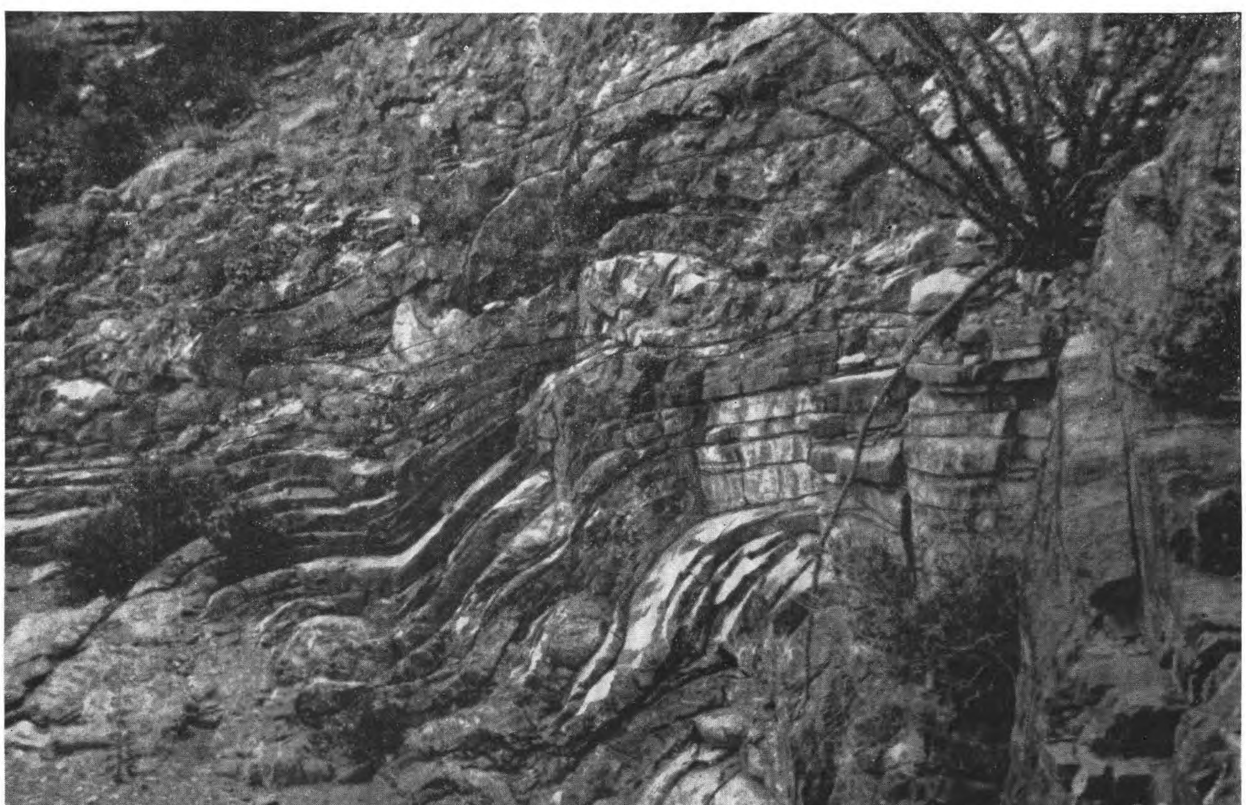
LAMINATED SEDIMENTS OF PERMIAN AGE.

The laminations may be varves, or annual deposits. Thin sections, in transmitted light.



A. TRUNCATED BEDS AND LOCAL UNCONFORMITIES IN NARROWS OF BONE CANYON, ¼ MILE WEST OF BONE SPRING.

At *a*, a small pocket filled by black limestone lies on one of the surfaces of unconformity. Photograph by N. H. Darton.



B. CONTORTED BEDS IN RAVINE 3½ MILES SOUTH-SOUTHEAST OF EL CAPITAN.

Note recumbent folds and vertical joints. Photograph by J. B. Knight.

STRUCTURAL FEATURES IN BLACK LIMESTONE OF BONE SPRING.

of the limestone and sandstone on the walls of the tributary gorges; it rises from a position beneath the observer to one several hundred feet above him on the farther wall. On the farther wall the black limestones are overlain by gray limestones which stand in a high projecting bench. These gray limestones constitute the Victorio Peak member and are the source of the boulders to the south.[65]

Brown sandstone ledges of the succeeding Brushy Canyon formation can be traced along the slopes above the limestone, rising less steeply northward than the limestone-sandstone contact. One group of them in middle distance, in the north fork of Shumard Canyon, is seen to overlap abruptly against the sloping surface.

Near the point where the sandstones overlap, one can find innumerable ripple marks on their bedding surfaces, suggesting that the sandstones were laid down near a shore. The shore itself, the sloping surface of the gray limestones, is a smooth face, cut across the edges of gently tilted beds. The sandstones contain no embedded detritus derived from the shore as they do at Bone Canyon to the south. Perhaps this area stood higher on the sea bottom so that the detritus was swept away, and deposited lower down the slope, as at Bone Canyon.

North of El Capitan the Bone Spring limestone is thus flexed into a position much higher than to the south. On the north side of Shumard Canyon the limestone stands 2,000 feet higher than it does south of El Capitan, and 1,000 feet higher than it does in Bone Canyon nearby. This uplift is only mildly shared by the overlying sandstones, and seems to have been largely completed before they were laid down. The upraised limestones were being eroded in early Delaware Mountain time, and the Brushy Canyon formation of that group overlaps their sloping surface. The overlap is so great that 1,000 feet of beds, the entire Brushy Canyon formation, is cut out between Bone Canyon and a point 2 miles to the north. The fold produced by this pre-Delaware Mountain uplift is known as the Bone Spring flexure.

The feature was named by Blanchard and Davis,[66] who called it the Bone Springs arch. It would seem from their paper that they considered the feature to be anticlinal, and to have a similar, opposing flank to the north. This view was contested at the time by De Ford.[67] My work has failed to disclose a north flank to the feature and the term flexure is therefore used instead of arch.

A good general view of the flexure can be seen in the panorama, plate 5, *B*, which shows the Bone Spring limestone rising from a low position below El Capitan to a high position below Shumard Peak, beyond which the beds flatten out northward. The structure of the beds shown in this view is given in section *K–K′*, plate 17. A closer view of the exposures in Shumard Canyon is shown on plate 12, *B*. The relations of the overlying and underlying beds to the flexure is shown on the map and sections of plate 9, and structure contours on the upraised surface of the Bone Spring limestone on the inset of figure 6.

[65] As first pointed out by Darton and Reeside (idem).

[66] Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 964, 1929.

[67] De Ford, R. K., discussion, Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 1031, 1929.

SOME DETAILS NEAR BONE CANYON

The broader stratigraphic relations of the Bone Spring limestone and Delaware Mountain group are clear, but near Bone and Shumard Canyons local complexities tend to obscure them and deserve further explanation.

The peculiar, cross-bedded structure of the black limestones, and the basins cut into the Victorio Peak gray member and filled by the Cutoff shaly member have already been described. To produce them, uplift and erosion must have taken place on the flexure before Bone Spring time came to an end. The conglomerates interbedded in the black limestone south of Bone Canyon, which are similar to those in the overlying Brushy Canyon formation, lend support to this idea, for they contain fragments not only of black, but also of gray limestone, and thus were not derived entirely from the break-up of the beds next beneath them. Along the unconformity below the Cutoff member, the Victorio Peak member is deeply eroded, and the break seems more important than those in the black limestones below. In places along Shumard Canyon, this unconformity is more prominently exposed than that between the Cutoff and the standstones above. This instance is local, however, and the general relations indicate that the younger unconformity is the major one.

The apparent trend of the Bone Spring flexure is east and west, at right angles to the northward trending outcrops, for most of the observable uplift and overlap take place in a northward direction, along the outcrop. Closer scrutiny of the rather narrow belt of outcrop, however, indicates that the actual trend of the flexure is north-northeast. The limestones on each west-projecting ridge rise higher than they do in the heads of the canyons to the east (inset, fig. 6), and a westward overlap of the overlying sandstones and conglomerates can be observed on the walls of Bone and other canyons (pl. 13, fig. *B*).

Overlying the conglomerates near Bone Spring is a bed of gray-brown, dolomitic limestone which closely resembles the limestones of the lower division of the Victorio Peak member, which lies at about the same altitude to the north. This forms the 28-foot interval in section 15, plate 13. It might be mistaken for a tongue of the lower division projecting into and intergrading with the sandstones of the Brushy Canyon formation were it not that on the south side of the next ravine north of Bone Canyon it can be found overlapping the similar, older, gray-brown limestones (as shown at point 14b, pl. 9, and on fig. *A*, pl. 13) with the unconformable contact clearly exposed. Moreover, beneath the limestone bed in Bone Canyon, the conglomerate contains fragments of the upper division of the Victorio Peak member as well as of the lower division, thus proving that the bed is much younger than the lower division.

Lloyd [68] considers that "the lower part of the sandstone series [Brushy Canyon] merges laterally with the gray limestone [Victorio Peak] just as the upper part merges into the lower part of the Capitan." His interpretation is based chiefly on the apparent relations of the limestone bed here referred to. This interpretation is not accepted in this report.

RELATIONS NORTH AND SOUTH OF FLEXURE

South of the Bone Spring flexure there appears to be a continuous, gradational sequence from the black limestones of the Bone Spring, through the shales of the Cutoff member, into the sandstones of the Brushy Canyon formation. Deposition probably was nearly continuous from one formation to the other in this region. The gray limestones of the Victorio Peak member are not present between the black limestones and the Cutoff member, but they are not believed to be missing on account of erosion; instead, during Victorio Peak time, black limestone was probably being deposited south of the flexure while the gray limestone was being deposited north of it.

North of the flexure, the unconformity between the Bone Spring limestone and the Delaware Mountain group is not evident, and the strata of the two units lie parallel. The beds next beneath the contact belong to the Cutoff shaly member of the Bone Spring, and those next above the contact to the sandstone tongue of the Cherry Canyon formation. Near the north edge of the flexure, however, the Cutoff member below has been eroded away. Also, on the flexure, a great thickness of beds older than the sandstone tongue wedge in below the Cherry Canyon formation, and constitute the Brushy Canyon formation (pl. 7, *A*). The absence of the latter north of the flexure indicates that a great, but nonevident break separates the Bone Spring limestone and Delaware Mountain group in that region.

FOSSILS

Invertebrate fossils occur in various degrees of abundance in all the members of the Bone Spring limestone. In general, the faunas of all the members are similar, but there are some differences which appear to be related to differences in lithologic facies of the enclosing rocks. Considered as a whole, the fauna is closely related to that in the overlying Guadalupe series, although of slightly more primitive character. It has few resemblances to that of the underlying Hueco, and still fewer resemblances to that of the Pennsylvanian beneath the Hueco.

Some of the fossils from the black limestone beds of the formation were described by Girty [69] in 1908, and the general aspect of the fauna of the Victorio Peak member was reviewed by him in 1926.[70] Some brachiopods from the formation in the Delaware Mountains and the Sierra Diablo were described by King [71] in 1931. The present investigation has furnished much additional information on the fauna, which is summarized below.

In this and succeeding discussions of the fossils of the Guadalupe Mountains section, information on the fusulinids is based on the work of Dunbar and Skinner,[72] and that on the cephalopods on the work of Miller and Furnish.[73] These studies, which to a great extent were based on collections made during the present survey, have already been published. Information on the other groups of fossils, particularly on the brachiopods, gastropods, and pelecypods, is based on the work of the late G. H. Girty, who was able to complete in manuscript a rather long summary of the collections shortly before his death in 1939. This summary, quoted in this report, is of particular value because it links the paleontological and stratigraphic ideas of his earlier work, in 1908, with the ideas obtained by other geologists from more detailed subsequent field work and collecting. Throughout his summary, Girty makes frequent comparisons between the faunas as he knew and described them in 1908 and faunas as they are revealed by the present larger collections.

Because of the fact that this report is primarily a description of the physical stratigraphy of the southern Guadalupe Mountains, because of the large size of the available collections, and because of the preliminary nature of the ideas on many of the fossil groups, it does not seem desirable at this place to include the customary fossil lists. Instead, in the summary written by Dr. Girty, the important features of each fauna are discussed, and only incidental reference is made to specific localities. A similar plan is followed in summarizing the results of Dunbar and Skinner and of Miller and Furnish, although the actual localities of their collections have been given in their publications. Although this method of presentation has some disadvantages, it is believed to have advantages for immediate purposes

[68] Lloyd, E. R., Capitan limestone and associated formations: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 650–657, 1929.

[69] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, p. 22, 1908.

[70] Quoted by Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 421–423, 1926.

[71] King, R. E., The geology of the Glass Mountains, part 2: Texas Univ. Bull. 3042, p. 11, 1931.

[72] Dunbar, C. O., and Skinner, J W., Permian Fusulinidae of Texas: Texas Univ. Bull. 3701, pp. 592–596, 726–731, 1937.

[73] Miller, A. K., and Furnish, W. M., Permian ammonoids of the Guadalupe Mountain region and adjacent areas: Geol. Soc. America Special Paper 26, pp. 9–12, 1940.

that outweigh the disadvantages. It is hoped that stratigraphers and paleontologists will find use for the material as it is given.

Although the summary by Dr. Girty quoted herein was completed shortly before his death, he was unable to edit the manuscript in the manner he had contemplated; in its original state it was essentially a rough draft. In order to prepare it for publication, therefore, it was edited by P. B. King and J. S. Williams. King condensed and rearranged certain parts, so that as here given they are not exactly as written by Girty, although the original meaning and style are retained. Williams reviewed the terminology of the genera and species, which were not everywhere consistent in the several parts of the manuscript. Where discrepancies were found an attempt was made to determine the usage actually preferred by Girty at the time of writing. Most of his preferences could be determined from statements in the manuscript itself, but supplementary evidence was obtained by examination of other notes and manuscripts written by Girty that were available to Williams.

Throughout the summary by Girty, the generic assignments given by him are retained, and no attempt has been made to incorporate generic changes that have appeared since Girty's death in 1939. In connection with the generic terminology as used, Girty comments as follows on that of the brachiopods.

I am using the generic name *Productus* in the broad sense and as typified as it has been for a century by *P. semireticulatus* Martin. In my opinion, the subdivisions of *Productus* to which distinctive names have been applied, such as *Pustula*, *Cancrinella*, and so on up to 50 or more, are not of generic rank, as genera are recognized in other types of brachiopods. I am employing some of these names as subgenera, but I do not know that I have employed them consistently or shall continue to apply them at all. *Neospirifer* seems even less useful as a subgenus of *Spirifer*.

The generic names used for the fusulinids are those employed by Dunbar and Skinner in their publication of 1937, and those for the ammonoids are those employed by Miller and Furnish in their publication of 1940.

BLACK LIMESTONE BEDS

In most of the black limestone beds fossils are scarce, being represented by only occasional specimens. In a few layers, which are generally lenticular or nodular, and somewhat more granular than the rest of the rock, they are more abundant, and from these layers most of the known fauna has been obtained. Slight differences exist between the fossil assemblages in the different beds. In some, brachiopods predominate, in others gastropods, pelecypods, and cephalopods. According to Dr. Girty, the differences between the assemblages are not fundamental.

One of the most striking features of the black limestone fauna is the abundance of ammonoids at numerous localities. Nearly all the collections that have been studied, however, came from exposures near or a short distance north of the crossing of the outcrop by United States Highway No. 62 (localities 2920, 2967, 7413, 7691, 7720, and 8596). These ammonoids belong mainly to three species: *Paraceltites elegans* Girty, *Texoceras texanum* (Girty), and *Peritrochia erebus* Girty. At one locality (7720) there is also *Agathiceras* cf. *A. girtyi* Böse, and at another (7701), *Perrinites hilli tardus* Miller and Furnish.[74] The genus *Perrinites*, although rare in the Guadalupe Mountains, is an abundant and characteristic fossil of the type Leonard series in the Glass Mountains, with which the Bone Spring limestone is correlated. According to Miller, a striking feature of the ammonoid specimens collected from the black limestone is that nearly all retain the living chamber, a fragile structure that is usually missing from specimens from other beds and other areas. This suggests that the shells were deposited in unusually quiet water.

Associated with the ammonoids are occasional nautiloids, which were represented in Girty's original collections by *Metacoceras shumardianum* (Girty). In the later collections Miller and Furnish[75] have identified the same species, and in addition, *Titanoceras* sp., "*Orthoceras*" sp., and *Stearoceras?* sp.

By contrast with the ammonoids, fusulinids are nearly absent from the black limestone, although they are abundant in the gray Victorio Peak limestone to the north, where ammonoids are absent (compare fig. 11). Their rarity in the black limestone contrasts with their abundance in most other beds of the Guadalupe Mountains section. Within the area studied they have so far been observed at only one locality in the black limestone (7923)—in a canyon a mile south of Bone Canyon. Here the black limestone contains *Schwagerina setum* Dunbar and Skinner, which is also found in the probably contemporaneous Victorio Peak limestones not far to the north.[76] At the point of the Delaware Mountains, 18 miles south of El Capitan, R. E. King in 1928 collected the genus *Parafusulina* from the black limestone.

Regarding the remaining, much greater part of the fauna, Dr. Girty reports as follows:

When the fauna of the "basal black limestone" was described in 1908, only two collections were available to me, and as they showed considerable difference in facies, it seemed probable that the fauna as a whole would prove to be a varied one. Although the two original collections made up a rather long composite faunal list, many of the species were so poorly represented that they were not identified specifically. To a number of these, King[77] later gave specific names, although in some instances the species were based upon specimens from other areas, and their identification in rocks of the Guadalupe Moun-

[74] Miller, A. K., and Furnish, W. M., op. cit., pp. 9–10, 1940.
[75] Miller, A. K., and Furnish, W. M., memorandum, May 1939.
[76] Dunbar, C. O., and Skinner, J. W., op. cit., p. 728, 1937.
[77] King, R. E., op. cit., 1931.

tains was not always made by comparison with specimens from that region.

In the original collections, the more primitive zoological groups were almost unrepresented. The fusulinids were especially noteworthy for their absence in view of their abundance in the Hueco limestone below, and in the Guadalupe series above. By reason of variety and especially number of individuals, this might be called a brachiopod fauna; the pelecypods and gastropods seemed to promise considerable variety also, but for the most part they were represented by so few and poor specimens that only generic identifications were practicable, and not all of these were very sound.

The later collections do not greatly amplify the knowledge of the more primitive zoological groups. Fusulinids have been found at only one locality [as noted above]. Corals and bryozoans are scatteringly represented, but offer no features of interest.

Much additional information, however, is now available on the other groups, and they prove to be more varied than the original descriptions would indicate. At the same time, the fauna now appears to be more closely bound to those of the higher Guadalupe series than it appeared when the earlier work was done. Most of the species found in the original collections persist throughout, but new ones also appear, as indicated in the discussion below.

Among the brachiopods, a species of *Enteletes* occurred in both the original collections, but as the specimens were poorly preserved, it was merely designated as *Enteletes* sp. c. The specific name *liumbonus* was subsequently given to it by King, and *E. liumbonus* King occurs in many of the later collections, and in most of them it is abundant.

In both the earlier and later collections, the Orthotetinae are mainly confined to the genus *Meekella*. In the earlier collections two species were recognized, *M. attenuata* Girty, and *M. multilirata* Girty; these are not so readily distinguishable in the later collections, although they are present in many of them and form a rather distinctive element of the fauna. In addition, two new species of the same genus may possibly be present.

In the original collections, *Chonetes* was represented by a single unidentified species, and the genus is neither common nor abundant in the later ones. Most of the specimens in the later collections can provisionally be identified with *C. subliratus* Girty.

One of the notable features of the fauna as originally known was the scarcity of Producti, only one species, cited as *Productus latidorsatus* Girty var., having been found. *Richthofenia* (now *Prorichthofenia*) *permiana* (Shumard) was, however, present in the collection, together with two species of *Aulosteges*, neither of them identified specifically.

In marked contrast to the earlier collections, productids prove to be abundant and varied in the later ones, but only the more common or the more conspicuous forms will be mentioned here. *Productus occidentalis* Newberry, or variants of it, are common; also *Productus* (*Pustula*) *subhorridus* Meek. These two species, with *P. guadalupensis* Girty, are perhaps the most abundant Producti in this fauna. The large and striking species commonly identified as *P. ivesi* Newberry is present in a number of collections, and is abundant in several. *P.* (*Pustula?*) *leonardensis* King, or a species closely related to it, occurs in a number of collections. Rarer, but more or less noteworthy, are *Productus* (*Cancrinella?*) *phosphaticus* Girty, *P.* (*Cancrinella*) *meekanus* Girty, *P.* (*Marginifera?*) *waagenianus* Girty, *P.* (*Waagenoconcha*) *montpelierensis* Girty, and *P.* (*Striatifera*) *pinnaformis* Girty. *Productus* (*Marginifera?*) *sublevis* King, *Aulosteges magnicostatus* Girty, and *A. subcostatus* King? are not rare. *Prorichthofenia permiana* (Shumard) is rather persistently present. The *Prorichthofenia* and two unidentified species of *Aulosteges*, it will be recalled, were found in the original collections.

Camerophoria venusta Girty, which was not one of the original members of the fauna, proves to be rather persistently present in the new collections, and more or less abundant.

The early collections furnished rhynchonellid shells in considerable abundance and variety, and a few of the later collections are notable for the same feature. The species originally recognized were described as *Pugnax nitida* Girty, *P. osagensis* Swallow, *P. bidentata* Girty, *P.*? *pusilla* Girty, and *Rhynchonella? longaeva* Girty. Most of these species are found in the later collections. *Rhynchopora* was not found in 1908, but *R. taylori* Girty occurs in one of the later collections. Three or four other species, apparently undescribed, may also be present.

Subsequently to 1908, Weller proposed the genus *Pugnoides* for shells of the general character of those in the fauna which were originally assigned to *Pugnax*, and King referred *P. bidentata* and *P. osagensis* to that genus. As the genus *Wellerella* has still more recently been erected for similar shells, with the Pennsylvanian species *W. tetrahedra* Dunbar and Condra as the genotype, *Wellerella* will tentatively be substituted for *Pugnoides* in this account, though the characteristics that would place these species under *Pugnax*, *Pugnoides*, or *Wellerella* are, broadly speaking, unknown. King did not treat of *Pugnax nitida* or *Rhynchonella longaeva*. He believes *P. osagensis* to be Shumard's *P. texana*, and he refers *P. pusilla* to the genus *Hustedia*. I [Girty] consider this erroneous. *P. pusilla* is a rhynchonellid, but its generic status is uncertain. The possibility that the form originally identified as *P. osagensis* might be Shumard's *Rhynchonella texana* was originally considered by me, and dismissed. At best, it is no more than a guess. However, it is almost certainly not *Wellerella osagensis*, as that species is now understood, so I shall use Shumard's name for the species until its relations can be determined.

The terebratuloids, which were unrepresented in the earlier collections, are rare in the later ones. They comprise only *Dielasma? scutulatum* Girty, found at two localities, and *Notothyris* n. sp. found at one.

The Spiriferidae were represented in the early collections by only one species, cited as *Spirifer* sp. b, while *Spiriferina* was not found at all. In the later collections, *Spirifer* proves to be rather abundant, but most of the specimens are much exfoliated and broken. Under these disadvantages, I hesitate to give them specific names. One form appears to be *Spirifer costella* King, and another which is larger and more coarsely plicated can be cited at present only as *Spirifer* aff. *S. triplicatus* Hall. Of course, both species belong in the pseudogenus *Neospirifer*. From one of the newer collections I now have a *Spiriferina*, or *Punctospirifer*, resembling *S. billingsi* (Shumard).

Squamularia and *Martinia*, two genera that were absent from the two early collections, are present in many of those recently acquired, and in some are abundant. Sound specific distinctions in these genera are difficult to make. Some of the *Squamulariae* may belong to *S. guadalupensis* (Shumard), and a few possibly to new species. *Martinia* is less abundant than *Squamularia*; the species appears to be undescribed. A third spiriferid genus, *Ambocoelia* (*A. arcuata* Branson), is introduced into the fauna by the new collections.

The never-failing *Composita* was present in the early collections (*C. mexicana guadalupensis* Girty), and of course is present in most of the later ones. None of the forms in either the old or new collections are novel, interesting, or significant in any way. Much the same can be said for *Hustedia*, of which the original collections contained *H. meekana* (Shumard) and *H. papillata* (Shumard)?. Shells of this genus run through most of the recent collections, forming a constant but relatively unimportant element in the fauna. Most of them are referable to *H. meekana.*

The notable genus *Leptodus*, which was not found in the original collections, occurs in two of the later ones. The species is probably *L. americanus* Girty.

In the original collections the pelecypods, though showing considerable differentiation, were represented by specimens so poor and so few that no specific identifications were made, and some of the generic identifications were more or less uncertain. The same conditions prevail in the recent collections, though some of the genera are surer, and the relation of some of the species more definite. It is somewhat remarkable that there does not appear to be a closer agreement in generic representation between the early collections and the later ones. Besides a number of forms that are identified only generically, mention may be made of *Edmondia* aff. *E. gibbosa* (McCoy), *Parallelodon* aff. *P. politus* Girty, *P.* aff. *P. sangamonense* (Worthen), *Solenomya* n. sp., *Anthaconeilo* n. sp., *Aviculopecten* n. sp., *Plagiostoma deltoideum* Girty, and *Cleidophorus pallasi delawarensis* Girty. I should note here that the diversified representation among the pelecypods is due mainly to their abundance in a few collections and that in those collections the brachiopod representation is small, especially among the Producti, which in other collections show much variety. This relation is much less true of the gastropods, whose features are noted below.

The gastropods of the original collection were represented by better material than the pelecypods, and the following forms were recognized: *Pleurotomaria? arenaria monilifera* Girty, *P. strigillata* Girty, *Straparollus sulcifer* (Girty) *Naticopsis* sp., *Loxonema? inconspicuum* Girty, and *Macrocheilina? modesta* Girty. Since the name *P. strigillata* has later proved to be preoccupied, I have proposed *P. pseudostrigillata* as a substitute. J. B. Knight's recent studies among the gastropods have necessitated a great many changes in nomenclature. No final revision of the species described in 1908 or adjustment to these changes can be made until the new material is given descriptive treatment. Consequently many of the gastropods cited below are given under generic names originally used, although it is recognized that they are subject to change.

The later collections contain most of the gastropod species cited above, and also many not previously known. Bellerophontids are rather numerous, but few of them are generically identifiable. *Bellerophon* s. s., *Bucanopsis*, and *Euphemites* are probably represented, although not by identifiable species. A species of *Omphalotrochus*, a species of *Eotrochus*, and one or two species of *Bulimorpha* can be added to the list.

Two trilobites were distinguished in the fauna as originally described, *Anisopyge perannulata* (Shumard) and *A.? antiqua* Girty. In the later collections the first species cited occurs rather persistently, and the second rather sparingly.—Girty manuscript.

VICTORIO PEAK GRAY MEMBER

Fossils are abundant in many beds of the Victorio Peak gray member, but are not always easy to collect, because of the hardness of the rock, and, in places, because of subsequent dolomitization or silicification. The material obtained during the present investigation therefore consists of a relatively small number of collections. Dr. Girty states that many of the specimens in these collections are so fragmentary that they can be identified only by careful comparisons, if at all.

According to Dr. Girty, the faunas of the member closely resemble those of the black limestone beds, and are distinguished more by the absence of forms that are present in the black limestone, than by the introduction of novel or instructive elements. Many of the collections consist entirely of brachiopods, and especially of the larger productids and spiriferoids. The fauna differs notably from that of the black limestone beds in the almost complete absence of cephalopods. No ammonoids have been found, and only one nautiloid (a *Tainoceras* according to A. K. Miller). The fauna differs from that of the black limestone also in the rather great abundance of fusulinids in certain beds in the upper division (fig. 11, *A*). They belong to two species, *Schwagerina setum* Dunbar and Skinner, and *Parafusulina fountaini* Dunbar and Skinner.

The lower division of the Victorio Peak member is represented by only one collection, made on the south bank of Shumard Canyon at its entrance (locality 7725). For it Dr. Girty gives the following provisional list, with several indeterminate forms omitted.

Lophophyllum? sp.
Enteletes liumbonus King
Meekella attenuata Girty
Chonetes subliratus Girty var.
Chonetes sp.
Productus ivesi Newberry
Productus occidentalis Newberry
Productus guadalupensis Girty?
Productus aff. *P. whitei*
Productus leonardensis King
Productus (*Pustula*) *subhorridus* Meek
Productus (*Cancrinella?*) *phosphaticus* Girty
Camerophoria venusta Girty
Wellerella? texana (Shumard)
Rhynchopora taylori Girty
Spirifer aff. *S. triplicatus* Hall
Squamularia guadalupensis (Shumard) var.
Edmondia? sp.

The upper division of the Victorio Peak gray member is somewhat better represented by collections. The material from each locality is rather scanty, however, and the specific representations are mostly confined to two or three specimens. The largest collections were obtained on the crest of the ridge between Shumard and Shirttail Canyons, whose summit stands at 6,402 feet (locality 7690). Regarding the fauna of the upper division, Dr. Girty writes:

The more primitive zoological groups, with the exception of fusulinids, are hardly represented at all. Among the brachiopods, *Enteletes liumbonus* King is present but is apparently scarce. *Meekella* (*M. attenuata* Girty) is fairly persistent. The Producti include *Productus ivesi* Newberry, which is generally persistent, and at station 7690 is abundant. Also worthy of note are *P.* (*Waagenoconcha*) *montpelierensis* Girty, *P.* (*Marginifera?*) *eucharis* Girty, and *Productus* (*Linoproductus*) *cora* D'Orbigny var., which is abundant at station 7690. A variety of *Camerophoria venusta* Girty (possibly a new species) is abundant at station 7680. Rhynchonellids, which were plentiful and varied in the black limestone are almost absent.

Spirifer aff. *S. triplicatus* Hall occurs in several of the collections from this zone, and is abundant at station 7680. As already remarked, it has seemed inexpedient to make a close identification of the spirifers on the material present, although a satisfactory classification may be possible with intensive study. A species of *Squamularia* (possibly new) is present in three of the collections. Pelecypods and gastropods, although present, are rare, and afford nothing worthy of note.—Girty manuscript.

CUTOFF SHALY MEMBER

As will be recalled, the name Cutoff shaly member is given to discontinuous sets of beds at the top of the Bone Spring limestone, which are exposed in three general districts: the northwest part of the area, from which the name is derived; in Shumard Canyon, not far from Bone Spring, where it is separable into two divisions; and along the base of the Delaware Mountains in the southern part of the area. In all of these districts, the member contains some fossils, but the collections which have been made so far are too scanty to furnish much information on the correlation of the beds in the different districts.

Fossils are least abundant in the northwestern exposures, from which the member is named, and in the main part of the member only a poorly preserved imprint of a pelecypod was seen (locality 7650). Some of the black limestone beds near the base, however, contain many small brachiopod shells, but they have not been collected or studied. Several miles north of the New Mexico line, the member contains rather abundant specimens of *Chonetes* (locality 7727).

Only one collection was made in the member in the Shumard Canyon area. This collection was obtained from a lens of massive limestone interbedded in the black limestones of the lower division of the member on the south side of the south fork of Shumard Canyon (locality 7675). Regarding it, Dr. Girty writes:

The collection comprises only 10 species, few of which are represented by more than one specimen. Consequently, the fauna, compared with the more varied ones which preceded it, is distinguished more by what is absent than by what is present. I do not find here either *Enteletes liumbonus* King, or *Productus ivesi* Newberry, or the numerous and varied rhynchonellids, but on the other hand, we do have *Meekella attenuata* Girty, *Productus occidentalis* Newberry, *Prorichthofenia permiana* (Shumard), and a species of *Spirifer* related to *S. triplicatus* Hall.—Girty manuscript.

Fossils are more numerous in the Cutoff shaly member in the southern part of the area, west of the Delaware Mountains. Here, many of the thin limestone beds contain fusulinids, which belong to an undetermined species of *Parafusulina*, and some contain brachiopods. The largest collection was made on the north side of Brushy Canyon in its lower course, from a limestone bed in the lower part of the member, which has here thickened to the rather unusual amount of 15 feet (locality 7666). On this collection, Dr. Girty reports as follows:

The collection is large, and the fauna is accordingly varied, comprising over 40 species. It contains a few bryozoans and a few pelecypods which afford nothing worthy of note, and the fauna is essentially a brachiopod fauna. *Enteletes liumbonus* King, which heretofore has been rather persistent and sometimes abundant, has not been found. *Meekella* is represented by *M. attenuata* Girty, and possibly by two new species. The Producti are highly diversified although, except for an abundant species that may provisionally be identified as *Productus occidentalis* Newberry, most of the forms are represented by only a few specimens. Species more or less closely allied to *P. occidentalis* occur in the Bone Spring faunas already passed in review, although they have not always been mentioned. Among the less abundant Producti, the most noteworthy are *P. guadalupensis* Girty, *P.* (*Marginifera?*) *waagenianus* Girty, *P.* (*Waagenoconcha*) *montpelierensis* Girty, *P.* (*Pustula*) *subhorrida* Meek var., besides which are *Aulosteges hispidus* Branson (not hitherto recognized in the Bone Spring fauna), *A. guadalupensis* Shumard, and *A. magnicostata* Girty, a species that has occurred sporadically in the Bone Spring faunas already reviewed. Here also belong *Prorichthofenia permiana* (Shumard), and a species of *Teguliferina?* that has not been encountered heretofore.

Camerophoria venusta Girty again makes its appearance and the Rhynchonellidae, though few in number, are varied. They include several species that may be provisionally referred to *Wellerella*, such as *W. bidentata* (Girty) and *W.? indentata* (Shumard).

The Spiriferidae, which are rather abundant, are represented by at least two species, one of which may be tentatively identified as *Spirifer costella* King, the other as *S.* aff. *S. triplicatus* Hall. Present also is *Martinia rhomboidalis* Girty, a species which is fairly abundant and is hardly distinguishable from the typical form that occurs in the Capitan limestone. We also have a species of *Squamularia*, a nondescript *Composita*, and the persistent *Hustedia meekana* (Shumard). *Leptodus americanus* Girty occurs here as it does at lower and higher horizons. The absence from this fauna of two species that have been found more or less persistently in the Bone Spring faunas previously reviewed is noteworthy. Neither *Enteletes liumbonus* King nor *Productus ivesi* Newberry have been recognized in the Cutoff shaly member.—Girty manuscript.

CONDITIONS OF DEPOSITION

GENERAL RELATIONS

The Permian rocks exposed in the Guadalupe and Delaware Mountains, and the Sierra Diablo, were laid down during a well-marked depositional cycle which formed the closing stages of the Paleozoic era. This cycle commenced with the Wolfcamp epoch of Carboniferous or Permian age. By the beginning of Wolfcamp time, the localized mountain-making and the still more widespread crustal unrest that had characterized the preceding Pennsylvanian time in the southwestern United States had largely ceased. Readjustments then began which brought into existence the depositional provinces of Permian time (shown on figure 3). These provinces appear to have been broad, persistent tectonic features, that had a marked influence on sedimentation.

At the opening of the Wolfcamp epoch, deposition began in an advancing sea which spread over a deformed and eroded surface of Pennsylvanian and older rocks. From this epoch to the end of the Permian, a distinctive and characteristic set of deposits was laid down in the west Texas region, and sedimentation was interrupted by only minor pulsations which serve to divide one epoch from the next. In this report, Permian geologic

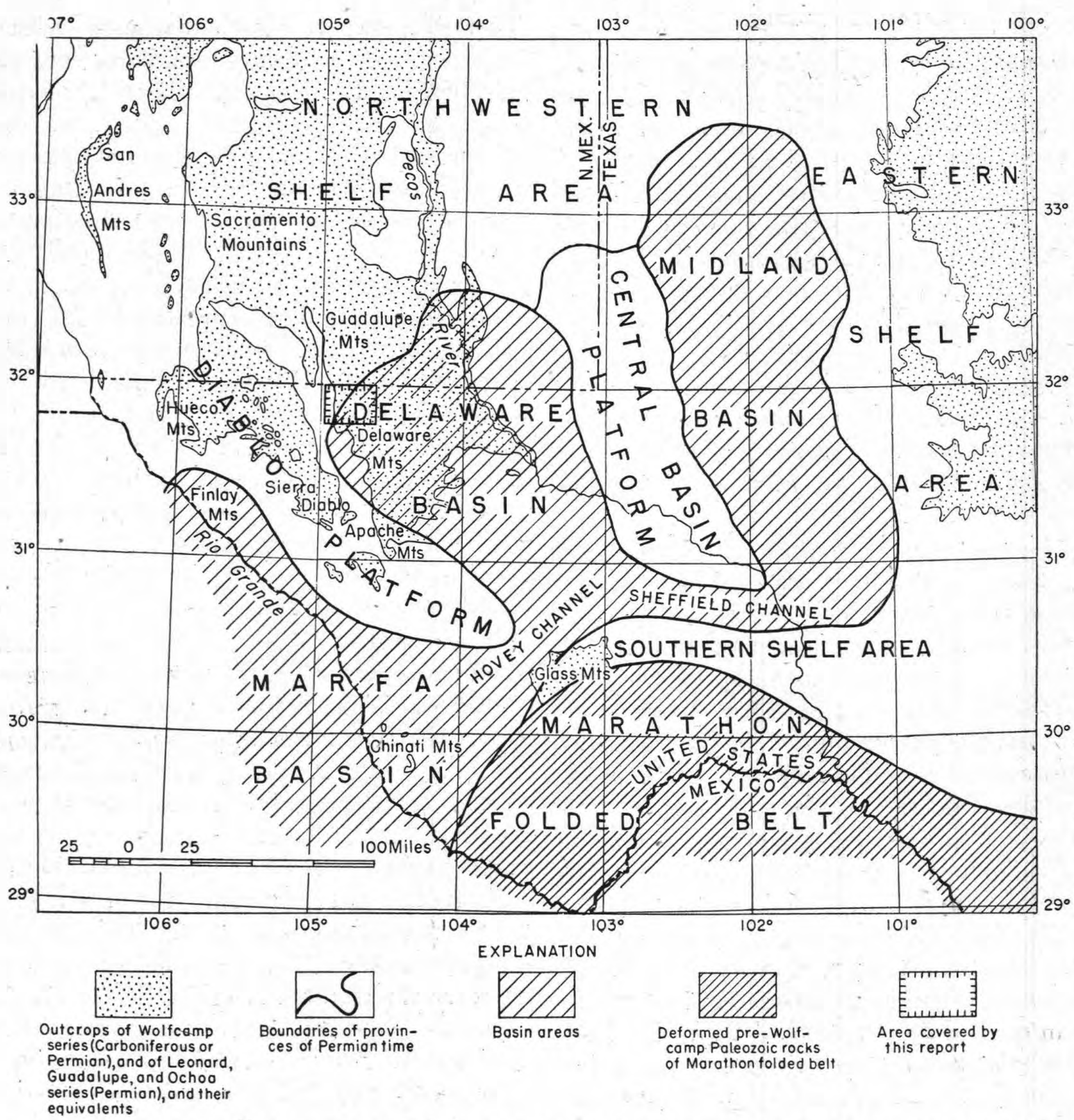


FIGURE 3.—Index map of parts of western Texas and southeastern New Mexico, showing provinces of Permian time.

history in west Texas is summarized at the end of the stratigraphic discussion, and on the maps of figures 13 and 14. Under the present heading, only those features that were directly related to the Guadalupe Mountains region are discussed.

In the Guadalupe Mountains region, the deposits of Wolfcamp and Leonard age are not completely revealed by exposures. Additional information is afforded, however, by the two wells already mentioned, and by exposures in the nearby Sierra Diablo. Judging by the thickness of sediments laid down (as suggested by plate 7, *B*), the Wolfcamp and Leonard epochs were fully as long and as important as the succeeding Guadalupe epoch, whose rocks are more completely exposed in the area of this report.

FACIES AND PROVINCES

During Leonard time (as represented by the Bone Spring limestone), and probably during Wolfcamp time (as represented by the Hueco limestone and other Beds), two unlike facies were deposited in the Guadalupe Mountains region. Deposits of the one are black, petroliferous, shaly limestone, and of the other are light-gray, thick-bedded to massive limestone. The two facies tended to persist in separate areas, which correspond closely to the provinces of Permian time shown on figures 3 and 16, *A*. Thus, the black limestone facies characterizes the southeast part of the Guadalupe Mountains region, or Delaware Basin of figure 16, *A*, and the gray limestone facies characterizes the northwest part, or Northwestern Shelf Area of that figure. The basin appears to have been a negative feature, with a marked tendency toward subsidence; the shelf was more positive, and either remained stable or did not subside as much. During Leonard time, the boundary between the provinces lay along the Bone Spring flexure of the Guadalupe Mountains which, it will be recalled, is bent down southeastward toward the basin area.

BLACK LIMESTONE FACIES

In the Delaware Basin conditions throughout the whole of Leonard time were nearly uniform and the black limestones were laid down in successive beds without the admixture of much other material.

Deposits representing this facies consist mainly of calcium carbonate, impregnated with bituminous material which imparts to them their characteristic color. There is also some argillaceous matter and a small amount of primary silica. Parts of the deposit are thinly laminated by light and dark bands in such a manner as to suggest that the amount of organic matter in the sea water fluctuated from seasonal or other causes, and that the water was sufficiently quiet for the material to be laid down in successive layers on the bottom.

Evidently the sea bottom during the time of deposition was not favorable to life, as great thicknesses of strata are nearly unfossiliferous. In many of the fossiliferous lenses, ammonoids are the chief fossils, and these animals were probably free-swimming organisms whose shells dropped to the bottom after death. The associated brachiopods and mollusks, which were certainly bottom-dwellers, are of a relatively few species, and fusulinids are absent. This general impoverishment, however, is not absolute, for some collections within the black limestone contain specimens of productids, spiriferoids, and other brachiopods that are abundant in the gray limestone facies. Further, the trilobites that have been found are not specialized forms but belong to the same species as those found elsewhere in the region in quite different types of deposits. Perhaps the less-specialized animals were occasional migrants into an environment that on the whole was not favorable to them.

The black limestones were evidently laid down in quiet water. The bituminous material with which they were impregnated could not have been preserved unless there was little circulation of the water and such a lack of oxygen near the bottom that organic matter was deposited faster than it decayed. These assumed conditions are confirmed by the general poverty of bottom-dwelling organisms in the fauna, and the relative abundance of ammonoids, which swam nearer the surface. Quiet water conditions near the bottom are further indicated by the presence in the ammonoid specimens of the fragile living chamber, which would have been destroyed if the shells had accumulated in agitated water. The conditions just outlined closely resemble those under which the black shales of earlier Paleozoic systems presumably formed.[78]

Quiet-water conditions during deposition of black shale and limestone deposits do not necessarily indicate the depth of water under which the beds accumulated. There is, however, some evidence to indicate that the beds in the Bone Spring limestone were deposited in deep water. Relations at the Bone Spring flexure, outlined below, suggest that the water was deeper to the southeast, in the black limestone area, than to the northwest, in the gray limestone area. Moreover, the gray limestone deposits seem to have accumulated in agitated water, and it is difficult to see how such differences of deposition could have existed unless there had been also a difference in depth. Further, the Delaware Basin or area of black limestone deposits, received a greater thickness of sediments during Leonard time than the shelf area or area of gray limestone deposits. This greater thickness indicates that the basin area subsided more than the shelf area, and thereby entrapped more sediments. It is possible that subsidence was so rapid that sedimentation did not entirely keep pace with it, and the sea floor stood lower in the basin than on the shelf (sec. *a*, pl. 7, *B*).

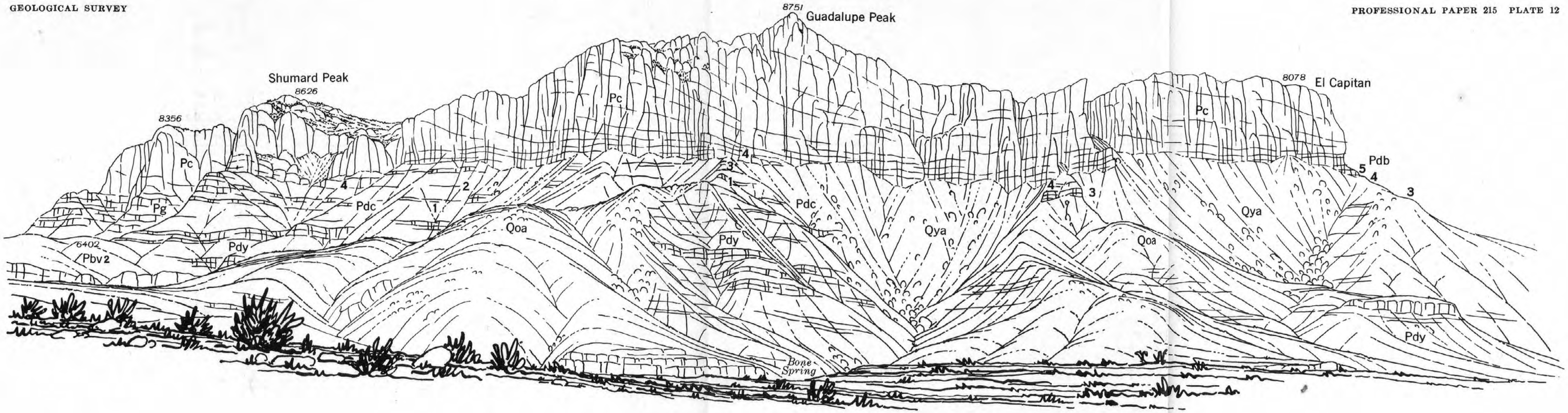
The black limestone deposits are notably poor in sand and other, coarser, clastics. The few thin, interbedded sandstone layers are very fine grained and consist of the more resistant minerals of igneous and metamorphic rocks. Evidently these sands were transported from a distant source. In its lack of coarser clastic material the black limestone contrasts markedly with the deposits of the Guadalupe series (Delaware Mountain group) that succeeded them, and also with contemporaneous deposits of the Leonard series in the Glass Mountains,[79] on the southeast side of the Delaware Basin (fig. 13, *B* and *C*). In the Glass Mountains, the deposits include sandstones and conglomerates derived from the erosion of older Paleozoic rocks of the newly uplifted Marathon folded belt. Evidently they were not spread far northwestward into the basin. The few sandstone beds in the black limestone might have been derived from this source, but the fact that similar sandstones are interbedded in the gray limestone toward the northwest suggests that at least some of the sand also probably came from the opposite direction.

MARGINAL AREA

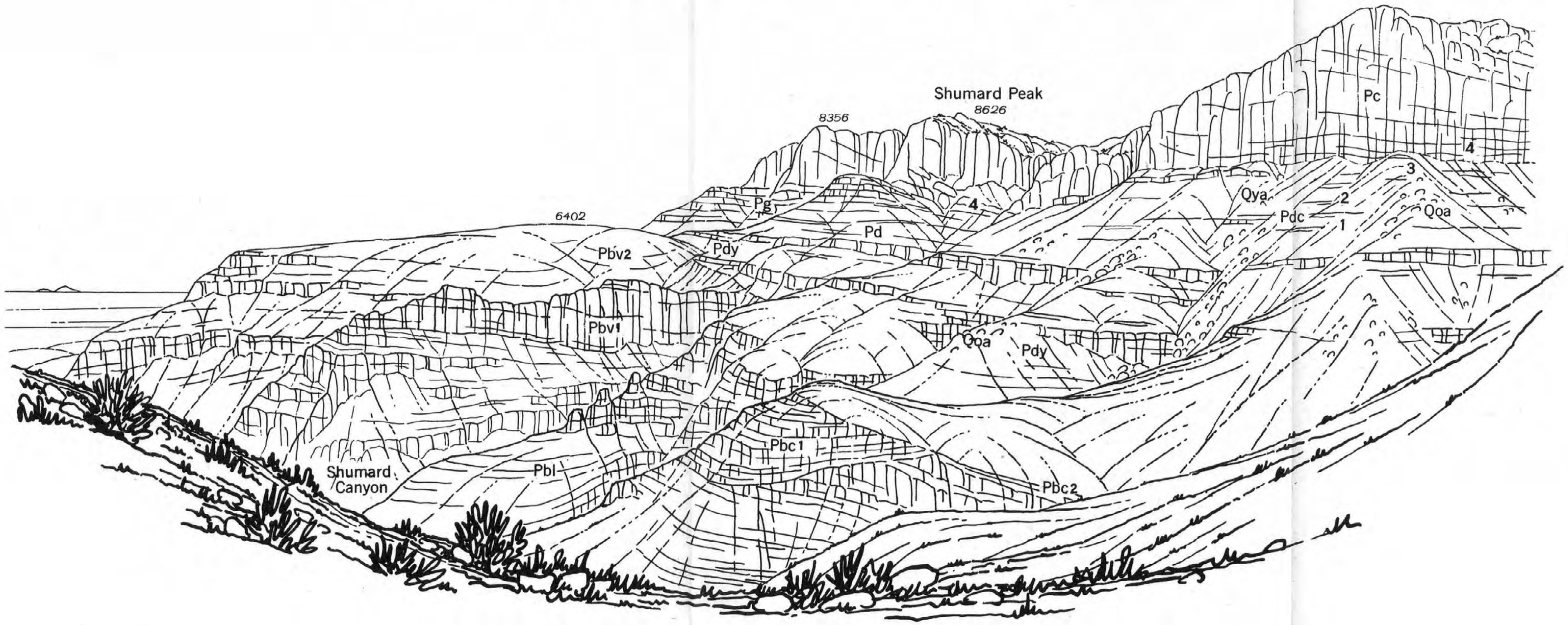
In the marginal area, between the Delaware Basin and the northwestern shelf area, deposits of the black limestone and gray limestone facies interfinger. During the last half of Leonard (Bone Spring) time, the gray Victorio Peak member was spread out on the shelf area, extending as far southeastward as the edge of the Delaware Basin, where it apparently intergraded with black limestone. During the first half of Leonard time, black limestones extended for several miles farther northwestward toward the shelf, underneath the gray Victorio Peak beds. In the Guadalupe Mountains, exposures of the black limestone do not extend

[78] Twenhofel, W. H., Treatise on sedimentation, 2d ed., pp. 259–265, Baltimore, 1932.

[79] King, P. B., Geology of the Glass Mountains, part 1: Texas Univ. Bull. 3038, pp. 63–69, 1931.



A. EL CAPITAN TO SHUMARD PEAK, LOOKING NORTHEAST FROM RIDGE ON SOUTH SIDE OF BONE CANYON.



B. NORTH SLOPE OF GUADALUPE PEAK TO SHUMARD PEAK, LOOKING NORTH FROM RIDGE ON SOUTH SIDE OF SHUMARD CANYON.

PANORAMIC VIEWS OF CLIFFS AND MOUNTAIN SLOPES NEAR BONE SPRING.

For locations, see plate 2. Show stratigraphic features in Bone Spring limestone, Delaware Mountain group, Goat Seep limestone, and Capitan limestone and the manner in which they have been eroded. Note slope deposits of various ages. *Qya,* Younger alluvial deposits; *Qoa,* older alluvial deposits; *Pc,* Capitan limestone; *Pdb,* Bell Canyon formation (5, Pinery limestone member, 4, Hegler limestone member); *Pg,* Goat Seep limestone; *Pdc,* Cherry Canyon formation (3, Manzanita limestone member, 2, South Wells limestone member, and 1, Getaway limestone member); *Pd,* Sandstone tongue of Cherry Canyon formation; *Pdy,* Brushy Canyon formation; *Pbc1* and *Pbc2,* lower and upper divisions of Cutoff shaly member of Bone Spring limestone, *Pbv1* and *Pbv2,* lower and upper divisions of Victorio Peak gray member, and *Pbl,* black limestone beds.

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deeply enough to indicate their relations to the shelf area. In the Sierra Diablo, however, they are replaced near the shelf by limestone reefs—a part of the gray limestone facies. They overlap shelfwards on a surface of unconformity that separates the Leonard from the underlying Wolfcamp series.

In the Guadalupe Mountains, the southeastern edge of the gray Victorio Peak limestones follows the upper part of the Bone Spring flexure. This relation of depositional facies to a tectonic feature is probably more than accidental, and implies that the flexure was in existence at the time of deposition. The unconformities in the Bone Spring limestone in Bone and Shumard Canyons suggest contemporaneous movements on the flexure. Possibly also, the small-scale contortion in the black limestone farther southeast was caused by subaqueous gliding of the newly deposited sediments away from the upraised surface of the flexure.

On the Bone Spring flexure, the unconformity at the top of the Bone Spring limestone (between it and the Delaware Mountain group) is clearly much greater than the local unconformities within the Bone Spring. This condition might be taken to indicate that the main movement on the flexure came at the end of Leonard (Bone Spring) time, were it not for opposing evidence. During Leonard time, the water in the basin southeast of the flexure was deep. Further movement on the flexure would either deepen the water in the basin still more, or cause a marked uplift in the shelf area. Neither of these events took place. Actually, as summarized in a later part of this report, the water in the basin during the first part of Guadalupe (Brushy Canyon) time, was probably much shallower than during Leonard time. Also, the shaly, poorly resistant Cutoff member, the last deposit of the Bone Spring limestone, underwent almost no pre-Guadalupe erosion in the shelf area, and its beds lie parallel to those of the succeeding series. These conditions suggest that no uplift took place in the shelf area.

The marked unconformity at the top of the Bone Spring limestone on the flexure thus probably resulted not so much from accentuation of tectonic movements along the edge of the Delaware Basin at the end of Leonard time as from some more widespread phenomenon, such as a general lowering of sea level in the basin, by regional uplift, eustatic change, or other causes.

The Bone Spring flexure, although exposed in only a small area in the Guadalupe Mountains, probably had a wide extent along the northwest edge of the Delaware Basin (fig. 16, *A*). During late Leonard and early Guadalupe time, it certainly extended southwestward for some distance, as indicated by certain relations at the north end of the Sierra Diablo. Here outliers of the Cherry Canyon, or middle formation of the Delaware Mountain group lie directly on the Bone Spring limestone, just as they do northwest of the flexure in the Guadalupe Mountains (pl. 7, *A*). The flexure is probably buried under the Salt Basin deposits east of the outliers, for farther east, in the Delaware Mountains, the Cherry Canyon is separated from the Bone Spring limestone by the full thickness of the Brushy Canyon or lower formation of the Delaware Mountain group.

GRAY LIMESTONE FACIES

The gray limestone deposits (Victorio Peak gray member) north of the Bone Spring flexure were probably laid down in shallower, clearer, better aerated water than the black limestones. Their moderately thick beds include layers, traceable for relatively long distances, that were spread out in broad sheets. They are thus unlike the irregularly bedded, massive limestone deposits higher in the section, which have the form of reefs. The Victorio Peak deposits are better designated as limestone banks than as limestone reefs.

The area of gray limestone deposition was a more favorable environment for life than the black limestone area. The many large, thick-shelled productids, spiriferoids, and other brachiopods found in the gray limestone probably found favorable living conditions in clear, shallow waters. The abundance of fusulinids in the gray limestones contrasts with their absence in the black limestones. Conversely, ammonoids which are abundant in the black facies are absent in the gray (fig. 11). It is possible that ammonoids originally lived in both areas, and in the gray limestone area their shells were largely destroyed in the agitated water and were not embedded in the sediments. Support for this suggestion is found in the fact that the nautiloids, whose life habits were similar to those of ammonoids but whose shells were stronger, are represented in the collections from both areas.

LOWER PART OF GUADALUPE SERIES

TERMINOLOGY OF DELAWARE MOUNTAIN GROUP

The great body of sandstone that forms the surface of the Delaware Mountains and parts of the slopes of the Guadalupe Mountains was noted during the first geological exploration of the region. In 1904, Richardson[80] named it the Delaware Mountain formation. Richardson's type section was at the south end of the Guadalupe Mountains, where the sandstones are limited above by the Capitan limestone. He included in the formation all the sandstones of the Delaware Mountains, the highest part of which is now known to be younger than the highest standstones of the type section. As originally defined the unit included the part of the Bone Spring limestone that is exposed at the base of the

[80] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railroad: Texas Univ. Bull. 23, p. 38, 1904.

mountains. At about the same time Girty [81] proposed the broader term Guadalupe or Guadalupian series (later classed as a group by the Survey), which included all the exposed fossiliferous rocks of the Guadalupe Mountains.

Subsequent work has resulted in some modifications in usage. The Bone Spring limestone was found to be such a well-marked entity, so different from the beds above, that it has been excluded in redefinitions of both Delaware Mountain [82] and Guadalupe.[83] In the Delaware Mountains, Beede [84] demonstrated that the Delaware Mountain beds above the Bone Spring limestone were divisible into three distinct and nearly equal parts, which later were considered of formation rank. These parts are now termed the Brushy Canyon, Cherry Canyon, and Bell Canyon formations of the Delaware Mountain group.[85]

In the Delaware Mountains, according to the new definitions, the Delaware Mountain group and the Guadalupe series have the same limits in the sequence, but each term has a different connotation. The name Delaware Mountain is applied to a distinctive facies of dominantly sandy rocks, which projects as tongues between other units of different facies but in part of the same age. The name Guadalupe, on the other hand, is used for a time unit, applied over the whole of the west Texas region to rocks of the same age.

SUBDIVISIONS OF GUADALUPE SERIES

From the standpoint of physical and faunal history, the Guadalupe series can conveniently be divided into three subordinate time units, whose limits correspond to those of the three formations of the Delaware Mountain group. The Guadalupe series is limited below and above by unconformities and abrupt changes in sedimentation, and the three subordinate units are parts of a continuous sequence of sediments lying between. They express more or less perfectly the gradual changes in sedimentation and faunas that took place, by virtue of the passage of time, within a single cycle of sedimentation.

In this report, it is convenient to consider the three subordinate units under separate headings—lower, middle, and upper parts of Guadalupe series—and to describe in turn the various features of each. As a result of this arrangement, it will be noted that the parts of the Delaware Mountain group are separately described under three successive headings, along with the formations with which each is correlative.

[81] Girty, G. H., The upper Permian of west Texas: Am. Jour. Sci., 4th ser., vol. 14, pp. 363–368, 1902.

[82] King, P. B., Permian stratigraphy of trans-Pecos Texas: Geol. Soc. America Bull., vol. 45, p. 765, 1934.

[83] Adams, J. E., and others, Standard Permian section of North America: Am. Assoc. Petroleum Geologists Bull., vol. 23, p. 1675, 1939.

[84] Beede, J. W., Report on the oil and gas possibilities of the University block 46 in Culberson County: Texas Univ. Bull. 2346, pp. 13–14, 1924.

[85] King, P. B., The Permian of west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 26, pp. 577–586, 1942.

BRUSHY CANYON FORMATION

In the Delaware Mountains, the Delaware Mountain group is a mass 2,700 to 3,475 feet thick, whose component formations divide it into approximately equal thirds. The lowest formation was described by Beede as consisting of "thick, yellowish standstones with rather distant shale partings"; it maintains this character over wide areas. Its present name is derived from Brushy Canyon, which drains westward across the Delaware Mountain escarpment a short distance south of United States Highway No. 62 (pl. 3); along its course the whole thickness of the formation is exposed. The Brushy Canyon formation rests on the Cutoff shaly member of the Bone Spring limestone, and its top is formed by a persistent, massive sandstone ledge that is nearly continuous throughout the area (pl. 7, *A*). The ledge is prominently developed on the slopes below El Capitan, where it forms a flat projecting bench about halfway up the slope from the black limestone bench to the limestone cliff above (pl. 1).

The Brushy Canyon formation crops out in a broad belt on the west side of the Delaware Mountains, and extends northward along the west slope of the Guadalupe Mountains. North of Bone Canyon, it thins by overlap on the Bone Spring limestone, and its outcrop comes to an end a few miles to the north. The formation is exposed also at many places west of the Delaware Mountains, where it has been downdropped by faulting. In the Delaware Mountains, its outcrop has been cut by many strike faults, so that its full thickness cannot be determined. Below El Capitan, it is about 1,000 feet thick (sec. 18, pl. 6), and in the Niehaus et al., Caldwell No. 1 well, 35 miles east-southeast of El Capitan, it is 1,152 feet thick (pl. 6).

The formation consists largely of sandstone, a part of which, coarser grained than the rest, stands out in massive, yellow or brown ledges or forms the caps of flat-topped mesas (pl. 14, *C*). Great, rectangular blocks of this sandstone are strewn on the slopes below the ledges. Between the massive sandstones are fine-grained, thin-bedded, or even shaly sandstones, which crop out on slopes.

The formation is easily recognizable on air photographs by its strong ledges, which contrast with the smoothly rounded slopes of the overlying Cherry Canyon formation; and by the abundance on it of cedar and other trees, which give its outcrop a speckled appearance in the photographs.

MASSIVE SANDSTONE BEDS

The massive beds that form the most conspicuous parts of the formation consist of buff or yellowish, medium-grained, friable sandstone, which on some weathered surfaces is coated with a brown crust. Many of the layers contain widely spaced, parallel laminae, and some are cross-bedded. Many of the bedding surfaces are ripple-marked, particularly north of Bone Canyon on the Bone Spring flexure, where the beds overlap the surface of the Bone Spring limestone. Here the general trend is northeastward, parallel to the edge of the flexure, and the same trend is also common farther south (fig. 6). Many of the massive sandstones rest on an undulatory, channeled surface of the thin-bedded sandstones next beneath.

The massive sandstone beds form members from a few feet to more than a hundred feet thick, which alternate with thinner-bedded sandstones. In the south part of the area the beds are thick and closely spaced, but below El Capitan there are only four or five such beds, and for about a mile along the outcrop near Bone

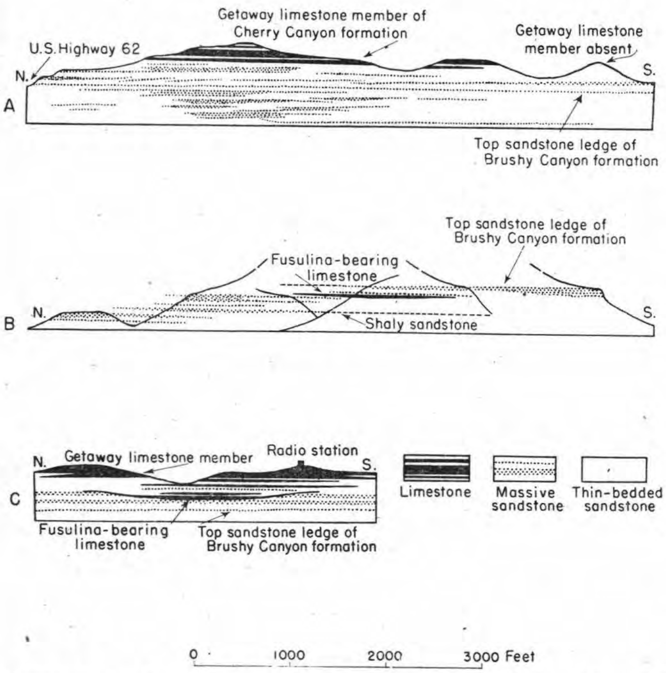


FIGURE 4.—Sections showing lenticular nature of massive sandstones of the Brushy Canyon formation, and of limestones of Getaway member of Cherry Canyon formation. *A*, East side of Guadalupe Canyon south of Guadalupe Pass; *B*, West slope of El Capitan; *C*, Delaware Mountain escarpment near Guadalupe Summit radio station.

Canyon they are absent entirely (secs. 14 and 15, pl. 6). The massive beds thicken and thin rapidly along the strike. On the south slope of El Capitan they are replaced laterally by layers of hard, shaly sandstone. At some localities, lenses of massive sandstone are arranged en echelon, as though a single channel or basin had migrated upward and laterally as sedimentation went on (fig. 4, *A* and *B*). A few of the beds are persistent; that at the top of the formation can be traced across nearly the entire area, and some others lower down persist for several miles.

Four specimens of sandstone from the massive beds were studied under the microscope by Ward Smith. The chief minerals are quartz, microcline, and plagioclase; they have a maximum grain size of 0.5 millimeter, and are set in a calcareous matrix. Small amounts of zircon and a few other accessory minerals are present. The grain size is notably coarser than that of other sandstones of the Delaware Mountain group or Bone Spring limestone, in which the maximum diameter is 0.1 to 0.2 millimeter. The only comparable sandstones are in the Goat Seep and Carlsbad formations, in the younger part of the Guadalupe series in the northwest part of the area. In the massive sandstones of the Brushy Canyon formation the accessory minerals are less abundant and varied than in the finer-grained sandstones of the Bone Spring limestone and Delaware Mountain group.

OTHER ROCKS

Many of the massive sandstones contain scattered calcareous tests of fusulinids, and in some lenticular beds these tests are so numerous and the sandstone matrix so scant that the rock is more properly called a limestone. Several of the larger of these beds in the Delaware Mountains are separately shown on the geologic map, plate 3. Some of the calcareous lenses contain abraded crinoid stems and brachiopod shells. The fusulinid tests tend in each layer to have a common orientation in some one direction, as shown on plate 19, *B*, but the direction may differ in different layers. Very commonly the trend is between north and west (fig. 6), or nearly at right angles to the prevailing trend of ripple marks in nearby beds.

The thin-bedded sandstones that lie between the massive beds are generally buff and fine-grained, and are marked by closely set, light and dark laminations, suggestive of varves. In places there are thin, interbedded layers of black, hard, platy, shaly sandstone.

At two localities in Guadalupe Canyon, 250 feet below the top of the formation, there are thin beds of green siliceous shale or chert (in secs. 24 and 27, pl. 6). They may consist of altered volcanic ash like similar rocks in the Manzanita limestone member of the overlying Cherry Canyon formation, but no verification is available because no thin sections were examined.

RELATIONS OF BRUSHY CANYON FORMATION IN BONE CANYON AND NORTHWARD

In Bone Canyon, at the lower end of the Bone Spring flexure, the basal 100 feet of the Brushy Canyon formation consists of conglomerate, limestone, and medium-grained, thin- to thick-bedded sandstone (as shown on pl. 13).

The conglomerates in the canyon form several beds, as much as 10 feet thick, interbedded with sandstone and composed of pebbles, cobbles, or even boulders up to 4 feet in diameter.[86] The smaller fragments are of black limestone like that in the underlying Bone Spring limestone, but many of the cobbles and boulders are of

[86] Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, p. 114, 1920. Darton, N. H., and Reeside, J. B., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 421–423, 1926.

gray limestone or dolomitic limestone, and a few are of calcareous sandstone. The latter can be matched with rocks seen in place in the Victorio Peak gray member of the Bone Spring limestone not far to the north (see pp. 18–19) and contain similar fossils. The conglomerates have a lenticular development along the outcrop for 1½ miles to the south, and boulders of gray limestone occur for a mile south of the canyon. North of the canyon, higher on the flexure, the sandstones of the Brushy Canyon formation rest on the Bone Spring with no intervening conglomerate.

In the vicinity of Bone Canyon, a layer of fine-grained, in part sandy, gray limestone as much as 30 feet thick overlies the basal conglomerates and sandstones. (This forms the 28-foot interval shown in sec. 15, pl. 13.) It overlaps on the Bone Spring limestone in the next ravine north of the canyon (pl. 13, fig. *A*). Southward it thins out and disappears in the sandstones. Near the point of its disappearance, a mile south of the canyon, another similar limestone bed occurs in the sandstones beneath. (This forms the 18-foot interval shown in sec. 55, pl. 13.)

In Shumard Canyon, north of Bone Canyon, beds of the Brushy Canyon formation that are younger than the conglomerate and limestone just described rest on the Bone Spring limestone. These beds include massive, medium-grained, brown sandstone beds, two groups of which form prominent ledges (secs. 11, 12, and 13, pl. 6). The lower passes out by overlap in the north branch of the canyon, where it has an original dip away from the limestone surface of more than 10 degrees. The upper, at the top of the formation, continues some miles farther but passes out by overlap against the Cutoff shaly member half a mile north of Shirttail Canyon. Apparently no beds of the Brushy Canyon formation were laid down any farther north. In this region, the Bone Spring limestone is overlain directly by higher beds of the Delaware Mountain group—the sandstone tongue of the Cherry Canyon formation (pl. 7, *A*).

STRATIGRAPHIC RELATIONS

After the hiatus that intervenes in places between the Leonard and Guadalupe series, deposition apparently went on with little interruption throughout Guadalupe time. At most places the first deposits of the series, the Brushy Canyon formation, extend without break into the succeeding Cherry Canyon formation. Locally, however, the uppermost beds of the Brushy Canyon formation have been cut by channels. One of these channels, shown in figure 4, *C*, is occupied by fusulinid limestones belonging to the basal Cherry Canyon. These channels seem to be of no more importance than others in the sandstones above and below; they were probably caused by submarine erosion.

FOSSILS

Except for fusulinids, fossils are not abundant in the Brushy Canyon formation, perhaps because the sandy facies of the deposits was not favorable for life, or because conditions were not favorable for the preservation of shells. The latter possibility is suggested by the fact that most of the fossils that have been collected are fragmentary and water-worn. The thousand feet of beds in the formation constitutes a conspicuous break in the paleontological sequence.

The great abundance of fusulinid tests in many of the sandstone beds of the formation has been noted in descriptions of the stratigraphy (p. 29, see also fig. 11, *A*), and was first observed by Shumard.[87] The fusulinids all belong to the genus *Parafusulina*, which occurs also in the Bone Spring limestone below and the Cherry Canyon formation above. The species in the Brushy Canyon are characteristically larger and more highly developed than those in the Bone Spring. They include *P. rothi* Dunbar and Skinner, *P. sellardsi* Dunbar and Skinner, *P. maleyi* Dunbar and Skinner, and *P. lineata* Dunbar and Skinner.[88] The first three of these species have been identified also in the lower part of the succeeding Cherry Canyon formation.

The other fossil groups are found only in occasional lenticular calcareous beds, and though considerable material has been obtained from some of the localities, Dr. Girty observes that "the preservation of the specimens is, in every instance, so poor as to hamper close identification." The largest collection was obtained on the southeast side of a gravel-capped butte 3 miles south-southeast of El Capitan and half a mile southwest of bench mark 4733 (locality 7656). A collection containing many of the same species and from nearly the same place (locality 2919) was described by Girty [89] in 1908.

Most of the identifiable material from this and other localities consists of brachiopods, although the presence of other groups is suggested by occasional specimens. Girty's original collection contains the bryozoan *Fistulipora grandis guadalupensis* Girty. The more recent collections from station 7656 include some fragmentary cephalopod shells, mostly unidentifiable, but acording to A. K. Miller probably including the nautiloid *Coloceras*. In addition, H. C. Fountain has noted the presence of abundant crinoid stems, and poorly preserved cup corals, pelecypods, and gastropods. Dr. Girty comments as follows on the brachiopod assemblage:

> *Enteletes* is a recurrent genus, but the specific relation of the few poor specimens is uncertain. *Meekella* (*M. attenuata* Girty)

[87] Shumard, G. G., Observations on the geology of the country between the Rio Pecos and Rio Grande, in New Mexico: St. Louis Acad. Sci. Trans., vol. 1, p. 280, 1858 [1860].

[88] Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas: Texas Univ. Bull. 3701, pp. 593 and 726, 1937.

[89] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, p. 21, 1908.

is better represented. *Chonetes* (*C. subliratus* Girty?) is for the first time rather abundant.

The productids are all small (which implies the absence of *Productus ivesi* Newberry), except for three poor specimens from station 7656, which are tentatively identified as *P. indicus* King (non Waagen). Among the smaller species, *P. guadalupensis* Girty is rather abundant. Also present are *P.* (*Marginifera?*) *waagenianus* Girty, *P.* (*Marginifera?*) *wordensis* (King), *P. indentatus* Girty, *P. geniculatus* Girty, and a species or two resembling *P. popei opimus* Girty. *Prorichthofenia* continues to be present.

A distinct change is thus indicated in the productid representation, but it may not be as marked as it first appears to be, for some of the forms which, because of abundance and good preservation are mentioned in this faunal assemblage, may have been passed over in others by reason of scarcity and fragmentary condition, a circumstance which can defeat even such tentative identifications as are here recorded. In this place, I may note also that the productid representatives of these lots from the Brushy Canyon formation have little in common among themselves.

Spirifers related to *Spirifer triplicatus* Hall occur in all three collections. *Squamularia* is present in one collection, but is not determinable specifically. *Ambocoelia*, *Spiriferina*, *Composita*, and *Hustedia* are all present but represented by specimens too poor for consideration. On the whole, the fauna of the Brushy Canyon formation, although its identification suffers from the poor preservation of the specimens, presents many departures from the fauna of the Cutoff shaly member below it.—Girty manuscript.

CONDITIONS OF DEPOSITION

REGIONAL RELATIONS

After the close of Leonard time, at the beginning of Guadalupe time, a marked change in sedimentation took place in the Guadalupe Mountains region. The preceding deposits were spread across the whole area, whereas those of the Brushy Canyon formation were restricted to the southeastern part, or Delaware Basin. The preceding deposits were limestones or very fine clastics, whereas the early Guadalupe (Brushy Canyon) deposits were dominantly sandstone, in part moderately coarse grained. The preceding deposits in the Delaware Basin (black limestone facies) show evidence of having been deposited in quiet and perhaps deep water, whereas many beds of the succeeding Brushy Canyon formation in the same area were laid down in agitated water, and the whole formation is probably a shallow-water deposit.

Some of the causes of this change in sedimentation have already been considered (p. 27). It was concluded that at the beginning of Guadalupe time the Delaware Basin became an area of shallow water, and the adjacent shelf areas were emergent, but did not stand high.

Because of this condition, sediments could be washed into the basin from almost any direction, and transportation of coarse material to it was probably less impeded than at any other time in the Permian. The occurrence of relatively coarse-grained sandstone in the Brushy Canyon deposits of the Delaware Basin thus does not necessarily indicate renewed uplift in the lands that supplied sediments to the region.

The coarser sands continue to the top of the Brushy Canyon formation, where they come to an end in a single, persistent layer; in the Delaware Basin no similar beds are seen in the higher Permian beds. Sands equally coarse, however, are found northwest of the basin in the younger Goat Seep and Carlsbad formations. These relations suggest that the source of the sands lay somewhere to the northwest, and that erosion of the source area continued after the close of lower Guadalupe time. Later on, southeastward transportation of the material into the basin was probably hindered by the development of limestone-reef barriers of middle and upper Guadalupe age (Goat Seep and Capitan limestones) and coarser sands could be laid down only in the shelf area northwest of the basin.

DETAILED FEATURES

The different types of sediment in the Brushy Canyon formation alternate in rude cycles, as shown on section 33, figure 5. Each massive sandstone generally rests on a channeled surface which records a time of maximum current action. They themselves contain ripple marks, cross beds, and oriented fusulinids, which indicate that they were laid down rapidly in agitated water, within reach of effective wave action. The massive beds are succeeded by thin-bedded, fine-grained sandstone, with varvelike laminae, which record slower, quieter deposition. Toward the top of each cycle are intercalations of dark, shaly sandstone, probably with a considerable bituminous content, which suggest an approach to the stagnant bottom conditions of the older black-limestone deposition. Each cycle is brought to an end by another period of channeling and deposition of coarser sandstone.

These rude cyclical units cannot be traced far along the outcrops, and it is questionable whether any one is of more than local extent. They indicate, however, a regular fluctuation in conditions of sedimentation from agitated to quiet water but probably with no accompanying changes in depth.

The ripple marks in the massive sandstones have nearly the same northeastward trend as the Bone Spring flexure, which formed the shore in lower Guadalupe time (fig. 6). They were evidently shaped by movements of the water oriented at right angles to the shore. These movements might have been undertow currents, caused by the return along the bottom of water that had previously been piled up on the shore by the waves. Or they might have been the to-and-fro oscillation of water within the waves themselves. Movements of the first sort would form current ripples, and of the second sort oscillation ripples.[90] The marks in

[90] Kindle, E. M., and Bucher, W. H., Ripple mark and its interpretation, in Twenhofel, W. H., and others, Treatise on sedimentation, 2d ed., pp. 644–653, Baltimore, 1932.

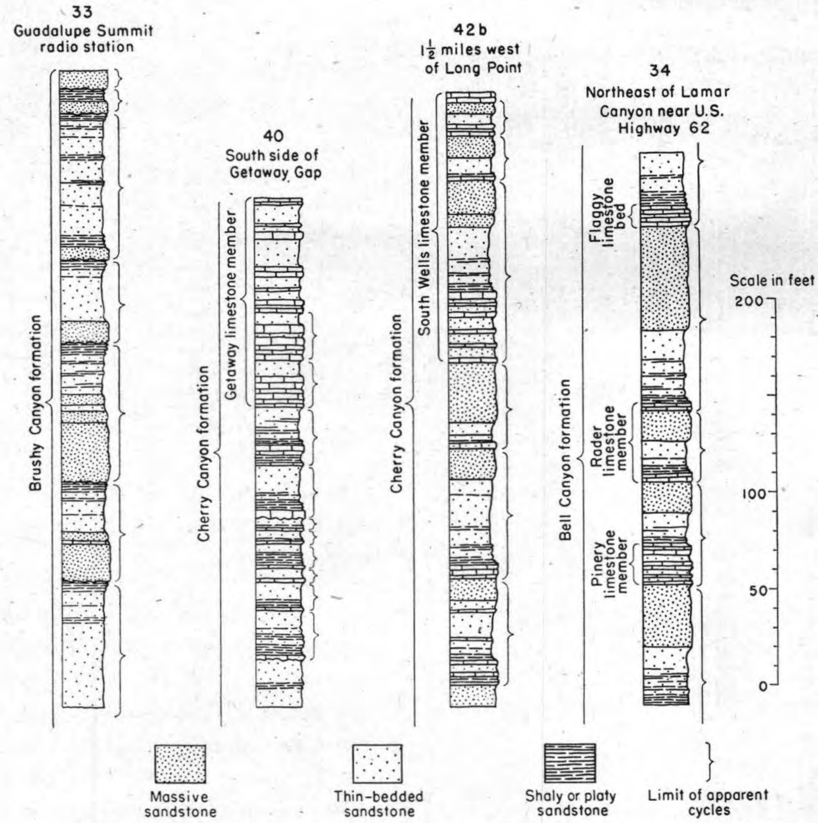


FIGURE 5.—Sections showing cyclical deposition in Brushy Canyon, Cherry Canyon, and Bell Canyon formations of the Delaware Mountain group. Numbers of sections correspond to sections shown on plate 6.

the Brushy Canyon formation appear to have a symmetrical cross section, which indicates they are oscillation rather than current ripple marks. However, no secondary crests are found, such as occur in many oscillation ripples. Current movements are indicated by the channeling of the associated deposits.

The fusulinid tests, which are commonly strung out in a northwestward direction, at right angles to the trend of the ripples, were probably placed in this position by the same oscillation movements of the water that produced the ripples. After the death of the animals, their many-chambered tests probably had considerable buoyancy, and were easily turned in the direction of least resistance to water motion; that is, elongate parallel to the movement.

The sea bottom during lower Guadalupe time was probably inhospitable to many forms of life, because of its sandy surface, and the probable agitation and turbidity of the overlying water. Shells of whatever bottom fauna existed were largely broken up before they could be fossilized. Whatever the conditions of life for most of the fauna, the lower Guadalupe sea was definitely favorable to the existence of fusulinids and the preservation of their tests as indicated by the enormous numbers of the tests that were enclosed in the sediments.

MIDDLE PART OF GUADALUPE SERIES

Beds of middle Guadalupe age form an assemblage considerably more varied than that of any of the units that preceded them (pl. 7, *A*). Toward the southeast, they consist of the Cherry Canyon formation, about 1,000 feet thick, which is a succession of fine-grained and generally thin-bedded sandstones, with a number of persistent limestone beds some of which are distinguished as named members. Toward the northwest, the limestone members thicken abruptly and form a continuous succession of limestones, the Goat Seep, which is equivalent to the upper three-fourths of the unit to the south. The lower fourth of the Cherry Canyon formation persists northward as a sandstone tongue a few hundred feet thick. Near the southeast edge of the Goat Seep limestone, the middle Guadalupe beds have a thickness of about 1,500 feet, but farther northwest they dwindle to 750 feet.

In the Delaware Mountains, the middle part of the Guadalupe series, or Cherry Canyon formation, crops out along the crest of the range in a belt 8 or 10 miles wide. Northward, the Cherry Canyon extends along the west face of the Guadalupe Mountains past El Capitan (pl. 3). Farther north, the Goat Seep limestone is extensively exposed along the lower slopes of escarpments and canyon walls that are capped by the younger

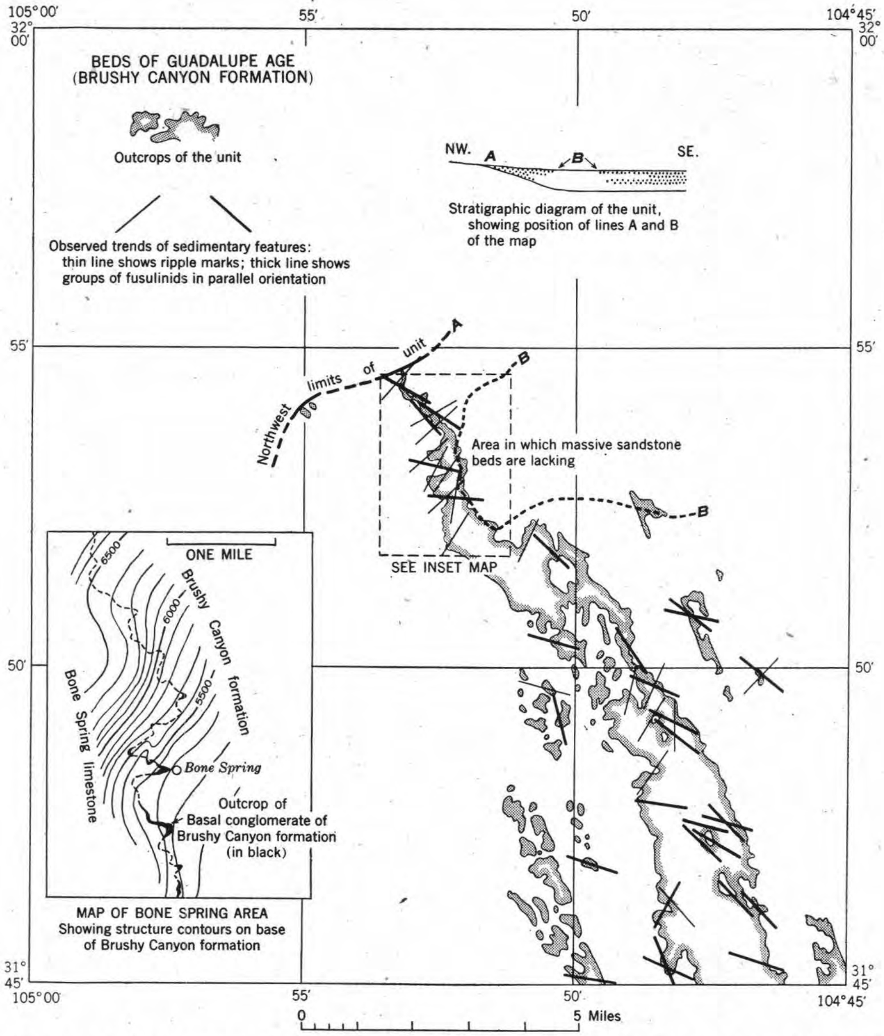


FIGURE 6.—Map of western part of area studied, showing distribution of facies and other stratigraphic features in beds of lower Guadalupe age (Brushy Canyon formation).

Capitan and Carlsbad limestones. The Cherry Canyon and Goat Seep formations are exposed also at many places in the downfaulted area west of the high mountains.

CHERRY CANYON FORMATION

The Cherry Canyon formation, as here distinguished, corresponds approximately to that part of the Delaware Mountain group recognized by Beede[91] as consisting of "brownish, rather bituminous shales, with limestones and some sandstones". Its name is taken from Cherry Canyon, which drains eastward across the summit of the Delaware Mountains for about 9 miles, from Pine Spring to a point 3 miles east of the D Ranch Headquarters where it joins Lamar Canyon. The course of Cherry Canyon crosses most of the outcrop of the formation; some parts of the formation near the canyon are covered by Quaternary gravels.

On the outcrop, the Cherry Canyon formation has a nearly constant thickness of 1,000 feet, but this thickness increases to 1,283 feet in the Niehaus et al., Caldwell No. 1 well, 35 miles east-southeast of El Capitan. In the broad belt along the crest of the Delaware Mountains, it dips at angles of a few degrees to the east-northeast, but toward the west it is considerably broken by strike faults of small displacement. East of the easternmost fault, which crosses the west end of Getaway Gap, the limestone members of the division stand in low, west-facing, frayed-out cuestas, whose eastern, back slopes are cut on the surfaces of resistant beds. The most conspicuous of them is Long Point, capped by limestones of the Manzanita member.

Outcrops of the Cherry Canyon formation are shown on the geologic map, plate 3. Note that to the south, as near section *D—D′*, the belt of outcrop is wide because of the gentle dips and low topographic relief; whereas to the north, as near section *B—B′*, the belt of outcrops is narrow, not because of steeper dips, but because of greater topographic relief. Views of this part of the outcrop, forming smooth slopes between the ledges of the Brushy Canyon formation and the cliffs of the Capitan limestone, are shown in plate 1, plate 5, *A*, and plate 12.

[91] Beede, J. W., Report on the oil and gas possibilities of the University block 46 in Culberson County: Texas Univ. Bull. 2346, p. 13, 1924.

Sections of the Cherry Canyon formation can be seen on the right-hand half of plate 6. Note that in the area of flat topography to the southeast, only incomplete sections are shown, or complete sections that have been pieced together from measurements in different places, as in sections 37 and 42. In this region, the record of the Niehaus well, also shown on the plate, provides a useful check on the surface measurements. The continuous sections farther to the left (secs. 12–18) are measured on the steep slopes at the south end of the Guadalupe Mountains. For general stratigraphic relations of the formation, see plate 7, *A*.

SANDSTONE BEDS

The standstones of the Cherry Canyon formation lie in beds a few inches thick, with occasional thicker layers and layers of hard, platy, shaly sandstone. The thinner beds are all marked by light and dark laminae, possibly varves, of which there are commonly 10 or 20 to the inch; there are occasional zones where they are more closely or more widely spaced. The sand

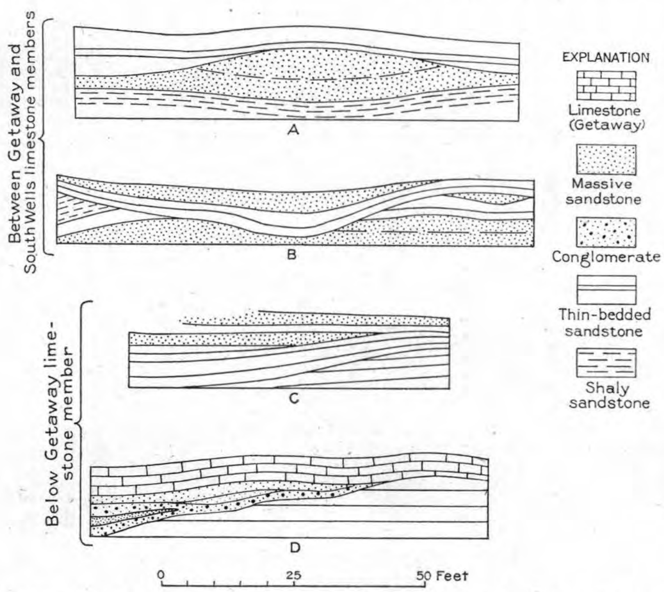


FIGURE 7.—Sections showing channeling and lenticular deposition of sandstones in lower part of Cherry Canyon formation. *A* and *B*, in Cherry Canyon, 2 to 3 miles southeast of Frijole Post Office. *C* and *D*, in Glover Canyon, 2½ miles south of Frijole Post Office.

grains are so fine that they cannot ordinarily be distinguished by the unaided eye. A single specimen of the sandstones was examined under the microscope by Ward Smith. It came from beds between the South Wells and Manzanita members at the base of the slope near Pine Spring, and is megascopically similar to the sandstones in other exposures of the formation. It consists of angular grains of quartz and some feldspar, with a maximum diameter of 0.15 millimeter, closely packed in a noncalcareous, argillaceous matrix. There are also a few grains of zircon and tourmaline.

The bedding surfaces in many of the sandstones are straight and smooth, but some are covered by shallow ripple marks, measuring several inches from crest to crest, which trend in a general northeasterly direction (fig. 8). In some exposures, individual beds can be traced for long distances. In others, the bedding is less regular, and the sandstones are cut by channels several feet deep, which are filled by more massive, more shaly, or more calcareous strata than those beneath (fig. 7). The material filling the channels is very irregularly bedded, but almost nowhere contains any conglomerate. Channeling of the sandstones is most common in the lower two-thirds of the formation.

At some localities the sandstone contains spherical or oval nodules, lenses, and thin beds of fine-grained, gray, sandy limestone or calcareous sandstone, but elsewhere great thicknesses of strata contain no calcareous beds. In some exposures, as on the south side of Getaway Gap, the various rock types appear in rude cyclical order through intervals of 10 or 20 feet of beds. Shaly sandstones below are followed by thin-bedded sandstones, and then by limestone lenses or nodules, after which the succession is repeated (see sec. 40, fig. 5).

LIMESTONE MEMBERS

The limestone beds in most of the Cherry Canyon formation are lenticular, consisting in places of solid limestone members 100 feet or more thick, and in places of thin limestone beds interbedded with thicker layers of sandstone, as shown diagrammatically on plate 7, *A*. They exhibit considerable variety in lithologic character from place to place. The two members distinguished in the lower part of the formation, the Getaway and South Wells limestones, change in this manner, and between them other thinner, less continuous limestone beds are locally prominent. The upper member of the formation, the Manzanita limestone, is more persistent than the lower members in lithologic character and thickness over wide areas.

The position and extent of the limestone members in this part of the succession has not been described hitherto although various authors have noted the occurrence of limestone interbedded in the sandstones of the Delaware Mountains. The lack of previous observations on the limestone members is partly because the members are poorly developed on the slopes below El Capitan, where most previous stratigraphic sections were measured.

GETAWAY LIMESTONE MEMBER

The Getaway limestone member is a group of limestone beds in the lower part of the Cherry Canyon formation that are widely exposed in the Delaware Mountains (pl. 3). The member caps the rim of the west-facing escarpment of the Delaware Mountains for many miles south of El Capitan, and is the first abundantly fossiliferous layer encountered in the section on passing upward from the Bone Spring limestone.

The member is named for Getaway Gap,[92] 6 miles southeast of El Capitan, on whose north and south sides it is well exposed. At the gap, the member has a thickness of 107 feet, and is separated from the uppermost massive sandstones of the Brushy Canyon formation by 192 feet of thin-bedded sandstone (sec. 40, pl. 6).

The member is well exposed also along Glover Canyon 2 miles north of the gap (sec. 37*a*), on the south side of Guadalupe Pass overlooking Guadalupe Canyon (sec. 27), and on the Delaware Mountains escarpment below Guadalupe Summit radio station (sec. 33). At these places, as much as 200 feet of nearly continuous limestone beds is present, but near the middle several layers of sandstone are generally interbedded. In other parts of the area, even at points close to these localities (as shown in fig. 4, *A* and *C*), the member thins to 50 feet or less. At some places, as on the slopes below El Capitan (sec. 18, pl. 6), the member nearly disappears, and in the interval where it is expected only a few limestone beds less than a foot thick are present. (Areas in which the member is thin or wanting are shown on fig. 8.)

The Getaway member consists largely of fine-textured black or dark-gray limestone, which weathers to mouse-gray or ashen-gray surfaces. Most of the beds are a few inches to a foot thick, but some parts are thinly laminated or platy. The more granular beds contain small, irregular chert nodules. Many of the bedding surfaces are straight and smooth, but others are nodular, wavy, and hummocky, with straighter-bedded layers deposited over the uneven surface. In exposures 2 to 3 miles east of El Capitan, some of the bedding surfaces are striated and fluted in the same manner as in the black limestones of the Bone Spring. Between some of the limestone beds are thin-bedded or platy sandstone layers and rare partings of marl.

Interbedded with the dark, thin-bedded limestones are some lenses of light-gray, more granular limestone, in places dolomitic, in massive beds 2 to 10 feet thick, which extend 25 to 100 feet along the outcrop. Some of them contain small, rounded limestone pebbles.

The following analyses of limestone from the Getaway limestone member were made:

Analyses, in percent, of limestone from the Getaway limestone member

[Analyses by K. J. Murata; notes on insoluble residues by Charles Milton]

Specimen locality	Insoluble		R_2O_3 (mostly Fe_2O_3)	$CaCO_3$	$MgCO_3$	$MnCO_3$	$Ca_3(PO_4)_2$	Total
	Inorganic	Organic						
1. Lower part of member, east bank of Glover Canyon at section 37 a, 3 miles southeast of Pine Spring Camp	11. 88	0. 63	0. 44	85. 06	1. 33	0. 03	0. 17	99. 54
2. Upper part of member, same locality as No. 1	8. 38	. 45	. 32	88. 76	1. 26	. 04	. 33	99. 54
3. 25 feet below top of member, rim of Delaware Mountains at section 33, at Guadalupe Summit radio station; granular phase	13. 71	. 10	. 73	81. 27	2. 70	. 09	1. 00	99. 60
4. Same locality and horizon as No. 3; compact phase	10. 66	. 08	. 19	87. 62	1. 17	. 06	. 06	99. 84
5. Near Lone Cone, west of Delaware Mountains; granular, sandy limestone, exfoliated by weathering	11. 06	. 24	. 30	86. 92	. 92	. 05	Trace	99. 49

Insoluble residues: 1, Dark brownish, with fine quartz, feldspar, and muscovite particles and much clayey material; 2, dark brownish, with large chert particles, quartz, feldspar, and occasional zircon; 3, gray, with very little clay, subrounded detrital quartz, feldspar, and occasional small zircon grains; 4, gray, very little clay, mostly cryptocrystalline quartz or chalcedony, some feldspar, and some spherulitic aggregates, possibly feldspar; 5, light gray, subrounded detrital quartz grains and feldspar, with a few small zircon grains.

Fossils are abundant in parts of the Getaway limestone member, and include a great diversity of types. They are particularly numerous and well preserved in the granular limestones, where they tend to be concentrated in lenses in the more barren rock. The bivalved shells in such beds are commonly joined together, as though they had not been greatly disturbed after the death of the animal. Some of the fossils are silicified on the weathered surface of the rock, but most of them can be discovered only by breaking the rock. Fusulinids are abundant in the denser limestones, and tend to be oriented in a general northwestward direction (fig. 8), in the same manner as in the sandstones of the underlying Brushy Canyon formation.

Where the limestone beds of the member thin out, their place is taken by platy, shaly sandstones that crop out in ragged ledges. These shaly sandstones contain zones of limestone nodules, which are probably the equivalent of continuous beds elsewhere. In places the nodules appear to be broken and rolled fragments, resulting from the destruction by wave action of a continuous limestone bed, after deposition and before burial.

[92] According to Mr. Walter Glover, in the early days of ranching in the country wild horses were frequently rounded up and captured in the basin west of the gap. Now and then, however, they made a dash for freedom, and "got away" through the gap.

BEDS ADJACENT TO GETAWAY LIMESTONE MEMBER

In the sandstones that underlie and overlie the Getaway limestone member are occasional limestone beds that are too thin or discontinuous to be mapped or named.

Beneath the Getaway member, in the 100 or 200 feet of beds that separate it from the top of the Brushy Canyon formation, are occasional lenses and channel fillings of clastic or sandy limestone, containing broken fragments of shells. The fossils collected from these beds are referred to below (pp. 41–42) as constituting the sub-Getaway fossil zone.

The interval between the Getaway limestone member and the succeeding South Wells limestone member consists largely of sandstone, but southeast of Getaway Gap a number of thin limestone beds occur (sec. 42, pl. 6). In places they contain fossils, but no collections have been made from them. The limestone beds give place along the outcrop to thin layers of slabby, reddish quartzite, which form resistant ledges that are widely traceable in the field and on aerial photographs. Some of these quartzite ledges are indicated on the geologic map (pl. 3).

SOUTH WELLS LIMESTONE MEMBER

About 200 feet above the Getaway member is another, less prominent, less continuous group of limestone ledges, which is named the South Wells limestone member. The type locality is at the South Wells of the D Ranch, 11 miles southeast of El Capitan (pl. 3).[93] The member here consists of several limestone beds as much as 20 feet thick, interbedded with sandstone, and locally replaced by massive sandstone beds.

In the southeast part of the area, near South Wells, the limestones are gray, fine-grained, and nondolomitic, and form beds a few inches to several feet thick, with some lenses and thin beds of dense, black limestone. The black beds contain numerous well-preserved ammonoids and a few species of brachiopods. The lighter beds have a more diversified brachiopod fauna. In places the limestone beds are replaced laterally by slabby, reddish quartzites. The sandstones beneath some of the limestone ledges are thick-bedded and crop out in bare, rounded slopes.

Farther north, in the southeastern foothills of the Guadalupe Mountains, black limestone beds disappear from the South Wells member. The member here contains beds as much as 10 feet thick of buff, or drab, fine-grained, dolomitic limestone, in part sandy, which weather into large slabs or blocks. Some of these beds contain seams of flat sandstone and limestone pebbles, and in places, irregular segregations of brown chert. Various fossils can be seen in the rock, but they are preserved only as casts or molds. Overlying each massive bed is a few feet of slabby, compact, dolomitic limestone. The limestones are associated with thick beds of brown, calcareous sandstone of a slightly coarser grain than the sandstones above and below. At some places, as in Cherry Canyon 3 miles east of Frijole Post Office, the limestone beds pinch out, and only the thick sandstone beds remain to indicate the position of the member.

The following analysis was made of a specimen of drab dolomitic limestone from the South Wells limestone member collected at the south base of Rader Ridge due north of Nipple Hill:

Analysis of dolomitic limestone from the South Wells limestone member

[Analysis by K. J. Murata; note on insoluble residue by Charles Milton]

	Percent
Inorganic insoluble	21.83
Organic insoluble	.29
R_2O_3 (mostly Fe_2O_3)	1.36
$CaCO_3$	43.03
$MgCO_3$	32.60
$MnCO_3$	.13
$Ca_3(PO_4)_2$	None
	99.24

Insoluble residue: Clayey, light gray, with quartz and alkalic feldspars, occasional green tourmaline, and other detrital minerals.

MANZANITA LIMESTONE MEMBER

Several hundred feet above the South Wells limestone member, near the top of the Cherry Canyon formation, are the persistent calcareous layers of the Manzanita limestone member (right-hand half of pl. 6). This member is named for Manzanita Spring, three-quarters of a mile east of Frijole Post Office; the type section is on Nipple Hill, a conical butte carved from the member, which rises from the plain near the spring (right-hand end of pl. 4, *B*). The member crops out as a thin band on the slopes below the limestone cliffs of the Guadalupe Mountains (pl. 9), and extends southward as a broad belt into the Delaware Mountains (pl. 3).

The member has a thickness of 75 to 150 feet, and consists of straight-bedded ledges a few inches to a foot thick, of dense, greenish-gray, earthy limestone, which weather to a striking orange-brown or yellow color. Under the microscope the limestones are seen to contain scattered detrital quartz grains. Some of the layers contain irregular cavities and pockets, part of which are geodes lined with calcite crystals. Some of the geodes were originally the molds of fossil shells. Fossils, however, are all poorly preserved, and none was collected by Fountain or me. Occasionally imprints of ammonoids and crinoid stems can be seen on the bedding surfaces.

The following analyses of limestone from the Manzanita limestone member were made:

[93] The northern of Beede's two sections includes beds exposed at this locality (op. cit., p. 6).

Analyses, in percent, of limestone from the Manzanita limestone member

[Analyses by K. J. Murata; notes on insoluble residues by Charles Milton]

Specimen locality	Insoluble		R_2O_3 (mostly Fe_2O_3)	$CaCO_3$	$MgCO_3$	$MnCO_3$	$Ca_3(PO_4)_2$	Total
	Inorganic	Organic						
1. Side ravine draining into Lamar Canyon from south, ¾ mile east of bench mark 4923	68. 29	0. 05	2. 74	14. 91	12. 58	0. 07	0. 10	99. 74
2. South side of Rader Ridge, due north of Nipple Hill	21. 70	. 11	1. 56	44. 09	31. 62	. 12	None	99. 20

Insoluble residues: 1, Light gray, many grains of subrounded quartz and feldspar, some muscovite of detrital origin; 2, light gray, clayey, with quartz and feldspar, some tourmaline, and other detrital minerals.

The limestone beds are generally separated by partings and thin beds of soft, fine-grained, greenish sandstone. Southeast of Nipple Hill, as near the D Ranch Headquarters in Cherry Canyon, the limestones are divided in the middle by a 50-foot bed of massive, fine-grained, greenish-gray sandstone, which crops out in rounded ledges. Similar sandstones 50 to 100 feet thick underlie the member.

The most distinctive feature of the Manzanita member is its intercalated beds of altered volcanic ash. These beds appear generally as pale, apple-green siliceous shales or cherts, but in places they are waxy, green, bentonitic clays. The cherts, because of their resistance, are widely distributed in the slope-wash deposits and stream gravels of the region, where they attract notice because of their unusual color. The volcanic ash forms beds as much as 2 feet thick that occur at various positions within the member. The beds are shown by a special symbol on the sections of plate 6.

Ash beds in the Delaware Mountain section, perhaps belonging to the Manzanita member, were noted by Crandall,[94] who speaks of "some thin layers of a peculiar hard, green argillite * * * 400 to 500 feet below the top of the [Delaware Mountain] formation."

Five thin-sections of the ash from different parts of the area have been examined by C. S. Ross of the Geological Survey. He states that ash structures are generally clearly recognizable under the microscope, although somewhat obscured by silicification, as well as by devitrification, which has produced clay minerals and secondary quartz. Some of the softer beds have been so altered to clay minerals that the ash structure, if originally present, is no longer evident.

Analyses, in percent, of bentonitic clay from the Manzanita limestone member

[Analyses by E. T. Erickson]

Specimen localities	SiO_2	R_2O_3 (mostly Al_2O_3)	MgO	CaO	Na_2O	K_2O	H_2O	Total
1. Side ravine draining into Lamar Canyon from south, ¾ mile east of bench mark 4923; shows ash structures under microscope	60. 88	19. 96	2. 72	1. 34	. 78	9. 24	4. 92	99. 84
2. South bank of Cherry Canyon on road leading south from D Ranch headquarters; does not show recognizable ash structures under microscope	51. 46	24. 84	5. 60	1. 78	. 80	5. 02	10. 42	99. 92

Characteristically, the volcanic ash beds in the Manzanita member are well developed far outside the local outcrop in the southern Guadalupe Mountains; they have been identified in numerous wells drilled in the Delaware Basin area down the dip to the east. They appear, for example, in the Niehaus et al., Caldwell No. 1 well, 35 miles east-southeast of El Capitan, whose log is shown on plate 6. They have been found also in the Getty Oil Co., Dooley No. 7 well in the Getty oil field, east of Carlsbad, N. Mex. (for location see fig. 2), and also in other wells farther east and southeast.

South of Delaware Creek, the orange-brown, straight-bedded limestones of the member change into dark-gray, lumpy limestones containing poorly preserved ammonoids and separated by crumbly greenish marl which contains small limestone lumps. (This facies is separately mapped on pl. 3; see also sec. 42, pl. 6.) The latter beds closely resemble those of the Hegler limestone member of the Bell Canyon formation along the southeast base of the Guadalupe Mountains, as described later in this report. Green chert (volcanic ash) is rare in this facies but was observed in a few places. The lumpy limestones cap many mesas and cuestas in

[94] Crandall, K. H., Permian stratigraphy of southeastern New Mexico and adjacent parts of western Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 931, 1929.

the southeast part of the area, of which the most conspicuous is Long Point. At Long Point (sec. 42), the most prominent part of the member is the lower calcareous division, below the medial sandstone. The upper division is represented by similar beds a few feet thick.

Between Bone and Shirttail Canyons on the west side of the Guadalupe Mountains, the Manzanita member thins out northward and disappears between the Hegler and Capitan limestones above, and the Goat Seep limestone beneath (between secs. 9 and 13, pl. 6).

CHERRY CANYON FORMATION IN AERIAL PHOTOGRAPHS

In aerial photographs, the Cherry Canyon formation is recognized as that belt of outcrop between the prominent sandstone ledges of the Brushy Canyon formation below and to the west, and the top of the Manzanita limestone cuesta above and to the east. As such, it can be traced through the Delaware Mountains for more than 30 miles south of the area studied.

The part below the South Wells member forms a topography of smooth, rounded ridges and hills, minutely dissected by valleys and ravines. Many of the valleys and ravines appear to follow faults or joints, some of which are traceable for many miles from one drainage area to the next. The Getaway limestone member does not make distinctive ledges and is not traceable on the photographs.

In the photographs, the upper part of the formation differs from the lower in having a well-marked cuesta topography, each cuesta consisting of an abrupt west-facing scarp, indented by each stream that drains across it, and of a broad back-slope descending eastward with about the same inclination as the dip of the beds. Two cuestas are more prominent than the rest, a lower westward one corresponding to the South Wells member, and a higher eastward one corresponding to the Manzanita member. The latter may be traced continuously from Long Point southward for nearly 20 miles beyond the area mapped, until it is lost in the faulted area of the southern Delaware Mountains.

SANDSTONE TONGUE OF CHERRY CANYON FORMATION

North of Shirttail Canyon, on the west side of the Guadalupe Mountains, the lower formation of the Delaware Mountain group (Brushy Canyon) is missing by overlap on the Bone Spring limestone, and the upper three-fourths of the succeeding formation (Cherry Canyon) interfingers with the Goat Seep limestone. The lower fourth of the Cherry Canyon formation, however, persists as a layer of sandstone 200 or 300 feet thick. Its outcrop extends northward past Cutoff Mountain into New Mexico, and forms a weak, sandy break in an otherwise continuous succession of limestone.[95] According to Crandall,[96] the sandstone pinches out entirely not far to the north in southern New Mexico.

For outcrops of the sandstone tongue, see the geologic map, plate 3. The slope on which it is exposed stands out prominently below Shumard Peak and Bush Mountain on the panorama, plate 5, *B*. The structure of the rocks appearing in a part of this view is shown on section *K–K′*, plate 17. Sections of the sandstone tongue appear on the left-hand third of plate 6, Nos. 1 to 9.

The sandstones are buff or pink, soft, and very fine-grained. In the upper part are some interbedded brown, sandy, cherty limestones that contain numerous silicified brachiopods. The sandstone grades into the overlying Goat Seep limestone, and the two types of rock are interbedded at the contact (as in sec. 7, pl. 6).

GOAT SEEP LIMESTONE

DEFINITION

The name Goat Seep limestone is here given to massive or thick-bedded limestones similar to the Capitan limestone, but of pre-Capitan (middle Guadalupe) age, which crop out in the Guadalupe Mountains (pl. 7, *A*). The name is taken from Goat Seep,[97] on the west slope of the mountains 1½ miles northwest of Guadalupe Peak (for location, see pls. 3 and 9). The limestones of the formation, in their southeastern, marginal facies, are exposed up the slope from the seep, which issues from sandstones of the underlying Delaware Mountain group. Complete, well-exposed sections of the formation are found on the west-facing escarpment of the Guadalupe Mountains for several miles north of the type locality.

In previous reports, the formation has been given various names. Crandall[98] termed it the "Chupadera limestone," a name imported from the central New Mexico sequence. The unit, however, does not include all of the type † Chupadera, and there is a strong probability that it is younger than any of the † Chupadera. For beds of approximately the same age in Dog Canyon, in the northern Guadalupe Mountains, Lang[99] proposed the name Dog Canyon limestone, and extended the term to include the beds here called Goat Seep in the southern Guadalupe Mountains. Petroleum geologists, engaged in regional stratigraphic studies, have found the name Dog Canyon confusing because of its similarity to the term Dog Creek shale, used in Oklahoma for beds of about the same age. The term is therefore abandoned, and in this report the name Goat

[95] First described by Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, p. 114, 1920; later described by Darton, N. H., and Reeside, J. B. Jr., Guadalupe group; Geol. Soc. America Bull., vol. 37, p. 423, 1926, and others. Darton and Reeside ascribed the northward thinning of the Delaware Mountain group entirely to overlap of the lower beds.

[96] Crandall, K. H., op. cit., p. 935.

[97] Shown as "Goat Spring" on the Guadalupe Peak topographic sheet of the Geological Survey, but Goat Seep is the form generally used by the inhabitants of the area.

[98] Crandall, K. H., op. cit., p. 933.

[99] Lang, W. B., The Permian formations of the Pecos valley of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., vol. 21, p. 858, 1937.

Seep, based on exposures within the area studied, is substituted for it.

The true stratigraphic relations of the Goat Seep limestone were clearly recognized by Baker,[1] and later on by Crandall,[2] but in most of the other reports written at that time it was confused with the similar but younger Capitan limestone. Darton and Reeside[3] erroneously identified the Goat Seep beds near the Texas-New Mexico State line as "upper dark limestone" (Pinery limestone member of Bell Canyon formation) and Capitan limestone. Blanchard and Davis[4] recognized the gradation of sandstones below the Capitan into limestones at Goat Seep, but considered it a local feature; they correlated all the limstones farther north with the Capitan.

GENERAL RELATIONS

The development of the Goat Seep limestone out of the sandstones of the Cherry Canyon formation can be observed to good advantage from the crest of the ridge between Bone and Shumard Canyons (pl. 12, *B*). The Capitan limestone rises to the east in a sheer wall, standing on the ledges of the "upper dark limestone" (Hegler and Pinery members of Bell Canyon formation). Below, long smooth slopes, broken here and there by limestone ledges (Getaway and South Wells members of Cherry Canyon formation) extend down toward the observer across the sandstones of the Delaware Mountain group. On the north side of Shumard Canyon, however, on the high spur that rises above the Victorio Peak limestone bench, thick limestone ledges are interbedded with the sandstones. At the same position on the next spur to the north, above Goat Seep and beyond Shirttail Canyon, the sandstone beds have disappeared and the limestones have merged into a single group of cliffs. They form the Goat Seep limestone, of which this is the type section. The two spurs are surmounted by the higher, steeper cliffs of the Capitan limestone, from which the Goat Seep cliffs are separated by ledges of the "upper dark limestone." This relationship indicates the Goat Seep limestone is of pre-Capitan age.

The view described above is shown on plate 12, *B*. The two spurs on which the Goat Seep limestone first appears lie below Shumard Peak near the middle of the view. The structure of the beds on the two spurs is shown on sections *A–A′* and *B–B′* of plate 9. The sequence on the two spurs is shown in sections 11 and 9, plate 6. Note how, in sections farther to the right on this plate, the Goat Seep limestones are traceable into the Getaway and South Wells limestone members.

To see the continuation of the Goat Seep toward the north, one must go several miles westward into the Salt Basin, where the whole west face of the mountains can be observed in panorama (pl. 5, *B*). The Goat Seep beds can there be traced northward along the mountain face from the two spurs near Shumard Canyon, rising and thickening, with the line of separation from the Capitan visible as a distinct, softer parting which rises diagonally across the cliffs until it reaches the mountain summit. Here the Goat Seep cliffs rise as high and stand as steeply as do the Capitan cliffs farther south, making it easy for the two units to be confused with each other. Nearer the observer, and fringing the base of the high mountains, are rugged lower limestone ridges which in another setting would be mountains in their own right. Closer examination shows that they are composed of downfaulted rocks, of which the most conspicuous constituent is again the Goat Seep limestone.

This view is seen in the panorama of plate 5, *B*, the structure of a part of which is shown on section *K–K′* of plate 17. The line of separation between the Goat Seep and Capitan appears low down on the cliff below summit 8356 (to left of Shumard Peak), and rises northward along it to the summit, which it reaches on the north slope of Bartlett Peak. Notice that between Shumard Peak and Bush Mountain the formation is massive and stands in sheer cliffs, but that farther north, near Blue Ridge, it is bedded and forms ledges.

SOUTHERN EXPOSURES

On the west side of the Guadalupe Mountains, the Goat Seep limestone thus makes its appearance above Goat Seep in Shirttail Canyon, or several miles north of the south edge of the Capitan limestone at El Capitan. It is formed by the northward thickening of the limestone beds of the Getaway and South Wells members (as shown on pl. 6). Like the Bone Spring flexure, the line of transition between it and the Cherry Canyon formation trends northeastward at an acute angle to the trend of the escarpment (fig. 8). Near Shumard and Shirttail Canyons more limestone is thus present on the points of the projecting spurs than in the canyons that are cut farther to the east.

The deposits, on the southeast margin of the Goat Seep, exposed on the ridge between Shumard and Shirttail Canyons (sec. 11, pl. 6), consist of massive lenticular, gray, dolomitic limestones in beds as much as 10 feet thick, many of which rest on channeled surfaces of the underlying sandstones or slabby limestones. The massive beds commonly contain angular limestone pebbles and fragments of fossils. Nearly all the intercalated sandstones pinch out a little farther north (sec. 9, pl. 6), but a layer at the top, in the position of the Manzanita member, persists for several miles, forming the parting of soft beds between the Goat Seep and Capitan which may be recognized on the cliffs from a distance.

North of Shirttail Canyon, the formation thickens rapidly to 1,200 feet at Bush Mountain, a prominent point on the escarpment 1½ miles beyond (sec. 6, pl.

[1] Baker, C. L., op. cit., p. 114.
[2] Crandall, K. H., op. cit., p. 933.
[3] Darton, N. H., and Reeside, J. B., op. cit., p. 422, fig. 4.
[4] Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, pl. 11, p. 969, 1929.

6). The lower half of the formation in this vicinity consists of light gray, dolomitic limestone, weathering to dirty-gray, jagged surfaces, in beds 10 to 50 feet thick, interbedded with some buff, calcareous, medium-grained sandstone. Some of the limestones are crowded with the remains of fusulinids, now preserved only as molds, and hence unidentifiable.

The upper half of the formation, below Bush Mountain, stands as a single, massive bed of limestone, without trace of bedding planes. Its upper part, where studied on the mountain crest a short distance south of Bush Mountain, is a sandy, buff, dolomitic limestone, containing casts of brachiopods, pelecypods, and fusulinids. Upper beds of the formation of similar character are exposed also on the slopes of the northern Patterson Hills to the southwest, and of the head branches of Pine Spring Canyon and North McKittrick Canyon to the northeast (pl. 3). The line of separation between them and the Capitan is not as clear as on the cliffs near Bush Mountain. They differ from the Capitan in being thick bedded, rather than wholly massive, as well as being more dolomitic, and in places somewhat sandy.

The following analysis was made of a white dolomite from the lower part of the Goat Seep limestone collected on one of the foothill ridges 2½ miles northwest of Bone Canyon:

Analysis of white dolomite from the lower part of the Goat Seep limestone

[Analysis by K. J. Murata ; note on insoluble residue by Charles Milton]

	Percent
Inorganic insoluble	0.85
Organic insoluble	.09
R_2O_3 (mostly Fe_2O_3)	.28
$CaCO_3$	55.21
$MgCO_3$	43.07
$Ca_3(PO4)_2$	None
	99.50

Insoluble residue: Light reddish-gray, with subrounded quartz and feldspar grains, occasional augite, and much turbid clay.

NORTHERN EXPOSURES

The Goat Seep forms a thick, homogeneous limestone mass only in the vicinity of Bush Mountain. Northward as well as southward, it thins and contains more interbedded sandstones.

At Cutoff Mountain (sec. 1, pl. 6), in the northwest part of the area, it is 560 feet thick. Here, most of the lower half of the formation is thick-bedded, buff, calcareous sandstone, with a few interbedded limestone layers. The sandstones, like those in the Brushy Canyon formation to the south, contain fusulinid molds, are cross-bedded, and are moderately coarse-grained. A specimen of one of the sandstones, studied under the microscope by Ward Smith, consists of well-rounded quartz grains as much as 0.5 millimeter in diameter, many calcite grains of clastic origin, and some grains of zircon, all set in a calcareous matrix.

In the upper half of the formation, the sandstones are finer-grained and form thinner members. Between are many thin- to thick-bedded, light-gray limestone layers. The limestones are similar to those in the overlying Carlsbad limestone (equivalent to the Capitan farther south), but are not as thinly laminated, have a darker weathered surface, and do not contain the calcareous pisolites that are characteristic of the Carlsbad. East of Cutoff Mountain, on the east side of West Dog Canyon a mile north of Lost Peak (sec. 2, pl. 6), there is near the top of the formation a bed of dense, gray, petroliferous, calcitic limestone, which contains brachiopods and pelecypods (locality 7603).

Rocks similar to those on Cutoff Mountain are exposed some miles to the east on the lower slopes of the escarpment on the east side of Dog Canyon. This is the area in which the name Dog Canyon limestone was applied by Lang.[5] Their exposures are shown in the panorama, plate 14, *A*, where they form the lower ledges on the distant escarpment, that are delimited above by slopes formed on the basal sandstone beds of the Carlsbad. As shown in the panorama, the rocks extend northward along the escarpment into New Mexico, beyond the area studied. They extend also into the head of North McKittrick Canyon, which appears in the distance on the panorama. In that canyon, as shown on plate 3 and on section *E–E′*, plate 17, they dip southeastward beneath the Capitan limestone.

STRATIGRAPHIC RELATIONS

In all parts of the area, there was probably continuous deposition from middle Guadalupe into upper Guadalupe time, with only slight changes in sedimentation and faunas.

In field mapping, an attempt was made to draw the upper boundary of formations assigned to the middle part of the Guadalupe series at horizons that could be successfully traced. Thus, in the Delaware Mountains to the southeast, the top of the Cherry Canyon formation is drawn at the base of the Hegler limestone member of the Bell Canyon formation. This is the base of the lowest bed that grades into the Capitan limestone to the northwest. In the northwest part of the area, the top of the Goat Seep limestone is drawn at the base of the prominent sandstone that forms the lowest bed of the Carlsbad limestone.

In the intervening area, however, beds of both middle and upper Guadalupe age are of reef facies, and massive Goat Seep limestone is overlain by massive Capitan limestone. Here, the boundary is not easy to trace, although it is believed that the contact in most places has been located with a fair degree of certainty.

[5] Lang, W. B., op. cit., p. 858.

FOSSILS

The middle part of the Guadalupe series in the area studied contains abundant and interesting faunas, very few of which were known prior to this investigation. Girty,[6] in his original work on the Guadalupian fauna described two lots of fossils (localities 2903 and 2931) from beds now known to belong to the lower part of the Cherry Canyon formation, but the main fossiliferous zones higher up had not then been discovered. However, his collections from beds higher and lower than the middle part of the Guadalupe series and from the southern Delaware Mountains included many of the species now known to occur in the middle part. Brachiopod species characteristic of the middle part of the Guadalupe series have been described by King [7] from equivalent strata in the Glass Mountains. Ammonoids from the Cherry Canyon formation were collected by J. W. Beede in the early 1920's, and were afterwards described by Plummer and Scott.[8]

In the southeast part of the area studied, three main fossiliferous horizons are represented in the new collections. The lowest, called for convenience in this report the sub-Getaway fossil zone, lies between the Getaway limestone member of the Cherry Canyon formation and the uppermost massive sandstones of the Brushy Canyon formation. The next lies in the Getaway limestone member, and the highest in the South Wells limestone member. Poorly preserved fossils occur also in thin limestone beds between the Getaway and South Wells limestone members, and in the overlying Manzanita limestone member, but none has been collected by Fountain or me. The interval between the South Wells member and the Hegler member at the base of the succeeding Bell Canyon formation, amounting to several hundred feet of beds, is thus poorly known paleontologically.

In the northwest part of the area, fossils occur sporadically in both the sandstone tongue of the Cherry Canyon formation and the Goat Seep limestone. These fossils were unknown prior to the present investigation, and even now are represented by only small collections.

CHERRY CANYON FORMATION

SUB-GETAWAY FOSSIL ZONE

The 100 to 200 feet of beds that separate the top of the Brushy Canyon formation from the base of the Getaway limestone member of the Cherry Canyon formation are mostly thin-bedded sandstone, but here and there occur lenses and channel fillings of sandy limestone in which fossils are abundant. The two lots of fossils (Nos. 2903 and 2931) from Guadalupe Canyon, described by Girty in 1908, apparently came from these beds. Included in these collections was the ammonoid *Pseudogastrioceras serratum* (Girty). Fusulinids are abundant in the sub-Getaway beds, but none has been collected or identified. The species that occur above and below the zone are the same, so it is unlikely that those in the zone between have any novel features. Dr. Girty reports as follows on the remainder of the recent collections:

This unit proves to be highly fossiliferous and the following summary covers five large collections which, taken together, present a rich and diversified fauna. One of the collections (No. 7729) appears to have been made at nearly the same locality and horizon as one of my original collections (No. 2931), which may be taken as a standard of comparison.

Fusulinids that were present in the original collection are present also in the later ones. Corals and bryozoans are sparingly represented in the later collections, and not at all in the original one. The corals belong to a single species of *Lophophyllum*, or a genus of similar construction. The bryozoans also have but a limited representation, the most common genus being *Fistulipora*, but with *Stenopora*, *Batostomella*, *Septopora*, and *Acanthocladia* also present.

Among the brachiopods, the orthoids are all but absent; they were entirely so in the original collection. A single specimen of *Enteletes* (*E. dumblei* Girty?) was found in one collection, and an indeterminable specimen of the same genus in another. *Meekella* continues to be present and is abundant in several collections. It seems to be confined to a single species which may provisionally be identified as *M. attenuata* Girty. Mention should also be made of a large and singularly marked dorsal valve which undoubtedly belongs to a new species, but the genus is uncertain as between *Derbya* and *Orthotetes*. The Orthotetinae were not represented at all in the original collection.

Chonetes, which has been rather sparingly present in the lower beds, occurs in all five collections. All but a few specimens belong to one species which appears to be a large form of *C. subliratus* Girty. The genus was found in the original collection, but the species was not determined.

The Producti are extremely abundant and varied. They are especially so at station 7471, and rather rare at station 7670. I propose to mention only the strongly characterized and interesting types, but there are many others whose relations are uncertain. The original collection contains species identified as *Productus guadalupensis* Girty, *P. meekanus* Girty, *P. signatus* Girty, *P. signatus* Girty var., *P.* sp. e, *P. subhorridus rugatulus* Girty, and *P. walcottianus* Girty. The later collections contain *P. guadalupensis* Girty with several varieties, *P.* (*Cancrinella*) *signatus* Girty, *P.* (*Pustula*) *subhorridus* Meek var., and *P. walcottianus* Girty. In addition, they contain the following species that had not previously been reported: *P. comancheanus* Girty, *P. texanus* Girty, *P.* aff. *P. popei* Shumard, *P.* aff. *P. longus* Meek, *P.* aff. *P. multistriatus* Meek, *P.* (*Waagenoconcha*) *montpelierensis* Girty, *P.* (*Cancrinella*) aff. *P. cancriniformis* Tschernyschew, and *P.* (*Marginifera?*) *eucharis* Girty. They also contain *Aulosteges guadalupensis* Shumard, which was not found in the original collection, and *Prorichthofenia permiana* (Shumard), which was.

Camerophoria (*C. venusta* Girty) occurs here, as in the lower beds. Rhynchonellids are abundant, especially *Wellerella texana* (Shumard), with several varieties. Among the novelties are two new species of *Wellerella* and *Leiorhynchus weeksi* var. *nobilis* (Girty), while *Rhynchopora taylori* Girty appears in every collection save one. None of these were represented in

[6] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, p. 21, 1908.

[7] King, R. E., The geology of the Glass Mountains, part 2: Texas Univ. Bull. 3042, 1931.

[8] Plummer, F. B., and Scott, Gayle, Upper Paleozoic ammonites in Texas: Texas Univ. Bull. 3701, p. 27, 1937.

the original collection except *Wellerella texana* (Shumard), which was assigned to *Pugnax osagensis* Swallow?.

Terebratuloids are almost absent, and they were entirely so in the original collection. Aside from three or four fragmentary specimens, there is one that appears to belong to *Dielasma cordatum* Girty. The original collection contained no representation of the genus *Spirifer*, but they are abundant in the later ones. *S. sulcifer* Shumard appears for the first time, and *S. pseudocameratus* Girty appears in several collections. This species has not been recognized in lower horizons, although at least some of the imperfect specimens cited as *S.* aff. *S. triplicatus* Hall may belong to it. *Spiriferina* is rather sparingly represented, but I recognize three species, *S. angulata* King, (probably a synonym of *S. haarmani* Haack) *S. laxa* Girty, and *S. hilli* Girty? The original collection contained only one species, provisionally referred to as *S. billingsi* (Shumard). *Ambocoelia* (*A. arcuata* Girty) is fairly abundant, but *Composita* is unusually rare. Most of the specimens seem to be referable to *C. emarginata affinis* Girty, but *C. angusta* King is also present. *Hustedia* is fairly abundant and persistent. Aside from the ubiquitous *H. meekana* (Shumard), I have identified *H. bipartita* Girty in one collection. Neither *Ambocoelia*, *Composita*, nor *Hustedia* were found in the original collection, but *Leptodus americanus* Girty occurs in both the original and later ones.

The original collection from this general horizon contained a varied pelecypod fauna, and it is closely reproduced in the later ones with, of course, some additions. In fact, the pelecypods for the the first time occur in sufficient numbers and quality to invite comment. It seems to be true of the collections that where the brachiopods are abundant and varied the pelecypods are few, and vice versa.

The original collection contained an unidentifiable species of *Edmondia* and a small specimen identified as *Edmondia? bellula* Girty, which was described from the Capitan limestone. The new collections contain a large, subcircular species (possibly *Edmondia* sp. f of Professional Paper 58), which resembles *E. circularis* Walcott, but is probably new. *Nucula*, represented in the original collection by an unidentified species, is not rare. It may be provisionally designated as *Nucula* aff. *N. beyrichi* von Schauroth.

Parallelodon was, in the original collection, represented by *P. multistriatus* Girty and *P. politus* Girty, both described from the Capitan limestone. In the recent collections, the genus is abundant and varied. In addition to the two species just named, there are two new ones. One is large and marked by very coarse and strong radial costae. It recalls *P. sangamonense* (Worthen), but is clearly distinct. The other is remarkable for an extremely prominent umbonal ridge.

Schizodus was not present in the original collections, but it appears to be rather abundant, and is represented by two species, *S. ferrieri* Girty, and *Schizodus* aff. *S. rossicus* de Verneuil. Three aviculoid shells were recognized in the original collection, identified as *Bakewellia?* sp., *Pteria richardsoni* Girty?, and *Pteria* sp. *P. richardsoni* has also been recognized in one of the later collections. The original collection contained a species of *Myalina*, cited as *M. permiana* Swallow?, and the same species occurs in several newer collections, although as to identification, we know Swallow's species only by the grace of Meek and Hayden, and even so, only as a probability.

The Pectens, in the broad sense, seem rather more varied in the original collection, where they were represented by forms identified as *Camptonectes? papillatus* Girty, *Aviculopecten delawarensis* Girty, *Acanthopecten* aff. *A. carboniferus* Stevens, and *Pernopecten obliquus* Girty. The more recent collections contain *Aviculopecten delawarensis* Girty (which should probably be removed to *Deltopecten*), with two additional species, *D. vanvleeti* Beede and *D. coreyanus* White. *Camptonectes papillatus* Girty is also present, and likewise a new species, apparently of the same genus, as well as *Pernopecten? obliquus* Girty. In this connection, mention may be made of two undetermined species which apparently belong to Branson's genus *Cyrtorostra*, although that name seems to cover about the same sort of shells that European writers, including Waagen, refer to *Oxytoma*. These forms were not found in the original collections, nor were any representatives of *Pseudomonotis*, which are present in the later ones. Two species can be distinguished: one is related to *P. hawni* Meek and Hayden, but is probably new; the other, also probably new, is distinguished by its very large size, but is too poorly represented to be identified or described.

Astartella nasuta Girty, which was described from the Glass Mountains, is present in both the original collection and the later ones. *Pleurophorus* was represented in the early collection by *P. delawarensis* Girty, and by the possibly related *Cleidophorus pallasi delawarensis* Girty, the type specimens of both species having been found at this horizon. Both species occur in the collections of recent date, besides several other species of *Pleurophorus*, one related to *P. occidentalis* Meek and Hayden, the others new or undetermined.

A scaphopod, identified as *Plagioglypta canna* White?, was found in the first collection, and in the new ones as well.

The gastropod representation in the early collection was no less varied than the pelecypod representation. It included eight species of *Pleurotomaria*, that term being employed in a broad sense. These are *P. multilineata* Girty, *P.* sp. d, *P. euglyphea* Girty, *P. pseudostrigillata* Girty? (the originals being from the Bone Spring limestone), *P. arenarea* Girty, *P.? planulata* Girty, *P.? delawarensis* Girty, and *P.? carinifera* Girty.

In the more recent collections also, the gastropods are well represented, but they are practically confined to one collection (locality 7729). The eight species of *Pleurotomaria* all occur in the later collections, besides one or two new ones. Details here would have little point, inasmuch as the new species cannot be cited without further study.

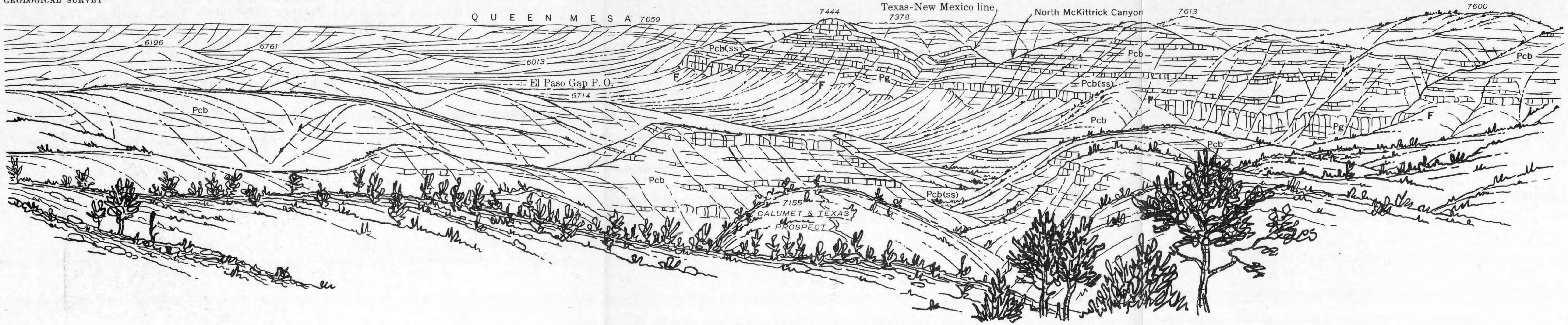
Among the bellerophontids, the original list included only *Bucanopsis* sp. and *Warthia americana* Girty. The new collections do but little better. They give us *Warthia americana*, two indeterminable species of *Bucanopsis*, and an indeterminable species of *Euphemites*, resembling *E. carbonarius* (Cox) on a large scale.

The residue of the gastropods in the original list consisted of *Naticopsis* sp., *Pseudomelania* sp. a, *Bulimorpha chrysalis delawarensis* Girty, and *Macrocheilina?* sp. a. In the new collections, we have *Naticopsis* sp., *Pseudomelania* sp. a, and *Bulimorpha chrysalis delawarensis* Girty, but in addition are a species of *Trochus?*, an indeterminable species of *Omphalotrochus*, and *Ianthinopsis* n. sp., which seems to be rather abundant.

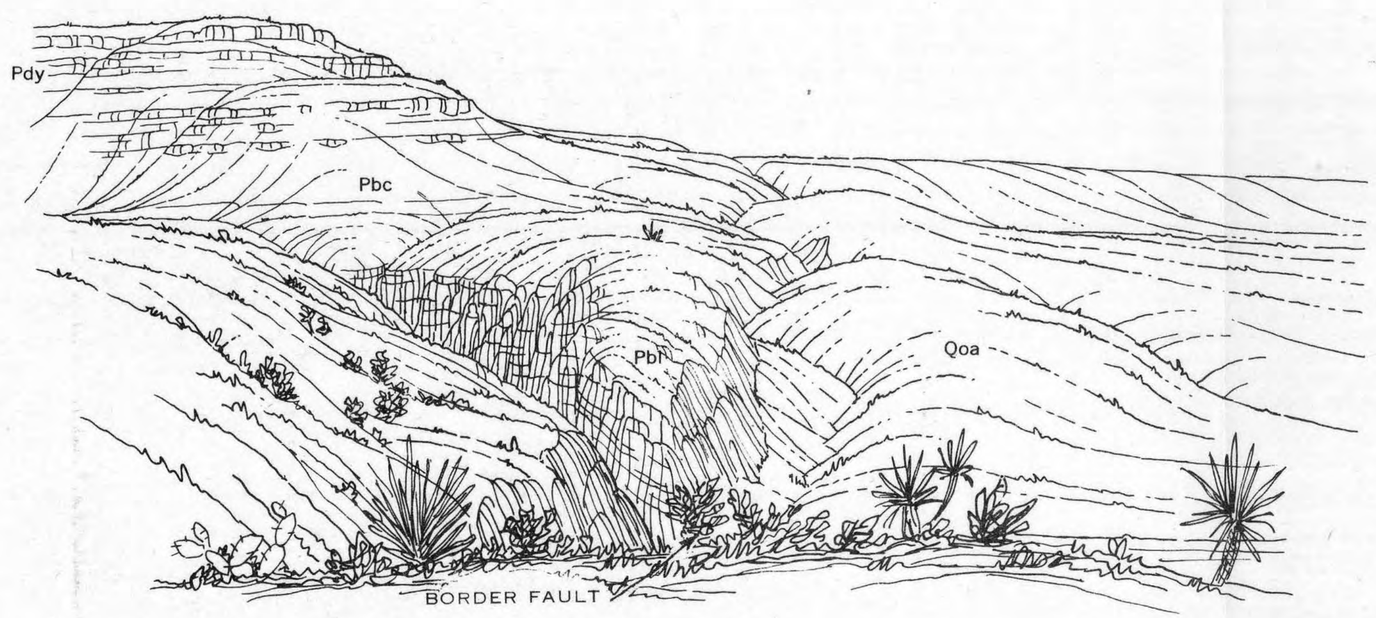
The trilobite *Anisopyge perannulata* (Shumard) occurs in the old collection and in the new ones, a survival from the Bone Spring limestone. It continues, in fact, into the highest fossiliferous beds of the Guadalupe section.—Girty manuscript.

GETAWAY LIMESTONE MEMBER

In the Getaway limestone member, which lies a short distance above the beds containing the above described fauna, fossils are still more abundant and have been collected at numerous localities, of which 13 are herein reported by Dr. Girty. All the collections came from the western part of the Delaware Mountains in an area extending some eight miles south of Pine Spring and El Capitan, and include material from Getaway Gap (7621), Guadalupe Summit radio station (7463, 7474,

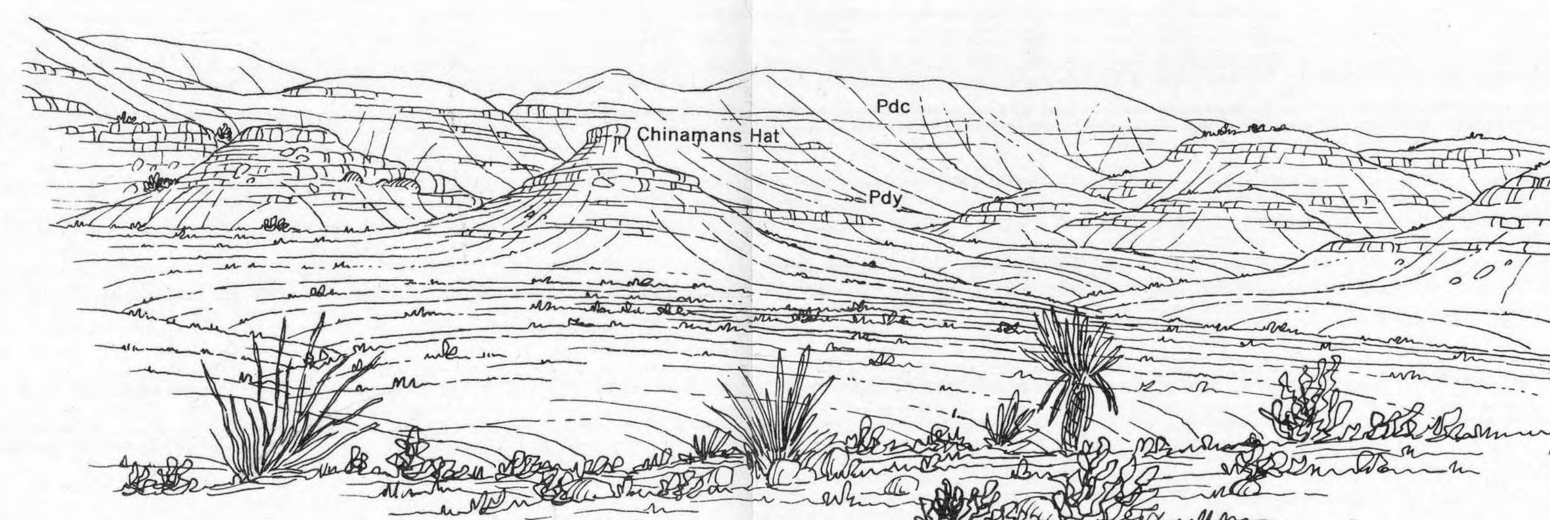


A. DOG CANYON AND ESCARPMENT ON ITS EAST SIDE, FROM LOST PEAK.



B. MOUTH OF CANYON WEST OF CHINAMAN'S HAT, LOOKING SOUTH.

Shows outcrop of Border fault.



C. VIEW EAST, SHOWING CHINAMAN'S HAT, WITH RIM OF DELAWARE MOUNTAINS IN BACKGROUND.

PANORAMIC VIEWS IN NORTHERN AND SOUTHERN PARTS OF AREA STUDIED.

Qoa, Older alluvial deposits; *Pcb*, Carlsbad limestone; *Pcb* (*ss*), basal sandstone member of Carlsbad limestone; *Pg*, Goat Seep limestone; *Pdc*, Cherry Canyon formation; *Pdy*, Brushy Canyon formation; *Pbc*, Cutoff shaly member, and *Pbl*, black limestone beds of Bone Spring limestone. *F*, Fault.

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7615), near Guadalupe Pass (7422, 7465, 7475), and the hills south of Pine Spring Camp (7406, 7470, 7641) (pl. 2). The member was apparently not represented by collections in the original work on the Guadalupian fauna.

The Getaway member contains numerous fusulinids belonging to the genus *Parafusulina*. Of them, the following species have been identified by Dunbar and Skinner:[9] *P. maleyi* Dunbar and Skinner, *P. maleyi referta* Dunbar and Skinner, *P. rothi* Dunbar and Skinner, and *P. sellardsi* Dunbar and Skinner?. It will be recalled that these same species occur also in the underlying Brushy Canyon formation. They have not been found above the Getaway member. In addition, Needham[10] has identified *P. dunbari* Needham from beds 700 feet below the Capitan limestone on the south slope of El Capitan. This horizon is probably in the Getaway member. Dunbar and Skinner[11] consider his species a synonym of their *P. rothi*.

Among the cephalopods, the nautiloids are represented by varied material, although only a few specimens are present in any one collection. In this group, Miller[12] has recognized the following: "*Orthoceras*" sp., *Titanoceras* sp., *Metacoceras shumardianum* (Girty), *Tainoceras* sp., and *Stenopoceras?* sp. The ammonoids are less well represented, only a few specimens having been found and these belonging to genera that are not of great value for zonation and correlation. From the member Miller and Furnish[13] have identified *Pseudogastrioceras roadense* (Böse)?, *Pseudogastrioceras* sp., *Medlicottia burckhardti* Böse, and *Paraceltites ornatus* Miller and Furnish?.

Regarding the remainder of the fauna, Dr. Girty reports as follows:

The sponges, which are a really remarkable feature of the Guadalupian fauna but heretofore have not figured to any extent, now appear in some force. Stable generic identifications must necessarily await more careful study than it has been possible to devote to this difficult group, but for present purposes record may be made of two new species of *Amblysiphonella*, a specimen of *Guadalupia zitteliana* Girty? (described from the Capitan limestone), and *Anthracosycon ficus* Girty?. The latter species, with another unnamed species of the same genus, was found in one of the original collections from the Bone Spring limestone, and these two are about the only representatives of this group that have been observed below the Getaway limestone member.

Corals continue to be poor in numbers and variety. They are exceptionally so when one considers the abundance and diversity of other forms in these collections. The cup corals appear in only six collections, mostly a single specimen in each. As provisionally identified, they represent but a single species, and it appears to be the same as that found in the preceding fauna, which was cited as *Lophophyllum?* sp. The columella in these corals is more complicated than it is in the more simple and typical forms of *Lophophyllum*, and more complicated than it is in some of the forms that pass as *L. proliferum* in the Carboniferous faunas of the Mid-continent area. Here for almost the first time appears the delicate compound coral *Cladopora spinulata* Girty, which was first described from the "upper dark limestone" (Pinery member of Bell Canyon formation).

Many bryozoans can be identified, even generically, only by means of thin-sections, so no more than a tentative outline can be given of those in the Getaway limestone. *Fistulipora*, represented by *F. grandis guadalupensis* Girty, and possibly a new species, is rather abundant, and also *Acanthocladia guadalupensis* Girty. Aside from these, however, the bryozoans, although varied, have a small and scattered representation. The following forms, many subject to reidentification, have been encountered: *Anisotrypa?* sp., *Leioclema?* sp., *Batostomella?* sp., *Fenestella* sev. sp., *Rhombopora* sp., *Coeloconus?* sp., *Rhabdomeson?* sp., *Cystodictya* sp., and *Domopora terminalis* Girty. The series of forms tentatively referred to as *Domopora* are much more abundant at higher horizons, and notably in the Pinery member.

The brachiopod genus *Enteletes*, which is so abundant in some of the older faunas, is absent from the Getaway limestone, as are the related genera *Rhipidomella* and *Schizophoria*, which occur here and there in lower horizons.

Of the Orthotetinae, *Meekella* continues to be by far the dominating type. *M. attenuata* Girty or *M. multilirata* Girty, or sometimes both, occur in most of the collections. We also have *Derbya* n. sp., a large and remarkable form, which was noted in the underlying fauna, but not identified because of the absence of the ventral valve. There are a few other rarer forms that do not belong to any of the three species mentioned, but whose generic status cannot be determined, as they are represented mostly by dorsal valves. One of these may be *Streptorhynchus pyramidale* King.

Chonetes occurs in almost every collection, and is generally abundant. We seem to have here both *C. subliratus* Girty, which was described from the Pinery limestone, and *C. hillanus* Girty, which was described from the Capitan limestone. Apparently the latter is more common, but the two species are difficult to distinguish.

The productids are exceedingly numerous and varied, almost thirty different forms having been discriminated, including a number of varieties and several new species. The following are the most noteworthy: *Productus popei* Shumard (in the sense of King, rather than Girty), *P. popei minor* King, *P. guadalupensis* Girty, *P. walcottianus* Girty, *P. walcottianus costatus* (King), *Productus* aff. *P. longus* Meek, *P.* aff. *P. geniculatus* Girty *P. occidentalis* Newberry, *P. texanus* Girty, *P. capitanensis* Girty, *P.* (*Pustula*) *subhorridus* Girty and one or two varieties, *P.* (*Pustula?*) *pileolus* Shumard, *P.* (*Waagenoconcha*) *montpelierensis* Girty, *P.* (*Cancrinella*) *signatus* Girty, and a number of varieties, *P.* (*Cancrinella?*) *phosphoticus* Girty, *P.* (*Marginifera?*) *wordensis* (King), *P.* (*Marginifera?*) *sublevis* King, and *P.* (*Avonia*) n. sp.

Some of these species, for instance *P. capitanensis* Girty and *P.* (*Pustula?*) *pileolus* Shumard, which were described from the Capitan limestone, have not been found in beds below the Getaway, and some of the species found in the underlying beds, for instance *P. comancheanus* Girty, *P.* aff. *P. multistriatus* Meek and others, have not been found in the Getaway limestone. There is, however, such a general homogeneity in the productid representation that it is doubtful whether these items of disagreement have much importance.

[9] Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas: Texas Univ. Bull. 3701, p. 593, 726–727, 729, 1937. Horizon cited as "limestone in lower part of middle division."

[10] Needham, C. E., Some New Mexico Fusulinidae: New Mexico School Mines Bull. 14, p. 13, 1937.

[11] Dunbar, C. O., and Skinner, J. W., personal communication, 1938.

[12] Miller, A. K., memorandum, May 1939.

[13] Miller, A. K., and Furnish, W. M., Permian ammonoids of the Guadalupe Mountain region and adjacent areas: Geol. Soc. America Special Paper 26, pp. 11–12, 1940.

A rather noteworthy change comes in at this horizon in the genus *Aulosteges*. In the black limestone beds of the Bone Spring *A. magnicostatus* Girty is abundant and also a species identified as *A. subcostatus* King. The genus was not present in the Victorio Peak gray member, but it reappears in the Cutoff shaly member, which contains the first-named species and also *A. hispidus* Branson and *A. guadalupensis* Girty?. In the Brushy Canyon formation I found a single specimen of doubtful affinities which was not mentioned in the summary of that fauna. In the Getaway, the genus occurs in nearly every collection and in abundance. The prevailing species resembles *A. guadalupensis* Shumard, but is varietally, if not specifically distinct, and is also distinct from species of the genus in underlying faunas. With it occurs a different and much rarer species, possibly related to *A. wolfcampensis* King, represented by only three specimens.

Prorichthofenia occurs in every collection save one, and is abundant in most. The species seems to be that of the preceding faunas, *P. permiana* (Shumard). *Leptodus* is fairly persistent in the collections, but is abundant in only one of them. In others, it is represented only by a specimen or two. Most or all of the specimens belong to *L. americanus* Girty.

Camerophoria continues to be represented by *C. venusta* Girty, but it is accompanied by a smaller species provisionally referred to *C. deloi* King, and a third form which may be only a variety of *C. venusta*.

The rhynchonellids are abundant and highly diversified. Many changes are noted from the rhynchonellid representation of the beds below. In general, these shells show a closer agreement with the rhynchonellid faunas higher in the section. A noteworthy feature of this element in the Getaway fauna is the introduction for the first time, and also at some localities in abundance, of the large shells cited under the genus *Liorhynchus*. More specifically, I recognize *Wellerella? swallowiana* (Shumard), *W.? swallowiana* var., *W.? pinguis* (Girty), *Wellerella* aff. *W.? indentata* (Shumard), *Camarotochea? longaeva* (Girty), *C.* n. sp., *Rhynchopora taylori* Girty, *R. illinoisensis* (Worthen), *Leiorhynchus weeksi nobilis* (Girty), and *L. bisulcatum* (Shumard).

The terebratuloids are rather numerous and varied. I recognize *Dielasma spatulatum* Girty, *D. prolongatum* Girty, *Dielasmina?* n. sp., *Heterelasma?* n. sp., and *Cryptocanthia* n. sp.

Spirifer is represented by two species, a large form which is common, and which is provisionally referred to *S. latus* King (his *Spirifer* (*Neospirifer*) *mexicanus latus*), and a much rarer form which may be *S. sulcifer* Shumard, if one may assume that Shumard's figure is poor (which is probable). *Spiriferina* is present in most collections, but the specimens are so few and so poor that most of them cannot safely be identified. Some, however, appear to belong to *S. hilli polypleurus* Girty, some to *S. laxa* Girty, and some to a species related to *S. welleri* Girty, but probably new. *Ambocoelia* is present in a number of collections and is abundant in some of them. It is a remarkably large species and the ventral valve looks like a rather small, gibbous *Squamularia*. The species is new.

Composita, as would be expected, is present in most of the collections, sometimes in abundance. There are at least two distinguishable species. One, which is exceptionally large, may be cited as *C. emarginata affinis* Girty. The other is a rather small form, but apparently mature, if one may judge by its strong convexity and well-developed fold and sinus. It closely resembles *C. mexicana* (Hall).

Hustedia also is represented in almost every collection, and in some abundantly. Most of the specimens are here identified as *H. meekana* (Shumard), although *H. bipartita* Girty and a variety of it are also present. The specimens of *H. meekana*, some of which are exceptionally large, show considerable variety, and under careful study may be susceptible of minor subdivision.

In general, the pelecypod fauna of the Getaway limestone, while showing some departures from that of the sub-Getaway zone, does not show as many as might be expected, in view of the fact that pelecypods are abundant at only two localities in the sub-Getaway.

Solenomya is represented by two more or less doubtful species, one of which appears to be related to *S. radiata* Meek and Worthen.

Edmondia is represented by several species, but most of the specimens are so poor that the generic identifications are hypothetical. Of the uncertain forms, one is a large subcircular species related to *E. circularis* Walcott, and not improbably the same species that was mentioned in the sub-Getaway fauna. The other is a much smaller form related to *E. gibbosa* Swallow. However, *Edmondia* and *Astartella* have a close superficial resemblance and are difficult to distinguish in poorly preserved material; the specimen may therefore be a very robust species of the latter.

Nucula and *Leda*, as in the preceding fauna, are almost unrepresented. The collection contains a single unidentifiable specimen of the one, and a single specimen of the other, related to the common *N. bellistriata* (Stevens).

Parallelodon has much the same representation as in the preceding fauna, although the preservation of the material leaves much to be desired. It comprises a large and very coarsely costate species which is undescribed, and another species without costae, which may be identical with *P. politus* Girty, and a third species which may be identified with *P. multistriatus* Girty.

Pteria (besides several doubtful species) is represented by a remarkable form resembling *P. longa* (Geinitz), but very much larger, nearly 80 millimeters long obliquely. This is probably the species figured in Professional Paper 58 as *Pteria* sp.

Myalina is moderately abundant in one collection but is represented by a single species in the others. Most of the specimens are in a poor state of preservation, and all may be referred to provisionally as *M. permiana* Swallow?, which was also identified in the sub-Getaway fauna.

Schizodus, which was scanty in the sub-Getaway fauna, and represented by small species related to *S. rossicus* de Verneuil, is here fairly abundant and represented by a large species. The specimens vary more or less in shape, some being similar to the Pennsylvanian species *S. affinis* Herrick, others to such species as *S. harei* Miller, and *S. ulrichi* Worthen. The possibility cannot be dismissed that this is *S. phosphorianus* Branson, for his type specimens appear to be fragmentary and preserved in a different manner from mine, which have been macerated.

The Pectenidae are numerous and diversified. Some of the species are uncommonly large. Many of the generic references are provisional, as are some of the specific identifications. Many of the specimens are not of the best, and obviously fail to show characters of importance. Besides a number of indeterminate forms, I recognize *Acanthopecten* n. sp., *A. coloradensis* (Newberry), *Girtypecten sublaqueatus* Girty, *Deltopecten* aff. *D. providencensis* (Cox), *D. delawarensis* (Girty), *D. guadalupensis* (Girty), *D. vanvleeti* Beede, and *D. coreyanus* White. The two species last mentioned are interpreted in the same manner as in my report on the fauna of the Manzano group. *Pernopecten? obliquus* Girty, which is rather rare, and *Camptonectes* n. sp. also belong here. The latter occurs sparingly in many collections, but is extremely abundant at station 7424. On the whole, this type of shell is more abundant and diversified than it was in the lower horizons. On the other hand, the interesting forms belonging to *Cyrtorostra* or *Oxytoma* have not been found. There is, however, an uncertain specimen that looks much like *Cyrtorostra sexradiata* Branson, if, indeed, his species is congeneric with the others.

Of *Lima* I have only one specimen, a large, finely striated form, which probably represents a new species, although the specimen is hardly suitable for use as a type.

The pleurophorids, although numerous and varied in the Getaway member, are difficult to identify generically or specifically. Some are broken, others have indefinite outlines. Some are internal molds or show no surface characters, and some may be compressed and have a different aspect from better preserved specimens that are probably of the same species. Because of their defects, many specimens cannot be distributed satisfactorily between the genera *Myoconcha*, *Pleurophorus*, and *Cleidophorus*. They suggest gradation between the genera, and becloud identification of species.

As in the preceding sub-Getaway fauna, the Getaway contains good representations of *Myoconcha costulata delawarensis* Girty, *Pleurophorus delawarensis* Girty, and *Cleidophorus pallasi delawarensis* Girty. The second species is represented by a few specimens of normal size and possibly by an extremely large internal mold of similar shape but nearly three times the size of the holotype. I have no misconception regarding the form called *Cleidophorus pallasi delawarensis*. It probably does not belong to the genus *Cleidophorus*, and may be a *Pleurophorus*. The formula adopted was for the purpose of noting a resemblance to the European species which has passed as *Cleidophorus pallasi* de Verneuil. The internal ridge or plate which has passed as characteristic of this genus, and a semblance of which has been found in my specimen also, is really the boundary of the anterior muscle scar.

In addition to these, the Getaway contains a shell that resembles *Myoconcha costulata delawarensis* in a general way. It is much larger than the holotype, and one of the specimens shows that the surface is marked by very fine radial striae, whereas the holotype is supposed to be without sculpture. There is also a very large fragmentary specimen which probably represents a new species of *Myoconcha*, but it could not be made the basis of a description.

Another smaller and still more refractory group of specimens are more the type of *Pleurophorus* as it is generally identified. It is doubtful whether the most careful work would resolve these shells satisfactorily into genera and species. Specimens of *Parallelodon* may be among them, especially representing such forms as are without radial striae or have only very fine ones. There may be also specimens of *Allorisma*—not *Allorisma* of the type *A. terminale* Hall, but of other types that have been referred to that genus. The absence of typical species of this genus (such as *A. terminale* Hall and *A. capax* Newberry) is a noteworthy feature of the fauna.

The gastropods of the Getaway limestone are fairly numerous and varied, and add considerably to the Guadalupian fauna. The information which they afford, however, is in many cases rendered indefinite because specimens have lost the surface characters, so that identification is rendered hazardous or impossible. This loss is even more detrimental in the case of the gastropods than it is with the pelecypods.

The bellerophontids are mainly in the form of molds and such specimens are beyond the pale of scientific classification. All belong to small species. Among those that are susceptible to some sort of classification there is one specimen that appears to be specifically identical with the form from the southern Delaware Mountains that I figured as *Bellerophon crassus* Meek and Worthen, an identification which I now propose to abandon. There are also two indeterminable species of *Bucanopsis*, represented by fragments, and a species of *Euphemites* which might be described as a large, slender form of *E. carbonarius* (Cox).

The pleurotomaroids, like the bellerophontids, are mostly indeterminable by reason of exfoliation, which has deprived them of their sculpture, upon which the specific and even the generic classification depends. There is a rather diversified pleurotomaroid fauna in the bed below the Getaway and some of the species will undoubtedly appear among the identifiable specimens from the Getaway itself. At present, I am prepared to identify *Pleurotomaria euglyphea* Girty, and *P.* n. sp.

Several poorly preserved specimens apparently belong to *Straparollus sulcifer* (Girty), described from the "upper dark limestone" (Pinery member), and the related genus *Omphalotrochus* is represented by a new species.

Naticopsis is represented by several species, although their relations to one another and to species in the literature are not readily determinable because of their condition. One species (it is an internal mold or partly macerated) which appears to belong to this genus is remarkable for its large size. Others, on the contrary, are very small. An undetermined species of *Naticopsis* was found in one of the original collections from the sub-Getaway zone, and it is quite likely that the same species occurs in the Getaway fauna. The peculiar shell that for the time being can be designated as *Ianthinopsis* n. sp. occurs in several collections. It has already been noted in the fauna preceding this one.

The characters on which rest the distinction between *Bulimorpha*, *Meekospira*, and *Strobeus* are rarely observed. With this qualification as to generic identification, the fauna of the Getaway limestone contains two species of *Bulimorpha*, one of them uncommonly large and both new. It is possible, however, that *B. chrysalis delawarensis* Girty, which was described from the sub-Getaway zone, was based on an immature specimen of one of them. There is also a small, globose species of *Strobeus* very similar to *S. littonanus* (Hall) of the Spergen limestone, which is also new. I might remark that the scarcity of shells of this genus in the Guadalupian fauna, as compared with a number of faunas of Pennsylvanian age, is a noteworthy feature.

The *Platyceras* tribe is met with for the first time in the section in the Getaway fauna. With full recognition that not only specific but generic distinctions in these shells are in dispute, it would appear that the three specimens in these collections probably represent two new species, one of *Platyceras*, and the other of *Orthonychia*.

Lastly, among the gastropods, we have two poor specimens which belong to a species that was briefly described in Professional Paper 58 as *Pseudomelania* sp. a. If not the same species, this is a closely related one, and it is remarkable for its numerous flat-sided whorls that make up the spire which appears to be more cylindrical than conical in shape. Unfortunately, the specimens are decorticated and no better generic reference than the one originally made can be suggested.

Of the crustaceans, the representation is all but restricted to the trilobite *Anisopyge perannulata* (Shumard), which is present in most of the collections. Ostracodes are a rare feature of the Guadalupian faunas, and they have not been mentioned in descriptions of the underlying faunas. In the Getaway limestone, they are also absent from all collections but one. In this one there is a small slab that is fairly packed with them.—Girty manuscript.

SOUTH WELLS LIMESTONE MEMBER

The South Wells limestone member is represented by collections from only the southeastern part of the area studied as: near Long Point (No. 7641), 2 miles southeast of the D Ranch South Wells (No. 7649), and in the Pinyon Hills (Nos. 7658, 7664, and 7665) (pl. 2). Most of the fauna was unknown before the time of the present investigation, although ammonoids were collected from it near the South Wells in the early 1920's by J. W. Beede, and were afterwards described by Plummer and Scott.[14] The sandy and dolomitic limestones of the member northwest of the localities mentioned, as in the foothills of the Guadalupe Mountains, contain poorly preserved fossils, but none has been collected and their character is unknown.

The fossil-bearing beds in the southeast part of the area have yielded collections that are relatively small compared with those from the underlying Getaway member; also the fauna appears to lack the diversity of the older one. Two more or less distinct facies are present: One is gray, granular limestone which contains fusulinids, productid and spiriferoid brachiopods, bryozoans, and some pelecypods; the other is black, dense limestone, reminiscent of the black limestones of the Bone Spring, and like them containing great numbers of ammonoids. Associated with the ammonoids are abundant rhynchonellid brachiopods, particularly of the genus *Leiorhynchus*. The gray limestone facies is dominant at the Pinyon Hills localities; the black limestone facies is dominant at Long Point and near South Wells, although here also some of the gray limestone facies is interbedded.

In comparison with the Getaway fauna, fusulinids are considerably reduced in numbers. They have been seen in the foothills of the Guadalupe Mountains, but are too poorly preserved there to be collected or identified. Some have been collected in the Pinyon Hills, from which Dunbar and Skinner[15] have identified *Leëlla fragilis* Dunbar and Skinner, and *Parafusulina* n. sp. This is the highest zone in the area at which the latter genus has been certainly identified. The next zone above from which fusulinids were collected during the present investigation is several hundred feet higher in the Hegler limestone member. Here the dominant genus is not *Parafusulina* but the related and younger genus *Polydiexodina*. In the southern Delaware Mountains, Skinner[16] reports that he has collected *Parafusulina* and *Polydiexodina* within 75 feet of each other in the section but has never seen them in association.

The ammonoids, which form an abundant and striking feature of collections made near Long Point and South Wells, have been described by Plummer and Scott on the basis of Beede's collections, and by Miller and Furnish[17] on the basis of collections made during the present study. From this area, the latter have identified *Medlicottia burckhardti* Böse, *Paraceltites ornatus* Miller and Furnish, *P. sellardsi* Miller and Furnish, *Pseudogastrioceras beedei* (Plummer and Scott), *P. roadense* (Böse), *Waagenoceras guadalupense* Girty, and *W. dieneri richardsoni* Plummer and Scott. A few similar forms have been obtained also in the Pinyon Hills. With the ammonoids are a few nautiloids, which A. K. Miller has identified as *Metacoceras* sp. and "*Orthoceras*" sp.

Regarding the remainder of the fauna, Dr. Girty reports as follows:

The more lowly organic types are poorly represented. Fusulinids are present, but not abundant, and the sponges are apparently absent altogether. The corals are represented by two specimens, apparently belonging to the same species that has been cited in the faunas already reviewed as *Lophophyllum* sp.

The bryozoans are poorly represented. *Fistulipora* (*F. grandis guadalupensis* Girty?) continues to be the most abundant type. There are probably two species of *Tabulipora*. *Domopora*, which is so characteristic of the Pinery fauna, is represented by *D. ocellata* Girty. The absence of *Fenestella*, *Polypora*, *Acanthocladia* and other genera is more or less noteworthy.

Turning to the brachiopods: *Enteletes* and related genera are absent entirely. *Meekella* is present, but is represented by a few poor specimens, provisionally identified as *M. attenuata* Girty. *Chonetes* is present at one locality. It is difficult to tell whether the specimens belong to *C. subliratus* Girty or *C. hillanus* Girty, or both.

Productids are reduced in numbers and variety, as compared with those of the Getaway limestone. Many of the species are the same, but the specimens are fewer and poorer. The following provisional identifications have been made: *Productus popei* Shumard (as interpreted by King), *P.* (*Marginifera?*) *wordensis* (King), *Productus* sp. (possibly *Avonia signata* as interpreted by King, *P.* (*Waagenoconcha*) *montpelierensis* Girty, *P.* (*Cancrinella*) *signatus* Girty with a variety or two, *P.* (*Cancrinella?*) *phosphaticus* Girty, and *P.* (*Marginifera?*) n. sp.

Aulosteges is present at one locality. The species seems to be the same as that which occurs in the Getaway limestone, where it was cited as *A. guadalupensis* Shumard var. *Prorichthofenia permiana* (Shumard) persists, and at one locality is relatively abundant. *Camerophoria* is represented by only a fragmentary specimen, probably *C. venusta* Girty.

The South Wells fauna is remarkable for the abundance and diversity of its rhynchonellid shells, and this fact is especially noteworthy in view of its paucity of other types. Some of the species are of large size, and they are especially abundant. Some of them resemble the species that were described by me as *Pugnax bisulcata* (Shumard), *P. weeksi* Girty and *P. weeksi nobilis* Girty. They appear to be the same species, wholly or in part, that King figures as *Leiorhynchus bisulcatum* (Shumard) and *L. weeksi nobilis* (Girty), but I am satisfied that my new specimens cannot be identified with the originals of the species just named in spite of a general resemblance to them. The shells of the present collection differ from the species named in size, and in number, strength, and distribution of the plications, so that if one wished, ten or a dozen species or varieties could be distinguished, all of them new. The best way to classify these protean shells must await more careful consideration than has yet been possible to give. The preceding Getaway fauna also was notable for the abundance and variety of its rhynchonellid shells, but in the South Wells fauna we seem

[14] Plummer, F. B., and Scott, Gayle, Upper Paleozoic ammonites in Texas: Texas Univ. Bull. 3701, p. 27, 1937.

[15] Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas: Texas Univ. Bull. 3701, pp. 593 and 727, 1937. Horizon referred to as "limestone in middle of middle division."

[16] Skinner, J. W., personal communication, August 1938.

[17] Miller, A. K., and Furnish, W. M., Permian ammonoids of the Guadalupe Mountain region and adjacent areas: Geol. Soc. America Special Paper 26, pp. 10–11, 1940.

to have a new dispensation. Many of the forms that occur in the South Wells fauna seem not to occur in the Getaway, and vice versa. Those forms that are similar or possibly the same are represented by few specimens. Among these forms mention may be made of *Wellerella bidentata* (Girty), *Wellerella? pinguis* (Girty)?, and *Wellerella* aff. *W.? indentata* (Shumard), all of which are scarce.

The terebratuloids are represented by *Dielasma cordatum* Girty, *Dielasmina guadalupensis* Girty, and probably by two species of *Cryptocanthia* (this generic reference subject to revision), one of them being a survival from the Getaway limestone. These shells are rather abundant and form a noteworthy feature of the fauna. Their large size is in striking contrast to the Pennsylvanian species of the genus and, as they have a septum in the dorsal valve, it is likely that they will prove to be generically new.

Spirifer is represented by one specimen which appears to be *S. sulcifer* Shumard as interpreted heretofore, and by fragments of what appear to be several other species, one of them related to *S. triplicatus* Hall. *Spiriferina* is in like manner represented by a few fragmentary specimens. Two species can be distinguished, one of which can provisionally be identified as *S. laxa* Girty. *Squamularia* is doubtfully represented by a single specimen.

Composita is represented by numerous specimens, and can be divided into two more or less interlocking species. One is *C. emarginata affinis* Girty; the other is very close to *C. subtilita* (Hall). *Hustedia* continues to be present as *H. meekana* (Shumard).

In consonance with the restricted representation of other groups, the pelecypods of the South Wells fauna are confined to the genus *Parallelodon*, to the Pectenidae, and to the genus *Myalina*. They are so poorly represented that they could hardly demonstrate any close affinity, or lack of it, with the pelecypod fauna of the Getaway limestone.

Parallelodon is represented by a small, fragmentary, and doubtfully identifiable specimen. It certainly does not belong to *P. politus* Girty, but might possibly be an immature specimen of *P. multistriatus* Girty. *Myalina* is doubtfully represented by a fragmentary specimen.

Among the Pectenidae, a fragmentary specimen of *Deltopecten* appears to be related to *D. guadalupensis* (Girty). A poor specimen of *Pernopectin* probably belongs to *P.? obliquus* (Girty). Finally, there is a peculiar form which suggests the species described as *Aviculopecten montpelierensis* Girty, a type of shell which has sometimes been referred to the genus *Streblopteria*. The Guadalupian form may not be congeneric with *A. montpelierensis*, and its generic relations are uncertain from the material at hand.

The gastropods are still less distinctive in their relationships than the pelecypods. They include a probable new species of *Capulus*, a doubtful species of *Pleurotomaria*, an imperfect specimen that probably belongs to *Bulimorpha*, an indeterminate species of *Euomphalus*, and an imperfect specimen that probably represents a new species of *Omphalotrochus*.

Anisopyge perannulata (Shumard), which has occurred in all the underlying faunas, and is encountered in those above, does not appear in the collections from the South Wells member.—Girty manuscript.

MANZANITA LIMESTONE MEMBER

During field work both Fountain and I observed at many places in the orange-brown, earthy limestones of the Manzanita member the molds of ammonoids, crinoid stems, fusulinids, and other fossils, but were unable to collect identifiable material. Since then, Clifton[18] has collected and identified fossils from the member at Long Point, apparently from the lumpy, slabby facies of the member. According to Clifton, the member here contains the following ammonoids: *Medlicottia* sp., *Paraceltites ornatus* Miller and Furnish, *Cibolites uddeni* Plummer and Scott, *Pseudogastrioceras altudense* (Böse), *P. roadense* (Böse), *P. beedei* (Plummer and Scott), *P.* cf. *P. texanum* Clifton, *Agathiceras girtyi* Böse, *Waagenoceras guadalupense* Girty, *W. dieneri Böse*, *W. richardsoni* Plummer and Scott, and *Timorites?* sp. Associated with the ammonoids are brachiopods, pelecypods, sponges, a gastropod, a crinoid, and an echinoid. Clifton also notes that he and his associates have collected fusulinids from the member on Nipple Hill, but the identity of the species is not stated.

SANDSTONE TONGUE OF CHERRY CANYON FORMATION

The four preceding faunas (sub-Getaway, Getaway, South Wells, and Manzanita) all occur in the Cherry Canyon formation in the southeast part of the area, and lie one above the other in normal stratigraphic order. The next two faunas (sandstone tongue of Cherry Canyon and Goat Seep) lie in the northwest part of the area, in beds of approximately the same age as the preceding four, but of different facies. As will be seen from the descriptions, these differences in facies are reflected in the composition of the faunas of the two areas. The two faunas to the northwest resemble each other more than they do any of the four faunas to the southeast.

In the upper part of the sandstone tongue of the Cherry Canyon formation are calcareous layers that contain poorly preserved fossils, most of which are so silicified that their internal structure is destroyed; many remain only as molds. Collections were made at four localities; three of them (Nos. 7634, 7651, and 7728, pl. 2) were in the outcrops between Goat Seep and Cutoff Mountain, and one (No. 7647) was northwest of Cutoff Mountain and about 3 miles north of the New Mexico line.

The last named collection contains large fusulinids, superficially similar to the species of *Parafusulina* in the Brushy Canyon and Getaway faunas to the southeast. The specimens are so completely silicified, however, that their internal structure is destroyed, and they are apparently not even generically identifiable. No ammonoids have been found in the sandstone tongue.

The greater part of the fauna consists of brachiopods, but a few bryozoans, pelecypods, and gastropods have been collected. Regarding these groups, Dr. Girty reports as follows:

[18] Clifton, R. L., Ammonoids from upper Cherry Canyon formation of Delaware Mountain group in Texas: Am. Assoc. Petroleum Geologists Bull., vol. 28, pp. 1644–1656, 1944.

Bryozoans are represented by a single specimen, probably belonging to the genus *Septopora*.

Enteletes is apparently represented by four species which may provisionally be identified as *E. liumbonus* King, *E. angulatus* Girty, a third uncommonly large form which may prove to be new, and a fourth distinguished by being marked with numerous fine plications. The specimens are, however, few and poorly preserved, adding difficulty to the discrimination of species in a genus in which discriminations are always difficult. The preservation of these specimens is poor but one or two may belong to the genus *Meekella*. This is especially true of the fourth species mentioned, which is represented by only internal molds of dorsal valves. These strongly suggest dorsal valves of *Meekella* (such as *M. skenoides* Girty), but the specimens seem to have a well-marked cardinal area and a cardinal process like that of *Enteletes*.

Chonetes is represented by an indeterminable specimen in the form of an internal mold.

Productids are fairly abundant and varied, relative to the other forms, but they almost defy classification. Most of the specimens are in the form of molds, so the identifications adopted indicate what the specimens might be if they were well preserved, rather than the presence of distinctive characters that can be definitely recognized. Besides several forms that are wholly unidentifiable, the following species may be cited as present: *Productus guadalupensis* Girty, *P. texanus* Girty, *Productus* sp. a (of Professional Paper 58), *P.* (*Cancrinella*) aff. *P. meekanus* Girty, and *P.* (*Marginifera*?) *waagenianus* Girty.

The rhynchonellids are represented by a single specimen which is very similar to *Wellerella*? *swallowiana* (Shumard). The terebratuloids are apparently absent. Poorly preserved specimens of *Leptodus* are present, apparently belonging to *Leptodus americanus* Girty.

Spiriferoids are fairly abundant. Three species of *Spirifer* can be distinguished, but they are more easily differentiated than identified. One which has fine fasciculate costae may be *S. costella* King. A second species which has coarse costae strongly grouped in bundles of three may be the species identified by King as *S. pseudocameratus* Girty, while a third form (a single poorly preserved specimen) may be the species he identified as *Spirifer sulcifer* Shumard.

To *Spiriferina* are attributed two specimens, although neither of them can be certainly distinguished from *Spirifer*. One may be cited tentatively as a large variety of *Spiriferina hilli* Girty. The other is more likely *S. hilli polypleurus* Girty. *Squamularia* is abundant in one collection. The specimens probably represent a new species related to *S. guadalupensis* (Shumard), but with a high cardinal area and fairly strong sinus in the ventral valve.

Of *Composita* there may be two species. One is very similar to *C. subtilita* (Hall), although reaching a rather large size in specimens. The other species is small, and is more comparable to *C. mexicana* (Hall). *Hustedia* persists in the common species *H. meekana* (Shumard).

The mollusks are all but missing. One pelecypod probably belongs to *Parallelodon multistriatus* Girty; another is an indeterminable species of *Aviculopecten;* and a third is a somewhat doubtful specimen of *Astartella* (apparently not *A. nasuta* Girty). A gastropod, apparently a species of *Strobeus*, completes the tale of the mollusks, and indeed of the entire fauna of this zone.—Girty manuscript.

From field relations, the sandstone tongue of the Cherry Canyon formation appears to be equivalent to beds between the base of the Cherry Canyon formation and the base of the Getaway limestone member toward the southeast. Its fauna should, therefore, be of about the same age as the sub-Getaway fauna, and should be a little older than the Getaway fauna. Dr. Girty, however, points out a number of marked differences between its fauna and that of the other two members. These differences are, perhaps, the result of differences in facies.

In the sandstone tongue, many genera and groups of brachiopods are absent or poorly represented, although they are well represented in the two faunas to the southeast. These faunas include the rhynchonellids and terebratuloids, and the genera *Meekella*, *Chonetes*, and *Ambocoelia*. Pelecypods and gastropods are likewise absent or poorly represented in the sandstone tongue, and are abundant to the southeast. Only one group of brachiopods—the orthoids—show any compensating increase in numbers; the genus *Enteletes* is common here, but is entirely missing to the southeast. Differences are not as striking among the productids and spiriferoids, so far as can be judged from the material collected; those of the sandstone tongue are found also to the southeast. The genus *Leptodus* also occurs in the same form in both areas.

GOAT SEEP LIMESTONE

Up to the time of the present investigation, no fossils had been described from the Goat Seep limestone of the southern Guadalupe Mountains. Some collections made by Darton and Reeside [19] from Last Chance Canyon in the northern Guadalupe Mountains (fig. 2) had been identified by G. H. Girty. They are now known to be from beds of approximately the same age and facies as the Goat Seep.

Even on the basis of the collections of the present investigation the fauna of the Goat Seep limestone is relatively poorly known. Fossils appear to be abundant in places, but are nearly all badly preserved on account of the prevailing dolomitization of the rock. Collections that have been made to date are therefore so few and widely scattered that they may not be representative of the fauna as a whole. The following report is based on six collections. Three are from the upper part, in the massive limestone facies, and were made on the summit of the range near Bartlett Peak (No. 7404) and in the northern Patterson Hills (Nos. 7482 and 7627) (pl. 2). Two others came from the basal beds on the west slope of the range (Nos. 7628 and 7646), and a third from the fossiliferous lens a mile north of Lost Peak on the east side of West Dog Canyon (No. 7603).

Nearly everywhere in the southern Guadalupe Mountains there are beds in the Goat Seep limestone that are crowded with fusulinids. Unfortunately, nearly all of these fusulinids are so dolomitized that the tests

[19] Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, p. 426, 1926. "Fossils from above the unconformity."

are preserved only as molds and show so few diagnostic characters, such as internal structure, that they cannot be identified. In the Last Chance Canyon area of the northern Guadalupe Mountains, from beds probably of the same age and facies, Skinner [20] has identified *Parafusulina rothi* Dunbar and Skinner and related species which occur also in the lower part of the equivalent Cherry Canyon formation in the southeast part of the area. From the Last Chance Canyon area Needham [21] has identified *Parafusulina dunbari* Needham, which Dunbar and Skinner consider to be a synonym of their *P. rothi* (see p. 43).

No cephalopods are known from the Goat Seep limestone, except some fragmentary specimens of "*Orthoceras*."

Dr. Girty's report on the remainder of the fauna is given below. This report gives no information on the occurrence of the forms cited at the individual localities, which is regrettable in view of the possible heterogeneity of the collections.

The collections include two sponges, one probably *Guadalupia zitteliana* Girty, the other of doubtful affinities, possibly a species of *Amblysiphonella*. Of corals, there are none, and of bryozoans, a doubtful species of *Fistulipora*.

Enteletes is present in one collection, and is not exactly rare. It probably belongs to *E. liumbonus* King. Some of the smaller but apparently mature specimens may be varietally distinct.

The Orthotetinae are fairly abundant and diversified, although the specimens themselves leave much to be desired. One species apparently belongs to *Orthotetes distortus* Girty. At one locality an uncommonly robust species of *Meekella* is abundantly represented by incomplete dorsal valves. It is identified as *M. globosa King*. A smaller form is identified as *M. skenoides* Girty, and a single specimen which apparently belongs to this genus much resembles some of King's figures of *M. irregularis texana* King.

Chonetes is represented only by molds, which are so poor that they cannot be identified specifically.

Productids are fairly numerous, but are not varied. They occur mostly as molds or impressions, few of which are good, so the group is possibly more differentiated than it appears to be. With some reservations, I will cite: *Productus guadalupensis* Girty, *P.* (*Cancrinella*) n. sp. (apparently *Avonia signata* (Girty) as identified by King), a finely marked variety or possibly a distinct species related to the same, *P. walcottianus* Girty, *P. popei* Shumard?, and *P.* (*Waagenoconcha*) *montpelierensis* Girty.

A species of *Aulosteges* is abundant in one collection, and is the same as that which has already been cited several times as *A. guadalupensis* Shumard var. *Prorichthofenia permiana* (Shumard) is represented by a single specimen in one collection, and *Teguliferina?* sp. (which is possibly an immature *Prorichthofenia*) in another.

Rhynchonellids are scarce, and only two species have been recognized. One is *Rhynchopora taylori* Girty, of which there is a single specimen. The other is a species that may be cited as *Wellerella? swallowiana* (Shumard)? and is rather abundant at one locality. Of the terebratuloids, I have a single unidentifiable specimen of *Dielasma*, and the generic position of that is open to question.

Spirifer occurs in but two collections, a large form with strong plications conspicuously grouped in fascicles of three, which may well be the species that King refers to as *Spirifer pseudocameratus* Girty. A single specimen of *Spiriferina* seems to be identical with *S. billingsi* Shumard.

Composita can be classed in two species, one *C. emarginata affinis* Girty, the other *C. subtilita* (Hall), or if not that species, at least one very close to it. A fragmentary specimen probably belongs to *Hustedia*, and if so to *H. meekana* (Shumard).

Pelecypods are few, and for the most part poorly preserved. A large, subcircular *Edmondia* resembles *E. circularis* Walcott, and is probably the same species as one that is mentioned in the sub-Getaway fauna. *Nucula* is represented by a small, indeterminable specimen. A coarsely costate *Parallelodon* may be an imperfect and immature specimen of the new species mentioned several times in preceding faunas.

Pectenidae are better represented in numbers and variety than any other group of pelecypods, but most of the specimens are indeterminate or belong to undescribed species. One large and fairly well-preserved specimen appears to be a left valve of the species that was referred to *Deltopecten vanvleeti* Beede in the fauna of the Manzano group. Another left valve appears to be a species of *Acanthopecten*, possibly new. A small right valve may belong with one of the Guadalupian species of *Camptonectes*. Besides these specimens of more distinguishable species there are several too imperfect to be worth citing. An imperfect specimen of *Myalina* may well be *M. permiana* Swallow.

Of the scaphopods, a single specimen probably belongs to the species that I have been accustomed to identify as *Plagioglypta canna* White.

The gastropods can barely be identified generically, for the most part. The bellerophontids are represented by a few small specimens, but as they are internal molds it is impossible to tell the genus to which they belong. The pleurotomaroids are not represented at all.

A fragmentary internal mold probably represents a medium sized species of *Naticopsis*. Another specimen in a similar condition evidently belongs to a many-whorled, high-spired shell, possibly a species of *Orthonema*. Still another specimen must originally have had a spreading conical shape like *Omphalotrochus* or *Euconospira*.

The trilobites are represented by the persistent *Anisopyge perannulata* (Shumard)—Girty manuscript.

Comparisons with other faunas of middle Guadalupe age are made difficult by the scantiness of the collections from the Goat Seep limestone. On the whole, the Goat Seep fauna resembles that of the underlying sandstone tongue more than it does the Cherry Canyon faunas to the southeast.

Like the fauna in the sandstone tongue, this one contains few or no brachiopods of the genera *Chonetes* and *Ambocoelia*, or of the groups of terebratuloids and rhynchonelloids. All these brachiopods are present in the faunas to the southeast, and in some they are abundant. The last named group is common in the Getaway fauna, and is markedly developed in the South Wells fauna. Like the fauna of the sandstone tongue, and unlike the faunas to the southeast, *Enteletes* is present. The Goat Seep fauna, however, differs from that of the sandstone tongue and resembles those to the southeast in the abundance and fairly diverse character of the

[20] Skinner, J. W., letter, 1939.

[21] Needham, C. E., Some New Mexico Fusulinidae: New Mexico School Mines Bull. 14, p. 13, 1937.

Orthotetinae (*Orthotetes* and *Meekella*). In the faunas both to the northwest and southeast, productids and spiriferoids are common, and appear to belong to the same general types, but collections from the Goat Seep and the sandstone tongue are too small to afford extensive comparisons with the faunas to the southeast.

Pelecypods and gastropods are better represented in the Goat Seep limestone than in the sandstone tongue, but are not as common as in the sub-Getaway and Getaway faunas. According to Girty:

> Each fauna contains a number of genera and of species that are not known in some of the others, but many of the species are new, and more detailed study is needed before an accurate delimitation of genera and species can be presented. The pelecypod and gastropod faunas of the Goat Seep are evidently extensive, and many of the differences between its fauna and the others can doubtless be charged to the accidents of collecting.—Girty manuscript.

Comparison of the description of the Goat Seep fauna with descriptions of the Capitan and Carlsbad faunas that are given on later pages suggests that there are considerable differences between them. This fact is of interest because the two limestone formations of upper Guadalupe age overlie the Goat Seep and are of such similar rock facies that it is difficult to distinguish the one from the other two in the field.

CONDITIONS OF DEPOSITION

REGIONAL RELATIONS

During middle Guadalupe time, deposits were laid down not only in the Delaware Basin, but also in the shelf area beyond. As compared with lower Guadalupe time, the area of deposition was greatly increased (sec. *c*, pl. 7, *B*). The deposits both in and beyond the Delaware Basin were of marine origin. If the region outside the basin was land during lower Guadalupe time, there was a readvance of the sea during middle Guadalupe time. At first, the marine sediments laid down in both the basin and the shelf were sandstones, but before long the limestones of the Goat Seep began to be built up along the margin of the basin. Sandstone continued to be the dominant deposit in the basin, and was also laid down between limestone layers of the Goat Seep northwest of its margin.

In the Delaware Basin, deposits of middle Guadalupe age have a nearly constant thickness of 1,000 feet, whereas beyond the basin to the northwest their thickness is only 750 feet. Along the margin of the basin, they reach 1,500 feet, the increased thickness being mostly in the limestone layers of the Goat Seep (pl. 7, *A*).

It is not easy to restore the structure of the sea bottom on which these deposits of various thicknesses, and the similar ones of upper Guadalupe age, were laid down. The lay of the beds has since been modified, especially by the tilting and faulting that accompanied the uplift of the mountains during Cenozoic time. Reconstructions (such as those of pl. 7, *B*) have been made in part on the basis of the beds exposed on escarpments and canyon walls (some of which are shown on pl. 17), where the effects of later deformation are evident or unimportant. Further data on the reconstruction has been obtained from the thickness of the unit in different parts of the area, and from the nature of the beds found there.

The exposures shown in section *K–K′*, plate 17, suggest that the great thickness of middle Guadalupe beds along the margin of the Delaware Basin was not accompanied by any local subsidence of the beds beneath, but rather that the thick deposits were laid down on a surface that sloped southeastward toward the basin. The section shows that the southeastward slope of the beds is steeper at the top than at the base of the unit, as though it had been accentuated during the period by greater deposition in the marginal area than in the basin. Less conclusive evidence from the exposures suggests, however, that there was no corresponding slope from the thick deposits of the marginal area towards the thinner deposits to the northwest; instead, the beds of the two areas appear to have joined in a nearly horizontal position (pl. 7, *B*).

These relations are explained by assuming that the Delaware Basin during middle Guadalupe time was a region of greater subsidence than the area outside it, and that the marginal area was consequently flexed down toward the basin in the same manner as it was during the formation of the older Bone Spring flexure but to a lesser degree. Under this assumption, sedimentation in the shelf and marginal areas kept pace more or less with subsidence, so where subsidence was moderate the deposits were thin, and where it was great the deposits were thick. The deposits are thinner within the basin itself than in the marginal area because sedimentation took place more slowly and thus did not keep pace with subsidence.

DEPOSITS OF THE DELAWARE BASIN

The source of the fine-grained sandstones of the Cherry Canyon formation is uncertain. Perhaps some of the material was derived from the south side of the basin, but here the equivalent beds, the Word formation of the Glass Mountains,[22] contain much less clastic material than the formations that preceded them (fig. 14. *A*). Apparently the land that had previously contributed clastics to the south part of the basin was now contributing little sediment.

On the other hand, sandstone does not appear to have moved freely into the basin from the northwest. The margin of the basin on this side was covered by limestone deposits of the Goat Seep, considerable thicknesses of which do not contain much sand. However,

[22] King, P. B., Geology of the Glass Mountains, part 1: Texas Univ. Bull. 3038, pp. 69–73, 1931.

the limestones of the Goat Seep formation farther northwest are interbedded with sand that is coarser than any in the basin, and more like that which filled the basin in lower Guadalupe (Brushy Canyon) time. This coarser material was probably trapped behind the limestone barrier, and the finer material was able to make its way into the basin, either directly across the barrier, or through such openings in it as may have existed. This infiltration may have gone on slowly. At any rate, the possibility is suggested that sedimentation in the basin was so slow that it failed to keep pace with the subsidence taking place there. This condition was probably caused by the Goat Seep barrier.

The volcanic ash of the Manzanita limestone member, near the top of the Cherry Canyon formation, had a different source from the rest of the clastics and was no doubt the wind-borne product of distant eruptions. The eruptions probably were to the south, for near Las Delicias, Coahuila, a thick sequence of volcanic rocks is exposed, whose fossils indicate them to be of Leonard and Guadalupe age.[23] Further evidence that the source of the ash beds was to the south is given by Adams,[24] who states, on the basis of subsurface work, that in the region farther east bentonite layers in equivalent beds thicken southward. As there are some less-continuous ash beds both above and possibly below the Manzanita member, the volcanic activity in the distant region was probably long continued. Assuming that conditions of transportation and preservation were the same throughout Guadalupe time, the ash falls in Manzanita time were caused by an eruption more violent than the rest.

Some of the sandstones of the Cherry Canyon formation were laid down in agitated water. In the lower half of the formation, many of them are cut by channels or marked by ripples. Channels are conspicuous along the southeast margin of the Goat Seep limestone mass.

The ripple marks in the sandstones, like those in the Brushy Canyon formation, have a general northeastward trend (fig. 8). In the Brushy Canyon formation, these ripple marks were explained as the result of wave motion or undertow currents oriented at right angles to the Bone Spring flexure, which was the shore at the time. In the Cherry Canyon formation, the shore lay much farther northwestward, but the Goat Seep limestone, whose southeast edge had a northeast trend similar to that of the flexure (fig. 8), apparently formed an area of shoals that probably had a similar influence on movements of the water. The channeling along the southeastern margin of the Goat Seep limestone is further evidence that it formed an obstruction to the waves. Most of the ripple marks in the Cherry Canyon formation are symmetrical, and were therefore formed directly by oscillation of the waves. A few asymmetrical ripples have been observed, however, whose steepest sides are to the southeast. These ripples were probably formed by undertow currents, moving away from the shoal water to the northwest.

Some of the limestone beds also appear to have been laid down in agitated water. Parts of the Getaway member contain pebbles eroded from the beds next beneath, and other parts contain fusulinids lying in parallel orientation, generally at right angles to the trends of ripples in adjacent beds. An environment of shallow, agitated water is suggested also by the rich and diversified bottom-dwelling fauna of the member. Similar pebble beds and oriented fusulinids are found in the gray, dolomitic limestones of the South Wells member along the northwest edge of the Delaware Basin. The irregular, lenticular development of the Getaway and South Wells limestone members suggest that they were laid down under disturbed conditions.

Some of the other beds of the Cherry Canyon formation were laid down in quieter water. The thin-bedded sandstones which form a large part of the sequence, with their thin, varvelike laminations, could not have been spread so evenly if the water had been much disturbed. Moreover, in the Getaway member, many of the bivalved shells are preserved entire, indicating that they had not been moved very far after the death of the animal. In fact, the bivalves may have been buried before the dead animal had decayed. Some of the beds are strongly bituminous, suggesting that from time to time the water was quiet enough to be fouled by decaying organic matter.

Bituminous limestones form a prominent part of the South Wells member in the southeast part of the area, away from the edge of the Delaware Basin. The fossils that they contain are less diverse than those in the Getaway member. The dominant group is the ammonoids, which were probably free-swimming organisms, whose shells settled into the fouled bottom water after death. The bottom-dwelling fauna is greatly reduced by comparison with that in the Getaway, except for rhynchonellid brachiopods. These brachiopods were probably more suited to inhospitable bottom conditions than other groups of animals. The Manzanita member also appears to have been laid down in quiet water, for its beds, including the volcanic ash layers, retain the same character and thickness over wide areas.

Indications of agitated water appear to be most common in the lower part of the Cherry Canyon formation, and of quiet water in the upper part. The channeling and ripple marking of the sandstones is found chiefly in the lower part. Likewise, the limestone beds in the upper part appear to have been laid down under quieter conditions than the limestone beds in the lower part.

[23] King, R. E., The Permian of southwestern Coahuila, Mexico: Am. Jour. Sci., 5th ser., vol. 27, pp. 98–112, 1934.

[24] Adams, J. E., Upper Permian stratigraphy of west Texas Permian basin: Am. Assoc. Petroleum Geologists Bull., vol. 19, p. 1016, 1935.

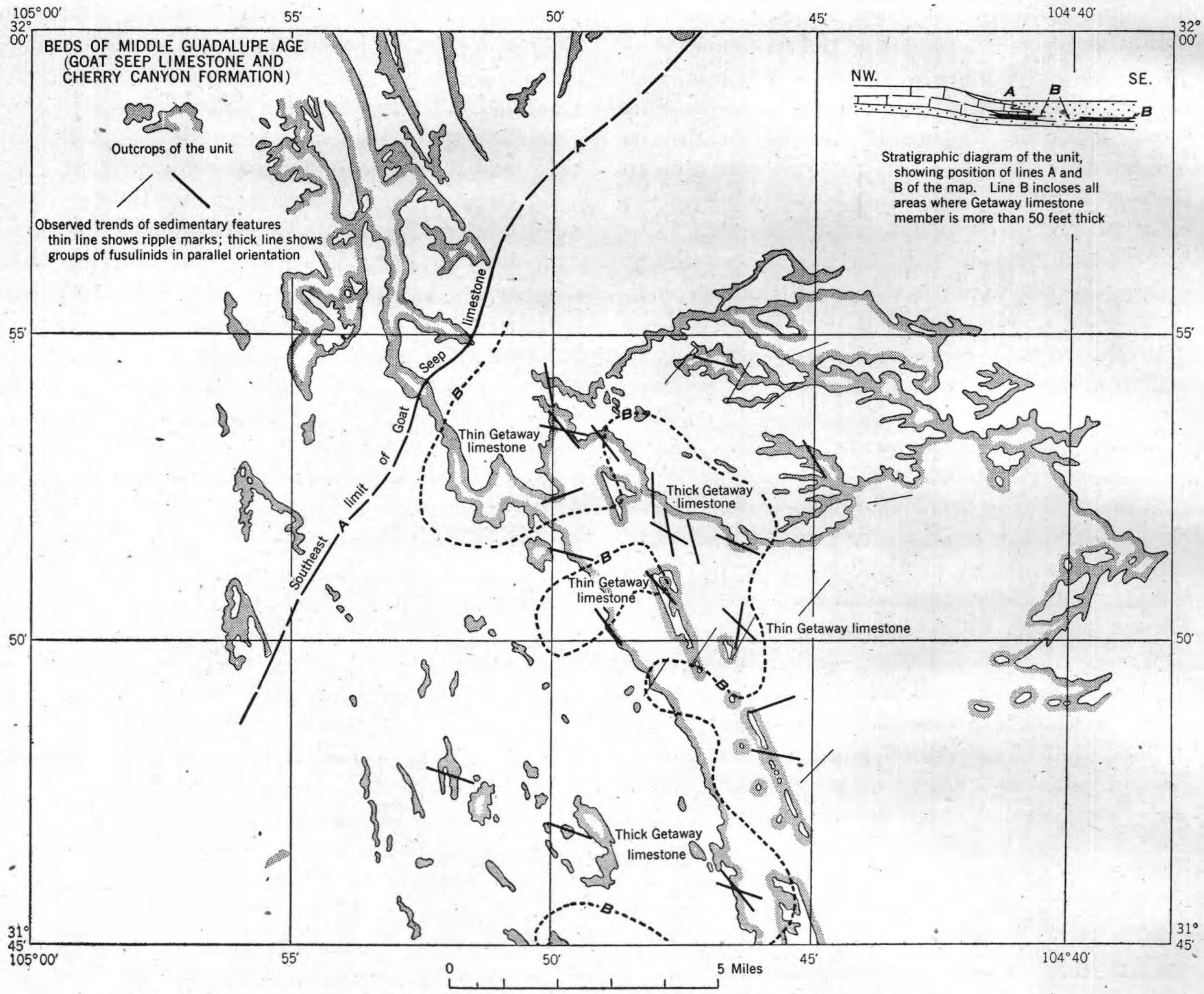


FIGURE 8.—Map of area studied, showing distribution of facies and other stratigraphic features in beds of middle Guadalupe age (Cherry Canyon and Goat Seep formations).

This change probably resulted from progressive deepening of the water during middle Guadalupe time.

In parts of the Cherry Canyon formation, the beds tend to be repeated in cyclical order. The repetition of the cycle of shaly sandstone, sandstone, and nodular limestone below the Getaway member at one locality has already been noted (sec. 40, fig. 5). Higher up, each limestone bed or member is commonly underlain by massive sandstone and is succeeded by thin-bedded sandstone; this succession is repeated several times upward in the section (sec. 42b, fig. 5).

DEPOSITS OF MARGINAL AREA (REEF ZONE)

During the time when the Cherry Canyon formation was being deposited in the Delaware Basin, the limestones of the Goat Seep were being built up in the marginal area. As exposed in cross-section on the west face of the mountains, the limestone forms a solid mass only a few miles wide and interfingers northwestward as well as southeastward with sandstone. Although the mass is not widely exposed on either side of the mountain face, the evidence there suggests that it had the form of a reef that lay in a narrow belt trending northeastward (line *B*, fig. 8).

The bedding planes of the limestone indicate that at first the reef grew slowly as a series of broad, low lenses. Later on, when it formed massive beds, it grew more rapidly and became thicker than the deposits to the northwest or southeast. During the latter part of its growth as it was laid down on a southeastward sloping foundation it rose several hundred feet above the floor of the Delaware Basin to the southeast. During this time, as already indicated, the deposits in the basin were laid down in less agitated (and perhaps deeper) water than the earlier deposits.

Like the other limestones along the margin of the Delaware Basin the Goat Seep limestone is quite generally dolomitized, with the result that many of the details of its original structure are now lost. Not many reef-building organisms have been collected from it. No corals have been found, but Dr. Girty reports the presence of sponges. It is not possible, therefore, to determine whether the Goat Seep reef was built by organic or by inorganic growth. By analogy with the succeeding similar Capitan limestone, organisms probably aided materially in its construction.

The margin of the Delaware Basin, where the bottom sloped down from the shallow shelf area into the deeper, more rapidly subsiding area of the basin, must have been a favorable place for such organisms to grow and to build up masses of limestone. The margin would be favorable also for direct precipitation of calcium carbonate, for water that moved into the warm, agitated shallows from the deeper, quieter, and perhaps cooler waters of the basin probably lost its dissolved carbon dioxide and thus became supersaturated with calcium carbonate.

UPPER PART OF GUADALUPE SERIES

The upper part of the Guadalupe series contains the last Permian deposits laid down under normal marine conditions in the region, and the greatest development of limestone reef deposits. Like the middle part of the series, the upper part consists of three dissimilar but contemporaneous facies composed of various sorts of limestone and sandstone (pl. 7, *A*). It is succeeded by beds of anhydrite and other evaporite deposits.

In the southeast part of the area studied, beds of upper Guadalupe age are classed as the Bell Canyon formation of the Delaware Mountain group. This formation is 670 to 1,040 feet thick and is composed of sandstone, with some thin, dark-gray limestone beds. Farther northwest, in the Guadalupe Mountains, the Bell Canyon changes into the white, massive Capitan limestone, which forms a reef mass. Here, the unit is 1,500 to 2,000 feet thick, or more than twice the thickness of the equivalent beds to the southeast. The Capitan does not extend far to the northwest, for within a few miles its massive limestones change into the thinner-bedded Carlsbad limestone. Tongues of the highest Carlsbad overlap the Capitan to the southeast and form flat benches on the summits of the Guadalupe Mountains.

The Bell Canyon formation crops out in a belt 5 to 10 miles wide on the east slope of the Delaware Mountains (pl. 3). Farther northwest, the Capitan and Carlsbad limestones spread as a plate over the Guadalupe Mountains and constitute its highest peaks and ridges. The limestones are exposed also in the downfaulted area west of the high mountains, where they form the Patterson Hills.

BELL CANYON FORMATION

The Bell Canyon formation, as here distinguished, is roughly equivalent to the highest part of the Delaware Mountain group described by Beede [25] as consisting of "very thick sandstones, alternating with less thick limestones, and rather hard shales." The formation is named for Bell Canyon, which lies in the northeast part of the area studied (pl. 3), heading on the Reef Escarpment of the Guadalupe Mountains and draining eastward 5½ miles to the old route of United States Highway No. 62, where it joins Lamar Canyon. In its course the canyon crosses only the lower part of the formation. The upper part is well exposed in the hills directly northeast of the canyon and is crossed by United States Highway No. 62.

The unit is classed as the uppermost formation of the Delaware Mountain group. Recent work indicates that it is nearly all younger than the typical Delaware Mountain, as defined by Richardson,[26] at the south end of the Guadalupe Mountains near El Capitan. It was mapped by Richardson, however, as part of the Delaware Mountain in his reconnaissance of the Delaware Mountains, and this practice has been followed in all subsequent geological reports.

In its outcrop on the east slope of the Delaware Mountains, the Bell Canyon formation forms a belt of rolling country 5 or 10 miles wide, in which the beds dip east-northeast or northeast at angles of a few degrees. Occasional mesas or lines of cuestas rise above their surroundings, and are capped by limestone members. Along the southeast base of the Guadalupe Mountains, large tracts underlain by the formation are covered by Quaternary gravel deposits. A short distance east of United States Highway No. 62, the formation has a measured thickness of 670 feet (sec. 34, pl. 6), but in the Niehaus et al., Caldwell No. 1 well, 35 miles east-southeast of El Capitan, the thickness has increased to 1,038 feet.

In the Guadalupe Mountains, the formation intergrades with the reef mass of the Capitan limestone, the change taking place farther southeast in the upper than in the lower part. The lower members thus extend northwestward for several miles beneath the Capitan limestone. They form ledges along the bases of the Capitan cliffs on the southeast and west sides of the mountains.

The outcrop of the Bell Canyon formation is shown on the geologic map, plate 3. Some of its outcrops in the Delaware Mountains appear in the northeastern part of the map, interrupted by patches of gravel. Larger areas of outcrop, not shown, lie beyond the map area to the east. Outcrops in the Guadalupe Mountains appear as a narrow band along their southeastern and western sides. The structure of the formation in the Guadalupe Mountains is shown on the sections of plate 17.

Views of the outcrops of the Bell Canyon formation on the southeast side of the Guadalupe Mountains appear in the panoramas of plate 4. In plate 4, *A*, its limestone members can be seen standing in benches,

[25] Beede, J. W., Report on the oil and gas possibilities of the University block 46 in Culberson County: Texas Univ. Bull. 2346, p. 14, 1924.

[26] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, p. 38, 1904.

mesas, and cuestas along the base of the Guadalupe Mountains escarpment; the highest member, the Lamar, appears at the extreme right. In the district shown on plate 4, *B*, erosion has advanced farther, and the members have been worn back to the base of the escarpment, where they project in ledges. The lower members can be seen again in the views of the western side of the mountains, as on plate 12, where they stand in ledges at the bases of the cliffs.

Stratigraphic sections of the formation are shown on the right-hand half of plate 6. Further stratigraphic details for the area along the southeast base of the Guadalupe Mountains are shown on plate 15.

SANDSTONE BEDS

The sandstone beds of the Bell Canyon formation, like those of the Cherry Canyon, are buff colored and extremely fine grained. Three thin sections of typical specimens were studied under the microscope by Ward Smith, one from the lower part from just above the Pinery member at El Capitan (sec. 18, pl. 6), and the other two from the upper part below and above the Lamar member at its type locality, 15 miles to the east (sec. 38, pl. 6). Their maximum grain size ranges from 0.1 to 0.2 millimeter in diameter. The dominant grains are quartz, microcline, and plagioclase, but in all three specimens the accessory minerals are diverse and fairly abundant, and include biotite, chlorite, tourmaline, zircon, apatite, and staurolite. A fresh surface of the specimen from the lower part shows a faint greenish color which is probably caused by the chlorite grains. In the specimen from above the Lamar member, the grains are finer in some laminae than others, and this structure, with an increase in the amount of clay in the same laminae gives the rock a platy layering. The matrix of the sandstone tends to be calcareous.

Aside from the occasional, persistent limestone members, the sandstones contain few or no calcareous beds or lenses, and there are no interbedded black, shaly layers of the sort found in the Cherry Canyon formation beneath. Some of the sandstones are in layers a few inches thick, some are thinner bedded or even platy, and some are thicker bedded or massive. Most of the beds show faint, closely spaced, light and dark laminations, but these laminations are absent in some of the massive beds. Each of the limestone members is underlain by 50 or 100 feet of very massive sandstone that crops out in prominent ledges bare of vegetation, or in rocky buttes. Most of them are overlain by platy sandstones (sec. 34, fig. 5). Thus, a tendency toward cyclical deposition is indicated.

In the Delaware Mountains, the bedding surfaces of most of the sandstones are straight and smooth. The sandstones contain no channeling or irregular bedding of the sort found at many places in the Cherry Canyon formation, and only a few ripple marks (fig. 11). Ripple marks are found occasionally as high in the unit as the Rader member, but are nearly absent above. Thus, in the extensive exposure of the sandstones extending 100 feet or so below the Lamar member, 1½ miles northeast of the junction of Bell and Lamar Canyons, a careful search showed only one bedding surface with ripple marks, and these marks were faint and shallow. All the other numerous exposed surfaces at this locality were smooth and featureless.

Along the Reef Escarpment of the Guadalupe Mountains, and nearer the Capitan reef, the sandstones have a somewhat different character. In the tongues that interfinger with the Capitan above the Rader member, the sandstones are coarser grained than to the southeast, and contain lenses and tongues of sandy dolomite extending out from the Capitan. A specimen of sandstone from one of the sandstone tongues near the head of Rader Ridge was examined under the microscope by Ward Smith. Its grains are coarser than those in the sandstones to the southeast, reaching a diameter of 0.4 mm., but like them consist of quartz, microcline, and plagioclase, with rather abundant accessory minerals, such as tourmaline and zircon. The matrix is calcite. The sandstones between the Lamar and Rader members at the mouth of McKittrick Canyon are cut by channels at one or two places, and many of the beds are ripple-marked.

LIMESTONE MEMBERS

Four limestone members are distinguished in the Bell Canyon formation. The Hegler, Pinery, and Rader members are closely spaced in the lower fourth of the unit, and are separated by several hundred feet of sandstone from the Lamar member which lies near its top (pl. 7, *A*). In addition, a thin limestone bed about halfway between the Rader and Lamar members has been mapped but has not been named, being designated merely as "flaggy limestone bed."

The limestone members are thinner, but more persistent, than those in the Cherry Canyon formation, and are separated by sandstones containing few calcerous beds. In the Delaware Mountains, the members are each 10 or 25 feet thick, dark gray to black, fine grained, and mostly thin bedded. They contain few fossils, in contrast to the Getaway member of the Cherry Canyon formation lower in the section with its abundant and diversified faunas. Toward the northwest, nearer the Capitan limestone reef, each limestone member thickens to 50 or 100 feet, and becomes lighter gray, thicker bedded, and more fossiliferous.

HEGLER LIMESTONE MEMBER

The Hegler limestone member, which forms the basal bed of the Bell Canyon formation, is named for the Hegler Ranch at the east end of Rader Ridge; on the hillsides near the ranch its thin ledges are well exposed (pl. 3).

In the southeast part of the area, it consists of 30 or 40 feet of dark-gray, fine-grained limestone in beds a few inches to a foot thick, interbedded with platy sandstone (as shown in sec. 34, pl. 6). The more granular layers contain small chert nodules, and some fusulinids, ammonoids, and brachiopods. Near the D Ranch headquarters and Long Point the limestone forms the caps of small knolls on the surface of mesas and cuestas of the Manzanita member of the Cherry Canyon formation. Northeast of the ranch headquarters, near Lamar Canyon, the bedding surfaces are hummocky and there are some irregular dips and small folds, perhaps of the same character as those in the Bone Spring limestone. In this district, at the junction of Cherry and Lamar Canyons, seams of white clay less than an inch thick are interbedded in the limestone. C. S. Ross states that these seams consist of volcanic tuff, showing good ash structures but partly altered to clay minerals.

At the type locality, and elsewhere along the southeastern edge of the Guadalupe Mountains, the limestones of the member are different, although they lie in the same position, that is, 25 feet or so above the Manzanita member of the Cherry Canyon formation (as shown in sec. 23, pl. 15). They consist of dark-gray, fine-grained limestone, made up of closely spaced lumps an inch or so thick. In most places these limestones stand in two groups of ledges with a total thickness of 12 to 25 feet, separated by a break of sand or marl. The limestones contain poorly preserved ammonoids, and some of the bedding surfaces are crossed by small tracks and trails. In some localities, as at Nipple Hill and on the northeast side of Guadalupe Canyon (sec. 19, pl. 6), the member disappears, and the first limestone above the Manzanita member is the Pinery member.

The following analysis of limestone from the Hegler limestone member was made. The limestone is of lumpy facies, characteristic of the member along the southeast side of the Guadalupe Mountains, and was collected on the south side of Rader Ridge north of Nipple Hill.

Analysis of limestone from the Hegler limestone member

[Analysis by K. J. Murata ; note on insoluble residue by Charles Milton]

	Percent
Inorganic insoluble	11.99
Organic insoluble	.34
R_2O_3 (mostly Fe_2O_3)	1.09
$CaCO_3$	83.72
$MgCO_3$	1.87
$MnCO_3$	.09
$Ca_3(PO_4)_2$	None
	99.10

Insoluble residue: Light gray, clayey, with quartz and feldspar and minute zircon and tourmaline particles.

The Hegler limestone member extends several miles northwestward beneath the Capitan limestone. On the west face of the Guadalupe Mountains below Guadalupe Peak, the lumpy, slabby limestone ledges can be traced northward into light-gray, thick-bedded, sparingly fossiliferous limestones more than 100 feet thick (as between secs. 14 and 15, pl. 6). Still farther north, near the head of Shirttail Canyon, these limestones grade into the Capitan limestone (sec. 9, pl. 6). Similar limestones crop out as inliers in the bed of Pine Spring Canyon near Devils Hall, and along South McKittrick Canyon between the Pratt and Grisham-Hunter Lodges (secs. *E–E′*, *F–F′*, and *I–I′*, pl. 17). At Devils Hall, the member is a dark-gray, hummocky limestone in beds a few inches to a foot thick (sec. 59, pl. 15), and nearby there are interbedded lenses of massive limestone (sec. 60, pl. 15, and fig. 9, *C*). Near the Pratt and Grisham-Hunter Lodges, the member is dense, light-gray, sparingly fossiliferous, thin-bedded limestone, with some interbedded massive layers in the upper part.

PINERY LIMESTONE MEMBER

The Pinery limestone member includes the main part of the dark-gray, bedded limestone, called the "upper dark limestone" by Girty,[27] which crops out beneath the Capitan limestone at the south end of the Guadalupe Mountains. This limestone formed member 2 of Shumard's section.[28] The name is taken from The Pinery,[29] the old stage station on the Butterfield Trail at the mouth of Pine Spring Canyon. The type section is on the hillside above Pine Spring, a short distance to the north (sec. 21, pls. 6 and 15). The greater part of Girty's "upper dark limestone" fauna was obtained from the lower part of the member at this locality.

In the southeast part of the area, the Pinery member consists of 25 feet of thin-bedded, dark-gray, fine-grained limestone, with a few sparingly fossiliferous, more granular, thicker beds, and much interbedded platy sandstone. It lies about 75 feet above the Hegler limestone, and crops out less prominently than that member. Its ledges are exposed on the north bank of Lamar Canyon for several miles southeast of its junction with Bell Canyon (sec. 34, pl. 6).

Farther northwest along the base of the Reef Escarpment on the southeast side of the Guadalupe Mountains, the member passes beneath the Capitan limestone, and forms prominent ledges on the slopes below the ragged Capitan cliffs; these ledges are well exposed

[27] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, pp. 17–19, 1908.

[28] Shumard, G. G., Observations on the geological formations of the country between the Rio Pecos and the Rio Grande, in New Mexico: St. Louis Acad. Sci. Trans., vol. 1, pp. 273–289, 1858 [1860].

[29] The names Pine Spring and Pinery date from the first visits to the region by Americans and are mentioned in the earliest publications on it. The names were applied because of the pine trees growing on the floor of Pine Spring Canyon in its lower course. According to local tradition, these trees were much more numerous at the time of the first visits than they are now. Shumard (idem, p. 280) refers to Pine Spring Canyon as The Pinery.

between Pine Spring and Frijole and are illustrated in the panorama, plate 4, *B*. Good exposures are found at Pine Spring (the type section), at Soldiers Lookout near Frijole (sec. 65, pl. 15), and on Rader Ridge to the northeast (sec. 23, pl. 15).

Along the base of the Reef Escarpment, the member reaches 150 feet in thickness, and consists of gray, fine-garined limestone in beds a few inches to a foot thick, containing small nodules and sheets of brown chert, many fusulinids, and a few crushed brachipod shells. Interbedded with the thinner-bedded limestones are lighter-gray, quite granular, thick-bedded to massive layers 5 to 10 feet thick. At Pine Spring, the most prominent massive layers are at the base, but there are several massive layers higher. The lower massive beds

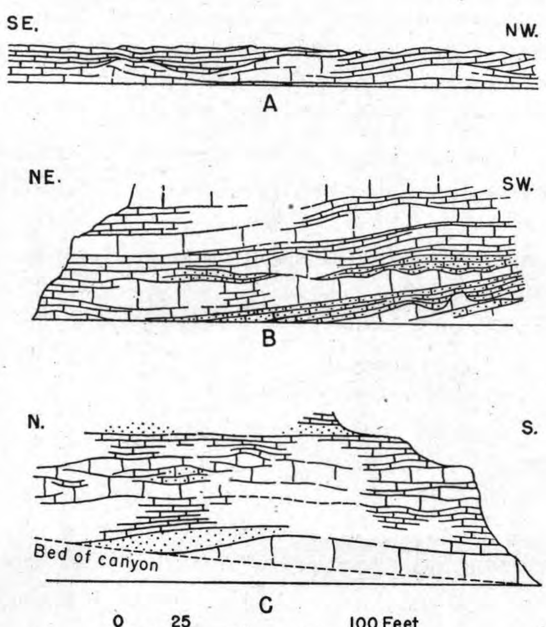


FIGURE 9.—Sections showing lenticular, reeflike features in limestone members of Bell Canyon formation adjacent to Capitan reef mass. *A*, Lamar limestone member, south bank of draw half a mile southeast of entrance to McKittrick Canyon; *B*, Pinery limestone member, southeast bank of McKittrick Canyon, a quarter of a mile east of Pratt Lodge; *C*, Hegler limestone member, northeast bank of Pine Spring Canyon southwest of Pinnacle.

are crowded with the silicified remains of bryozoans (such as *Domopora*), fusulinids, cup corals, small brachiopods, and occasional calyces of small echinoderms (such as *Coenocystis*). The member is separated from the Capitan above by about 100 feet of interbedded sandstone and limestone.

The following analysis of limestone from the Pinery limestone member was made. The limestone is gray and granular, and is of a facies that is characteristic of the member on the southeast edge of the Guadalupe Mountains. It was collected on the south side of Rader Ridge north of Nipple Hill.

Analysis of limestone from the Pinery limestone member

[Analysis by K. J. Murata; note on insoluble residue by Charles Milton]

	Percent
Inorganic insoluble	4.39
Organic insoluble	.32
R_2O_3 (mostly Fe_2O_3)	.45
$CaCO_3$	92.95
$MgCO_3$	1.64
$MnCO_3$	.07
$Ca_3(PO_4)_2$	.06
	99.88

Insoluble residue: Gray, consisting of clay and organic matter, with quartz and feldspar particles and occasional green tourmaline.

Farther northwest, in Pine Spring Canyon, the member changes to lighter gray, the chert disappears, and the sandstones between the member and the Capitan give place to limestones like those below (as shown in sec. 61, pl. 15). The beds of massive limestone increase in number and the thinner-bedded limestones contain lenticular bodies of massive limestone (as shown in figure 9, *B*). Similar beds are exposed on the west side of the Guadalupe Mountains as far north as Guadalupe Peak, and in McKittrick Canyon, half a mile east of the Pratt Lodge (secs. *E–E′* and *K–K′*, pl. 17.) Farther northwest, the member is replaced by a part of the Capitan limestone.

RADER LIMESTONE MEMBER

The Rader limestone member is named for Rader Ridge,[30] a series of benches and mesas that project southeastward from the Guadalupe Mountains northeast of Frijole Post Office. They are capped by outliers of the member (sec. *G–G′*, pl. 17).

In the southeast part of the area, as at the junction of Bell and Lamar Canyons, the member is 15 feet thick and lies 30 or 40 feet above the Pinery member (sec. 34, pl. 6). It consists of several layers, as much as 3 feet thick, of gray, granular limestone, with numerous rounded pebbles, fragments of bryozoans, cup corals, and fusulinids, and of interbedded, thinner, darker-gray limestone. At several places in this region it contains a bed as much as 2 feet thick of apple-green, silicified volcanic ash. One specimen, from 1 mile east of the junction of Cherry and Lamar Canyons, was studied under the microscope by C. S. Ross, who states that it contains well-preserved ash structures and primary fragments of euhedral orthoclase, plagioclase, and quartz. The original glass has been completely altered to secondary quartz, and perhaps to kaolin. A specimen from another locality, similar megascopically, is said by Ross to contain no grains that are definitely of volcanic origin.

[30] According to Mr. J. T. Smith, the ridge was named for the Rader family; they were early settlers and had a ranch near it.

To the northwest, on Rader Ridge and elsewhere near the Reef Escarpment, the member is 30 to 100 feet thick (sec. 23, pl. 15), and consists of rounded ledges of very massive, granular or dense, light gray or white limestone, much like the Capitan limestone in appearance. Some of the beds contain angular limestone cobbles. Fossils are common, consisting mostly of Capitan species, but including numerous bryozoans, a group not common in the Capitan. Occasional lenses of sandstone and dark gray, slabby limestone are found in depressions on the undulatory upper surfaces of the massive beds.

The following analysis of limestone from the Rader limestone member was made. The limestone is light gray and of a facies characteristic of the member on the southeast edge of the Guadalupe Mountains. The specimen was collected from one of the massive beds near the head of Rader Ridge, north of Nipple Hill.

Analysis of limestone from the Rader limestone member

[Analysis by K. J. Murata; note on insoluble residue by Charles Milton]

	Percent
Inorganic insoluble	1.11
Organic insoluble	.05
R_2O_3 (mostly Fe_2O_3)	.24
$CaCO_3$	97.66
$MgCO_3$	1.71
$MnCO_3$	.07
$Ca_3(PO_4)_2$	None
	100.84

Insoluble residue: Light gray, with detrital quartz and feldspar and euhedral, doubly terminated quartz, possibly of authigenic origin.

In the vicinity of Rader Ridge, the Rader limestone member is separated from the Capitan limestone by several hundred feet of sandstone and thin-bedded limestone. When traced to the southwest along the escarpment, the intervening beds are replaced by the Capitan limestone, and about a mile west of Frijole the member itself merges with the Capitan. (These relations can be traced out on the ridges to the left of Smith Canyon illustrated in the panorama, pl. 4, *B*.)

FLAGGY LIMESTONE BED

About 100 feet above the Rader member in the Delaware Mountains is a 10-foot layer of straight-bedded, fine-grained, gray limestone, in part sandy, forming flaggy beds a few inches thick (as in secs. 32 and 34, pl. 6). The flags have been quarried on the McCombs Ranch and farther southeast, and have been used locally for building purposes. The same bed is present also in the exposures of downfaulted rocks west of the Delaware Mountains.

LAMAR LIMESTONE MEMBER

The Lamar limestone member is a bed of dark limestone lying near the top of the Bell Canyon formation. It crops out in a belt of northeast-sloping cuestas that extend southeastward from the mouth of McKittrick Canyon into the Delaware Mountains. It has been named for Lamar Canyon,[31] and its type locality is on the escarpment northeast of the El Paso Natural Gas Company's road across the canyon, about 15 miles east of El Capitan and east of the area shown on plate 3. The name Frijole limestone has previously been used for the member,[32] but this name is abandoned because the member does not crop out near Frijole Post Office, and the dark limestones there are of Hegler and Pinery age (see sec. 65, pl. 15).

The confusion in terminology has perhaps arisen from difficulties encountered by previous geologists in tracing the limestones exposed below the Capitan near Frijole northeastward along the Guadalupe Mountain escarpment toward McKittrick Canyon, where the Lamar member is exposed. Blanchard and Davis, and Darton and Reeside[33] considered the beds at the two places to be the same.

Near the type locality, and elsewhere in the southeast part of the area, the member consists of 15 to 30 feet of gray, dark gray, or black, fine-grained limestone, weathering brown and rough-surfaced, and forming beds a few inches thick, with some lenticular, thicker beds (secs. 34 and 38, pl. 6). Some of the rock is thinly laminated and contains small chert nodules. Near the crossing of United States Highway No. 62 over its outcrop, a few feet of platy sandstone is interbedded in the middle. In most of the Delaware Mountains the member is unfossiliferous, but to the northwest, within a few miles of the edge of the Guadalupe Mountains, some ledges contain brachiopods and other fossils.

In the vicinity of United States Highway No. 62, the limestones of the Lamar member are somewhat contorted, in a manner that resembles the contortion of the black limestones of the Bone Spring limestone. Bedding surfaces are undulatory, and some of the less competent beds are twisted and rolled into lenses. Some of the bedding surfaces are fluted and striated in a general north-south direction. These marks are perhaps the "ripple marks" reported by Crandall[34] from this vicinity. I did not see the features that he suggested might be mud cracks when I visited the locality.

[31] Lang, W. B., The Permian formations of the Pecos Valley of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., vol. 21, pp. 874–875, 1937.

[32] Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 973, 1929.

[33] Darton, N. H., and Reeside, J. B., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 423–424, 1926.

[34] Crandall, K. H., Permian stratigraphy of southeastern New Mexico and adjacent parts of western Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 933, 1929.

Farther northwest along the base of the Reef Escarpment on the southeast side of the Guadalupe Mountains, as at the mouth of McKittrick Canyon,[35] the member thickens to 150 feet or more, and is lighter gray, more granular, and more fossiliferous (sec. 28, pl. 6). The fossils are strewn abundantly over the bedding surfaces, and many of them are silicified. The shells are closely packed, and the valves of most of the brachiopods are separated, or at least twisted, in a manner suggesting some transportation before burial. By far the most common fossil is a large *Squamularia*, but there are other brachiopods, mostly of Capitan type, and also some gastropods, pelecypods, bryozoans, and trilobites. Fusulinids and ammonoids are absent. About a mile southwest of the entrance to the canyon on the south side of the stream, the Lamar member contains moundlike, massive limestone lenses up to 10 feet in thickness, which interfinger laterally with thinner-bedded limestones (fig. 9, *A*).

The following analyses of limestone from the Lamar limestone member were made:

Analyses, in percent, of limestone from the Lamar limestone member

[Analyses by K. J. Murata; notes on insoluble residues by Charles Milton]

Specimen locality	Insoluble		R_2O_3 (mostly Fe_2O_3)	$CaCO_3$	$MgCO_3$	$MnCO_3$	$Ca_3(PO_4)_2$	Total
	Inorganic	Organic						
1. Middle part of member, north side of U. S. Highway No. 62, ¼ mile west of bench mark 4729	1. 81	0. 13	0. 23	96. 02	1. 02	0. 06	None	99. 27
2. Highest beds of member, south side of U. S. Highway No. 62 about a mile northeast of No. 1; this specimen and No. 1 are typical of the facies of the member in the southeastern exposures	1. 86	. 19	. 26	95. 67	2. 61	None	0. 13	100. 72
3. Fine-grained, gray limestone from middle of member, south side of McKittrick Canyon at entrance. These beds grade into Capitan limestone a few hundred yards to northwest. Analyses of the latter rock are given as Nos. 3 and 4 under Capitan limestone	2. 96	. 13	. 17	94. 56	1. 77	None	. 03	99. 62

Insoluble residues: 1, Brown, organically colored, with much chert and little detrital material; 2, dark brown, similar to No. 1; 3, brown, similar to No. 1.

Northeast of McKittrick Canyon toward Big Canyon, the Lamar member spreads out in a broad area at the base of the mountains (pl. 3), forming low, dark-colored hills, covered by a growth of lechuguilla. Southwest of the canyon for several miles the member forms the cap of benches that project along the base of the Reef Escarpment (as shown on the left side of pl. 18). Beyond, at the head of Rader Ridge (sec. 23, pl. 15, and sec. *L–L'*, pl. 17) and on the ridge northeast of Guadalupe Canyon (sec. *J–J'*, pl. 17), only small remnants of the member are preserved projecting as tongues into the Capitan limestone. They consist of white, platy limestone, containing crushed brachiopod shells.

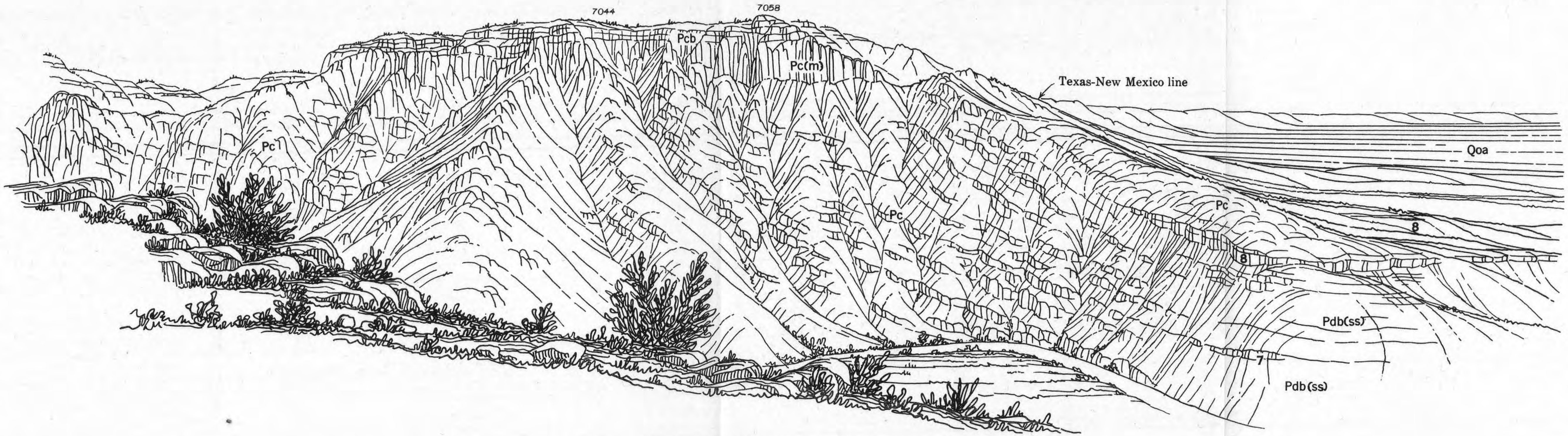
HIGHEST BEDS OF BELL CANYON FORMATION

Some miles southeast of the Capitan limestone on the Reef Escarpment, well out in the area of the Delaware Basin, the limestones of the Lamar member are overlain directly by thinly laminated limestones and anhydrites that are the basal beds of the Castile formation. This relation of Lamar to Castile was observed also on the outcrops in the downfaulted area west of the Delaware Mountains, at the south edge of the area studied (pl. 3). It is reported also in wells drilled east of the outcrops, as in the Niehaus et al., Caldwell No. 1 well, 35 miles east-southeast of El Capitan (pl. 6).

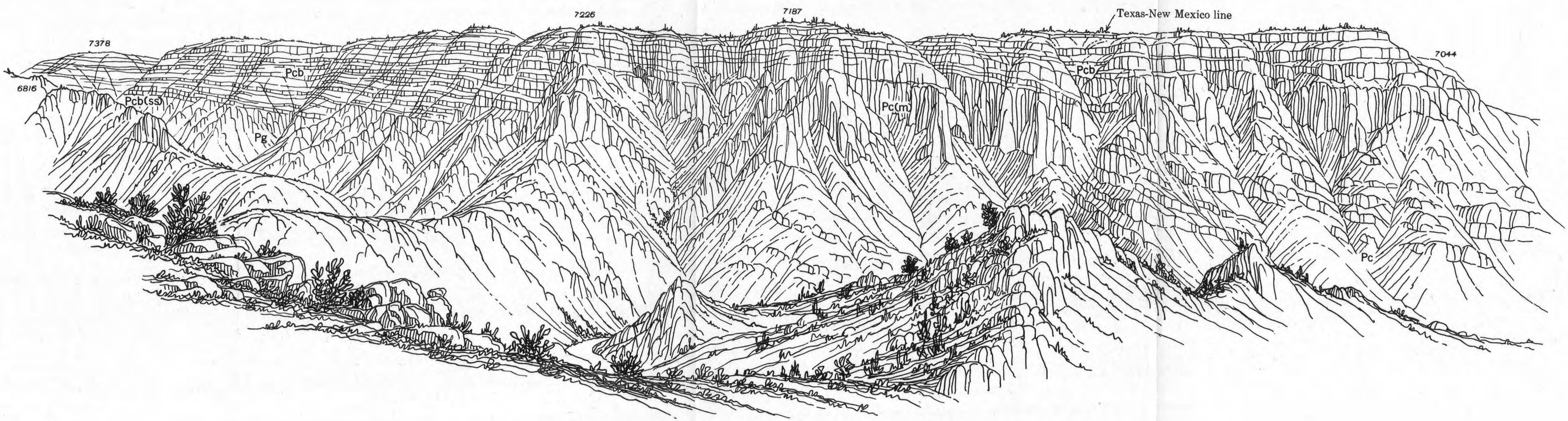
Farther northwest, within several miles of the Reef Escarpment, the Lamar member is separated from the Castile formation by a small thickness of younger Bell Canyon beds. In the exposures in the Delaware Mountains southeast of United States Highway No. 62, these beds consist of 20 feet of very fine grained sandstone (secs. 34 and 38, pl. 6), whose petrographic character has already been noted (p. 54). The rock is thinly laminated, its bedding surfaces are flat and smooth, and it breaks out in thin, flat plates. The beds are well exposed a short distance southeast of the highway, on the north bank of a creek, half a mile northeast of bench mark 4729 (pl. 3), where their relations to the Lamar below and Castile above can be observed.

Northwest of the highway, and nearer the Reef Escarpment, the beds are thicker, and include some limestone. Between McKittrick and Big Canyon Draws, they are preserved as scattered outliers, which form light-colored knolls on the tops of the darker-colored hills of Lamar limestone. Some of these beds are less than a mile from the base of the Reef Escarpment. The best exposure is on the north side of Big Canyon Draw near the State line, and three-quarters

[35] The member at this place has been described previously by N. H. Darton and J. B. Reeside, Jr. (op. cit., p. 424), and by K. H. Crandall (op. cit., p. 933).



A. NORTH WALL OF McKITTRICK CANYON FROM PEAK ON SOUTH SIDE AT ENTRANCE.



B. NORTHEAST WALL OF NORTH McKITTRICK CANYON FROM PEAK ON SOUTHWEST SIDE 1 MILE NORTHWEST OF PRATT LODGE.

PANORAMIC VIEWS IN McKITTRICK CANYON.

For locations, see plate 2. Shows structural features of Capitan limestone and related formations. *Qoa*, Older alluvial deposits; *Pcb*, Carlsbad limestone; *Pcb (ss)*, basal sandstone member of Carlsbad limestone; *Pc*, Capitan limestone; *Pc (m)*, massive beds of Capitan limestone; *Pdb*, Bell Canyon formation (*ss*, sandstone bed, 8, Lamar limestone member, 7, flaggy limestone bed); *Pg*, Goat Seep limestone.

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of a mile northwest of the Gray Ranch (pl. 3). Here the Lamar is overlain by 20 feet of fine-grained sandstone, and this by 15 feet of light-gray or white slabby limestone, containing crushed brachiopod shells. This is topped by the basal laminated limestones of the Castile. In other exposures near the Reef Escarpment, the sandstones are thinner, and most of the beds above the Lamar are slabby limestone.

At the base of the Reef Escarpment itself, at McKittrick Canyon and elsewhere, the Lamar member is overlain by a small thickness of massive dolomitic Capitan limestone. This limestone is evidently equivalent to the sandstones and slabby limestones not far to the southeast, but the actual connection between them has been removed by erosion, so that the change cannot be traced from one outcrop to the other.

BELL CANYON FORMATION IN AERIAL PHOTOGRAPHS

In aerial photographs the Bell Canyon formation can be recognized as that belt of outcrop between the back slope of the cuesta of the Manzanita limestone member of the Cherry Canyon formation on the west, and the low, light-colored outcrops of the Castile formation on the east. The outcrops of the Bell Canyon formation form an eastward continuation of the cuesta topography already described as characterizing the upper part of the Cherry Canyon formation.

Cuestas are poorly developed in the lower part of the formation, although the photographs indicate the traces of numerous ledges that belong to the Hegler and Pinery limestone members. The first strong cuesta east of and above those of the Manzanita limestone member is formed by the Rader limestone member. Still farther east is a low but prominent cuesta formed by the flaggy limestone bed. It has a persistent development southeast and south of the area studied, and indicates that this limestone is a continuous and persistent unit. Still farther east is the high and prominent cuesta of the Lamar limestone member. It has a steep west-facing scarp, frayed by erosion into numerous promontories, outliers, and indentations. The sandstones overlying the Lamar can be recognized as far south as Delaware Creek but are indistinguishable beyond. The dark-colored back slope of this cuesta is bordered on the east by lighter-colored outcrops of the anhydrites of the Castile formation.

The Lamar limestone cuesta can be traced 30 miles or more south of the area studied, along the east slope of the Delaware Mountains, or nearly to Seven Heart Gap at the north edge of the Apache Mountains. However, about 20 miles south of the area studied, the ledges and cuestas of the underlying members merge into a nearly continuous succession of ledges, evidently a nearly solid limestone body. This limestone body continues southward to the Apache Mountains.

CAPITAN LIMESTONE

DEFINITION

The Capitan limestone was named by Richardson,[36] its type locality being on Guadalupe Peak, about a mile north of the summit here called El Capitan.[37] The exposures in the vicinity of the two peaks were first studied by Shumard,[38] who set off the white limestone of the formation as member 1 of his section (pl. 1). According to present usage,[39] the formation includes the thick-bedded or massive white limestones of reef facies and upper Guadalupe age, that crop out in the Guadalupe Mountains (pl. 7, *A*).

RELATIONS TO BELL CANYON FORMATION

Near the top of the Cherry Canyon formation is the Manzanita limestone member, whose outcrop extends across the Delaware Mountains and into the southern Guadalupe Mountains. Its orange-brown ledges and its intercalated seams of volcanic ash retain the same character over wide areas, and form an unmistakable horizon marker (pl. 6).

The sequence above the Manzanita member in the Delaware Mountains, however, is profoundly different from that in the Guadalupe Mountains (as may be seen by comparing secs. 34 and 14, pl. 6). In the Delaware Mountains, as along United States Highway No. 62, the member is overlain by several hundred feet of sandstones and thin limestones, forming the Bell Canyon formation, and these in turn by the anhydrites of the Castile formation. The Bell Canyon formation crops out northeast of, and down the dip from the Manzanita member in low hills (such as those shown in the center and right foreground of pl. 4, *A*). In the southeast part of the Guadalupe Mountains, the member is overlain by a few hundred feet of thin-bedded limestones, the Hegler and Pinery members, and these by several thousand feet of massive Capitan limestone. Here, the Manzanita member forms ledges that fringe the bases of lofty cliffs.

Looking northwest from the low hills of the Delaware Mountains near United States Highway No. 62, one can see a steep escarpment that rises in jagged spurs and irregular cliffs 2,000 feet or more above the observer (forming the background of pl. 4, *A*). This is the Reef Escarpment, which forms the southeastern edge of the Guadalupe Mountains and is composed largely of Capitan limestone. Behind it, the Capitan crops out on rugged canyon walls (some of which are shown on pl. 18). Southeast of it, in the Delaware Mountains, no

[36] Richardson, G. B., Report of a reconnaissance in trans-Pecos, Texas, north of the Texas and Pacific Railway: Texas Univ. Bull. 23, p. 41, 1904.

[37] For a discussion of the geographic terminology see Lang, W. B., op. cit., pp. 839–844.

[38] Shumard, G. G., Observations on the geology of the country between the Rio Pecos and Rio Grande, in New Mexico: St. Louis Acad. Sci. Trans., vol. 1, p. 280, 1858 [1860].

[39] Lang, W. B., op. cit., p. 163.

remnants of the Capitan are present, if indeed they ever existed.

The Lamar limestone member, near the top of the Bell Canyon formation in the Delaware Mountains can be traced northwestward along a line of cuestas to the base of the Reef Escarpment at the mouth of McKittrick Canyon. Viewed from a distance (as shown on pl. 4, *A*), the member seems to extend beneath the Capitan limestone at the canyon, for the Capitan rises 1,500 feet above the cuestas to the flat benches of Carlsbad limestone which form the rim of the escarpment.

That this is not the true relation is at once evident, however, when one climbs a little distance up the spurs on either side of the canyon mouth (pl. 16, *A*). Viewed now in cross section, the Capitan limestone is seen to be made up of thick beds which dip to the southeast at an angle of 20°, or at about the same angle as the slope of the escarpment itself. The Lamar member, forming benches of well-bedded limestone at the mouth of the canyon, changes northwestward into thick beds, indistinguishable from the rest of the Capitan, which can be traced up the surface of the escarpment until they lie directly beneath the ledges of Carlsbad limestone on its rim. The greater part of the Capitan limestone which lies beneath these beds is thus clearly older than the Lamar member. These relations have been described by Lloyd [40] and other authors. They are well illustrated in a diagram by Cartwright.[41]

The structure of the beds shown in the panorama of plate 16, *A*, is given on the right-hand end of section *E–E′*, plate 17. For a more general view, which shows that the same relation exists on nearby spurs of the escarpment, see the aerial photograph, plate 18.

Beneath the Lamar member at the mouth of McKittrick Canyon, several hundred feet of sandstones and some thin, interbedded limestones are exposed (sec. 28, pl. 6). These limestones also crop out here and there along the edge of the escarpment to the southwest. Several miles southwest of McKittrick Canyon, near the head of Rader Ridge, where the beds stand higher and erosion has cut deeper, the sandstones are seen to be underlain by the Rader limestone member (sec. 23, pl. 6). Here, on the point of each spur is a slope carved from the sandstone, but in the ravines between, cut back a little farther into the escarpment, there are no sandstone beds. Instead, limestone tongues appear between the sandstone on the sides of the spurs, and thicken into a continuous succession of massive Capitan limestone along the bed of each ravine. The Rader limestone member itself can be seen to merge with the Capitan limestone a mile or so southwest of Rader Ridge.

The mountain spurs above Rader Ridge can be seen below point 8078 at the right-hand end of the panorama, plate 4, *B*. Note the manner in which the Capitan limestone ledges dip to the right, down the spurs, to be succeeded at the ends by slopes cut on sandstone. The structure of the spurs is shown on section *G—G′* and in greater detail on section *L—L′*, of plate 17. The merging of the Rader member with the Capitan can be seen on plate 4, *B*. Note how, when traced to the left from Smith Canyon, the slope between it and the Capitan disappears, and in the next canyon beyond, the member is the lowest of a continuous series of ledges.

The intergradation of Bell Canyon beds and Capitan limestone, between the Rader and Lamar members is shown also by the stratigraphic sections on plate 6 (between numbers 21 and 32), and in greater detail on plate 15 (right-hand half). The distance in which the change takes place is not as great as that which separates the sections, for the sections show only the sequences on the points of the spurs, and not the very different sequences exposed in the nearby ravines.

At the point where the Rader member merges with the Capitan limestone southwest of Rader Ridge, it is underlain by two other limestone beds belonging to the Bell Canyon formation, the Pinery and Hegler members. These limestones stand in ledges at the base of the escarpment (pl. 4, *B*). They can be traced southwestward across Pine Spring and Guadalupe Canyons to El Capitan, where they form the pedestal on which the great cliff of Capitan limestone rests. This cliff extends northwestward from El Capitan along the west side of the mountains.

Viewed from below near Bone Canyon (pl. 12, *A*), the ledges of the Pinery and Hegler members can be traced northwestward along the bases of the cliffs, but near the head of Shirttail Canyon (below summit 8356) they are absent, and the Capitan cliff stands directly on ledges of the Goat Seep limestone. The two members do not pinch out northwestward; instead, as each of their thin dark-colored beds is traced from El Capitan, it becomes lighter colored and thicker, and extends upward along the cliff, merging with the massive Capitan limestone. In this manner, all the Pinery member disappears into Capitan below Guadalupe Peak, and all the Hegler member at the head of Shirttail Canyon. The northwestward thickening and increase in dip of each bed is so great that the stratum equivalent to the top of the Pinery member rises to the summit of the cliff on the north slope of Guadalupe Peak. The Capitan limestone as developed farther northwest is therefore wholly of Pinery and Hegler age.

The structure of the panorama, plate 12, *A*, is shown on section *K–K′*, plate 17. The change from the Pinery and Hegler members into the Capitan limestone is also shown by the stratigraphic sections on plate 6 (between numbers 9 and 18). Similar relations, worked out in greater detail in Pine Spring Canyon to the northeast, are shown on the left-hand half of plate 15.

These observations show that the Capitan limestone consists, at different places, of beds equivalent to various parts of the Bell Canyon formation (pl. 7, *A*). Toward the northwest, it is chiefly of Hegler and Pinery age, but

[40] Lloyd, E. R., Capitan limestone and associated formations of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 649, 1929.

[41] Cartwright, L. D., Transverse section of Permian basin: Am. Assoc. Petroleum Geologists Bull., vol. 14, fig. 3, p. 978, 1930.

farther southeast there are younger, similar limestones of Rader to Lamar age. Only several hundred feet of the highest Capitan and Carlsbad limestones, overlying the Lamar equivalent in McKittrick Canyon, cannot be traced directly into beds of the Bell Canyon formation, because their southeastward extensions have been eroded away. As already indicated (pp. 58–59), these several hundred feet are probably equivalent to the slabby limestones and sandstones above the Lamar member southeast of the Reef Escarpment.

The limestone members of the Bell Canyon formation change into the Capitan limestone by an increase in thickness of each layer, and by a change in color and texture. As the change takes place, the intervening sandstone beds disappear, partly by interfingering with numerous limestone tongues and partly by a change into sandy limestone and thence into pure limestone.

OUTCROP

The Capitan limestone extends northwestward into the Guadalupe Mountains for about 4 miles northwest of its edge along the Reef Escarpment. Farther northwest, its place is taken by thin-bedded limestones of the Carlsbad. Toward the northeast, along the trend of the Reef Escarpment, its extent is much greater. Its outcrop extends for many miles into New Mexico, and it has been recognized in wells farther northeastward. To the southwest, along the same trend, it crops out in the Patterson Hills.

The northwestern and southeastern limits of the Capitan within the area studied are shown by lines *B* and *E* on figure 10, and its outcrops are shown on the geologic map, plate 3. The probable regional extent of the belt of Capitan limestone is suggested on figure 14, *B*. A view of the outcrops of the Patterson Hills can be seen on the left half of the panorama of plate 5, *A*. Note the contrast in height between the outcrops here and those in the mountains on the right half of the panorama. The structural relations between the two areas are shown on sections *B–B′* and *C–C′* accompanying plate 3.

Along the canyons and ridges of the Guadalupe Mountains, the formation crops out as lines of irregular cliffs or as steep, rocky slopes which support a growth of forest in protected places (pl. 18). Along the north side of Pine Spring Canyon, erosion along joints has carved the rock into closely spaced, steep-sided pinnacles; elsewhere it weathers to rounded, bouldery masses. On the west side of the mountains, near Guadalupe Peak and El Capitan, the formation stands in a cliff, 1,000 feet or more high. The form of the cliff is controlled by joints, many of which can be seen traversing it from top to base. Its steepness has been maintained by undercutting of the weaker beds below.

THICKNESS

Within the area studied, the Capitan limestone has a variable thickness, nowhere less than 1,000 feet and nowhere greater than 2,000 feet. On the west face of Guadalupe Peak, where it is underlain by the Hegler member and overlain by the Carlsbad limestone, it is about 1,350 feet thick (sec. 14, pl. 6). At several places in McKittrick Canyon (as in sections *E–E′* and *F–F′*, pl. 17) there are exposures 1,500 to 2,000 feet high.

The Capitan limestone is, however, a facies that extends irregularly through the upper part of the Guadalupe series, and its top and base are therefore not of the same age at all places. Within the area studied it is everywhere underlain by some beds of the Bell Canyon formation and overlain by some beds of the Carlsbad limestone, the first tending to replace it to the southeast, and the second to the northwest (pl. 7, *A*). At no place within the area does the Capitan limestone facies extend continuously from the base to the top of the upper part of the Guadalupe series.

Outside the area studied, the Capitan is reported to have a much greater thickness. In the Getty Oil Co., Dooley No. 7 well, in the Getty oil field east of Carlsbad, N. Mex. (for location, see fig. 2), the interval from the base of the Ochoa series downward to the top of the bentonites of the Manzanita member of the Cherry Canyon formation is more than 2,700 feet.[42] Most of this interval is occupied by a single mass of white limestone, probably of Capitan facies, although some thinner-bedded, or darker, or sandy limestones are present at the top and base. A similar thickness is present in the Ohio Oil Co., Tracey No. 1 well, drilled a few miles west of the town of Carlsbad.[43] It is likely that in the neighborhood of these wells there are more beds in the upper part of the Guadalupe series belonging to the Capitan facies than in a single section at any point on the outcrop.

LITHOLOGIC FEATURES

The Capitan limestone consists in part of compact, light-gray, cream-colored, or white calcitic limestone, which breaks under the hammer into splinters and conchoidal chips. Some beds contain numerous, beautifully preserved fossil shells. At one locality Mr. H. C. Fountain broke from the limestone several gastropod shells on which the original color markings are still preserved. The calcitic limestones crop out in bouldery masses or smooth-surfaced ledges, and in places stand in smooth, light-gray cliffs.

Associated with the calcitic limestones are dolomitic limestones. They are gray or buff, finely crystalline, and contain occasional tiny cavities, which suggest that the process of dolomitization has changed the volume of the rock. Scattered crystals of calcite are embedded here and there, and also irregular bodies of crystalline

[42] King, P. B., The Permian of west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 26, fig. 7, p. 585, 1942.

[43] Bybee, H. B., and others, Detailed cross section from Yates area, Pecos County, Texas, into southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 15, pl. 1, p. 1088, 1931.

calcite as much as 6 inches across. The dolomitic limestones contain fossils similar to those in the calcitic limestones, but the shells have been so greatly recrystallized that they remain only as "ghosts". The dolomitic rocks weather to dirty gray, pitted or jagged surfaces, which in many places show a rude exfoliation.

The following analyses of Capitan limestone were made:

Analyses, in percent, of Capitan limestone

[Analyses by K. J. Murata; notes on insoluble residues by Charles Milton]

Specimen locality	Insoluble		R_2O_3 (mostly Fe_2O_3)	$CaCO_3$	$MgCO_3$	$MnCO_3$	$Ca_3(PO_4)_2$	Total
	Inorganic	Organic						
1. Compact, light-gray, calcitic limestone, on trail leading north out of Pine Spring Canyon	0.21	0.06	0.08	92.06	7.23	None	None	99.64
2. Compact, splintery, white, translucent calcitic limestone, typical of fossiliferous beds of formation; from another point on same trail	.15	.03	None	98.83	.62	None	None	99.63
3. Light gray, granular, dolomitic limestone, stratigraphically equivalent to limestones of Lamar member to southeast; south bank of McKittrick Canyon at its mouth	.36	.05	.28	71.47	27.84	None	None	100.00
4. Compact, calcitic limestone from adjacent bed at same locality as No. 3	.27	.03	.17	98.60	.80	None	None	99.87

Insoluble residues: 1, Light gray, with abundant euhedral, doubly terminated quartz crystals and occasional green tourmaline; 2, dark brown, with abundant euhedral quartz, also detrital angular grains, and brown biotite, zircon, and microcline; 3, brown, very fine-grained, occasional chert fragments and extremely small green tourmaline; 4, dark brown, similar to No. 3.

Both the calcitic limestones and dolomitic limestones are irregularly distributed through the formation. The dolomitic type is somewhat more abundant than the calcitic; it is found at all places, whereas the calcitic limestones disappear in places. On Guadalupe Peak and near the mouth of McKittrick Canyon, the youngest beds of the Capitan, of Lamar or younger age, are mostly calcitic limestone, and are underlain by dolomitic limestone. In the older parts of the formation, the two types are interbedded. Thus, on the trail up the west wall of South McKittrick Canyon near the Grisham-Hunter Lodge, there are two 400-foot members of calcitic limestone, separated by a 700-foot member of dolomitic limestone. Here, the Helger limestone member lies below and the Carlsbad limestone above. Near the Grisham-Hunter Camp, 3 miles to the southwest, richly fossiliferous, calcitic limestones lie at the base of the Capitan and are probably of Hegler age. They are overlain by dolomitic limestones.

In the main mass of the Capitan limestone, none of the beds are sandy, and there is no interbedded sandstone. Along its southeastern edge, a few streaks of sandstone extend back for about half a mile into the limestone from the thicker beds of sandstone of the Bell Canyon formation.

A rich and abundant fauna has been collected from some of the nondolomitized parts of the Capitan,[44] the most abundant groups being brachiopods, gastropods, pelecypods, nautiloids, and trilobites. Rather extensive collecting by H. C. Fountain and me has convinced us that these fossils occur only in relatively thin, lenticular strata, not differing greatly in lithologic character from the inclosing rock. According to our observations, the greater mass of the formation contains little else than the abundant remains of sponges, a few crinoid stems, and some calcareous masses that may be of algal origin. The dolomitic limestones, which were probably altered from an original calcitic limestone, seem also to contain both the brachiopod-gastropod, etc., assemblage and the sponge-crinoid, etc., assemblage.

BEDDING

The Capitan limestone consists of beds 15 to more than 100 feet thick, separated by indistinct bedding planes, and with very few interbedded, thinner layers. The bedding planes are well exposed in the cliffs on the west side of the mountains (pl. 12, *A*), but on the gentler slopes to the northeast they are not as clearly evident (pl. 16).

In the McKittrick Canyon region there are some prominent, quite massive members 100 to 300 feet thick. One of them, approximately of Lamar age, lies just under the Carlsbad limestone along the top of the escarpment near the mouth of the Canyon. Farther northwest are several older members, one of which rises in lines of cliffs along the north and south branches of the canyon. Because it lies above the inliers of the Pinery member in the canyon, and dips downstream beneath the Lamar member, it is approximately of Rader age. Each massive bed grades northwestward within a short distance into the thin-bedded Carlsbad limestone and tends to change southeastward into more steeply inclined, thick-bedded limestone.

[44] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, pp. 15–17, 1908.

The massive member that is approximately of Lamar age can be seen forming a cliff just below point 7058 on the panorama, plate 16, *A*. Cliffs formed by the member that is approximately of Rader age appear on the farther side of McKittrick Canyon in the aerial view, plate 18. The manner in which the massive members join the Carlsbad limestone farther northwest, in North McKittrick Canyon, is suggested by the panorama, plate 16, *B*. The massive members are separately indicated on the geologic map, plate 3, and on sections *E–E′* and *F–F′* plate 17.

Both on the Reef Escarpment and within the mountains, the bedding planes in the Capitan limestone dip southeastward at angles of 10° to 30° (as shown on the sections of pl. 17). To a large degree, this dip is not shared by the beds beneath. Thus, the summit of El Capitan consists of a number of southeast-sloping surfaces cut on the inclined bedding planes of the limestone, and other inclined beds can be seen on the cliffs below. However, the beds in the lower part of the cliff are less inclined, and the dark limestones of the Pinery and Hegler at the base are nearly horizontal. The underlying bedded limestones at some of the inliers within the mountains have dips of more than 10° (as in South McKittrick Canyon, shown in sec. *F–F′*, pl. 17). Because these beds were deposited near the edge of the Capitan limestone mass, their inclination may have been original.

The inclination of the bedding was caused by the greater amount of deposition in the Capitan area than in the area to the southeast, where the Bell Canyon formation was deposited. Thus, as each bed of the Bell Canyon formation changes into Capitan facies, it swells to several times its previous thickness, and acquires a dip to the southeast, partly from the slope of its own surface and partly from the slope of the overthickened beds on which it was deposited. The face of the Reef Escarpment on the southeast side of the Capitan mass is approximately the surface of the last of the inclined beds deposited, somewhat modified by erosion (fig. 20, *B*).

The dips were probably accentuated by slight tilting of the rocks at various times after Capitan deposition. The much later Cenozoic uplift of the mountains imparted to all the Permian rocks an east-northeast component of dip. There seems to have been also a pre-Cenozoic southeastward tilting, perhaps of later Permian, post-Guadalupe age, as there is a slight southeastward dip of the well-bedded limestones associated with the Capitan. Thus, the Hegler member at inliers within the mountains lies 1,000 feet higher than on the points of Rader Ridge, 4 miles to the southeast (compare secs. *I–I′* and *G–G′*, pl. 17), and the Carlsbad limestone on the mountain summits dips southeastward at angles of 3° to 5° (as in secs. *E–E′* and *H–H′*, pl. 17). The tilted Carlsbad beds are truncated by the upland surface of the mountains, which is probably a peneplain formed before the Cenozoic uplift of the range. At least a part of the dip of the Carlsbad is therefore pre-Cenozoic.

According to Johnson [45] the Capitan limestone in outcrops near Carlsbad and Carlsbad Cavern can be divided into 1, a reef face, or rough slope along the sea side of the reef, composed of massive, inclined beds of dolomitic limestone; 2, a reef crest, forming a low, narrow ridge at the top of the reef face and rising slightly higher than the reef platform behind; and 3, a reef flat a few hundred to 1,800 feet wide, composed of poorly bedded dolomitic limestones. The reef flat grades in turn into lagoonal deposits of the Carlsbad limestone. No details based on specific localities are given. While these subdivisions correspond in a general way with features observed during the present work, one wonders whether the observations are wholly objective, or are unduly influenced by comparisons with modern reef deposits, some of which may not be justified.

BRECCIA PHASE OF CAPITAN LIMESTONE

At three places in the mountains the normal Capitan limestone is replaced by a dolomitic, sandy breccia. Exposures are found in South McKittrick Canyon near the Grisham-Hunter Lodge, in Pine Spring Canyon near Devils Hall, and on the nearly inaccessible cliffs on the west side of the mountains north of Guadalupe Peak. At each place the breccia lies on the Hegler limestone member, apparently with unconformable contact, and it seems to have been deposited in deep pockets and on knobs and sharp pinnacles of the underlying limestone. So far as the Capitan beds above the breccia can be traced, they seem to be equivalent to the Pinery member. The breccia somewhat resembles caliche-cemented talus of Quaternary age which in places lies on the Capitan. It is actually distinct and is a part of the Capitan and of Permian age.

The breccia consists of cavernous, sandy, light-buff or pink dolomitic limestone, of tufalike appearance, with irregularly developed, rude bedding. It stands in irregular cliffs and crags, with numerous small caves, and is less jointed than the limestones above and below. Embedded in the sandy dolomitic matrix are tumbled and disordered limestone blocks from six inches to several feet in diameter. Near the Grisham-Hunter Lodge the matrix contains imprints of fossils. The breccia contains lenses of fine-grained, well-bedded, calcareous sandstone, and toward the top it is interbedded with dolomitic limestone. It apparently grades both upward and laterally into the more normal Capitan deposits. The greatest thickness observed is 380 feet.

For general stratigraphic relations of the breccia, see plate 7, *A*. Its structure in Pine Spring Canyon is

[45] Johnson, J. H., Permian lime-secreting algae from the Guadalupe Mountains, New Mexico: Geol. Soc. America Bull., vol. 53, pp. 216–217, 1942.

shown on section $I-I'$ and on the west face of the mountains on section $K-K'$ of plate 17. A stratigraphic section of the breccia in Pine Spring Canyon is given on plate 15 (No. 58), and on the west side of the mountains on plate 6 (Nos. 12 and 13). Note the manner in which it overlies the Hegler limestone member, and is apparently traceable beneath the Pinery limestone member in the sections to the southeast.

CARLSBAD LIMESTONE

DEFINITION

The name Carlsbad limestone was given by members of the Geological Survey [46] in 1926 to beds exposed in the vicinity of Carlsbad, N. Mex. Thin-bedded limestones of the Carlsbad facies had been described previously by Tarr,[47] Richardson,[48] and Baker.[49] The rocks at the type locality are thin-bedded limestones of late Capitan age and are of a facies that is extensively developed in the Guadalupe Mountains.

The name Carlsbad has been used by some geologists for a tongue of the thin-bedded limestone which in New Mexico projects northward into red beds and evaporite deposits,[50] now called the Azotea tongue, and by others for both thin-bedded and massive limestones which correspond to the upper part of the Capitan limestone at its type locality.[51] It seems more proper, however, to apply the name to all the thin-bedded limestones equivalent to the massive Capitan limestone,[52] and this usage is followed in the present report.

RELATION TO CAPITAN LIMESTONE

The relations between the Carlsbad limestone and the Capitan limestone are best exposed on the northeast wall of North McKittrick Canyon, which cuts transversely through the upper part of the Capitan limestone mass (pl. 3).

Toward the southeast, at the mouth of McKittrick Canyon, the rim of the northeast wall is formed by a small thickness of thin-bedded, flat-lying Carlsbad limestone, slightly younger in age than the Lamar limestone member of the Bell Canyon formation (pl. 16, *A*). The flat-lying Carlsbad limestone rests on southeastward-sloping, thick-bedded or massive layers of Capitan limestone. At first view, the difference in dip between the two formations is so striking that they appear to be separated by an unconformity. However, when the Capitan layers are traced up the canyon wall to the northwest, they lose their inclination and change within a short distance into flat-lying, thin-bedded limestones similar to but older than those which form the rim at the mouth of the canyon. These limestones continue northwestward into the mountains, either in a horizontal position or with a low dip to the southeast.

As each bed of the Capitan is traced to the northwest along the wall of North McKittrick Canyon, it changes in this manner into Carlsbad limestone (pl. 16, *B*). Finally, at the head of North McKittrick Canyon, at the pass which leads down into Dog Canyon near El Paso Gap Post Office (pl. 3), the thin-bedded Carlsbad limestone and its basal sandstone member rest directly on the Goat Seep limestone of pre-Capitan age (pl. 14, *A*). The ledges of white, thin-bedded limestone that form the walls of Dog and West Dog Canyons beyond contrast greatly with the ragged cliffs of massive or thick-bedded limestone of the same age that form the walls of McKittrick Canyon and its branches a few miles to the southeast.

The two panoramas in McKittrick Canyon, plate 16, *A*, and *B*, give a nearly complete cross section through the Capitan and Carlsbad limestones. They join each other at their ends, so that point 7044 on the rim of the canyon appears in both views. In addition, the relations farther northwest are shown on plate 14, *A*. Note that point 7378 near the head of North McKittrick Canyon, shown at the left end of plate 16, *B*, appears also in the right-hand part of plate 14, *A*. The contrast in the appearance of the mountain slopes to the northwest with those to the southeast, both carved from rocks of the same age, can be seen by comparing plate 14, *A* with plate 16, *B*.

The structure of the beds shown in the three panoramas is assembled on section $E-E'$, plate 17. On this plate, note the similar transition northwestward from Capitan into Carlsbad limestone shown on sections $F-F'$, $H-H'$, and $I-I'$. The transition from Capitan into Carlsbad is not represented on section $K-K'$, plate 17, or on the stratigraphic sections of plate 6 because on the west side of the mountains, where the sections were measured, the beds of upper Guadalupe age have been eroded away in the critical area at the head of Pine Spring Canyon between Bush Mountain and Bartlett Peak.

As shown on the walls of North McKittrick Canyon, the southeastern edge of the oldest beds of Carlsbad facies lies northwest of the youngest beds of Carlsbad facies. (The southeast edge of the oldest beds is shown

[46] Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, p. 419, 1926. Meinzer, O. E., Renick, B. C., and Bryan, Kirk, Geology of number 3 reservoir site of the Carlsbad irrigation project, New Mexico: U. S. Geol. Survey Water-Supply Paper 580, p. 12, 1926.

[47] Tarr, R. S., Reconnaissance of the Guadalupe Mountains: Texas Geol. Survey Bull. 3, pp. 29–30, 1892.

[48] Richardson, G. B., Stratigraphy of the upper Carboniferous in west Texas and southeast New Mexico: Am. Jour. Sci., 4th ser., vol. 22, p. 336, 1910.

[49] Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, p. 115, 1920.

[50] Fiedler, A. G., and Nye, S. S., Geology and ground-water resources of the Roswell artesian basin, New Mexico: U. S. Geol. Survey Water-Supply Paper 639, pp. 53–55, 1933.

[51] Darton, N. H., "Red Beds" and associated formations in New Mexico: U. S. Geol. Survey Bull. 794, p. 224, 1928. Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 983–985, 1929.

[52] Crandall, K. H., Permian stratigraphy of southeastern New Mexico and adjacent parts of western Texas: Am. Assoc. Petroleum Geologist Bull., vol. 13, p. 938, 1929. Lang, W. B., The Permian formations of the Pecos valley of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., vol. 21, p. 868, 1937.

as line *B*, fig. 10.) The southeastward advance of the Carlsbad limestone, however, does not take place bed by bed. Instead, there is a tendency for groups of beds up to several hundred feet in thickness to change southeastward into the Capitan at the same place. In section *E–E′* of plate 17, which gives the most complete section through the transition zone, there are 7 such groups of beds. Similar groups of beds, which are possibly equivalent to some of these, are shown on the other sections of plate 17.

THICKNESS

The Carlsbad limestone on the walls of North McKittrick Canyon dips southeastward at angles of a few degrees. Each thin-bedded layer which comes out of the Capitan mass, when traced northwestward is cut off in a few miles by erosion, so that the upland surface of the mountains bevels the gently dipping beds (sec. *E–E′*, pl. 17). Here and elsewhere in the southern Guadalupe Mountains this surface, which is probably an uplifted peneplain of post-Permian and pre-Cretaceous age, cuts off the beds in such a manner that no complete section of the Carlsbad limestone exists. Where the lower part of the formation is exposed, its top is eroded, and where its top is exposed, most of the lower part has changed into rocks of Capitan facies (pl. 7, *A*).

The greatest thickness measured in the area, 787 feet, is found on the slopes of Lost Peak between Dog Canyon and West Dog Canyon (sec. 3, pl. 6), where the formation rests on the Goat Seep limestone. In the upper course of North McKittrick Canyon as much as 1,000 feet of Carlsbad limestone appears to be present above the Goat Seep limestone. According to Lang[53] and others familiar with the region in New Mexico to the north the total thickness of the Carlsbad and the associated Chalk Bluff formation of that area is about 1,000 feet. This amount is about the same as the maximum thickness observed in the area of this report.

LIMESTONE OF SOUTHEASTERN EXPOSURES

Where the Carlsbad overlies the Capitan in the southeast part of the area, it consists of thin-bedded, white or gray dolomitic limestone. The straight, smooth bedding planes are a few inches to a foot apart, and some beds are thinly laminated. Many of the layers are crowded with pisolites. These pisolites have been considered by some paleontologists to be of algal origin. They have been described and figured by Ruedemann,[54] Ackers and others,[55] Lang,[56] and Johnson.[57] They are concentric, subspherical, calcareous bodies ranging in size from that of a pea to that of a ball more than an inch across (pl. 19, *A*). The pisolites are discussed further on pp. 79–80. Other beds are crowded with fusulinids which are commonly oriented in a northwestward direction, perhaps by waves or currents (fig. 10). The parallel orientation was noted by Girty[58] on the summit of Guadalupe Peak. The fusulinids and pisolites are found in the same exposures of the formation, but commonly occupy distinct beds. Some of the interbedded layers are barren.

In many of the dolomitic limestones, cross sections of other fossils can be seen, but the rock is so hard and brittle that it generally breaks across them. In occasional calcareous beds a considerable fauna, somewhat resembling that of the Capitan, has been collected. This fauna includes several species of brachiopods; the gastropods outnumber all other groups. Many of the gastropods and fusulinids are coated with a concentric, calcareous growth, possibly made by the same encrusting agent that formed the pisolites. A similar description of these rocks as exposed in New Mexico has been given by Johnson.[59]

LIMESTONE OF NORTHWESTERN EXPOSURES

In the northwestern part of the area, where the Carlsbad lies directly on beds older than the Capitan, its dolomitic limestones are more compact, thinner-bedded, and with a greater variety of colors than in the southeastern exposures. Fusulinids, pisolites, and all traces of other fossils are absent. The change from one type of rock to the other takes place along a fairly definite line, which passes a short distance north of Lost Peak (line *A*, fig. 10).

About 460 feet of such beds overlie the Goat Seep limestone a mile north of Lost Peak (sec. 2, pl. 6). They include prominent ledges, consisting of compact, dolomitic limestones, which are separated by slabby, brown, pink, or reddish dolomitic limestone, and some platy sandstone. Some of the slabby limestones are full of round holes up to an inch in diameter, possibly caused by solution of soluble minerals. A layer of brick-red, sandy shale lies 300 feet above the base. The same layer is also recognizable on many of the hillsides between Dog and West Dog Canyons.

The following analyses of limestone from the Carlsbad of the southeastern and northwestern exposures were made:

[53] Lang, W. B., op. cit., p. 820, and personal communication, 1937.

[54] Ruedemann, Rudolf, Coralline algae, Guadalupe Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1079–1080, 1929.

[55] Ackers, A. L., and others, Hendrick field, Winkler County, Texas: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 932 (figs. 9, 10), 940, 1930.

[56] Lang, W. B., op. cit., p. 869.

[57] Johnson, J. H., Permian lime-secreting algae from the Guadalupe Mountains, New Mexico: Geol. Soc. America Bull., vol. 53, pl. 6, p. 225, 1942.

[58] Girty, G. H., op. cit., p. 15.

[59] Johnson, J. H., op. cit., p. 217.

Analyses, in percent, of Carlsbad limestone

[Analyses by K. J. Murata; notes on insoluble residues by Charles Milton]

Specimen locality	Insoluble		R_2O_3 (mostly Fe_2O_3)	$CaCO_3$	$MgCO_3$	$MnCO_3$	$Ca_3(PO4)_2$	Total
	Inorganic	Organic						
1. White, fine-grained, dolomitic limestone, characteristic of southeastern facies of formation; head of trail on north side of Pine Spring Canyon	1. 36	0. 06	0. 17	60. 96	27. 02	None	None	99. 57
2. Buff, dense, dolomitic limestone, characteristic of northwestern facies of formation; ridge between Lost Peak and Dog Canyon	. 46	. 06	. 44	54. 61	43. 98	0. 02	None	99. 57

Insoluble residues: 1, Light gray, with many euhedral, six-sided plates of muscovite, prismatic doubly terminated quartz, and occasional green tourmaline; 2, light gray, mainly very small imperfectly crystallized stubby quartz grains.

SANDSTONE OF SOUTHEASTERN EXPOSURES

Interbedded with the limestones of both the southeastern and northwestern exposures are many sandstone beds. They are thickest and most prominent toward the northwest.

Along the southeast edge of the Guadalupe Mountains, the sandstones form occasional beds up to a foot in thickness, which are difficult to trace because of the heavy cover of forest and brush. One member in the upper part, more prominent than the rest, caps the ridges between North and South McKittrick Canyons, and those near the headwaters of Dog Canyon. It has a thickness of about 50 feet, and contains relatively few, thin, interbedded limestones. This member and a few other beds are separately mapped on plate 3. It may be equivalent to the Yates sandstone,[60] which has been traced widely in subsurface work in the area east of the Guadalupe Mountains.

The sandstones of the southeastern exposures are brown, fine-grained, in part calcareous, and form slabby beds or rounded ledges. Many of them weather reddish brown, thus giving the false impression that they are red-bed layers. Three specimens of the sandstone, from the region between Pine Spring Canyon and the Grisham-Hunter Cabin, were studied under the microscope by Ward Smith. The maximum grain size varies in the different specimens from 0.15 to 0.50 millimeters in diameter; in the coarsest-grained specimens the spaces between the large grains are filled by finer detrital grains and clay. The principal mineral is quartz. Some of the quartz in one of the specimens shows lines of inclusions and is clearly of igneous origin. Some other grains are microcrystalline. There are also grains of feldspar, zircon, tourmaline, and chlorite. At one locality, a sandstone containing small chert pebbles was noted, but no material as coarse as this was found in other places.

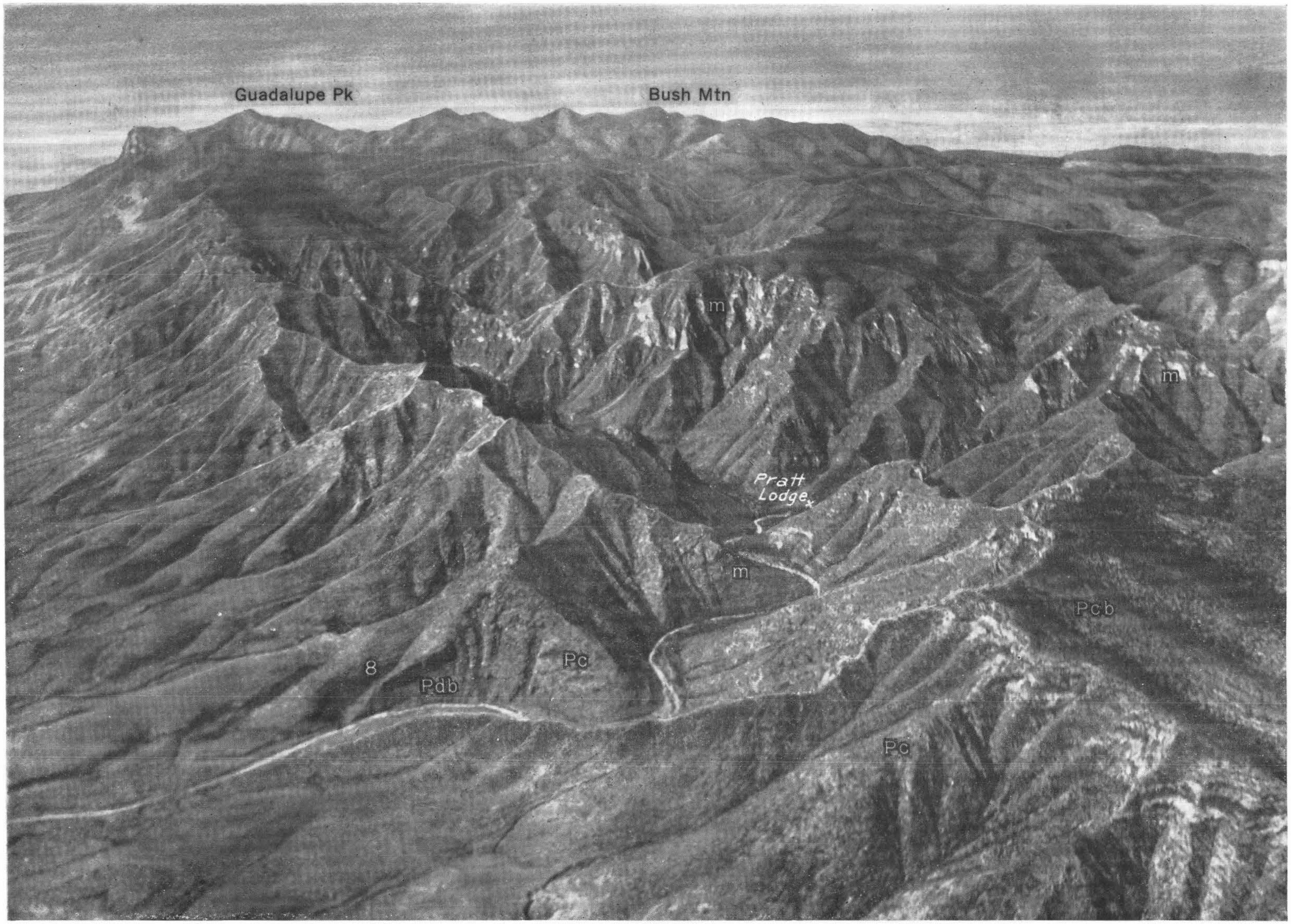
[60] Gester, G. C., and Hawley, H. J., Yates field, Pecos County, Texas, Structure of typical American oil fields, vol. 2, pp. 480–499. Tulsa, 1929.

SANDSTONE OF NORTHWESTERN EXPOSURES

In the northwestern part of the area, the sandstone beds in the Carlsbad limestone are thicker and more numerous, and form persistent members 5 to more than 50 feet thick. At Lost Peak the 787 feet of section contains 9 such members; the thickest is at the base (sec. 3, pl. 6).

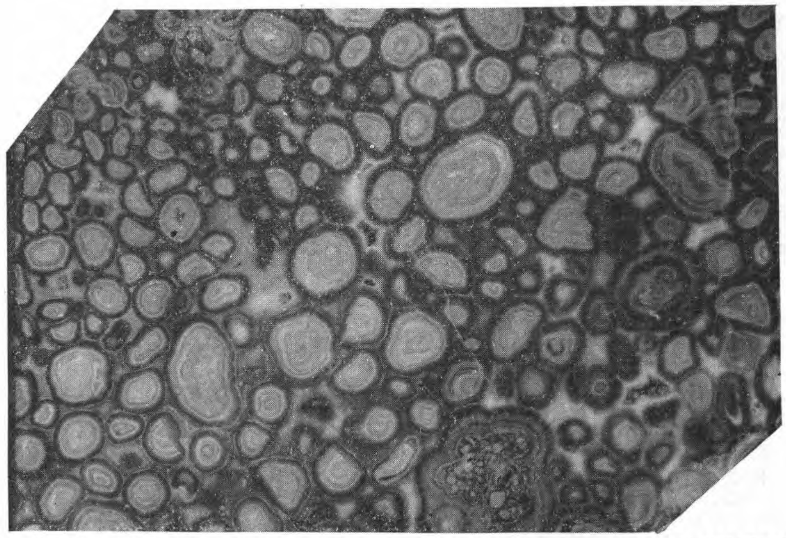
This basal sandstone member, which lies on the Goat Seep limestone, appears to be a widely traceable horizon. On the escarpments on the east sides of Dog and West Dog Canyons, it is buff, fine-grained, and somewhat calcareous, with some cross-bedding, and occasional limonite nodules. It crops out in prominent, brown-colored ledges as much as 10 feet thick. Southward on the two escarpments, and on Cutoff Mountain, the sandstone becomes more thinly bedded, and is of buff or reddish color. In this vicinity it contains much interbedded, platy, white or pink dolomite. A specimen of sandstone from the member, collected near Cutoff Mountain and studied under the microscope by Ward Smith, consists of quartz and feldspar grains, with a few grains of zircon and clastic calcite, all loosely packed in a calcite matrix. The maximum diameter of the grains is 0.2 millimeter.

When traced toward the southeast along several lines of outcrop the basal sandstone member of the Carlsbad limestone appears to extend either into the basal beds of the Capitan limestone or into beds just beneath it. One line of outcrop is along the west edge of the mountains. Here the thinned equivalent of the sandstone seems to be traceable, near Bush Mountain, into the sandstone break that separates the Goat Seep and Capitan limestones (as suggested by correlation lines between secs. 4 and 11, pl. 6). Another line of outcrop extends from Dog Canyon, near El Paso Gap Post Office, into North McKittrick Canyon. Here also the sandstone thins southeastward, and its equivalent appears to lie near the boundary between the Goat Seep and Capitan (sec. *E–E′*, pl. 17, and pl. 3).

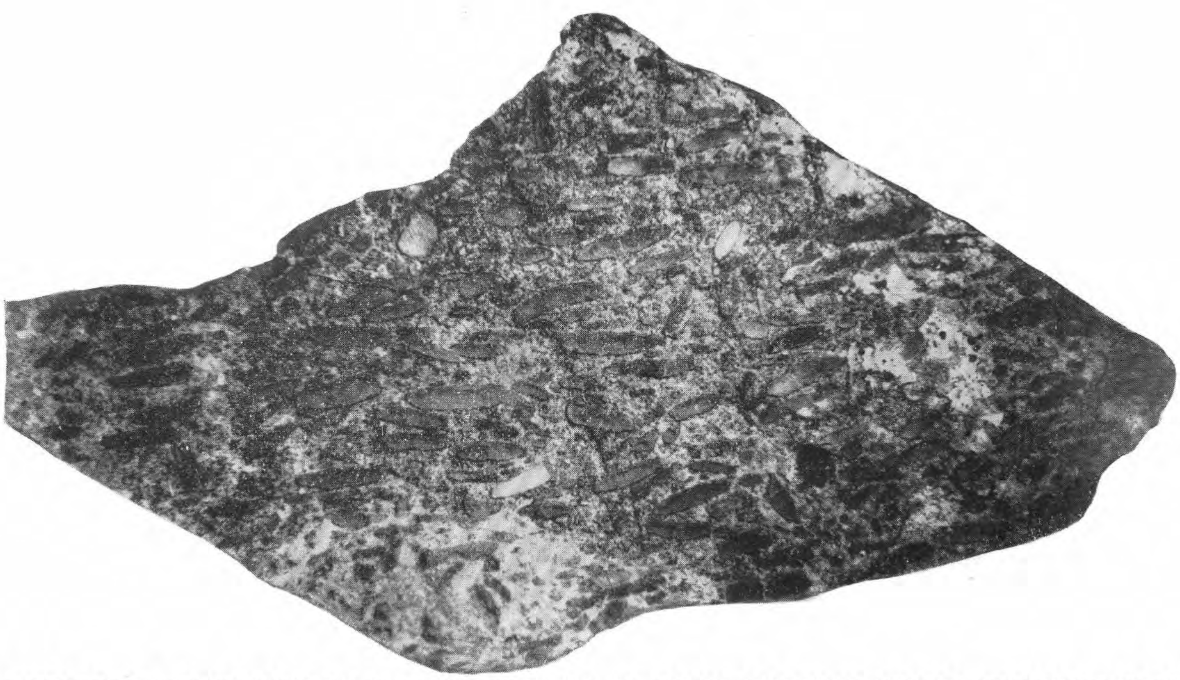


AERIAL VIEW OF GUADALUPE MOUNTAINS, LOOKING SOUTHWESTWARD FROM McKITTRICK CANYON TOWARD GUADALUPE PEAK.

Reef escarpment to left, Texas-New Mexico line near right-hand margin. *Pdb*, Bell Canyon formation, including Lamar limestone member (8); *Pc*, Capitan limestone, including massive beds (*m*); *Pcb*, Carlsbad limestone. Photograph by Edgar Tobin Aerial Surveys.



A. PISOLITES, PROBABLY IN PART OF ALGAL ORIGIN, FROM CARLSBAD LIMESTONE.



B. FUSULINIDS (PARAFUSULINA SP.) IN SANDSTONE OF BRUSHY CANYON FORMATION, SHOWING TENDENCY TOWARD PARALLEL ORIENTATION.

SOME FOSSILS FROM GUADALUPE MOUNTAINS.

All figures are natural size.

The basal sandstone member of the Carlsbad limestone also is traceable northward along the east side of Dog Canyon into New Mexico. It was studied from distant views, such as that shown on plate 14, *A*. In this direction the bed seems to rise toward the top of the escarpment and finally to spread over the mountain crest in the vicinity of Queen Mesa (for location, see fig. 2). It therefore may be the same as the Queen sandstone member of the Chalk Bluff formation, which was described in that area by Blanchard and Davis [61] and by Lang.[62]

If the correlations just outlined are correct, the Queen sandstone is of early upper Guadalupe age, and is equivalent to beds at the base of the Carlsbad and Capitan limestones. In some earlier reports it has been correlated with much higher parts of the Capitan limestone. Thus, Blanchard and Davis [63] state that they have traced the Queen southwestward to within a mile northeast of Guadalupe Peak, and that it lies stratigraphically within 300 feet of the top beds of the peak. According to observations made during the present work, there are many thin sandstone beds at different levels in the Carlsbad limestone near the peak, but no continuous traceable layer. These sandstone beds are here interpreted as lying much higher stratigraphically than the Queen and associated sandstones farther north.

NORTHERN GUADALUPE MOUNTAINS

In the northern Guadalupe Mountains, which lie in New Mexico, outside the area studied, the Carlsbad limestone interfingers with rocks of another facies, composed of anhydrites and other evaporites, thin dolomites, red beds, and sandstones. These rocks form the Chalk Bluff formation of Lang,[64] and are of the same age and facies as the Whitehorse group, as that term is used by geologists engaged in subsurface work east of the Guadalupe Mountains.[65] The beds in the northern Guadalupe Mountains were laid down farther away from the Delaware Basin, and farther within the shelf area, than any beds within the area of this report.

The beds in question are exposed east of the central ridge of the Guadalupe Mountains toward the Pecos River, where they form the Seven Rivers Embayment and the northeastern prong of the mountains (fig. 2). In the embayment and prong area, the Carlsbad and Chalk Bluff formations interpenetrate as a series of tongues. At the base is the Queen sandstone member of the Chalk Bluff, which extends up over parts of the central ridge (as on Queen Mesa), where it overlies the Goat Seep limestone or its equivalents. Above it is the Seven Rivers gypsiferous member of the Chalk Bluff, consisting mainly of anhydrite and red beds. This member is poorly resistant to erosion, and has been carved into the Seven Rivers Embayment, a low-lying plain, down the dip from and east of the central ridge, and between the ridge and the northeastern prong of the mountains. The embayment is wedge-shaped, with its point to the south, where the central ridge and the prong come together (fig. 2). This topographic relation is a reflection of the southward disappearance of the Seven Rivers member along the outcrop, by intergradation with the more resistant and topographically more prominent Carlsbad limestone.

The northeastern prong of the Guadalupe Mountains, down dip to the east of the embayment, is capped by a sheet of Carlsbad limestone that forms the Azotea tongue of Lang. It partly overlies the Seven Rivers member, but intergrades with it toward the northwest, as exhibited in excellent exposures along Rocky Arroyo, in the gorge cut by it through the prong.[66] The outcrop of the tongue crosses the Pecos River northwest of Avalon Lake, where the tongue forms a rapidly thinning wedge enclosed above and below by beds of the Chalk Bluff formation.[67]

Overlying the Azotea tongue of the Carlsbad limestone in the north part of the northeastern prong is a higher tongue of the Chalk Bluff formation, called the Three Twins member by Lang. This tongue intergrades with the Carlsbad limestone a short distance northwest of Carlsbad. According to De Ford and Riggs,[68] it includes the Yates sandstone of subsurface nomenclature, and an overlying unit, which they call the Tansill formation. As shown by drilling east of the outcrop, the Three Twins member is overlain by the basal beds of the Salado formation, a part of the Ochoa series.

North of the area covered by figure 2, the tongues of Carlsbad limestone wedge out entirely, and all the beds of upper Guadalupe age are of Chalk Bluff type. Still

[61] Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 972, 1929.

[62] Lang, W. B., op. cit., p. 859.

[63] Blanchard, W. G., and Davis, M. J., idem, p. 972.

[64] Lang, W. B., The Permian formations of the Pecos Valley of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., vol. 21, pp. 855–857, 859–863, 1937.

[65] De Ford, R. K., and Lloyd, E. R., Editorial introduction [to west Texas Permian symposium]: Am. Assoc. Petroleum Geologists Bull., vol. 24, pp. 8–9, 1940.

[66] First described by C. L. Baker, Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, p. 115, 1920. For detailed description see Bates, R. L., Lateral gradation in the Seven Rivers formation, Rocky Arroyo, Eddy County, New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 26, pp. 80–99, 1942.

[67] Exposures of the tongue at this locality were described by O. E. Meinzer, B. C. Renick, and Kirk Bryan, Geology of number 3 reservoir site of the Carlsbad irrigation project, New Mexico: U. S. Geol. Survey Water-Supply Paper 580, pp. 12–13, 1926. The overlying beds, which they termed Castile formation, are now known to belong to the Three Twins member of the Chalk Bluff formation.

[68] De Ford, R. K., Riggs, G. D., Tansill formation, west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 25, pp. 1713–1728, 1941.

farther north, limestones of middle Guadalupe age, equivalent to the Goat Seep limestone, also disappear, their place being taken by rocks of Chalk Bluff type. In its northern exposures, the Chalk Bluff formation is thus partly of upper Guadalupe age and partly of middle Guadalupe age.

The description of the relations of the beds of middle and upper Guadalupe age in the northern Guadalupe Mountains, as given in this report, is based on nomenclature adopted by the Geological Survey, which emphasizes lithologic units. A different system has been used by petroleum geologists, both in subsurface correlations and surface mapping, which emphasizes time units, regardless of their lithologic variations from place to place. By the latter system, the beds here discussed are termed the Whitehorse group, which is divided from below upward into the Grayburg, Seven Rivers, Yates, and Tansill formations. These formations are delimited and traced in both the Chalk Bluff and Carlsbad facies of present usage. Both systems of terminology have merit and originated for specific needs. The lithologic units are of value for reconnaissance surface mapping, and the time units are of value for subsurface work, such as well-log correlations and the recognition of subsurface structural features.

STRATIGRAPHIC RELATIONS

FIELD RELATIONS

In the Delaware Mountains, the Bell Canyon formation, at the top of the Guadalupe series, is overlain by the Castile formation. In the Guadalupe Mountains, no beds younger than the Guadalupe series are present. The highest beds of that area are the Carlsbad and Capitan limestones of Guadalupe age, which have been deeply eroded. The top of the Bell Canyon formation of the Delaware Mountains lies at a much lower altitude than the Carlsbad and Capitan limestones of the Guadalupe Mountains, with the overlying Castile extending up to the base of the Reef Escarpment. Near the Gray Ranch in Big Canyon Draw (northeast corner of pl. 3) the Castile crops out within a mile of the Reef Escarpment and stands more than 1,000 feet below the crest of the escarpment.

The contact between the Bell Canyon and the Castile in the Delaware Mountains appears to be conformable. The highest sandstones of the Bell Canyon give place abruptly to thinly laminated limestone of the Castile, which grades upward in turn into laminated anhydrite. There is no sign of erosion at the contact.

ALTERNATIVE INTERPRETATIONS

The features just outlined would seem to require some special explanation; they have puzzled geologists since the time of the first work in the region. Three principal explanations have been offered:

1. The Capitan limestone could have been laid down across the Delaware Mountain area but was eroded entirely away before deposition of the Castile, so the Castile was deposited on beds older than the Capitan,[69] 2, the Castile anhydrites could be the southeastward equivalent of the Capitan limestone, the two deposits grading into each other near the present Reef Escarpment;[70] and 3, the Capitan limestone could be older than the Castile formation and pass laterally into the Bell Canyon formation, the difference in altitude between the two being the result of irregularities in the original depositional surface.

The present field work indicates that the third explanation is the correct one, and demonstrates that the greater part of the Capitan limestone is of the same age as the Lamar and underlying members of the Bell Canyon formation.

Although the greater part of the Capitan limestone can be traced along the outcrop into the Bell Canyon formation, a few hundred feet of Capitan and Carlsbad limestones that are younger than the Lamar member and form the top and face of the escarpment at McKittrick Canyon cannot be traced southeastward because they are cut off by erosion. Their correlation with the Bell Canyon formation of the Delaware Mountains is thus somewhat uncertain. To the northeast, in New Mexico, greater thicknesses of Carlsbad limestone than at McKittrick Canyon extend to the edge of the escarpment. Some geologists have suggested that although most of the Capitan limestone is equivalent to the Bell Canyon formation the highest beds at McKittrick Canyon are contemporaneous with the Castile formation, and that the thick Carlsbad limestones to the northeast include strata that are younger than those at the canyon.[71]

The youngest Capitan and Carlsbad limestones at McKittrick Canyon and farther northeast are identical in character with those of the older parts of the same formations elsewhere in the mountains. If they were laid down at the same time as the Castile formation, the conditions of their deposition would have been very different from those of the older beds. It seems probable, therefore, that they are equivalent to the 20 to 35 feet of thin sandstone and limestone beds that lie between the Lamar member and the Castile formation southeast of the Reef Escarpment. These beds are much thinner than the limestones on the escarpment, but the older sandstone and limestone members of the Bell Canyon formation are likewise thinner than that part of the Capitan limestone which has been proved to be equivalent to them.

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[69] Richardson, G. B., Reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, pp. 43–44, 1904. Darton, N. H., and Reeside, J. B., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 420–421, 1926.

[70] Baker, C. L., op. cit., pp. 116–117. This view was widely held by other geologists about 1925, but apparently none of them published their conclusions.

[71] Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 985, 1929.

Whether any limestones younger than those at McKittrick Canyon come in to the northeast remains to be proved. In view of the widespread and often abrupt replacement of the Capitan by the Carlsbad limestones, it is probable that the limestones of the two areas are of about the same age.

INFERRED STRATIGRAPHIC RELATIONS

The Castile formation may have been deposited on the highest sandstones of the Bell Canyon formation with little or no break in deposition. The sandstones, it is true, record a time of clastic deposition in a body of water connected with the ocean, whereas the anhydrites indicate deposition caused by concentration of salts in a partly inclosed body of sea water. Both, however, seem to have been deposited slowly in quiet water, and the change in character of the sediments probably resulted from events outside the area, such as the growth of a barrier across the entrance of the Delaware Basin (as suggested in fig. 14, *C*).

Toward the margins of the basin the stratigraphic relations are probably different. If all the Capitan and Carlsbad limestones are older than the Castile, they formed a mass that projected above the sea bottom of the Delaware Basin in somewhat the manner as the Reef Escarpment now rises above the plains to the southeast of it. Deposits laid down in the Delaware Basin in post-Capitan time probably overlapped the more elevated Capitan deposits. The nonresistant Castile formation has now been entirely eroded from the face of the escarpment, so this relation cannot be proved in the area studied. Farther east, however, where the Capitan and Castile formations pass beneath the surface, the evidence of drill records is interpreted by many geologists to indicate that the Castile does overlap unconformably on the surface of the Capitan at the edge of the Delaware Basin (as suggested in sec. *e*, pl. 7, *B*).[72]

FOSSILS

The upper part of the Guadalupe series contains abundant fossils at many places. Its faunas were, in fact, the ones best known in the Guadalupe Mountains before the present investigation, because they furnished a large part of the material previously described by Girty [73] in his Guadalupian fauna. In addition, collections of this fauna made later by Darton and Reeside,[74] have been reviewed by Girty.

In the discussion that follows, as in that on the faunas previously discussed, the information on the fossils is largely based on the work of Dunbar and Skinner,[75] Miller, and Furnish,[76] and G. H. Girty. In addition, some information is taken from the recent work of Pia [77] and Johnson [78] on algae, of Edwin Kirk on crinoids, of L. G. Henbest on Foraminifera, and of N. D. Newell [79] on pelecypods.

In the upper part of the Guadalupe series, fossils occur in varying abundance. They are very common in the reef mass of the Capitan limestone and in immediately adjacent parts of the Bell Canyon formation and Carlsbad limestone. In the Bell Canyon formation farther southeast and in the Carlsbad limestone farther northwest they are less common, and in many beds are absent entirely. Like the rocks that contain them, the faunas differ markedly in facies from one part of the area to another, even in contemporaneous beds. The first group of faunas, described below from the limestone members of the Bell Canyon formation, lie in a normal, ascending stratigraphic sequence. The next group of faunas, described from the Capitan and Carlsbad limestones, are from beds of the same age as part or all of the members of the Bell Canyon formation. The fossils from each of these two formations are considered as units and no separate zones have been distinguished in them.

BELL CANYON FORMATION

HEGLER LIMESTONE MEMBER

The Hegler limestone member at the base of the Bell Canyon formation contains fossils at numerous places, but they are never abundant or varied, and many are so poorly preserved that collections made from it are small. According to Girty, "The member has a rather extensive fauna, but most of the species are represented only by a specimen or two in the collections in which they occur. The collections occur in rocks of several distinct lithologic types, but the faunal characters are much the same and the differences do not seem to be significant."

Collections were made from the thin-bedded, granular facies of the member in the Delaware Mountains in the southeast part of the area, and in the downfaulted area to the west. They were made also from the lumpy facies along the Reef Escarpment, on the southeast side of the Guadalupe Mountains, and from the light-gray, bedded facies in McKittrick Canyon.

[72] Cartwright, L. D., Transverse section of Permian basin: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 979–980, 1930. Kroenlein, A. A., Salt potash and anhydrite in the Castile formation of southeast New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 23, figs. 2 and 3, pp. 1685 and 1687, 1939.

[73] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, pp. 15–20, 1908.

[74] Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 414–416, 424, 427–428, 1926.

[75] Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas: Texas Univ. Bull. 3701, pp. 594–596, 727–731, 1937.

[76] Miller, A. K., and Furnish, W. M., Permian ammonoids of the Guadalupe Mountains region and adjacent areas: Geol. Soc. America Special Paper 26, pp. 11–12, 1940.

[77] Pia, J. V., Bie wichtigsten kalkalgen des Jungpalaozoikums und ihre geologische bedeutung: Compte rendu du deuxième congress pour l'avancement des études Carbonifère, pp. 813–837, Heerlen, 1937; Vorläufige übersicht der kalkalgen des Perms von Nordamerika: Akad. Wiss. Wien, Math.-Natuurwiss. Kl., Anz. 9, preprint, June 13, 1940.

[78] Johnson, J. H., Calcareous algae from the Carlsbad limestone of New Mexico [abstract]: Geol. Soc. America Bull., vol. 49, p. 1889, 1938; Ecologic distribution of lime-secreting algae of the Permian Carlsbad reef, Guadalupe Mountains, N. Mex. [abstract]: Geol. Soc. America Bull., vol. 50, p. 1915, 1939; Permian lime-secreting algae from the Guadalupe Mountains, N. Mex.: Geol. Soc. America Bull., vol. 53, pp. 195–226, 1942.

[79] Newell, N. D., Invertebrate fauna of the late Permian Whitehorse sandstone: Geol. Soc. America Bull., vol. 51, pp. 279–280, 1939.

Fusulinids are rare in the Hegler member, but at a few localities, as at 7622 in McKittrick Canyon, there are specimens of *Polydiexodina shumardi* Dunbar and Skinner. The genus has not been found below this member in the Guadalupe section.

The cephalopods are represented by ammonoids only, no nautiloids having been found. Collections from the Hegler member have furnished a greater number and variety of ammonoids than were found in any other member of the Bell Canyon formation. Ammonoids are especially common in the thin-bedded, granular facies in the southeast part of the area, but they are found also in the lumpy facies to the northwest, where they are seldom well preserved. From the Hegler member, Miller and Furnish have identified *Medlicottia girtyi* Miller and Furnish, *Paraceltites altudensis* (Böse), *Pseudogastrioceras altudense* (Böse), *P. beedei* (Plummer and Scott), *Xenaspis skinneri* Miller and Furnish, *Cibolites uddeni* Plummer and Scott, *Waagenoceras guadalupense* Girty, and *Timorites schuchert* Miller and Furnish.

By far the most abundant type is the *Waagenoceras*, which occurs in great numbers at all collection localities. Considerably less abundant, but still common, is the genus *Pseudogastrioceras*. The *Timorites* occurs at only a single locality (7694), but is of some significance, because Miller and Furnish [80] have used it to name the Permian ammonoid zone next above the zone of *Waagenoceras*. Here and elsewhere, however, *Timorites* and *Waagenoceras* occur in association in the lower part of the zone of *Timorites*. That the Hegler member is of later Permian age is suggested by *Xenaspis* which occurs high in the Permian sequences of the island of Timor (Netherlands East Indies), and of the Salt Range of India.

Regarding the remainder of the fauna, Dr. Girty reports:

The corals are somewhat more diversified than is common in the Guadalupian faunas, although they cannot at this time be safely identified even generically. A few specimens may belong to the form cited in the collections from lower beds as *Lophophyllum* sp. There seems to be a second species constructed along similar lines, but forming long, slender coralites resembling *Amplexus*. *Cyathaxonia* appears to be present in one collection, and in another the small compound coral described as *Cladopora spinulata* Girty is not rare.

Bryozoans are fairly well represented and abundant in one collection, but not in the others. In this one collection (No. 7622) *Fistulipora* is as usual the most abundant genus. The specimens have the form of rather slender cylindrical stems and belong to the species described as *F. grandis guadalupensis* Girty. A few slender branches are provisionally referred to *Batostomella*, but a more definite assignment must await study by means of thin sections. Some coarsely silicified fronds belong to *Fenestella* or *Polypora*, or both. *Acanthocladia guadalupensis* Girty is fairly abundant, as are some slender stems belonging to the species described as *Domopora ocellata* Girty.

Turning now to the brachiopods, we find that the orthoids are distinguished by their absence. The Orthotetinae are represented by a few small and poor specimens whose identification would hardly be profitable. Only one is a ventral valve; it probably belongs to the genus *Orthotetes*. *Chonetes* is represented by two species, *C. subliratus* Girty, and *C. permianus* Shumard, which is here encountered for the first time.

The productids are much reduced in numbers and variety, and half the species are represented by but a single specimen. Aside from several species that, in the present state of my investigations, are indeterminable, we have here *Productus capitanensis* Girty, *P. popei opimus* Girty, *Productus* aff. *P. occidentalis* Newberry, and two species which in Professional Paper 58 were distinguished as *Productus* sp. a and *Productus* sp. d, and finally I would judge, the species that King described as *Avonia walcottiana costata*.

Of *Aulosteges*, there are apparently two species, each represented by a single specimen. One of them, which is fragmentary, may belong to *A. guadalupensis* Shumard. The other begins with an ornamentation of large, elongated nodes, which farther forward develop into coarse, irregular costae; the species is apparently new.

Prorichthofenia is present at two localities and is fairly abundant at one of them. Pending detailed study, the species may be included under *P. permiana* (Shumard). *Camarophoria* is represented, if at all, by a mere fragment. It might belong to *C. venusta* Girty.

The rhynchonellids of the Hegler limestone are rather abundant and diversified, always remembering that this member is not highly fossiliferous. I recognize *Leiorhynchus? bisulcatum* (Shumard), *L.? bisulcatum seminuloides* (Girty), *Leiorhynchus?* n. sp., *Wellerella? shumardiana* (Girty), *Wellerella? swallowiana* (Shumard), and *Wellerella? indentata* (Shumard).

Only two terebratuloids are present, one an indeterminable species of *Dielasma*, the other *Dielasmina guadalupensis* Girty.

The spiriferoids are represented by rather numerous species, but by few individuals. I may name *Spirifer mexicanus* Shumard, *S. sulcifer* Shumard?, *S. sulcifer* var., *Spirifer* n. sp., *Spiriferina billingsi* Shumard, and *Spiriferina pyramidalis* Girty?. This group seems to show marked Capitan affinities.

Composita is numerous at one locality, but few of the specimens are well preserved. Two species can be distinguished, which may be called *Composita* aff. *C. subtilita* (Hall) and *C. emarginata affinis* Girty. Some of the latter are very large. *Hustedia* is represented by few specimens, but they appear to belong to three species, *H. meekana* (Shumard), *Hustedia* aff. *H. mormoni* (Marcou), and *Hustedia* aff. *H. bipartita* Girty.

The pelecypods, following the general paucity of fossils in this unit, are scantily represented, and many of the specimens are not identifiable. There is a doubtful species of *Sedgwickia* and a doubtful species of *Parallelodon*. As in the faunas already discussed, the pectenoids are more plentiful and varied than the other groups. I may record *Pernipecten? obliquus* Girty?, *Girtypecten sublaqueatus* (Girty)?, *Deltopecten* n. sp., *Camptonectes sculptilis* Girty?, and *Camptonites?* n. sp.

Of the gastropods, the collections afford a single fragmentary specimen, which might belong either to *Euomphalus* or *Omphalotrochus*. Lastly, the trilobites are represented by a few fragments, probably belonging to *Anisopyge perannulata* (Shumard).—Girty manuscript.

In comparison with the fauna of the preceding South Wells member, Dr. Girty notes the reappearance in the Hegler member of bryozoans and spiriferoid brachiopods, which were absent in the South Wells and common in still lower horizons; the absence in both of

[80] Miller, A. K., and Furnish, W. M., op. cit., p. 29.

Enteletes, although it was present in the Goat Seep limestone; and the absence in the Hegler of *Meekella* and *Cryptocanthia*, which were present in the South Wells. *Chonetes permianus* Shumard, which occurs in the Hegler, has not been found at lower horizons. The productids seem to differ considerably from those of the older faunas. Both they and the spiriferoids closely resemble those of the Capitan limestone. According to Girty, "like the South Wells fauna, the Hegler fauna shows an abundance and diversity of rhynchonellids, but the specific representation is different. The South Wells fauna is conspicuous for its large forms, such as *Liorhynchus weeksi* (Girty), and *L. weeksi nobilis* (Girty), neither of which occurs here."

PINERY LIMESTONE MEMBER

The Pinery member contains the assemblage described by Shumard and Girty as the "upper dark limestone" fauna. Most of the material on which the earlier descriptions were based came from the hillside above Pine Spring, the type section of the member (Girty's locality 2930). Subsequent collections were made at the same locality by Darton and Reeside[81] (No. 5815) and during the present investigation (Nos. 7420, 7477, and 7703). (See pl. 2.)

Collections made here and elsewhere along the base of the Reef Escarpment reveal abundant and diverse fossils, constituting a fauna of relatively constant character. Similar fossils, but with a considerable admixture of Capitan species, occur in the lighter-colored limestones of the member farther northwest (as at locality 7412), where the member begins to change over into the Capitan facies. Southeast of the Reef Escarpment, in the Delaware Mountains, however, large numbers of the characteristic elements of the fauna disappear. A collection from this last named region (locality 7643) contained abundant fusulinids, ammonoids, and rhynchonellid brachiopods, a few productids and pelecypods, and nothing else.

Fusulinids occur in nearly all exposures of the member, regardless of facies. According to Dunbar and Skinner, they belong to the large species *Polydiexodina shumardi* Dunbar and Skinner and *P. capitanensis* Dunbar and Skinner, and to the small species *Lëlla bellula* Dunbar and Skinner and *Codonofusiella paradoxica* Dunbar and Skinner.

Ammonoids are represented by fewer collections than those from the underlying Hegler member, but belong to the same species. From the Pinery, Miller and Furnish have identified *Waagenoceras guadalupense* Girty, *Xenaspis skinneri* Miller and Furnish, and *Pseudogastrioceras* sp. No nautiloids have been found, either in recent or earlier collections.

At several localities along the base of the Reef Escarpment, as at Pine Spring, several minute crinoids have been collected. They may possibly prove to be index fossils of the horizon, for they have been found at no other bed in the section. According to Edwin Kirk, they include *Coenocystis richardsoni* Girty and *Allegecrinus* sp. The genus *Coenocystis* and its species were established by Girty[82] on the basis of material from a locality in the southern Delaware Mountains (No. 2969). The stratigraphic position of this collection is unknown, but it is probably of the same age as the Pinery member. According to Girty, the Pinery member of the Guadalupe Mountains also contains spines and plates of the echinoid *Archaeocidaris*.

Dr. Girty writes as follows on the remainder of the fauna, the theme of his report being a comparison between his original collection at locality 2930, and the later collections from the same and nearby localities:

The original collections contained two sponges (*Polysiphon mirabilis* Girty and *Steinmannia americana* Girty), neither of which has been recognized in the new collections.

Of the corals, five are listed from station 2930, *Lindstroemia permiana* Girty, *L. permiana* var., *L. cylindrica* Girty, *Lindstroemia* sp., and *Cladopora spinulata* Girty. The four species referred under *Lindstroemia* have, in a general way, the structural features of *Lophophyllum*, and the forms loosely cited in these reports as *Lophophyllum?* sp. will, when studied, closely represent the same species as the above. They may prove to belong to neither *Lophphyllum* nor *Lindstroemia*. In the recent collections I recognize, besides *Lophophyllum?* sp., both *Cladopora spinulata* Girty and *C. tabulata* Girty.

Among the bryozoans, station 2930 furnished a long list, containing no less than 15 species under the genera *Domopora*, *Fistulipora*, *Stenopora* (now *Tabulipora*), *Fenestella*, *Polypora*, and *Acanthocladia*. The same genera, and probably the same species, occur amongst the bryozoans in the recent collections, although for obvious reasons I have not gone into the matter of specific differentiation.

Among the brachiopods, the original list contained *Crania* sp., *Derbya* sp., and three species of *Chonetes* (*C. permianus* Shumard, *C. hillanus* Girty, and *C. subliratus* Girty). The new collections are more varied. *Crania* is unrepresented, but in the Orthotetinae I find *Derbya nasuta* Girty var., *Derbya* n. sp., *Derbya?* n. sp., and *Streptorhynchus?* sp. *Chonetes* is represented by the same three species as in the original list.

The early collection contained 8 species of *Productus*, as well as *Aulosteges guadalupensis* Shumard and *Prorichthofenia permiana* (Shumard). The productids comprised the following species: *Productus capitanensis* Girty, *P. popei* Shumard, *P. popei opimus* Girty, *P. indentatus* Girty, *P. occidentalis* Newberry, *P. pileolus* Shumard, *P. limbatus* Girty, and *Prorichthofenia* sp. d. The newer collections contain most of these (*P. limbatus* being the most notable absentee), together with *P. leonardensis* King?, and *Productus* (*Marginifera?*) *sublevis* (King). The species of *Aulosteges* and *Prorichthofenia* are likewise present.

The original list included *Leiorhynchus? bisulcatum* (Shumard), together with its varieties *L.? b. seminuloides* (Girty) and *L.? b. gratiosa* (Girty), *Wellerella? swallowiana* (Shumard)?, *W. texana* (Shumard), *W. bidentata* (Girty)?, *W.? pinguis* (Girty), *Wellerella* sp. a, and *W.? indentata* (Shumard). This list is practically duplicated in the new collections, which contain also a few *Camerophoria venusta* Girty.

[81] Darton, N. H., and Reeside, J. B., Jr., op. cit., p. 416.

[82] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, pp. 108–109, 1908.

Terebratuloids in the original collection were limited to three species: *Dielasma spatulatum* Girty, *Dielasmina guadalupensis* Girty, and *Notothyris schuchertensis ovata* Girty?. The same assemblage occurs in the new collections, except for the species last named.

The spiriferoids in the collection from station 2930 comprised *Spirifer mexicanus* Shumard var., *Spirifer* sp. a, *Spiriferina billingsi* Shumard, *S. laxa* Girty, *S. hilli polypleura* Girty, and *S. welleri* Girty. This group is more generously represented in the recent collections. I provisionally identify *Spirifer sulcifer* Shumard, *S. pseudocameratus* Girty, *S. mexicanus latus* King (which probably covers *S. mexicanus* var., *Spirifer* sp. a, and possibly *S. mexicanus* of the old collection), besides *Spiriferina hilli* Girty, *S. billingsi* Shumard, *S. laxa* Girty, *Spiriferina* n. sp., and *Squamularia* sp.

The original collection contained only one *Composita*, which was identified as *C. emarginata* Girty. The recent ones contain a large species, apparently the one King figures as *C. emarginata affinis* Girty.

The brachiopods of the original list included also *Hustedia meekana* (Shumard), *H. meekana trigonalis* Girty, *H. papillata* Shumard, and *H. bipartita* Girty. The new collections contain the same assemblage, except for the variety *trigonalis*. *Leptodus*, not recorded at this horizon before, continues its upward range.

Among the pelecypods, the original collection from station 2930 contained *Myalina squamosa* Sowerby?, *Deltopecten guadalupensis* (Girty), and *Deltopecten* sp. a. The more recent collections have a much better representation of this group, and contain *Edmondia* aff. *E. ovata* Meek and Worthen, *Parallelodon multistriatus* Girty, *P. politus* Girty?, *Parallelodon* n. sp.?, a small *Myalina* having the configuration usually ascribed to *M. permiana* Swallow, some imperfect specimens of *Aviculopecten* that are provisionally identified as *A. guadalupensis* Girty and *A. guadalupensis* var., *Myoconcha costulata* Girty, and *Pseudomonotis?* n. sp.

The gastropods in the original list are represented only by *Straparollus sulcifer* (Girty) and *S. sulcifer angulatus* (Girty). In addition to these, the new collections contain a species of *Platyceras*, one of *Omphalotrochus*, and a number of indeterminable specimens of *Euphemites*, besides a miscellaneous lot of indeterminable bellerophontid shells.

Both the old and new collections contain the long-ranging trilobite *Anisopyge perannulata* (Shumard).—Girty manuscript.

In summarizing the collections, Dr. Girty notes the close resemblance between the Pinery fauna and the underlying Hegler fauna, the main difference being the greater abundance and diversity of the Pinery fauna. In his original work Girty[83] made the following comparison between the Pinery and Capitan faunas. Some of the differences mentioned have been removed by subsequent collecting, but most of them persist.

The Capitan fauna, as exemplified by the collections obtained in its middle portion at station 2926, and the fauna of the "dark limestone" show well-marked differences. * * * Some of the more distinguishing characteristics of the "dark limestone" fauna are the abundance of *Fusulina elongata* * * *, the greater abundance of cup corals, the presence of *Cladopora spinulata*, the greater abundance of the Domoporas and other Bryozoa, the presence of *Chonetes permianus* and *C. subliratus*, the abundance of small *Producti* of the *semireticulatus* group, such as *P. popei*, *P. indentatus*, etc., the presence of *Aulosteges guadalupensis* and *Spiriferina laxa*, the abundance of the group of *Pugnax bisulcata*, the presence of *Aviculopecten guadalupensis*, and of *Euomphalus sulcifer*[84] and its variety *angulatus*, and the abundance of *Anisopyge perannulata*. An equal number of distinctive forms might be named on the part of the Capitan fauna.

[83] Girty, G. H., op. cit., p. 19.

RADER LIMESTONE MEMBER

The Rader limestone member is represented by fewer collections than the underlying Pinery member, and is apparently not as fossiliferous. The largest collections came from the vicinity of Rader Ridge (Nos. 7480, 7600, 7668, and 7693, pl. 2), from light-gray, massive limestone resembling the Capitan facies, or from dark-gray, bedded limestone resembling the Pinery facies. Smaller collections were made farther southeast; one of them from east of the area mapped on the south side of Lamar Canyon contains only ammonoids (No. 7654); another contains only fusulinids (No. 7921); and two others contain only smaller Foraminifera.

The fusulinids, represented in two collections (Nos. 7480 and 7921), have been identified by Dunbar and Skinner as *Polydiexodina capitanensis* Dunbar and Skinner, and *P. shumardi* Dunbar and Skinner. This genus is characteristic of the beds of upper Guadalupe age. Smaller Foraminifera were obtained by H. C. Fountain from two localities in the eastern part of the area. They were found in thin marl layers interbedded with the limestone and were separated from their matrix by washing. According to Henbest[85] the following forms are present:

Foraminifera from Lamar Canyon

	Locality 1	Locality 2
Textularia sp	×	×
Deckerella laheei Cushman and Waters	------	×
Climacammina sp	------	×
Tetrataxis aff. *T. conica* Ehrenberg	------	×
Globivalvulina n. sp	×	×
Polytaxis, 2 sp	×	------
Ruditaxis sp	×	------
Geinitzina ciscoensis Cushman and Waters	------	×
Geinitzina n. sp	×	×
Monogenerina sp	×	×
Spandelina sp	×	×
Spandelinoides aff. *S. striatella* Cushman and Waters?	×	------
Ozawainella delawarensis Dunbar and Skinner?	×	×
Staffella sp	------	×
N. gen. aff. *Ozawainella*	×	×
Juvenaria of fusiform fusulinids	×	×
Crinoid columnals	×	------
Spicule of siliceous sponge (with bulbous termini)	×	------

1. In Lamar Canyon 1½ miles east-southeast of its junction with Cherry Canyon.

2. On northeast bank of Lamar Canyon, three-quarters of a mile northwest of its junction with Cherry Canyon, in the gully east of the windmill.

[84] Equivalent to *Straparollus sulcifer* of Girty manuscript just above.

[85] Henbest, L. G., memorandum, May 1938.

Ammonoids from locality 7654 have been identified by Miller and Furnish as *Xenaspis skinneri* Miller and Furnish, and *Waagenoceras guadalupense* Girty. The first genus and species does not range below the upper part of the Guadalupe series, and the second does not range below the middle part. Except for a few fragments, no nautiloids have been collected.

Regarding the remainder of the fauna, most of which was obtained from the localities near Rader Ridge, Dr. Girty writes:

The corals comprise the following: *Cladopora spinulata* Girty, *C. tabulata* Girty?, *Cladochonus* sp. (fragment), *Lophophyllum?* sp., and *Amplexus?* sp.

The bryozoans appear to be well diversified but, as many of them require study by thin sections, this group must at present be treated in a cursory manner. The identifications made are subject to revision. *Fistulipora* is fairly abundant and apparently belongs to a single species, *F. grandis guadalupensis* Girty. The singular series of forms provisionally referred to the genus *Domopora* is plentiful and diversified. I recognize *D. ocellata* Girty, *D. terminalis* Girty, and *D. vittata* Girty. Besides these, we have *Batostomella?* sp., *Leioclema?* sp., *Fenestella* (fragment), *Acanthocladia guadalupensis* Girty, and *Rhombopora?* sp.

Among the brachiopods the orthoids, as is usual in the higher Guadalupian faunas, are unrepresented, and the Orthotetinae are very scarce. There are only a few poor specimens of the genus *Derbya*, which might be a small variety of *D. nasuta* Girty. The absence of *Chonetes* is a noteworthy feature of the fauna.

The productids, together with the related genera *Aulosteges*, *Prorichthofenia*, and *Scacchinella*, are diversified but by no means bountiful in individuals, and the individuals are mostly poorly preserved. They comprise *Productus capitanensis* Girty, *P. popei* Shumard, *P. popei opimus* Girty, *P.* (*Buxtonia?*) sp., and the peculiar *P.* (*Pustula?*) *pileolus* Shumard. A number of specimens are more or less closely related to another peculiar form, described as *Productus limbatus* Girty, and the question again arises ,without being answered, as to whether this species is not actually an *Aulosteges*. To the latter genus belong *A. guadalupensis* Shumard, and possibly a very small, smooth form of doubtful affinities. *Prorichthofenia permiana* (Shumard) occurs in several collections, and a single small specimen is doubtfully referred to *Scacchinella*.

Camarophoria continues to be represented, although scantily, by *C. venusta* Girty, and there is another form, unfortunately not generically determinable, which resembles *C. venusta* except that it has notably finer and more numerous costae.

The rhynchonellids are diversified and fairly abundant. The outstanding species are *Leiorhynchus? bisulcatum* (Shumard) and *L.? bisulcatum seminuloides* (Girty). *Wellerella? indentata* (Shumard) is also present, with one or two varieties or related species.

The representation of the terebratuloids holds closely to type. I recognize *Dielasma spatulatum* Girty, *D. cordatum* Girty, *Dielasmina guadalupensis* Girty, and a new species of the same genus or possibly a diminutive variety of the same species.

The spiriferoids are represented only by the genera *Spirifer* and *Spiriferina*. They include *Spirifer mexicanus* Shumard, another species which may be *S. sulcifer* Shumard, *Spiriferina billingsi* Shumard, *S. angulata* King and *S. laxa* Girty.

Of *Composita*, there are several species represented by selected specimens. Besides *C. emarginata* Girty, we have the variety *affinis* Girty, a form very similar to *C. subtilita* (Hall) and another related to *C. mexicana* (Hall).

The pelecypods are few in number and poor in preservation. Only the following have been recognized: *Solenomya?* sp., *Aviculopecten* sp., *Fasciculiconcha* sp., *Pernopectin obliquus* Girty, *Camptonectes sculptilis* Girty, and *Myalina permiana* Swallow? Gastropods are all but absent. The only forms noted are *Bucanopsis* sp., together with a few indeterminable bellerophontid shells and *Trachydomia?* sp. Finally comes the ever-present *Anisopyge perannulata* (Shumard), and some undetermined ostracods.—Girty manuscript.

According to Girty, the Rader fauna is similar to that of the Pinery, but (as can be expected from the smaller collections) is much less varied. Among the brachiopods, the fewer Orthotetinae and the absence of *Chonetes* are notable. Other groups, such as productids, rhynchonelloids, terebratuloids, spiriferoids, and the genera *Camarophoria*, *Composita*, *Hustedia*, and *Leptodus* are about the same in both faunas.

LIMESTONE BEDS BETWEEN RADER AND LAMAR MEMBERS

In the Delaware Mountains, the several hundred feet of beds between the Rader and Lamar members are all sandstone, except one flaggy limestone bed, and no fossils have been observed in any of them. Along the Reef Escarpment, the interval contains a number of fossiliferous limestone beds which are, in fact, tongues of the Capitan limestone. These beds are represented by three collections, two from the mouth of McKittrick Canyon (Nos. 7608 and 7708), and one from the head of Rader Ridge (No. 7360).

The latter, obtained from beds a few feet above the Rader member, contains fusulinids. They have been identified by Dunbar and Skinner as *Ozawainella delawarensis* Dunbar and Skinner, and *Polydiexodina shumardi* Dunbar and Skinner. No cephalopods have been found in the interval.

Regarding the remainder of the fauna, Dr. Girty reports as follows:

Sponges are represented by a specimen of *Amblysiphonella?* sp., another species of doubtful nature, and *Cystothalamia nodulifera* Girty?.

The corals are represented by a single specimen belonging to the species described in Professional Paper 58 as *Lindstroemia cylindrica* Girty. Similar corals have been cited as *Lophophyllum?* sp. in discussions of underlying faunas. A quite novel type is *Chaetetes?* sp., which grew upon, but apparently did not form a part of, the sponge cited as *Amblysiphonella?* sp. It is of doubtful nature, and differs from *Chaetetes* in that the slender cells do not seem to be closed by tabulae. However, many silicified specimens of *Chaetetes* fail to show the tabulae that they originally possessed.

The following bryozoans are each represented by a single specimen: *Fistulipora* sp., *Domopora terminalis* Girty, *D. ocellata* Girty, *Septopora?* sp., *Phyllopora?* sp., and *Acanthocladia guadalupensis* Girty.

The brachiopod group of Orthotetinae, which have been abundant and diversified in some of the faunas previously discussed, are represented by a few specimens identified as *Orthotetes guadalupensis* Girty. *Chonetes* is absent.

The productids are well represented, but in only one of the three collections under consideration (No. 7608), and the specific representation is not large. It is as follows: *Productus capi-*

tanensis Girty, *P.* (*Marginifera?*) *waagenianus* Girty, *P. popei* Shumard, *P. popei* var., *Productus* aff. *P.* (*Pustula?*) *latidorsatus* Girty, *P.* (*Striatifera*) *pinniformis* Girty, *Aulosteges guadalupensis* Shumard, *Prorichthofenia permiana* (Shumard), and *Scacchinella?* sp. The generic relations of *P. pinniformis*, which is rather abundant, are uncertain. Some of my specimens give evidence of having been attached by cementation, and the general configuration suggests that of *Aulosteges*, but I have been unable to ascertain that a cardinal area is present. Altogether, the productid fauna of this horizon is reminiscent of that of the Capitan limestone.

Camerophoria continues to be represented, although very scantily, by *C. venusta* Girty.

The rhynchonellid fauna is considerably diversified, but each collection seems to have its own set of species, and most of the species are represented by single specimens. These shells are classified as *Wellerella? swallowiana* (Shumard), *W.? shumardiana* (Girty), *W.? pinguis* (Girty), *W.? indentata* (Shumard)?, and *Leiorhynchus? bisulcatum seminuloides* (Girty)?.

Terebratuloids are feebly represented by a single small specimen of *Dielasma cordatum* Girty, and several indeterminate specimens.

The spiriferoids include a single specimen of *Spirifer*, possibly *S. sulcifer* Shumard as identified by King (which is doubtfully the authentic *S. sulcifer*). *Spiriferina* is represented by *S. welleri* Girty, *S. billingsi* Shumard, and *S. evax* Girty?. The group also includes *Martinia shumardiana* Girty and *Squamularia guadalupensis* (Shumard).

Composita, although by no means scarce, is so poorly preserved that little that is definite can be said about it. *C. emarginata* Girty is definitely present, and some specimens suggest *C. subtilita* (Hall), and *C. mexicana* (Hall). Of *Hustedia*, the collections contain only two specimens, one referable to *H. meekana* (Shumard), and the other to *H. papillata* (Shumard). *Leptodus americanus* Girty is present in two collections, with one specimen in each.

The few pelecypods present belong mostly to the pectenoids, and few of the forms can be identified. I cite only *Aviculopecten* n. sp., *Fasciculiconcha* sp., and *Acanthopecten coloradoensis* (Newberry)?. Mention should be made here also, but with great reserve, of a fairly large specimen referred provisionally to *Pseudomonotis*. Only the anterior half is present, and even that is for the most part an internal mold. It is marked by fairly strong plications which are very irregular in size, spacing, and even in direction. Aside from the species cited, there remains only an imperfect specimen provisionally referred to the genus *Myoconcha*.

The gastropods comprise only a few bellerophontid shells which cannot be determined generically, and *Worthenia?* n. sp. No trilobites are present.—Girty manuscript.

In summary, Dr. Girty notes that the fauna of this interval is closely related to the underlying fauna. The main differences lie in the closer similarity of the fauna of this interval to that of the Capitan, a fact to be expected in view of the similarity of the facies of the containing beds to that of the Capitan, their close proximity to the Capitan, and their gradational relations with it. Among the Capitan affinities of the fauna is the presence of Calcispongia, of *Martinia* and *Squamularia*, and of the productid species *Productus* (*Pustula?*) *latidorsatus* Girty, P. (*Striatifera*) *pinniformis* Girty, and *P.* (*Marginifera?*) *waagenianus* Girty, none of which were found in the Rader fauna. By contrast, rhynchonellids of the type *Leiorhynchus bisulcatum* (Shumard), and also *Spirifer* and *Spiriferina*, which were common in the Rader fauna, are absent here.

LAMAR LIMESTONE MEMBER

The Lamar limestone member contains abundant fossils along the Reef Escarpment, near the Capitan reef mass, but they are nearly or completely absent farther southeast. Although they occur in gray or dark-gray, bedded limestone, very different from the Capitan limestone in appearance, Dr. Girty notes that, "taken as a whole, the fauna of the Lamar member is a typical Capitan fauna."

Collections obtained from the member by Darton and Reeside [86] had been identified by Girty prior to the present investigation. These collections came from the mouth of Big Canyon, in New Mexico. Darton and Reeside erroneously suggested a correlation of the member with the "upper dark limestone" (Pinery). During the present investigation a large collection was made at the mouth of McKittrick Canyon (No. 7401), not far southwest of Big Canyon, and others were obtained in the downfaulted area west of the Delaware Mountains (Nos. 7630, 7647, and 7663, pl. 2).

No fusulinids have been collected from the member on the outcrop, but some have been obtained from the uppermost limestones of the Bell Canyon formation (probably Lamar) in wells drilled east and southeast of the outcrops. In the Ohio Oil Company, Popham No. 1 well, in southern Reeves County, 90 miles southeast of the Guadalupe Mountains, Skinner [87] has identified *Ozawainella*, *Leella*, and *Codonofusiella* from this horizon.

The member contains a few nautiloids, one of which was identified by A. K. Miller as *Metacoceras* sp. Ammonoids occur at a single locality west of the Delaware Mountains (No. 7663), which has yielded three specimens. According to Miller and Furnish,[88]

All these represent only one species, *Strigogoniatites fountaini* Miller and Furnish. The genus *Strigogoniatites* has not been found elsewhere in Texas, but in Coahuila [Las Delicias area, Mexico] a rather primitive representative of it occurs in the Capitan horizon. An advanced representative of the genus is known from Timor [Netherlands East Indies], probably from the Amarassi horizon. *S. fountaini* is the youngest Permian ammonoid known from the United States, but it may be older than *Cibolites?* sp. of the Las Delicias beds of Coahuila.

Regarding the remainder of the fauna, Dr. Girty writes:

Of the simpler classes of invertebrate life, this fauna contains an unidentified sponge, the corals *Lophophyllum?* sp., and *Cladopora spinulata* Girty, crinoid plates, and the spines, jaws, and interambulacral plates of several species of echinoids.

[86] Darton, N. H., and Reeside, J. B., Guadalupe group: Geol. Soc. America Bull. vol. 37, p. 424, 1926.

[87] Skinner, J. W., personal communication, January 1939.

[88] Miller, A. K., and Furnish, W. M., Permian ammonoids of the Guadalupe Mountains region and adjacent areas: Geol. Soc. America Special Paper 26, p. 12, 1940.

The bryozoans have been less intensively studied than most other groups. I recognize *Fistulipora* sp., *Domopora terminalis* Girty, *D. ocellata* Girty, *Batistomella?* sp., *Fenestella* sp., and *Acanthocladia guadalupensis* Girty.

Among the brachiopods, the Orthotetinae are varied, comprising *Orthotetes guadalupensis* Girty (abundant), *Streptorynchus gregarium* Girty, *Geyerella?* sp., and *Derbya* sp. *Chonetes* is abundant and all but one small specimen have been referred to *C. hillanus* Girty; it is possible, however, that *C. subliratus* Girty may also be present.

The productids are rather restricted in numbers and variety. I recognize only the following: *Productus capitanensis* Girty, *P.* (*Pustula?*) *latidorsatus* Girty, *P. popei opimus* Girty, and *P.* (*Marginifera?*) sp. Besides these there are several species belonging to a small, attached genus that would commonly be called *Strophalosia.* The persistent *Prorichthofenia permiana* (Shumard) is also present.

Camerophoria is fairly abundant, and for the present all specimens are referred to *C. venusta* Girty, although they show so much diversity that further distinctions may be practicable on closer study.

Rhynchonellids are fairly abundant, but many of the specimens are crushed or otherwise in poor condition. All seem to be of the general type of *Wellerella osagensis* (Swallow) and may provisionally be referred to that genus. They contain no striking types and are only sufficiently diversified to be difficult to classify. For present purposes they have been identified as *Wellerella? shumardiana* (Girty), *W.? shumardiana* var., *W.? swallowiana* (Shumard), and one or two indeterminate forms.

Terebratuloids are only fairly abundant, but they show considerable diversity. I identify *Dielasma sulcatum* Girty, together with two undetermined species of the same genus, *Heterelasma shumardianum* Girty, *Heterelasma?* sp., *Notothyris schuchertensis* Girty, and *N. schuchertensis* var.

The spiriferoids are represented by the genera *Spirifer, Spiriferina, Martinia,* and *Ambocoelia. Spirifer* itself shows little diversity. I recognize only *S. mexicanus* Shumard, and the variety *compacta* Girty. *Spiriferina* is much more diversified, being represented by *S. billingsi* Shumard, *S. sulcata* Girty, *S. welleri* Girty, and *Spiriferina* aff. *S. hilli polypleura* Girty. *Squamularia* is abundant, but confined to a single species, *S. guadalupensis* (Shumard). *Martinia* is less abundant than *Squamularia,* but is not rare. Like *Squamularia,* it is represented by a single species, *M. rhomboidalis* Girty. *Ambocoelia* is fairly abundant in one locality, but here again only one species is present, *A. planoconvexa guadalupensis* Girty.

Composita, as usual, is fairly abundant but the species are poorly characterized. They may be identified as *C. emarginata* Girty? and *C. emarginata affinis* Girty. Some of the latter might pass as *C. subtilita* (Hall).

One of the collections contains several species of *Cleiothyrida,* a small form resembling the common Pennsylvania species *C. orbicularis* (McChesney), with which it is provisionally identified. The occurrence is interesting, not only on this account, but also because the genus has not heretofore been recognized in the Guadalupian faunas. It was not known when Professional Paper 58 was published (1908), and it has not been found in any of the faunas so far discussed.

Another genus that is not rare, but affords only a single species is *Hustedia,* represented by *H. meekana* (Shumard). *Leptodus americanus* Girty is fairly abundant, and affords material for further study.

The pelecypods are rare compared with the brachiopods, and they are distributed among the genera *Parallelodon, Schizodus, Aviculopecten, Girtypecten, Streblopteria, Pteria, Myoconcha, Myalina,* and *Cleidophorus.*

These collections furnish only three specimens of *Parallelodon* two indeterminable and one identified as *P. multistriatus* Girty. *Schizodus* is represented by a single poor specimen, of which more can hardly be said than that it does not belong to *S. securus* (Shumard)?, the only one that was recognized in Professional Paper 58.

The pectenoids include *Aviculopecten bellatulus* Newell, *Aviculopecten* sp., *Girtypecten sublaqueatus* (Girty), and *Streblochondria?* sp.

Pteria is represented by a single indeterminable specimen. Of *Myoconcha,* I have three forms which are generically doubtful and specifically undeterminable. Finally, we have a doubtful and indeterminable specimen of *Myalina* and a small form identified as *Cleidophorus pallasi delawarensis* Girty.

A large, straight scaphopod, provisionally referred to *Plagioglypta canna* White, is rather abundant.

The gastropods are few and poorly preserved. The bellerophontids are represented by two indeterminable species. The pleurotomariids have as yet not been studied critically. Probably three species can be distinguished, but their preservation is such that they may not be identifiable. There are also a large *Eotrochus?* (possibly *Euconospira*), a doubtfully identifiable species of *Actaeonina?, Bulimorpha* sp. *Omphalotrochus* n. sp., and an indeterminable species of *Naticopsis.*

The characteristic Guadalupian trilobite *Anisopyge perannulata* (Shumard) persists in moderate abundance.—Girty manuscript.

CAPITAN LIMESTONE

The fauna of the Capitan limestone was described in considerable detail in Girty's original publication,[89] for the material at his disposal was extensive. Most of it was obtained at various points on the east slope of Guadalupe Peak (as at localities 2926 and 2966, pl. 2). The collections made during the present investigation have added somewhat to the details of the fauna as originally described but have not materially changed its broader features. Some of the collections (such as 7405) were made in the vicinity of the older localities, but one of the largest (No. 7417) came from a new area, along the channel of South McKittrick Canyon near the Grisham-Hunter Camp. This collection is probably from an older part of the Capitan than the previous ones, being perhaps of Hegler age, whereas the others are perhaps of Rader or younger age.

The manner of occurrence of fossils in the Capitan limestone, and the faunal facies represented, have been discussed on page 62.

The Capitan limestone apparently contains considerable numbers of lime-secreting algae, but few observations were made on them during the present investigation. Algae were reported from the Capitan by Ruedemann.[90] The specimen figured, however, consists of pisolites of the sort common in the Carlsbad limestone. Subsequent observations have failed to confirm the presence in the Capitan of concentric structures of the size

[89] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, pp. 15–18, 1908.

[90] Ruedemann, Rudolf, cited in King, P. B., and King, R. E., Pennsylvanian and Permian stratigraphy of the Glass Mountains: Texas Univ. Bull. 2801, p. 139, 1928; Ruedemann, Rudolf, Coralline algae, Guadalupe Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1079–1080, 1929.

and abundance reported by Ruedemann. Some of the algae described by Pia and Johnson from the Guadalupe Mountains may have come from the Capitan limestone. The following species described by Johnson appear, from the localities cited by him, to occur in the Capitan:

Solenopora centurionis Pia
Solenopora sp.
Mizzia velebitana Schubert
Mizzia yabei (Karpinsky)
Diplopora? sp.

Pia suggests that some of the forms described from the Capitan by Girty as the sponge *Guadalupia* are actually the alga *Mizzia*.

According to Johnson [91] that part of the Capitan interpreted by him as the reef face (p. 63) contains "filamentous green and possibly blue-green algae with red algae becoming abundant near the crest." The reef crest of his interpretation "is composed almost entirely of encrusting algal material (green and red) with colonies of *Solenopora* locally abundant on the inner slope. Fragments of Dasycladacae occur." The reef flat of his interpretation contains "encrusting and filamentous algae [and] colonies of *Solenopora.* * * * Algal pisolites occur."

Fusulinids are fairly common in the Capitan limestone, although not as abundant as in the adjacent parts of the Bell Canyon and Carlsbad formations. From the Capitan, Dunbar and Skinner have identified *Polydiexodina capitanensis* Dunbar and Skinner and *P. shumardi* Dunbar and Skinner.

Cephalopods occur at a number of places. Of them, the nautiloids are most abundant. According to observations of Girty and Miller, they generally belong to *Metacoceras shumardianum* (Girty), but Miller has identified a *Titanoceras* and Girty an "*Orthoceras*". According to Girty, the collections also contain fragments that probably represent three or four other species. In addition, a few ammonoids have been collected, especially at locality 7417. According to Miller and Furnish, they all belong to the single species *Waagenoceras guadalupense* Girty.

Regarding the remainder of the fauna, Dr. Girty makes the following comparisons between the original and the later collections:

The Capitan fauna is noteworthy for the variety of its sponges. In Professional Paper 58, they were classified as *Anthracosycon ficus capitanense* Girty, *Virgula neptunia* Girty, *V. rigida* Girty, *V. rigida constricta* Girty, *Pseudovirgula tenuis* Girty, *Guadalupia zittelilana* Girty, *G. zitteliana* var., *G. cylindrica* Girty, *G. cylindrica concreta* Girty, *G. digitata* Girty, *G. favosa* Girty, *Cystothalmia nodulifera* Girty, *Cystothalamia?* sp., *Steinmannia americana* Girty, *Sollasia?* sp., and *Amblysiphonella guadalupensis* Girty. I now feel that some of the forms listed were too imperfectly known to have deserved naming. Sponges are also abundant in the new collections, which contain *Guadalupia zitteliana* Girty, *G. cylindrica* Girty, *Anthracosycon ficus guadalupensis* Girty, *Amblysiphonella guadalupensis* Girty, *Amblysiphonella* sp., *Amblysiphonella?* n. sp., besides the usual indeterminata. These determinations are provisional and the original material, which was relatively scanty, is in need of revision.

In the two original collections I recognized but two species of corals, *Lindstroemia permiana* Girty and *Campophyllum texanum* Shumard?. In the new collections, corals are also poorly represented. I find *Campophyllum texanum* and probably the form that was described as *Lindstroemia cylindrica* Girty. These new specimens, however, show a structure suggesting *Chonophyllum*, but with a much simpler central zone, in the midst of which is a styliform columella; only the columella and the septa showed in the silicified holotype. Definite relationships cannot be established until these two forms have been closely studied by means of thin sections.

Among the bryozoans, the original collections contained *Fistulipora grandis guadalupensis* Girty, *F. guadalupae* Girty, *Domopora ocellata* Girty?, *D. terminalis* Girty, *Tabulipora polyspinosa richardsoni* (Girty), *Leioclema shumardi* Girty?, *Fenestella spinulosa* Condra?, *F. capitanensis* Girty, *Acanthocladia guadalupensis* Girty, *Acanthocladia* sp., and *Goniocladia americana* Girty. The bryozoan fauna of the new collections is much smaller. I find only *Fistulipora grandis guadalupensis* Girty, *F. guadalupae* Girty, *Tabulipora* sp., *Leioclema shumardi* Girty?, and a few poorly preserved specimens of *Fenestella*. I will repeat that identifications of bryozoans made without the study of thin sections are extremely provisional.

Turning to the brachiopods, a species of *Crania* found in the original collections has no representative in the ones recently made.

Of the Orthotetinae, *Streptorhynchus gregarium* Girty, *Derbya* sp. a, *Derbya* sp. b, *Orthotetes guadalupensis* Girty, *O. declivis* Girty, *O. distortus* Girty, *O. distortus campanulatus* Girty, *Geyerella americana* Girty, and *Orthotetina* sp. were originally distinguished. The new collections contain only *Orthotetes* sp., *O. distortus* Girty?, *Derbya* sp. a, *Plicatoderbya?* n. sp., and *Meekella* n. sp. The differences in this group between the old and new are truly noteworthy. *Orthotetes*, which there was abundant is here scarce, but on the other hand we have here *Plicatoderbya?* and *Meekella*, two genera that did not appear in the original collections at all. *Meekella* is particularly interesting, because it is abundant in the older faunas of the section, but is missing from the Bell Canyon formation.

Only one species of *Chonetes* was recognized in the original collections and the same species, *C. hillanus* Girty, is found in those recently made.

The productids, as originally listed, consisted of *Productus* (*Marginifera?*) *waagenianus* Girty, *P. capitanensis* Girty, *P. occidentalis* Newberry, *P.* (*Pustula?*) *latidorsatus* Girty, *P.* (*Striatifera*) *pinnaformis* Girty, *P.* (*Pustula?*) *pileolus* Shumard, *Aulosteges medlicottianus americanus* Girty, and *Prorichthofenia permiana* (Shumard). Only a few of these species have been recognized in the new collections which, on the other hand, contain a number of forms that are at least allied to some that occur in the Pinery limestone. Under this head I would include *Productus popei* Shumard?, *P. popei opimus* Girty?, *Productus* aff. *P. limbatus* Girty, and *Aulosteges guadalupensis* Shumard. Of the species listed from the original collections, the new collections contain *Productus capitanensis* Girty (abundant), *P.* (*Pustula?*) *latidorsatus* Girty, and *Prorichthofenia permiana* (Shumard). Besides the species mentioned, there are a few not found in either the Capitan or Pinery faunas as previously described: *Productus* (*Avonia?*) n. sp., *P.* (*Pustula*) n. sp., and *Teguliferina?* sp.

Products (*Avonia?*) n. sp., which is abundant at one locality, may be the form that King identified as *Avonia signata*

[91] Johnson, J. H., Permian lime-secreting algae from the Guadalupe Mountains, New Mexico: Geol. Soc. America Bull., vol. 53, pp. 216–217, 1942.

(Girty). *P.* (*Pustula*) n. sp. may be the form that he identified as *Avonia meekana* (Girty). The authentic *meekana* belongs to the subgenus *Cancrinella.* The form cited as *Productus* aff. *P. limbatus* Girty is not as well preserved as could be wished, and I am unable to state its relations. This interesting form has features which suggest *Aulosteges magnicostatus* Girty, but it is certainly not the same species, and probably does not belong to the same genus. *Teguliferina?* sp. is problematical; it is apparently related to, or derived from *Productus* or *Teguliferina*, but is apparently constructed somewhat after the fashion of *Proboscidella.* It can hardly belong to the latter genus, however, and is apparently new. As already intimated, the productid fauna of the new collections is perhaps more closely related to the fauna of the Pinery limestone member than to that of the Capitan limestone as originally described. At all events, it is in part a combination of species from each fauna.

The only pentameroid from the fauna of the Guadalupe Mountains, *Camerophoria*, is represented by the common *C. venusta* Girty in both the old and the new collections.

The rhynchonellids in the original collections included *Leiorhynchus? bisulcatum seminuloides* (Girty), *Wellerella? swallowiana* (Shumard), *W.? elegans* (Girty), *W.? shumardiana* (Girty), *W.? indentata* (Shumard), and *Camarotoechia? longaeva* (Girty). This group has much the same representation in the new collections, except that the first-named species is absent. *Wellerella? indentata* and *W.? swallowiana* are reversed in point of abundance, the former being relatively abundant in the new collections and the latter relatively rare, and represented by poor, doubtful specimens. In the new collections there are also several doubtful forms, possibly belonging to new species.

Among the terebratuloids, the old collections contained *Dielasma spatulatum* Girty, *D. cordatum* Girty, *D. sulcatum* Girty, *D.? scutulatum* Girty, *Dielasmina guadalupensis* Girty, *Notothyris schuchertensis* Girty, *N. schuchertensis ovata* Girty, *Heterelasma shumardianum* Girty, and *H. venustulum* Girty. The new collections are less diversified, and contain only *Dielasma cordatum, D. spatulatum, D. prolongatum* Girty, *Dielasmina guadalupensis*, and *Heterelasma venustulum.*

The spiriferoids were represented in the old collections by numerous species of *Spirifer, Spiriferina, Squamularia, Martinia*, and *Ambocoelia.* The same genera occur in the new collections, but the specific representation is smaller. Under *Spirifer* itself, I originally recognized *S. mexicanus* Shumard and the variety *compactus* Girty. In the new collections, I find *S. mexicanus*, the varieties *compactus* and *latus* King, and also *S. sulcifer* Shumard?. Under *Spiriferina*, I originally recognized *S. welleri* Girty, *S. pyramidalis* Girty, *S. billingsi* Shumard, *S. billingsi retusa* Girty, *S. evax* Girty, and *S. sulcata* Girty. The new collections contain the first three species named, and also *S. laxa* Girty (described from the Pinery), and *Spiriferina* n. sp.

Under *Squamularia*, I originally recognized *S. guadalupensis* (Shumard), with the varieties *S. g. subquadrata* Girty and *S. g. ovalis* Girty, but I now think the last two hardly deserved varietal names. Only one of the new collections contains shells of this genus, and I am referring all of them to *S. guadalupensis.* Under the genus *Martinia*, I originally described two species, *M. rhomboidalis* Girty and *M. shumardiana* Girty. In the new collections, the genus occurs at only one locality. Pending more careful study, I am referring all the specimens to *M. rhomboidalis. Ambocoelia planiconvexa guadalupensis* Girty occurs in both the old and new collections, and is the only representative of this genus.

Composita, in the old collections, was represented only by *C. emarginata* Girty and the variety *affinis* Girty. In the new collections, the genus is abundant and decidedly more diversified. Most striking is a very large species which is provisionally compared with *C. gigantea* Branson. There is also present a species which may be cited as *Composita* aff. *C. subtilita* (Hall). *C. emarginata* is doubtfully identified, save in one collection. Specimens have also been referred to its variety *C. e. affinis*, and to *C. mira* (Girty)?

Hustedia, in the old collections, was represented by *H. meekana* (Shumard) and the variety *H. m. trigonalis* Girty. The new collections contain only a few specimens of this genus, all of which are provisionally referred to *H. meekana.*

Leptodus is present in the new collections, as in the old. It is rather abundant, and some of the specimens are of large size. All, however, are for the present referred to *L. americanus* Girty.

The pelecypod fauna, as originally described, was diversified, although but few of the species were represented by more than a specimen or two. They were classified under *Edmondia, Parallelodon, Pteria, Myalina, Schizodus, Camptonectes, Aviculipecten, Euchondria, Pernopecten, Plagiostoma, Limatulina, Myoconcha*, and *Cypricardinia.* Most of the same genera are represented in the new collections, but some of the species are not the same. This suggests that the pelecypod fauna is highly diversified, but poor in individuals. I might add that more than half the pelecypods considered in the following paragraphs occur in a single collection (No. 7417, from older part of formation near Grisham-Hunter Camp).

Allorisma, a genus not found in the old collections, is represented by a single doubtful specimen. It is a fragment of a large shell marked by concentric lirae and fairly strong concentric corrugations. The lirae are covered with small, rounded tubercules set close together.

The old collections contained a small form described as *Edmondia? bellula* Girty. The new collections contain a species equally doubtful as to generic position, but of large size. It does not belong to the strongly corrugated section of the genus, but is apparently almost smooth and is related to a number of smooth, transverse shells referred to *Edmondia*, especially to the Mississippian species *E. fountainensis* Weller. My specimens are few and in poor condition.

Parallelodon had two species in the old collections, *P. politus* Girty and *P. multistriatus* Girty, neither of which is notable for its size. This is not true of the specimens recently collected. *P. politus* has not been definitely identified among them, but there is a finely striated species which may belong to *P. multistriatus*, although some of the specimens are very much larger than the type. There is another large species (n. sp. b), marked by coarse, strong costae which were apparently crossed by strong concentric lamellae. A third species (n. sp. a) is represented by a single specimen of enormous size, showing at the anterior end (where alone the shell is present) only strong, flaring lamellae which interrupt a few subdued, moderately coarse costae. A fourth specimen of doubtful relations represents the median part of a still larger specimen. The surface is marked by fine, radial striae and rather fine, concentric lirae, together with varices of growth of different size and intensity. In places, especially toward the ventral border, the striae appear to be interrupted and to have the form of pustules, but by their linear arrangement to maintain the appearance of radial costae. To some extent, then, this fragment recalls the one cited as *Allerisma?* sp., and it is not impossible (although at present it seems improbable), that both may belong to the same species but represent different parts of the shell. One very conspicuous difference is that in this form the ornamentation (including the pustules) is conspicuously radial, and in the other it is conspicuously concentric.

Pteria, represented in the old collections by *P. guadalupensis* Girty, has not been recognized in the new ones. *Myalina squamosa* Sowerby? was included in the original fauna, but the genus is represented in the new collections by only two doubtful specimens, neither of which is the same as the species cited. *Schizodus* was represented in the original collections by a rather small form identified as *S. securus* Shumard?. In the new collections, the congeneric species is large, and more comparable to *S. symmetrica* Calvin than to any other of our later Paleozoic species. Three species were described under *Camptonectes?* in the original collections, *C. ? asperatus* Girty, *C. ? papillatus* Girty, and *C. ? sculptilis* Girty. The specimens in the new collections seem to belong to the first two of the species named.

Under the genus *Aviculipecten*, the old collections had three species, described under the names *A. infelix* Girty, *A. laqueatus* Girty, and *A. sublaqueatus* Girty. A recent revision of our upper Paleozoic pectenoids redistributes these specimens generically. They thus become *Streblochondria? infelix* (Girty), *Acanthopecten laqueatus* (Girty), and *Girtypecten sublaqueatus* (Girty). The new collections contain *Girtypecten sublaqueatus* and *Acanthopecten?* n. sp. besides two indeterminable species of *Aviculopecten*. Still among the pectenoids, the old collections contain *Euchondria?* sp. and *Pernopecten obliquus* Girty. The new collections contain the latter species, and also a remarkable specimen that suggests the genus *Obliquipecten*, and may belong to that genus so far as the facts are known. It is somewhat imperfect and the greater part of the shell is missing. At first glance the specimen looks like a left valve of a fair-sized *Myalina*, of the type in which the anterior outline is strongly concave. On closer examination, however, one sees an incomplete anterior auricle and also a few fine radial costae on the anterior side of the umbo, which is the only part where the shell is preserved. Some irregularities on the internal mold by which the greater part of the specimen is represented suggests the presence of a few coarse, weak costae. I would be disinclined to place this form under *Pseudomonotis*, which is suggested by the surface characters, because of the configuration, especially because it is so strongly prosogyrate. The shape, on the other hand, corresponds remarkably to that of the ventral valve of *Obliquipecten*.

To *Pseudomonotis*, a genus not represented in the early collections, I am referring three species from the new collections. All are decorticated and probably not of use in describing the new species which they apparently represent. One is a large form which is nearly flat, and is smooth except for a few large, loose, marginal plications. It has the general appearance of *P. spinosa* Sayre, but of course little or nothing is known about the surface characters. The second form is much smaller, with large, strong, irregular plications. A much smaller portion of the umbonal region is relatively smooth. Here again, finer details of the surface are unknown. A third species, represented by a single specimen, is small, narrow, and highly convex. Part of the shell is preserved, showing very strong, rather fine, radial costae, alternating in size and closely arranged. No large irregularities of surface are developed.

The Limidae were represented by two species in the old collections, *Plagiostoma deltoideum* Girty and *Limatulina striaticostata* Girty. Only the latter is present in the new collections.

The genus *Pinna*, not represented in the old material from the Guadalupe Mountains, is represented in the new collections by a single specimen. It is smooth-surfaced, and if the sculpture possessed by most species of *Aviculopinna* is characteristic of that genus, the specimen in question does not belong to it. On the other hand, it certainly does not belong to *Pinna peracuta* Shumard, for it is much smaller, and has much more rapidly diverging outlines.

The old collections contain a species described as *Myoconcha costulata* Girty. The new ones contain a similar, but apparently distinct species. They also contain two other species that are perhaps congeneric. One is small, but considerably larger than *M. costulata*, and is disinguished from it by being entirely smooth. The third form is large, and represented by a considerable number of specimens. Nevertheless, all of them are more or less imperfect and more study is required before one can reconstruct the original characters. This form may not be congeneric with *M. costulata*, but wherever it belongs, it is a species new to the fauna.

The old collections contain a species of *Cypricardinia* (*C? contracta* Girty), but nothing of the sort has been found in the new ones. On the other hand, *Pleurophorus* was not represented in the old collections, whereas one, and possibly two species are found in the new ones. One species is a small and elegant form related to *P. occidentalis* Meek and Hayden, as usually interpreted. The other is an uncommonly large shell of doubtful affinities. It may prove not to belong to the genus at all.

Before leaving the pelecypods, mention should be made of a remarkable genus which, so far as I know, is new to our American later Paleozoic faunas, if not to science. The shell is fairly large, the valves elongated, oblique, and extremely convex, leading back to an umbo which is compressed and strongly prosogyrate. In fact, the valves, taken separately, resemble one of those platyceroid shells that make only part of a turn and are narrowly rounded across the anterior surface. The only specimen in my collection, however, retains the valves in articulation and half open. Furthermore, the surface is marked by fine, faint, regular radial lirae.

The scaphopods, which are not found in the old collections, occur in one of the new ones in moderate abundance. Only one species is recognized, which attains a rather large size. It is elongated, straight, and gently tapering. The surface seems to be smooth, or at most marked only by incremental lines. So far as the characters are shown, this might be the species that I customarily identify as *Plagioglypta canna* White. Mention should be made of one remarkable slab in which three of these specimens occur almost in contact, and directed to a common center. Whether they lived in that relation, or were so arranged by current action, is uncertain.

The fauna as originally described contains the following gastropods: *Patella capitanensis* Girty, *Pleurotomaria mica* Girty, *P. discoidea* Girty, *P. neglecta* Girty, *Euconospira obsoleta* Girty, *Trochus?* sp., and *Zygopleura swallowiana* (Shumard). The absence from this list of any of the bellerophontids is noteworthy. A few bellerophontids occur in the collections recently made, but their preservation is such that definite generic assignments are impracticable.

The pleurotomaroids are mostly small shells, and their classification requires more careful study and deliberate consideration than it has been possible to devote to them. Without going into details, I may predict that some of the species cited in Professional Paper 58 do not occur in the new collections, but that the new collections contain a number of species not there cited. One species of this family, however, *Euconospira obsoleta* Girty, is fairly common, and may prove to be the type of a new genus. Some of the specimens of it in the new collections are remarkable for the fact that color markings are still preserved on the surface.

The only other gastropods cited from the Capitan in Professional Paper 58 are a small, indeterminable shell, and *Zygopleura swallowiana* (Shumard), a species which was described by Shumard, but which I did not recognize in my collections. No species of *Zygopleura* has been recognized in the new collections, but they contain a number of genera not heretofore known in this fauna. At one locality, fragments that belong to *Naticopsis*, or some closely related genus, belong to one or more species of relatively huge proportions. Another collection has furnished one, and possibly two species of *Naticopsis* of more moderate size, provided they are not young specimens of the larger species. A fragmentary specimen from another locality represents an elongate, deeply embracing shell, probably belonging to the genus *Meekospira*, and the same locality has furnished two imperfect specimens of a form that at first suggests a very large, spreading species of *Zygopleura*, whose flat, sloping sides bear coarse, transverse plications. The basal surface, however, is flat or even concave, and the columella appears to be perforate. The generic position of this curious species is uncertain for the shell is in large measure destroyed.

The trilobites continue to be represented by the characteristic species *Anisopyge perannulata* (Shumard), which ranges practically throughout the Guadalupe Mountains section.—Girty manuscript.

CARLSBAD LIMESTONE

The fauna of the Carlsbad limestone was largely unknown before the present investigation. One of Girty's original collections (No. 2905) may belong to the formation, but is hardly typical of its fauna as now known. Another collection, made later by Darton and Reeside [92] from near Carlsbad Cave and reported on by Girty, is more nearly like the assemblages observed during the present work. The report that follows is based primarily on three rather large collections made by H. C. Fountain (Nos. 7415, 7416, and 7427, pl. 2), all of which came from the summits of the Guadalupe Mountains northeast of Guadalupe Peak. The manner of preservation of the fauna has already been noted (p. 65).

The Carlsbad fauna has some resemblances to the Capitan fauna, but the collections reveal marked differences between them. These differences are more startling because collections from the two formations are from rocks of approximately the same age, that lie only a few miles from each other. In particular, as indicated by Dr. Girty's report, a number of characteristic later Paleozoic brachiopod groups and genera are not present, although they occur in all the other rocks of the Guadalupe Mountains section.

Near the Capitan reef, the Carlsbad limestone contains numerous lime-secreting algae, some of which have been identified by Pia and Johnson. Some of the species cited below may have come from the Capitan rather than the Carlsbad limestone, and Johnson cites a number that occur in both formations. From collections near Carlsbad Cavern by G. A. Kroenlein and J. E. Adams, and from my collections in the southern Guadalupe Mountains, Pia lists:

Mizzia velebitana Schubert	*Solenopora centurionis* Pia
Macroporella verticillata Pia	*Solenopora* sp.
M. calcipora Pia	*Gymnocodium* n. sp.

From collections between Carlsbad Cavern and Carlsbad, Johnson lists:

Solenopora centurionis Pia	*Anthracoporella* sp.?
Solenopora sp.	*Diplopora* sp.?
Mizzia minuta Johnson and Dorr	*Girvanella* sp.
Mizzia yabei (Karpinsky)	*Colenella guadalupensis* Johnson
Macroporella sp.?	

[92] Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 427–428, 1926.

The pisolites which occur abundantly in the Carlsbad limestone have been mentioned on page 65, and are considered by some paleontologists to be of algal origin. They are described as follows by Johnson: [93]

> As typically developed the "pisolites" are spherical or subspherical with flattened base and top. The average size is from 0.6 to 1.1 centimeter, and in many deposits they are surprisingly uniform. In very rare cases they grow much larger, and smaller ones also occur. They are formed of thin layers of material more or less concentrically arranged around a nucleus. In small "pisolites" and in the central portions of larger ones the layers are concentric, completely enveloping those beneath. As the object becomes larger, however, the layers tend to envelop the mass only partially, and the "pisolites" become flattened and rudely elliptical in cross section. The individual layers are seldom of uniform thickness. The irregularity becomes more pronounced in the outer layers where they thin out toward the margins. The nucleus may be a small gastropod, foraminifer, a segment of a Dasycladacae, or a fragment of some other fossil; only rarely is the nucleus of inorganic material.
>
> Microscopic examination shows the layers to be composed of very fine particles of calcium carbonate in most cases. Some show a definitely crystalline structure. This is considered as probably secondary since it is best developed in the outer layers. Even under high magnification no cellular structure could be definitely observed although vague suggestions of a feltlike mat of filaments were occasionally found. A few *Girvanella* tubes were observed in some of the "pisolites." However, these were also observed in about the same abundance in most of the other objects studied, so their presence is considered more or less accidental.
>
> In some localities small "pisolites" occur which show a structure of fine radiating needle-like crystals with concentric layers absent or poorly developed. Except for size these are like the small oölites present in many of the specimens. These are interpreted as of inorganic origin.

The pisolites have been variously interpreted. Johnson considers them of organic origin, whereas Pia believes they are inorganic. Johnson [94] states:

> The writer believes that the majority of the "pisolites" are of algal origin, representing calcareous material deposited around the outer (growing) layers of colonies of low types of blue-green algae and fine silt and organic debris caught in the outer growing layers of such colonies. The structure suggests growth layers which start as a coating about a small object and grow concentrically until the colony becomes large enough to cut off the light from the basal portion, which, as the mass becomes larger, is more and more likely to be partly buried in the fine debris of the lagoon bottom. It may be that from time to time they were rolled over by tides or storm waves or other causes, and growth continued on the upper surfaces.

Pia [95] states:

> Johnson (1938) states that he has observed the genus *Girvanella* in the Carlsbad limestone. I have not seen anything of the sort in my material. It seems probable that Johnson has considered certain pisolites to be *Girvanella*, perhaps the same ones that Ruedemann called "coralline algae." The commonest of

[93] Johnson, J. H., Permian lime-secreting algae from the Guadalupe Mountains, New Mexico: Geol. Soc. America Bull., vol. 53, p. 213, 1942.

[94] Johnson, J. H., op. cit., p. 213.

[95] Pia, J. V., Vorläufige übersicht der kalkalgen des Perms von Nordamerika: Akad. Wiss. Wien, Math.-Natuurwiss. Kl., Anz., 9, preprint, June 13, 1940. Translation by John Rodgers.

these appear to be approximately spherical forms with fine concentric lamination. The samples of rock at my disposal contain balls from 1 millimeter to 7 centimeters in diameter. * * * Besides these pisolites, there are also irregularly sinuous laminations in the rocks, radiating sinter, and finely tufted growths. All these structures appear in places in the lagoon facies behind the reefs. * * * The chief interest of the structures mentioned lies in their surprising similarity to the well-known concretions in the Magnesian Limestone of Durham, in England. Probably we are dealing in both areas with similar chemical processes. It is noteworthy that such processes took place in two such widely separated regions at approximately the same time, and that they took place in a quantity that has not been recorded from any other part of the section, with perhaps the exception of the Algonkian.

In the same area that has yielded the algae, associated beds contain numerous fusulinids. According to Dunbar and Skinner, they include the large species *Polydiexodina capitanensis* Dunbar and Skinner, and *P. shumardi* Dunbar and Skinner, and the small species *Leëlla bellula* Dunbar and Skinner, *Codonofusiella paradoxica* Dunbar and Skinner, and *Staffella fountaini* Dunbar and Skinner.

Regarding the remainder of the fauna, Dr. Girty reports:

The sponges of the formation belong to only one species, provisionally identified as *Guadalupia cylindrica* Girty. The corals are still present, but are represented by a single specimen which does not show structure sufficiently for even a tentative identification. Bryozoans are without a single representative.

Among the brachiopods, the orthoids are unrepresented, as they have been in several of the preceding units.

The Orthotetinae are represented by two rather remarkable species *Plicatoderbya*, n. sp. and *Derbya* n. sp. besides which one dorsal valve is provisionally referred to *Streptorhynchus pygmaeum* Girty. Aside from these, none of the other Guadalupian genera are present. The *Plicatoderbya* is of uncommon size, with a rather highly convex dorsal valve and a rather high ventral valve. The surface is marked by very fine and very irregular radiating lirae. In addition, the surface in varying degree is very uneven, after a somewhat definite pattern. Where most conspicuous, this feature consists of innumerable small pits which necessarily leave short ridges between them. The pits may be fine or coarse, few or very numerous, and in some specimens the pits, in other the ridges, are the most obvious features. The ridges show no linear arrangement, but where an arrangement is slightly apparent, it is rather decussating than radial. The form is referred to *Plicatoderbya*, in spite of the lack of definite radial plications, for it seems less out of place in that relationship than in *Derbya*. The internal structure appears to be that of *Derbya*, the septum reaching to and coalescing with the deltidium, although the plates are considerably thickened and confused with callus. The *Derbya* n. sp. is small and in shape rather elongate than transverse. The ventral valve is very high and the growth very irregular. It is possible that this *Derbya* may be an extreme variety of the other species, in spite of the numerous differences shown. This form is represented by only a few specimens, whereas the other is abundant.

Chonetes is unrepresented, and what is remarkable for a later Paleozoic fauna, so are all the tribes of productids. *Prorichthofenia*, on the other hand, occurs in great abundance. I am not sure, however, that all the specimens belong to the same species, for some are uncommonly large, others uncommonly long and tapering. Provisionally, all of them may be referred to *P. permiana* (Shumard).

Camerophoria, which has ranged throughout the many units of the section, is unrepresented.

Rhynchonellids still persist, but are reduced in numbers and variety. I recognize two species, *Wellerella? swallowiana* (Shumard) var. and *Camarotoechia? longaeva* (Girty). The first type is distinguished from typical *Wellerella? swallowiana* by having two instead of three plications on the fold, and all the specimens in the new collections are of this character. Similar forms have also been observed in the Capitan limestone. The second type is identified on the basis of a single, immature specimen.

Terebratuloids are uncommonly abundant and diversified. The following species are tentatively distinguished: *Dielasma? scutulatum* Girty?, *Dielasma* sp., *Dielasmina guadalupensis* Girty, *Dielasmina* n. sp. ?, *Cryptocanthia* n. sp., *Notothyris?* sp.

The entire family of the spiriferoids is unrepresented.

Composita is represented by two species, or by what one might regard as a small-sized and large-sized variety of the same species. The large form resembles *C. ovata* Mather, as figured by Dunbar and Condra,[96] and may be so identified. The small form has the characters of *C. mexicana* (Hall), where the fold and sinus are strong, and of *C. argentea* (Shepard) (as identified by Dunbar and Condra), where the fold and sinus are relatively weak. These shells were found at two localities and all of those from one locality are of the small species, and all of those from the other locality of the large species.

Hustedia and *Leptodus*, both of which have ranged throughout the section, and occur in the Capitan limestone, have not been recognized in the collections from the Carlsbad.

Among the pelecypods, the genus *Parallelodon* is represented by at least two very distinct species. One is large and marked by very coarse radial costae, cancellated by strong concentric lamellae. This species is clearly allied to the one designated as *Parallelodon* sp. b of the Capitan fauna, if not identical with it. The other is smaller and much more finely marked. It may be identified as *P. multistriatus* Girty, which was also found in the Capitan limestone.

The pectenoids, insofar as hinge structure is concerned, are not determinable generically, and as none is complete as to outline and few retain more than patches of the shell, they cannot in some instances be distinguished specifically. For this reason, there is some doubt whether any of the species in this fauna are present in the Capitan limestone. On the other hand, it is certain that some of the Capitan species are not found here. Again, although none of the species is sufficiently well preserved for description, several show enough characteristics to indicate that they have not yet been described.

In this group, I recognize the following: *Acanthopecten* n. sp. (this is not the same as *Acanthopecten?* sp. of the Capitan fauna, but is more nearly related to *A. carboniferus* Stevens; *Fasciculoconcha* n. sp. (a large form with large costae, which occur in groups of three subcostae, a large one in the middle and a small one on each side, with a still smaller one in the grooves between the costae); *Aviculopecten* sp. a (a large form with moderately coarse costae, rising abruptly from somewhat narrow striae. The costae are flat on top, with a somewhat faint median groove, and all are crossed by fine, strong, regular, closely spaced crenulations). Besides these three sharply defined species, there are a number of specimens that suggest still other species, but are too poorly preserved for their relations to be determined.

Other pelecypods have been classed as *Camptonectes sculptilis* Girty, *Streblochondria?* sp., *Pernopecten obliquus* Girty, *Myalina* aff. *M. perattenuata* Meek and Hayden, *Conocardium*

[96] Dunbar, C. O., and Condra, G. E., Brachiopoda of the Pennsylvanian system in Nebraska: Nebraska Geol. Survey Bull. 5, 2d ser., pl. 43, fig. 14, 1932.

n. sp., *Pseudomonotis?* sp., *Myoconcha* sp. a, *Myoconcha* sp. b, *Pleurophorus* aff. *P. tropidophorus* Meek, *Cypricardinia* aff. *carbonaria* Meek. Some of these species have been recognized in the Capitan fauna (*Pernopecten obliquus*, *Myaconcha* spp. a and b). Others belong to the same genera but are different specifically (*Camptonectes* and *Pleurophorus*). Comments upon two of these species may not be out of place. The *Conocardium* is a rather small form with a very high, stout carina on the umbonal swelling. *Pseudomonotis?* sp. is used for a single rather small specimen which is nearly flat and marked only by concentric lines and varices of growth. Similar shells have sometimes been referred to *Placunopsis*.

Scaphopods seem to be rather abundant, but of course are fragmentary, and most of the specimens are internal molds. They are long, straight, gently tapering shells and where any surface characters are shown at all they consist only of obscure, transverse striae. So far as can be determined this is the same species that occurs in the Capitan fauna, and that one I have identified as *Plagioglypta canna* White.

The gastropods show a wide differentiation, and are uncommonly numerous.

Bellerophontid shells are numerous, in fact much more so than in the Capitan limestone, but most of them are so exfoliated that their generic relations can only be guessed. Many of them are of large size, and one may be cited as *Bellerophon* aff. *B. giganteus* Worthen, although neither Worthen's type nor the Guadalupian shell can be definitely referred to *Bellerophon* s s. *Bucanopsis* and *Euphemites* can be recognized generically, but the specific relations of the specimens so referred are uncertain, save that they probably belong to species as yet undescribed.

As already mentioned, most of the Guadalupian pleurotomaroids are small shells with fine sculpture. For the detailed study required to classify them intelligently, I have not yet had time. For the most part, therefore, only general remarks can safely be made. Shells of this family are extremely abundant and, as already noted, mostly small. Many specimens are too poor for classification. *Pleurotomaria richardsoni* Girty, and forms related to it, far outnumber all the other types put together. Besides *P. richardsoni* there are two or three closely related forms which can be recognized as distinct varieties. Aside from this group there are a considerable number of distinguishable species, all probably new, but many of them represented by material too poor for descriptive purposes. The only large species, the one that was described in Professional Paper 58 as *Euconospira obsoleta* Girty, is fairly abundant. Its occurrence in the Capitan fauna has already been noted.

One of the outstanding features of the present fauna is the development of naticoid shells. One form which may be designated as *Naticopsis* n. sp. a, is notable for its size. Even *Naticopsis altonensis gigantea* Meek and Worthen looks small beside it. Nor, indeed, does it belong to the *altonensis* group at all, as it has regularly rounded whorls and is marked only by fine incremental lines. The spire is moderately high and the suture recessed. It resembles somewhat *N. madisonensis* Worthen, but is more spherical in shape. Another species may be cited as *Naticopsis* aff. *N. tayloriana* Girty. This species is very abundant at one locality and a few unusually large specimens have been referred to it from another. It has the general configuration of *N. tayloriana* but is three or four times as large, for the species named is a rather diminutive shell. The species, however, is very much smaller than *Naticopsis* n. sp. a. The following also belong in this group: *Naticopsis* aff. *N. gracillis* Branson (a shell of moderate size with a very low spire), *Naticopsis* aff. *N. hartti* Bell (a rather small, elongated shell, consisting of a few volutions, of which the last one comprises most of the height), *Naticopsis* aff. *N. permiana* Beede (a species with rather numerous, rounded volutions and a moderately high spire. It is of the same general configuration as Beede's species but differs in its surface characters. All the Guadalupian shells are without surface markings, except for incremental lines). Most, if not all, of these species are probably new and several at least are sufficiently well known for description.

Trachydomia is represented by five species, all probably new. One is related to *T. wheeleri* (Swallow), *T. owenii* Knight, and similar forms, but is small, slender, and high-spired. For another, I know of no closely comparable species. The third may possibly belong to the genus *Turbonitella*. Two may prove to represent an undescribed genus. These shells are large and extremely ornate, with nodes of different sizes, and in addition the surface is crossed by fine, sharp, transverse lirae, which have a very irregular course that follows the nodes decorating the surface. I have never seen any species similar to these in our Carboniferous faunas. This type is fairly abundant, but because of its exceedingly rough surface the shell tends to peel off and leave only internal molds. When the specimens have been sufficiently cleaned from the matrix for close study, it is not unlikely that they will be classified into more than the two species here recorded.

In addition to the forms already discussed, there are various other gastropod types in the Carlsbad. Some of these have not yet been accurately placed as to genera and many of the species appear to be new; some are represented by specimens too poor for a description. At present, they may be listed as follows: *Zygopleura* of two or three species, *Helicostylus* sp., *Bulimorpha chrysalis delawarensis* Girty, another long and slender species of the same genus, *Strobeus?* sp., *Trochus?* sp., *Eotrochus?* sp., *Aclisina?* sp., *Orthonema?* sp., and *Streptacis?* of three species. This last name is employed for slender, high-spired shells with rounded, smooth, and slightly embracing volutions. In no instance has the peculiar character distinctive of the genus been observed; in fact, most of the specimens are in a poor state of preservation.

The cephalopods are represented only by a fragmentary "*Orthoceras*," possibly "*O.*" *guadalupense* Girty, and a very small and doubtful ammonoid. The trilobite, *Anisopyge perannulata* (Shumard), continues to be present, and in one collection is abundant.—Girty manuscript.

In considering the Carlsbad fauna as a whole, and in comparing it with other faunas of the Guadalupe Mountains, Dr. Girty makes the following summary:

The fauna of the Carlsbad limestone offers many contrasts to that of the Capitan limestone, but none are more notable than in the brachiopods. As against nearly 50 species in the Capitan, the Carlsbad contains but 14. What is more remarkable, the two great groups of later Paleozoic brachiopods, the productids and spiriferoids, are unrepresented. Moreover, the genera *Meekella*, *Chonetes*, *Aulosteges*, *Camerophoria*, *Hustedia*, and *Leptodus* are no longer present, and the rhynchonellids are reduced in number. The forms chiefly present belong to the Orthotetinae and the Terebratulidae, but *Prorichthofenia* continues to be fairly abundant, as it was in the other faunas.

Pelecypods are well represented in both faunas as regards variety, but they are much more numerous in the Capitan which has afforded almost twice as many species as the Carlsbad. Some of the species are held in common by the two faunas, but a number of genera are different, and where the genera are the same the species are sometimes different. For instance, under *Camptonectes* the Capitan fauna has *C. asperatus* Girty and *C. papillatus* Girty, whereas the Carlsbad fauna has *C. sculptilis* Girty. Again, in *Pleurophorus*, the Capitan fauna has a species related to *P. occidentalis* Meek and Hayden, whereas the Carlsbad fauna has a species related to *P. tropidophorus* Meek. As our knowledge of the two faunas, which at present is but scattering, becomes more complete, it is not unlikely that some of these differences will disappear.

If the Capitan fauna has the most pelecypods, the Carlsbad fauna has the most gastropods, the ratio probably being nearly two to one. It would not be safe to go into details in this matter, for the recognition of genera and species among Paleozoic gastropods requires such close study that any details given now would probably require numerous corrections after the descriptive work was done. It is safe to say that the gastropod fauna of the Carlsbad is much richer in individuals than the Capitan, and also is more varied, and that a marked difference in the pleurotomaroids will be found, and also in the naticoid shells, especially in the large and beautiful shells at present included under *Trachydomia*.

Neither fauna has any cephalopods to boast of, and the trilobite representation is the same in both.

One more difference between the Carlsbad and Capitan faunas should not be passed over. The calcisponges, which were diverse and abundant in the Capitan, are reduced to a single species in the Carlsbad.—Girty manuscript.

Considerably to the north of the area treated in this report, in the Seven Rivers Hills (fig. 2), the Azotea tongue of the Carlsbad limestone contains a few fossils at localities first discovered by Beede.[97] This area lay much farther northwest of the Delaware Basin and Capitan reef zone than any part of the area of this report, and most of the rocks of the vicinity, belonging to the Carlsbad and Chalk Bluff formations, are unfossiliferous. The fossils that occur are impoverished in number and variety, and so far as known are not like those in the Carlsbad limestone farther south.

From a locality on the north side of the Seven Rivers Hills, 6 miles southwest of Lakewood, N. Mex., which was originally discovered by Beede, Newell[98] has collected and identified the pelecypods *Dozierella gouldii* (Beede) and *Pleurophorus albequus* Beede. According to Beede, minute gastropods and casts of ostracods occur at the same place. Beede mentions another locality 13 miles west of Carlsbad and 5 miles west of McKittrick Spring, where similar fossils were collected.

This northern fauna of the Carlsbad is of interest because it closely resembles that of the fossiliferous beds in the lower part of the Whitehorse group in central Texas and southwestern Oklahoma. This relationship was first noted by Beede, and is confirmed by the two species identified by Newell, which also occur in the Whitehorse. The correlation suggested by the fossils has been verified by physical methods, on the basis of subsurface information.

CONDITIONS OF DEPOSITION

REGIONAL RELATIONS

During upper Guadalupe time strata of three contrasting facies were deposited in different parts of the southern Guadalupe Mountains area. To the southeast, in what is now the Delaware Mountains, the Delaware Basin received deposits of sandstone with a few thin limestone beds; farther northwest, on the southeast edge of what is now the Guadalupe Mountains, massive limestone deposits of the Capitan accumulated along the margin of the basin; a few miles farther northwest, these gave place to thin-bedded limestones and associated sandstones of the Carlsbad which were spread extensively over the shelf area (pl. 7, *A*).

The boundaries of the three facies, marked by the places at which the Capitan limestone changes on the one hand into the Bell Canyon deposits and on the other hand into the Carlsbad deposits, extend in a north-northeast direction across the area (lines *B* and *E*, fig. 10). Minor, and seemingly unrelated changes have the same trend so far as they have been traced. Thus, the change from the fusulinid and pisolite-bearing Carlsbad limestone into the unfossiliferous, varicolored northwestern facies (line *A*), and also the changes in the texture and color of the limestone members of the Bell Canyon formation (lines *F* and *G*), all take place along north-northeast-trending lines.

The rocks of the three facies, each representing approximately the same interval of time, have very different thicknesses. The Bell Canyon formation is 600 or 700 feet thick, the Capitan limestone and associated deposits are 1,500 to 2,000 feet thick, and the Carlsbad limestone and associated deposits are 800 to 1,000 feet thick. The deposits along the margin of the Delaware Basin were thus much thicker than those on either side, and the deposits outside the basin were somewhat thicker than those within it.

In reconstructing the form of these deposits of various thicknesses, the same methods have been used as for the similar deposits of the middle part of the Guadalupe series. Observations have been made on the structure of the deposits exposed along escarpments and canyon walls where the effects of later deformation can be accounted for, and deductions have been made, from the nature of the deposits themselves, as to the environments in which they were laid down.

The present structure of the deposits of the upper part of the Guadalupe series is shown by the sections on plate 17, of which *E–E′* and *K–K′* are particularly instructive, because they provide long, continuous views of the rocks of the unit, the first covering its upper half, and the second its lower half. Less continuous, but similar views are shown on the other sections, which suggest that the relations are the same in the intervening areas. The observations thus obtained are summarized on plate 7, *A*, which shows the probable arrangement of the rocks as they existed at the close of Permian time. The probable form of the deposits at the close of Guadalupe time are shown in section *d*, plate 7, *B*.

The surface of the deposits at the time of deposition probably consisted of: a broad, shallow sea bottom in

[97] Beede, J. W., The correlation of the Guadalupian and Kansas sections: Am. Jour. Sci., 4th ser., vol. 30, pp. 135–136, 1910.

[98] Newell, N. D., Invertibrate fauna of the late Permian Whitehorse sandstone: Geol. Soc. America Bull., vol. 51, locality 11, pp. 279–280, 1939.

the shelf area, where the Carlsbad deposits were laid down; a steep, southeastward slope across the marginal area, where the Capitan reef was laid down; and a deep-lying, more or less level floor in the basin itself, where the Bell Canyon formation was deposited.

The form assumed by the deposits was probably controlled by the differential subsidence of the area, which thereby brought about a set of contrasting environments of sedimentation. As during the preceding stages, the Delaware Basin continued to subside to a greater extent and more rapidly than the surrounding areas. Sedimentation outside the basin and along its margin kept pace with the subsidence, so that its approximate measure is given by the thickness of the beds laid down there. Within the basin, where the deposits are thinner, the influx of sediments was probably slow and the sea floor was not built up to the same height as in the surrounding areas. At the margin of the Delaware Basin, between the areas of greater and less subsidence, the beds were probably flexed down to the southeast in a similar manner, but to a less degree, than the beds were during an earlier period along the Bone Spring flexure.

SANDS OF THE DELAWARE BASIN

The sands in the Bell Canyon formation, which were laid down in the Delaware Basin, are very fine grained, with abundant accessory minerals derived from igneous and metamorphic rocks. The material must have entered the basin very slowly, as only a small thickness of deposit was laid down there, in comparison with the greater thickness of contemporaneous deposits outside the basin. The basin was at this time nearly encircled by higher-standing, more continuous, purer limestone deposits than before (fig. 14, *B*), which probably acted as a barrier and hindered material from being washed in from the sides. Shorewards from the barrier, however, some sands were being deposited in the Carlsbad limestone which are coarser than those in the basin. At the end of Guadalupe time, deposition of sandstone ended abruptly; the great thicknesses of the succeeding Ochoa series contain no embedded clastic material.

The occurrence of coarse sandstones interbedded with the Carlsbad limestone indicates that clastic material was being washed into the region from the north, and it may be that some of this sand was able to reach the basin through small openings in the surrounding limestone barriers. Where could such openings exist? The Capitan reef is best known along the outcrops in the Guadalupe, Apache, and Glass Mountains, and in the subsurface on the east side of the Delaware Basin (fig. 3). Here the reef is thick and contains no interbedded sandstone. In these areas, it trends in nearly straight lines in several directions (fig. 14, *B*). These directions may have been controlled by lines of weakness in the underlying rocks that served to outline the edges of the basin. Between these straight stretches, the reef apparently curved from one trend to the other, with little or no structural control. Such places probably exist beneath the Salt Basin southwest of the Guadalupe Mountains, at the entrance to the Sheffield Channel northeast of the Glass Mountains, and in southeastern New Mexico, but their existence cannot be proved because the reef is comparatively little known in these areas. In the areas between the straight stretches, the Capitan deposit may have been less pure, less continuous, or dispersed over a wider area. If so, it is at such places that small openings in the reef existed, through which sands coming from the north were able to reach the basin. It has been suggested by Adams [99] that the sand in the basin is of such fine texture that it could have been carried there by the wind.

Other possibilities are suggested by the absence of clastic material in the overlying Ochoa series. According to the interpretation here adopted, limestone barriers were no longer growing around the edge of the basin during early Ochoa (Castile) time (fig. 14, *C*), and any clastic material being washed toward the basin from the north was free to enter it. As very little clastic material did enter the basin in Ochoa time, the lands to the north from which it was derived in Guadalupe time had probably been peneplaned or buried.

The Ochoa series, beginning with the Castile formation at the base, is dominantly of evaporite facies, and was probably deposited in water that was partly shut off from free access to the sea. This closing off probably resulted from the growth of a barrier across the southwestern entrance of the Delaware Basin at the beginning of Ochoa time (fig. 14, *C*). If any considerable part of the sands laid down in the basin in Guadalupe time had come from this direction rather than from the north, the barrier would have prevented them from entering during Ochoa time. The same barrier that brought about the deposition of evaporites in the Delaware Basin may, therefore, have caused the ending of sandstone deposition in the same area.

The two discontinuous volcanic ash layers in the Hegler and Rader members of the Bell Canyon formation probably had the same source as the more extensive ash beds in the preceding Manzanita member. This source was probably in the volcanic area to the south, in Mexico. The two ash beds in the Bell Canyon indicate less violent eruptions in that area than those of Manzanita time.

Most of the sandstones of the Bell Canyon formation were deposited in quiet water. They are thinly laminated, and their bedding surfaces are flat and smooth. No channeling is found as in the Cherry Canyon formation. Shallow ripple marks are seen

[99] Adams, J. E., Oil pool of open reservoir type: Am. Assoc. Petroleum Geologists Bull., vol. 20, p. 789, 1936.

occasionally in the lower part of the formation, and indicate a slight movement of the water, but they are missing higher up. Somewhat more disturbed conditions existed at the margins of the basin, along the edge of the Capitan reef mass. Here, the sandstones between the Rader and Lamar members are somewhat channeled, and ripple marks are fairly abundant. Possibly these markings were caused by waves breaking against the face of the higher-standing Capitan reef, and by undertow moving down the surface. There was, therefore, some movement of water at the bottom near the margin of the Delaware Basin, even though the water was fairly deep. The ripple marks have a northeastward trend (fig. 10), indicating that the water movements that caused them were probably alined at right angles to the face of the northeast-trending Capitan mass. The sands near the edge of the Capitan are distinctly coarser than those farther southeast, and the finer material was probably picked up near the edge and carried farther out into the basin by the undertow.

LIMESTONES OF DELAWARE BASIN

The limestone members of the Bell Canyon formation record times when calcareous material spread southeastward from the edge of the Capitan mass over the floor of the Delaware Basin. The members are tongue-like projections from the Capitan limestone (pl. 7, *A*), but their lithologic character is not like that of the Capitan. They were probably laid down in a very different environment.

Near the southeast margin of the Capitan area, the limestones are better bedded than the Capitan. They are of grayer color because they contain small amounts of bituminous material. Small, lenticular bodies of massive limestone found in them (fig. 9) indicate the occasional existence of Capitan-like conditions. Thick layers of granular limestone that are interbedded seem to have had a clastic origin, and originally may have been calcareous sands spread along the lower edge of the Capitan reef. Some of the clastic, calcareous material may have been derived by wave erosion from the face of the reef itself. The angular pebbles which are com-

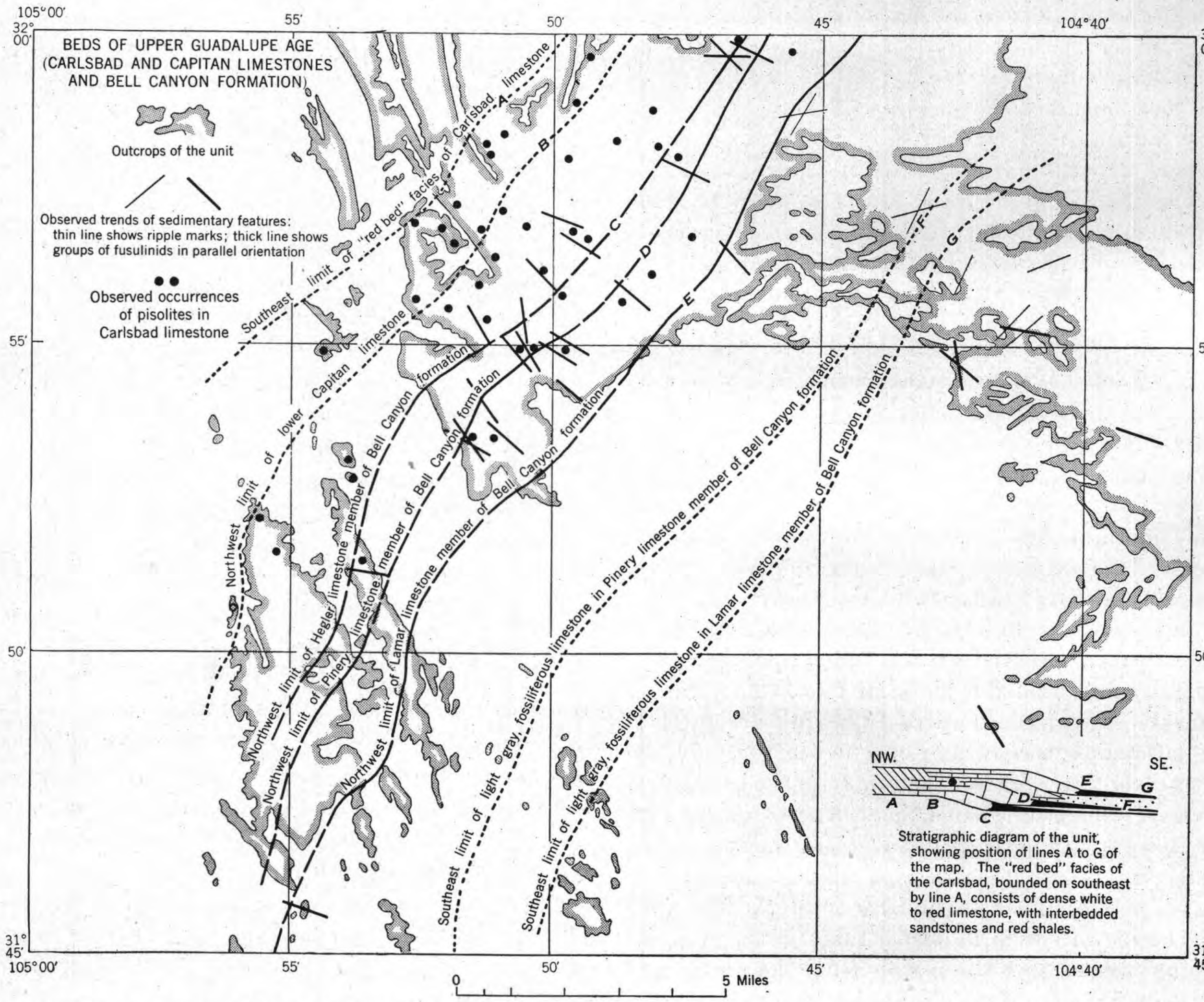

FIGURE 10.—Map of area studied, showing distribution of facies and other stratigraphic features in beds of upper Guadalupe age (Bell Canyon, Capitan, and Carlsbad formations).

mon in the Rader member seem to have had such an origin. The fossil shells found in the granular limestones are abraded, indicating they had been transported before they were deposited, and some of them may have been carried in from the Capitan area. This was especially likely during Lamar time, for shells found in this member are nearly all of Capitan species. The Rader and Pinery members, however, contain a fauna similar to, but distinct from the Capitan, including numerous bryozoans, which are uncommon in the Capitan itself. An indigenous fauna thus clearly existed at the foot of the reef and along the edge of the basin, at least in the earlier part of Bell Canyon time. The fauna was adapted to an environment of fairly deep but perhaps clear and agitated water along the outer edge of the higher-standing reef mass.

Several miles southeast of the edge of the Capitan reef, the light-gray, thick-bedded, granular, abundantly fossiliferous beds disappear from the limestone members; their place is entirely taken by thin-bedded, fine-textured, bituminous limestones, of dark gray or black color. The boundary between the two facies in Pinery and Lamar time is indicated by lines *F* and *G* in figure 10. The environment in which these limestones were deposited was not as favorable to life as that to the northwest, and most of the fossil groups except rhynchonellid brachiopods, fusulinids, and ammonoids are missing. The ammonoids were probably free-swimming, rather than bottom-dwelling forms. Probably the limestones of this area were laid down in quiet water, a condition which would have allowed their thin layers to be spread widely and evenly and would have allowed organic matter to accumulate faster than it could decay or be destroyed by bacteria. They record brief repetitions of the conditions that prevailed during the deposition of the black limestone of the Bone Spring.

In the Bell Canyon formation the sandstones and limestones tend to be repeated in cyclical order. The cycles resemble those in the upper part of the Cherry Canyon formation (p. 52). Limestone members are generally underlain by massive sandstones and overlain by thin-bedded sandstones (sec. 34, fig. 5). In the section near United States Highway No. 62 (sec. 34, pl. 6), there are 5 such cycles in the 670-foot thickness of the formation.

DEPTH OF WATER IN DELAWARE BASIN

During upper Guadalupe time, the sediments of the Delaware Basin were, on the whole, laid down in quiet water. This fact suggests that the water may have been deep, and this inference is confirmed by the relations of the sediments in the basin to those of the Capitan reef along its margin.

Bedding planes in the Capitan limestone slope southeastward toward the deposits of the Delaware Basin at angles of 10 to 30 degrees. This slope must have been largely original in the deposit, because the Capitan is underlain and overlain by well-bedded limestones which either dip at a much lower angle or lie horizontally. The upper surface of the sloping Capitan beds probably rose nearly to sea level, so that, aside from the effects of later tilting, the height of their upper ends above their lower ends, where they merge with the deposits of the Delaware Basin, would be the approximate measure of the depth of water in the basin at the time of deposition (as suggested on section *d* of pl. 7, *B*).

The upper surface of the Capitan deposits thus rose above the deposits of the Delaware Basin much as the Reef Escarpment rises above the plains of the Delaware Mountain area at the present time. Conditions were not exactly comparable, however, for although the present scarp is the exhumed face of the Capitan deposits, it has been considerably modified by erosion (fig. 20, *B*). As shown by the dip of the overlying Carlsbad beds (sections *E–E′* and *I–I′*, pl. 17), there has been some southeastward tilting toward the basin after Capitan time. The erosion and tilting make the present scarp higher than the ancient Capitan depositional surface.

Estimates of the original difference in altitude between the upper surface of the Capitan reef and the sea bottom in the Delaware Basin can be made by tracing some single bedding plane through the Capitan limestone and into the Bell Canyon deposits on such profiles as sections *E–E′* and *K–K′* of plate 17. Correction for later tilting can be made approximately by assuming that the overlying, southeast-dipping Carlsbad beds were horizontal at the time of deposition. Such estimates indicate that the Capitan reef stood 1,000 feet above the basin floor in Lamar time (as shown on sec. *d*, pl. 7, *B*). Less conclusive estimates suggest a slightly smaller figure for early Capitan time. Adams[1] states his belief that "in the center of the basin, the bottom was between 1,800 and 2,400 feet below the level of the Permian sea" at the end of Guadalupe time. This belief may be correct, although evidence is not stated. Under this condition the sea floor in the center of the basin would have been much deeper than along the margin, near the base of the Capitan reef.

FORM OF CAPITAN REEF

As shown by its outcrops (pl. 3), the Capitan limestone mass is only a few miles wide, yet it extends northeast-southwest in a belt for many miles following the margin of the Delaware Basin. Southeastward the mass sloped down steeply toward the equivalent deposits of the Bell Canyon formation. There was, however, no corresponding slope toward the northwest. In this direction, where the Capitan grades into the Carlsbad

[1] Adams, J. E., Oil pool of open reservoir type: Am. Assoc. Petroleum Geologists Bull., vol. 20, p. 789, 1936.

deposits, bedding planes extend almost horizontally from one to the other. The Capitan deposits thus formed a high-standing, shelf-like limestone reef along the edge of the Delaware Basin.[2]

The southeastward sloping Capitan beds rest on a foundation of older rocks that dip at angles of a few degrees in the same directions. A part of this dip is of post-Capitan age, because it is shared by the Carlsbad limestone which overlies the Capitan. A part of it, however, such as the surface of the Goat Seep limestone, probably existed at the beginning of Capitan time. It was on this southeastward slope of the Goat Seep limestone that the first Capitan deposits were laid down, evidently because this was a favorable place for the building up of limestone deposits.

At any particular time, the surface that received Capitan deposits was narrower than the final width of the whole mass, as younger parts of both the Capitan and Carlsbad were deposited farther southeast than the older parts (pl. 7, *A*). The width of the mass in Hegler time is the distance between the northwest edge of the well-bedded Hegler limestone, and the southeast edge of the oldest Carlsbad limestone (lines *B* and *C*, figure 10). This width ranges from 1 to 2 miles. The deposits during Lamar time, as seen in McKittrick Canyon, seem to have had a similar width, but the width cannot be determined as easily for the intervening stages between Hegler and Lamar time.

The forward growth of the reef is illustrated by the lines *C*, *D*, and *E* on figure 10, which represent its southeastern edge during successive stages. Because of its forward growth, the edge by Lamar time had advanced 3 miles southeastward from the edge at the beginning of Capitan deposition, in Hegler time. During the earlier stages (from Hegler to Rader time) the advance was rapid, but during the later stages (from Rader to Lamar time), the edge of the mass remained in about the same position, and growth was more in an upward than a forward direction. These two directions of growth, forward and upward, appear to be related to the rate of subsidence of the area. In order to maintain itself, the growing part of the reef had to remain at a relatively constant depth. Without subsidence, such depths could be maintained only by forward growth. With subsidence, upward growth would be necessary. The observed relations suggest that the rate of subsidence was less in early Capitan time than in later Capitan time.

In the McKittrick Canyon region, the Capitan contains a number of very massive limestone bodies several hundred feet thick. Toward the northwest each one grades into thin-bedded Carlsbad limestone, and to the southeast each splits into a number of rudely bedded layers that slope down to the deposits of the Delaware Basin. Each massive body lies farther southeast than the one that preceded it, as a result of the forward growth of the deposit as a whole. The massive bodies seem to have been accumulations of rapidly growing calcareous material. They protected the area to the northwest of them so well from wave attack that thin-bedded deposits could be laid down, as in the lagoon of a modern reef. The sloping beds to the southeast probably were sheets of detrital limestone spread out in front of the growing material.

The breccia found at several places in the Capitan was probably derived from the breaking up of the sloping face of the deposit. The angular form of the fragments, their lack of sorting, and the lack of bedding in the matrix suggest that the deposit was a submarine landslip. The irregular surfaces of the bedded limestones on which they rest may have resulted from the ploughing up of the still unconsolidated sea-bottom deposits at the foot of the slope by the moving material. Such landslips probably resulted from the deposition of limestone on the slope until it reached the angle of rest of the material, and a loosening of the material either by its own weight, or by the force of a great storm or an earthquake. Because all the occurrences of the breccia are in beds of about the same age, storms or earthquakes are the most probable agents because they would affect the whole region at about the same time.

NATURE AND ORIGIN OF CAPITAN DEPOSITS

Why and how was the Capitan limestone deposited? A precise answer cannot be given, because there are a number of possible causes, one or several of which may have dominated. Field evidence so far obtained is not conclusive, and the original structure of the rock in a large part of the formation has been destroyed by subsequent dolomitization. I assume, however, that the dolomitized parts of the formation were originally about the same as the parts that still remain as calcitic limestone.

From a study of the calcitic limestone, it is clear that lime-secreting organisms contributed to the formation of the rock. Brachiopods, various mollusks, and some other groups are very abundant in certain beds. These organisms, however, do not show any special adaptation to a reef environment. There is not, for example, a noteworthy abundance of thick-shelled forms that would thrive in strong currents and pounding waves of the exposed parts of a reef and would, therefore, contribute a considerable amount of limestone to the deposit; instead, the assemblage seems to be a normal neritic fauna, such as would grow in any region of clear, shallow water.

I have already noted the observation by H. C. Fountain and me that these fossils occur only in occasional lenses and are not uniformly distributed throughout the formation. The greater part of the mass of rock con-

[2] Lloyd, E. R., Capitan limestone and associated formations: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 646, 648, 1929.

tains little else than the remains of calcareous sponges, which constitute a group that is likely to build up colonies in agitated water and make important contributions of limestone to the deposit. It may be that the more varied assemblages of fossils grew in sheltered depressions between the masses of growing sponges.

Other reef-building organisms may have grown with the sponges, but their nature is not as well known. Apparently algae were common, for their remains have been described by several observers. Moreover, a considerable amount of the fine-textured, featureless matrix of the sponge rock was probably a calcareous mud, derived from precipitated algal remains that were later broken up by the waves. Crinoids also may have been abundant, for their stem segments are scattered through parts of the sponge rock. Neither corals nor bryozoans, however, seem to have been very common.

All these different organisms thrive in shallow, agitated water, and therefore, would be likely to find foothold in the shoals on the margins of the Delaware Basin, such as those formed by the older Goat Seep reef mass. In the basin to the southeast, the sea bottom was too deep for their growth. In the area to the northwest, the sea bottom was shallow, but the water was also less disturbed, and probably contained too great a concentration of dissolved salts, as is suggested by the change northwestward of the Carlsbad limestone into the evaporites of the Chalk Bluff formation.

The shoals along the margin of the Delaware Basin were probably also favorable places for the growth of lime-secreting organisms because the waters here were more nearly saturated with calcium carbonate than those to the southeast. The waters to the southeast were deeper, quieter, and perhaps cooler. Those on the shoals were warm and agitated, and therefore would cause the amount of dissolved carbon dioxide to be reduced, thereby diminishing the solubility of calcium carbonate.[3] Warm water may actually contain less calcium carbonate than cold water. One should not, however, confuse concentration of a solution with its degree of saturation. With increased warmth of the water, the degree of saturation of calcium carbonate increases, without any increase in concentration. This is largely determined by the fact that the amount of dissolved carbon dioxide tends to decrease in warm water. The concentration of calcium carbonate was probably being increased by the evaporation of sea water in the area to the northwest. Under such conditions, the organisms would find an abundant supply of lime available for building their skeletons, and the saturation of the water would prevent the skeletons from being leached after death; thus there would be an abundance of calcareous remains incorporated in the deposit.

[3] Twenhofel, W. H., Treatise on sedimentation, p. 321, 2d ed., Baltimore, 1932.

Such conditions would favor the direct precipitation of calcium carbonate without the aid of organisms. To what extent this took place is difficult to determine, but probably part of the mass of the Capitan reef was built up by inorganic processes.

The dolomitization of large parts of the Capitan limestone probably took place shortly after the sediments were deposited, in the same manner as it has taken place in modern reef deposits. That it did not take place in later times is suggested by the lack of relation between dolomitic limestones and faults, igneous intrusions, and the present land surface. Chemical analyses indicate that the amount of magnesium carbonate does not exceed 28 percent—far less than that contained in the mineral dolomite. The process of dolomitization thus appears never to have been carried to completion.

Dolomitization of the limestones of the Capitan shortly after deposition implies that the chemistry of the sea water at the time was such that calcium carbonate was a less stable precipitate than calcium-magnesium carbonate. This may have resulted from a saturation of magnesium carbonate in the sea water by proper conditions of atmospheric temperature and pressure, or by a concentration of magnesium carbonate in the water as a result of excessive evaporation.

Johnson [4] notes that:

> Algae were probably responsible for much if not all the magnesium carbonate present in the dolomite as magnesium is an essential constituent in chlorophyll, that green pigment characteristic of plants. * * * The writer believes that the importance of these plants in relation to the origin of dolomite has not been appreciated by geologists.

Dolomitization of the limestones shortly after deposition implies that they remained unburied, or within reach of the sea water a sufficiently long time for the calcium carbonate to be converted into the more stable calcium-magnesium carbonate. According to Twenhofel,[5]

> it is possible that enrichment in magnesium carbonate may be connected with the relation that deposited sediments had to the base-level of deposition. Calcium carbonate deposits built up to this level would be subjected to leaching and replacement for a long time, provided the waters were not already high in calcium carbonate. This might lead to the formation of a mag nesium-rock layer at the top of each layer of sediment.

This relation may explain the irregular interbedding of dolomitic limestone and calcitic limestone in the Capitan. The dolomitic beds probably represent deposits that stood for long periods near the base-level of deposition, at times when subsidence was slow or absent. The calcitic limestones are probably deposits laid down during times of more rapid subsidence, when sediments were more quickly buried.

[4] Johnson, J. H., Permian lime-secreting algae from the Guadalupe Mountains, New Mexico: Geol. Soc. America Bull., vol. 53, p. 215, 1942.

[5] Twenhofel, W. H., op. cit., p. 348.

DEPOSITS OF THE SHELF AREA

The shelf area, outside the Delaware Basin and northwest of the Capitan reef, was apparently a shallow sea, because layers of the Carlsbad limestone seem to have been deposited in a lagoonal area at about the same altitude as the top of the Capitan reef. The waters were apparently quiet because the limestones formed thin, widely spread layers; perhaps the area was protected from the force of the waves and currents by the reef barrier to the southeast. Some movement of the water, however, is indicated by the parallel orientation of the fusulinids that occur in many beds. Their dominant trend is northwestward (fig. 10). If they acquired this position by wave motion, the waves must have trended northeastward, parallel to the edge of the reef.

The limestone deposits of the shelf area are generally dolomitic and apparently of two sorts. Toward the southeast, near the Capitan reef, they have a granular texture and contain fossils in moderate abundance; farther northwest they are dense, lithographic limestones, with no traces of life. Those of the first sort were probably deposited originally as limestones and were afterwards diagenetically altered. Those of the second sort were probably direct chemical precipitates of dolomite, formed as a result of extreme evaporation of the sea water, a condition that is proved by the passing of the deposits into evaporites a short distance farther northwest. Chemical analyses indicate that the magnesium content is higher in this second type than in the merely diagenetically altered limestones of either the Carlsbad or the Capitan. The chemical composition of the second type approaches that of the mineral dolomite.

The area extending some miles behind the Capitan reef was apparently favorable to the existence of some forms of life. Fusulinids and algae were abundant, gastropods were common, and some families of pelecypods and brachiopods were present. There is, however, a notable absence of some groups and families of invertebrates that are common elsewhere in the rocks of the mountains, suggesting that they could not exist in the Carlsbad environment. Farther northwest, the concentration of dissolved salts in the sea water resulting from evaporation was probably so great that little or no life could exist.

COMPARISON WITH MODERN LIMESTONE REEFS

The Capitan limestone reef, and other reefs in the west Texas Permian have many resemblances to those that were built up in tropical seas during the Cenozoic time, and in part are still growing in modern tropical seas.[6] In these seas, as in those of west Texas during Capitan time, there are thick accumulations of limestone, parts of which are elongate reef masses, constructed by colonies of corals, calcareous algae, and numerous other lime-secreting organisms. The reefs generally slope abruptly seaward into deep water and merge landward into flat-lying lagoonal deposits.

The differences between the modern features and their ancient Permian counterparts seem to result chiefly from their respective geographic settings. The modern features lie mainly along continental margins or on the slopes of oceanic islands. In nearly all of them the sea bottom descends to oceanic depths in front, and the ground surface rises to hilly or mountainous heights behind. In contrast, the Permian features were formed in a nearly land-locked embayment of the sea, bordered in part by a low-lying continental surface. One result is that in the modern examples the lagoonal areas are relatively narrow, whereas in the Permian examples the areas corresponding to the lagoons were very broad. Modern lagoonal deposits are thus dominantly marine, whereas the Permian deposits include broad sheets of evaporites and terrigenous clastic sediments.

Possibly the closest modern analog to the Permian deposits exists in the Bahama Islands, southeast of the United States.[7] In this region are numerous broad, flat-topped banks, covered by shallow water and rising here and there in low islands. These banks slope abruptly into tongues, sounds, and channels of water many thousands of feet deep and are separated by them. The known surfaces of the banks consist of calcareous deposits, including limestone reefs, and similar rock may extend to great depths. A particularly suggestive comparison can be made between the cul-de-sac of the Tongue of the Ocean, between Andros and New Providence Islands, and the Delaware Basin in west Texas. Unlike west Texas, however, the Bahamas lie a considerable distance from any marginal lands, and their deposits probably include little or no clastic terrigenous sediments.

OCHOA SERIES

Overlying the Guadalupe series is a thick mass of strata, consisting largely of evaporites, which forms the Ochoa series.[8] This series is exposed in the Gypsum Plain and Rustler Hills east of the Delaware and Guadalupe Mountains (fig. 2), and only a small thickness of its basal beds is present in the area of this report. (pl. 3).

Outcrops of the series were first described by Richardson,[9] who divided the rocks of the series as now known

[6] These have been described in numerous publications. See, for example, Davis, W. M., The coral reef problem: Am. Geog. Soc. Special Pub. 9, 1928.

[7] Hess, H. H., Interpretation of geological and geophysical observations, The Navy-Princeton Gravity Expedition to the West Indies in 1932: U. S. Hydrographic Office, pp. 38–54, 1933. Schuchert, Charles, Historical geology of the Antillean-Caribbean region, pp. 528–540, New York, 1935.

[8] Adams, J. E., and others, Standard Permian section of North America: Am. Assoc. Petroleum Geologists Bull., vol. 23, pp. 1676–1677, 1939.

[9] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23; pp. 43–45, 1904.

into the Castile gypsum, the Rustler limestone, and a rather indefinite unit that he termed "the red beds of the Pecos Valley." The rocks of most of the series tend to break down readily on weathering. Because of this tendency and other circumstances, the exposures are less instructive than the records of wells that have been drilled through it. Since 1925 many wells have been drilled down the dip and east of the outcrops. Study of the records has given a much more complete idea of the series and its relations than was hitherto available.[10]

On the basis of this later work, the Ochoa series is now divided, in ascending order, into the Castile, Salado, Rustler, and Dewey Lake formations. The first unit is composed mainly of anhydrite, the second contains large amounts of salt, the third has many limestone beds, and the fourth consists of red beds. In the Pinal Dome Oil Co., Means No. 1 well, Loving County, 160 miles east of the Guadalupe Mountains, the series is 4,200 feet thick. Over considerable areas, the Rustler formation is unconformable on the Salado. Adams[11] interprets the relations of the Castile and Salado as unconformable. The series thus comprises two or more subcycles of sedimentation. Because of the unconformity between the Salado and Rustler, most of the Salado is missing from the outcrop in the Gypsum Plain and Rustler Hills.

CASTILE FORMATION

DEFINITION

The Castile formation was named by Richardson[12] for Castile Spring, which issues from the Gypsum Plain east of the area studied (fig. 2). On the outcrop, the formation consists largely of gypsum, an alteration product of an original deposit of anhydrite. As originally defined it was bounded above by limestones of the Rustler formation, but subsequent drilling has indicated that a great thickness of beds wedge in east of the outcrop, between the Rustler and the highest exposed underlying beds of the Castile. These upper beds, few or none of which crop out, are of evaporite facies like those beneath, but unlike them, consist dominantly of salt rather than of anhydrite.

For a time the upper beds were classed as a member of the Castile formation,[13] but later the name Salado formation was proposed for them by Lang.[14] As now defined, the Castile includes those beds in the lower part of the Ochoa series that are confined in their extent to the Delaware Basin and overlap the sloping surface of the Capitan limestone along its margins. The Salado includes higher beds, which occur both in the basin and beyond its margins (compare fig. 14, *C* and *D*). As thus defined, the Castile is dominantly anhydrite-bearing and the Salado is dominantly salt-bearing, but these distinctions are not absolute. In places, the Castile contains beds of salt, and toward the south the salt of the Salado tends to give place to anhydrite.[15]

CHARACTER

The Castile formation consists largely of anhydrite, which is marked throughout by thin, light and dark laminae that may be varves.[16] These laminae are best seen in well cores, but appear also in all reasonably fresh exposures of the formation, even where the rock has altered to gypsum. The light-colored laminae are relatively pure anhydrite; the darker are strongly bituminous and in many places calcareous. The calcareous content increases downward, so that the basal few feet, while still characteristically laminated, consist more of calcitic limestone than of anhydrite. Limestone beds a few inches thick are interbedded at wide intervals higher up. Drill records indicate that near the center of the Delaware Basin the formation has a maximum thickness of between 1,500 and 2,000 feet.

CASTILE OF AREA OF THIS REPORT

Within the area studied, the Castile formation crops out in small patches, and only the basal beds are present (pl. 3). Some small outcrops are found in the northeast part of the area, down the dip from the Bell Canyon formation, and the formation probably underlies wide areas elsewhere that are mantled by Quaternary gravels. One exposure appears a short distance southeast of United States Highway No. 62, on the north bank of a creek half a mile northeast of bench mark 4729; two others occur near Big Canyon Draw, south and northwest of the Gray Ranch. The last named locality is less than a mile from the base of the Reef Escarpment.

The formation is exposed also in several patches west of the Delaware Mountains, near the south edge of the area studied, where it has been downdropped by faulting (sec. *D–D′*, pl. 3). It is absent in the Guadalupe Mountains.

At all these localities, 25 to 50 feet of the basal beds of the formation lie on the uppermost beds of the Bell

[10] Lang, W. B., Upper Permian formations of the Delaware Basin of Texas and New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 262–270, 1935. Adams, J. E., Oil pool of open reservoir type: Am. Assoc. Petroleum Geologists Bull., vol. 20, pp. 780–796, 1936. Kroenlein, G. E., Salt, potash, and anhydrite in Castile formation of southeast New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 23, pp. 1682–1693, 1939. Adams, J. E., Upper Permian Ochoa series of Delaware Basin, west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 28, pp. 1596–1625, 1944.

[11] Adams, J. E., Upper Permian Ochoa series of Delaware Basin, west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 28, p. 1612, 1944.

[12] Richardson, G. B., op. cit., p. 43.

[13] Cartwright, L. D., Transverse section of Permian basin in west Texas and southeast New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 14, p. 979, 1930.

[14] Lang, W. B., op. cit., pp. 265–267; Salado formation of the Permian basin: Am. Assoc. Petroleum Geologists Bull., vol. 23, pp. 1569–1572, 1939.

[15] Kroenlein, G. A., op. cit., fig. 3, p. 1687.

[16] Udden, J. A., Laminated anhydrite in Texas: Geol. Soc. America Bull., vol. 35, pp. 347–354, 1924.

Canyon formation. At the base are a few feet of dark-gray, bituminous, very thinly laminated, calcitic limestone, which emits a strong petroliferous odor when struck. Several more beds of limestone occur higher up, where they are interbedded with laminated gypsum, probably altered from an original anhydrite. Some beds are contorted into parallel, ripplelike corrugations an inch across from crest to crest.

In places, the laminated rock gives place to cavernous, bouldery masses several feet thick, of rotten, gypsiferous limestone, containing angular fragments of laminated gypsum. This rock is probably a weathering product.

Tests were made on a specimen of laminated, gypsiferous, calcitic limestone from the basal beds of the Castile formation at the locality northeast of B. M. 4729. The chemical analysis follows:

Analysis of limestone from the basal beds of the Castile formation

[Analysis by K. J. Murata; note on insoluble residue by Charles Milton]

	Percent
Inorganic insoluble	1.25
Organic insoluble	.17
R_2O_3 (mostly Fe_2O_3)	.15
$CaCO_3$	96.63
$MgCO_3$	1.17
$MnCO_3$	None
$CaSO_4$	.47
$Ca_3(PO_4)_2$	None
	99.84

Insoluble residue: Dark brown, with cherty particles, and some quartz, perhaps of detrital origin.

CASTILE OF GYPSUM PLAIN

Outcrops of the Castile formation are much more extensive east of the area mapped. They constitute most of the Gypsum Plain, a broad belt that lies between the Delaware Mountains on the west and the Rustler Hills on the east (fig. 2). According to Adams,[17] some outcrops of the overlying Salado formation are present at the eastern edge of the plain. "The only Salado outcrops are * * * discontinuous, poorly exposed patches of unbanded gypsum along the main drainage lines west of the Rustler Hills. * * * Along many of the divides, tongues of the Rustler still lap over onto the beveled edges of the Castile." Northwest of the Gypsum Plain, in the drainage of Black River, near the Reef Escarpment that forms the southeast side of the Guadalupe Mountains, the Castile formation is mostly covered with Quaternary gravels.

The Gypsum Plain consists of wide, grassy plains from which rise broad, domelike hills and ridges coated with crumbly, white, impure gypsum or gypsite (Reeves chalk of soil reports), which support a scanty growth of grass.[18] On aerial photographs, these areas appear lighter colored than the adjacent outcrops of the Delaware Mountain group and Rustler formation, and show no bedrock structure.

Drainage in the gypsite hills is generally along shallow swales, thinly floored by alluvium. Some of the larger streams in the plain are entrenched as narrow, shallow canyons. For some miles on either side of these canyons, the tributaries are likewise entrenched as steep-sided arroyos. In parts of the plain, but not everywhere, the surface is dotted with sink holes, the smallest covering only a few acres, the largest a square mile or more. Some of the larger sinks contain intermittent lakes and receive the drainage of many square miles of surrounding area.

Rising above the plain are steep-sided gypsum buttes. Here and there are the features termed "castiles" by Adams.[19] They are low mounds, haystack buttes, and castellate peaks which have a core, a few square feet to many acres in extent, of limestone and banded calcite. Adams interprets the core as resulting from localized secondary replacement of the original anhydrite and gypsum. The castiles are prominent features on the aerial photographs and are widely distributed over the Gypsum Plain, either singly or in clusters.

One of the most remarkable peculiarities of the Gypsum Plain, as seen in aerial photographs, is a series of linear features, or long white streaks, extending across the plain in a nearly east-west direction. They are known only from the photographs, and have not been examined by me on the ground. Many of the linear features seem to be merely lines of coloration, without much surface relief, but many others form low, straight, distinct scarps, which offset the drainage, and across which roads are detoured. In places, pairs of scarps a quarter or half a mile apart face each other, the lower ground between being floored with alluvium. Where the linear features are most numerous and closely spaced, they impart a trellis pattern to the drainage.

The linear features begin on the west at the base of the formation or top of the Bell Canyon formation, but do not extend into the Bell Canyon formation (pl. 21). They extend eastward about halfway across the Gypsum Plain and fade out in the outcrops of the upper part of the Castile formation before the outcrops of the Rustler formation are reached. Most single features are two or three miles long, but some are 10 miles or more long.

These superficial linear features probably resulted from differential erosion of cemented east-west fractures that have developed in the anhydrites of the Castile formation. The origin of the fractures is unknown,

[17] Adams, J. E., Upper Permian Ochoa series of Delaware Basin, west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 28, p. 1608, 1944.

[18] Porch, E. L., The Rustler Springs sulphur deposits: Texas Univ. Bull. 1722, pp. 24–25, 1918. Carter, W. T., and others, Soil survey (reconnaissance) of the trans-Pecos area, Texas: U. S. Dept. Agr., ser. 1928, No. 35, p. 30, 1928.

[19] Adams, J. E., op. cit., pp. 1606, 1622.

but they seem to be confined to the lower part of the Castile formation.

During the present investigation, outcrops in the Gypsum Plain were studied in two places outside of the area mapped, one along the county road to the Nine K Ranch, about 4 miles southeast of United States Highway No. 62, and the other along the highway not far northeast of the Texas-New Mexico line, on the southwest side of the Yeso Hills (fig. 2). The beds in this region are higher in the section than those within the area studied, and probably lie several hundred feet above the base of the formation.

A specimen typical of these higher beds was collected at the first locality, from the banks of an arroyo just west of the county road (pl. 10, *B*). According to R. C. Wells, of the Geological Survey, it consists entirely of gypsum, not anhydrite; nevertheless, its original stratification is still well preserved. It consists of alternating light-gray gypsum bands and dark-gray, bituminous, slightly calcareous bands, each a few millimeters thick. The dark, calcareous bands stand out in low relief on weathered surfaces. Most of the laminations are straight and parallel, but in some there is a minute crenulation not shared by beds above and below. Scattered through the rock are occasional white gypsum knots as much as a quarter of an inch across, around which the laminae are bent. In describing a well core Lang [20] points out similar knots, which he interprets as "initial points of alteration of anhydrite into gypsum." Because of the complete alteration of anhydrite into gypsum in the outcrop specimens, this suggestion cannot be verified.

At the second locality, the highway, in descending southwestward from the Yeso Hills, has been cut deeply into the original surface, so there are road cuts as much as 40 feet high. In these road cuts the Castile formation is wonderfully exposed. Most of the rock consists of thinly laminated gypsum, similar to that just described, but at one place there is an interbedded, dense, gray limestone 6 inches thick. An interesting feature of this locality is the contortion of the beds, which is on a much larger scale than the crenulations noted at previous localities, and involves masses 10 to 50 feet across. Most of the beds lie horizontally or dip gently, but in places they are sharply folded, and here and there they are vertical. This contortion may be related to the linear features described above, as aerial photographs indicate that some of the linear features extend through the locality.

HIGHER FORMATIONS OF OCHOA SERIES

The formations overlying the Castile formation are not exposed in the area studied, but their character is summarized here, on the basis of published descriptions of outcrops and of drill records farther east.

SALADO FORMATION

The Salado may be exposed here and there in the Gypsum Plain, near the west base of the Rustler Hills, but most of it is cut out in this region by the unconformity at the base of the Rustler formation. The Salado exhibits its full thickness east of the outcrops.

The formation contains the thickest beds of salt in the west Texas Permian section. They have been referred to as the "upper" or "main" salt in many of the older reports on the region. It contains numerous potash beds, some of which are being mined east of Carlsbad, N. Mex. (fig. 1).[21] There are some interbedded layers of anhydrite, and thin ones of dolomitic limestone and red beds. Some lamination is present, which is perhaps comparable to that in the underlying anhydrite of the Castile, but there are no bituminous layers. As indicated by the records of wells drilled east of the outcrops, the maximum thickness of the formation in the Delaware Basin is somewhat more than 2,000 feet. In the shelf areas, north and east of the basin, it is 1,000 feet or less.

RUSTLER FORMATION

Overlying the Salado formation, in places unconformably, is the Rustler formation, which crops out in the low Rustler Hills (fig. 2). On the outcrop, it consists of dolomitic limestones, containing a few poorly preserved fossils, underlain by sandstone and chert pebble conglomerate. Eastward beneath the surface, the dolomitic limestone is overlain by anhydrite, red beds, and salt, which constitute an upper member of the formation. Here, its maximum thickness is nearly 400 feet. The Rustler formation contains the uppermost evaporites in the Permian section. Like the Salado, it was deposited in both the Delaware Basin and the shelf areas beyond.

DEWEY LAKE RED BEDS

Overlying the Rustler formation east of its outcrop are a few hundred feet of red beds, part of which are classed as of Permian and part of Triassic age. According to Adams [22] "most of the red beds of the Delaware Basin previously classed as Permian belong in the Triassic Pierce Canyon formation. Uppermost Permian red beds, present in a few localities, are assigned to the Dewey Lake formation."

The Dewey Lake red beds were named by Page and Adams [23] and have their type section in the Midland

[20] Lang, W. B., Upper Permian formations of the Delaware Basin of Texas and New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 19, fig. 5, p. 267, 1935.

[21] Mansfield, G. R., and Lang, W. B., The Texas-New Mexico potash deposits: Texas Univ. Bull. 3401, pp. 641–832, 1935.

[22] Adams, J. E., op. cit., p. 1601.

[23] Page, L. R., and Adams, J. E., Stratigraphy, eastern Midland Basin, Texas; Am. Assoc. Petroleum Geologists Bull., vol. 24, pp. 62–63, 1940. Adams, J. E., Upper Permian Ochon series of Delaware Basin, west Texas; Am. Assoc. Petroleum Geologists Bull., vol. 24, pp. 62–63, 1940. Bull., vol. 28, pp. 1601, 1615–1616, 1944.

Basin (fig. 3). The Dewey Lake consists of unfossiliferous fine-grained, orange-red sandstones and silts, many of which are cemented by anhydrite. They have a thickness of 250 to 350 feet and "are separated by an unconformity that is commonly marked by a zone of bleaching." In the Delaware Basin, according to Adams,[24] "the formation is limited to the structurally low areas along the east and south edges * * *, and no outcrops are known. Apparently pre-Triassic erosion stripped the unconsolidated red beds from the surface of all the higher exposed areas, leaving a Rustler pavement."

In southeastern New Mexico, east of the Pecos River, are many outcrops of red beds that overlie the Rustler formation. They have been penetrated in nearby wells. The beds are termed the Pierce Canyon formation by Lang.[25] They occupy the same stratigraphic position as the Dewey Lake red beds and have been correlated with it by some geologists. Lang, however, considers the Pierce Canyon to be unconformable on the underlying Rustler and conformable with the main mass of the Dockum group above, and hence of Triassic age, an interpretation with which Adams[26] agrees.

STRATIGRAPHIC RELATIONS

Within the area of this report, and in the Guadalupe Mountains in general, Permian rocks belonging to the Guadalupe and Ochoa series are overlain by Quaternary gravel deposits, and no intervening formations are known. On pages 104–105 and 140 it is deduced that the Permian rocks of the region were at one time peneplaned, and then covered unconformably by Cretaceous rocks. All trace of these Cretaceous rocks has since been removed by erosion in the Guadalupe Mountains, but remnants of the Cretaceous still lie on the Permian farther south in the Rustler Hills and the Apache Mountains (for location, see fig. 1).

East of the Pecos River, older Mesozoic deposits intervene between the Permian and the Cretaceous. They form the Dockum group, of which the Pierce Canyon red beds are classed as the basal unit. The group contains terrestrial fossils in places[27] and is classed as of Upper (?) Triassic age by the Geological Survey. As indicated by the work of Page and Adams,[28] the Dockum apparently lies unconformably on the Dewey Lake red beds.

FOSSILS AND AGE

The Ochoa series is nearly unfossiliferous, probably because the waters in which it was deposited were so saturated with dissolved salts that little or no life could exist in them.

The Castile formation contains no fossils, but there is evidence that life existed somewhere in the vicinity during its deposition. The calcareous laminae, intercalated with its anhydrite laminae, are bituminous and this material was doubtless derived from marine plants or animals. They were perhaps forms that swam or floated near the surface of the body of water in which the Castile was deposited, where the concentration of dissolved salts was less than at the bottom; or, the bituminous material may have been swept in from areas of marine water farther south which were poorly connected with the area of Castile deposition.

In the Rustler formation, higher in the section, a few pelecypods and plants were collected by Richardson.[29] They are too poorly preserved to afford much evidence as to their age, and paleontologists who have studied them express indecision as to whether they are Paleozoic or Mesozoic forms.

Because of the lack of fossils, there is no paleontological evidence as to the age of the Ochoa series. It is of post-Guadalupe (later Permian) and pre-Dockum (Upper (?) Triassic) age, and may therefore be either late Permian or Lower to Middle Triassic. A Lower Triassic age has been suggested for it by Roth,[30] but most geologists consider it to be of late Permian age, and it is so classed by the Geological Survey.

This conclusion is based mainly on physical relations, which suggest that the series is more closely bound to the underlying than to the overlying beds. In places, but not everywhere, it is separated from the underlying Guadalupe series by an unconformity, but the greatest unconformity appears to be at its top, beneath the Dockum group. Moreover, the evaporites, dolomites, and red beds of the series are very similar to the sediments of the Guadalupe and older Permian series in the shelf areas. The deposits in both the Ochoa and older series were apparently laid down under water, in areas that were intermittently connected with the sea. The Dockum group above is likewise of red-bed facies, but it seems to be entirely a terrestrial deposit, laid down on river flood plains and in lakes. No evaporites like those in the underlying rocks are known in it.

CONDITIONS OF DEPOSITION

During the Ochoa epoch, the west Texas region was dominantly an area of evaporite deposition, although marine conditions probably persisted farther south. The thickest and most extensive evaporite deposits of the west Texas Permian were laid down at this time. Conditions of deposition during the epoch, especially those concerned with the origin of the evaporites, have

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24 Adams, J. E., op. cit., p. 1615.

25 Lang, W. B., The Permian formations of the Pecos valley of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., vol. 21, p. 876, 1937.

26 Adams, J. E., op. cit., p. 1601.

27 Adkins, W. S., Mesozoic systems, in The geology of Texas, vol. 1: Texas Univ. Bull. 3232, pp. 246–247, 1933.

28 Page, L. R., and Adams, J. E., op. cit., pp. 62–63.

29 Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas, north of the Texas and Pacific Railway: Texas Univ. Bull. 23, pp. 44–45, 1904.

30 Roth, Robert, Evidence indicating the limits of Triassic in Kansas, Oklahoma, and Texas: Jour. Geology, vol. 40, p. 709, 1943.

been discussed in a number of previous publications.[31] Details of the discussions in these papers need not be repeated here, but a description of some of the broader paleogeographic features of the epoch, which were not adequately treated in some of the papers cited is worth while. Especial attention is given to features of the environment under which the first formation, the Castile, was deposited.

BEGINNING OF OCHOA TIME

In the Delaware Basin, the sandstones of the Bell Canyon formation, of Guadalupe age, are succeeded by the anhydrites of the Castile formation, of Ochoa age. The change in sedimentation from the one to the other is one of the most abrupt and striking in the west Texas region, and takes place in an apparently conformable sequence, within a few inches of beds. Marine conditions in the basin then came to an end, and with them, the abundant invertebrate life of the adjacent Capitan reef.

This change has been discussed by Kroenlein,[32] who states that "continued excess of evaporation lowered the surface water level and associated reef environment to a point where the accumulated brine killed life on the reef. This caused the death of the reef and closed Capitan time. Further excess of evaporation over marine inflow resulted in concentration sufficient to deposit anhydrite and marks the beginning of Castile deposition."

It seems unlikely, however, that conditions described by Kroenlein could have brought about the change in sedimentation without the aid of other factors. The effects of Kroenlein's conditions would have been gradual, whereas the change is actually abrupt. Moreover, these conditions would not have ended the deposition of sandstone in the basin, whereas deposition of sandstone did end with the beginning of evaporite deposition.

It is therefore probable that the change in sedimentation resulted not only from an excess of evaporation over inflow, but also from a shutting off of the sea from free access to the water of the area, presumably by the growth of a barrier across the southwestern entrance to the Delaware Basin (fig. 14, *C* and *D*). South of this barrier, marine conditions probably continued, and over it water still flowed gradually or periodically into the basin, where it evaporated and supplied the great quantity of anhydrite and other evaporites laid down during Castile time.

The nature and location of this barrier is uncertain. According to Adams[33] "a sand dune ridge, perhaps made up of calcareous sands and protected by organic reefs, would be a logical type of barrier to shut off migration [of sea water] through such channels. Breaches could be produced by storm waves and sealed off by normal wind action." The writer[34] has suggested that the barrier lay near the south end of the basin, in the vicinity of Hovey, not far northwest of the present Glass Mountains. Adams[35] notes that the Castile in the Seven Heart Gap area of the southern Delaware Mountains contains a greater quantity of limestone than elsewhere, and suggests that an entrance to the basin may have existed in that vicinity.

GENERAL ENVIRONMENT OF CASTILE TIME

The primary relief on the sea floor during Castile time was inherited from Guadalupe time, when the Capitan reef was built high above the bottom of the nearby Delaware Basin. This relief may have been accentuated by still further subsidence in the basin area during Castile time. The Carlsbad limestone in the southern Guadalupe Mountains dips southeast, probably as a result of tilting toward the basin in late Permian time (pp. 85–86); similar tilting is reported near Carlsbad Cavern.[36] Published cross sections of the Ochoa series in the Delaware Basin[37] indicate that the Castile and Salado formations as a whole, and each of their individual members, increase in thickness toward the center of the basin. This increase may in part have been brought about by continued subsidence of the basin area.

The Castile deposits are chemical precipitates, which could be derived only from water whose concentration of dissolved salts was greater than that in the open sea. The concentration was probably caused by evaporation of water which was prevented from free communication with the sea by a barrier. Adams[38] outlined the conditions of deposition of the Castile as follows:

> Evaporation of sea water in a restricted container, such as a beaker, produces a regular sequence of precipitates mixed with

[31] Udden, J. A., Laminated anhydrite in Texas: Geol. Soc. America Bull., vol. 35, pp. 347–354, 1924.
Hoots, W. H., Geology of a part of western Texas and southeastern New Mexico, with special reference to salt and potash: U. S. Geol. Survey Bull. 780 B, pp. 122–126, 1925.
Baker, C. L., Depositional history of the red beds and saline residues of the Texas Permian: Texas Univ. Bull. 2901, pp. 9–72, 1929.
Cunningham, W. A., The potassium sulphate mineral polyhalite in Texas: Texas Univ. Bull. 3401, pp. 860–867, 1935.
Adams, J. E., Oil pool of open reservoir type: Am. Assoc. Petroleum Geologists Bull., vol. 20, p. 789, 1936.
Lang, W. B., The Permian formations of the Pecos Valley of New Mexico and Texas: Am. Assoc. Petroleum Geologists Bull., vol. 21, pp. 884–888, 1937.
Mansfield, G. R., Role of physical chemistry in stratigraphic problems: Econ. Geol., vol. 32, pp. 541–549, 1937.
Kroenlein, G. A., Salt, potash, and anhydrite in Castile formation of southeast New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 23, pp. 1682–1693, 1939.
Adams, J. E., Upper Permian Ochoa series of Delaware Basin, west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 28, pp. 1616–1622, 1944.

[32] Kroenlein, G. A., op. cit., p. 1684.

[33] Adams, J. E., Upper Permian Ochoa series of Delaware Basin, west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 28, p. 1617, 1944.

[34] King, P. B., Permian of west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 26, pp. 758–760, 1942.

[35] Adams, J. E., op. cit., p. 1621.

[36] Lang, W. B., op. cit., pp. 892–895.

[37] Kroenlein, G. A., op. cit., fig. 2, p. 1685. Adams, J. E., op. cit., figs. 2–4, pp. 1600–1603.

[38] Adams, J. E., op. cit., pp. 1616–1617.

or superposed one upon the other. In larger, natural, barred basins, tens or hundreds of miles across, with a single continuous marine connection, equal evaporation per unit of area would cause an inward slope across the evaporating pan and a consequent continuous migration of the brine from the entrance to the innermost end of the basin. Increasing concentration during this journey would cause successive precipitation of the least soluble constituents in a lateral rather than a vertical sequence. The normal order of the geologically important evaporite sediments is limestone, dolomite, anhydrite, salt, and rare bitterns. Intermittent marine connections in a sizable basin should produce deposits similar in distribution to those of the laboratory experiments. During closed periods evaporation would lower the surface of the water in the barred basin below that of the adjacent sea. Upon the breaking down of the barrier great quantities of sea water would rush in to fill the basin up to sea level. The water would spread over the whole area and only after it became practically stationary would evaporation produce any appreciable decrease in volume or increase in concentration.

The Castile formation seems to fulfill the requirements for intermittent marine connections while almost all the other Permian evaporites appear to have been deposited in barred basins with nearly continuous marine connections. The Castile is fairly consistent lithologically from bottom to top and from one end of the basin to the other. It seems that the minor differences can be most readily explained if we assume, in addition to the intermittent marine connections, that the beds were deposited in waters of greater than normal depth and in a relatively restricted basin. * * *

Recurrent closing and opening of the barrier would allow the waters in the basin to be lowered by evaporation or to be raised by freshening floods. Initially the waters of the Castile sea were fairly uniform in composition, and because they were derived from the open sea, salt concentrations would be those normal to the waters of the Permian oceans, which probably closely approached those of the present sea. Waters drawn across the bar would be of the same character and would carry a normal planktonic fauna. As soon as a solid barrier shut off the marine inflow, evaporation would start decreasing the volume of the relict waters and this would cause precipitation of the salts in the reverse order of their solubilities. Increased concentration would eventually cause the death of most of the organisms in the barred basin waters.

ORIGIN OF LAMINATIONS

The laminated structure of the Castile formation is of much interest, and has been discussed by Udden [39] and various subsequent authors. The laminae are structures original in the deposit. In the succeeding Salado formation there is evidence of extensive replacement and reconstitution of the originally deposited minerals, so that much of the original structure of the beds has been destroyed.[40] If such processes acted on the Castile deposits, they were not extensive enough to destroy the lamination.

Adams [41] suggests the following process for the formation of the laminations:

The calcium carbonate precipitated from the surface waters would be mixed with considerable organic material. On consolidation this would produce the brown calcite laminae so typical of the Castile. During the colder season of the year evaporation would be very slow compared with summer losses, and the coolness of the atmosphere would tend to cool the water and increase its power to hold CO_2 in solution. It is, therefore, probable that the calcite laminae each represent the deposits of a summer or a portion thereof.

Further evaporation and concentration would cause the precipitation of gypsum. Upon consolidation under pressure the gypsum would be dehydrated to anhydrite. Ordinarily by the time a fraction of an inch of gypsum had been precipitated, there would be a new incursion of the sea and the process would be repeated. This would explain the regular alternation of calcite and anhydrite laminae. An extensive, uninterrupted period of evaporation would result in the formation of a thick anhydrite. The next incursion of the sea would find the surface of the brine a greater distance than normal below sea level, and the filling of the basin would result in a much thicker layer of new water, most of which must be evaporated before a renewal of gypsum precipitation could take place.

Studies made by Udden and his associates suggest that the laminations may be grouped into several still-greater cycles, possibly related to sunspot cycles, but the grouping is not perfect, and no very definite results have been obtained.[42]

LATER PARTS OF OCHOA TIME

By the end of Castile time, the deep depression of the Delaware Basin had been largely filled by deposits, and the succeeding Salado formation was probably deposited in shallower water.[43] With the filling of the basin, the area of deposition began to spread beyond the basin into the surrounding areas (fig. 14, *D*). This general spread was partly because of the general submergence of the region. However, Kroenlein [44] states that the Salado deposits pass into a near-shore facies near the Pecos River, considerably east of the west edge of the Delaware Basin. He concludes that the area of deposition was tilted eastward near the beginning of Salado time, causing the eastern edge of the area to spread farther east beyond the margin of the Delaware Basin.

Salado time closed with a period of movement, by which the formation was tilted, uplifted, and eroded. In places along the thinned edge of the deposit, erosion cut deeply enough to remove the whole formation and lay bare the Castile or other pre-Salado beds. After this the Rustler and Dewey Lake formations were laid down. Rustler and Dewey Lake time was probably shorter than preceding Castile and Salado time, for it is not represented by as great a thickness of deposits.

The Rustler formation, which overlapped the eroded surface of the older beds, is also dominantly of evaporite facies, and its deposits were laid down over much the

[39] Udden, J. A., op. cit., pp. 347–354.

[40] Mansfield, G. R., Role of physical chemistry in stratigraphic problems: Econ. Geology, vol. 32, pp. 541–549, 1939.

[41] Adams, J. E., op. cit., p. 1619.

[42] Udden, J. A., Study of the laminated structure of certain drill cores obtained from the Permian rocks of Texas: Carnegie Inst. Washington Year Book, vol. 27, p. 363, 1928.

[43] Adams, J. E., Oil pool of open reservoir type: Am. Assoc. Petroleum Geologists Bull., vol. 20, p. 789, 1936.

[44] Kroenlein, G. A., Salt, potash, and anhydrite in Castile formation of southeast New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 23, pp. 1686–1688, 1939.

same area as those of the Salado. During Rustler time parts of the area were covered by dolomitic limestones. They formed under conditions that permitted the existence of an impoverished pelecypod fauna. The waters in which they were laid down were probably of more normal salinity than elsewhere. Conditions were not favorable enough for a rich invertebrate life, like that of Guadalupe time, to return to the region.

At the end of Rustler time, the supersaline waters in which the formation was deposited disappeared from the west Texas region, and whatever access there had been to the basin from the open sea came to an end. The fine-grained red clastics of the Dewey Lake redbeds were then spread over the preceding evaporite deposits. They were probably washed in from the surrounding marginal lands, most of which by this time had been worn down to low relief. Dewey Lake time was relatively brief, and when deposition ceased, the Ochoa epoch came to an end, and with it the Permian period.

BROADER FEATURES OF PERMIAN STRATIGRAPHY

SUMMARY OF THE SECTION

THICKNESS

The rocks exposed in and near the southern Guadalupe Mountains constitute a great sequence of Permian strata, thicker by far than most other Permian sections in North America. No single set of outcrops, and no single well, extends through the whole system, but its approximate measure is indicated by combining incomplete sections. Thus, the Wolfcamp (Carboniferous or Permian) and Leonard series in the Anderson and Prichard, Borders No. 1 well in the Delaware Mountains are about 4,500 feet thick (pl. 8). The Guadalupe series in the Niehaus et al., Caldwell No. 1 well, down dip to the east of the Delaware Mountains, is about 3,500 feet thick (pl. 6). The Ochoa series in the Pinal Dome Oil Co., Means No. 1 well in Loving County east of the Pecos River, is about 4,200 feet thick.[45] Taken together, these figures indicate a thickness for the Permian system (if the Wolfcamp is included) of more than 12,000 feet. The three wells were drilled in the Delaware Basin area, in which maximum thicknesses are expected. In the shelf area to the northwest, outcrop and well sections [46] suggest a thickness of 7,000 feet or less.

CHARACTER

The rocks comprising this thickness of 7,000 to 12,000 feet include a great number of facies, deposited in varied environments, with the different facies giving place to one another both vertically and horizontally. Most of the section consists of sedimentary rocks of marine origin. These rocks are mainly limestones and sandstones, but include minor amounts of shale, conglomerate, and chert. Many of them contain abundant invertebrate fossils. In the upper part of the section evaporite beds make their appearance, indicating that the area at that time began to be shut off from free access to the sea, perhaps because of the general retreat of the seas from the continent that characterized Permian time. The first evaporites in the Guadalupe Mountains region are found in the Guadalupe series, where they occur only in the shelf areas. In the succeeding Ochoa series they spread over the entire region.

SUBDIVISIONS

Despite the complexity of the local details of the stratigraphy, and the interfingering of numerous facies, certain broad groupings of the Permian rocks are evident. They are expressed by the subdivision of the sequence into the Wolfcamp, Leonard, Guadalupe, and Ochoa series. These groupings are of both lithologic and faunal significance, and represent distinct cycles of sedimentation.

In the vicinity of the Guadalupe Mountains the four series just named are separated from one another by well-marked changes in sedimentation, and in places by unconformities. A major structural unconformity separates the Wolfcamp series from the beds below, and a minor one, perhaps involving some deformation, lies between the Wolfcamp and Leonard series. Other unconformities are present between the Leonard and Guadalupe series, and between the Guadalupe and Ochoa series. The last two unconformities seem to have been caused not so much by deformation as by widespread withdrawals and readvances of the sea. The unconformities that separate the series are usually poorly marked or absent in the Delaware Basin area, but increase in distinctness in the shelf areas, where the beds above and below are separated by considerable time gaps. Both the structural unconformities and the unconformities caused by withdrawals and readvances of the sea are of more than local significance and are, therefore, of aid in correlating the Guadalupe Mountains section with sections in adjacent parts of the Midcontinent and Cordilleran provinces.

Between some of the series, and at the same levels as the unconformities, there are rather striking changes in sedimentation. They are usually most pronounced in the Delaware Basin area, and less so in the shelf areas where rocks of similar facies were deposited through most of the period. One change in sedimentation took place at the beginning of Guadalupe time, when the basal sands of the Delaware Mountain group spread over the black limestones of the Bone Spring. Another took place at the top of the same series, when deposition of sandstones of the Delaware Mountain

[45] Lang, W. B., Upper Permian formations of the Delaware Basin of Texas and New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 264–269, 1935.

[46] Bybee, H. P., and others, Detailed cross section from Yates area, Pecos County, Texas, into southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 15, pl. 2, p. 1088, 1931.

group was followed abruptly by deposition of evaporites of the Ochoa series.

TIME SPAN OF GUADALUPE MOUNTAINS SECTION

The thickness of the Permian rocks in the vicinity of the Guadalupe Mountains is impressive, and suggests the possibility that Permian time is more or less completely represented by deposits. Proof of this suggestion, however, must be obtained not from the physical relations, but from the fossils, and especially from those fossil groups whose genera have relatively narrow stratigraphic ranges and are widely distributed throughout the world. In this connection, recent studies of ammonoids and fusulinids are of interest, for they permit comparison of the Guadalupe Mountains section, not only with other parts of North America, but also with the well-known Permian marine sections of Europe and Asia. Such comparisons have recently been made by Miller,[47] Dunbar,[48] and Miller and Furnish.[49]

These comparisons suggest that the Guadalupe Mountains section contains a more or less uninterrupted sequence upward from the Pennsylvanian, comparable to that in Russia and other old-world sections. The age of the highest beds is somewhat uncertain, however, because of the general absence of fossils in the Ochoa series. The beds next beneath, in the upper part of the Guadalupe series, contain the zones of *Polydiexodina* and *Timorites*, which are evidently of upper Permian age. No fusulinid zones younger than that of *Polydiexodina* are known elsewhere, but an ammonoid zone, that of *Cyclolobus*, is considered to be younger than the zone of *Timorites*. This genus occurs in the highest Permian beds of the Salt Range of India, and also in the Himalayas and Madagascar. Miller and Furnish suggest that the Ochoa series may be equivalent to the beds containing *Cyclolobus*. If so, the top of the Ochoa series reaches nearly, if not quite, to the top of the Permian as defined.

FAUNAL SUMMARY

GENERAL CHARACTER OF FAUNAS

The Leonard and Guadalupe series of the Guadalupe Mountains contain numerous invertebrate fossils. These fossils have considerable diversity from zone to zone and facies to facies, but enough genera and species extend through the whole to give the faunas of the two series a similar aspect.

The faunas of the two series were collectively referred to as the "Guadalupian fauna" by Girty[50] in his monographic report and various shorter papers. This term is not used here because of differences between faunas of the various zones and because of possible confusion between the term and the name Guadalupe series, which is now restricted to a part of the section in the Guadalupe Mountains.

The faunas of the Leonard and Guadalupe series are definitely of later Paleozoic type, and are not like any known Triassic fauna. Here, as in the Mississippian and Pennsylvanian, one finds brachiopods, mollusks, bryozoans, crinoids, and corals belonging to well-known later Paleozoic groups. Among the brachiopods, productids and spiriferoids abound, and the cephalopods belong to the same families as those found in the beds below. As in the Pennsylvanian the most abundant Foraminifera are the fusulinids. The faunas compare favorably with those of the Mississippian and Pennsylvanian rocks in numerical abundance, in the number of invertebrate groups represented, and in the number of genera and species. In these respects they form a notable exception to the general rule that Permian faunas are impoverished and marked by the absence of numerous later Paleozoic families and genera.

Despite the broader resemblances of the Leonard and Guadalupe faunas to other Paleozoic faunas, in detail they differ notably from those elsewhere in North America, either older or contemporaneous. Many genera extend up from the underlying Pennsylvanian, and other genera seem to have developed from Pennsylvanian types, but there are few or no species in common. Some fossils, not clearly related to those below, are probably migrants from other regions. Among the distinctive features of the fauna are fusulinids and ammonoids of larger size and more complex internal structure than those of the Pennsylvanian (such as *Parafusulina*, *Polydiexodina*, *Perrinites*, and *Medlicottia*). The brachiopods include specialized genera with high cardinal areas (such as *Geyerella*, *Scacchinella*, and *Prorichthofenia*), or with other unusual modifications (such as *Leptodus*).

RELATION TO OLDER FAUNAS

The change from the Pennsylvanian fauna to the Leonard fauna begins to be evident in the intervening Wolfcamp series, or below the level of the rocks exposed in the Guadalupe Mountains. In the Wolfcamp series, as exposed in trans-Pecos Texas, some of the Leonard and Guadalupe genera and species (such as *Squamularia guadalupensis* and *Camerophoria venusta*) make their first appearance in faunas that are dominantly of Pennsylvanian aspect. The Wolfcamp series contains also a distinctive assemblage of fusulinids, including the genus *Pseudoschwagerina*. Many of the Pennsylvanian genera and most of the species come to an end at the top of the Wolfcamp series, and only a few generalized types (such as various species of *Composita*) persist. In the succeeding Leonard and

[47] Miller, A. K., Comparison of Permian ammonoid zones of Soviet Russia with those of North America: Am. Assoc. Petroleum Geologists Bull., vol. 22, pp. 1014–1019, 1938.

[48] Dunbar, C. O., The type Permian; its classification and correlation: Am. Assoc. Petroleum Geologists Bull., vol. 24, pp. 265–273, 1940.

[49] Miller, A. K., and Furnish, W. M., Permian ammonoids of the Guadalupe Mountain region and adjacent areas: Geol. Soc. America Special Paper 26, pp. 24–30, 1940.

[50] Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, 1908.

Guadalupe beds, many of the genera and most of the species are new.

RELATION TO OTHER PERMIAN FAUNAS OF NORTH AMERICA

Compared with other Permian faunas of the continent, those of the Leonard and Guadalupe series are distinguished by their diversity and novelty. Many of the faunas in other areas contain more species allied to those in the beds below, and some of them differ from those below by the disappearance of certain fossil groups, and the greater abundance of other groups, probably as a result of environmental changes. Most of the faunas in the other areas contain fewer groups than are found in the Leonard and Guadalupe faunas, probably because they were laid down in environments that were less favorable to the majority of invertebrate groups. Thus, faunas in the Cordilleran region (such as the Kaibab and Phosphoria) contain species of brachiopods that are similar to or identical with those in the Leonard and Guadalupe series, and the faunas of the Mid-continent area include ammonoids like those in the Leonard series. Yet many other fossil groups associated with these forms in the Guadalupe Mountains fail to extend into the other two provinces.

Evidently a marine environment persisted in the Guadalupe Mountains region that was as congenial to life as were the seas in other parts of the continent during preceding periods. Life continued here as before, developing into new forms that impart a distinctive aspect to the fauna. Elsewhere in the continent more rigorous conditions set in and species, genera, and even whole groups disappeared, leaving behind only those forms that were able to withstand the new environment.

DISTRIBUTION OF THE FAUNAS OUTSIDE THE GUADALUPE MOUNTAINS

The faunas of the Leonard and Guadalupe series have been recognized in several mountain areas of the trans-Pecos region south of the Guadalupe Mountains. They can be traced southward through the Delaware and Apache Mountains, which form the topographic continuation of the Guadalupe Mountains on the south (fig. 1), and are found again in the Sierra Diablo across the Salt Basin to the west. Farther southeast, in the Glass Mountains, where the Permian rocks rise again from beneath the Mesozoic and Cenozoic rocks, fossils of the Leonard and Guadalupe faunas occur abundantly. Occasional fossils of the same type have been recovered from well cores farther east. All these occurrences are in or closely adjacent to the Delaware Basin (fig. 3), which was a structural and depositional feature extending across part of the west Texas region during Permian time. The basin appears to have constituted the head of an embayment extending northward into the continent from the open sea.

ZONE FOSSILS

The faunas of the Leonard and Guadalupe series show both vertical and lateral changes in character, which have been pointed out in the discussion of the individual faunas. Many of these changes are caused by differences in facies from place to place and time to time. Some of the vertical differences, however, appear to result from gradual evolutionary changes in the character of the organisms with the passage of time. In all the fossil groups, one finds a record of the appearance, development, and disappearance of genera and species in successive beds. Further, such groups as the ammonoids and fusulinids seem to have more complex shells in the higher beds than the lower ones.

Some of these features are illustrated by figure 11, in which the known occurrences of some fusulinid and ammonoid genera are plotted on stratigraphic diagrams. Equally interesting diagrams no doubt could be prepared for other invertebrate groups were sufficient data available.

Ammonoids appear to be strongly influenced by the facies and, except for a few occurrences in the Capitan limestone, are confined to the Delaware Basin area (right half of fig. 11, *B*). By contrast, the fusulinids seem to be fairly common in all types of rock (fig. 11, *A*).

Many of the genera selected have been interpreted as closely related to one another, and some of the younger ones are thought to have developed from the older ones. Thus, Dunbar and Skinner [51] suggest that *Parafusulina* developed from *Schwagerina* and gave rise in turn to *Polydiexodina*. Also, Miller and Furnish [52] suggest that *Timorites* developed from *Waagenoceras*. The ranges of some of these genera overlap. Thus, *Schwagerina* and *Parafusulina* both occur in the upper part of the Bone Spring limestone (fig. 11, *A*), and *Waagenoceras* and *Timorites* both occur in the Bell Canyon formation (fig. 11, *B*). By contrast, so far as known, *Parafusulina* and *Polydiexodina* nowhere occur together; one is common in the Cherry Canyon formation, the other in the overlying Bell Canyon formation.

The lowest fossil zone of the Guadalupe Mountains section is in the upper part of the Bone Spring limestone of the Leonard series. Its characteristic fossils include the fusulinid genus *Schwagerina*, which first appears in the underlying Wolfcamp series, and does not extend into the overlying Guadalupe series. With it are older species of *Parafusulina*, which are smaller and less highly developed than species of the same genus in the Guadalupe series above. Ammonoids are represented by a characteristic group of species of the

[51] Dunbar, C. O., and Skinner, J. W., Permian Fusulinidae of Texas: Texas Univ. Bull. 3701, p. 581, 1937.

[52] Miller, A. K., and Furnish, W. M., Permian ammonoids of the Guadalupe Mountain region and adjacent areas: Geol. Soc. America Special Paper 26, pp. 29, 174–175, 1940.

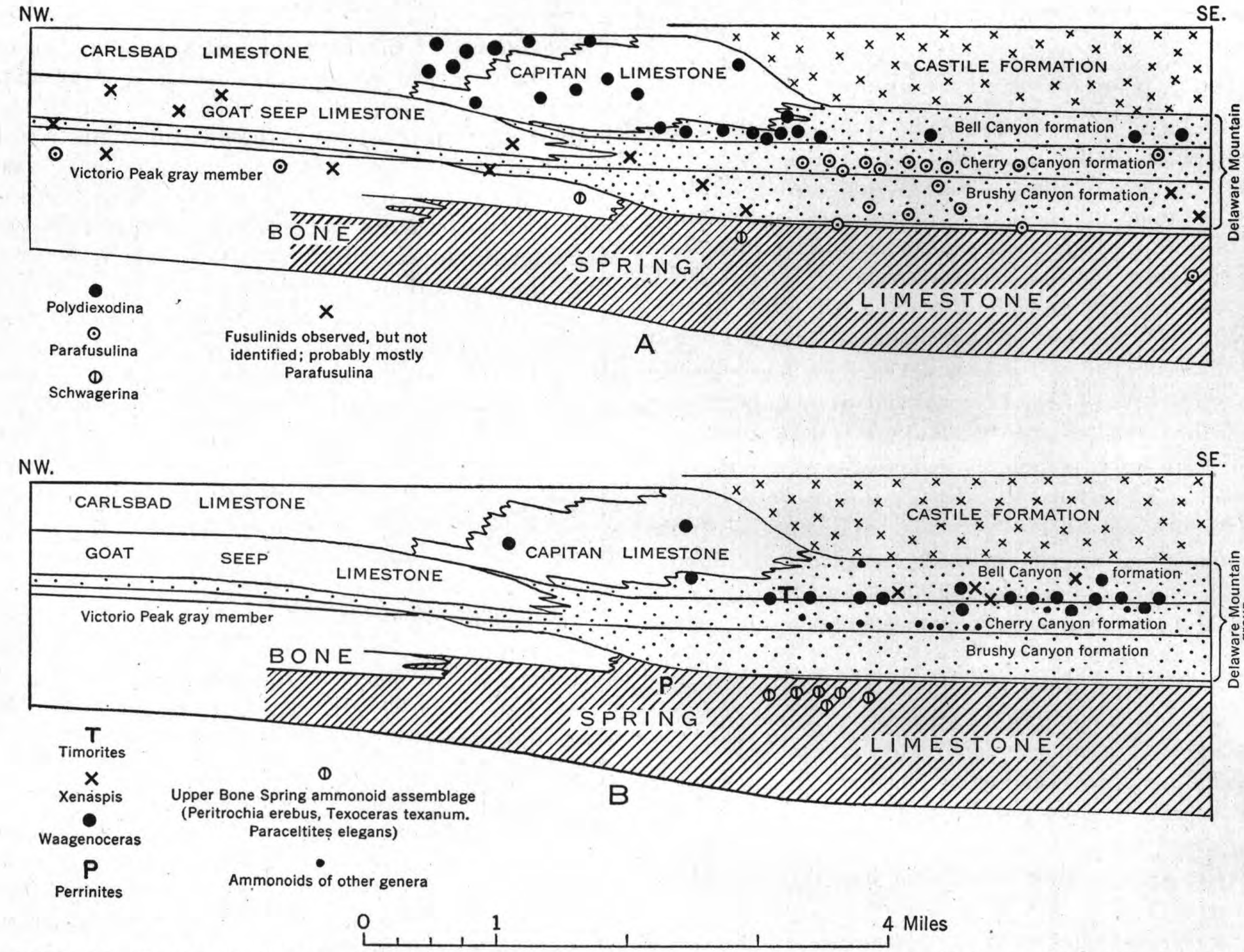


FIGURE 11.—Stratigraphic diagrams of exposed Permian rocks of southern Guadalupe Mountains, showing known distribution of two fossil groups. *A*, Fusulinids (note their occurrence in all types of rocks); *B*, Ammonoids (note their relation to rock facies).

genera *Peritrochia*, *Texoceras*, and *Paraceltites*; and by the genus *Perrinites*. The latter is rare in the Guadalupe Mountains, but very common in other west Texas sections; neither here nor elsewhere does it occur in beds younger than the Leonard. The brachiopods include a number of species not found in lower or higher beds, such as *Productus ivesi* Newberry, *P. leonardensis* King, and *Enteletes liumbonus* King. The collections suggest that many of the characteristic brachiopods disappear in the highest part of the zone, or Cutoff shaly member.

The second fossil zone lies in the lower part of the Guadalupe series, or Brushy Canyon formation. The information yielded by this unit is disappointing because many invertebrate groups are poorly represented or absent. Little is therefore known of the nature of the transition from the Leonard fauna to the Guadalupe fauna. So far as is known, however, the fauna of this zone more closely resembles those of higher rather than of lower zones. Thus, the fusulinids are all large, highly developed species of the genus *Parafusulina*, quite distinct from those in the Leonard series but identical with those in the lower part of the middle of the Guadalupe series. Also, the small brachiopod fauna contains none of the characteristic Leonard forms but contains instead such species as *Chonetes subliratus* Girty, *Productus capitanensis* Girty, *P. wordensis* King, *P. indentatus* Girty, and *P. popei opimus* Girty, that characterize the higher parts of the Guadalupe series.

The third fossil zone occupies the middle part of the Guadalupe series, or the Cherry Canyon and Goat Seep formations and associated beds. Here facies are so well differentiated that faunas in the different members of the Cherry Canyon formation differ notably from one another and also from the fauna of the Goat Seep limestone. However, all the faunas taken together constitute a relatively well characterized assemblage that differs notably from that of the Leonard series, and has many differences from that of the upper part of the Guadalupe series.

The Cherry Canyon formation contains the youngest representatives of the fusulinid *Parafusulina*, the species in the lower part being the same as those in the underlying Brushy Canyon formation. It contains ammonoids at several horizons, but only the South Wells limestone member in the upper part contains diagnostic genera, such as *Waagenoceras*. The Getaway limestone member and Goat Seep limestone contain considerable numbers of sponges, which foreshadow their still greater development in the overlying Capitan limestone.

The brachiopods, although similar to the few that are known in the underlying Brushy Canyon formation, are notably different from those in the Leonard series beneath but have many resemblances to those in the upper part of the Guadalupe series. There are, for example, species of *Productus*, *Aulosteges*, and *Spirifer* that are absent from lower horizons (*Productus pileolus* Shumard, *P. popei* Shumard, *Aulosteges guadalupensis* Shumard, *Spirifer sulcifer* Shumard, *S. pseudocameratus* Girty and *Spiriferina billingsi* Shumard). Similar relations are found in the rhynchonellid group. The greater abundance and diversity of the terebratuloids foreshadows the conditions of later Guadalupe time. An exception to the general rule is the genus *Enteletes*, which is an abundant and characteristic genus in the underlying Leonard, Wolfcamp, and older faunas. It occurs in the Goat Seep limestone but is apparently near the upper limit of its range, for it is absent from the higher beds. In his report on the faunas of the middle part of the Guadalupe series, Dr. Girty compares many of the brachiopod and mollusk species with species in Permian formations of the Cordilleran region.

The fourth fossil zone in the Guadalupe Mountains section occupies the upper part of the Guadalupe series, or Bell Canyon, Capitan, and Carlsbad formations. Here, as in the third fossil zone, faunal facies are marked, but here again, the sum of the faunas is a distinctive and characteristic assemblage.

The faunas of the zone all contain the complex, highly developed fusulinid genus *Polydiexodina*, and are thus readily distinguishable from those of the middle part of the Guadalupe series, which contain *Parafusulina*. The ammonoids are less distinctive. The most abundant genus is *Waagenoceras*, which is also characteristic of the underlying South Wells fauna. With it, however, at one locality, is *Timorites*, a genus that is believed to have developed out of *Waagenoceras*. *Xenaspis* is encountered for the first time, and is of interest because it also occurs high in the Permian sections in Asia.

The brachiopods include many species in common with those in the middle part of the Guadalupe series, but some are more abundant here than below. There are, however, some new species, such as *Chonetes permianus* Shumard, *Productus latidorsatus* Girty, *P. pileolus* Shumard, and *P. limbatus Girty*. Terebratuloids are very common, especially in the Capitan and Carlsbad formations, but *Enteletes* is no longer present. It may be significant that in his reports on the faunas of the zone Dr. Girty makes no comparisons with species of other regions, as he did for the middle Guadalupe faunas. The upper Guadalupe faunas may be younger than the Permian faunas of other regions, or there may have been no longer any marine connection between them.

With the upper Guadalupe faunas, the definite fossil record of the Permian of the area comes to an end. The few fossils and evidences of life in the overlying Ochoa series are too meager to permit one to trace the development of invertebrate life through them.

FACIES FOSSILS

Faunal facies are a marked feature of the Permian faunas of the Guadalupe Mountains. The most important differentiations in facies depend on the position of the faunas in relation to the Delaware Basin. Faunas in the basin differ from those in the reef deposits on the margin. In upper Guadalupe time, a third facies may be recognized in the back-reef Carlsbad beds deposited in the shelf area. Another type of facies differentiation is found in successive beds in the Delaware Basin sequence and probably depends on changes in the depth of water that took place there from time to time.

Differences in facies are expressed mainly by variations in the abundance of certain groups, genera, and species. Some groups are exceedingly abundant in one facies, and entirely absent in others. By contrast, a few groups, such as the fusulinids, appear to continue unchanged in number through nearly all types of deposits in the area.

The facies that developed in the Delaware Basin, in its extreme form, is characterized by an abundance of ammonoids and rhynchonellid brachiopods, and by the absence of most other groups. Some of the forms were bottom-dwellers that were able to persist in an environment of deep, stagnant water; others were swimmers or floaters whose shells sank to the bottom after death. Faunas of this type characterize the Delaware Basin area during Leonard time, during part of middle Guadalupe time (South Wells member), and during upper Guadalupe time. During lower Guadalupe time, and part of middle Guadalupe time, however, the facies are somewhat different, owing perhaps to decrease in depth and increase in agitation of the water in the basin area. During this interval, the faunas are much more diversified in the basin; there is a great increase in the numbers of pelecypods and gastropods, and many more groups of brachiopods are represented.

The reef or marginal facies is characterized by a general abundance of brachiopods, pelecypods, and gastropods, of a sort that thrive in clear, shallow waters. In this respect it resembles the normal neritic facies of other later Paleozoic systems. This condition appears to be the cause of the occurrence of *Enteletes* in the Goat Seep limestone, but not in the contemporaneous Cherry

Canyon formation;[53] and of *Meekella* in the Capitan limestone but not in the contemporaneous Bell Canyon formation. The same condition applies to the productids and spirifers that are numerically so much more abundant in the Victorio Peak gray member of the Bone Spring limestone than in the equivalent black limestone, and to the spiriferoids *Martinia* and *Squamularia* that are common in the Capitan. In addition to these features, some of the deposits (especially the Capitan) contain true reef-building forms, such as sponges and algae. In the field, their numerical abundance is far more impressive than is the diversity of genera and species.

In the upper part of the Guadalupe series, a more or less distinct subfacies may be recognized in the limestone members of the Bell Canyon formation along the base of the Capitan reef. This subfacies differs markedly from the facies in the Delaware Basin that characterizes the same limestone members farther southeast and is much more like the Capitan reef facies. It differs from the Capitan reef facies, however, in the greater abundance of bryozoans, in the presence of brachiopod and mollusk species not found in the Capitan, in its lack of sponges, and in the absence of some Capitan species belonging to other groups.

One of the most striking changes in faunal facies in the area takes place between the Capitan reef and the back-reef or Carlsbad deposits. In the back-reef facies gastropods greatly increase in numbers, but sponges nearly disappear and brachiopods are greatly reduced in numbers. Moreover, numerous important brachiopod families and genera (such as the productids and spiriferoids) that characterize most other later Paleozoic faunas are absent from the Carlsbad, although they occur in the Capitan deposits only a few miles away.

CORRELATION OF GUADALUPE MOUNTAINS SECTION WITH PERMIAN ROCKS OF OTHER REGIONS

Correlation of the Permian rocks of the Guadalupe Mountains section with the Permian rocks of other regions involves many difficulties because of the extreme variations in lithologic features and faunas in the Permian rocks. Correlation of the Guadalupe Mountains section with other sections in the Delaware and Marfa Basins is more successful than with sections in other regions because fossils of the same general facies are abundant throughout the two basins, and because the physical histories of the different parts were similar.

Correlation of the Guadalupe Mountains section, and others in the Delaware and Marfa Basins, with sections to the northwest and northeast is more difficult, because many fossil groups drop out, and many changes in lithologic character take place in these directions. For such purposes, however, the Guadalupe Mountains section is strategically located. Toward the northeast the formations of the Guadalupe Mountains pass beneath the surface but can be recognized in many wells. From such wells, their correlatives can be traced northeastward by subsurface methods into the outcrops of the Mid-continent area. Toward the northwest, beds can be traced on the surface into the central New Mexico sequence.

Questions of correlation have been discussed in some detail in another paper [54] and need not be repeated here. The conclusions given in that paper are summarized on the correlation chart, figure 12. It should be recognized that any correlation chart of the Permian prepared at this stage can be only tentative, and can represent only one of a number of possible interpretations. This chart is no exception. Various other correlations have been proposed, both recently and in the past.[55] To the writer, the correlations given on the chart appear to be the most satisfactory, but they are subject to modification as new evidence is obtained.

PALEOGEOGRAPHY

The geologic history of Permian time in the southern Guadalupe Mountains has been described and interpreted in earlier parts of the text (pp. 24–95). The geologic record in this area is probably of more than local significance, and may resemble that of considerable areas in the Delaware Basin and its margins. However, in other parts of the region of Permian deposition in the southwestern United States different conditions prevailed. The general paleogeography of this large region of Permian deposition has been discussed in other papers,[56] and is not repeated here. It is summarized in the paleogeographic maps on figures 13 and 14, which illustrate the relations during Permian time of the southern Guadalupe Mountains area to the larger region of which it formed a part.

MESOZOIC ERA

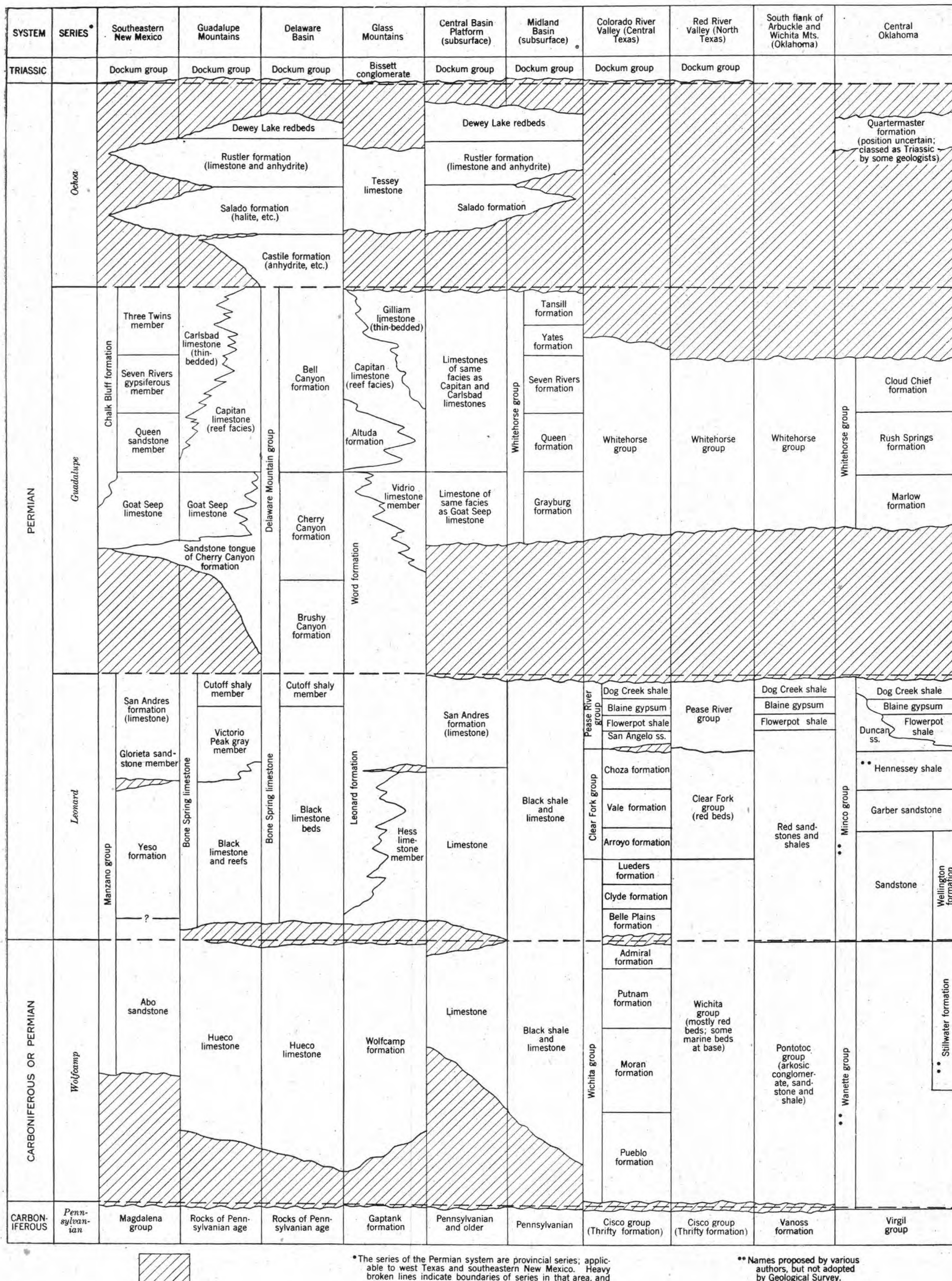
No record of Mesozoic time now remains in the rocks of the southern Guadalupe Mountains, although at one time the area was probably covered at least by Cretaceous sediments. Some deductions regarding Mesozoic time, however, can be made from tectonic features and land forms in the southern Guadalupe Mountains and from the Mesozoic rocks in nearby areas. They are mentioned in other places in this paper, and illustrated by some of the figures.

[53] Compare King, P. B., Limestone reefs in the Leonard and Hess formations of trans-Pecos Texas: Am. Jour. Sci., 5th ser., vol. 24, pp. 350–351, 1932.

[54] King, P. B., Permian of west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 26, pp. 664–711, pl. 2, 1942.

[55] For a notably different recent interpretation see Skinner, J. W., Correlation of Permian of west Texas and southeast New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 30, pp. 1857–1874, 1946.

[56] King, P. B., op. cit., pp. 711–763. Hills, J. M., Rhythm of Permian seas, a paleogeographic study: Am. Assoc. Petroleum Geologists Bull., vol. 26, pp. 217–255, 1942.



Hiatus

* The series of the Permian system are provincial series; applicable to west Texas and southeastern New Mexico. Heavy broken lines indicate boundaries of series in that area, and their correlation with sections in central and northern Texas, and Oklahoma.

** Names proposed by various authors, but not adopted by Geological Survey.

FIGURE 12.—Correlation chart of Permian rocks in parts of Texas, New Mexico, and Oklahoma.

The relations of the Mesozoic rocks of the Guadalupe Mountains region to the Permian rocks are discussed on pages 105–108 and are illustrated in figure 15, *B*. An ancient peneplain on the summits of the Guadalupe Mountains, which may be the now exhumed surface on which the Cretaceous sediments were once deposited, is described and interpreted on pp. 139–140, and is illustrated on plates 18 and 22.

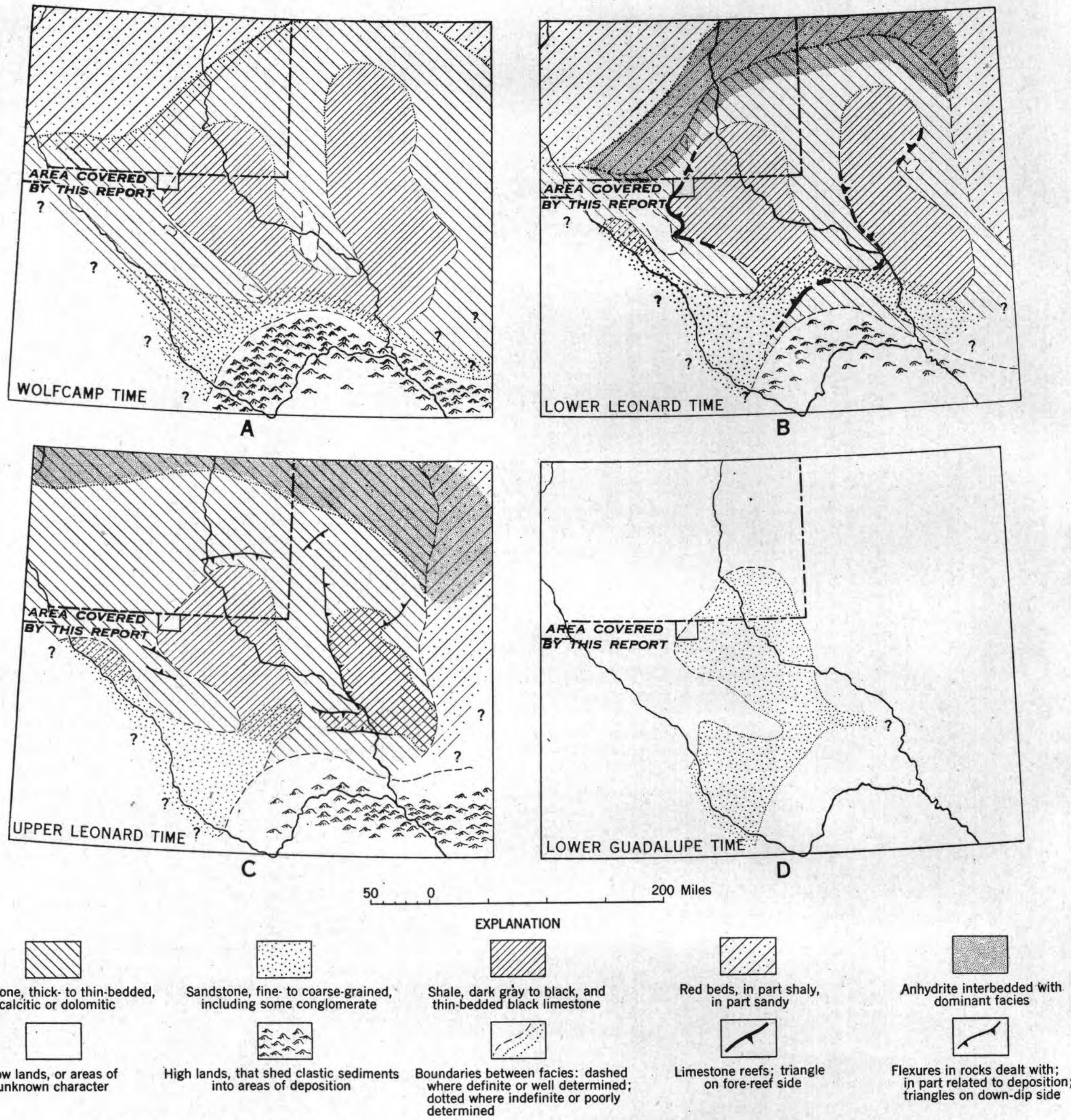


FIGURE 13.—Paleogeographic maps of western Texas during Permian time. *A*, Wolfcamp time; *B*, lower Leonard time; *C*, upper Leonard time; *D*, lower Guadalupe time.

TERTIARY IGNEOUS ROCKS

The trans-Pecos mountain area was the scene of much igneous activity during early Tertiary time. Great sheets of lava were spread over the Davis Mountains and adjacent areas, across a surface of Cretaceous and older rocks (for location of Davis Mountains, see fig. 1). Both the lavas and sedimentary rocks are penetrated by a host of small to large intrusive masses, some of which are far removed from the Davis Mountains volcanic field. In the Guadalupe Mountains region, however, little record remains of these events, and very

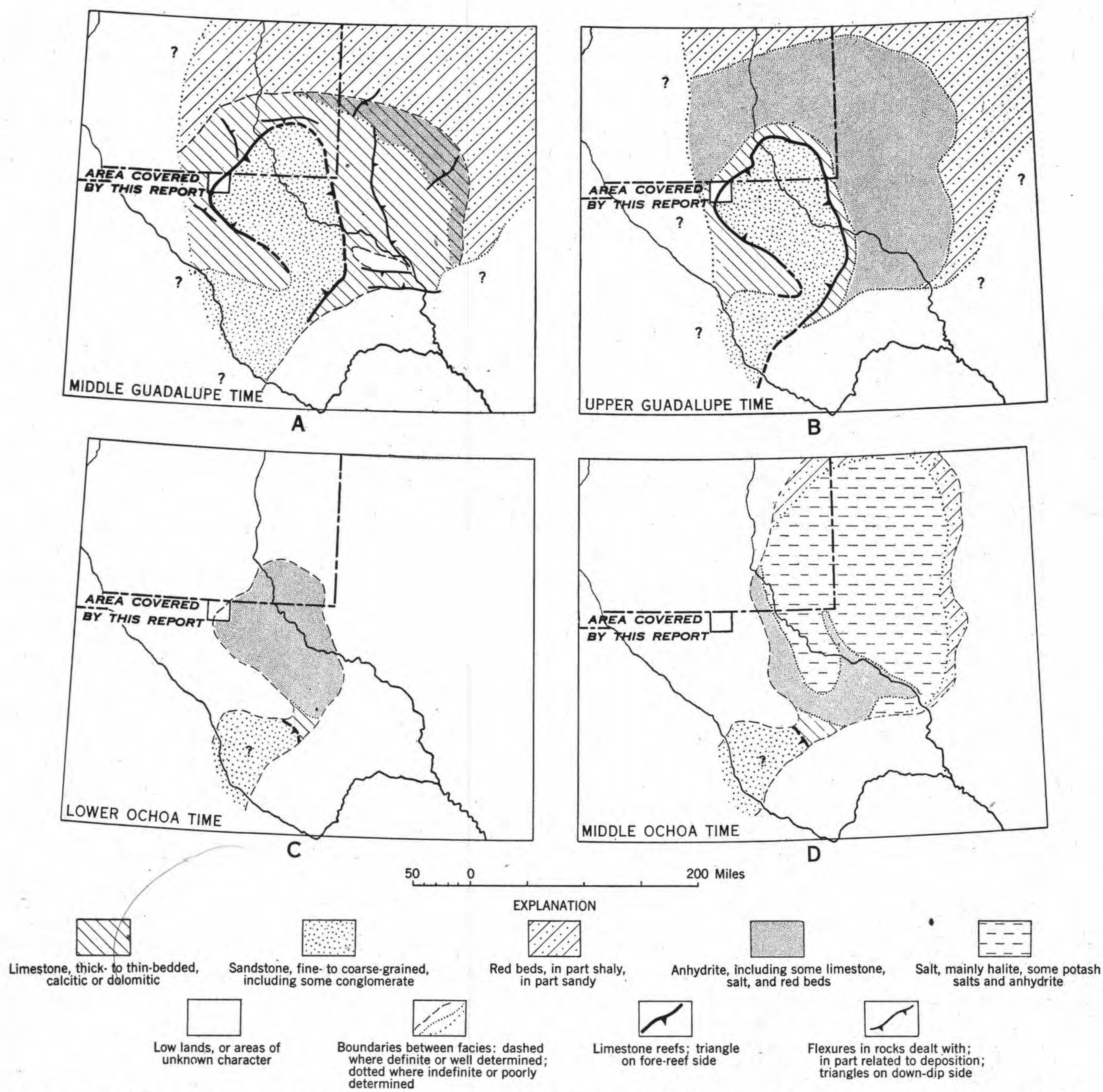


FIGURE 14.—Paleogeographic maps of western Texas during Permian time. *A*, Middle Guadalupe time; *B*, upper Guadalupe time; *C*, lower Ochoa (Castile) time; *D*, middle Ochoa (Salado) time.

little igneous activity took place there. One small intrusive plug was found within the area studied, and only a few have been found elsewhere in the mountains.

This plug, discovered by H. C. Fountain, is situated in the Delaware Mountains, in a small ravine half a mile north of Lamar Canyon and 1½ miles east of the junction of Cherry and Lamar Canyons (pl. 3). It forms a low ridge several hundred feet long, and cuts sandstones not far above the level of the Rader limestone member of the Bell Canyon formation. The sandstones have been tilted, baked, and silicified for about 10 feet from the edge of the plug. The rock itself is light gray and aphanitic and is probably a trachyte.

There is possibly another, still buried intrusive in the Guadalupe Mountains beneath the northeast slope of Lost Peak (pl. 3). Here, at the prospect known as the Calumet and Texas Mine, the Carlsbad limestone has been replaced by copper, lead, zinc, and iron minerals, which probably emanated from an igneous source beneath.

Northeast of the area studied, in the northeast part of T. 26 S., R. 24 E., Eddy County, New Mexico, a dike of igneous rock cuts the anhydrites of the Castile formation. I have not visited this locality, and know nothing of the character of the rock.

TECTONICS

Guadalupe Peak, the highest summit of the Guadalupe Mountains, lies at the crest of their wedge-shaped southern end (fig. 2). From its top, one may on clear days look out over a large section of the trans-Pecos region of Texas and New Mexico, to a horizon 100 miles or more away. One's most lasting memory of the view from the peak is the contrast that it reveals between the country to the east and to the west.

Eastward the mountains descend in a long slope to the Pecos River, 50 miles away, whose valley may be seen as a dark band in the distance. On the sky line beyond the river is the white rim of the Llano Estacado; there are no more mountains in this direction (fig. 1). As the eye scans the land on the nearer side of the river, diverse elements in the sloping surface of the mountains become evident, which may be distinguished by their form, color, and height. To the south are the flat-topped, brown, desolate ridges of the Delaware Mountains, standing several thousand feet lower than the peak. East of them, down the slope, are the gray, rounded hills of the Gypsum Plain (fig. 2). Northeastward are the much higher, sharper ridges of the Guadalupe Mountains, with white limestone ledges here and there, interspersed with darker patches of forest.

Erosion has left its mark over the whole sloping surface. The Delaware Mountains and Gypsum Plain are penetrated by an intricate network of water courses, and the Guadalupe Mountains are trenched by steep-sided canyons. The dip of the rocks on the sloping surface appears to be gentle and unbroken. In the Delaware Mountains, one can distinguish thin, straight, bedding planes, inclined at a low angle to the east.

Toward the west, the observer finds a land of entirely different aspect. He is standing on the edge of a precipice, of which the peak is the highest point, and looks out, not over plains and plateaus, but over an expanse of varied, irregularly placed mountain ranges and intervening desert basins. The effects of erosion are not as impressive as toward the east. The mountain sides are gashed by many short, steep water courses, but the eye fails to distinguish any canyons penetrating deeply into the mountains. In the desert basins, instead of long drainage lines and a network of tributaries, one sees a host of alkaline flats and ephemeral lakes, whose white crusts gleam in the sun. One notes also the steep-sided, rectilinear edges of the mountain ranges, and the occasional outcrops of tilted strata. One infers that the land to the west may derive its form more from the raising and lowering of blocks of the earth's crust than from the wearing down of the basins between the mountains.

Toward the west, the gently sloping surface of the Guadalupe and Delaware Mountains breaks off abruptly in a west-facing escarpment. The precipice on the west side of Guadalupe Peak forms the local rim of the escarpment. Below it, the declivity continues across steep rock slopes, and then over more gently sloping alluvial aprons, which extend out into the Salt Basin, the desert basin that flanks the escarpment on the west. The precipice ends a short distance south of the peak in the monolithic rock of El Capitan, but the steep slopes below continue southward along the same trend in a steplike escarpment that forms the western edge of the Delaware Mountains. The outer ends of the rock spurs of the escarpment meet the alluvial apron along an even base line, as though they had been outlined by faults.

Projecting from the alluvial apron, between the base of the escarpment and the floor of the Salt Basin, are occasional low ridges, whose conspicuous ledges indicate that they are islands of bedrock, not quite engulfed by alluvium. The color and texture of the outcrops leads one to suspect that the ridges are composed of essentially the same rocks as those in the Guadalupe and Delaware Mountains. Many of the ridges are cuestas whose steep faces are toward the east, indicating that the strata dip more steeply here than in the mountains, and that the dip is in a reverse direction, or westward toward the basin.

Viewed from the peak, the Guadalupe and Delaware Mountains are thus seen to be a great asymmetrical block of the earth's crust, elongated north and south, with a gentle slope on the east and a steep escarpment on the west. Apparently the block has been uplifted, the uplift having been sufficiently recent for the surface form to reflect rather well the underlying structure. It is therefore probably of Cenozoic age. The uplift appears to have tilted the east side of the block but to have faulted off its western side, leaving a narrow, downthrown flank, remnants of which project here and there from the alluvial apron to the west. East of the Guadalupe and Delaware Mountains, the rocks flatten out beneath the Llano Estacado, but to the west, to judge from the ranges in view from the peak, are other, similar, faulted uplifts.

TECTONIC FEATURES OLDER THAN THE UPLIFT OF THE MOUNTAINS

The strata of the Guadalupe and Delaware Mountains are tilted eastward, away from the crest of the mountain uplift with a dip sufficiently low to produce plateaulike and cuestalike land forms. The faults that fringe the base of the west-facing escarpment of the mountains lie parallel to the north-south elongation of the uplift. These relations suggest that the tilting and faulting of the rocks are features related to the uplift of the mountain area and that the uplifted rocks had hitherto been little disturbed.

Detailed study of the Guadalupe Mountains and adjacent ranges, however, indicates that the region was disturbed several times, in various degrees of intensity, before the mountains were uplifted in their present form. The effects of three of these earlier disturbances (during the late Carboniferous, during the Permian, and during the early Mesozoic) are suggested by figures 15 and 16.

FEATURES OF PRE-PERMIAN AGE

The oldest known tectonic features near the Guadalupe Mountains are displayed in the pre-Cambrian rocks exposed in the south part of the Sierra Diablo (shown by special patterns on figure 15, *A*, and plate 21). These features have been summarized in another paper;[57] their strikes are suggested on plate 21. The pre-Cambrian rocks are exposed over too small an area for much to be learned about their regional pattern or their relation to later tectonic features.

The next important tectonic features are of late Pennsylvanian, pre-Wolfcamp age. They are widely exposed in the Sierra Diablo, and some evidence regarding them can be obtained from wells drilled near the Guadalupe Mountains. The nature of the features is suggested by figure 16, *B*, which is a paleogeologic map of the surface on which the Wolfcamp series was deposited. As indicated by this map, the Sierra Diablo area was uplifted, faulted, and deeply eroded before Wolfcamp time, but the Guadalupe Mountains area was little disturbed. Of special interest are the west-northwestward trending faults and belts of outcrop in the Sierra Diablo, which lie parallel to younger tectonic features described below.

FEATURES OF PERMIAN AGE

The Permian rocks of the Guadalupe Mountains, the Sierra Diablo, and nearby ranges contain a number of features, partly of depositional and partly of tectonic origin, that are apparently of Permian age. The features in the southern Guadalupe Mountains have been described in the chapter on Permian stratigraphy (pp. 18–86) and are illustrated in the sections on plate 17. Their regional relations are summarized in figure 16, *A*, which is a map showing the positions of monoclinal flexures and reef zones in the Permian rocks and their relation to the northwest part of the Delaware Basin.

One of the features, the Bone Spring flexure, is exposed in the southern Guadalupe Mountains, and is overlain by the Goat Seep and Capitan reefs, of Guadalupe age, which form zones with the same northeastward trend. Two other features, the Babb and Victorio flexures, are exposed in the Sierra Diablo and trend west-northwest. Through parts of their courses, these flexures are followed by reefs of Leonard age. To the east, in the Apache Mountains, a reef zone is formed by the Capitan limestone which likewise trends westnorthwest. On the Victorio flexure exposures extend into the basement rocks, and these basement beds are flexed downward in the same manner as the younger beds.

All three flexures appear to have been in existence during the deposition of the Permian rocks that now cover them. Not only are they followed by Permian reef zones of the same trend, but the deposits on the lower sides, seem to have been laid down in deeper water than those on the upper sides. Moreover, on the Bone Spring flexure, the Delaware Mountain group overlaps the Bone Spring limestone; near the Babb flexure the Bone Spring overlaps the Hueco limestone; and on the Victorio flexure the Bone Spring contains conglomerates apparently derived from the Hueco. The flexures apparently outlined the margins of the northwest part of the Delaware Basin, which was an area of subsidence in Permian time. Perhaps they were caused by deformation along local lines of weakness during the sinking of the crust in the basin area.

The flexures and reef zones of Permian age are crossed by the dominant later tectonic trends; those in the Guadalupe Mountains are cut cleanly by the younger north-northwestward trending faults and are unrelated to them or other tectonic features. Those in the Sierra Diablo, however, are parallel to prominent sets of westnorthwestward trending faults and joints, as shown on plate 21. As indicated by figure 16, *B*, this trend was already in existence during the late Pennsylvanian, pre-Wolfcamp disturbance.

FEATURES OF EARLY MESOZOIC AGE

Further disturbances probably took place in post-Permian and pre-Cretaceous time. At any rate, the Cretaceous rocks that are extensively exposed south of the Guadalupe Mountains lie on a variety of Permian formations, and in the southern Sierra Diablo they overlap onto the pre-Cambrian formations. These relations are shown on figure 15, *B*, which is a paleogeologic map of the surface on which the Cretaceous rocks were deposited. The map is partly hypothetical, in that the Cretaceous is now missing entirely in some areas, such as the Guadalupe Mountains. It was assumed that the summit peneplain that bevels the rocks of the Guadalupe Mountains was approximately the surface on which the Cretaceous sediments were once deposited.

The features shown on figure 15, *B*, are largely a reflection of those of Permian time, as may be seen by comparison with figure 16, *A*. The semicircular outline of the Delaware Basin is still evident, and also the positive area of the southern Sierra Diablo. This persistence raises a question as to what extent the features shown on figure 15, *B*, were merely formed by peneplanation of Permian and older Paleozoic features. Positive areas of Paleozoic time were covered by thinner sequences of deposits than the negative areas,

[57] King, P. B., Older rocks of the Van Horn region, Texas: Am. Assoc. Petroleum Geologists Bull., vol. 24, pp. 145–151, 1940.

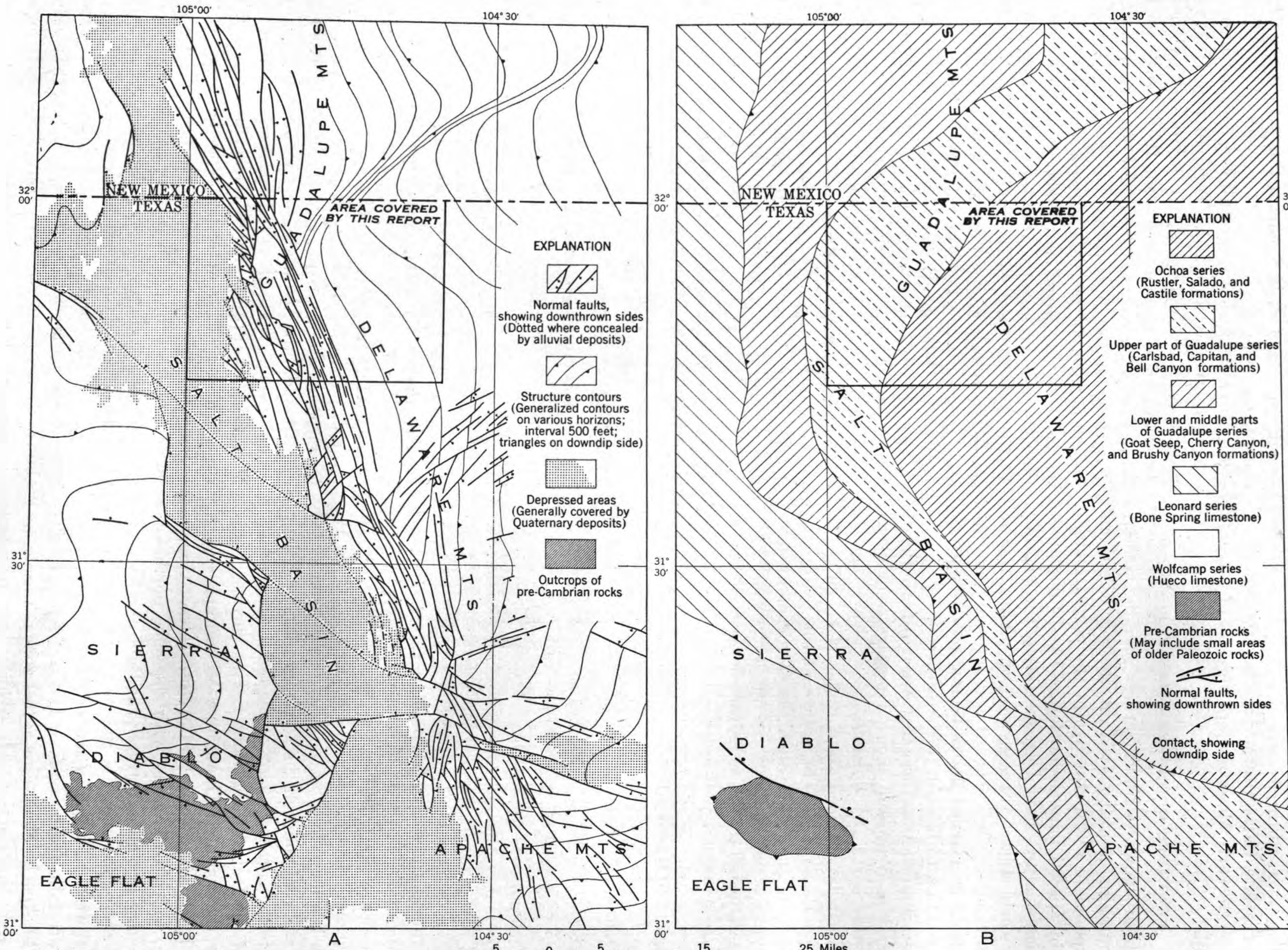


FIGURE 15.—Maps showing tectonic features of Guadalupe Mountains and vicinity during different periods. *A*, Tectonic features of Cenozoic time; *B*, Tectonic features of early Mesozoic time, as suggested by paleogeologic map of surface on which Cretaceous was deposited.

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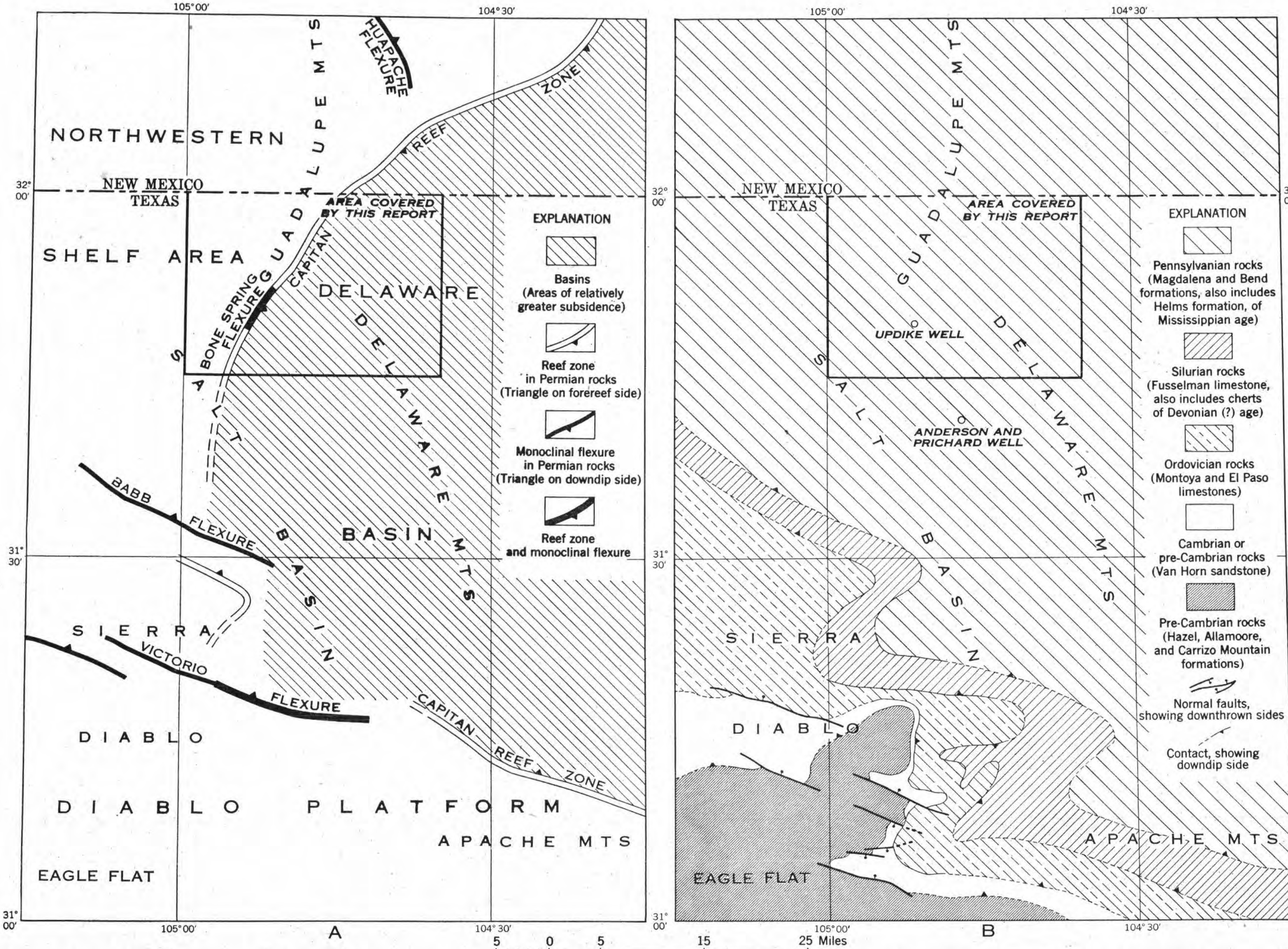

FIGURE 16.—Maps showing tectonic features of Guadalupe Mountains and vicinity during different periods. *A*, Tectonic features of Permian time; *B*, Tectonic features of late Carboniferous time, as suggested by paleogeologic map of surface on which Wolfcamp series was deposited.

hence early Mesozoic erosion penetrated the older rocks more readily in those places than in others. Most of the features shown on figure 16, *B*, could therefore have been formed by erosion of Paleozoic structural features during the early Mesozoic, without the aid of any early Mesozoic movement. Some movement during early Mesozoic time, however, is suggested by the fault indicated on the north side of the pre-Cambrian inlier in the southern Sierra Diablo.

Whatever their cause, the early Mesozoic features have had an important influence on the aspect of the modern mountain ranges. As indicated by the westward overlap of the Cretaceous, which lies on the Ochoa series to the east and in places on the pre-Cambrian to the west, the dip away from the east flank of the Guadalupe and Delaware Mountains uplift is in part of pre-Cretaceous age. Further, the Guadalupe Mountains now stand several thousand feet higher than the Sierra Diablo, yet they expose only later Permian rocks, whereas the latter exposes older Permian, older Paleozoic, and pre-Cambrian rocks. Structure contours drawn on the top of the pre-Cambrian indicate that the pre-Cambrian [58] in the south part of the Sierra Diablo stands higher than in any other area in trans-Pecos Texas. Most of this uplift resulted from the greater structural height of the Sierra Diablo in early Mesozoic time, for the range was not uplifted as much as the Guadalupe Mountains in Cenozoic time. Similar conclusions were reached by Adams.[59]

FEATURES OF EARLY CENOZOIC AGE

The Permian rocks now exposed in the Guadalupe Mountains had a broadly warped structure by Cretaceous time. Afterwards, as shown on figure 15, *A*, and plate 21, they were broken into tilted fault blocks. The close relation of the fault blocks to the present topography suggests that most of the post-Cretaceous disturbance took place in later Cenozoic time, which implies that the region was little deformed during early Cenozoic time.

Some movements probably took place in early Cenozoic time, however, for elsewhere in the Cordilleran province, even nearby in trans-Pecos Texas, there were important disturbances during this period. Cretaceous rocks that were closely folded and overthrust during the early Cenozoic crop out, for example, in Devil Ridge, about 70 miles southwest of the Guadalupe Mountains, (shown in the southwest corner of pl. 21).[60] These rocks are a part of a larger area of deformed rocks that includes the Malone, Quitman, and Eagle Mountains (fig. 1).[61]

In southern trans-Pecos Texas, there appear to have been at least two early Cenozoic movements, one older and the other younger than such volcanic rocks as are found in the Davis Mountains area. The volcanics have been shown by plant and vertebrate fossils to be of Eocene and Oligocene age.[62] The older movement therefore took place in late Cretaceous or early Tertiary time, and corresponds to the Laramide movements of other parts of the Cordilleran province. The younger movement took place in post-Oligocene time, and perhaps in the mid-Tertiary, because the folded rocks are cut by normal faults that are presumably of late Tertiary age.[63]

If disturbances took place in the Guadalupe Mountains during these epochs, they were of small magnitude. Broadly considered, the total result of all the Cenozoic movements in the area studied is not great. If most of the movements are of later Cenozoic age, those of early Cenozoic age were only a small fraction of the whole.

TECTONIC FEATURES RELATED TO THE UPLIFT OF THE MOUNTAINS

FORM OF THE UPLIFT

GENERAL RELATIONS

The area studied is a typical part of the uplifted block of the Guadalupe and Delaware Mountains, whose broader features have already been noted in the view from Guadalupe Peak. It includes a segment of the crest of the uplift about 18 miles long, and extends 12 miles east and 7 miles west from the crest.

The broader tectonic features of the area are suggested by the topography, for the higher parts of the area are those which have been uplifted, and the lower parts are those which have been depressed. The original form of the uplift, however, has been considerably modified by surface agencies. The higher parts have been worn away by erosion, and the lower parts have been more or less filled by alluvial deposits.

The tectonic features are shown by the four sections on plate 3, and by the contour lines on the tectonic map (pl. 20). The contours have been drawn on the base of

[58] Moss, R. G., Buried pre-Cambrian surface in the United States: Geol. Soc. America Bull., vol. 47, pl. 4, p. 948, and p. 959, 1936.

[59] Adams, J. E., Highest structural point in Texas: Am. Asso. Petroleum Geologists Bull., vol. 28, pp. 562–564, 1944.

[60] Smith, J. F., Stratigraphy and structure of the Devil Ridge area, Texas: Geol. Soc. America Bull., vol. 51, pp. 629–636, 1940.

[61] Baker, C. L., Exploratory geology of a part of southwestern trans-Pecos Texas: Texas Univ. Bull. 2745, pp. 44–47, 1927; Baker, C. L., Structural geology of trans-Pecos Texas, in the geology of Texas, vol. 2: Texas Univ. Bull. 3401, pp. 201–203, 1935. Albritton, C. C., Stratigraphy and structure of the Malone Mountains, Texas: Geol. Soc. America Bull., vol. 49, pp. 1801–1804, 1938. Huffington, R. M., Geology of the northern Quitman Mountains, trans-Pecos Texas: Geol. Soc. America Bull., vol 54, pp. 987–1048, 1943.

[62] Berry, E. W., An Eocene flora from trans-Pecos Texas: U. S. Geol. Survey Prof. Paper 125, pp. 1–9, 1921. Sellards, E. H., Adkins, W. S., and Plummer, F. B., The geology of Texas, vol. 1, stratigraphy: Texas Univ. Bull. 3232, p. 805, 1933.

[63] King, P. B., Outline of structural development of trans-Pecos Texas: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 251–252, 1935.

the middle part of the Guadalupe series—that is, on the contact between the Cherry Canyon and Brushy Canyon formations of the Delaware Mountain group to the southeast and on the contact between the sandstone tongue of the Cherry Canyon formation and the Bone Spring limestone to the northwest. This key horizon lies near the middle of the exposed section, or above the prominently flexed lower beds and below the irregular reef deposits of the younger beds. Contours drawn on it thus show mainly the warping and faulting associated with the uplift of the mountains. Most of the features of Permian age are eliminated, except possibly the mild flexing of the latter part of the period.

As shown by the contours, the strata rise from a low position at the east and west edges of the area studied to a high position near the center. The altitude of the base of the middle part of the Guadalupe series at the east edge of the area is 3,000 feet above sea level, and near the west edge is 2,000 feet. Near the center of the area, not far north of Guadalupe Peak, it rises to more than 6,750 feet above sea level. The crest of the uplift extends north and south from this place along the escarpment at the west edge of the Guadalupe and Delaware Mountains.

The simple, archlike form suggested by these figures is greatly complicated by faulting. The rocks along the crest and western flank of the uplift in a belt about 10 miles wide, are broken by numerous faults whose general trend is parallel to that of the crest. East of the belt, as shown by wide exposures, the rocks are not faulted. The west edge of the fault belt is not known, as the bedrock on this side is overlapped by the alluvial deposits of the Salt Basin. From the latitude of Guadalupe Peak southward, the crest of the uplift is flanked by one of several faults, here called the Border fault zone because the faults serve to outline the western border of the mountains. In a narrow belt on the west, or downthrown side of the zone, the key horizon sinks to 2,500 feet above sea level, or to about its altitude at the east and west edges of the area mapped.

CREST AND EASTERN FLANK

Within the area studied, the crest of the Guadalupe and Delaware Mountain uplift lies at the western edge of the mountains, and along the east side of the Border fault zone. Its highest point is a short distance north of Guadalupe Peak, where the altitude of the key horizon is more than 6,750 feet above sea level (pl. 20). Here the rocks are bent into a half dome, convex to the east. Northward and southward along the crest the altitude of the key horizon sinks to a little more than 5,000 feet.

The half dome may have its origin in movements older than the faulting, for its crest lies near the upper end of the Bone Spring flexure, of Permian age. Other, less-definite, much-faulted, high-standing areas to the northeast and southwest may lie on the extension of the same older tectonic trend. There is also a vague suggestion of northeast-trending cross-folds to the south. Thus, the low point on one fault block is likely to be adjacent to the low point on the next block, although it has a different structural height. Further, on the unfaulted eastern flank of the uplift, local variations may be observed in the angle of dip and direction of strike. Most of them are too small to influence the trend and spacing of the contour lines, but in the vicinity of Frijole Post Office there is more pronounced warping, which apparently has a northeast trend.

East of the crest of the uplift the strata dip at an angle of 2° or 3° east-northeast, or at the rate of about 250 feet per mile. (Some of these tilted strata appear in the foreground of plate 4, *A*.) The continuity of the slope is much disturbed by faults for about 4 miles east of the Border fault zone, but farther east it extends unbroken past the edge of the area studied, and far beyond to the eastern base of the uplift along the Pecos River (pl. 21).

The faults that disturb the strata in the 4-mile belt east of the Border fault zone have straight or gently curved traces which trend generally north-northwest, parallel to the crest of the uplift (pl. 20). Most of them are of small displacement, and many are downthrown westward. Through most of the area studied, the easternmost faults of the group are a part of the feature here called the Lost Peak fault zone, which pursues a remarkably straight, north-northwestward course across the area, and makes a sharp separation between the faulted tract to the west and the undisturbed tract to the east (as shown in section *D–D*, pl. 3).

Within the faulted belt one large tract in which there are no faults stands out prominently. It is here named the Guadalupe Peak horst, from the peak that lies near its center. The horst is about 9 miles long and 2 to 3 miles wide, and is elongate north-northwestward. Within it is the half dome that is the highest part of the uplift. It includes the highest mountains of the area, carved from the Capitan limestone and associated formations. The horst is bounded on the west by the Border fault zone and on the north and east by smaller faults, all of which are downthrown away from it. To the southeast, it is not bounded by a single fault, but is penetrated by numerous, small, north-northwestward trending minor faults that die out northwards in the horst.

The areal relations of the Guadelupe Peak horst may be seen on the two geologic maps, plates 3 and 20. On the latter, note the greater structural height of the horst than its surroundings, as indicated by the contours. An idea of the structure of the horst may be gained from section *B–B′*, plate 3, although this section crosses its southern end where the continuity of the strata is interrupted in the middle by a pair of minor faults. The topographic features of the horst, including the lofty cliffs and peaks of limestone, can be seen on plates 1 and 5, *A* (as viewed from the south) and plate 5, *B* (as viewed from the west).

Between the Guadalupe Peak horst and the Lost Peak fault zone at the eastern edge of the faulted belt is a graben, or strip of downfaulted rocks, as much as 1½ miles wide and cut by several minor faults. North of the horst the graben is followed by the north-draining depression of West Dog Canyon. South of the horst it forms the Getaway graben. Near Getaway Gap, from which the graben is named, the downfaulted rocks have been carved into a prominent, longitudinal topographic depression.

The areal relations of the graben are shown on plates 3 and 20. On the former, note the outliers of the Bell Canyon formation along it in the south part of the area, far to the west of their normal position on the east flank of the mountains. On the latter, note how its structurally low position in relation to its surroundings is indicated by the contours. For the structure of the graben, see sections *A-A′* and *D-D′*, plate 3, in each of which it appears to the left of the Lost Peak fault zone.

Near the north edge of the area studied, a large fault appears east of the Lost Peak fault zone, and continues northward into New Mexico along the east side of Dog Canyon. The fault trends north-northeast in this area, but to the north, in New Mexico, it curves to a northerly, or even a north-northwesterly course (pl. 21). In New Mexico it and the associated faults, here called the Dog Canyon fault zone, form the eastern boundary of the faulted belt; the crest of the uplift lies along their eastern side. To the west, in the depression drained by Dog Canyon and in the somewhat higher Brokeoff Mountains beyond, the rocks are structurally lower, and are faulted into many narrow slices. Some of the fault slices of the Brokeoff Mountains extend southward, west of the Lost Peak fault zone, into the area studied. In this direction, the strata rise toward the Guadalupe Peak horst, which bounds the fault slices on the south.

The Dog Canyon fault zone extends for only a few miles into the area covered by the two geologic maps, plates 3 and 20. Its structure in this segment is shown on section *A-A′*, plate 3. For its extension northward into New Mexico, see the regional tectonic map, plate 21. Compare this with the topographic relations shown on figure 2, where the position of the zone is suggested by a west-facing escarpment that extends northward from El Paso Gap. For a view of the region crossed by the Dog Canyon fault zone, see the panorama, plate 14, *A*, where the escarpment above noted stands out prominently in the middle distance. On figure 2, note also the topography of the Brokeoff Mountains, which reflects the structure to a large degree.

BORDER FAULT ZONE

Beginning somewhat north of the latitude of Guadalupe Peak, and extending southward, the crest of the Guadalupe and Delaware Mountains uplift is broken off on the west by the Border fault zone. The faults of the zone drop the strata westward from 2,000 to 4,000 feet. In places, as west of Guadalupe Peak, the fault separates the uplifted bedrock on the east from alluvial deposits that cover the depressed rocks on the west; in places the alluvium covers the trace of the fault itself; elsewhere, as in the Delaware Mountains, the fault separates uplifted rocks from downfaulted, much disturbed rocks, which crop out in low hills to the west.

The displacement on the zone is especially well revealed for several miles northwest of the point where it is crossed by United States Highway No. 62. Here, one may stand on ledges of downfaulted rocks near the fault and, looking northward, see the same beds projecting from the slopes of Guadalupe Peak and El Capitan, 2,000 feet higher.

The areal relations of the Border fault zone are shown on the two geologic maps, plates 3 and 20. On the former, the displacement on the zone is suggested by the relatively young Permian rocks which project through the alluvium to the west of it, as compared with the relatively old rocks on its east side. The displacement is more strikingly shown on the accompanying structure sections *B–B′*, *C–C′*, and *D–D′*, and by means of structure contours on plate 20. For a view of an exposure of one of the faults in the zone, see plate 14, *B*, where the Bone Spring limestone is upfaulted against older Quaternary gravel deposits. The displacement of the gravel in this vicinity is relatively slight, as compared with that in the underlying bedrock, as is shown on figure 17, *B*.

The exposures north of United States Highway No. 62 may be seen on plate 5, *A*. Those of the downfaulted rocks, including formations of the Delaware Mountain group, fringe the outer bench of the escarpment below Pine Top Mountain, and the same beds in the upfaulted block form the slopes below El Capitan, a little to the left.

At most places the large displacement of the rocks along the zone takes place along a single fault. None of these single faults is continuous along the entire course of the zone, and the greatest break lies now to the east and now to the west of its general north-northwestward course. Unlike the smaller faults to the east, the faults of the Border zone trend in highly varying directions. Some are straight, others curved, some trend north-northwest, and others east of north. Some of the offset parts of the zone are connected by west-northwest trending faults. The zone bends to the west around the Guadalupe Peak horst, whose western side projects as a blunt salient into the downfaulted area beyond.

CUTOFF MOUNTAIN AREA

A mile or so north of the latitude of Guadalupe Peak, the Border fault zone passes into the interior of the mountains, and near the north end of the Guadalupe Peak horst splits into several branches, no one of which has a large displacement. The high escarpment that rises east of the Border fault persists northward to the northwest corner of the horst, but fades out beyond.

The bedrock west of the zone in the latitude of Guadalupe Peak is mostly covered by alluvium, but it rises northward into low mountains that fringe the western base of the high escarpment. Where the high escarpment fades out, the low mountains themselves form the edge of the Guadalupe range. They are a part of the Brokeoff Mountains, which are better developed to the north, in New Mexico. Their highest summit within the area studied is Cutoff Mountain.

These relations can be seen on the panorama, plate 5, *B*, a view of the Guadalupe Mountains from the west, but the features shown on it should be compared with their appearance on the two maps, plates 3 and 20. On plate 5, *B*, note the high escarpment that rises east of the Border fault, which extends north from El Capitan to the Blue Ridge, beyond which it disappears. Below and in front of it, note the foothills of downfaulted rock, which to the south (as near point 4909) are low and discontinuous, but to the north (as near points 5284 and 6305) stand in high ridges. The Cutoff Mountain section is to the north (left) of the Blue Ridge. To see the difference in structure between this segment of the escarpment and that farther south, compare sections *A–A′* and *B–B′*, plate 3.

Near Cutoff Mountain, and elsewhere in this area, the rocks bend over from a nearly horizontal position on the rim of the mountains to an inclined position on the face of the escarpment, and at the base dip beneath the alluvial deposits of the Salt Basin. The beds on the face of the escarpment dip as steeply as 45°, and many of the resistant layers are carved into dip slopes (such as those below point 5443, pl. 5, *B*). The inclined beds are crossed diagonally by interlacing, northwest-trending faults of small displacement, many of which are downthrown to the northeast in the opposite direction to the dip of the beds. Each fault originates to the southeast as a branch of the Border zone and disappears to the northwest by passing under the alluvial deposits beyond the escarpment. The escarpment in this area is thus bordered by no single fault, and has been outlined more by flexing than by faulting.

WESTERN FOOTHILL AREA

South of the latitude of Guadalupe Peak and west of the Border fault zone the bed rock projects in many low foothill ridges. The ridges are surrounded and separated by alluvial deposits, and the structure is less easy to decipher than in the mountains to the east where the exposures are continuous. Some of the alluvial cover is thin, but in places it has apparently been deposited to a considerable thickness in deeply depressed fault blocks. The highest foothills are southwest of Guadalupe Peak, where the Capitan and associated limestones form the steep-sided ridges of the Patterson Hills. Southeast of the Patterson Hills the foothills are lower, but more because they are composed of poorly resistant sandstones (Delaware Mountain group) than because of any diminution in their structural height.

The rocks of the foothill area are the same as those that form the mountains to the east, but they have been depressed to a much lower position. They dip generally west-southwest at an angle of about 15°, but in some places they dip at angles as low as 5° or as high as 45°. In general, the older rocks of the succession lie to the east and the younger rocks to the west, in harmony with the prevailing dip. Along United States Highway No. 62 the first rocks seen west of the Border fault zone are thus the prominently exposed, massive sandstones of the Brushy Canyon formation, tilted westward, away from the mountains. Farther west the higher rocks of the succession are encountered, such as the Capitan limestone, and are seen to dip in the same direction until they pass beneath the alluvial deposits of the Salt Basin beyond. One thus receives the impression at first that the rocks of the Delaware and Guadalupe Mountains bend over to the west as a great fold, with little or no faulting,[64] but this impression is modified by further study. Older rocks are found in the foothills considerably west of their anticipated positions, and younger rocks are found close to the Border fault zone. Closely adjacent exposures are discovered that consist of rocks many hundreds of feet apart stratigraphically. It is thus clear that the structure of the foothill area is greatly complicated by faulting.

For the areal relations of the foothill zone, see the two geologic maps, plates 3 and 20. Note on the former the disconnected nature of the exposures of Permian rocks, and the extensive areas of alluvium. Note also that the same beds are exposed in the area as in the mountains to the east, but in more confused, less regular order. On plate 20, the structure contours show that the beds stand at a much lower height than in the mountains.

The panorama, plate 5, *A*, shows the rocks of the foothill area that are exposed near United States Highway No. 62. The Border fault zone follows the bench at the foot of the mountains in the middle distance, in the center and right-hand parts of the view. Note that the rocks beyond it are either horizontal or dip gently to the east (right), whereas those on the nearer side, projecting in occasional hills, dip more steeply to the west (left). The apparent anticlinal structure is suggested by the outcrops designated by letter symbols on the view, such as those of the Brushy Canyon formation near the Border fault and of the Capitan limestone farther west, in the Patterson Hills. Note, however, that one outcrop of Bell Canyon formation is indicated close to the Border fault, which suggests that the relations are more complicated. The true structure of the nearby hills is shown in section *C–C′*, plate 3, and of the more distant hills in section *B–B′*.

The faults of the foothill area are not easy to map, as their traces are widely covered by alluvium. So far as they have been worked out, their general trend is

[64] As represented, for example, in Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, pp. 53–55, 1904; Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. Amer. Bull., vol. 37, section 5, fig. 2, p. 417, 1926.

north-northwest, but there are some of west-northwest and some of north-northeast trend. Most of them are downthrown to the east, opposite to the direction of dip and in the opposite direction from the faults of the Border zone. The fault blocks immediately west of the Border zone thus stand much lower than those on either side of them, somewhat after the fashion of a sunken keystone (as in section *D–D′*, pl. 3).

The sunken tract west of the Border zone is expressed prominently in the topography west and southwest of Guadalupe Peak. Here, a straight-sided trench 4 miles long and 1 mile wide lies between the even base of the Guadalupe Mountain escarpment on the east and the straight front of the eastern ridge of the Patterson Hills on the west. It is shown just west of Shumard Peak on plate 5, *A*. The trench is floored by coarse fanglomerate washed down from the Guadalupe Mountains, which probably fills it to a great thickness, and the bedrock beneath may be deeply depressed (as suggested in sec. *B–B′*, pl. 3). At the south end of the trench, bedrock crops out in patches in the space between the Guadalupe Mountains and the Patterson Hills, and the graben beneath the trench apparently ends against higher-standing fault blocks.

On one of the higher-standing blocks south of the end of the trench and close to the Border zone, the N. B. Updike, Williams No. 1 well reached the Bone Spring limestone within less than 100 feet of the surface (sec. 47, pl. 8), or less than 500 feet below its position on the Guadalupe Peak horst to the east (sec. *C–C′*, pl. 3). Between this block and the horst, however, are a number of deeply depressed, narrow wedges, which lie in the angle formed by the Border zone where it turns westward around the blunt salient of the Guadalupe Peak horst. The wedges stand at unlike structural heights, some nearly level with the rocks to the east and west, and others as much as 2,000 feet lower (as indicated by the structure contours on the structure map, pl. 20).

West of the Delaware Mountains, the sunken tract on the west side of the Border fault zone is again well defined. Between the Border fault and another a mile and a half to the west, the surface rocks are much younger than those on either side and include the Castile formation, or highest member of the bedrock succession preserved in the area (sec. *D–D′*, pl. 3). The rocks of the tract are broken by numerous branching and intersecting faults of various trends. Its east side, next to the Border fault zone, is more deeply depressed than the rest, and forms a graben less than half a mile wide.

FAULTS

FAULT PATTERN

As already suggested, and as indicated on the tectonic map, plate 20, the faults of the area lie in a belt about 10 miles wide which follows the crest and west flank of the Guadalupe and Delaware Mountains uplift. To the east, the rocks are not faulted, and to the west the structure of the bedrock is concealed by the alluvial deposits of the Salt Basin.

Most of the faults trend north-northwest, parallel to the axis of uplift of the mountains and to the trend of the fault belt as a whole. Faults of this trend east of the Border zone are remarkably straight and parallel for long distances, and depart from the general course only in gentle curves. Those of the Border zone and the foothill area west of it are somewhat less regular, with many curves and some sharply bent offsets. Parts of the more strongly curved faults trend north or east of north. The larger curved faults, such as those in the Dog Canyon and Border zones, are concave toward the downthrow. Some short faults in the Border zone and foothill area trend west-northwest, north-northeast, and east-northeast. In the Cutoff Mountain section the faults that extend diagonally across the escarpment have more of a northwestward than a north-northwestward course.

The faults of the belt are spaced, on the average, about three-quarters of a mile apart, but the belt extends around the large, unfaulted tract of the Guadalupe Peak horst, and includes some intensely shattered tracts where there are 6 or more faults to the mile (pl. 20). None of the faults continues across the whole length of the area. Some are only a few miles long, others extend 10 miles or more without a break. The discontinuity of the faults is caused partly by a dying out of the displacement at their ends, and partly by branching. Branching faults are more common in and west of the Border zone than east of it. In places, as in the Cutoff Mountain section, the branching and rejoining of the faults gives them an interlacing pattern. The zones of displacement that form the Dog Canyon, Lost Peak, and Border fault zones are longer than the faults that constitute them. When one fault dies out, another with similar displacement makes its appearance, lying en echelon with it. There are, however, no systematically arranged belts of echelon faults in the area.

DISPLACEMENT ALONG FAULTS

A large number of the faults in the area are downthrown in a direction opposite to the dip of the strata, and toward the axis of the uplift. They have moved, therefore, in opposition to the general uplift of the mountain area.[65] Most of the faults west of the Border zone are thus downthrown to the east, and many of those east of it are downthrown to the west. The faults of the Border zone itself, by contrast, have moved in harmony with the general uplift. East of the Border zone

[65] Balk, Robert, Structure elements of domes: Am. Assoc. Petroleum Geologists Bull., vol. 20, pp. 59–61, 1936; Structural behavior of igneous rocks: Geol. Soc. America Memoir 5, p. 29, 1937. Such faults have been termed antithetic by geologists of the Cloos school. For the opposite kind, the faults that have moved in harmony with the general uplift, the term synthetic has been used.

the faults downthrown to the west alternate with those downthrown to the east, thereby producing a horst and graben structure (as shown in sec. *D–D′*, pl. 3). The displacements along the faults range from a few hundred to several thousand feet. The largest displacements are along faults of the Border zone, which are downthrown to the west as much as 4,000 feet.

Movements on the faults appear to have been largely down the dip as suggested by nearly vertical slickensides observed on the occasional exposures of the fault surfaces. Baker [66] reports that an exposure of the surface of the Border fault not far southwest of El Capitan displays well-developed slickensides inclined slightly to the vertical. Any large amount of horizontal movement on the Border faults or others in the area is unlikely. Not only are there no consistent, well-developed belts of echelon faults, but the angular offsets in the trace of the Border zone would prevent the blocks on either side from moving past one another horizontally for any appreciable distance. Moreover, the facies boundaries in the Permian rocks, and especially the southeast edge of the Capitan limestone (lines *C*, *D*, and *E*, figure 10), are not offset by the fault belt, but extend in straight lines across the area.

DIPS OF FAULTS

The planes of most of the faults in the area either dip steeply in the direction of downthrow or stand vertical. This attitude is indicated both by occasional outcrops of the fault surfaces and by the straightness of the fault traces, even where the faults extend through mountainous country. The observations that have been made suggest that the fault planes tend to lie nearly perpendicular to the bedding planes, and that where the beds are most steeply tilted, the faults dip at the lowest angles.

Steep dips may be inferred if not proved for most of the faults east of the Border zone; in fact, the plane of the fault on the east side of the Getaway graben which has been observed at many places near Getaway Gap and to the north, stands vertical in each exposure. Also, the two faults that bound a narrow graben near the head of Guadalupe Canyon (shown just east of Guadalupe Peak in sec. *B–B′*, pl. 3), extend through country with 2,000 feet of relief, and yet their traces are no closer in the lower places than in the higher suggesting nearly vertical dips of the fault planes. An exception to the generalization of steep dips is the Dog Canyon fault, the trace of whose outcrop indicates that it dips 60° toward the downthrown side.

The planes of the faults of the Border zone are exposed in many of the canyons and ravines that cross it, as shown in plate 14, *B*, and dip at angles of 70° or more toward the downthrown side.

[66] Baker, C. L., Structural geology of trans-Pecos Texas: Texas Univ. Bull. 3401, p. 159, 1935.

In the area west of the Border fault zone, the dips of the fault planes may be less than farther east. Here, the beds are more steeply tilted than east of the zone, and the joints of the region are mostly perpendicular to the bedding. Possibly the fault planes are parallel to the joint planes. In the Cutoff Mountain section, where the fault traces are well exposed on the mountain sides, many of the faults appear to dip at angles of 60° or less toward the downthrown side. In the foothill area farther south, the fault planes are mostly covered by alluvial deposits and no observations have been made regarding their dips.

MINOR DEFORMATIONAL FEATURES

No crumpling has been observed near the faults of the area and very little dragging of the beds. On the downthrown sides of some of the faults, the beds dip outward at a low angle, and in some narrow fault blocks the beds are much more steeply tilted. On the upthrown sides, the beds generally extend horizontally even to the fault lines; for example, the black limestones of the Bone Spring, which form the upthrown sides of the faults of the Border zone, are undisturbed even at the planes of the faults themselves. Near most of the faults the joints parallel to them are very abundant and closely spaced.

Vein deposits and breccias are common along the faults. At many exposures of the faults of the Border zone the fault surface of the upthrown block, cut on black limestones of the Bone Spring, is covered by a straight-sided mass of calcite 5 or 10 feet thick, in which angular fragments of black limestone are embedded. Similar calcite veins and masses have been seen on other faults in the area, especially on the one that bounds the east side of the Getaway graben. It is not known whether the veins are lenticular or continuous bodies.

RELATION TO QUATERNARY DEPOSITS AND TOPOGRAPHIC FEATURES

Some faults within a few miles west of the Border fault zone have displaced Quaternary gravels and fanglomerates. For instance, 2 miles southwest of El Capitan, older fanglomerate deposits project in low hills whose eastern edges are straight, north-northwestward trending scarps 25 to 50 feet high which stand out prominently on aerial photographs. These scarps are probably fault scarps. Farther south, west of the Delaware Mountains, Quaternary gravels laid down on an old pediment surface stand at different heights in adjacent fault blocks. These differences are results of faulting, and the actual planes along which the gravels have moved are exposed in places (fig. 17, *A*). The displacement of the gravels, however, is only about a tenth as great as the displacement of the bedrock beneath (as shown on figure 17, *B*). These faults, therefore, underwent at least two movements, the first of which was the larger. Faults that appear to have offset the Quaternary deposits are shown by a different color than the rest on the map of Cenozoic deposits and land forms (pl. 22).

There may have been movements at the same time along the faults of the Border zone. The older fanglomerates and gravel deposits west of it, whose displacement along faults has been described above, consist of fragments of rocks derived only from the upper part of the escarpment to the east, and contain none from its lower, outer bench. Later fanglomerates of the same type contain rocks from the lower bench abundantly. In places the older deposits lie in fault contact with the rocks of the outer bench along the Border zone (as shown in plate 14, *B*). The outer bench ends along an even, little-dented base line, which follows the trace of the Border zone. It seems to be less eroded than the upper part of the scarp, as though it had been only recently raised. On the upper part of the

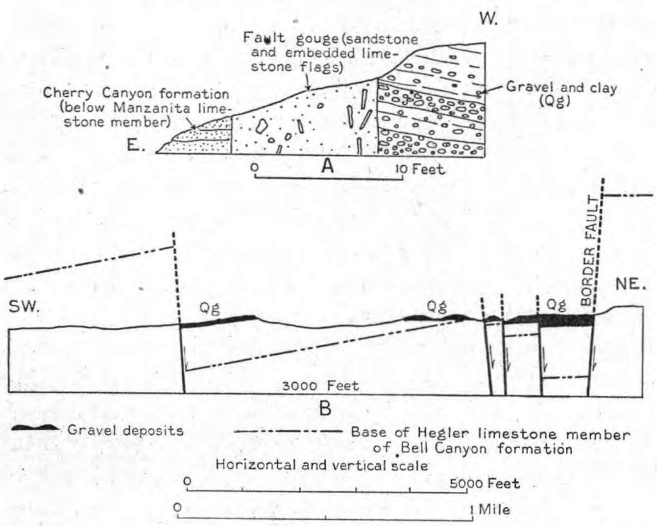

FIGURE 17.—Sections showing faulting of gravel deposits west of Delaware Mountain escarpment. *A*, Exposure on creek bank 1¼ miles west of Chinaman's Hat; *B*, Section near south edge of area studied, showing relative displacement of gravel and bedrock.

scarp near Guadalupe Peak are remnants of an old, well-rounded topography, now deeply dissected, which probably was carved at the time when the older fanglomerates to the west were being laid down and before the last faulting. The possible history of the Border zone and the faults to the west of it is shown diagrammatically on figure 22, *B*.

The faults farther east and west of the Border zone are generally followed on their upthrown sides by escarpments. Some of these escarpments, such as those along the Getaway graben, are resequent fault-line scarps; that is, they were formed by the more rapid erosion of the rocks on the downthrown side than those on the upthrown (pl. 22). The scarps are younger than any movements along the faults because the Quaternary gravel deposits in places cross the traces of the faults without displacement. Other scarps along faults east and west of the Border zone are of less certain origin. The scarps in the Guadalupe Mountains are approximately of the same height as the throw of the faults along which they lie. They may be old, greatly eroded fault scarps, or they may be resequent fault-line scarps from whose faces weak beds have been carried away by erosion. Whatever their origin, their character suggests that no recent displacements have taken place along the faults that fringe their bases.

JOINTS

At nearly every exposure in the area, the rocks are cut by joints, which are in part closely and in part widely spaced, and which generally trend in two or more directions. Observations were made on them during the field work because of the possible information they might furnish as to the origin of the larger tectonic features.

FIELD OBSERVATIONS

Observations made on the joints were incidental to other field work and are therefore incomplete. In some areas many observations were made, in other areas none were made, although joints were present in the rocks. Stations at which observations were made are shown by black circles on plate 20. At these stations, only qualitative information was obtained on the relative abundance and perfection of the different sets of joints, and on their dip. It was assumed that their most important feature was their trend, and measurements of the trends of the different sets therefore constitute the bulk of the information obtained on them. The notes on the joints contain 1,141 such measurements, made at 407 stations.

CHARACTER

Most of the joints are straight and smooth in all sorts of rock, though some in the sandstones of the Delaware Mountain group are curved and some poorly developed joints are jagged and irregular. The surfaces of the straight joints are smooth, even where they cut through irregularly bedded rocks, or alternations of hard and soft layers. No slickensides have been observed on them. At the surface, many of the joints are open fissures, some are narrow cracks, and a few are filled by vein calcite. The open fissures were probably formed by weathering, and give little indication of the nature of the joints at depth.

Single joints commonly extend across the entire length of any exposure, although some close and come to an end. The joints have a great vertical as well as a great lateral extent. Individual joints can be traced from the tops to the bases of the limestone cliffs near Guadalupe Peak and El Capitan, or through a distance of 1,000 feet or more.

Where several sets of joints are present, they commonly cross one another without deflection, although in places subordinate sets may either end against or branch from the dominant sets. The observations made on the intersections of the joint sets are not sufficient to show whether some are of different ages than others. Such differences might be revealed by closer scrutiny.

SPACING

The spacing of the joints (which is only imperfectly suggested by those plotted on the tectonic map, pl. 20) is quite variable. It depends to a certain extent on the nature of the rocks, for thin-bedded, brittle rocks are likely to be more jointed than massive rocks. To a larger extent it depends on the tectonic relations, for the joints of one area tend to be more abundant in all types of rock than those of another area.

In the eastern part of the area, where the rocks are not faulted, the joints are for the most part widely spaced. In many exposures in this area, only two sets of joints are present, in some only one, and in a few broad exposures there are none.

In the faulted area to the west, between the Lost Peak and Border fault zones, joints are much more numerous than elsewhere. In nearly every exposure two or more sets are present, and they are generally spaced only a few feet apart. At most places one set is more closely spaced than the others, and this is likely to be one that is widely distributed through the region. Near faults the joints parallel to them are more closely spaced than elsewhere, and the other sets of joints are poorly developed. In the Guadalupe Peak horst, the unfaulted tract that lies in the middle of the faulted belt, both field observations and air photographs indicate that joints are as numerous as in the faulted areas nearby.

Joints are numerous also in the area west of the Border fault zone, and tend to be closely spaced. The number of sets present is greater than to the east, and 3 or more are likely to be found at most exposures.

DIPS OF JOINTS

East of the Border fault zone, the joints commonly stand nearly vertically. This relation is best shown near Guadalupe Peak and El Capitan, where the joints can be traced down through the limestone cliffs for long distances. The rocks east of the Border fault zone are horizontal or gently tilted, so that these vertical joints stand nearly normal to most of the bedding planes. In some of the formations, however, the bedding planes have an original depositional slope, as in the Capitan limestone, or are tilted and contorted as a result of Permian movements, as in the Bone Spring limestone. The joints cut through these rocks without deflection from their vertical position, as shown on plate 11, *B*. A few joints dipping at angles of 60° or less were noted in the Capitan limestone, but they are minor features. No horizontal or gently dipping joints were observed, either in well-bedded strata or in the massive Capitan limestone.

West of the Border fault zone, both in the Cutoff Mountain section and in the foothill area to the south, the dips of the joints are less than to the east. The rocks of this region dip at angles up to 45°, and so far as observations have been made the sloping joints stand approximately normal to the bedding. Joints trending in the direction of dip are thus vertical, but those parallel to the strike depart from the vertical by the amount of dip of the strata. This relation is barely perceptible in rocks tilted at angles of 10° or less, but is a striking feature in rocks tilted at angles approaching 45°.

JOINT TRENDS

On the accompanying maps, plates 20 and 21, observations of the trends of the joints have been summarized by several methods of plotting. On plate 20, the observed joint trends at each station are indicated by radiating lines of equal length. As the joints are shown only where observed, such plotting does not show the actual abundance of the joints of different trends on the ground.

The observations made, however, are sufficiently representative to give a fair sample of the number of joints of each set actually present. The observations can thus be summarized statistically. The area shown on plate 20 is therefore divided into 10 unit areas, and the relative abundance of different joint sets in each unit is plotted as "roses." (Note that the north-south boundaries of the unit areas follow structure lines, and that the east-west boundaries are chosen arbitrarily.) On the regional tectonic map, plate 21, the area of plate 20 has been divided into two large unit areas, one east of the Border fault zone (constituting areas 2, 3, 4, 6, and 10 of pl. 20) and the other west of it (constituting areas 5, 8, and 9). For each of these areas, a more generalized rose has been prepared.

Each rose shows the relative abundance of joints in every 5° of arc, expressed in percentage of the total number observed. Five-degree units were chosen because 5° is the approximate limit of error in the observations, and is the amount of variation which joint sets, or even individual joints show in single exposures. As originally worked out, wide variations were found between percentages at some of the adjacent points on the arcs, which apparently resulted from a personal equation in making the observations. The percentages were therefore evened by means of sliding averages. Each figure used in plotting the roses is thus the average of the original percentage for the point shown and the percentage of the two points lying 5° on each side of it.

Some of the roses, such as those for areas 1, 5, 8, and 9 of plate 20, contain a possible error in that observations were made in part on inclined joints, which are normal to the planes of tilted beds. If such joints were rotated to vertical positions, those in the directions of the dip and strike of the beds would have the same trend as before, but those at intermediate positions would be deflected, and would thus have a new relation to the strike and dip joints. In beds dipping 45° (the maximum observed in the area) joints diverging at an angle of 45° from the strike would, when rotated to vertical, diverge about 55° from the strike—a deflection of about 10°. Few observations were made, however, on beds so steeply tilted. More than 90 percent in each unit area were made where the beds dip 10° or less, for which the deflection would be about 1°. This is well within the limits of error for the observations.

The type of rose selected for plotting has the advantage of showing clearly the dominant joint sets for the areas. As the trends plotted extend radially from the center of the rose, the minor joint sets tend to be crowded more closely than the dominant ones. The latter are thereby exaggerated. Some of the minor trends are actually more important than their insignificant appearance on the roses suggests.

As shown by this statistical method, by far the most abundant joints in the area studied trend north-northwest. This set is especially abundant in the region east of the Border fault zone (roses 2, 3, 4, 6, 7, and 10, pl. 20). Air photographs of the region northeast of Guadalupe Peak show innumerable north-northwesterly joints traversing the Capitan limestone on the mountain sides. On the ground, the joints of this set commonly appear as long, parallel, open fractures, and are more prominent than any of the other joints. The set trends in about the same direction nearly everywhere, although near McKittrick Canyon in the northeast part of the area (area 4), joints that may belong to the same system have a northwestward course. The north-northwesterly set is present also, though less abundantly, in the foothill area west of the Border fault zone (roses 5, 8, and 9), and less conspicuously in the Cutoff Mountain section farther north (rose 1).

Associated with the north-northwesterly joint set at most exposures, and particularly east of the Border fault zone, is another at nearly right angles, or with east-northeasterly trend (roses 2, 3, 4, 6, 7, 9, and 10). In places in the eastern part of the area the north-northwesterly and east-northeasterly sets are the only two present. There is a tendency for the second set to trend more nearly eastward in the southeast part of the area than in the northeast part, as may be seen by comparing roses 4 and 10. The set is generally represented by fewer and less-open fractures than the north-northwesterly set. In the extreme northeast part of the area (rose 4), however, its numbers equal or exceed those of the north-northwesterly set. In the field, the east-northeasterly set appears to trend parallel to the face of the Reef Escarpment, but plotting of numerous observations suggests that its members actually diverge from the trend of the escarpment at an acute angle.

The third abundant joint set in the area trends north-northeast, forming an angle of about 50° with the dominant north-northwesterly set. It is most abundant in the foothill area west of the Border fault zone (roses 5 and 8). In the northwestern Patterson Hills it is the dominant fracture in many of the exposures. Traces of it are detected in parts of the area east of the Border zone (roses 6, 7, and especially 10). At many places it is associated with another fairly abundant set, lying nearly at right angles, or trending west-northwest.

In the Cutoff Mountain area observations, which are unfortunately inadequate, suggest that the dominant joints trend northwest, parallel to the faults of the district (rose 1). In addition to the sets described, there are some joints of other trends unrelated to the four dominant ones. These joints occur in various parts of the area, and particularly west of the Border fault zone. In some places there are well-marked north-south and east-west joints. None of these other sets is very common.

There is thus a distinct difference between the joint sets in the east and west parts of the area, the line of demarcation being approximately along the Border fault zone (pl. 20). To the east, the north-northwesterly and east-northeasterly sets are dominant, almost to the exclusion of the others. To the west, the north-northeasterly and west-northwesterly sets are prominent, although the two other sets are present, but less abundantly developed.

RELATION OF JOINTS TO OTHER TECTONIC FEATURES

As shown by the preceding descriptions, the joints seem to be younger than the tectonic features of Permian age in the mountains. They are much more closely related to the younger tectonic features, formed during the uplift of the Guadalupe and Delaware Mountains. Thus, the dominant north-northwesterly joint set is parallel to the dominant north-northwesterly fault system, and its members are much more closely spaced near the faults. The west-northwesterly and north-northeasterly joint sets are likewise followed by some faults, especially west of the Border fault zone, where such joints are abundant. There are, however, no faults parallel to the east-northeasterly set. The three joint sets first named therefore may be of the same age as the faults; or they may be somewhat older and have prepared the way for the later faulting. The absence of faults of east-northeasterly trend may indicate that the joints of this set are of a different age, or that they were tighter than the other sets and hence gave less encouragement to movement along them.

The joints are related also to the form of the Guadalupe and Delaware Mountains as a whole. The dominant, north-northwesterly set trends parallel to the longer axis of the mountains and the east-northeasterly set trends at right angles to it. The other two are diagonal to the axis but are more abundant west of the axis than to the east of it, indicating that they are somehow related to the uplift. The fact that the joint sets extend without deflection across local changes in the dip and strike of the beds indicates that they have originated from regional, rather than from local forces.

The dips of the joints are related in some manner to the tilting of the strata. Where the strata are horizontal the joints are nearly vertical, but where the strata are tilted the joints remain normal to the bedding planes. This condition is most evident west of the Border fault zone, where the tilting has resulted from rotation of the beds during block faulting. The joints may have formed during or after the tilting of the strata, in which case stresses were transmitted along the beds in the same manner as if they had been horizontal. The joints, however, may have been formed before the tilting; if so, they were subsequently rotated to their present positions. The latter interpretation has been adopted by Melton for similar joints normal to tilted beds in Oklahoma.[67]

The age relations of the different joint sets to one another have not been determined, although evidence on the question might be obtainable by detailed study of their intersections. The close relation of the four dominant joint sets to the Guadalupe and Delaware Mountains uplift and associated features suggests that they were all formed at about the same time. Some of the minor sets that have no clear relation to the uplift were possibly formed at another time, perhaps during the period after the deposition of the Permian and before the mountains were uplifted. It is difficult to believe that jointing of some sort did not take place in the region during this long and probably eventful time interval.

REGIONAL RELATIONS OF THE YOUNGER TECTONIC FEATURES

GUADALUPE AND DELAWARE MOUNTAINS

The Guadalupe and Delaware Mountains, of which the area studied is a part, constitute an uplifted block of the earth's crust more than 100 miles long in a north-northwesterly direction and about 50 miles wide (fig. 1). Both in the area studied and elsewhere the uplifted block is asymmetrical. The broad eastern flank dips gently, without folding or faulting, toward the Pecos Valley and the Llano Estacado; the narrow western flank dips steeply toward the Salt Basin. At its south end, in the Apache Mountains, the uplift flattens out and pitches southward toward the lava plateaus of the Davis Mountains; at its north end it fades out on the east slope of the Sacramento Mountains. The Sacramento Mountains form a similar broad uplifted block, but their crest lies west of the crest of the Guadalupe Mountains and en echelon with it.

Both in the area studied and outside the crest and west flank of the uplifted block are much broken by faults, most of which have a north-northwest trend parallel to the axis (fig. 15, *A*, and pl. 21). Extending irregularly through the faulted belt, but generally flanking the mountain crest on the west, are several major faults, on which the strata are downthrown westward. Within the area studied and southward in the Delaware Mountains they form the Border fault zone. Farther north, in the Guadalupe Mountains of New Mexico, they form the Dog Canyon fault zone, which lies en echelon to the Border zone and about 5 miles east of it. In New Mexico the space between the Border and Dog Canyon fault zones is occupied by the Brokeoff Mountains, which are lower than the crest of the mountains east of Dog Canyon (fig. 2). The minor faults east and west of the major faults are downthrown in such a manner as to somewhat counteract the effects of uplift caused by the major faulting and tilting of the strata.

In parts of the Guadalupe and Delaware Mountains uplift are faults trending in other directions than north-northwest. About 10 miles south of the area studied is a prominent system that trends northeast (pl. 21). Individual members are discontinuous, but the system as a whole extends from the Border fault zone on the west to the outcrops of the Castile formation on the east. These northeasterly faults are prominent features on aerial photographs, and are indicated not only by offsets of the beds, but by numerous straight valleys. Apparently the northeasterly fault system is accompanied by strong jointing, likewise indicated by drainage. They may be related to the east-northeasterly joints within the area studied.

Farther south, in the south part of the Guadalupe and Delaware Mountains uplift, is another system of faults that trends west-northwest. The most prominent members of the system bound the north side of the Apache Mountains, but others are found to the north and south.

The faults on the north side of the Apache Mountains extend diagonally across the south end of the Guadalupe and Delaware Mountains uplift, and raise the strata to the south, contrary to its southward pitch. They cross the belt of north-northwesterly faults near Seven Heart Gap.[68] Both systems of faults are apparently of later Cenozoic age, but the west-northwesterly system has the same trend as the reef zone in the Permian rocks of the Apache Mountains. This relation suggests that it was formed by renewed movement on an older tectonic trend (figs. 15, *A*, and 16, *A*).

[67] Melton, F. A., A reconnaissance of the joint systems in the Ouachita Mountains and central plains of Oklahoma: Jour. Geology, vol. 37, pp. 734–735, 738–741, 1929.

[68] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Van Horn folio (No. 194), p. 7 and areal geology sheet, 1914.

SIERRA DIABLO [69]

West of the Apache Mountains across the Salt Basin is the Sierra Diablo (fig. 1). Like the Guadalupe and Delaware Mountains, it is a broad, asymmetrical uplift, but its faulted flank is on the east and its tilted flank on the west. Toward the south, its east flank consists of several blocks of gently dipping strata, such as the Baylor Mountains. The blocks stand lower than the main uplift and descend in steps toward the basin. Toward the north, thick alluvial deposits extend up to the main fault at the edge of the uplift, and few remnants of the depressed eastern flank are exposed.

The main faults of the Sierra Diablo have an average northerly trend, but the trend of individual faults is more variable than in the Guadalupe and Delaware Mountains (pl. 21). The group that outlines the east side of the uplift includes a north-northeasterly fault, and a fault made up of several curves, whose average trend is northward. These faults have had much the same history as those of the Border zone in the Guadalupe Mountains. The rims of their escarpments have receded some distance from the fault traces, and are indented by several large canyons, as though the first faulting took place some time ago. Later movements are suggested by the manner in which the bases of the escarpments follow the fault lines, by the well-developed alluvial fans on their downthrown sides, by scarps in the alluvial deposits, and by uplifted terraces in the mountains.

Extending diagonally across the Sierra Diablo in the same manner as in the Apache Mountains is a set of west-northwesterly faults. Most of them are of smaller displacement than the northward trending faults along the eastern border. Larger faults of west-northwesterly trend bound the north and south sides of the uplift. Several of the west-northwesterly faults stand nearly in line with faults of the same trend near Seven Heart Gap in the Apache Mountains and may be continuous beneath the alluvial deposits of the Salt Basin.

The age relations between the northerly and the west-northwesterly fault systems are complex. The last movements on the west-northwesterly faults are older than the last on the northerly faults, for their scarps have been much eroded and show none of the evidences of recent movement seen on the others. They may have formed at about the same time as the older movements on the other set, however, because faults of either trend are likely to terminate against those of the other. Ancient movements, some dating back to Paleozoic time, took place along, or on the same trend as, the west-northwesterly faults (figs. 15, *A* and 16, *A* and *B*). The west-northwesterly faults therefore may have resulted from Cenozoic movements along old trend lines at a time when the forces were such as to produce dominant, northward trending tectonic features.

SALT BASIN

The Salt Basin, which lies between the Sierra Diablo on the west and the Guadalupe and Delaware Mountains on the east, is a great depression 5 to 15 miles wide and of about the same length as the mountain ranges themselves (fig. 1). Except for outcrops of bedrock along its margins, it is floored entirely by unconsolidated Cenozoic deposits. Well records show that these deposits are hundreds or even thousands of feet thick.[70]

The basin is a sunken block of the earth's crust. Outcrops along its borders consist of rocks that lie high on the mountains to the east and west, and have been warped down or faulted down to their present positions. At the north and south ends, known as Crow Flat and Ryan Flat, respectively, the basin appears to be a downwarp, but in the longer central section, faulting dominated. The structure of the bedrock beneath the unconsolidated deposits of the basin is unknown but is assumed to be complex.

The high points on the opposite sides of the basin do not correspond in height. The high point on the east side, near Guadalupe Peak, lies opposite a low-lying section of the Diablo Plateau to the west. The high point on the west side, in the Sierra Diablo, lies 30 miles or more to the south, opposite the lower Apache and southern Delaware Mountains.

BASIN AND RANGE PROVINCE IN TEXAS AND NEW MEXICO

The Guadalupe, Delaware, and Apache Mountains, and the Sierra Diablo constitute a small part of the Basin and Range province, which extends far to the west and northwest.[71] Nearby parts of the province resemble the area studied in tectonic and geomorphic features. These parts, which include northern trans-Pecos Texas, and that part of New Mexico between the Pecos River and the Rio Grande, are known as the Sacramento section.[72] Tectonically, this section could be classed as a fracture belt of low mobility.[73] It resembles many other block-faulted regions of the earth, including the rift-valley area of East Africa.[74] It differs from the latter mainly in the smaller scale of its features.

The Sacramento section consists of alternating block mountains and desert basins with a general northward alinement (fig. 1). Most of the mountains have a steep escarpment on one side, outlined by faults, and a gentle slope on the other which follows the dip of the beds. The mountains are made up of a plate of Paleozoic and

[69] Richardson, G. B., op. cit., p. 7 and areal geology sheet. King, P. B., and Knight, J. B. Sierra Diablo region, Culberson and Hudspeth Counties, Texas: U. S. Geol. Survey Oil and Gas Investigations, Preliminary map 2, 1944.

[70] Richardson, G. B., op. cit., p. 8. Baker, C. L., Structural geology of trans-Pecos Texas: Texas Univ. Bull. 3401, p. 171, 1935.

[71] Fenneman, N. M., Physiographic divisions of the United States: Assoc. Am. Geographers Annals, vol. 6, pp. 88–93, 1917.

[72] Fenneman, N. M., idem., p. 93. Physiography of the western United States, pp. 393–395, New York, 1931.

[73] Bucher, W. H., The deformation of the earth's crust, p. 325, Princeton, 1933.

[74] Baker, C. L., op. cit., p. 169, 1935.

Mesozoic sedimentary rocks several thousand feet thick, and of an underlying basement of pre-Cambrian crystalline rocks. The sedimentary rocks are little disturbed except by the uplift of the ranges themselves, which were raised in Cenozoic time. They appear to have been only lightly affected by earlier movements, such as those of older Cenozoic time. There are, however, some large masses of intrusive igneous rock in the western part of the Sacramento section that are of post-Cretaceous age though probably older than the faulting. In some of the desert basins, thin sheets of basaltic lava are interbedded with or are spread over the surface of the basin deposits. These sheets of lava are mostly younger than the faulting but may be related to it.

Superficially there is an apparent gradation in the Sacramento section from block mountains into fold mountains. The Sierra Diablo, for example, is decidedly blocklike, and any tilting of the strata is the direct result of faulting. The Guadalupe and Delaware Mountains, however, are more archlike, but with the arch greatly modified by faults. The Sacramento and Sandia Mountains farther north have the form of broad domes or arches, faulted on one side and pitching down at their north and south ends.[75] The Sangre de Cristo Mountains, which lie next north of the Sandia Mountains, are true folded ranges, and are the southernmost prongs of the Rocky Mountains. Along their axes, a core of pre-Cambrian rocks is exposed, and their sides are broken in places by thrust faults.[76]

This northward gradation from one sort of tectonic feature into another is more apparent than real, as the folding and block faulting took place at different times. The folding of the southern Rocky Mountains is mainly of late Cretaceous and early Tertiary (Laramide) age, and the block faulting farther south is mainly of later Cenozoic age. Whatever folding there is in the mountains to the south may have been inherited from a deformation that was contemporaneous with the folding of the mountains to the north. At the time of the block faulting of the mountains to the south, the mountains to the north were not only broadly uplifted but locally broken by normal faults such as those that lie between the west side of the Sangre de Cristo Mountains and the Rio Grande depression.[77] A similar interpretation for the Sacramento section has been made by Bryan [78] and for the Great Basin of Utah, Nevada, and California by Nolan.[79]

REGIONAL RELATIONS OF JOINTS

Some observations have been made on the regional arrangement and distribution of joints in the area surrounding the southern Guadalupe Mountains. In addition to the field observations in the area studied, extensive field observations have been made by me in the Sierra Diablo.[80] Recently I have also studied aerial photographs of the region embracing the Guadalupe and Delaware Mountains and the Sierra Diablo, and from them have obtained information on the regional relations of the joints. The regional relations as now known are summarized on plate 21; on this plate, field observations on joints in the southern Guadalupe Mountains and the Sierra Diablo are summarized on roses.

North-northwesterly joints are probably dominant the entire length of the crest of the Guadalupe and Delaware Mountains uplift, as are the faults of the same trend. They are dominant near the crest in the area studied, and aerial photographs indicate that they are also dominant farther south. East-northeasterly (or northeasterly) joints are not prominently expressed in the aerial photographs except in the region immediately south of the area studied, or about midway along the length of the Guadalupe and Delaware Mountains uplift. They may be present elsewhere, but have little topographic expression. As indicated below (p. 124), these two joint sets are probably closely related to the Cenozoic uplift of the mountains.

Farther east and northeast, on the long, gently tilted east slope of the uplift, other fractures seem to dominate. The east-west linear features (probably fracture zones) in the Castile formation of the Gypsum Plain have already been noted (pp. 90–91). They seem to have formed by readjustments within the Castile which do not influence the overlying and underlying formations. North of the Gypsum Plain, at Carlsbad Cavern (in the Capitan and Carlsbad limestones of the Reef Escarpment), cave openings have been carved along two major joint sets, the dominant one trending east-northeast to east, with the other nearly at right angles.[81] Near the Reef Escarpment in this vicinity, as shown on aerial mosaics and the new topographic map of the Carlsbad Cavern quadrangle, ridges and valleys in the limestone have the same east-northeast to east trend, but they pursue a sinuous course, parallel to the curves in the Reef Escarpment and the Capitan reef. This indicates that the joints in this vicinity are more closely related to Permian structural features than to Cenozoic struc-

[75] Darton, N. H., Tectonics of Arizona and New Mexico [abstract]: Geol. Soc. America Bull., vol. 39, p. 182, 1928. "Red beds" and associated formations of New Mexico: U. S. Geol. Survey Bull. 794, p. 99, 1928.

[76] Burbank, W. S., and Goddard, E. N., Thrusting in Huerfano Park and related problems of orogeny in the Sangre de Cristo Mountains: Geol. Soc. America Bull., vol. 48, pp. 931–976, 1937.

[77] Cabot, E. C., Fault border of the Sangre de Cristo Mountains north of Santa Fe, New Mexico: Jour. Geol., vol. 46, pp. 97–104, 1938. Burbank, W. S., and Goddard, E. N., op. cit., pp. 965–966.

[78] Bryan, Kirk, Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico, in Rio Grande Joint Investigation: Nat. Resources Comm., Regional Planning, part 6, pp. 204–215, 1938.

[79] Nolan, T. B., Basin and Range province in Utah, Nevada, and California: U. S. Geol. Survey Prof. Paper 197–D, pp. 183–186, 1943.

[80] King, P. B., and Knight, J. B., op. cit., inset structure map, 1944.

[81] For map of the cavern, see Lee, W. T., New discoveries in Carlsbad Cavern: Nat. Geog. Mag., vol. 48, p. 302, 1925. Unfortunately, the map is incorrectly oriented, for its edges trend N. 15° W.

tural features formed during the uplift of the mountains.

Near the south end of the Guadalupe and Delaware Mountains uplift, the north-northwesterly joints are crossed by another set of west-northwest trend, parallel to the faults along the north side of the Apache Mountains. In aerial photographs they are prominently displayed in Permian limestones along the crest of the Apache Mountains, and also in the Cretaceous rocks along the same trend to the southeast. In the Sierra Diablo, across the Salt Basin to the west, similar joints prevail. They are indicated by field observations summarized by the roses on plate 21, and are also prominently displayed on aerial photographs. They are parallel to one of the prominent systems of faults in the Sierra Diablo. Few joints in the Sierra Diablo are parallel to the northerly faults that bound its eastern side.

The west-northwesterly set of joints in the Apache Mountains and the Sierra Diablo is probably related to structural features older than the uplift of the Guadalupe and Delaware Mountains, in part perhaps of Paleozoic age.

Only fragmentary information on the trends of joints is available away from the immediate vicinity of the Guadalupe and Delaware Mountains. To the east, Melton [82] has noted joints in the cap rock of the Llano Estacado that trend mainly west-northwest. They are probably unrelated to any of the systems just described in the Guadalupe and Delaware Mountains. To the west, joints have been noted by Richardson [83] and Dunham [84] in the Franklin and Organ Mountains. The structure here is more complicated than farther east, and there are extensive igneous intrusions. The joints of these mountains therefore may be more of local than regional significance.

HISTORY OF GUADALUPE AND DELAWARE MOUNTAINS UPLIFT

In order to understand the Guadalupe and Delaware Mountains uplift, the time relations as well as the physical features and space relations must be known. Something of its history can be deduced from the features already described, and more can be obtained from the Cenozoic deposits and land forms that are described later. In addition, parts of the history of which there is little record in the mountains themselves can be inferred by comparison with adjacent, similar regions where the record is better known. These lines of evidence and the inferences to be drawn from them are summarized here.

[82] Melton, F. A., Fracture systems in central Texas: Texas Univ. Bull. 3401, p. 122, 1935.

[83] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, El Paso folio (No. 166), p. 8, 1909.

[84] Dunham, E. C., The geology of the Organ Mountains: New Mexico School of Mines Bull. 11, p. 144, 1935.

FEATURES OLDER THAN THE UPLIFT

The Guadalupe and Delaware Mountains uplift is of post-Cretaceous age. Evidence from adjacent parts of trans-Pecos Texas and New Mexico indicates that Cretaceous seas covered the entire region. They spread over a nearly level surface, or peneplain, that was formed in older Mesozoic time. The peneplain is now exposed at many places in the region, and the summit peneplain of the Guadalupe Mountains is probably a part of it, although now stripped of its postulated Cretaceous cover. The peneplain bevels Paleozoic features, such as those shown on figure 15, *B*, and is tilted and faulted by the movements that produced the present ranges. It is, therefore, a convenient datum plane for separating older and younger tectonic features.

Farther south in trans-Pecos Texas there are extensive masses of volcanic rocks of early Cenozoic age. They lie unconformably on deformed Cretaceous rocks, and are themselves folded and faulted. In this area, therefore, movements took place in late Cretaceous or early Tertiary (Laramide) time and after the volcanic epoch, perhaps in Oligocene or Miocene time (p. 108). These movements probably also affected the Guadalupe Mountains area.

EARLY PHASES

The early phases of the uplift of the Guadalupe and Delaware Mountains are imperfectly recorded in the region. The initial uplift, however, may have taken place at the same time as that farther northwest in the Sacramento section, where deposits, land forms, and tectonic features related to it are well exposed and have been studied by Kirk Bryan and his students.[85] According to Bryan, the initial uplifts here took place before the deposition of the Santa Fe formation, and hence were probably of Miocene or early Pliocene age. They thus correspond approximately to the post-volcanic deformation in trans-Pecos Texas.

East and west of the Guadalupe Mountains, deposits of about the same age as the Santa Fe formation were formed as a result of erosion that followed the initial uplifts. To the east they form the cap of the Llano Estacado and are a part of the Ogallala formation. To the west, they probably form the main mass of the thick, unconsolidated deposits of the Salt Basin. The nature of the latter deposits is little known, however, because they are everywhere covered by Quaternary deposits.

In the mountains themselves, some indication of the nature of the initial uplift is given by the present stream patterns in the limestone uplands (fig. 19). Some of the streams seem to be unrelated, and hence antecedent, to the fault blocks that they cross; thus, the stream in South McKittrick Canyon crosses from the downthrown to the upthrown side of the Lost Peak fault zone with little or no deflection (pl. 22). Other streams,

[85] Their results have appeared in numerous papers. For a summary, see Bryan, Kirk, op. cit., pp. 197–225.

such as those in the upper courses of Dog and West Dog Canyons, follow depressed fault blocks, and appear to belong to a later generation. In the parts of the mountains where no faulting has taken place, the two generations of streams cannot be differentiated. It seems plausible, however, that most of them were consequent on the surface of the original uplift, and that in the limestone areas their courses became relatively fixed by incision into the resistant rock.

As indicated by the stream pattern, the initial uplift was a broad arch, not broken by as many faults as at present. The crest of the arch was probably near the present summits of the southern Guadalupe Mountains, for the supposedly consequent streams radiate northeastward, northward, and northwestward from it (fig. 19). The slopes of the arch seem to have been more gentle than the present slopes of the mountains, and its crest may not have stood as high. The incised streams of the limestone areas have distinctive, meandering courses, and join one another at wide angles, forming an open, dendritic pattern, as though they originally flowed down a gentle slope. This pattern, shown in the stippled areas of figure 19, is unlike that shown in the southeast part of figure 19, where the rocks are less resistant, and where the streams could adjust their courses to the steeper gradients of later periods.

Part of the jointing of the rocks of the Guadalupe and Delaware Mountains probably took place during the initial uplift. Fracturing of the rocks near the surface is likely to take place, even under the application of stresses too gentle to produce faults. If the rocks were jointed during the early phases of the uplift, the faults that came into existence later followed the preexisting fractures.

If it could be proved that the joints normal to tilted beds in the western part of the area were originally formed in a vertical position, and had been rotated along with the beds at the time of block faulting, the suggested conclusion that the joints were older than the faults would be confirmed. It is equally possible, however, that the joints originated in their present attitudes, after the beds had been tilted.

MAIN PHASE

In the northwest part of the Sacramento section, according to Bryan,[86] the main block faulting, by which the present basins and mountain ranges were outlined, took place after Santa Fe deposition, and hence in late Pliocene or early Pleistocene time. According to Bryan:

> Most of the existing mountains and highland areas were also mountains in Santa Fe time. They were reduced in Pliocene time and were rejuvenated to form the present ranges. Other mountains appear to have been new-born * * *. So far as present information goes, all the ranges, with [a few exceptions] * * *, owe their present positions to the post-Santa Fe uplift.

These post-Santa Fe movements appear to be of the same age as the main phase of the uplift of the Guadalupe and Delaware Mountains.

During this phase the mountains were raised nearly to their present height and were given nearly their present form and outlines. The probable archlike form of the initial uplift was at this time broken into many fault blocks, especially near its crest. These blocks gave rise to the second generation of consequent streams, such as those in Dog and West Dog Canyons. The faulting did not result from the collapse of the initial arch, for it is deduced that the arch was not raised as high during the initial phase as it was afterwards, during the main phase. The main phase of the uplift probably resulted from continued application of stresses like those which caused the initial uplift, but of sufficient intensity to cause the mountain area to be further uplifted and to be broken into fault blocks.

Most of the faults in the area probably date from the main phase of the uplift. The scarps that follow faults east and west of the Border zone are eroded to the same degree where they are cut on the same sort of rocks, such as the Capitan limestone. Moreover, the scarp along the Border zone exhibits remnants of a topography equally mature, although most of the present features of the scarp indicate modification by renewed erosion resulting from subsequent movements.

LATER PHASE

Younger movements in the Guadalupe and Delaware Mountains are indicated by the faulting of deposits of probable older Pleistocene age. The movements took place after an extended period of quiescence, for some of the deposits that are now faulted were laid down on a pediment carved from the disturbed Permian rocks.

Movements appear to have taken place only along faults that were already in existence, and to have resulted in displacements in the same direction as during the main phase. The displacements, however, were only about a tenth as great as the older ones, amounting at most to several hundred feet (p. 113). Movement took place along the faults of the Border zone and those immediately west of it, or in a much narrower belt than during the main phase. Faults to the east and west were undisturbed.

No definite evidence is available as to whether or not the faulting of the later phase was accompanied by further uplift of the mountain area. An increase in the relief of the mountains with respect to the floor of the Salt Basin is indicated not only by the displacements on the faults themselves but also by the dissection of the older, probably early Pleistocene deposits, which was caused by the accelerated activity of streams resulting from a change in base level. This dissection,

[86] Bryan, Kirk, op. cit., pp. 209–215.

however, may have been caused by a subsidence of the basin, rather than by an uplift of the mountains. The dissection of similar older deposits on the east flank of the mountains by streams draining into the Pecos River may have resulted in part from actual uplift of the mountains, although it was undoubtedly influenced by other factors.

The later phase of the uplift is younger than the deposits of probable early Pleistocene age and older than deposits of Recent and perhaps later Pleistocene age, which are undisturbed by it. It is, therefore, perhaps of later Pleistocene age. No evidence for any still younger movements has been found in the Guadalupe and Delaware Mountains.

THEORETICAL PROBLEMS

NATURE OF STRUCTURE BENEATH THE SURFACE

Most of the available information on the tectonics of the Guadalupe Mountains and their surroundings relates to features at or near the surface, and very little is known of the structure of the deeper-lying rocks. A little information on the subsurface structure is afforded by wells. Some in the Salt Basin have been drilled in the unconsolidated Cenozoic deposits, and two in the Guadalupe and Delaware Mountains have been drilled through the Permian into the underlying rocks. No geophysical studies have been made in the region.

Some idea of the nature of the structure at depth can be obtained by projecting downward the features seen at the surface. On figure 18 the four structure sections of plate 3 have been redrawn and expanded downward to the top of the basement rocks. The top of the basement is assumed to lie 8,000 feet below the top of the Bone Spring limestone, and faults are assumed to have plane surfaces, dipping at the same angle underground as on the outcrop.

The actual details of the features shown on the expanded sections may be modified by changes in the structure with depth. The conditions assumed in drawing them are obviously too idealized, and may be even unnatural. Thus, the depths to the basement rocks, although based on thicknesses at the nearest outcrops, may not be the true figures for the area, and the depth may change from place to place across the area. Also, the faults may die out with depth or change their dip.

Dying out of the major faults with depth seems unlikely, however, because it would imply a mass of incompetent rocks below the surface, whereas, so far as known from nearby outcrops, the beds between the Bone Spring and the basement rocks are competent limestones and sandstones. Moreover, in nearby mountain ranges, such as the Sierra Diablo and the Sacramento and San Andres Mountains (fig. 1), the basement rocks are broken by faults of the same sort as those in the overlying rocks and as those in the Guadalupe Mountains.

Little can be said as to possible changes in dip of the faults at depth. Within the limits of observation,

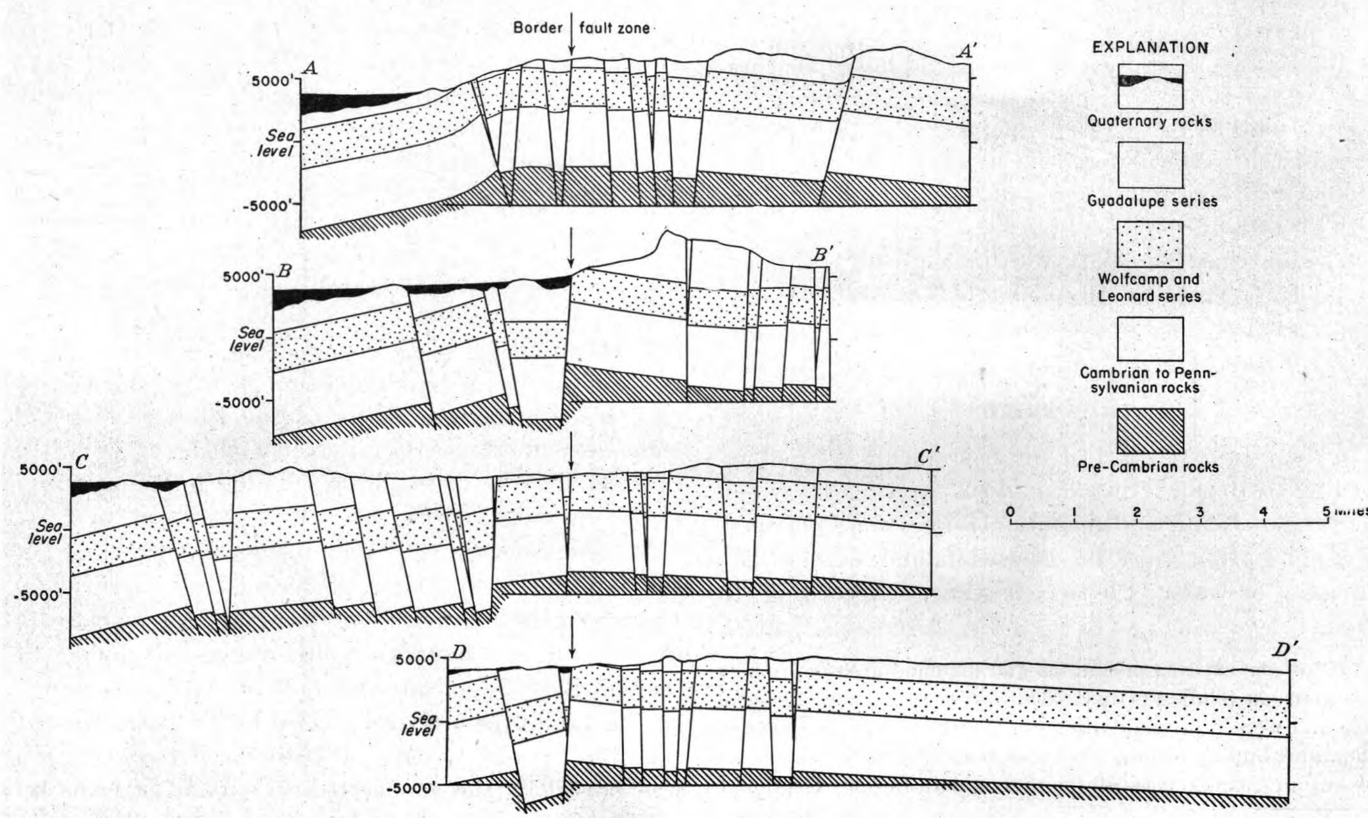

FIGURE 18.—Cross sections, the same as those on plate 3, but expanded downward to the top of the basement rocks.

even where the faults cross areas of high relief, they seem to have plane surfaces. However, some of the major faults have curved traces, concave toward the downthrow, and this may indicate a similar curvature in vertical section. Further, some of the fault blocks west of the Border zone have been rotated, and it has been suggested that "a tilted block can only rotate against a curved surface." [87]

As shown on the sections of figure 18, the amount of vertical displacement by faulting and tilting is small when compared with the width of the belt of uplifted rocks or the thickness of the sedimentary shell. There appears to be a tendency toward simplification of the structure downward by the joining of closely spaced faults, so that, at the top of the basement rocks, the faulting is concentrated along several large breaks, rather than dispersed along smaller breaks. Details of these conclusions may be modified by the factors just discussed. Thus, if the faults are concave on their downthrown sides, they must intersect at shallower depths than shown on figure 18.

RELATIVE VERSUS ACTUAL MOVEMENTS

In describing the structure of the region, the Guadalupe and Delaware Mountains were said to have been uplifted, and the Salt Basin to have been depressed. These are relative terms. So far as one can tell from the present relations between the fault blocks, their situations might have resulted from differential uplift of the entire area, from differential subsidence, or from a combination of the two.

EVIDENCE FOR ACTUAL UPLIFT

Evidence as to the actual nature of the movements in the Guadalupe and Delaware Mountains is clearer than in the ranges farther west which are surrounded by complex tectonic features. The east flank of the Guadalupe and Delaware Mountains is hinged on the gently dipping rocks of the Pecos Valley and Llano Estacado, which stand at a much lower altitude and remained relatively stable during the late Cenozoic movements. The difference in altitude between the mountains and the Llano Estacado thus furnishes some measure of the actual uplift which has taken place in the mountains.

Before the uplift, which took place after Cretaceous time, the region probably lay near sea level. The present height of the mountains has resulted from uplift above this position, partly by epeirogenic movements which also raised the plains to the east, and partly by more localized disturbances which occurred in several stages. During the first stage, as suggested by the stream patterns, the mountain area did not rise to its present height. A much greater elevation evidently took place during the second stage. Further uplift during the third stage is possible but not proved. Apparently the mountains never stood much higher than they stand today.

EVIDENCE FOR ACTUAL DEPRESSION

The actual movements that have taken place in the Salt Basin are less certain than those in the mountains. The basin has been deeply filled with unconsolidated deposits, but this deep filling is due more to the absence of through-flowing drainage than to any actual elevation or depression. The basin may have subsided while the mountains were being uplifted, it may have been raised to a slighter extent than its surroundings, or it may have remained at about its original position, while the mountains were raised around it.

The depth of the rock floor below the surface of the unconsolidated deposits of the Salt Basin is uncertain, as even the deepest wells drilled in the basin have failed to reach bedrock. One well, drilled near the southwest corner of the area studied, was still in unconsolidated deposits at a depth of 1,620 feet;[88] hence the underlying rock floor lies 2,000 feet or less above sea level. This level is lower than the surface of the Llano Estacado east of the mountains, but it may still be higher than the altitude of the region before Cenozoic disturbances.

In nearby basins, scanty well records indicate that in places the rock floor beneath the unconsolidated deposits lies considerably above sea level, and in other places lies at or below sea level.[89] These relations suggest that the intermontane basins on the whole were raised above their original positions, but by smaller amounts than the adjacent mountains, and that actual subsidence took place only in a few areas.

ORIGIN OF LATER TECTONIC FEATURES

By what means did the later tectonic features of the Guadalupe and Delaware Mountains come into existence? The features are much simpler than those in regions where folding and overthrusting prevail, yet their origin is elusive because of their very simplicity. In folded and overthrust regions, lateral compression of the crust is an obvious, dominant force. Here, the effects of such compression are not clearly evident, yet the crust has been raised and lowered into mountains and basins, and has been fractured by faults and joints. Is this another manifestation of lateral compression, or have the tectonic features arisen from some other set of forces?

ORIGIN OF JOINTS

The faults and joints that have fractured the rocks of the region are closely related to the formation of the mountains and basins. The manner in which they are

[87] Washburne, C. W., Curvature of faults [abstract]: Geol. Soc. America Bull., vol. 39, p. 176, 1928.

[88] Baker, C. L., Structural geology of trans-Pecos Texas: Texas Univ. Bull. 3401, p. 171, 1935. Locality given as "10 or 12 miles north of Figure Two Ranch."

[89] Sayre, A. N., and Livingston, Penn, Ground-water resources of El Paso area, Texas: U. S. Geol. Survey Water-supply Paper 919, pp. 33–35, 1945.

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arranged may furnish tangible clues to the orientation of the stresses that deformed the region. The joints are more widely distributed and are possibly older than the faults, hence their origin will be considered first.

Final interpretation of the joints probably cannot be made from the study of a small area alone, for there are likely to be significant regional variations in their patterns that can be determined only by a study of a wider area. Such variations are suggested, for example, by comparing the observations in the southern Guadalupe Mountains with those in the Sierra Diablo (pl. 21). In view of the present lack of detailed knowledge of these regional variations, conclusions based on joint studies in the area of this report must be regarded as tentative.

An explanation of the joints in the area must recognize the large number of joint sets present, the parallel and transverse relations of the most abundant pair to the axis of uplift, and the greater development of the next most abundant pair on one side of the axis than on the other. It must recognize also the common habit of joint sets to lie at right angles to one another, the absence of inclined joints except in tilted beds, and the lack of horizontal shift of one part of the area relative to another.

The effects of deformation have been pictured diagrammatically by the figure known as the strain ellipsoid.[90] When this figure is compressed, fracturing may take place normal to its long axis (parallel to its short axis) as a result of tension, or diagonally to the axes as a result of shearing. Most joints of regional extent are probably either tension joints or shear joints. In the Guadalupe Mountains, where the joints are dominantly vertical, the long and short axes of an ellipsoid would lie horizontally, and the forces causing the jointing would be directed in a horizontal plane.

The dominant joint set in the area, the one that trends north-northwest parallel to the axis of uplift, is probably of tensional origin, and results from a stretching of the rocks east-northeastward and west-southwestward. This origin is suggested by the great number of faults parallel to it, which implies that it was the most open of all the sets of fracture, and therefore the most subject to movement.[91] The pair of joint sets diagonal to the dominant set, trending north-northeast and west-northwest, may be the result of shear. They are less open than the first, and they are followed by fewer faults.

The origin of the east-northeasterly joints at right angles to the dominant set is less easy to explain. If formed at the same time as the others, they should lie normal to the direction of greatest compression, or along planes on which fracturing is not expected to occur. Some difference between them and the others must exist, as they are not followed by any faults. Moreover, they seem to be distributed differently than the dominant set. The latter, and the faults of the same trend, are found in greatest abundance close to the axis of uplift, as shown on plate 21, and apparently are less prominent eastward, away from the axis. The east-northeasterly joints are not only common near the axis, but seem to prevail about halfway between the north and south ends of the uplift (not far south of the area studied, pl. 21), and to extend for some distance east of the axis.

The east-northeasterly joints may be older, more fundamental features than the other joints, formed as a result of tension like the dominant set, as a byproduct of compression at right angles to the axis of uplift, before it was raised to great height. Their abundance about halfway between the north and south ends of the uplift is in harmony with this interpretation. If the east-northeasterly joints are older, they may have originated during the early phase of the uplift of the mountains, of mid-Tertiary and older age (pp. 108 and 120).

Under this explanation, the dominant, north-northwesterly younger joints resulted from a reversal of forces. During the main phase of the uplift of the mountains, compression continued at right angles to the axis of uplift but was transmitted into the superficial rocks in the form of vertically acting movements. As a result of these vertical movements, tension developed in an east-northeast and west-southwest direction, causing the formation of the dominant north-northwest joints along the axis of uplift. This may have taken place at the same time as, or slightly before, the faulting.

ORIGIN OF FAULTS

The faulting of the area may have taken place after the jointing as a result of movements along the fractures thus formed. If of different age, the faults arose from a set of stresses different from that which caused the joints, and merely followed the lines of weakness already created. More probably, they resulted from similar stresses, acting on the rocks with greater force than before.

The faults seem to be tensional features. Wherever observed, their planes dip toward the downthrow, in the usual manner of normal faults in other regions. Study of the structure sections as drawn suggests that some extension of the crust resulted from the faulting (fig. 18). Moreover, the narrow and in part deeply depressed grabens found in many places could result only

[90] Leith, C. K., Structural geology, revised ed., pp. 21–27, 1923.

[91] In most textbooks of structural geology, tension joints are described as characteristically open and gaping, with irregular, uneven courses, and rough parting surfaces. (Leith, C. K., op. cit., pp. 47–58; Willis, Bailey, and Willis, Robin, Geologic structures, 3rd ed., p. 118, 1934; Nevin, C. M., Principles of structural geology, 2nd ed., p. 153, 1936). These features do not seem to be valid criteria in nature, as shown by the work of Cloos and his associates on plutonic igneous rocks, where the direction of stresses can be worked out more clearly than in other types of rock. (Balk, Robert, Structural behavior of igneous rocks: Geol. Soc. America Memoir 5, pp. 27–33, 1937.)

from an extension of the outer crust. The faults of the Border zone, following a zigzag course across the faulted tract (pl. 21), give the impression of a major tensional break whose trace was determined by already existing lines of weakness. Near the faults there is no crumpling or folding, such as one expects from compression. Further, the faults are in many places filled by veins, which suggests that they were under tension rather than compression.

ORIGIN OF UPLIFT

The uplift of the mountains and the displacement of its rocks by faults are closely related movements, yet they result to a certain extent from opposing forces. Tensional faulting can lower sections of the earth's crust in the direction of gravity; it cannot raise them. Nevertheless, the mountains have been progressively raised against gravity, and from the known geologic history, it would seem that the raising of the mountains went hand in hand with the faulting. The opposition of the two forces is illustrated by sections *B–B′* and *C–C′* of figure 18. If the now disrupted beds in these sections were reconnected by moving each fault block back to its original position, the uplift would be much higher than it now is.

Apparently the uplift and the downfaulting were not caused by isostatic readjustment, resulting from loading of the depressed areas by the deposition of basin deposits, and from unloading of the elevated areas by erosion. This factor has been analysed by Gilluly.[92] As he points out, isostasy would not explain the formation of the initial uplifts and basins. From computations based on an area similar to the Guadalupe and Delaware Mountains region, he finds that "local compensation could theoretically account for perhaps one-third to one-half of the observed displacement." He concludes, however, that the factor of isostasy is subordinate and "that the ultimate cause of the first faulting has likewise been the prime factor in continuing the movement."

Tectonic features, such as those in the Guadalupe and Delaware Mountains, which include both normal faults and uplifted areas, have been explained by Bucher[93] as resulting from alternations of rather brief, severe times of compression, and of longer periods of relaxation and tension, both of which are of wide areal extent. "Regional tension created the basins and furrows * * * while the epochs of compression forced up the positive units." This implies that the faulting, which is of tensional origin, took place during long intervals between brief times of uplift of the mountains.

This theory explains many features of the region, but it also raises many difficulties. There is no evidence that the times of uplift were distinct from the times of faulting; instead, the two seem to have gone hand in hand. There is also no evidence that the times of uplift were of shorter duration than the times of faulting. The last period of faulting, which displaced the older unconsolidated deposits seems, in fact, to have been relatively brief, and to have been preceded and followed by times of quiescence during which pediment cutting and other erosion processes acted for a long period without interruption.

Moreover, considering the region in its relation to other parts of the southwestern United States it is difficult, by any means of correlation that we now possess, to separate the times of uplift and faulting in such ranges as the Guadalupe and Delaware Mountains from times of compressive deformation elsewhere. Thus, the first uplift suggested for the mountains, possibly of pre-Pliocene age, corresponds closely in time to the period of post-Oligocene folding that is manifested elsewhere in trans-Pecos Texas. The second uplift and faulting, of late Pliocene and early Pleistocene age, took place at about the same time as the broad uplift of the San Juan Mountains in Colorado[94] and the strong folding of the Coast Ranges in California.[95] This correlation suggests that a single epoch of deformation resulted in one place in block faulting, in another in epirogeny, and in a third in orogeny.

As suggested when interpreting the joints (p. 124) the Guadalupe and Delaware Mountains may have arisen as a result of deep-seated compression, manifested at the surface by essentially vertical uplift, which put the surface rocks under tension, thereby producing along the crest of the uplifted region an extensive system of tension joints and normal faults.

This interpretation closely resembles the early suggestion by Gilbert[96]

> that in the case of the Appalachians the primary phenomena are superficial; and in that of the Basin Ranges they are deep-seated, the superficial being secondary; that such a force as has crowded together the strata of the Appalachians * * * has acted in the Ranges on some portion of the earth's crust below the immediate surface; and the upper strata, by continually adapting themselves, under gravity, to the inequalities of the lower, have assumed the forms we see. Such a hypothesis [implies] * * * that a ridge, created below, and slowly upheaving the superposed strata, would find them at one point coherent and flexible, and there produces an anticlinal; at another hard and rigid, and there uplifts a fractured monoclinal; and at a third, seamed and incoherent, and there produces a pseudo-anticlinal.

[92] Gilluly, James, Basin range faults along the Oquirrh Range, Utah: Geol. Soc. America Bull., vol. 39, pp. 1123–1130, 1928.

[93] Bucher, W. H., The deformation of the earth's crust, pp. 323, 325, Princeton, 1933.

[94] Atwood, W. W., and Mather, K. F., Physiography and Quaternary geology of the San Juan Mountains, Colorado: U. S. Geol. Survey Prof. Paper 166, pp. 25–26, 1932.

[95] Reed, R. D., and Hollister, J. S., Structural evolution of southern California: Am. Assoc. Petroleum Geologists Bull., vol. 20, p. 1595, 1936.

[96] Gilbert, G. K., Report upon the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872: U. S. Geog. and Geol. Surveys W. 100th Mer. (Wheeler Survey), vol. 3, p. 62, 1875.

CENOZOIC DEPOSITS AND LAND FORMS

THE RECORD OF CENOZOIC HISTORY

The present section of this report deals with the Cenozoic history of the southern Guadalupe Mountains and their surroundings. Here, a different method must be adopted from that used in interpreting Permian history. For Permian time, a relatively complete record is contained in the rocks which form the present mountains, and this record can be dealt with, step by step, by following the stratigraphic sequence upward. For Cenozoic time, the stratigraphic record is incomplete and scattered, being represented in the southern Guadalupe Mountains by various unconsolidated deposits. Gaps in the record must be filled in by interpreting the land forms, the sequence of tectonic events, and the stratigraphic record in nearby regions.

Spreading over the consolidated rocks of the southern Guadalupe Mountains are unconsolidated deposits of later Cenozoic age (shown on plate 22). They are generally found in the lower places where they form either a thin veneer over previously graded rock-cut surfaces (pediments), or a thick fill in areas of decided tectonic relief where the bedrock lies far beneath the surface (bajadas). The unconsolidated deposits, which have an obvious source in the present mountains, consist of fragments washed in from the higher parts of the area that were being eroded while the deposits were forming.

Although these deposits were laid down after the mountains had attained nearly their present form, the aspect of the mountains is still relatively youthful. Their escarpments are high and straight and the canyons that trench them are deep and V-shaped. The plains that surround them are generally bajadas, characteristic of the early phases of degradation of a mountain area. Pediments, which are characteristic of more stable conditions, occupy only small areas. Moreover, some of the older unconsolidated deposits are faulted and tilted, indicating that the mountains continued to be uplifted after the deposits began to be spread over the region.

The unconsolidated deposits are doubtless all of later Cenozoic age. Deposits that lie near the present streams are obviously of Recent age; others, which are now dissected and disturbed, must be as old as the Pleistocene. Still other deposits, perhaps of Pliocene age, may lie beneath the surface of the Salt Basin west of the mountains, for deposits of that age are known in the more-dissected desert basins nearby. In the Salt Basin, however, they are wholly concealed from view, as the younger deposits that cover the floor of the basin have been penetrated very little by erosion.

The higher-standing parts of the area have been undergoing erosion ever since the mountains were uplifted, and have not been covered by deposits. Although their slopes are still being worn back, certain relic features persist, inherited from earlier periods. Some of those in the mountains are probably older than any unconsolidated deposits now visible in the plains, and may date from the early phases of the uplift of the area, or even before.

RELATION BETWEEN PRESENT AND PAST

Some of the surface features of the Guadalupe Mountains region are of modern origin, but most of them have been in growth throughout a long span of Cenozoic time. During most of this time the surface features were shaped by processes conditioned by an arid climate. The extensive mountain areas composed of limestone and the widespread interior drainage system could not have persisted as well in a humid climate, nor would the mountain ridges have retained their present harsh outlines or be so poorly mantled by soil. The deposits of the old debris aprons (bajadas), like those forming today, consist of slightly decayed rock fragments, and the subsoil on both young and old land surfaces is impregnated by caliche, a product of soil formation that exists only in regions of scanty rainfall.

A few of the surface features of the region seem to be relics of processes no longer at work. Such processes existed in part during interludes of more humid climate in Pleistocene time; in general, however, the interludes were too brief to have left much of a mark on the landscape.

Because of the fact that present and past conditions are closely related, I feel it desirable, before taking up the Cenozoic history, to consider the modern landscape and processes at work on it. The landscape and the processes are probably similar to those of the past and their understanding will aid in the interpretation of Cenozoic history.

THE MODERN LANDSCAPE AND PROCESSES AT WORK ON IT

CONTROLLING FACTORS

CLIMATE

The southwestern arid region of the United States, lying south of the middle of the temperate zone, has short, mild winters, and relatively high temperatures during most of the year.[97] In the Guadalupe Mountains, periods of freezing weather are of short duration, and frost action is much less effective than at higher latitudes.

To judge from the record of nearby stations, the rainfall of the Guadalupe Mountain region varies from 10 inches on the plains to nearly 14 inches on the mountain

[97] Thornthwaite, C. W., The Climates of North America according to a new classification: Geog. Rev., vol. 21, pp. 633–655, pl. 3, 1931.

summits,[98] the increase in rainfall with altitude being clearly reflected by the upward increase in the density of the vegetation. Like other high-standing desert ranges, the mountains are a gathering ground for clouds, and they are likely to capture much rainfall that otherwise would never reach the ground.

More than half the normal year's rainfall comes in July, August, and September, and is of the convectional, thunderstorm type. "The individual afternoon thunderstorm does not cover much territory. Clouds gather over a mountain range, where the instability of the air becomes particularly great; thunder begins to roll at noon, or in early afternoon, and a short, brisk downpour covers part of the land that has lain in the shadow of the thunder heads."[99] These rains are not necessarily torrential. Although the run-off that follows them is rapid, this is less because of the volume and rapidity of the downpour than because of the barrenness of the land that receives it.[1] Occasional rainstorms during the summer and other seasons are of cyclonic type. They last longer and cover a wider expanse of territory than the thunderstorms. Evaporation is rapid, and surfaces wet by the rains dry out rather quickly afterwards, thereby reducing the effectiveness of the precipitation as an aid to plant growth.

Mean annual figures express only poorly the actual rainfall of the arid region, for actual rainfall fluctuates from year to year within wide limits. During some years the rainfall, largely by an increase in the number of cyclonic storms, may be so excessive as to create temporary subhumid conditions; during others, it may be so deficient as to create desert conditions.[2] Such fluctuations seem to take place in 5- to 10-year periods, and indications of still longer cycles of 50 to 100 years are suggested by tree-ring records, and by meteorological observations which are as yet insufficient for any final conclusion.[3]

Because of their height and exposed position, the Guadalupe Mountains are swept by strong winds, which increase in frequency and violence during the drier years. The full force of the gales is directed against the mountain crests, saddles, and plateau surfaces; because of the strong relief, some points in the canyons and near the bases of steep slopes are sheltered from winds from certain directions.

[98] Carter, W. T., and others, Soil survey (reconnaissance) of the trans-Pecos area, Texas: U. S. Dept. Agr., ser. 1928, No. 35, pp. 14–16, fig. 4, 1928.

[99] Sauer, Carl, Basin and Range forms in the Chiricahua area: California Univ. Pub. in Geog., vol. 3, p. 344, 1930.

[1] Russell, R. J., The desert-rainfall factor in denudation: 16th Internat. Geol. Cong. Rept., vol. 2, pp. 761–762, 1936.

[2] Russell, R. J., Dry climates of the United States: California Univ. Pubs. in Geog., vol. 5, pp. 245–274, 1932. Kendall, H. M., Notes on climatic boundaries in eastern United States: Geog. Rev., vol. 25, fig. 1, pp. 118–119, 1935.

[3] Bowman, Isaiah, Our expanding and contracting "deserts": Geog. Rev., vol. 25, pp. 46–49, 1935.

SOILS AND VEGETATION

The surface of the area is more or less mantled by typical arid-climate soils, which are thin, poor, calcareous, and generally impregnated by caliche at depth.[4] The soil profiles of the area, however, may not result entirely from processes now at work, but may reflect a climate of the near past, which differed somewhat in the amount of rainfall, and other features.[5]

Within the Guadalupe Mountains and its foothills are extensive tracts of bare rock and rough, stony land, interspersed with patches of immature, residual soils, generally full of rock fragments (Ector series).[6] Despite the somewhat greater rainfall of the mountain areas, soils there do not have an opportunity to reach maturity because they are constantly being washed away. The higher summits and sheltered slopes of the mountains support a sparse forest growth, resulting not so much from favorable soil conditions as from favorable rainfall. In the lower, drier parts of the mountains, where the soils are more extensive, the surface is thinly carpeted with grass, interspersed with sotol, lechuguilla, other woody shrubs, and a few trees.

On the detrital aprons that fringe the Guadalupe Mountains are more extensive, transported, calcareous soils (Reeves series).[7] On the higher parts of the alluvial slopes they are gravelly loams and gravelly fine sands. Farther out are silty clay loams, fine sandy loams, and areas of fine sand that are blown into low dunes by the wind. The alluvial slopes support variously spaced clusters of creosote bushes and other woody shrubs, between which is a sparse grass cover. At the bases of the alluvial slopes is the nearly level expanse of the Salt Basin, which is mantled by a deep, gypsiferous, alkaline soil (Reeves chalk),[8] on which is a moderately thick growth of wiry yeso grass, salt grass, and mesquite.

The inadequate soil cover and sparse vegetation greatly facilitate run-off. The cover of vegetation however, is somewhat more effective in resisting erosion than might be supposed. Sauer [9] has pointed out that in the similar area of southeastern Arizona "The rainfall regime is such that it favors the development of an adequate cover of vegetation prior to the heavier rains. The grasses are dormant until the summer rains set in, but then get under way with great rapidity. The heavier summer rains are almost never at the beginning, but rather toward the end of the rainy season, when the vegetation is already well established."

Climatic fluctuations have a largely unknown but probably important influence on the vegetative cover.

[4] Price, W. A., Reynosa problem of south Texas and origin of caliche: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 502–515, 1933.

[5] Bryan, Kirk, Gully gravure, a method of slope retreat: Jour. Geomorphology, vol. 3, pp. 101–102, 1940.

[6] Carter, W. T., and others, op. cit., pp. 44–46.

[7] Carter, W. T., and others, op. cit., pp. 26–30.

[8] Carter, W. T., and others, op. cit., p. 30.

[9] Sauer, Carl, op. cit., pp. 342–344.

"A sharp desert year may have more effect on crops, tree seedlings, and soil erosion than half a dozen normally moist years. Likewise, a single exceptionally wet year may start a grass cover that will survive less favorable years."[10] During extended dry periods, the cover may be so reduced as to permit extensive soil erosion. Bryan and Albritton[11] report ancient, now filled arroyos in the flood plains of some New Mexico and Texas streams, that were cut during such dry periods, long before the region was occupied by white settlers.

Conditions of this sort probably have been intensified by the manner in which the land has been used since white settlement. By a combination of drought and overgrazing, the grass and shrub cover in places has been seriously depleted. Much soil erosion is in evidence, and formerly level alluvial flats are now penetrated by steep-walled arroyos.

STREAMS AND THEIR WORK

RELATION TO BASE LEVEL

Streams that flow east from the crest of the Guadalupe and Delaware Mountains drain into the Pecos River, a through-flowing stream at the base of the slope, 50 miles away. Because these streams are members of a through-flowing system, they are adjusted to either a constant or gradually lowering base level. Material transported by them is ordinarily carried out of the region, and no doubt eventually finds it way to the sea.

Streams on the west slope have steeper gradients and shorter courses than those on the east slope and are reducing the asymmetry of the mountain block by cutting headward into the area drained by the east-flowing streams. Because they drain into the Salt Basin, a region of interior drainage, they cannot take material out of the region, but must deposit their loads at the bases of the steep slopes. They are probably adjusted to a slowly rising base level, although accretion of new material on the basin floor seems to be taking place very slowly at the present time. It is even possible that the floor of the Salt Basin is being lowered by deflation, but to the east toward which the dominant winds must blow, the enclosing mountains seem to rise too steeply for much material to be blown over them, and so out of the region.

CHARACTER

Because of the arid climate, no streams flow permanently in the area, except in sheltered canyons within the Guadalupe Mountains. During most of the year the stream channels of the region are dry gravel washes, and what water exists percolates beneath the surface. Only after rains do the channels spring into action, and for a short time become filled by rushing torrents. During their brief existence the torrents pick up the gravel and finer detritus and shift it downstream, and by so doing corrade the bed and banks of the channel.

The streams of the region are thus effective agents of erosion only during parts of the year, yet they dominate the sculpture of the landscape. Except on the floor of the Salt Basin, the whole surface is penetrated by channels, each traversing a valley or detrital slope of its own creation. Not only have the streams been able to cut valleys and build up detrital slopes, but many of them, particularly those draining eastward from the crest of the mountains, have been able to cut down to grade or have reached that condition of balance "in which the ability of transporting forces to do work is equal to the work they have to do."[12]

INTERSTREAM AREAS

Between the stream channels that penetrate the region is a complex of sloping surfaces, across which storm waters and weathered rock fragments travel and are collected and carried away by the streams below. Some of them are gently inclined and form plains of various sorts, which are graded with respect to the streams and related agencies at work on them. Other surfaces rise steeply, forming the foothills and mountains, and are as yet unconsumed by the attacking streams. One might suppose, because of their steepness and height, that such surfaces were unstable. Actually, except where they have recently been unbalanced by tectonic or climatic changes, they themselves are graded for the processes at work on them, and their inclination is just steep enough for material to be carried across them.[13]

The steeper slopes, although graded, remain steep because the processes at work on them are less effective than on the gentler slopes. The fragments that lie on them, being close to their sources, are little broken down, and being of relatively large size, are not easy to transport. At the same time running water performs less work, for it has not yet gathered into streams, but is deployed in sheets, rills, and streamlets. In humid regions, where the steep slopes are mantled by residual soil, its downward creep is the chief transporting force. In dry regions, such as the Guadalupe Mountains area, where the soil cover is thin or absent, gravity is a dominant force, acting directly rather than as an aid to soil or stream movement. The steep slopes thus stand at an angle only a little less than the angle of rest of the fragments that cover them. The fragments can almost slide or roll of their own weight, and need but little water to urge them forward.

[10] Bowman, Isaiah, op. cit., p. 59.

[11] Bryan, Kirk, Recent deposits of Chaco Canyon, New Mexico, in relation to the life of the pre-historic peoples of Pueblo Bonito [abstract]: Washington Acad. Sci. Jour., vol. 16, pp. 75–76, 1926. Albritton, C. C., and Bryan, Kirk, Quaternary stratigraphy in the Davis Mountains, trans-Pecos Texas: Geol. Soc. America Bull., vol. 50, pp. 1453–1454, 1939.

[12] Davis, W. M., The geographical cycle: Geographical essays, p. 267, Boston, 1909.

[13] Davis, W. M., Base-level, grade, and peneplain: Geographical essays, Boston, pp. 400–403, 1909.

In granitic mountains of arid regions, it has been observed that the steeper graded slopes change with an abrupt angle into the gentler graded slopes at their bases.[14] In nongranitic mountains, however, such as those in the area of this report, the steep slopes characteristically grade into the gentle ones through a concave arc.[15] This difference in profile is probably caused by the difference in sorts of weathered materials that lie on the two types of surfaces. Those in nongranitic mountains are likely to be smaller, and subject to more rapid disintegration as they move down the slope, than are those in granitic mountains. Hence, the grade needed to transport them lessens down the slope, resulting in a curved profile. In the nongranitic area of the southern Guadalupe Mountains such features are characteristic, and the mountain slopes change gradually rather than abruptly into the plains at their bases.

The gentler-graded slopes have a lower angle because of the greater effectiveness of the transporting processes. Fragments that reach them have been in process of transport for a longer time, and hence have been reduced in size by breakage when falling, by abrasion when carried by water, and by weathering when at rest. Here, running water has gathered into streams of small to large size. The gentler slopes are, to a large degree, graded with respect to the streams, either by cutting down the bedrock, or by building up the areas below grade through deposition. The worn-down bedrock surfaces of arid regions are called pediments,[16] and the built-up surfaces underlain by deposits are called bajadas.[17]

CONTROL OF DEGRADATION BY STREAMS

Degradation of such an area as the Guadalupe Mountains, made up of graded surfaces of varying degrees of steepness, takes place by the propagation of activity backward and sideward from the streams that drain it, thereby extending the gentler slopes, which become adjusted to the more effective transporting agents, at the expense of the steeper slopes, which are adjusted to the less effective transporting agents. By cutting downward, the larger streams renew the activity of the smaller ones on the adjacent pediments and bajadas. They are not only lowered, but are also extended mountainward, thus reviving the activity of sheet wash and gravity on the graded mountain slopes. As a result, the mountain slopes retreat in their turn.

Degradation of the Guadalupe Mountains region has not yet reached an advanced stage, largely because the mountains are still geologically young. Although most of the surfaces are graded, steep slopes still dominate, and pediments are narrow. The gentler slopes along the western edge of the mountains are mostly bajadas "characteristic of disturbed conditions." [18] They are formed during the early stages of degradation of a tectonically unbalanced region by the effort of streams to attain a graded slope.

MOUNTAIN SLOPES

KINDS OF SLOPES

In the Guadalupe Mountains region, the steep slopes of the mountains and foothills are carved from limestones, sandstones, and other stratified sedimentary rocks. The inclination of the slopes depends to a large degree on the nature of the rocks from which they are carved.[19] Rocks that are massive and little jointed weather out in large blocks that are difficult to transport, and hence form steep slopes or cliffs. The rocks that break up into small fragments are worn back into surfaces with a lower inclination. Here, as in the country described by Bryan,[20] the mountain slopes can be classified, according to steepness, into cliffy slopes, boulder-controlled slopes, and rain-washed slopes.

Because of the arid climate and consequent ineffectiveness of solution weathering, the limestones of the region are resistant to erosion. Some of those in the Guadalupe Mountains, belonging to the Capitan and Goat Seep formations, are so indistinctly bedded that they behave as massive rocks. In most places they form steep, graded, boulder-controlled slopes, but on the west side of the mountains, where underlying, poorly resistant sandstones are laid bare to erosion, sapping at their bases has maintained them in cliffy slopes.

In other parts of the region the limestones and sandstones are well bedded. Some of these well-bedded rocks give rise to weathered blocks so large that they form boulder-controlled slopes almost as steep as those of the massive limestones. The sandstones of the Delaware Mountain group form steep slopes of this sort in places, even though they consist largely of thin-bedded material, because layers supplying large weathered blocks are either interbedded with them or overlie them. Elsewhere, the thin-bedded sandstones are cut back into gentle rain-washed slopes graded for the transportation of their own fine-textured weathered detritus.

Because of the general absence of soil creep in the dry region, the different classes of slopes tend to maintain their identity, even when erosion is far advanced.[21] Massive rocks continue to project as cliffy slopes. Boulder-controlled slopes and rain-washed slopes stand at nearly the same angle during their retreat, instead of being worn down to more subdued surfaces.

[14] Bryan, Kirk, Erosion and sedimentation in the Papago country, Arizona: U. S. Geol. Survey, Bull. 730, p. 55, 1923.

[15] Davis, W. M., Sheetfloods and streamfloods: Geol. Soc. America Bull., vol. 49, pp. 1374–1379, 1938.

[16] Bryan, Kirk, op. cit., p. 52.

[17] Tolman, C. F., Erosion and sedimentation in the southern Arizona bolson region: Jour. Geology, vol. 17, pp. 141–142, 1909.

[18] Blackwelder, Eliot, Desert plains: Jour. Geology, vol. 39, pp. 138–139, 1931.

[19] Lawson, A. C., Epigene profiles of the desert: California Univ. Dept. Geol. Bull., vol. 9, p. 29, 1915.

[20] Bryan, Kirk, op. cit., p. 42.

[21] Davis, W. M., Rock floors in arid and humid regions: Jour. Geology, vol. 38, p. 146, 1930.

WEATHERING PROCESSES

The rocks uncovered on the slopes already contain planes of weakness (bedding and joints) which determine to a large degree the size and shape of the fragments into which the rock will subsequently break. When the rocks are exposed to the weather, the processes of disintegration and decay work inward along these planes, loosening the intervening fragments and modifying their surfaces. Weathering takes place mainly by chemical, and partly by physical processes.

The calcitic and dolomitic limestones weather mainly by chemical processes and especially by the dissolving action of water, although its work is retarded by the dry climate. In South McKittrick Canyon, the openings of numerous solution caverns can be seen on the mountain sides, and the stream itself is so charged with calcium carbonate dissolved from the limestones of its drainage area that it is depositing masses of travertine in its channel. At one place in Pine Spring Canyon, solution of the limestones along joints has etched these rocks into groups of pinnacles. Elsewhere, solution has produced less striking forms, yet it has been at work on nearly every outcrop, producing jagged surfaces, and dividing the rock into blocks along widened joints.

Physical processes of weathering have aided in breaking down the limestones, as many of their surfaces are exfoliated. Ledges and residual blocks are in places bounded by curved surfaces, and contain incipient curved cracks within the rock. Broken spalls lie near them on the ground. The exfoliating blocks range from a few feet to 5 or 10 feet in diameter. In the area of Goat Seep limestone in the western foothills of the mountains, the spalls have angular outer surfaces, deeply pitted by solution, but smoothly curving, fresh, clean-cut inner surfaces, indicating that blocks previously shaped by solution had suddenly been split. Analyses of the spalls here and elsewhere show them to consist of calcium or magnesium carbonate, with few impurities.

These features are not easy to explain, for both calcitic and dolomitic limestones have a low coefficient of expansion, which would make their breaking by normal temperature changes unlikely. Moreover, they do not contain minerals that change in volume during chemical decomposition, and thereby set up strains within the rock. It is possible that some of the exfoliation was caused by the heat of brush or forest fires.[22] Some of the most prominent spalling is in exposed, rocky areas, that do not support much vegetation, where its origin is not clear.

The thicker-bedded sandstones weather mainly by such physical processes as exfoliation and granular decay. Weathering along joints and the sapping of weaker beds beneath break them into great, rectangular blocks. Exfoliation reduces many of these blocks to rounded boulders or shapes them into pedestal rocks. Exfoliation shells are constantly developing. Thus, some Indian pictographs in a shallow recess near Chinamans Hat are partly destroyed by the scaling off of thin sheets of the rock on which they were painted. Some chemical processes work hand in hand with the physical processes. Ferruginous material tends to concentrate as a desert varnish near the surface of the sandstones, forming a resistant brown crust over the softer, more friable rock. Later weathering has sought out weak places in the coating, and has cut out pockets that extend behind it.

The thin-bedded sandstones weather, largely by physical processes, into fine-textured debris, such as chips and plates broken out along closely spaced bedding planes and joints, and into sandy soil produced by granular disintegration.

PROCESSES THAT LOOSEN WEATHERED BLOCKS

After being split by weathering, the rock debris is set free in various ways from its parent ledges, and is made available for transportation. Large amounts of material are no doubt thus released by the weathering away or washing out of the rocks that support them, especially if the supporting rocks belong to a poorly resistant stratum. Some are loosened during the colder months by frost. Thus, on a warm, sunny day that followed a period of freezing weather in November 1934, H. C. Fountain and I saw and heard many rocks fall from the cliffs near Guadalupe Peak. Water that had run into crevices and frozen there had pried the rocks apart, and the melting of the ice was no doubt letting the newly broken rocks fall. The work of frost in this region, however, is less effective than at higher altitudes and latitudes.

Some fragments may be broken from their parent ledges by catastrophic forces. Fresh scars that dot the slopes of the Guadalupe Mountains, where blocks have recently come off, have been pointed out to me by local residents as marks left by lightning. It is true that lightning plays about the mountain sides during every thunder storm, and trees riven by lightning bolts can be seen on most ridges. The suggestion that lightning made the scars in the rocks, however, seems to be based on inference rather than observation, and it is unlikely that it could break free any more than small rock masses. Some blocks previously loosened by weathering may be shaken free by earthquakes. Thus, W. B. Lang reports that during the Valentine earthquake of 1931, whose intensity in the area was VI, there were slides of rock in the McKittrick and Dog Canyon areas.[23] Mr. A. J. Williams, who lived near the cliffs on the west side of the mountains, however, did not observe any rock falls from them at this time.

[22] Blackwelder, Eliot, Fire as an agent in rock weathering: Jour. Geology, vol. 35, pp. 134–140, 1927.

[23] Sellards, E. H., The Valentine, Texas, earthquake: Texas Univ. Bull. 3201, pp. 116 (map), 125, 1933.

Some of the largest rock falls in the area have come from a place near the top of the cliffs on the west side of the Guadalupe Mountains a few hundred yards north of El Capitan. According to Mr. J. T. Smith, of Frijole, one of them took place about 1920, when so large a mass was suddenly loosened that its impact shook the windows of his ranch, 4 miles away. Another mass fell from the same place in December 1934, when H. C. Fountain and I were in the region. The cause of these rock falls is undetermined, but they seem to come from a place on the cliffs that has been much weakened by weathering.

TRANSPORTATION OF MATERIAL ON SLOPES

After being set free, the weathered fragments are moved down the slopes by transporting agents. On the cliffs, where they can fall to the base without hindrance, transportation is by gravity alone. Elsewhere, although fragments may be able to roll for short distances, they must be continually urged forward by rainwash. Most of the mountain sides are graded to a combination of gravity and washing. According to Bryan,[24]

> The processes of transportation on slopes are complex and interrelated; frost action, creep, and rain wash, as well as chemical and biological activities are complex in character, and each one enters into the intricate combination of processes that are active on any one slope. * * * For periods of several or even scores of years, the rate of removal of material may be moderate, and thus the retreat of slopes in any one locality may appear relatively slight. The secular processes of chemical decay, of creep, and of rain wash may appear to be dominant but also inconsequential. Suddenly this quiet, progressive action may be interrupted by the relatively violent action of great storms. * * * The formation of gullies appears to be a recurrent phenomenon, dependent on the incidence of great storms. The periodicity of such storms is one of the most important characteristics of the climatic regime, and the retreat of slopes in the desert of Arizona, and perhaps elsewhere, is a pulsatory phenomenon, depending on the irregular incidence of major storms.

The material in transport on the boulder-controlled slopes consists of boulders and smaller fragments, down to pebble size, generally of angular shape and either scattered singly or gathered in waste streams approximately one boulder deep. Soil is almost absent, and soil creep plays little part in the movement of detritus. In most places, the bedrock is scarcely or not at all concealed by the surficial material.

On boulder-controlled slopes carved from interbedded thin- and thick-bedded sandstones, large blocks from the thicker layers strew the surface in great numbers. They seem to be so lightly placed that one expects their movement will be rapid; in fact, Mr. Walter Glover reports that where United States Highway No. 62 has been cut into one of the slopes of Guadalupe Canyon, several sandstone blocks have fallen on the road in recent years. Close study of the sandstone blocks on the slopes, however, shows that in most places their movement must be very slow. Most of them rest on flat faces or have been rather firmly anchored by the surrounding debris. Few of them can be pushed by hand from their present positions, and those few are generally caught again by other blocks after rolling a few feet down the slope. On one of the slopes of Gualalupe Canyon not far from the cut of the highway a large block has an Indian pictograph on one face. This pictograph is in such a position that the block cannot have moved appreciably in the hundred years or more since it was made.

Large blocks lie on the lower slopes of Pine Spring and McKittrick Canyons. They are of massive limestone, and some are more than 30 feet across. They do not seem to be in the process of movement at the present time. They may have rolled to their present positions after having been released from the steeper slopes above. Probably they have not moved since, except during violently torrential rainstorms.

On the slopes carved from the nonresistant rocks, such as thin-bedded sandstone and anhydrite, weathering has produced more soil than elsewhere. Movement of material by soil creep here may be of some importance. At any rate, the land surface, particularly in the anhydrite area, is reduced to subdued, gently rounded forms, which resemble the soil-cloaked slopes of humid regions more closely than do any others in the area.

CLIFFY SLOPES

The most prominent cliffs in the area are those near Guadalupe Peak and El Capitan at the south end of the Guadalupe Mountains, which form the top of a high escarpment, and are themselves 500 to 1,500 feet high. They are carved from calcitic and dolomitic limestones of the Capitan and Goat Seep formations, whose bedding planes are either so indistinct, or so welded together, that they have little influence on the weathering of the rock. The rock is traversed by several sets of joints, many of which extend through the full height of the cliff.

In horizontal plan, the cliffs consist of several segments of north-northwest trend, parallel to the dominant joint set of the region, and of shorter offsets of west-northwest trend. In vertical profile, they consist of smooth, fresh, vertical parts that follow single joint planes, separated by craggy parts carved from the rocks between the joints. The craggy parts are more weathered than the vertical parts, and in places some vegetation has obtained foothold upon them.

At their tops, the cliffs intersect gentler slopes that drain to the east. The angle of intersection is generally sharp, as though the cliffs were being cut back more rapidly than the slopes. The profile of the cliff summits as seen from the west is undulatory, each low place marking the beheaded end of an east-draining valley.

[24] Bryan, Kirk, Gully gravure, a method of slope retreat: Jour. Geomorphology, vol. 3, pp. 90–91, 1940.

The map relations of the cliffs are shown on plate 3, and in greater detail on plate 9. Their structure is shown on the sections of plate 9, and section *K–K′*, plate 17. For views of them, see the aerial photograph, plate 1, and the panoramas, plate 5, *A* (which shows their appearance from the south), and plates 5, *B* and 12 (which show their appearance from the west).

The relations of the cliffs to jointing can be seen on the structure map, plate 20, where the pattern of the cliffs can be compared with observed joint trends. The joints are suggested on plate 12, *A*, where many of the vertical lines are drawn along actual joint planes. The undulatory profile of the cliff summits is well shown in the view from the west, plate 5, *B*.

Through most of their length, the cliffs surmount a slope 500 to 2,000 feet high, carved from the underlying less resistant sandstones of the Delaware Mountain group. The sandstone slopes are more or less mantled by blocks of limestone that have fallen from the cliffs above and have gathered into long waste streams between projecting rock spurs. The heads of the waste streams conceal the top of the poorly resistant sandstones and generally extend up to, but not above, the base of the overlying cliff-making formations. In places, however, the waste streams extend headward above their base along recesses cut along cross joints.

The cliffs in this district owe their prominence to the lofty position of the massive limestones, and to the poor resistance to erosion of the beds which underlie them. The cliffs stand high above the base-level of the Salt Basin to the west, in whose drainage system they lie, and are separated from its flanking bajada by mountain slopes thousands of feet high. Ordinarily the cliff-making rocks would wear back to graded, boulder-controlled slopes as they do in other parts of the area, but here they are continually renewed by the rapid erosion of the beds beneath. The beds beneath, moreover, form steeper slopes than they would assume without the capping of massive rock, because they are graded for carrying away not their own weathered fragments, but the larger, more unwieldly fragments from the cliffs above.

Views of the slopes below the cliffs can be seen on plate 12, *A*, the waste streams appearing most prominently below El Capitan and Guadalupe Peak. Waste streams now in the process of formation (labeled "younger slope deposits") are shown on plate 22. Figure 23, *B*, shows profiles of the slopes below the cliffs, including both a surface being cut in the present cycle, and one formed in a past cycle. The profiles of figure 23, *A*, show hypothetically the successive stages in the erosion of cliffs like those described, which stand above slopes carved from less resistant beds.

The slopes below the cliffs seem to have just attained grade (stages 3 and 4, fig. 23, *A*). Before grade was reached, the slopes were being cut back, either from an original steep fault surface (stage 1), or from a graded surface of a previous cycle. Then (stage 2) they were free of waste because blocks that fell on them from the cliffs could roll to their bases. The poorly resistant beds next beneath the cliff-making formations were thus exposed to erosion, allowing the cliff bases to be sapped, loosening slices of rocks from the cliffs. During this period, there was little time for weathering at the tops of the cliffs, and the cliffs cut off the graded slopes to the east at an acute angle.

Now that the slopes below the cliffs have been graded (stage 3), a mantle of talus and other waste has spread over them, which is just thick enough to be kept in motion by gravity and rain wash. This has so concealed the poorly resistant beds beneath the cliffs that the cliffs are being cut back more by weathering than by sapping. In places, the weathering of recesses in the cliffs has permitted the waste to encroach upward onto the cliff-making formations themselves (stage 4). Weathering of the tops of the cliffs has become important, tending to round their angle of intersection with the slopes behind. Material that is now falling from the cliffs comes from their tops, rather than their bases. To judge from the processes now at work, continued erosion will cause the waste streams to be extended farther up on the cliff-making formations (stage 5), and cause the cliff tops to be lowered by weathering.

BOULDER-CONTROLLED SLOPES ON MASSIVE ROCKS

The cliffs into which the massive Capitan and Goat Seep limestones have been carved are exceptional features in the region. In most places the same rocks form sloping mountain sides with an average inclination of 30 to 35 degrees. Such slopes are well developed in the southeast part of the Guadalupe Mountains, in the area drained by Pine Spring and McKittrick Canyons, and form the whole surface of the Patterson Hills southwest of the mountains.

A general view of the slopes of this sort can be seen in the aerial view, plate 18. Note the similarity in angle of slope on all the ridges. More detailed views of the boulder-controlled slopes which form the walls of North McKittrick Canyon can be seen in plate 16, *B*.

These slopes have been carved from rocks of the same composition and with the same spacing of bedding planes and joints as those which make the cliffs. Slopes rather than cliffs have formed because the underlying poorly resistant sandstones are scarcely or not at all exposed at the bases of the limestones. Instead of surmounting a long sandstone slope, the slopes on the massive limestones rise almost directly from the stream beds, pediments, or bajadas below, so they cannot be steepened by sapping at the base. They are therefore graded slopes, adjusted to the transportation across them of their own weathered rock fragments by gravity and rain wash.

On broader view, the mountain sides cut on massive rocks are smooth, but in detail they are a complex of bouldery rock surfaces, discontinuous ledges, clifflets, and patches of stony soil and slope wash. The clifflets form where the rocks are most massive and least jointed, and are not especially maintained by undercutting below. Ridge crests carved from the massive rocks alone are likely to be serrate or slightly rounded, but many of those in the southeastern Guadalupe Mountains are capped by flat-topped remnants of the overlying, well-bedded Carlsbad limestone. (Summits of both kinds appear in pl. 18.)

BOULDER-CONTROLLED SLOPES ON BEDDED ROCKS

Below the cliffs on the west side of the Guadalupe Mountains are slopes several thousand feet high, carved from bedded sandstones of the Delaware Mountain group. Similar slopes form most of the surface of the west-facing escarpment of the Delaware Mountains to the south. The slopes have been carved for the most part from soft, friable, thin-bedded sandstones that weather into small fragments. They would have been cut back to a low angle were it not that they are graded for the transportation across them of large, unwieldy fragments. In the Guadalupe Mountains, these fragments are of massive limestone and have fallen from the cliffs above. Elsewhere, they are of thick-bedded sandstone and limestone that come from layers interbedded in the thin-bedded sandstone. Slopes controlled by such boulders are likely to be as steep as those carved from the massive limestone.

Along the Delaware Mountains escarpment, most of the interbedded thick layers are of massive sandstone in beds as much as 100 feet thick, but near the rim of the escarpment there are several limestone beds. The thick-bedded sandstones form benches and lines of clifflets on the mountain sides, and one of them projects as a broad shelf about halfway up the slope below El Capitan. Where there has been considerable dissection, the massive beds form the caps of flat-topped mesas and castellated buttes, and where the strata are tilted, as in the foothills west of the mountains, they rise in hogback ridges.

For a general view of slopes of this sort see the panaroma, plate 5, *A*, where they form most of the escarpment of the mountains below the cliffs, in the center and right-hand parts of the view. A more detailed view of the slopes below El Capitan appears on plate 1, and of the slopes in the Delaware Mountains farther south on plate 14, *C*. The latter shows some of the characteristic butte-and-mesa topography of the area.

Steep slopes carved from bedded rocks of another sort form most of the surface in the northwest part of the southern Guadalupe Mountains. These rocks are dolomitic limestones of the Goat Seep and Carlsbad formations, which lie in thin, even beds, with occasional breaks of softer, more marly or more sandy material. Slopes carved from them are not as steep as those carved from the massive limestones, and they have a very different aspect. Weathering has accentuated the already well-marked bedding planes, so as to give the mountain sides a banded appearance. Each white band is a ledge of limestone somewhat thicker than the rest, and each intervening dark band is a soil-covered slope cut on thinner-bedded limestone, sandstone, or marl.

A typical view of slopes of this sort can be seen in the panorama, plate 14, *A*. Their appearance can be compared with that of boulder-controlled slopes cut on massive rocks on plate 16, *B*, where slopes of bedded rock form most of the canyon wall to the left, and slopes of massive rock most of the canyon wall to the right.

Ridge crests on the bedded dolomitic limestones are likely to be gently rounded, spreading out into flattish surfaces on the broader divides, and narrowing into castellated walls between closely adjacent valleys. Few of the ridge crests follow any single bedding plane, but near Cutoff Mountain where the rocks are steeply tilted, broad dip slopes have been cut on some of the surfaces of the limestone beds in the Goat Seep and Bone Spring formations.

RAIN-WASHED SLOPES

Besides the high, steeply sloping mountain sides that dominate the landscape in the southern Guadalupe Mountain region, there are other surfaces, as yet not reduced by streams, that have angles of 20 degrees or less. Slopes of this type form the summit and east slope of the Delaware Mountains in the southeast part of the area studied, and the hillsides of the Gypsum Plain to the east. They have been cut from thin-bedded sandstones of the Delaware Mountain group, from limestone layers interbedded with them, from anhydrite of the Castile formation, and from Quaternary gravels that in places spread over the bedrock.

A typical view of such topography can be seen in the panorama, plate 4, *A*, where the sandstones form the slopes and valley bottoms, and the limestones and gravels the mesa tops.

The thin-bedded sandstones are similar to those from which the steeper escarpments to the west have been carved. Here, however, few of the harder, thicker, interbedded layers are exposed on any individual hillside. Few large blocks are therefore contributed to the slope deposits, and the slopes are graded mainly for the transportation of fine-textured debris. Where unprotected by harder beds, the sandstones are worn back into gently rounded, grass-covered hills.

Where harder limestones are interbedded, the overlying poorly resistant sandstones have generally been stripped from the limestone surfaces, and the limestones form the caps of flat-topped mesas or of gently sloping cuestas. At the edges of the mesas and cuestas the limestones break off in low cliffs or chains of ledges, below which are slopes formed on the underlying sandstone, whose angles are steeper than those where no capping is present.

The Quaternary gravels, which spread as a sheet over the rocks of the Delaware Mountain group for several miles southeast of the edge of the Guadalupe Mountains (pl. 22), are almost as resistant to erosion as the hard limestone and sandstone layers interbedded with the thin-bedded sandstones. The deposit consists of closely packed cobbles and pebbles of resistant limestone washed out from the Guadalupe Mountains, cemented in many places by caliche. Even where not cemented, however, the gravels are probably so porous that water falling on them mostly sinks in, and erosion by rain wash and rills is therefore retarded.[25] Because of their resistance to erosion, the now dissected remnants of gravel stand as sloping plains scored by narrow ravines or, where more greatly reduced, as flat-topped patches on the divides, not unlike the mesas carved from the hard layers of the bedrock.

PLAINS

The Guadalupe and Delaware Mountains and neighboring ranges of the arid region, composed of slopes of the sorts just described, rise abruptly from gently inclined plains which surround them like pedestals. To one who travels through the region, the mountains appear to dominate the scene, and the plains seem foreshortened to the eye. By comparison with the diverse and rugged mountainsides, their surfaces appear featureless and monotonous. Actually, the plains of the arid country occupy as wide an area as the mountains, and their surfaces, although less impressive, are equally diverse in form and origin.[26]

Large areas of the plains, particularly near the mountain bases, are dominated by the work of streams, which, in an effort to accomplish a graded slope, have shaped the plains into characteristic profiles. In part the plains are bajadas which have been built up by the deposition of detritus, and in part they are pediments, which have been carved out of the bedrock. West of the bajada that fringes the western base of the Guadalupe Mountains is the broad, nearly level floor of the Salt Basin, a typical desert bolson.[27] Here, there is little evidence of stream work, and many of the features found on its surface seem to have been shaped by the wind.

ORIGIN OF BAJADAS AND PEDIMENTS

Bajadas are graded depositional surfaces built up by streams.[28] Streams lay down deposits where they lose the power to transport the loads that they were carrying in their upper courses, either by loss of volume or loss of gradient. Volume is lost at the edge of the mountains partly because the mountains are the chief source of rainfall, and streams are not renewed on the plain, and partly because the streams sink into previously formed deposits, or dry up by evaporation. Gradient is lost because the stream enters either a region whose slopes have been changed by tectonic activity, or one in which the slopes were planed off to a low gradient under earlier, more favorable climatic conditions. Deposition continues until streams reach grade, and are able to carry their loads across the slope.

During the earlier stages of the degradation of a region after tectonic activity has ceased, when much coarse detritus is available and when many surface irregularities must be smoothed out, streams occupy themselves mainly with building up the depressed areas. Most of the plains along the mountain bases at that stage are bajadas or constructional surfaces. Later on, as the period of crustal stability lengthens, the streams begin to plane off the lower margins of the uplifted blocks, and wear down their rocks into pediments or erosional surfaces. Along the flanks of the Guadalupe and Delaware Mountains, which are still geologically young, most of the plains are bajadas, and pediments are narrow or absent. Pediments, however, have developed extensively during times of stillstand in the past. They are continuing to form, and if there are no great tectonic or climatic disturbances in the future, their area will be further extended.

Because pediments and bajadas are graded surfaces, they are cut down or built up until there is a balance between the transporting forces and the load to be carried. The strength of the transporting forces and the nature of the load varies, however, in response to renewed tectonic activity, to changes in the amount of rainfall, or to reduction of the mountain masses by degradation. Some of the larger tectonic or climatic fluctuations that occupy a long span of time so disturb the balance between transporting forces and load that they are reflected in the land forms. As a result, pediments may be dissected by accelerated erosion, and bajadas covered with sheets of material supplied by renewed aggradation. Also, bajadas may be dissected and pediments aggraded, thereby superimposing one contrasting type of land form upon the other. Such land forms of mixed origin are common in the Guadalupe Mountains region, suggesting a varied geomorphic history in the near past.

PEDIMENTS

The pediments of the area have been cut only on the less resistant rocks, such as the sandstones of the Delaware Mountain group. They are most extensively developed where that group crops out on the east slope of the Delaware Mountains, and in the foothills to the west. Here, broad pediments have been cut in the past, and narrower ones are now being cut at lower levels. The limestones of the Guadalupe Mountains have been planed off very little, and most of the streams that drain them still flow in V-shaped canyons. The pediments of

[25] Rich, J. L., Gravel as a resistant rock: Jour. Geology, vol. 19, p. 494, 1911.

[26] Blackwelder, Eliot, Desert plains: Jour. Geology, vol. 39, pp. 133–140, 1931.

[27] Hill, R. T., Physical geography of the Texas region: U. S. Geol. Survey Topographic Folio 3, p. 8, 1900.

[28] Johnson, W. D., The High Plains and their utilization: U. S. Geol. Survey, 21st Ann. Rept., pt. 4, pp. 613–622, 1901. Tolman, C. F., Erosion and sedimentation in the southern Arizona bolson country: Jour. Geology, vol. 17, pp. 155–158, 1909.

the area appear to have been cut by streams rather than sheet floods.[29]

The areal distribution of the pediments that are forming today is shown on plate 22, where they occupy the areas labeled "younger pediments" and "stream alluvium and cover of younger pediments." A small pediment area in the Delaware Mountains, thinly covered by deposits, can be seen along the stream channels in the foreground of plate 4, *A*. A more extensive pediment area, west of the Delaware Mountains, extends across the foreground of plate 5, *A*. Here, most of the lower ground is covered by deposits whose surfaces merge northward into a bajada which may be seen in the distance.

The pediments on the east slope of the Delaware Mountains are strips of flattish ground spread out sideward from the flood plains of the streams, into which they merge at their lower edges. In places they are mantled only by coatings of residual and transported soil; elsewhere they are thinly covered by fine-grained alluvium. Older pediments, later buried under a sheet of gravel and now dissected to depths as great as 100 feet, occur in the same area and fringe the southeast base of the Guadalupe Mountains.

The pediments west of the Delaware Mountains form an irregular network that penetrates the foothill ridges of harder rock and mesalike remnants of an older, higher-standing, gravel-capped pediment. The pediments have been extended sideward from streams that flow westward across the foothills to the bajada at the edge of the Salt Basin. Owing, perhaps, to a gradual rising of the base level of the streams, most of the pediment areas are covered by alluvial deposits, probably of small thickness. Toward the divides, however, the rock surface is laid bare, and rises here and there in low protuberances, which probably mark the sites of former buttes, whose hard cappings have now been eroded away.

BAJADAS

A bajada extends as a wide belt along the west side of the Guadalupe and Delaware Mountains, between the base of their west-facing escarpment and the floor of the Salt Basin. The unconsolidated deposits which compose the bajada are spread over a bedrock surface that probably has many irregularities of tectonic origin, and in places the deposits may be very thick. A somewhat similar area extends along the base of the Reef Escarpment, southeast of the Guadalupe Mountains. Here, however, the unconsolidated deposits are spread over the surface of the older pediment noted above, and are of no great thickness. They are now being dissected, and no further deposition is taking place on them at the present time.

The bajada on the west side of the mountains is shown on plate 22, where it occupies the area labeled "younger fanglomerate." Note the pattern of the streams on its surface, which are shown in a separate symbol. The bajada forms the foreground of plate 5, *B*. Its relations to the underlying rocks are shown on sections *A–A′* and *B–B′*, plate 3. A schematic section across it, based on several actual profiles, is shown on figure 22, *A*.

The bajada west of the mountains is 2 to 4 miles wide and rises 500 to 1,500 feet from the floor of the Salt Basin to the bases of the mountains. In the northern part of the area studied, it is a succession of coalesced alluvial fans, interrupted only at wide intervals by rock ridges, which project above it like islands. Each fan slightly indents the mountain front at its apex where a canyon leading down from the mountains drains onto its surfaces. Each fan merges sidewise with adjacent fans, and ends forward on the floor of the Salt Basin. The slopes of the fans are concave upward (fig. 22, *A*). Those with the flatter gradients and longer radii are fed by canyons that drain the larger areas in the mountains. As most of the canyons in this district drain only a few square miles of area, all the fans tend to be of nearly equal size and gradient.

Between the fans in many places are strips of ground with gentler gradient that extend toward the mountain front (not separated from the fanglomerate areas on pl. 22). Some of these strips have been shielded from depositing streams so long that they are smooth and soil covered.[30] Other interfan strips down which streams have recently been deflected from the fans, are choked by coarse detritus. All the soil-covered strips will doubtless be covered by such material at some time in the future. Down-slope from some of the interfan strips into which streams have been deflected are small, secondary alluvial fans.

Farther south, where the foothill ridges are higher and more continuous, the bajada is more irregular. Material washed out from the Guadalupe Mountains has accumulated behind the foothill ridges until drainage can overflow the lower saddles, or be deflected around the ends. Instead of forming a continuous slope, different segments of the bajada are thus interrupted by ridges. As a result of the deflection by the ridges, drainage tends to be concentrated in places and dispersed in others, so fans of greatly different sizes have been built west of the foothills. Two fans with large radii and low gradients have thus formed at the north and south ends of the Patterson Hills, where many streams coming from the mountains approach one another. In the intervening area there are smaller, steeper fans, built by streams draining from the Patterson Hills alone.

Along the south edge of the area studied, where the high-standing rocks of the foothills are poorly resistant to erosion and have been worn down to pediments and low ridges, the bajada occupies a relatively narrow area between the foothills and the floor of the Salt Basin

[29] Davis, W. M., Sheetfloods and streamfloods: Geol. Soc. America Bull., vol. 49, pp. 1337–1416, 1938.

[30] Similar features have been termed "interfan remnants" by R. J. Russell (Land forms of San Gorgonio Pass, southern California: California Univ. Pub. Geog., vol. 6, pp. 74, 79, 1932).

to the west. South of the area studied, the foothills gradually disappear, and a bajada again extends up to the base of the Delaware Mountains.

The material on the bajada is derived mainly from the escarpment of the Guadalupe and Delaware Mountains to the east of it. It includes resistant fragments of bedded or massive limestone, which predominates toward the north, and of bedded sandstone and black limestone, which predominate toward the south. Fragments of similar rocks are contributed to a smaller extent by the foothill ridges. Near the head of the fans, angular blocks 10 feet or more across are common, and are clustered in trains that extend out from the canyon mouths above. No doubt these blocks were washed out by exceptionally large floods or mud flows. Between the trains is an unstratified aggregate of finer-textured, angular debris, probably laid down during times of more normal stream flow. Farther out, trenches eroded in the bajada expose finer-textured deposits, consisting of alternating beds of cobble or pebble conglomerate, and of loesslike, in part gypsiferous, clay. Stratification is parallel to the bajada surface, gently inclined to the west. The surface of the bajada, even to its edge, is a gravelly soil, which supports a characteristic vegetation of lechuguillas, yuccas, daggers, and creosote bushes.

As a result of the conical shapes of the fans, due to excess deposition opposite the canyon mouths, streams that flow across them radiate from the apices. (These are shown as "streams consequent on bajada surfaces" on pl. 22.) The placing of the main channel is fortuitous, and depends on minor depositional irregularities. On some fans the main channel leads directly down the slope along the crest; on others, it is deflected sideward, near or against the mountain front, toward the adjacent interfan area. The channels increase in number outward, but this increase is less from the bifurcation of the main channel than from the implantation of new channels, whose heads are on the fan surfaces. Many channels, instead of bifurcating, come together down the slope.

Some of the channels that cross the fans are anastomosing, gravel-floored washes, whose surfaces are nearly level with the interstream areas. Near them the boulder deposits consist of fresh or slightly weathered fragments, suggesting that such channels are actively depositing material today; however, by far the greater number of the channels entrench the fan surface. Near the apices of the fans, the trenches reach as much as 50 feet in depth, but they are shallower down the slope. Some of the entrenched channels are possibly the normal beds and banks of the larger torrents that occasionally follow them.[31] However, boulders near the entrenched channels are usually much weathered, soil covered, and overgrown by vegetation, as though the processes that placed them there had now ceased, and as though the entrenched streams no longer overflowed the sides of their channels. If so, the streams have now been cut down to a gradient lower and flatter than that which had controlled the building of the bajada.

Such down cutting may have been brought about during the normal progress of degradation of the mountain area, and without an interruption by tectonic or climatic causes.[32] At first, when the mountains were newly uplifted, their slopes were high and steep, and the material delivered to the surrounding bajadas was coarse textured. The surfaces of the bajadas were then graded to a relatively steep angle. Later on, after the mountain slopes were worn back, material carried across them was weathered to smaller fragments before reaching the bajadas. The streams then adjusted their grade to a lower angle of slope. As a result, they entrenched the upper parts of the fans, and shifted the material thus picked up to lower places on the slope. The bajadas in the Guadalupe Mountains region seem to have passed into this later stage of development.

FLOOR OF SALT BASIN

West of the bajada that slopes down from the escarpment of the Guadalupe and Delaware Mountains is the broad floor of the Salt Basin. The bajadas on its periphery do not merge with the central floor by a gradual flattening of profile and diminution in texture of the deposits toward the axis of the basin. Instead, the bajada descends 100 feet or more in the last mile to its edge, and then gives place to the basin floor which is essentially horizontal (fig. 22, *A*). With this change in gradient, there is a corresponding abrupt change from coarse- to fine-textured soil, although in places this relation has been modified by drifting of the surface material by the wind. Soil changes are emphasized by the vegetation, for the creosote bush assemblage of the bajada gives place within a few feet along the boundary to the yeso grass assemblage of the basin floor.

Within the area studied, and over wide expanses elsewhere, the floor of the Salt Basin lies between 3,620 and 3,640 feet above sea level. There is not sufficient gradient for water discharged on it to flow in any particular direction, and it has no drainage channels. Ground water stands nearly level, within a short distance of the surface. At Williams Lower Ranch west of the Patterson Hills, it is reached by a well at a depth of 28 feet, and it is probably at or a little below the surface in the alkali flats to the west, whose altitude is 22 feet lower than that of the ranch. Richardson[33] reports similar depths to ground water elsewhere in the basin.

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[31] Russell, R. J., op. cit., p. 84.

[32] Baker, C. L., Notes on the later Cenozoic history of the Mojave desert region in southeastern California: California Univ. Dept. Geol. Bull., vol. 6, pp. 374–377, 1911. Eckis, Rollin, Alluvial fans of the Cucamonga district, southern California: Jour. Geology, vol. 36, pp. 237–238, 1928.

[33] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, p. 89, 1904.

The basin floor within the area studied is but a small segment of the whole expanse, which extends about 5 miles farther north and 35 miles farther south, and has a maximum width of 15 miles (pl. 23). The Salt Basin itself continues farther north and south than the ends of the floor, but here the outer edges of the bajadas from either side meet at the center in broad axial troughs. Aerial photographs indicate that the troughs are followed by more or less definite stream channels that drain toward the lower-lying floor in the central segment of the basin.

The floor of the Salt Basin is underlain by fine-grained unconsolidated deposits which probably extend to great depths. It does not seem to be receiving any important amounts of new material at the present time. Most of the detritus washed out from the mountains and foothills is deposited on the bajada and does not reach the floor. The lower edge of the bajada, where it meets the basin floor, seems to be the outer limit of effective stream action at present. The chief process now at work on the basin floor is the wind, which is not bringing in any new material, but is shifting about what is already there. Instead of leveling the surface, the wind is increasing the relief, scooping out hollows, and piling up material. The processes that leveled the floor are, therefore, no longer at work, and the floor has been inherited from an earlier period. As indicated in a later section, the floor was probably the bottom of a lake or succession of lakes which filled the lowest part of the Salt Basin in Pleistocene time (pp. 151–152, 156–157).

Brief field observations on the surface features of the basin floor were made during the present investigation; they have been subsequently studied by me in aerial photographs. They closely resemble those in other nearby desert basins, which have been described and interpreted in some detail by Meinzer.[34] The features comprise alkali flats, sand dunes, clay hills, meadows, and beach ridges. They are distinguished by separate patterns on the map, plate 22.

The alkali flats, locally known as salt lakes, are among the most conspicuous features of the basin floor. Several occur in the western part of the area studied; one is well displayed where crossed by U. S. Highway 62. Outside the area studied, the flats are not adequately shown on any published map,[35] but they are strikingly exhibited on aerial photographs. The alkali flats within the area studied are part of a series of flats that extend 8 miles westward, 4 miles northward, and 15 miles southward (pl. 23). The larger flats lie west of the area studied, where some are over 5 miles long and 2 miles wide. The alkali flats of the series have a curious arrangement, tending to lie in chains on the east and west edges of the basin floor, with ground as much as 20 feet higher in the intervening central area. This higher ground with its flanking depressions is a relatively old feature, for aerial photographs show that it is marked by concentric beach lines, perhaps dating from the lacustrine period of late Pleistocene time (pl. 23).

The surfaces of the alkali flats are level expanses of alkaline clay, bare of any vegetation. For short periods after rains, they are likely to be covered by thin sheets of water, and for somewhat longer periods the clay is damp and sticky, and dotted with saline pools. At other times their surfaces are dry, hard, and sun-cracked, and mirages often give them the appearance of containing water. All the flats are coated with a thin efflorescence of various salts. On one of them, which lies a short distance west of the area studied and from which salt has been dug for many years, the efflorescence is continually forming, and is renewed within a few weeks after it has been stripped away (p. 161).[36]

The flats are bordered at the edges by low, steep banks 10 to 20 feet high, which are scored in places by small ravines that are cutting headward into the surrounding country. These ravines indicate that the banks are being maintained or even cut back at the present time. The banks pursue a highly irregular course, curving around numerous promontories and fingerlike embayments. In the middles of some of the flats are island-like areas of higher ground with similar steep banks along their edges. On the large alkali flat in the southwest part of the area studied (pl. 22), the greatest irregularity of the edges is on the west side; the eastern edge is nearly straight.

The alkali flats probably originated as shallow or intermittent lakes that filled slight depressions in the basin floor. Old beach lines on higher ground nearby indicate that the flats lie in relatively ancient depressions. Lacustrine action is not effective at the present time, as the flats are covered by water only at long intervals, yet the surfaces remain smooth and open, and the steepness of the banks at the edges is being maintained. As suggested by Meinzer,[37] the flats are probably swept clear—and are even being extended—by wind erosion. The surfaces of all the flats in the area, whether connected or not, stand at an altitude a few feet above 3,620 feet, or near ground-water level. Apparently the wind has carried away all the dry earth above ground-water level, and has found an effective downward limit of cutting on the surface of the saturated earth below.

[34] Meinzer, O. E., Geology and ground-water resources of Estancia valley, New Mexico: U. S. Geol. Survey Water-Supply Paper 275, pp. 10–11, 16–27, 1911. Meinzer, O. E., and Hare, R. F., Geology and water resources of Tularosa Basin, New Mexico: U. S. Geol. Survey Water-Supply Paper 343, pp. 40–53, 1915.

[35] The approximate limits of those west of the area studied are indicated on the Salt Basin topographic sheet, but they are incorrectly marked as marsh land.

[36] Richardson, G. B., op. cit., pp. 62–64, 1904.

[37] Meinzer, O. E., op. cit., pp. 26–27. Meinzer, O. E., and Hare, R. F., op. cit., pp. 44–45.

The next most conspicuous features of the basin floor are the sand dunes. These are well developed in the area studied, perhaps to a greater extent than elsewhere in the Salt Basin (pl. 23). In places the sand is white, and consists of grains of crystalline gypsum; elsewhere it has a reddish hue and consists of quartz. The two minerals are not mingled, and their dunes occupy separate areas.

The dunes of quartz sand are found in two areas, one north and the other south of the ends of the Patterson Hills. They spread over the edge of the basin floor and up the slopes of the bajadas to the east. The dunes reach a maximum height of 30 feet in the northern area. They are of irregular form and are separated by irregularly placed depressions. Mesquite and yucca commonly grow between the dunes, but many of the dune surfaces are bare and ripple marked. The bare sand is so loosely placed that even moderate winds can blow it about. The dune sand on the bajada thins gradually toward the mountains, and the easternmost dunes are separated by depressions in which the underlying deposits of the bajada are exposed. East of the main dune area, some sand is banked against the eastern or lee side of low rock foothills that project from the bajada.

The sand appears to be moving eastward up the bajada slope, urged forward by winds from the west. According to local residents, the sand is encroaching year by year on the land to the east. There is thus a steady conflict between the eastward-blowing winds and the westward-flowing streams of the bajada. As the wind is at work for longer periods than the streams, it fills their channels with sand during the dry periods. One channel was traced through the dune area. Up the slope, east of the dunes, it is a gravel-floored arroyo with steep banks 20 feet high. Within the dunes it narrows and its bed contains only tiny pebbles. It lies in a shallow swale, across which the sand has drifted in many places. Apparently the stream that flows in it during each freshet loses its vigor in the dune area, perhaps because much of its water sinks in the sand and what remains must work to clear the channel of drifted sand.

The source of the quartz sand seems to be the unconsolidated deposits along the western edge of the bajada and the eastern edge of the basin floor. The basin deposits are more sandy in some places than others, the sand having been deposited by streams draining areas of sandstone in the mountains to the east. It is significant that there are no areas of quartz sand dunes west of the Patterson Hills where the basin deposits contain little mountain-derived detritus.

Dunes of gypsum sand are much less extensive than dunes of quartz sand, in fact there is only one large tract in the Salt Basin. This tract lies on the floor of the basin within the area studied, and has an area of about four square miles. The northeast end of the tract is a crescent-shaped ridge a mile across, made up of white, shifting dunes, bare of vegetation, with an appearance similar to the well-known White Sands area of the Tularosa Basin in New Mexico.[38] The northeast side of the ridge is steep-faced, and the white sand ends abruptly along its base, as though the dunes were moving northeast. Farther southwest, the dunes are low and considerably masked by vegetation. Aerial photographs indicate that the lower dunes extend 5 miles southwestward, nearly to the edge of a large alkali flat west of the area studied. In this area they extend across beach ridges and other older features.

The sand of the gypsum dunes in the Salt Basin, like that in the Tularosa Basin, is probably derived from the gypsiferous clay blown out of the alkali flats that lie to the west and southwest. As Talmage suggests, the sand may have been derived from crystals that had grown in the clay.

Elsewhere in the Salt Basin, particularly south of the area studied, are numerous low, rolling hills of gypsiferous clay which likewise were probably heaped up by the wind. Here, however, the gypsum is not granular and was probably derived from earthy rather than crystalline material. Wide areas in the basin on its west side, and smaller tracts between the dunes and clay hills farther east, are flat meadowland underlain by brown clay. The difference in texture between the clays of the meadows and the earthy gypsum of the hills becomes evident after a rain, when the clays are wet and sticky, and the gypsum relatively dry and hard. The meadows are covered with a thick growth of wiry yeso grass and salt grass, and in the moister places there are clumps and groves of mesquite.

Beach ridges are present in many places on the floor of the Salt Basin, and show prominently on aerial photographs (pl. 23). They are relics of Pleistocene time when the floor was covered by standing water and are discussed under a later heading (pp. 156–157).

PRE-PLEISTOCENE (?) TOPOGRAPHIC FEATURES AND DEPOSITS

Having now reviewed the modern landscape and processes at work on it, attention will be directed to features formed in older Cenozoic time, proceeding from the oldest features to the youngest.

The earliest period, probably pre-Pleistocene, is very poorly recorded, and many gaps must be filled by inference and deduction. The oldest topographic feature in the Guadalupe Mountains, the summit peneplain, is probably not Cenozoic, but pre-Cretaceous. It antedates the uplift of the mountain area and serves as a convenient datum from which to gage the effects of later events. The next younger features in the

[38] Herrick, C. L., Geology of the white sands of New Mexico: Jour. Geology, vol. 8, pp. 112–128, 1900. Meinzer, O. E., and Hare, R. F., op. cit., pp. 45–47. Talmage, S. B., Origin of the gypsum sands of Tularosa valley [abstract]: Geol. Soc. America Bull., vol. 43, pp. 185–186, 1932.

mountains are the courses of certain streams which appear to have flowed down the slopes of the initial uplift, and to have been consequent on these slopes. These streams were probably older than the faulting of the area. At the time that these streams were taking their courses in the mountains, deposits were probably forming in the lower country east and west of the mountains. Not much is known about the deposits near the Guadalupe and Delaware Mountains, but comparable deposits exposed in surrounding areas have been dated by fossils as of Pliocene age. A period of movement later than the initial uplift is suggested by a second generation of consequent streams. During this later movement, faulting dominated, for the second generation of consequent streams flow in fault troughs.

SUMMIT PENEPLAIN

CHARACTER

Anyone who crosses the Guadalupe Mountains is soon aware that their summits are notably even-crested. For considerable distances the trails, which afford the only means of travel through the region, cross a succession of broad swales and gently rounded hilltops, much overgrown by timber, with here and there a glimpse into a steep-walled canyon incised to great depth below. If the trail descends into such a canyon, it is likely to rise on the other side to another patch of relatively flat ground of about the same altitude as the first.

The even crests seem readily explainable at first. The rock of most of them is the well-bedded limestone of the Carlsbad, and for short distances the crests are cut on single layers of the bedded rock. However, when any ridge is viewed in panorama, the bedded rocks on its sides are seen to dip at a low angle to the southeast and to rise and terminate on its crest to the northwest. The rocks at the summits are thus of different ages from place to place. Toward the southeast, near the rim of the Reef Escarpment, the rocks belong to the top of the Guadalupe series, whereas a few miles to the northwest, they belong to the base of the upper part of that series, nearly 1,000 feet lower (fig. 15, *B*).

The even crests of the mountains are therefore not wholly caused by the bedding of their rocks; instead, they seem to be remnants of a formerly more continuous surface that extended across the edges of the rocks. This surface was no doubt formed by erosion when the geography of the region was very different from that of today; it is probably an ancient peneplain. Remnants of this peneplain have persisted in the Guadalupe Mountains because the resistance of the limestones in the upland has retarded the widening of the canyons that now incise it. Boulder-controlled slopes rising from the bottoms of two adjacent canyons thus rarely meet at their upper ends, but are separated by fairly broad dividing ridges. Degradation has no doubt been at work on the ridges, yet it has proceeded so slowly that the divides still retain something of the form of the original surface.

Although the remnants of the peneplain bevel the underlying strata, the peneplain seems to have shared the tilting and faulting of the mountains themselves. On the northeast side of the mountains, in the vicinity of McKittrick Canyon, the crests rise southwestward from altitudes of 7,000 feet or less, to 8,000 feet or more, at the rate of several hundred feet to the mile. Near the headwaters of the canyon, where the rocks are much faulted, the crests remain at accordant heights in single fault blocks, but stand higher or lower in adjacent blocks by an amount corresponding to the throw of the intervening fault. No higher ground appears to have projected above the peneplain except what has been raised by subsequent movements.

Plate 18 is an aerial view across the region in which the summit peneplain is preserved. Note the occasional patches of level ground on the divides, such as that in the right foreground and that near the center in the middle distance. The irregularity of the surface toward the background results from faulting. On sections *E–E′*, *H–H′*, and *I–I′*, plate 17, tracing of the beds that form the canyon rims and ridge crests shows that they are truncated northwestward by the summit peneplain. Displacement of the peneplain by faulting appears on plate 14, *A*, where it forms the sky line in the background, and also the summits of the lower ridges in the foreground. The structure in this vicinity is shown in the right-hand part of section *A–A′*, plate 3.

POSITION OF SUMMIT PENEPLAIN IN SURROUNDING AREAS

The crests of the southern Guadalupe Mountains, outlined by the summit peneplain, project far above the surrounding areas. Southward and southeastward the land surface descends abruptly over the Reef Escarpment to the Delaware Mountains and Gypsum Plain 1,000 feet or more below. Because remnants of the peneplain extend without change in attitude to the rim of the escarpment, and because there is no tectonic break along its edge, any former extension of the peneplain in this direction must have lain high above the existent land surface. All traces of it have been destroyed because the rocks of the region are sandstones and anhydrites, less resistant to erosion than the limestones of the Guadalupe Mountains, and have been degraded to lower levels. Between the streams, the rocks have been worn down to gentle, rain-washed slopes rather than to steep, boulder-controlled slopes. These slopes meet at their upper ends in divides that stand far below the original surface of the country.

The southeastward termination of the summit peneplain along the Reef Escarpment can be seen on plate 4, *A*. Note the accordant summits on the skyline, at the top of the escarpment, and the low, rolling hills and shallow valleys along its base, which are characteristic of the country to the south. The same relation is shown diagrammatically on figure 20, *A*, and in profile on figure 21, *A*. On the latter, note the difference in altitude between the summit peneplain and the land surface southeast of it.

The land also descends northward and northeastward from the southern Guadalupe Mountains into the northern Guadalupe Mountains, but without an abrupt topographic break. The same limestone plate as that which caps the southern Guadalupe Mountains extends into this region, and here also, remnants of the peneplain are probably preserved on the mountain summits. Queen Mesa, one of the summit areas northeast of the area studied, is of considerable extent. West of the southern Guadalupe Mountains, the limestone plate is preserved in the lower ridges of the Brokeoff Mountains and Patterson Hills, but has been much disturbed by faulting and tilting. Extensions of the summit peneplain, which have no doubt been correspondingly faulted and tilted, probably at one time outlined the crests and slopes of these ridges, but degradation has now almost obliterated their original form.

The northward extension of the summit peneplain beyond the area studied can be seen on plate 14, *A*. Note the even sky line in the distance, formed by the peneplain, and the manner in which it joins Queen Mesa to the north (left). Some idea of the wide extent of the upland surfaces in the northern Guadalupe Mountains can be gained from figure 2.

AGE OF SUMMIT PENEPLAIN

The summit peneplain is the oldest land form preserved in the area, and is probably older than the uplift of the mountains themselves. No remnants of original higher ground project above the peneplain as one would expect if the peneplain had been carved from a previously existing mountain area. Further, the peneplain is now tilted away from the axis of uplift of the mountains, and is displaced by faults to the same extent as the rocks that underlie it. It is true that the peneplain bevels the underlying rocks, but it bevels them in a northwestward direction, unrelated to the present trend of the uplift. This beveling is related to a southeastward tilting of the Permian rocks which took place during the subsidence of the Delaware Basin in Permian time.

The summit peneplain, therefore, is younger than the Permian and is probably older than the uplift of the mountains. It may be of Mesozoic age and may be the exhumed surface on which Cretaceous rocks were once deposited. Similar surfaces, on which remnants of Cretaceous rocks are still preserved, form the crests of the Glass Mountains,[39] the Sierra Diablo, and other ranges of trans-Pecos Texas. In the Guadalupe Mountains, so far as known, no remnants of the former cover of Cretaceous rocks remain.

The summit peneplain of the Guadalupe Mountains is probably older than peneplains that have been described in the mountains to the northwest, in New Mexico. One of these peneplains has been observed high up in the Sacramento Mountains (Sacramento plain) and another in the San Andres Mountains (see fig. 1).[40] Both surfaces stand lower than the highest summits of the ranges. They were probably formed after the first uplift of the mountains, but before the main uplift; a Pliocene age has been suggested for them.

FORMER COVER OF SUMMIT PENEPLAIN

If the summit peneplain is of pre-Cretaceous age, it was probably covered at one time by Cretaceous sediments, similar to those whose remnants are now found in surrounding regions. Such sediments may have been less resistant to erosion than the underlying limestones, and hence easily stripped away (as suggested on secs. 1 and 2, fig. 22, *B*). Cretaceous rocks may have covered the area when the mountains were first uplifted, but proof for this suggestion is not available.

OLDER CONSEQUENT STREAMS

Viewed broadly, the streams of the Guadalupe and Delaware Mountains flow east and west from the tectonic and topographic crest of the range, and their gross pattern is consequent to the original tectonic surface. In detail there are many complications, resulting from modifications since the mountains were uplifted. Some streams have been deflected along fault troughs, others have been cut as subsequents on weak beds, and still others flow across alluvial slopes without regard to the bedrock structure beneath. Under this and succeeding headings the complex history of the streams of the area will be analyzed.

The stream pattern of the Guadalupe Mountains as a whole can be seen on figure 2. The pattern in the immediate vicinity of the area studied is shown in more detail on figure 19. On plate 22, the streams of the area studied are classified according to possible origin. Note especially the "streams consequent on tilted rock surfaces" and "streams consequent on tilted fault blocks"; these form the basis of the present discussion.

STREAMS CONSEQUENT ON TILTED ROCK SURFACES

The larger streams on the east slope of the mountains all pursue east-northeastward courses, and are probably consequent streams whose direction of flow was determined by the slope of the mountain block. However, only those to the north, in the limestone upland of the Guadalupe Mountains, preserve any semblance of their original aspect. Farther south, in the Delaware Mountains, erosion has worn down the whole area far below the level of the summit peneplain, and the streams have been able to modify their original courses in harmony with later conditions.

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

[40] Fiedler, A. G., and Nye, S. S., Geology and ground-water resources of the Roswell artesian basin, New Mexico: U. S. Geol. Survey Water-Supply Paper 639, pp. 14–15, 1933. Dunham, K. H., Geology of the Organ Mountains: New Mexico School of Mines Bull. 11, p. 176, 1935.

The streams to the north, in the limestone upland, flow in deep, narrow canyons, and join one another at nearly right angles, forming an open dendritic pattern (fig. 19). Most of them have winding courses, consisting of a succession of inclosed meanders.[41] They probably have much the same pattern as they did when first formed, and furnish information as to the probable nature of the original consequent drainage.

Typical stream valleys of the limestone upland are shown on the aerial view, plate 18. The area drained by them is indicated by stippling on figure 19. On this map note the broad similarity between the direction of flow of the streams in the upland and those to the south, type or the other are generally lacking. In McKittrick Canyon some sideward cutting is going on, but it appears to be relatively ineffective because of the great height of the canyon walls; moreover, the ridges between the meanders do not have the low-angled profile of slip-off slopes, as though there had not been much sideward migration in the past.

The dendritic pattern of the drainage, and the possibility that the inclosed meanders result at least in part from entrenchment suggests that the surface down which the consequent streams originally flowed probably had a lower gradient than the present one, and

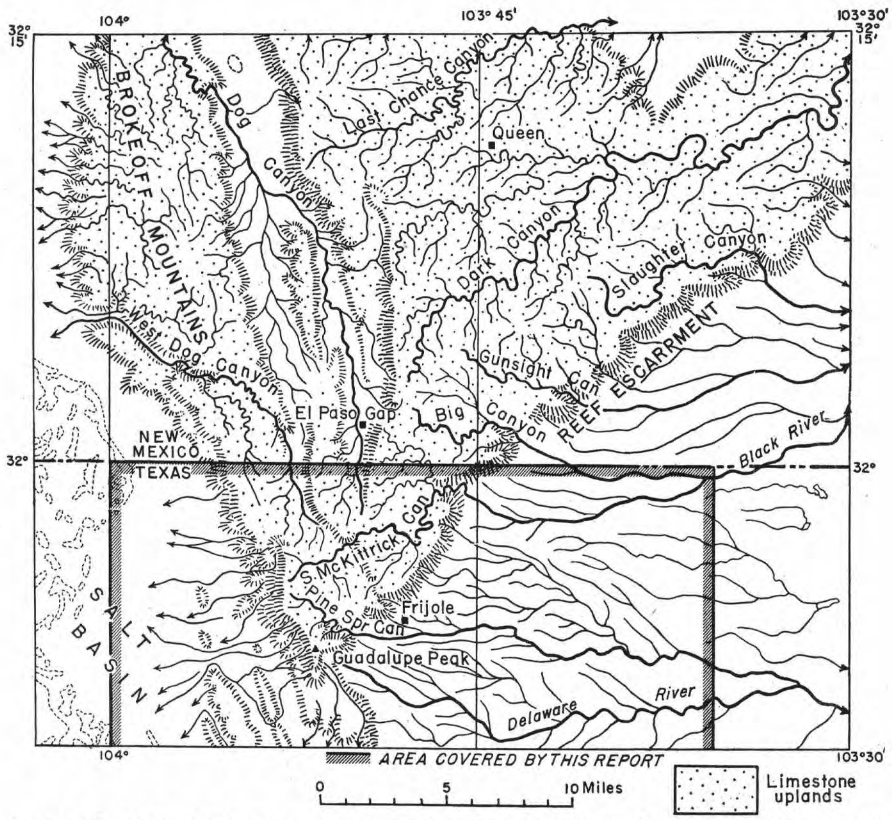

FIGURE 19.—Map showing stream pattern of southern Guadalupe Mountains and its relation to the limestone upland.

and yet the great contrast between their detailed patterns.

The origin of the inclosed meanders of the streams in the limestone uplands is uncertain. They may be entrenched from previously meandering courses, formed on an original surface of low relief; they may have become ingrown (incised) by sideward cutting at the same time that the streams cut downward, or they may have originated from a combination of these and other conditions.[42] Distinctive criteria that would suggest one that at the time they were formed the mountains did not stand as high as they do today.

The streams of the limestone upland appear to be superimposed on the Reef Escarpment (fig. 20). The east-northeastward courses of the streams that cross it intersect the northeastward course of the Reef Escarpment at an acute angle. Because of the acute-angled intersection, the notches cut in the escarpment by the streams characteristically have narrow, serrate southwest walls and blunt-angled northeast walls. Such features occur on South McKittrick Canyon in the area studied, and on Big, Gunsight, and Slaughter Canyons in the region to the northeast (fig. 2). These relations suggest that the streams began their courses at a much higher level than that at which they are flowing today, above the varied bedrock that forms the present

[41] A term suggested by R. C. Moore (Origin of the inclosed meanders on streams of the Colorado Plateau: Jour. Geology, vol. 34, p. 46, 1926) for "any meander more or less inclosed by rock walls", regardless of origin.

[42] Davis, W. M., Incised meandering valleys: Geog. Soc. Philadelphia Bull., vol. 4, pp. 182–192, 1906. Rich, J. L., Certain types of stream valleys and their meaning: Jour. Geology, vol. 22, pp. 469–497, 1914. Moore, R. C., op. cit., pp. 29–57.

mountains, and perhaps near or above the surface of the summit peneplain.

Some of the streams are probably antecedent to the faulting within the mountains, because they cross upraised fault blocks with little deflection. Thus, within the area studied, South McKittrick Canyon crosses the Lost Peak fault zone from the downthrow to the upthrow side (pl. 22), and some streams in the Brokeoff Mountains to the northwest cross other faults in a similar manner. The streams on the east slope of the mountains, where the rocks are not faulted, may have originated at the same time as those mentioned, but this correlation cannot be determined definitely.

Some of the east-flowing streams of the limestone upland may once have headed farther west than they now do, and west of the present west-facing escarpment. Two of them, which drain Pine Spring and South McKittrick Canyons, now head on the rim of the escarpment and have lost their original sources by an eastward recession of the rim. The original sources, however, were not much farther west, for near the point of beheading both streams are split into numerous branches (pl. 22), no one of which would have been capable of draining a former large territory to the west.

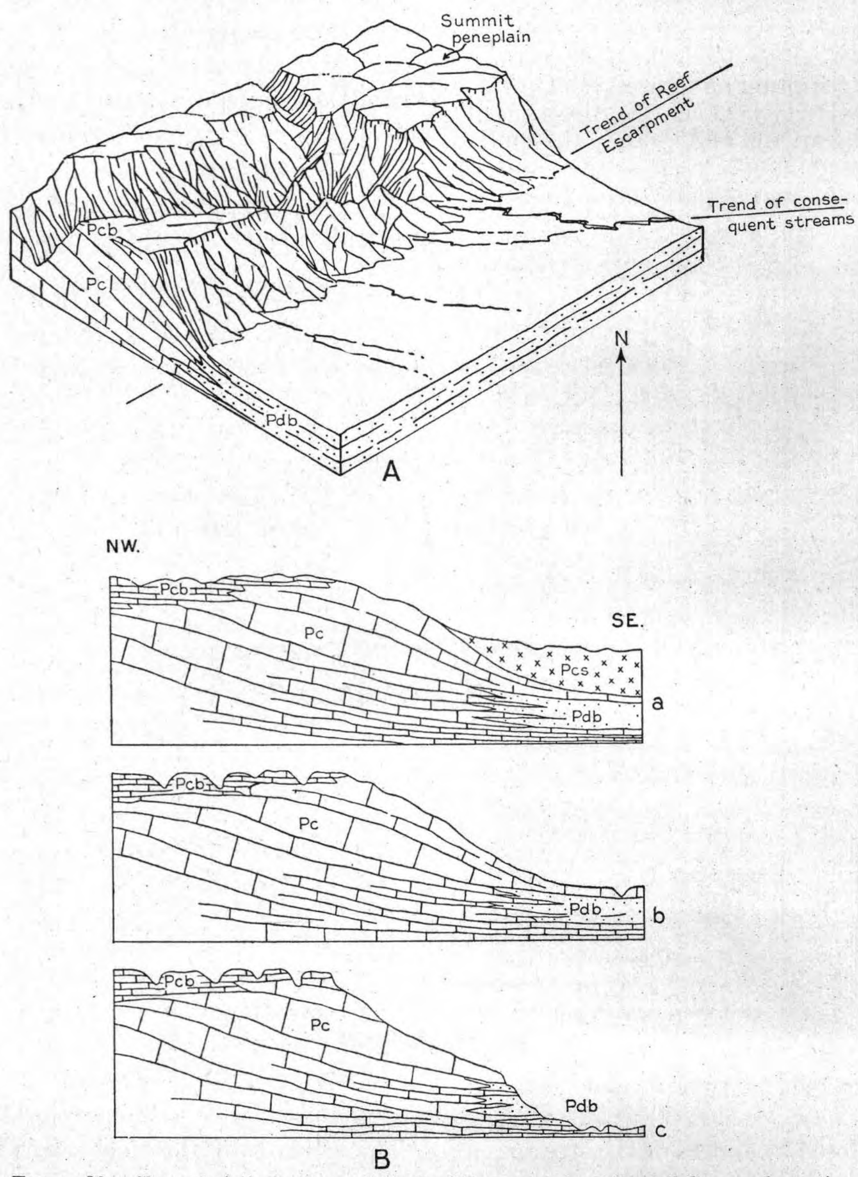

FIGURE 20.—Characteristic features of the Reef Escarpment. *Pdb*, Bell Canyon formation, *Pc*, Capitan limestone, *Pcb*, Carlsbad limestone, *Pcs*, Castile formation (anhydrite). *A*, Block diagram showing manner in which consequent streams cross the escarpment at an acute angle as a result of superimposition; *B*, Sections showing depth of erosion in different areas—*a*, northeast of McKittrick Canyon, *b*, near McKittrick Canyon, *c*, southwest of McKittrick Canyon near Frijole Post Office.

The evidence listed suggests that the streams of the limestone uplands are consequents resulting from the first uplift of the mountain area. The slope of the uplifted surface was low enough for them to acquire an open dendritic pattern, and the surface was probably not faulted. It probably lay above the rocks that now form the Reef Escarpment. The stream pattern suggests that the surface after the original uplift had the form of a broad dome, whose axis lay near the present crest of the mountains. Its eastern flank is indicated by the east-northeastward flowing streams, and the west flank by the streams of the Brokeoff Mountains which drain northwestward or westward to the Salt Basin (fig. 19).

STREAMS CONSEQUENT ON TILTED FAULT BLOCKS

In the western part of the Guadalupe Mountains, where the rocks are broken by faults, there is another type of consequent steam. Here, many streams follow the downfaulted areas and are evidently consequent on tilted fault blocks.

The age relations of the two sets of consequent streams is suggested along South McKittrick Canyon. This canyon crosses the Lost Peak fault zone without deflection, is probably older than the faulting, and is antecedent to the upraised fault block to the east. On the downthrown side to the west, it is joined from the north and south by two tributaries which probably originated on the downfaulted surface. The tributaries are therefore younger than the faulting.

Streams that belong to this post-faulting generation are prominently developed north of the McKittrick Canyon area. Here, the stream in West Dog Canyon follows the downthrown side of the Lost Peak fault zone and the stream in Dog Canyon follows the downthrown side of the Dog Canyon fault zone (fig. 19). Farther north both streams pass into the limestone upland of the Brokeoff Mountains and appear to cut across the fault blocks. Perhaps they were relatively short consequent streams at first, and acquired large headward extensions when fault blocks sank across their upper courses.

If the streams consequent on tilted rock surfaces can be correlated with the initial uplift of the Guadalupe and Delaware Mountains, it is possible that the streams consequent on tilted fault blocks are to be correlated with the main uplift of the mountains, in which faulting apparently was a dominant feature. It cannot be determined whether the major movement on the Border fault zone took place at this time, as distinctive geomorphic features in that area have been obliterated. If such major movement took place on the Border zone, the streams draining the west-facing escarpment of the southern Guadalupe Mountains are of the same generation as those in Dog Canyon and West Dog Canyon.

DEPOSITS CONTEMPORANEOUS WITH PRE-PLEISTOCENE (?) TOPOGRAPHIC FEATURES

As indicated above, the initial uplift of the Guadalupe and Delaware Mountains may have taken place immediately before the development of the streams consequent on tilted rock surfaces, and long before the development of streams consequent on tilted fault blocks.

At the time of this initial uplift, many of the ranges of the Sacramento section [43] were sheeted over by poorly resistant Cretaceous and other Mesozoic rocks. In the Guadalupe Mountains, this cover may have overlain the surface of the summit peneplain. The Mesozoic sediments were no doubt stripped rather rapidly by the streams until the hard Paleozoic limestones beneath were exposed. Streams overloaded with such material probably deposited great quantities of it in the structurally lower areas roundabout. Some of it probably filled the depressions between the ranges, and some was spread as a vast detrital apron over the surface of the Llano Estacado east of the mountains.

DEPOSITS OF THE GUADALUPE MOUNTAINS REGION

Within the Guadalupe Mountains region, deposits that formed in response to the first uplift of the ranges are poorly known.

The Salt Basin west of the Gaudalupe Mountains probably received a large volume of the early deposits, but its surface has been eroded so little that none is exposed. As indicated by wells drilled there, the unconsolidated deposits beneath the surface of the Salt Basin reach a great thickness.[44] They are probably similar to those exposed in the Hueco Bolson, the next desert basin to the west (fig. 1). The deposits in the Hueco Bolson are gray to flesh-colored silts, in part gypsiferous, with some sandy lenses, and near the bordering mountains are interbedded with fanglomerates and mudflow deposits. They probably accumulated in an enclosed depression, not drained as today by a through-flowing stream. They were perhaps deposited in a shallow, intermittent lake. The fanglomerates along the edges were no doubt deposited on bajadas that fringed the primitive mountain ranges.

The deposits of the Llano Estacado, now exposed east of the Pecos River, 90 miles away, perhaps once extended farther west, over the present river valley, and up to the bases of the Guadalupe and Sacramento Mountains beyond. In the Sacramento Mountains, according to Nye,[45] the subsummit or Sacramento Plain can be projected eastward across the present valley, and beneath the deposits on the other side. It was probably carved by streams that were at the same time laying down deposits farther east.

AGE OF DEPOSITS

Older unconsolidated deposits laid down in intermontane areas of the Sacramento section, and in the Llano Estacado to the east, contain vertebrates in a few places

[43] Fenneman, N. M., Physiographic divisions of the United States: Assoc. Amer. Geographers Annals, vol. 6, p. 93, 1917.

[44] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Van Horn folio (No. 194), p. 6, 1914. Baker, C. L., Structural geology of trans-Pecos Texas: Texas Univ. Bull. 3401, p. 171, 1935.

[45] Fiedler, A. G., and Nye, S. S., op. cit., pp. 11 (fig. 1), 14–15, 96–97.

that are considered to be of Pliocene age.[46] Over wide areas the deposits resemble one another so closely in lithologic character, conditions of deposition, and degree of deformation, that they are probably all of about the same age. Near El Paso, the older unconsolidated deposits are overlain unconformably by gravels that contain vertebrates considered to be of early Pleistocene age by Hay.[47]

If these older deposits are Pliocene, if they formed in response to the initial uplifts of the mountains of the Sacramento section, and if the Guadalupe and Delaware Mountains had a history similar to the Sacramento section as a whole—a rather extensive series of assumptions—then the older deposits serve to give an approximate date to the initial uplift of the region. Such a dating serves to justify assigning the features and deposits so far discussed as pre-Pleistocene(?).

EARLY PLEISTOCENE (?) TOPOGRAPHIC FEATURES AND DEPOSITS

In the Guadalupe Mountains, a period of movement later than the initial (Pliocene?) uplift is suggested by the second generation of consequent streams—those consequent on tilted fault blocks. During this second period of movement, faulting was apparently a dominant feature. The second period of movement was probably a major uplift, comparable to major uplifts farther northwest in the Sacramento section, which are assigned to a post-Santa Fe (late Pliocene or early Pleistocene) age. According to Bryan:[48]

> Most of the existing mountains and highland areas were also mountains in Santa Fe time. They were reduced in Pliocene time and were rejuvenated to form the present ranges. Other mountains appear to have been new-born * * *. So far as the present information goes, all the ranges [with a few exceptions] * * * owe their present positions to post-Santa Fe uplift.

This major uplift probably gave the Guadalupe and Delaware Mountains their present tectonic form and accelerated the degradation of the mountains. Processes were initiated that carved them into the outlines we see today.

After the uplift, degradation went on without any recorded pause until the streams on the east slope of the mountains had cut 1,000 feet or more below the summit peneplain, and until other parts of the region had been correspondingly reduced. This degradation was followed by a major period of still stand during which streams widened their valleys, broad pediments were formed, and the west slope of the mountains was shaped into a gently rounded surface. Afterwards a part of these erosion features was covered by deposits. Some of these deposits remain today and are the oldest Cenozoic deposits exposed in the region. They are probably of early Pleistocene age.

The early Pleistocene (?) deposits are complex in that they are scattered over the area in many diverse situations. On the east slope of the mountains they form a thin sheet of gravel, spread out on the plains southeast of the Reef Escarpment. These deposits were laid down on a pediment, extensions of which may be seen farther south, and which may be related to benches or shoulders in the canyons to the north. On the west slope of the mountains deposits occur, not on a stream-graded surface, but on steep slopes. Farther west, beyond the base of the escarpment, are fanglomerates laid down on bajadas at the edge of the Salt Basin.

All these deposits are of some antiquity, as they lie above present stream grade and have been dissected. The fanglomerates west of the mountains also have been disturbed and faulted, indicating that they are older than the last tectonic movements in the mountain area.

GUADALUPE AND DELAWARE MOUNTAINS

GRAVEL DEPOSITS

Fringing the base of the Reef Escarpment, along the southeast side of the Guadalupe Mountains, and extending out for several miles into the Delaware Mountains and Gypsum Plain to the southeast is a gravel-covered plain, or pediment, which records an extended period of planation and deposition. Throughout its extent the plain is trenched, to depths ranging from a few to more than 100 feet, by streams which in places expose the underlying bedrock in their channels. The plain is therefore a product of conditions no longer existing in the region.

The extent of the gravel deposits is shown on the map, plate 22, where two subdivisions are distinguished. "Higher gravels," apparently older than the main deposits, occupy relatively small areas. The main body is designated as "gravels deposited on older pediments." Two views across the gravel plain toward the Reef Escarpment are shown on plate 4. On plate 4, *B*, the surface is little dissected and probably has much its original form. Below Pine Top Mountain it has the form of an alluvial fan. Plate 4, *A*, shows the appearance of the plain where dissection is more advanced. Much of the flat-topped surface in the middle distance is a part of it, although in places benches of bedrock rise to about the same level. Figure 21, *A*, shows a profile across the plain and includes not only the main deposits but also some remnants of the higher gravels.

Rising above the main gravel plain in places are small, flat-topped remnants of an older set of gravel

[46] Plummer, F. B., Cenozoic systems, in The Geology of Texas, vol. 1: Texas Univ. Bull. 3232, pp. 774–776, 1933. Bryan, Kirk, Geology and ground-water conditions of the Rio Grande depression in Colorado and New Mexico: Nat. Resources Comm., Regional planning, Part 6, Rio Grande joint investigation, p. 205, 1938.

[47] Richardson, G. B., U. S. Geol. Survey Atlas, El Paso folio (No. 166), pp. 5–6, 1909. Hay, O. P., The Pleistocene of the middle region of North America and its vertebrated animals: Carnegie Inst. Washington Pub. 322 A, p. 134, 1924. Sayre, A. N., and Livingston, Penn, Ground-water resources of the El Paso area, Texas: U. S. Geol. Survey Water-supply Paper 919, pp. 37–39, 1945.

[48] Bryan, Kirk, op. cit., p. 209.

deposits (the "higher gravels" of pl. 22). They stand 50 feet or more above the main plain, from which they are separated by rock-cut slopes, and lie 150 feet or more above present drainage. They are made up of fragments derived from the Guadalupe Mountains which resemble those in the main or younger gravel deposits. The patches of higher gravels are probably remnants of deposits formed in restricted level-floored stream valleys, rather than remnants of a nearly continuous gravel plain like that described below.

The deposits of the main gravel plain ("gravels deposited on older pediments" of pl. 22) consist of fragments washed out from the Guadalupe Mountains. The most abundant pieces are of massive (Capitan) limestone, but also include some bedded, light-gray (Carlsbad) limestone, and dark-gray (Pinery) limestone. Sandstone fragments from the Delaware Mountain group are not common.

The fragments are subangular to subrounded. Near the mountains blocks up to 6 feet across are enclosed in the finer material, and along McKittrick Draw, 3 miles from the mountains, blocks 3½ feet across are present. Some miles away from the mountains, however, cobbles and pebbles a few inches across prevail. Near the mountains the material is poorly sorted and poorly bedded; farther out the gravels lie in regular beds, with some intercalated layers of buff clay. At a deep cut in Pine Spring Canyon about a mile west of Pine Spring, there is at the base a 10-foot bed of flat-lying reddish clay, above which is 100 feet of cobbles and boulders with inclined layers that slope down the sides of an alluvial fan. Elsewhere, the gravels rest directly on the rock surface below. Over wide areas the gravels are loosely cemented by caliche.

The gravels are thickest near the Guadalupe Mountains, from which they were derived, and thinnest to the southeast, where they probably come to a feather edge. Near the Guadalupe Mountains, some stream cuts show exposures of gravel 100 feet or more thick. Their present upper surface appears to have been their original depositional surface, for at the mouths of some of the canyons leading out from the mountains they are heaped into low alluvial fans. Besides the alluvial fan in Pine Spring Canyon just mentioned, another, below Pine Top Mountain, is noted on plate 4, *B*. They are not rock fans, as stream cuts show that the gravel deposits are thicker beneath the fans than elsewhere.

No vertebrate bones have been seen in the gravel deposits, but here and there the deposits contain mollusks. A small collection of the mollusks, made by H. C. Fountain, has been identified by J. P. E. Morrison of the United States National Museum. The species are listed below, along with those contained in a collection of living shells from the same area, made by Fountain for comparative purposes.

Mollusks from gravel deposits of the Guadalupe and Delaware Mountains

[All of these are land-dwelling types except those marked with a dagger, which are land-dwelling types but are most commonly found in damp or marshy places, and those marked with an asterisk, which are fresh-water types]

	1	2	3	4
Gastropods:				
Ashumunella kochi amblia Pilsbry	×			×
Bulimulus dealbatus pecosensis Pilsbry and Ferriss				×
Discus cronkhitei (Newcomb)	×			
Hawaiia minuscula neomexicana (Pilsbry and Ferriss)	×			
Holospira n. sp				×
Humboldtiana ultima Pilsbry	×			×
Oreohelix yavapai compactula Cockrell	×			
Pupilla muscorum (Linnaeus)	×			
Retinella indentata paucilirata (Morelet) (young)	×			
Thysanophora hornii (Gabb)			×	
Vallonia cyclophorella (Ancey)	×			
Zonitoides arboreus (Say)	×	×		
Succinea luteola Gould†		×	×	
Physa anatina Lea*			×	
Fossaria obrussa (Say)*			×	
Pelecypods:				
Pisidium sp*			×	

1. Flat-lying reddish clay at base of deposit 1 mile west of Pine Spring on north side of Pine Spring Canyon.
2. Coarse gravel on east side of Bell Canyon 1 mile northwest of Hegler ranch house.
3. Extensive terrace along Bell Canyon near prominent bend 1 mile north of Hegler ranch house.
4. Living species from sheltered places along cliffs high up on south wall of Pine Spring Canyon.

According to Morrison, all the species listed are living forms, and are within their present ranges. The Guadalupe Mountains are near the northern limit of the present range of the species of *Humboldtiana*. A slight difference in climate from that of the present is suggested by lot 3, with its fresh-water forms, for water is not permanent in this part of Bell Canyon today; the difference may have resulted from only a slight variation from the present annual rainfall. The fossils listed do not confirm the geomorphologic evidence that the gravel deposits are old, but according to Morrison they do not deny it. He believes that the assemblage could well be of Pleistocene age.

ROCK SURFACE BELOW GRAVEL DEPOSITS

The surface of the bedrock below the gravel is fairly even in most places, and was no doubt a pediment of wide extent. At a few places, however, irregularities are observed in it. South of Rader Ridge, over the belt of outcrop of the South Wells limestone member of the Cherry Canyon formation, the gravels are only a few feet thick, but, as shown by stream cuts, they thicken to

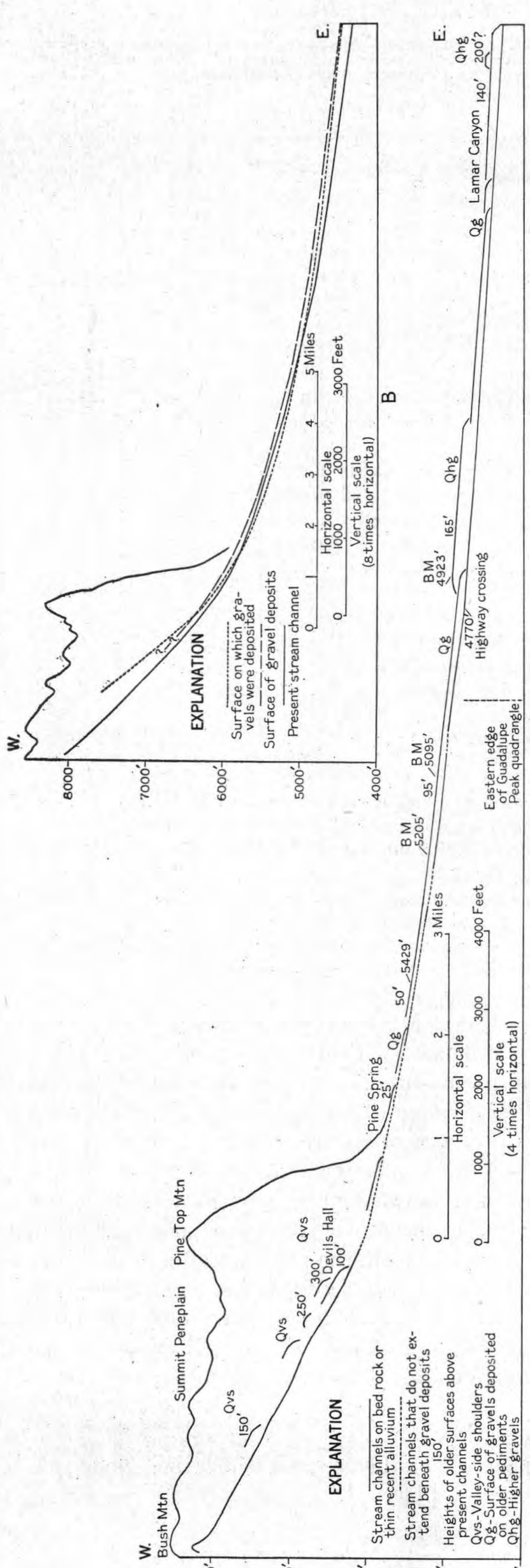

FIGURE 21.—Profiles along Pine Spring and Cherry Canyons, showing surfaces formed during successive stages as a result of erosion and deposition. *A*, Actual profile; *B*, Idealized profiles, to show different concavities of the surfaces.

more than 100 feet a short distance to the west. At this place, the South Wells limestone apparently projected above the pediment as a low cuesta, which was afterwards entirely buried under the sloping sheet of gravel.

A significant comparison can be made between the profile of the gravel surface, the profile of the pediment on which the gravels rest, and the profile of the present streams, which entrench them both (fig. 21, *B*). The present streams have a concave upward profile, which is steepest in the Guadalupe Mountains, and gentlest in the plains to the southeast. The surface of the gravels is also concave upward, but apparently more so than the stream profiles, as the streams entrench it to depths of 100 feet or more southeast of the mountains, and less than 50 feet near their base. The surface of the pediment beneath the gravels is still more concave. Like the gravel surface, it stands well above the present streams southeast of the mountains. Near the mountains, however, it lies near or below the stream channels, many of which fail to penetrate it. As all three profiles were probably formed by streams flowing at or near grade, the differences in concavity suggest changes in conditions of stream equilibrium.

STREAMS CONSEQUENT ON GRAVEL DEPOSITS

The streams that drain the gravel plain were developed on its depositional surface and are consequent to it (shown as "streams consequent on gravel deposits" on pl. 22). They thus belong to a later generation than the two sets of consequent streams previously described (pp. 140–143). When the gravel deposits were being laid down, each consequent stream that flowed east-northeast out of the Guadalupe Mountains aggraded its course and built up a low alluvial fan at the foot of the Reef Escarpment. As deposition progressed, the streams were deflected this way and that from the canyon mouths. Later, the new courses became fixed by renewed entrenchment. The net result has been to deflect streams draining east-northeast from the mountains to a more easterly or southeasterly course on the plain (fig. 19).

The streams consequent on gravel deposits follow straight courses and are closely spaced and nearly parallel. As a result, the gravel deposits are scored by a series of ravines which run side by side for long distances and join each other at acute angles. The streams tend to radiate from each canyon mouth of the Reef Escarpment, in the manner of streams on alluvial fans. Some streams on the gravel plain which are fed by the same canyon of the mountains thus diverge widely from one another away from the mountains. In this manner, a part of the drainage from Pine Spring Canyon flows east into Cherry Canyon, and part flows south into Delaware Creek, the bifurcation taking place near the foot of the mountains at Pine Spring Camp.

With renewed dissection of the area, the streams consequent on the gravel deposits have been superimposed on the bedrock beneath. In places they cross the hills of the former topographic surface, as along the outcrop of the South Wells limestone member of the Cherry Canyon formation south of Rader Ridge (pp. 145–146). Southeast of the present gravel area, some streams now flowing on bedrock were probably superimposed on it through a former sheet of gravel, afterwards destroyed by erosion.

OLDER PEDIMENTS

Within the area studied, the gravel deposits extend southeastward into the Delaware Mountains for about 4 miles from the Reef Escarpment. Farther southeastward, they have been removed by Delaware Creek and its tributaries. Where the gravels are lacking, either by nondeposition or erosion, many of the even-crested hilltops stand at about the same level, and are probably remnants of the same older pediment as that on which the gravels rest (shown as "older pediments" on pl. 22). The even crests are conspicuous on each side of the depression carved from downfaulted rocks near Getaway Gap, and also along the rim of the Delaware Mountains. The rim maintains its height even where the resistant Getaway limestone member that caps it fades out into poorly resistant sandy beds. The possibility that the rim to the south is part of an older pediment is confirmed by relations farther north, near Guadalupe Pass, where the rim is capped by older gravel deposits.

VALLEY-SIDE SHOULDERS

Along Pine Spring, McKittrick, and other canyons that drain the limestone upland of the Guadalupe Mountains are features that probably formed at about the same time as the gravel plain to the southeast. These canyons have been incised several thousand feet below the summit peneplain that forms their rims. Their walls, which are boulder-controlled slopes cut on massive or rudely bedded rock, rise from the channels to the rims at angles of 30° or more. The slope, however, is not continuous but in many places seems to have a two-storied profile, resulting in valley-side shoulders 100 feet or more above the present stream channels.

When viewed from about midheight on the canyon wall, each spur projecting into the canyon is seen to sweep down from the rim to a rounded shoulder near its lower end, and then to plunge 100 feet or more in steep rock slopes to the channel below (shown as "valley-side shoulders" on pl. 22). The aspect of the upper part of the canyon is thus broad and open, whereas its lower part is narrow, tortuous, and steep-sided. In detail, these features are complex. All the shoulders and the canyon walls above and below them are greatly modified by weathering and erosion, and few of the shoulders stand at exactly the same height. Some are only 100 feet above the channel, and others are as much as 300 feet above it (fig. 21, *A*).

The valley-side shoulders are not caused by any difference in the nature of the rocks, for the rocks are all rather uniformly massive and are of different ages from place to place along the canyons. The shoulders apparently record a time in the past when the downcutting of the canyons ceased long enough for some widening of their banks to have taken place.

Proof that some of the shoulders were formed during a pause in downcutting is given by relations at Devils Hall in Pine Spring Canyon. Here, on one side or the other of the channel and about 100 feet above it, are narrow benches floored by stream gravel, above which the higher slopes are in places over-steepened, as though by sideward cutting of the former stream. By means of the gravel remnants, a former meandering course can be reconstructed. Across this course the present stream passes through Devils Hall, in a straighter course that follows a line of weaknesses caused by closely spaced joints. Other less well preserved valley-side shoulders occur farther up the same canyon, but they lie at different heights above the stream channel. Whether they belong to a single epoch of valley widening contemporaneous with the gravel-capped benches at Devils Hall, or to several epochs, cannot be determined.

WEST-FACING ESCARPMENT

FAULT SCARP VERSUS FAULT-LINE SCARP

The steep west-facing escarpment of the Guadalupe and Delaware Mountains is so closely associated with the Border fault zone that it probably is genetically related to it. The escarpment originated either from an exposed surface of tectonic origin which has since been modified by erosion (fault scarp), or from the erosion of weak beds from the downthrown side, leaving the strong beds on the upthrown side to form the present escarpment (fault-line scarp).[49] It probably came into existence during the major uplift of the mountains in late Pliocene or early Pleistocene time.

If any weak beds ever lay on the downthrown side of the fault they could not be a part of the succession now exposed in the region, for the strata exposed on the downthrown side, along the base of the escarpment, comprise the Carlsbad and Capitan limestones, the Lamar limestone member of the Bell Canyon formation and the Castile formation which lie at the top of the known section. The beds named are the ones that lay immediately beneath the summit peneplain. They may have been covered by weak Cretaceous rocks that overlay the peneplain even at the time of the faulting. If so, immediately after the faulting these weak rocks for a time covered a part of the fault surface (as suggested in stage 1, fig. 22, *B*), but they were removed

[49] Blackwelder, Eliot, Recognition of fault scarps: Jour. Geology, vol. 36, pp. 289–294, 1928.

rather rapidly, and were redeposited in the deeper parts of the Salt Basin farther west (as shown in stage 2 of fig. 22, *B*).

As shown earlier (p. 110), however, the displacement along the Border faults ranges from 2,000 to 4,000 feet. It seems very unlikely that a sequence of beds as thick as this covered the rocks now found in the region at the time of the faulting, or that fault surfaces of such height were entirely concealed by them. It is therefore probable that the present escarpment is at least in part a fault scarp. After the faulting its height was

tectonic surface, as indicated by the faults exposed along its base, probably dipped at angles of 70° or more to the downthrown side (stage 1, fig. 23, *A*), whereas with the exception of the cliffs, the graded slopes formed from it as a result of slope retreat have angles of 45° or less (stage 3, fig. 23, *A*). Streams draining the escarpment have much steeper gradients than those draining the country behind it, so they are able to cut actively headward. By a combination of slope retreat and headward cutting, the rim of the escarpment has receded a mile or more east of its original position.

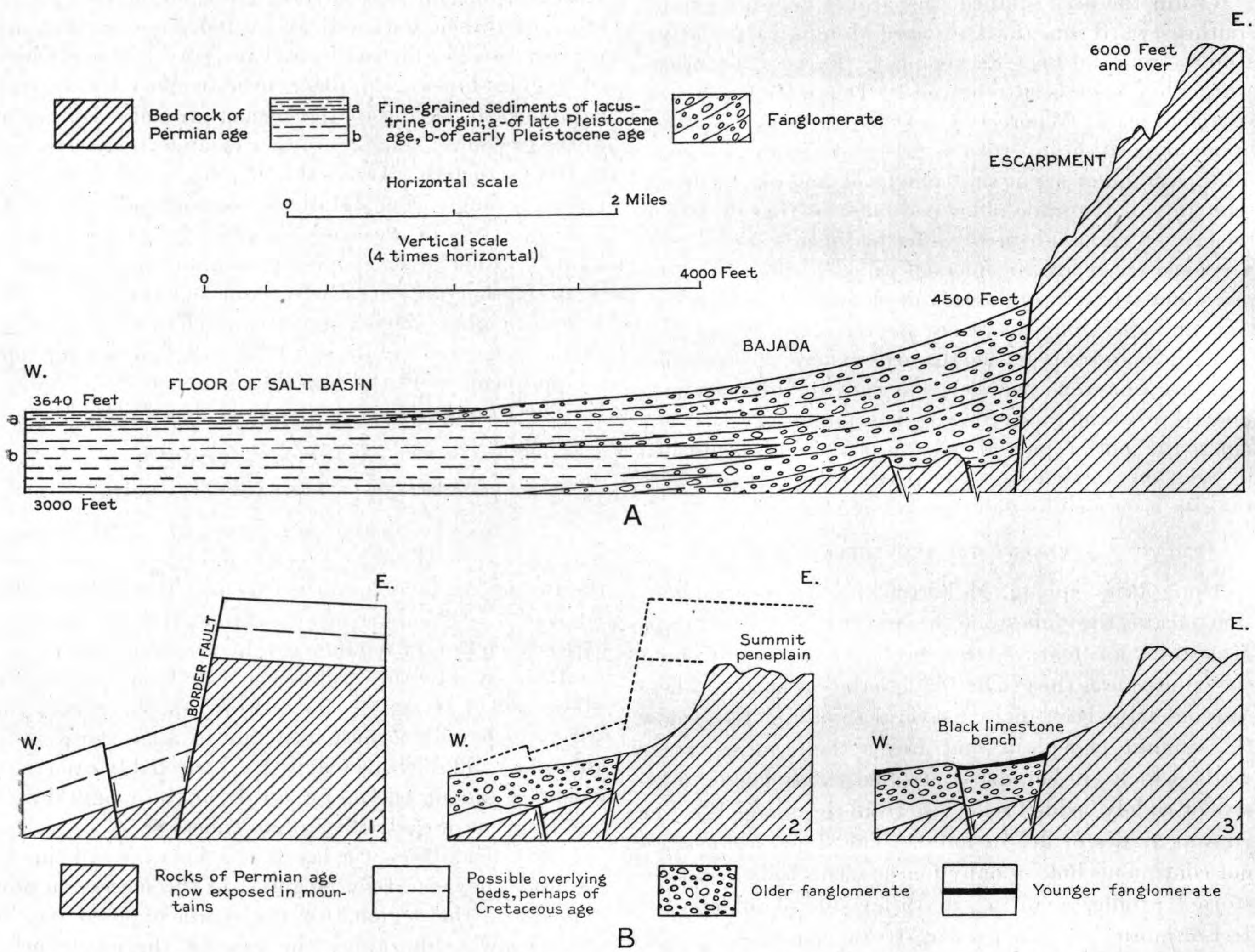

FIGURE 22.—Sections of westward-facing escarpment. *A*, Sketch section, showing relation of fanglomerate to basin deposits, generalized from several sections northwest of Guadalupe Peak; *B*, Sketches showing probable history of escarpment—stage 1, potential structural surface formed by main uplift, stage 2, the same after erosion and deposition, stage 3, the present escarpment after renewed faulting and further erosion and deposition.

probably increased by the removal of weak beds from the lower part of its surface, in which case the part originally covered is a fault-line scarp.

EROSION OF ESCARPMENT

After the face of the escarpment was laid bare, either by the original faulting or by subsequent erosion, processes of degradation set to work on the tectonic surface, and caused its rim to be shifted toward the east. The

The escarpment has not only receded, but its top has been lowered to a greater or less degree, as indicated by the occurrance from place to place along the rim of bedrock of different ages. Near Guadalupe Peak and El Capitan the upper part of the escarpment is formed by the same limestones that spread as a plate over the Guadalupe Mountains, on whose surface the summit peneplain has been cut. In this area the rim has been lowered very little below the summit peneplain, remnants of which extend to the rim, although any weak beds that overlay the peneplain (stage 1, fig. 22, *B*) have long since been removed. Farther south, however, the rim was worn down a great distance below its original height while the Delaware Mountains and Gypsum Plain to the east of it were being degraded. Most of the lowering of the rim in this area was accomplished before the gravel plain to the east was formed, as gravel remnants cap the rim near Guadalupe Pass (fig. 24, *A*).

The streams that drain the escarpment (indicated as "streams of complex origin" on pl. 22) are probably mainly consequents that took their courses down the original tectonic surface. Their history, however, has been complex, for there have been several periods of movement, and each movement has modified the preexisting surface and thereby influenced the streams that drain it. Moreover, by headward cutting the streams have acquired obsequent extensions at the expense of streams draining eastward from the rim. Other streams may have acquired new courses on the surfaces of deposits laid down over the bedrock on the escarpment or west of it.

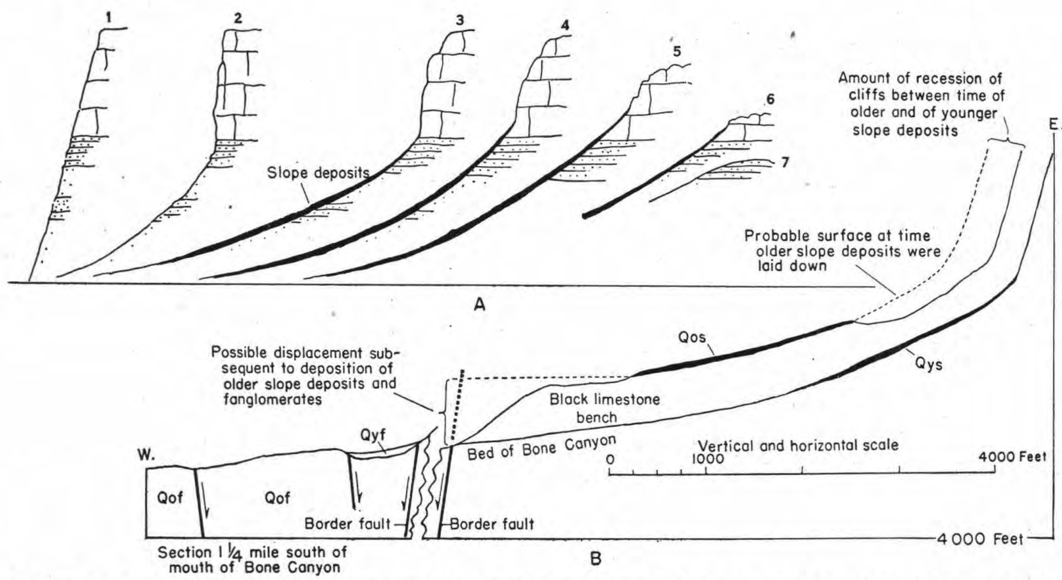

FIGURE 23.—Sections and profiles of westward-facing escarpment near Guadalupe Peak. *Qos*, Older slope deposits; *Qof*, older fanglomerates; *Qys*, younger slope deposits; *Qyf*, younger fanglomerate. *A*, Sketch sections showing probable past and future stages in erosion of escarpment, which has now reached stages 3 and 4; *B*, Profiles across escarpment near Bone Canyon, showing relation of older to younger deposits and land forms.

SLOPE DEPOSITS

On the west side of the southern Guadalupe Mountains, between Shumard Peak and El Capitan, are many steeply sloping, dissected remnants of slope deposits (shown as "older slope deposits" on pl. 22) which indicate a well-marked pause in the erosion of the escarpment. On the south slope of El Capitan similar deposits form the caps of ridges and mesas and stand high above the channels of Guadalupe Canyon and other streams. Apparently these deposits were formerly continuous with remnants of gravel on the rim of the Delaware Mountains near Guadalupe Pass, east of Guadalupe Canyon. This interpretation suggests that the older slope deposits are of about the same age as the older gravels of the Delaware Mountains.

Older slope deposits are not present on other parts of the west-facing escarpment, either north of Shumard Peak in the Guadalupe Mountains or south of El Capitan in the Delaware Mountains.

The relation of the gravel plain of the Delaware Mountains to the older slope deposits is suggested on figure 24, *A*, where the gravels on the rim of the Delaware Mountains near Guadalupe Pass are shown on the farthest section, and the slope deposits on the tops of ridges and mesas are shown in the nearer sections. The amount of subsequent erosion can be determined by their relation to the profile of Guadalupe Canyon, also shown on the figure. Their relations to present topography are also suggested on plate 1, where they are designated by the letter *a*.

The older slope deposits farther north, on the west side of the mountains below Guadalupe Peak are shown on plate 12, *A*, and on the profiles of figure 23, *B*.

The gravel remnants below Guadalupe Peak lie on the smoothed faces of spurs projecting from the escarpment between the waste-covered embayments at the heads of the present canyons. They stand several hundred feet above and forward from the embayments, but like them have a slope of about 30° (fig. 23 *B*). The upper ends of the remnants are several hundred feet below the bases of the cliffs that surmount the escarpment, and stand slightly forward from them, as though they were formed when the cliffs had not receded as far east as now. The lower ends flatten over the top of the black limestone bench at the edge of the escarpment, whereas the younger waste streams extend down into the canyons cut into the bench.

The slope deposits of the remnants consist of unsorted angular blocks of massive (Capitan) limestone from a few feet to more than 10 feet across, which in many places are rather firmly cemented by caliche. Many of the blocks are deeply pitted by weathering, as though they had not been disturbed for a long period. The deposits have a thickness of as much as 10 feet, or about that of the diameter of the largest boulders embedded in them. The fragments have all fallen or rolled from the cliffs above in the same manner as those in the younger waste-streams.

The position of the remnants of older slope deposits suggests that they formed under conditions similar to those under which the younger slope deposits are now forming. Both sets of deposits are composed of the same type of material, and have the same type of slope (fig. 23, *B*). Most of the remnants are now on the points of spurs, between recesses covered by modern waste-streams. At the time of their deposition, this relation was probably reversed in places, and remnants on the present spurs accumulated in the recesses of the earlier time. In general, however, the older deposits appear to have accumulated on a surface more subdued than the present one, and with fewer rock spurs projecting from it, and fewer canyons (such as Guadalupe Canyon) cut below it.

Some indication as to the age of the deposits can be obtained south of El Capitan. Here, on a canyon wall 150 to 250 feet below the nearest remnants of the older slope deposits, is the Indian Cave (fig. 24, *B*), which has yielded a fauna that includes a number of extinct late Pleistocene or early Recent vertebrates.[50] The fossils will be discussed in a later section of the report (p. 158).

[50] Ayer, M. Y., The Archeological and faunal material from Williams Cave, Guadalupe Mountains, Texas: Acad. Nat. Sci. Philadelphia Proc., vol. 88, pp. 599–618, 1936.

The relations imply that deep erosion took place after the slope deposits were laid down and before the fauna accumulated in the cave, in which case the slope deposits are probably of Pleistocene age.

FOOTHILL AREA

OLDER FANGLOMERATE

Ever since the first uplift of the mountain area, material eroded from its west side has been washed out and deposited in or along the edges of the tectonically lower Salt Basin. The process was furthered by the lack of through-flowing drainage in the basin. Coarser-textured detritus was laid down as a fanglomerate on the bajada along the edge of the mountains, and was built up until the streams were able to attain a graded profile across it. These processes, however, were probably interrupted several times by renewed uplift or climatic changes.

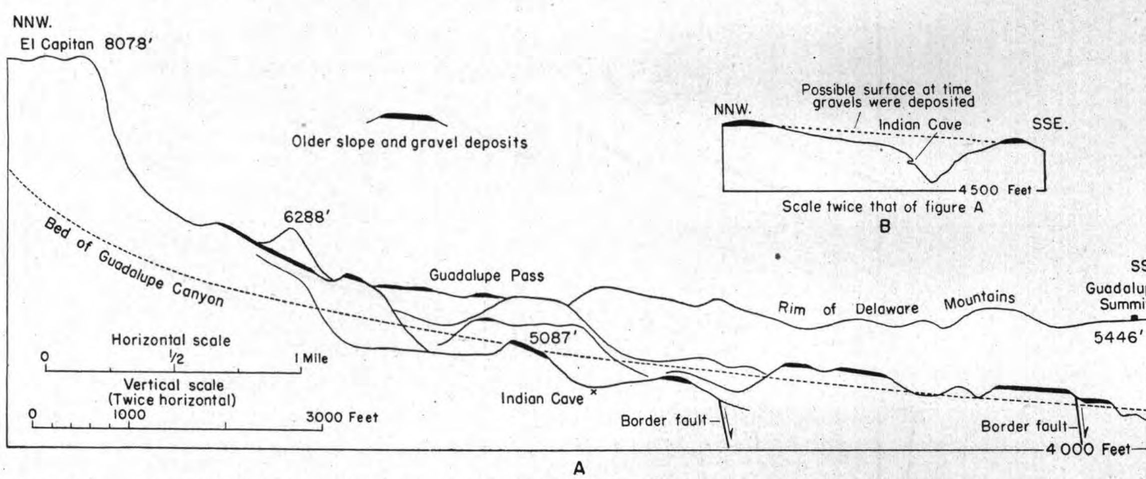

FIGURE 24.—Sections south of El Capitan. *A*, Projected profiles, showing relation of older slope deposits to present topography; *B*, Section showing relation of older slope deposits to Indian Cave, which contains late Pleistocene or early Recent fossils.

The bajada on the west side of the mountains is underlain by a complex of fanglomerates, laid down during successive stages of the uplift and degradation of the mountain area. Most of the fanglomerate that now lies at the surface is probably of fairly recent origin (shown as "younger fanglomerate" on pl. 22), but some deposits are exposed in places that appear to be older (shown as "older fanglomerate" on pl. 22).

West of the escarpment near Guadalupe Peak is a tectonic trench a mile wide, lying between the outer bench of the escarpment and the easternmost ridge of the Patterson Hills (pl. 20). It is covered everywhere, except a few rock hills that project from it, probably to great depth, by fanglomerates composed of fragments washed out from the escarpment to the east (pl. 22).

Several miles southwest of Guadalupe Peak some low ridges project above their surroundings in the trench. They are composed of fanglomerates rather firmly cemented by caliche, which appear to be older than those underlying the lower country around them. They consist mostly of great blocks of massive Capitan limestone, but include a few blocks of sandstone from the Delaware Mountain group. They contain no fragments of black limestone from the outer bench of the escarpment, which rises several hundred feet above them a short distance to the east, whereas the surrounding younger fanglomerates contain abundant black limestone fragments. These older fanglomerates resemble the older slope deposits on the escarpment to the east in composition and degree of consolidation, and are probably of the same age.

The western slopes of the ridges of older fanglomerate are gently rounded surfaces, but each one breaks off on its eastern side in a straight, abrupt scarp 25 to 50 feet high. These scarps appear to be fault scarps (as shown in figure 23, *B*), and indicate that the fanglomerate was disturbed after it was deposited.

OLDER PEDIMENT AND ITS GRAVEL COVER

South of the trench that lies west of Guadalupe Peak, bedrock is exposed in many places, and has been worn down to pediments and low hills. The bedrock is covered in many places by a thin mantle of unconsolidated deposits (shown as "stream alluvium and cover of younger pediments" on pl. 22). Standing 50 feet or so above are terracelike remnants of an older, gravel-capped pediment (shown as "gravels deposited on older pediments" on pl. 22). They are well displayed near Guadalupe Arroyo along United States Highway No. 62, and also occur farther east, toward the base of the Delaware Mountains.

The gravels on the older pediment near the base of the Delaware Mountains reach a thickness of 100 feet, but they thin toward the west, and near Guadalupe Arroyo are less than 20 feet thick.

Near the Delaware Mountains (as in the exposure shown on fig. 17, *A*), the deposit is a rudely stratified aggregate of limestone cobbles and broken flags, embedded in a buff sandy clay matrix, and interstratified with some beds of clay as much as 5 feet thick. Most of the fragments are dark-colored, bedded limestone derived mainly from the Getaway limestone member of the Cherry Canyon formation, which now forms the rim of the mountains to the east. However, limestone fragments with features characteristic of the Pinery and Lamar limestone members of the Bell Canyon formation much higher in the section can also be recognized. These members do not crop out near the rim of the Delaware Mountains to the east, but they are exposed not far from the gravel areas in the foothills to the west. One gravel remnant 2½ miles southeast of the forks of the Van Horn and El Paso roads contains rounded cobbles of light-gray, massive Capitan limestone. The gravels contain no fragments of the black limestone (Bone Spring) that now crops out east of the Border fault along the base of the Delaware Mountains escarpment, nor of the coarse-grained sandstone (Brushy Canyon) that immediately overlies it.

It is difficult to tell much about the original form of the older gravels and the pediment on which they rest, for they now occur only as remnants. Moreover, some of the remnants seem to have been displaced by faulting. Near the base of the Delaware Mountains, closely adjacent remnants stand as much as 100 feet higher or lower in different fault blocks (fig. 17, *B*), and in the ravines that cut them they are seen to be traversed by fault planes or to lie in fault contact with the bedrock (fig. 17, *A*). At one exposure 4 miles south of El Capitan (shown at right-hand end of fig. 24, *A*), the gravels seem to have been displaced about 60 feet by one of the faults of the Border zone. The remnants farther west, near Guadalupe Arroyo, were probably disturbed in the same manner; for example, one remnant on the south side of the arroyo a mile southwest of the junction of the Van Horn and El Paso roads ends eastward along a straight scarp 40 feet high that is in line with an exposed fault in the bedrock 3 miles to the north.

FLOOR OF SALT BASIN

West of the mountains, and beyond the bajadas that fringe their base, is the level floor of the Salt Basin (pp. 136–138). No outcrops of early Pleistocene deposits have been identified on the floor, and it is not known to what extent they have been covered by later Pleistocene and Recent deposits. The older slope and fanglomerate deposits cannot be traced into the basin from the mountains to the east because the intervening area is covered by later deposits.

The basin floor was probably leveled by deposition in lakes that occupied the central part of the basin from time to time during Pleistocene and perhaps earlier periods. Surface features on the floor indicate that a lake existed there during late Pleistocene time (pp. 156–157). Whether present surface features were shaped entirely by the late Pleistocene lake cannot be determined. As deposition on the floor has proceeded much more slowly than on the adjacent bajadas, it is possible that some of the surface features are inherited from earlier Pleistocene time.

South of the area studied, the basin floor appears to have been deformed. In the latitude of the northern part of the Sierra Diablo, the cross section of the basin is asymmetrical, with the lowest point at the western side, at the foot of the bajada that fringes the high Sierra Diablo scarp (pl. 23). To the east, the floor rises gradually to the more distant and lower Delaware Mountains, which is the reverse of what would be expected if the surface had been shaped by depositional processes alone. Evidently the floor has been tilted toward the west. The tilting is older than the late Pleistocene lake, as its beach lines extend horizontally around the area. It probably took place at the same time as the later faulting along the nearby Sierra

Diablo scarp, this faulting probably being of the same age as that which disturbed the older gravel deposits within the area studied.

AGE OF DEPOSITS

The older gravels, slope deposits, and fanglomerates in the vicinity of the southern Guadalupe Mountains contain few fossils, so their age cannot be given precisely. The gravels southeast of the Guadalupe Mountains contain a few terrestrial mollusks which are long-ranging forms that might be either of Pleistocene or Recent age. At Indian Cave, the relation of the older slope deposits indicates that they are much older than the late Pleistocene or early Recent vertebrates contained in the cave (fig. 24, *B*).

The older gravels, slope deposits, and fanglomerates have one characteristic in common. They are older—perhaps much older—than the modern and relatively recent features. All have been deeply eroded, and many stand high above present drainage. Some have been faulted and tilted. Although direct evidence is lacking, these relations suggest that they are of early Pleistocene age.

INTERPRETATION OF EARLY PLEISTOCENE(?) FEATURES AND DEPOSITS

The early Pleistocene(?) features and deposits came into existence toward the close of a long period of crustal stability which succeeded the major uplift of the mountains in late Pliocene or early Pleistocene time. The features and deposits seem to record a common history—first, a well-marked pause in downcutting indicated by extensive pediments in the lower areas, and mature slope forms on canyon walls and escarpments in the mountains; then, a period of aggradation indicated by deposits laid down on the pediments. This history was controlled by a number of factors. The most important is fluctuation in climate, a characteristic feature of Pleistocene time, which would affect all drainage basins equally. In addition, the emplacement of the Pecos River east of the mountains undoubtedly influenced all streams draining in that direction from the crest.

VOLUME OF EARLY PLEISTOCENE (?) DEPOSITS

Review of the tectonic events and sequence of deposits in the Sacramento section (including the Guadalupe and Delaware Mountains) indicates an anomaly. The initial uplift of the ranges was followed by deposition of great volumes of Pliocene deposits, both in the intermontane basins and the plains to the east. The later and presumably main uplift of the ranges was followed by the deposition of only thin and scattered Pleistocene deposits such as those seen in the Guadalupe and Delaware Mountains.[51]

The smaller volume of deposits in Pleistocene time is attributed in part at least to the development of such through-flowing drainage systems as the Pecos and Rio Grande, which were able to carry material out of the region. The total volume of deposits, however, may have been small even in such depressions as the Salt Basin which were not connected with through-flowing drainage. The main reason for the smaller volume of deposits in Pleistocene time seems to be that less material was shed from the mountains after the second uplift than after the first because most of the poorly resistant rocks had already been stripped from them, leaving only a core of resistant Paleozoic limestones and other rocks. This suggestion may account for the fact that the Guadalupe Mountains and other ranges of the Sacramento section still project high above their surroundings, even though the main uplift was at least as old as the early Pleistocene, and though subsequent disturbances have been relatively small.

DEVELOPMENT OF PECOS RIVER

A profound change took place on the eastern slope of the Guadalupe and Delaware Mountains during the Pleistocene because of the development of the Pecos River. Previously, drainage had flowed eastward to the aggrading surface of the Llano Estacado and had become adjusted to a relatively high-standing, rising base-level. The Pecos River developed at nearly right angles to the older drainage, and at a much lower level, along the eastern base of the Guadalupe, Delaware, and other mountains of the Sacramento section.[52] Drainage on the eastern slope of the mountains was then adjusted to a low-lying, descending base level controlled by the river.

The Pecos River apparently originated in the Edwards Plateau south of the Llano Estacado as a short consequent tributary to the Rio Grande. The gradient of the original stream probably was so much steeper than those of streams flowing east to the Llano Estacado that it was able to extend its original course headwards, thereby capturing the headwaters of each of these eastward-flowing streams in turn.[53] Headward cutting toward the north was aided by the fact that a belt of poorly resistant upper Permian and lower Mesozoic rocks lies between the mountains of resistant older rock to the west and the resistant, caliche-capped sheet of Pliocene deposits on the Llano Estacado to the east. At least a part of the capture of other streams by the Pecos was facilitated by large-scale collapse of rocks along this belt of poorly resistant rocks as layers of

[51] For relations in the El Paso area, see Sayre, A. N., and Livingston, Penn, Ground-water resources of the El Paso area, Texas: U. S. Geol. Survey Water-Supply Paper 919, p. 37, 1945.

[52] Fiedler, A. G., and Nye, S. S., Geology and ground-water resources of the Roswell artesian basin, New Mexico: U. S. Geol. Survey Water-Supply Paper 639, pp. 99–100, 1933.

[53] The most definitely proved example of beheading of eastward-flowing streams by the Pecos is in the Portales Valley of east-central New Mexico. See Baker, C. L., Geology and underground waters of the northern Llano Estacado: Texas Univ. Bull. 57, pp. 52–54, 1915. Theis, C. V., Report on the ground water in Curry and Roosevelt Counties, New Mexico: New Mexico State Eng. 10th Bienn. Rept., pp. 98–146, 1932.

interbedded soluble salts were removed by ground water.[54]

These events have not been definitely dated. They are certainly later than deposition of the Pliocene rocks of the Llano Estacado, and are older than deposition of the quartzose conglomerate[55] and Gatuña formation,[56] which are the oldest formations that fill the valley of the Pecos River. The latter deposits are overlain unconformably by younger Quaternary deposits and are probably of older Pleistocene age. If these deposits are older Pleistocene, the development of the river probably took place in early Pleistocene time.

As a result of the development of the Pecos River, streams flowing east from the crest of the Guadalupe and Delaware Mountains became adjusted to a low-lying, descending base-level controlled by the river, instead of to a high-standing, rising base-level as before. During each successive cycle, such as the pediment cutting and the gravel deposition on the pediments described above, erosion and deposition therefore took place at a lower level than during the preceding cycles. A series of successively lower plains and terraces were thus developed. Moreover, material washed out from the mountains was not deposited in any large volume in the lower country, but much of it was carried out of the region toward the sea.

CLIMATIC FLUCTUATIONS

The fluctuation in conditions suggested by widespread cutting of pediments and other features, followed by deposition on the pediments, was probably caused in large part by a fluctuation in climate. It could not have been due entirely to changes in regimen of the Pecos River for the areas draining into the Salt Basin to show a similar history. Only climatic changes would have equal effect on all drainage basins.

As shown by the relations along Pine Spring and Cherry Canyons (fig. 21, *B*), the streams that cut the pediments had a more concave profile than the present ones. Concavity of profile results from a downstream increase in the effectiveness of the transporting power, which may be brought about in increase in volume, by decrease in the coarseness of the load, or by both. Each of these factors would be enhanced by greater rainfall; thus streams lose their steep headward declivity in a shorter distance in humid than in arid climates.

The gravel deposits on the pediment apparently resulted from a change in climate toward aridity. The profile of the deposits, as shown along Pine Spring and Cherry Canyons (fig. 21, *B*) is less concave than the surface on which they rest. Both the gravels on the pediments and the probably contemporaneous slope deposits and fanglomerates are strongly impregnated by caliche, a soil feature characteristic of dry climates. An exposure in Pine Spring Canyon one mile west of Pine Spring (p. 145) suggests that this change may have taken place rapidly. The layer of fine-grained sediments at its base was laid down when little material was being washed off the adjacent mountains. This layer is succeeded by fanglomerates, laid down when erosion of the adjacent slopes was actively renewed and more coarse material was washed in than the stream could carry away.

With the change toward an arid climate, both the volume and the coarseness of the material eroded from the mountain areas was increased. The cloak of vegetation on the mountains was reduced, the soils stripped away, and the bedrock exposed to attack by mechanical weathering. A return to more humid conditions at the end of the period of deposition is suggested by the subsequent dissection of the gravel deposits. These subsequent events are discussed under the heading of later Pleistocene and Recent features.

RELATION OF CLIMATIC FLUCTUATIONS TO PLEISTOCENE GLACIATION

The fluctuations in climate between humid and arid conditions indicated by the early Pleistocene pediments and deposits were probably related to the glacial and interglacial stages of Pleistocene time. A period of humid conditions probably corresponds to one of the glacial stages, and a period of arid conditions probably corresponds to one of the interglacial stages.

Erosion surfaces and unconsolidated deposits along the Pecos River in the nearby Roswell area in New Mexico which are similar to those in the area studied, have been tentatively correlated by Nye[57] with the specific Pleistocene glacial and interglacial stages. Such correlations, however, cannot rest on a secure basis until studies have been made of much broader areas than those near Roswell and in the Guadalupe Mountains. In particular it is desirable to know more about the geomorphic history of the region which separates these two areas from the nearest centers of Pleistocene glaciation.

Features of probable glacial origin have been reported from the Sangre de Cristo Mountains and the Sierra Blanca in New Mexico,[58] but the nearest area in which an extensive glacial history is recorded is in the San Juan Mountains of Colorado.[59] Geomorphologic studies of areas not far south of the San Juan Moun-

[54] Lee, W. T., Erosion by solution and fill: U. S. Geol. Survey Bull. 760, p. 121, 1925.

[55] Fiedler, A. G., and Nye, S. S., op. cit., pp. 109–111.

[56] Robinson, T. W., and Lang, W. B., Geology and ground-water conditions of the Pecos River valley in the vicinity of Laguna Grande de la Sal: New Mexico State Eng. 12th and 13th Bienn. Rept., pp. 84–85, 1939.

[57] Fiedler, A. G., and Nye, S. S., Geology and ground-water resources of the Roswell artesian basin, New Mexico: U. S. Geol. Surv. Water Supply Paper 639, pp. 111–113, 1933.

[58] Ellis, R. W., The Red River lobe of the Moreno glacier: New Mexico Univ. Bull., Geol. Ser., vol. 4, No. 3, 1931. Antevs, Ernst, The age of the Clovis lake clays: Acad. Nat. Sci. Philadelphia Proc., vol. 87, p. 307, 1936.

[59] Atwood, W. W., and Mather, K. F., Physiography and Quaternary geology of the San Juan Mountains, Colorado: U. S. Geol. Survey Prof. Paper 166, pp. 27–31, 1932.

tains are now being carried on by Kirk Bryan and his associates,[60] and as this and other work is extended, more conclusions can be reached as to the Pleistocene history of the region south of the glaciated areas.

LATER PLEISTOCENE AND RECENT FEATURES AND DEPOSITS

After the older land forms had been carved and were mantled by deposits, degradation of the region was renewed, and the land forms and deposits were thereby dissected. During this time of degradation, the mountains were given the form they now possess. The younger land forms and deposits came into existence during the time of degradation; those now in the process of formation have been described in an earlier section (pp. 126–138), and need be mentioned further only to place them in their historical perspective. In addition, some features will be described that are older than the modern features and younger than the older topographic features and deposits.

TECTONIC FEATURES

EVIDENCE FOR FAULTING

In the Guadalupe and Delaware Mountains, later Pleistocene time was one of some tectonic instability. Reference has already been made to the fact that in the foothill area the older fanglomerates and the gravels deposited on older pediments have been displaced by faults, which are indicated in some places by low fault scarps and in others by fault planes traversing the deposits (pp. 113–114). These faults are all west of the Border fault zone and it is probable that this zone moved again at about the same time. This movement is indicated by relations along the black limestone bench that flanks it on the east, described below.

BLACK LIMESTONE BENCH

Along the west base of the Guadalupe and Delaware Mountains from the latitude of Guadalupe Peak southward, the black limestone at the base of the Permian succession projects as a bench that rises a few feet to more than 300 feet above the downfaulted rocks to the west. Above the bench are gentle slopes carved from the overlying sandstones. A bench has formed on the black limestone because its resistance to erosion is greater than that of the sandstones that overlie it. The surfaces of the bench are boulder-controlled slopes, adjusted to the movement of weathered black limestone fragments across them.

The bench is prominently in view along the base of the escarpment in the panorama, plate 5, *A*, and the right-hand end of the panorama, plate 5, *B*. On plate 14, *B*, a nearer view of the bench, its relation to the Border fault may be seen. A profile across the bench is given on figure 23, *B*.

The bench seems to be more intimately related to the Border fault zone than are the higher parts of the escarpment. Its western edge is a nearly straight line that follows the traces of the faults throughout its entire distance, and it is scarcely dented by the streams that have incised narrow gorges across it. Thus it has receded very little from its original tectonic surface. In places, older fanglomerates and gravel deposits lie against the black limestones on the upthrown sides of the Border faults (pl. 14, *B*) in such a manner as to suggest that the fanglomerates had been faulted against the black limestones. In one place, older gravels appear to be displaced by one of the faults of the zone (right-hand end of fig. 24, *A*). Black limestone fragments are absent from the older fanglomerates and gravels west of the Border fault zone, which contain only rocks from the higher parts of the escarpment. On the other hand, such fragments are abundant in the younger rocks of the same district.

These relations suggest that the black limestone bench may have been partly or wholly concealed at the time the older slope, fanglomerate, and pediment deposits were laid down, and that it did not reach its present height until later, when renewed movements on the Border fault zone took place (stage 3, fig. 22). Such movements may have amounted to several hundred feet in places (fig. 23 *B*). The face of the black limestone bench is probably a slightly eroded fault scarp, much younger than the greatly eroded fault scarp or fault-line scarp that forms the higher part of the escarpment.

RELATION OF FAULTING TO EROSIONAL FEATURES

The faulting just described interrupted the development of the older features and deposits, which had been forming during a long period of crustal stability. The displacements were relatively small, amounting to a few hundred feet at most, but they were sufficient to cause the dissection of the various older features on the west-facing escarpment and the foothills to the west. Because of the movements, the features were placed in a new relation to the adjacent drainage, and may have been shifted upward relative to the base-level of the Salt Basin, either by depression of the basin or uplift of the mountains.

EROSIONAL AND DEPOSITIONAL FEATURES

DISSECTION OF OLDER FEATURES AND DEPOSITS

The older topographic features and deposits have not only been dissected where they are faulted, but in parts of the area where they are not faulted. Thus, the streams in the canyons of the Guadalupe Mountains have cut more than 100 feet below the valley-side shoulders on their walls, and now flow in narrow, inner gorges, with imperfectly graded channels. In like

[60] Bryan, Kirk, Geology and ground-water resources of the Rio Grande depression in Colorado and New Mexico: Nat. Resources Comm., Regional planning, Part 6, Rio Grande joint investigation, pp. 197–225, 1938.

manner, the gravel plain to the southeast is trenched as much as 100 feet by narrow gorges that in places extend into the underlying bedrock. Farther south broad plains flank the larger streams; they are pediments adjusted to the grade of these streams. The plains stand at a lower altitude than the older gravel plains and older pediment remnants, and represent a new cycle of base leveling at a lower level.

The widespread dissection of the older features resulted from the interaction of numerous factors, whose relative importance is difficult to evaluate. It is possible that the mountains were uplifted at the time of the later faulting along the Border zone and in the foothills. If so, they were shifted upward relative to the base levels of the streams that drained them. Climatic changes also probably took place, some of which encouraged downcutting by the streams. Moreover, as degradation of the mountains progressed, the size of materials carried by the streams decreased, and the streams tended to cut down to increasingly lower gradients.

On the east slope of the mountains, in the area drained by the Pecos River, dissection by streams also took place as a result of lowered base levels caused by deeper cutting of the river. Aerial photographs of the area east of the mountains, in the Gypsum Plain and Rustler Hills, indicate that at some place along each of the major streams draining toward the Pecos there are abrupt descents from wide alluvial valleys upstream to steep-sided, headward-cutting gorges downstream. Some of the major streams have more than one such descent. These descents represent impulses toward renewed downcutting that are being generated upstream from the river along each tributary. In addition to normal downcutting of the river, such impulses may have been influenced in part by eustatic changes in sea level that are known to have taken place during Pleistocene time.

SUBSEQUENT STREAMS

The dissection of the older topographic features and deposits furthered the development of subsequent streams (shown by a separate symbol on pl. 22), although some of these streams may have come into existence during earlier periods.

On the east slope of the Delaware Mountains, the structure is such that the surface is made up of many strike belts of poorly resistant sandstone, lying between belts of more resistant sandstone and limestone. Along them drainage leading into the larger consequent streams has cut headward to form subsequent streams, such as Bell Canyon (pl. 22). In other places in the same area belts of poorly resistant sandstone are faulted down to the same altitude as more resistant rocks. Along one of these belts, the Getaway graben, a depression was hollowed out by two subsequent tributaries of Getaway Canyon. The more resistant limestones to the east and west rise above it in resequent fault-line scarps, whose tops are remnants of an older pediment, probably of the same age as the gravel plain farther north (pl. 22).

On the west slope of the Delaware Mountains a number of belts of weak rock extend along fault lines, perhaps because of the close spacing of joints. In this area, during dissection of the older features, subsequent streams were cut in the weak belts; the largest of them is the stream of Guadalupe Canyon (pl. 22).

TERRACES

Along the sides of some valleys that trench the gravel plain southeast of the Guadalupe Mountains are terraces that lie between the plain and the present channels. They record pauses in the dissection of the plain.

Along Lamar and Cherry Canyons east of the D Ranch Headquarters are remnants of a gravel-capped, rock-cut terrace 50 feet above the present stream and 50 feet or more below the surface of the gravel plain (pl. 22). The deposits on the remnants consist of limestone fragments, derived from the Guadalupe Mountains, that were either washed out from the mountains at the time the terraces were formed or were reworked from the older deposits of identical composition on the gravel plain.

In Glover and Getaway Canyons, two headwater tributaries of Delaware Creek, are terraces of different character. Here, remnants of alluvium lie on the sides of the present valleys, as much as 50 feet above the present channels or within 100 feet of the hilltops whose surface is equivalent to the gravel plain. The alluvium consists of fine-grained limestone gravel and buff silt. In this region, after the valleys were first cut, they were filled to a considerable depth and then reexcavated. Terraces probably of similar structure but consisting wholly of coarse gravel lie along Pine Spring Canyon for about a mile west of Pine Spring (pl. 22).

The terraces in Glover, Getaway, and Pine Spring Canyons are the only examples that have been observed in the region of the sort of alluvial terraces that have been described in other parts of the southwest.[61] Such terraces are especially prominent along the Pecos River near Roswell, N. Mex. They are supposed to have been formed by successive stream-cutting and stream-filling as a result of changes from wet to dry climate. The development of alluvial terraces in the area studied is poor, probably because the area lies near the sources of the streams that drain it and too far from the Pecos River to have been much affected by temporary changes in its regimen.

[61] Huntington, Ellsworth, The climatic factor as illustrated in arid America: Carnegie Inst. Washington Pub. 192, pp. 24–26, 1914. Fiedler, A. G., and Nye, S. S., op. cit., pp. 10–12, 30–35, 106–109. Bryan, Kirk, Pre-Columbian agriculture in the southwest, as conditioned by periods of alluviation: Assoc. Am. Geog. Annals, vol. 31, pp. 226–237, 1941.

ALLUVIUM

Alluvial deposits on the flood plains of the modern streams occupy relatively small tracts in the area of this report, and only the larger of them have been mapped (shown as "stream alluvium and cover of younger pediments" on pl. 22). The largest areas are along Delaware Creek on the east slope of the Delaware Mountains, and near Guadalupe Arroyo in the foothills west of the Delaware Mountains. The alluvium consists mostly of buff or brown clay, somewhat impregnated by caliche, with lenses of fine gravel. Along Delaware Creek it is about 25 feet thick, but on the west side of the mountains it may be somewhat thicker. Away from the flood plains, the alluvial deposits grade into a relatively thin sheet that forms the cover of younger pediments.

YOUNGER SLOPE DEPOSITS AND FANGLOMERATES

The character and origin of the younger slope deposits and fanglomerates have already been discussed (pp. 133, 135–136), and need not be repeated here. These deposits seem to have formed in much the same manner as the older slope deposits but later than the period of renewed faulting and uplift in which the older ones were dissected. The younger fanglomerates, which form the bajada west of the mountains, were probably built up at the same time, as a result of the renewed faulting.

Deposition of the younger fanglomerates gave rise to a new generation of consequent streams (shown as "streams consequent on bajada surface" on pl. 22). Streams like them no doubt existed on the bajada ever since the first uplift of the mountain area, but because they are constantly shifting, the streams now seen there have occupied their present positions for only a relatively short time.

In some places material washed out from the mountains has filled the depressions between the mountains and the foothill ridges to such an extent that streams consequent on the bajada have been able to flow over these ridges at their lowest places. In this way they have acquired new courses across barriers in the original tectonic surface.

RECENT DISSECTION

In some places younger deposits are still gathering on slopes, pediments, and bajadas, but in others they are now being dissected. Dissection of the younger fanglomerates on the bajadas has already been discussed (p. 136).

Dissection of younger slope deposits is taking place south of El Capitan, as shown on plate 1. Here, two waste streams (indicated by the letter *b*) are trenched by ravines to depths as great as 50 feet, and in places cut into bedrock. Some of the steeper slopes between the waste streams, only lightly covered by deposits, are scored by gullies, and between them the surfaces are broadly rounded. Similar features were observed on the east slope of the Delaware Mountains, notably on the cuesta formed by the Lamar limestone member of the Bell Canyon formation northeast of the junction of Bell and Lamar Canyons. The sandstones forming the slope of the cuesta are generally stripped of all soil and deposits, but here and there are remnant patches of an older, rounded, soil-covered surface.

These features may be relics of climatic changes in the geologically recent past. The rounded, soil-covered slopes were formed during a time of relatively humid climate, and the dissection that followed probably took place during a time of relatively dry climate. The dissection seems to be considerably older than the arroyo cutting described below.

The alluvium in many of the flood plains of the area has been trenched to depths as great as 20 feet by steep-walled arroyos. According to Mr. Walter Glover, a local resident, the arroyos near Getaway Gap have been cut since about 1905. Before that time, the valley bottom at the upper end of the gap was a smooth flat, easily crossed in all directions by a wagon, whereas since then the arroyos have widened so much that a wagon can now be driven along their channels.

The arroyo cutting resembles that which has recently taken place in many other parts of the arid southwestern United States.[62] It seems to have resulted from modern depletion of the vegetation cover, thereby quickening run-off and soil erosion. This depletion probably happened because of overgrazing of the country by stock, for in the regions where I have observed it, arroyo cutting has taken place within a few score years after the country was settled. Periods of drought in recent years have greatly increased the overgrazing, for the cattle that remained on the land during the dry periods were forced to crop the grass down to its roots, and to eat plants such as the prickly pear and sotol that they usually avoid. It is entirely possible, however, that the artificial depletion of the vegetation merely accelerated a natural depletion resulting from an increasingly dry climate, and that conditions favorable to soil erosion existed at the time of the arrival of the first settlers.

LAKE FEATURES

As already indicated, the center of the Salt Basin, beyond the edges of the bajadas on either side forms a remarkably even floor, which stands at an altitude a little above 3,620 feet (pp. 136–138). It marks the extent of the gypsiferous clay hills and intervening meadows mapped as Reeves chalk in the soil report.[63] This floor is a former lake bed, which from time to time in the past was covered by standing water. On it are many fea-

[62] Bryan, Kirk, Date of channel trenching (arroyo cutting) in the arid southwest: Science, new ser., vol. 52, pp. 338–344, 1925. Bailey, R. W., Epicycles of erosion in the valleys of the Colorado Plateau province: Jour. Geology, vol. 43, pp. 337–355, 1935.

[63] Carter, W. T., and others, Soil survey (reconnaissance) of the trans-Pecos area, Texas: U. S. Bur. Chemistry and Soils, Soil Survey Rept., 1928, No. 35, p. 30, 1928.

tures formed by a lake that is probably of late Pleistocene or early Recent age.

BEACH RIDGES

The lacustrine features are most clearly indicated on aerial photographs. Old beaches stand out clearly as curving, concentric bands, encircling the margins of the floor and the sides of low protuberances on the floor itself (pl. 23). The beaches can be seen also when the floor is viewed from the mountain tops to the east, but their pattern and character is less evident. Such features are difficult to recognize on the ground, but they have been studied in the field a mile southwest of the old P X Ranch within the area of this report, and near the mouth of Victorio Canyon east of the Sierra Diablo south of the area of this report.

On aerial photographs the beaches appear as low, light-colored ridges, a few hundred feet to nearly a quarter of a mile across, that extend as bands along the contours, bending outward around the outer ends of alluvial fans, and recessed between them. The highest beaches lie about 40 feet above the lowest points on the floor, or at an altitude of about 3,660 feet. They are indefinite and discontinuous, and hence probably older than the lower beaches. The most definite beaches lie at a lower altitude and about 20 feet above the lowest points on the floor; others lie both above and below. Although the beaches are not far apart in altitude, the very gentle slopes on the floor cause them to be in places as much as a mile apart laterally.

The two beaches studied in the field are both parts of the 20-foot beach. At the locality southwest of the P X Ranch the beach is a narrow embankment of gypsiferous clay which rises about 10 feet above its surroundings and is about 20 feet higher than the nearby alkali flats on the lowest part of the floor. At the locality east of the mouth of Victorio Canyon, the outer edge of the bajada is cut off in a scarp 10 to 20 feet high, which descends steeply from the bajada to a flat meadow containing alkali flats. The scarp is composed of buff loam, with a capping of gypsiferous clay. In places, the top of the scarp is a few feet higher than the surface of the bajada behind it.

HISTORY OF LAKE

The beaches indicate the one-time existence of a lake which was at first about 40 feet deep, and covered the whole expanse of the basin floor. Later, the lake receded but maintained a depth of about 20 feet for a considerable period, when well-marked shore features were formed. During the 20-foot period, slightly higher areas within the floor of the basin rose about lake level, such as the higher ground west of the area studied, between the chains of alkali flats on the east and west sides of the basin. The gypsiferous clay of the clay hills and the brown clay of the meadows, which are the characteristic surface material of the basin floor, are probably lacustrine deposits, later shifted somewhat by the wind. These lacustrine deposits were built up in standing water to form the nearly level surface of the basin floor, and may have been laid down over the outer edges of the bajadas, thus causing the sharp boundary between the topography and soils of the two features.

After most of the waters of the lake had disappeared and most of the floor of the basin was uncovered, a few remnants in the form of intermittent water bodies remained at the lowest places on the floor. These low places were somewhat enlarged by subsequent wind action and form the alkali flats that are a characteristic feature of the modern basin floor.

AGE

The lake in the Salt Basin is probably of the same age as that which once filled the Estancia Basin of central New Mexico [64] where there are many well-preserved shore features. Antevs [65] suggests that the lake in the Estancia Basin existed during the "pluvial period" which came at the end of the Pleistocene.

CAVES

The limestones of the area studied contain numerous caves, but there are no large ones comparable to Carlsbad Cavern and others in the Carlsbad and Capitan limestones not far to the northeast. Most of the caves observed in the area studied are shallow openings, recesses, and shelters.

AGE

Most of the caves here and elsewhere in the Guadalupe Mountains were probably formed when the topography was approaching its present form. The smaller ones occur in the present canyon walls and escarpments. The larger ones could have been cut to their present size and depth only by underground drainage whose outlets were near the levels of the modern streams. The time of cave formation was probably related to times of still stand expressed elsewhere by gravel plains, terraces, and other surface features.

According to interpretations made in this report, the Guadalupe Mountains did not begin to assume their present form until the beginning of Pleistocene time, and the development of the present surface features took place during the Pleistocene and Recent. Because of their close relation to surface features, the caves of the region also probably formed during these epochs. This conclusion has been previously suggested by Gardner.[66]

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[64] Meinzer, O. E., Geology and ground-water resources of Estancia Valley, New Mexico: U. S. Geol. Survey Water-Supply Paper 275, pp. 18–25, 1911.

[65] Antevs, Ernst, Age of the Clovis lake clays: Acad. Nat. Sci. Philadelphia Proc., vol. 87, pp. 304–312, 1936.

[66] Gardner, J. H., Origin and development of limestone caverns: Geol. Soc. America Bull., vol. 46, pp. 1270–1272, 1935.

CAVE FAUNAS

Some caves in the Guadalupe Mountains contain vertebrate bones and archeological material. One of them, the Indian Cave on the Williams Ranch, south of El Capitan, lies within the area studied. Its contents have been described by Ayer [67] as including not only various living species, but also the extinct horse, dire wolf, and ground sloth (dung only). She states:

> Twenty-two forms of mammals are here reported from Williams Cave, of these 22.7 percent are extinct, 31.8 percent are living but not found in the Guadalupe Mountain region of Texas, and 45.5 percent are now found in western Texas and are reported from the Guadalupe Mountains. It is of importance to note that some of the cave forms now living in sections other than western Texas are found to the north and in many cases in the higher mountains where vegetation is quite distinct from the desert flora now found about the cave. This would seem to indicate that in this region, at one time, the climate was quite different. On the other hand, these animals may have strayed down from the top of the Guadalupe Mountains in search of food, thereby accounting for their presence in the cave material.

The Burnet Cave, in the Guadalupe Mountains near Three Forks, north of the area studied (fig. 2), has yielded still larger collections. The faunal and archeological material from it has been described by Howard and Schultz.[68] The vertebrates include extinct species of bear, horse, camel, musk-ox-like bovid, and bison. According to these authors:

> Forty-three forms of mammals were found in Burnet Cave. Of these, 23 percent are extinct, 12 percent are living but are not found in New Mexico, 30 percent are now living in the Guadalupe Mountain region, and 35 percent are living in New Mexico but are not reported from the Guadalupe Mountains. * * * It is interesting to note that many of the cave forms, now living in regions other than the Guadalupe Mountains, are found to the north and in many cases in the higher mountains. Several of these species and varieties now live in life zones as high as the Arctic-Alpine zone. There is a strong indication that the climate of the region of the cave, during the time of the pre-Basket Maker occupation, was much different than it is today.

EVIDENCE FOR RECENT CLIMATIC CHANGES

In various places in the preceding descriptions, reference has been made to features that probably formed as a result of certain climatic conditions, or of changes in climate. Some of them are relatively ancient, and perhaps of Pleistocene age; others are of relatively recent age. Such interpretations of climatic conditions are not absolute, because of possible complications resulting from other factors, but evidence regarding the climatic conditions affecting younger features appears to be more obvious than for the older. The various features indicate various things and not all of them are in harmony, and not all of them took place at the same time. Evidence is still too scattered and indefinite to fit the observed features into any comprehensive climatic history.

EVIDENCE FOR CLIMATIC CHANGES IN AREA STUDIED

A formerly more humid climate is suggested by the evidence of lacustrine conditions on the floor of the Salt Basin in late Pleistocene time. Humid climate is suggested also by rounded, soil-covered slopes on some of the mountain sides and cuesta faces. A change to a drier climate is suggested by dissection and partial stripping away of this cover. Arroyo cutting in the alluvial deposits, though perhaps mostly the result of overgrazing, may have been influenced by increased dryness within modern times.

A formerly colder climate is suggested by the nature of the vertebrate faunas mentioned above, which came from two caves in the Guadalupe Mountains. Their nature may be explained partly by other factors, but these other factors probably do not account for all the features observed in the faunas.

EVIDENCE FOR CLIMATIC CHANGES IN NEARBY AREAS

Possible recent climatic changes in the southwestern United States have been discussed at some length by Huntington,[69] who concluded that within the last few thousand years the climate has become distinctly more arid than before. Geomorphological, botanical, and archeological evidence is cited, not all of which is entirely convincing. Much more evidence has been accumulated since Huntington's publication appeared, but not all of it agrees with his conclusion. He has pointed out, however, that large climatic changes are the net effect of much more complex minor fluctuations, and some of these minor fluctuations may have been strong enough to have left some record of their passing.

Huntington [70] discusses the results of the work of E. E. Free on the alkali flats and sand dunes of the Tularosa Basin west of the Sacramento Mountains (fig. 1). Free recognizes three or more sets of gypsum deposits of different ages in the basin, all presumably of aeolian origin, and all perhaps indicating periods of dry climate, similar to that under which the White Sands of the area are now forming.[71]

The conclusions of Antevs [72] regarding the pluvial period at the end of the Pleistocene have already been mentioned (p. 157). He suggests that the extinct lake in the Estancia Basin and others near Clovis, N. Mex., were formed during this period. There is supposed to have been a moister climate than at present. Aeolian sand that covers the lake deposits is cited as evidence

[67] Ayer, M. Y., The archeological and faunal material from Williams Cave, Guadalupe Mountains, Texas: Acad. Nat. Sci. Philadelphia Proc., vol. 88, pp. 599–618, 1936.

[68] Howard, E. B., Evidence of early man in North America: Museum Jour. (Univ. Pennsylvania), vol. 24, pp. 62–79, 1935. Schultz, C. B., and Howard, E. B., The fauna of Burnet Cave, Guadalupe Mountains, New Mexico: Acad. Nat. Sci. Philadelphia Proc., vol. 87, pp. 273–296, 1935.

[69] Huntington, Ellsworth, The climatic factor as illustrated in arid America: Carnegie Inst. Washington Pub. 192, pp. 9–93, 1914.

[70] Huntington, Ellsworth, idem, pp. 37–42.

[71] Compare Huffington, R. M., and Albritton, C. C., Quaternary sands on the southern High Plains of western Texas: Am. Jour. Sci., vol. 239, pp. 325–388, 1941.

[72] Antevs, Ernst, Age of the Clovis lake clays: Acad. Nat. Sci. Philadelphia Proc., vol. 87, pp. 304–311, 1935.

that there was a later change toward more arid conditions.

Bryan and Albritton[73] have discussed features in the alluvial deposits of New Mexico and Texas that suggest climatic fluctuations, some of which probably took place within the last few thousand years. In the Davis Mountains area three alluvial formations supposedly laid down during humid periods are recognized; they are separated by unconformities due to erosion, which supposedly occurred during drier periods. During some of the erosion periods, channel trenching took place which resembles that going on today.

Evidence for climatic fluctuations based on other features has been suggested. Cave silts, wind-polished rocks, and sand dunes of various ages are cited as evidence for dry periods, which may correspond to unconformities in the alluvial sequence above noted.[74] Bryan [75] has attempted a tentative interpretation of soil profiles and weathered slopes near Alpine, Tex., in terms of climatic changes. A succession of an early, long period of aridity followed by moister conditions and finally by modern, drier conditions, is suggested.

BROADER RELATIONS OF CENOZOIC HISTORY

EVOLUTION OF THE MOUNTAIN AREA

The evolution of the surface features of the Guadalupe and Delaware Mountains can be considered under the headings of structure, process, and stage.[76] The mountains have the structure of an uplift, much broken by faults. The structural surface has been acted on by subaerial processes of degradation, under the influence of an arid climate, and dominated by the work of streams. Degradation has reached a stage wherein considerable modifications may now be seen in detail, although the original structure is still reflected in the broader configuration.

Changes in the aspect of the mountains following their original uplift have been brought about partly by renewed uplift and faulting during several succeeding periods, and partly by the erosion of a large amount of material from the upraised areas, some of it being deposited in the adjacent depressed areas. Poorly resistant rocks, of which no trace now remains, may at the time of the uplift have covered the summit peneplain—the oldest land form in the area; moreover, toward the south, a great thickness of sandstone and anhydrite below the level of the peneplain has been stripped off the mountain summits.

The escarpment that forms the western side of the mountains, although outlined by the faults along its base, is not as high as the tectonic relief of the rocks that compose it (fig. 22, *B*). Its crest has been lowered by erosion, and its base raised by the deposition of unconsolidated material on the bajada to the west. It is also not as steep as the original tectonic surface, as it has been cut back into graded slopes.

BASIN-RANGE PROBLEM

The Guadalupe Mountains lie in the Basin and Range province, "characterized by isolated, subparallel mountain ranges rising abruptly above desert plains." [77] The origin of the surface features in the province has long been debated.[78]

As worked out by Gilbert, Davis, and others, the ranges are composed of rocks that had previously been more or less deformed and degraded, and originated as uplifted blocks, outlined on one or more sides by faults that cut across the older tectonic features. The adjacent plains are believed to be underlain by rocks that were depressed so far at the time of the uplift of the ranges that they have been entirely buried by detritus washed out from the uplifted areas. The faults along the edges of the ranges are therefore seldom exposed to view, but must be deduced from evidence afforded by the land forms. This interpretation has been challenged by Spurr, Keyes, and others, who consider that the ranges have resulted from the differential erosion of a previously deformed terrain.

As may be seen from the interpretations of the Guadalupe and Delaware Mountains that are made in this report, these mountains correspond, at least generically, to the type of Basin-Range origin advocated by Gilbert and Davis, although possessing many specific features of their own. They depart from the ideal in that their rocks are only mildly deformed, in the probable absence of remnants of the prefaulting topography (assuming that the summit peneplain is pre-Cretaceous), and in the complications resulting from several periods of upheaval and faulting. The Guadalupe Mountains are, therefore, one of the "Basin-Range types" in the sense used by Davis.[79]

The conclusions reached for the Guadalupe and Delaware Mountains should not, however, be considered as

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[73] Bryan, Kirk, Recent deposits of Chaco Canyon, New Mexico, in relation to the life of the pre-historic peoples of Pueblo Bonito [abstract]: Washington Acad. Sci. Jour., vol. 16, pp. 75–76, 1926. Albritton, C. C., and Bryan, Kirk, Quaternary stratigraphy in the Davis Mountains, trans-Pecos Texas: Geol. Soc. America Bull., vol. 50, pp. 1423–1474, 1939. Bryan, Kirk, Pre-Columbian agriculture in the southwest, as conditioned by periods of alluviation: Assoc. Am. Geographers Annals, vol. 31, pp. 219–242, 1941.

[74] Bryan, Kirk, and Albritton, C. C., Wind polished rocks in trans-Pecos Texas [abstract]: Geol. Soc. America Bull., vol. 50, p. 1902, 1939. Huffington, R. M., and Albritton, C. C., op. cit., 325–388.

[75] Bryan, Kirk, Gully gravure, a method of slope retreat: Jour. Geomorphology, vol. 3, pp. 101–105, 1940.

[76] Davis, W. M., The geographical cycle: Geographical essays, p. 249, 1902.

[77] Fenneman, N. M., Physiographic divisions of the United States: Assoc. Am. Geog. Annals, vol. 6, p. 42, 1917.

[78] Davis, W. M., The Basin Range problem: Nat. Acad. Sci. Proc., vol. 6, pp. 387–392, 1925. Gilbert, G. K., Studies of Basin-Range structure: U. S. Geol. Survey Prof. Paper 153, pp. 1–9, 1928. Sauer, Carl, Basin and range forms in the Chiricahua area: California Univ., Pub. Georg., vol. 3, pp. 346–349, 1930. Fenneman, N. M., Physiography of western United States, pp. 330–340, New York, McGraw-Hill Book Co., Inc., 1931. These contain many references to other publications.

[79] Davis, W. M., Basin Range types: Science, new ser., vol. 76, pp. 242–245, 1932.

favoring the general application of the interpretations of Gilbert and Davis to all the mountains of the Basin and Range province. Each range in the area has tectonic peculiarities of its own. Study of the ranges in recent years demonstrates that some, such as the Guadalupe Mountains, have indeed been raised by block faulting, but that others have been raised by arching and warping, and that some have been shaped largely by erosion.

In a region as vast as the Basin and Range province, the tectonic features and geologic history of whose parts is so varied, one is led to suspect that the characteristic surface features have not been caused by any one tectonic process, so much as by the all-pervading dry climate, which has allowed the drainage to remain poorly integrated, and has prevented the surface from being worn down to the subdued forms of humid regions.

ECONOMIC GEOLOGY

The southern Guadalupe Mountains are not rich in natural resources. It seems unlikely that their rocks will ever be productive of oil or metals, however much scientific treasure they may yield to the geologist and paleontologist. The resource most worthy of investigation and conservation is ground water, as it makes life possible in a land that is otherwise barren.

ORE DEPOSITS

The almost complete absence of igneous rocks in the area has already been noted (pp. 102–103). There is a corresponding lack of mineralization, except at a few localities. One of these localities is at the prospect known as the Calumet and Texas mine, in the headwaters of Dog Canyon about a mile northeast of Lost Peak (pl. 3), where veins in the Carlsbad limestone contain copper minerals. The minerals have been prospected from time to time since about 1900, but the workings are small and had been abandoned before our visit in 1934. A brief examination of the locality was made, and a small collection of specimens was taken from material on the dumps. These specimens were submitted to Mr. Charles Milton, of the Geological Survey, who reports as follows:

There are three varieties of material:

1. Fine-grained, chocolate-brown, siliceous rock, impregnated with iron and copper oxides, the former more or less hydrous.

2. Buff to brown, clayey, bedded rock, with coatings of green and blue copper minerals. The blue mineral is azurite. The green mineral, which has a spherulitic structure, is either aurichalcite, 2 (Zn, Cu) CO_3 3 (Zn, Cu) $(OH)_2$ or zinc-bearing malachite $(Cu,Zn)CO_3$. $(Cu,Zn)(OH)_2$. The clayey rock itself has an appreciable content of zinc and may be a zinciferous clay, such as has been described from other western localities.

3. Siliceous rock, carrying a heavy coating of yellow, powdery substance. This mineral is beaverite, $CuO.PbO.Fe_2O_3.2SO_3.4H_2O$. As viewed under the microscope, it consists of minute grains, of high [refractive] index (greater than 1.78), with zero birefringence, in part with hexagonal, in part with cuboid shapes. An analysis of the grains showed the following composition:

	Percent		*Percent*
Insoluble	20.82	CaO	.86
PbO	23.56	MgO	.15
CuO	8.85	Al_2O_3 and P_2O_5	.30
Fe_2O_3	19.45		
SO_3	18.32		99.40
H_2O	7.09		

Field examination indicates that the deposit is not extensive, and the valuable minerals seem too diffusely spread through the rock to give economic value to the deposit. Moreover, the prospect is so far from any road that development would be expensive and difficult.

Two other smaller mineralized areas have been reported in the southern Guadalupe Mountains, but were not visited during the present investigation. According to Wallace Pratt,[80]

There are two other openings (shallow shafts) on mineralized limestone in the area; one is about a mile west of Bell Spring on the mountain flank, the prospector having camped at Bell Spring; the other opening is on the edge of the high plateau, a couple of hundred yards northeast of the trail from the Grisham-Hunter Lodge on South McKittrick Canyon to Grisham-Hunter Camp, at a point about a mile as the crow flies west of Grisham-Hunter Lodge. Both these openings uncover concentrated black iron oxides, with a trace of copper. Local tradition claims that silver also is present. The first described opening is in the upper part of the Bell Canyon formation and the second is in the Carlsbad limestone, at the base of a sandstone phase.

FLUORSPAR

In the vicinity of the Pratt Lodge, and forming ledges at the bottom of McKittrick Canyon, are beds of dark limestone that probably belong to the Hegler limestone member of the Bell Canyon formation (section *E–E′*, pl. 17). Here and there these beds contain vugs filled with a blue, crystalline substance, which, according to Charles Milton of the Geological Survey, is fluorite. He states that "in order to distinguish this positively from the similar-appearing and optically similar yttrocerite and yttrofluorite, tests were made for rare earths, but with negative results." The fluorite is too dispersed in the rock to be of any value. Its origin is unknown.

SALT

A few miles southwest of the southwest corner of the area of this report are some salt workings which represent the first mineral deposit opened near the southern Guadalupe Mountains, and the only one producing today. The workings were described by Richardson [81] in 1904, and were visited by John C. Dunlap of the Geological Survey in May 1946. Most of the data given below are taken from an unpublished report by Dunlap.

The salt deposits are in small alkali flats or salt lakes lying a little west of the main alkali flats on the floor of the Salt Basin. The present workings are in the Zimpleman Salt Lake, which lies about a mile southwest of the

[80] Wallace Pratt, letter of January 1945.

[81] Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, pp. 61–64, 1904.

southwest corner of the area studied, and a mile south of United States Highway No. 62. The lake is about half a mile long and a quarter of a mile wide. It is owned in part by Mrs. W. Z. Copprell, of New York, N. Y., and in part by the Texas and Pacific Railroad. At present it is under lease to Arthur Grable, of Van Horn, Tex. Older workings are in the Maverick Salt Lake, about two miles south of the Zimpleman lake. This lake is about a mile long and a quarter of a mile wide. It is owned by the heirs of S. A. Maverick. It was apparently the first deposit to be opened, but is not known to have produced any salt since about 1900.

The salt deposits were first opened about 1863, when Mexican residents of the El Paso area, in Texas and adjacent parts of Chihuahua, Mexico, opened roads to the deposits and began extraction of salt for household and other uses. Shortly thereafter, various attempts were made by individuals to file claims to the land, with the intention of obtaining a monopoly of the deposits. This resulted in bad feeling among the Mexican population, and much local political strife, and culminated in the so-called "Salt War" in 1877, when some claim holders and Texas Rangers were killed by a mob at San Elizario.[82]

When the area was visited by Richardson in 1903, the Zimpleman Salt Lake was in production, the salt being extensively used by ranchmen, and also by the amalgamation works at the Shafter silver mine, 150 miles to the south. "No careful records are kept of the amount of salt hauled away, but certainly immense quantities have been used, and apparently there is as much in sight as there was forty years ago [1863]."[83]

According to Dunlap, records indicate almost continuous production from the Zimpleman lake by various lessees from 1911 to 1946. He states that Arthur Grable, the present lessee, believes that more salt has been produced since 1932 than in all the previous period. Dunlap estimates that the total production from the lake has been between 5,000 and 15,000 tons. The salt is now being used by ranchmen in the surrounding area for livestock, and is also being used in El Paso for various industrial purposes.

The Zimpleman Salt Lake occupies a shallow depression in one of the lower parts of the Salt Basin. The low, gently sloping banks that surround it are composed of sand, clay, and some gypsum. A dike one to two feet high has been built around the entire lake about 100 feet from the shore. A dike of equal height extends across the lake about 350 feet from the north end. In addition to these long dikes, shorter ones have been constructed at the north end and at the southwest corner to form brine vats. Corduroy roads with a gravel surface lead into most of the brine vats, thus providing access for trucks that are used to haul the salt.

On May 26, 1946, the entire surface of the lake, inside the outer dike, was covered with a crust of salt that averaged about half an inch thick. This crust was nearly free of wind-blown sand and clay and so must have formed since the heaviest sand storms in March. To judge by taste and appearance, the crust is mainly sodium chloride, although the somewhat bitter taste of sulfates can be detected in it. Brine is present immediately below the surface crust and this, in turn, is underlain by the next solid material, which is salt mixed with clay and fine sand. This layer of clayey salt is about six inches thick, according to Mr. Grable, and forms a "hardpan" that will support a loaded truck. Beneath the "hardpan" the salt, clay, and sand is soft, porous, and permeable.

Richardson[84] gives various analyses of salt crusts, salt crystals, and brines from this vicinity. He gives the following analysis of salt from the crust on the Zimpleman lake:

	Percent		*Percent*
Silica	0.6	Potash	None
Alumina	0.6	Sodium sulfate	1.4
Iron	Trace	Sodium chloride	97.3
Magnesia	Trace		
Lime	Trace		99.9

He also describes a test hole a few feet deep that was dug in the surface of the salt lake and states that analysis of the material penetrated "shows the presence of silica, lime, magnesia, soda, sulfur trioxide, carbon dioxide, and traces of potash and lithium, but no borax. Borax, however, occurs in at least one locality nearby."

During the period between 1929 and 1932, a shallow sump was put in and a centrifugal pump was installed with a capacity of at least 1,000 gallons per minute. The dikes now present in the lake were built at this time to confine the brine that was pumped to the surface. Greater production of salt was obtained by pumping brine, but resulted in a lower-grade product that consumers claimed contained "alkali." With the above exception, all salt harvested from the lake has formed as a result of natural evaporation of surface and subsurface waters that left their contained salts as a surface crust. During the period that brine was being pumped, a crust was allowed to form on the brine ponds about once each month and was harvested by means of forks, the tines of which are closely enough spaced to support the salt crust. The salt crust produced by natural rise and evaporation of brine is harvested in the same manner. After being stripped from the lake surface, the salt is either hauled directly to the consumer or is hauled to stock piles near the lake. It is not refined in any way to remove objectionable impurities.

[82] El Paso troubles in Texas: 45th Cong. 2d sess., H. Ex. Doc. 93, 1878. Raht, C. G., The romance of Davis Mountains and Big Bend country, pp. 208–214, El Paso, 1919.

[83] Richardson, G. B., op. cit., p. 64.

[84] Richardson, G. B., op. cit., pp. 62–64.

Demand for salt from this deposit has fallen off in recent years because of competition from other sources, notably the salt mines in Kansas and the potash mines near Carlsbad, N. Mex., where salt is produced as a by-product. The reserves of salt at the deposit are apparently adequate for continued production at the present scale of operations, and there will probably continue to be a small local market for the product.

OIL AND GAS

The southern Guadalupe Mountains are of interest to petroleum geologists because features there exposed at the surface are analogous to features known only from drilling in the oil fields to the east. However, within the area itself the chances of obtaining commercial quantities of oil or gas are probably small. There are no surface indications of oil in the region, nor have any noteworthy showings been found in the four wells that have been drilled in or near it. The positions of these wells are indicated on figure 2, and they are listed below.

Test wells drilled in or near the Guadalupe Mountains

N. B. Updike, Williams No. 1. Located within area of this report, 3 miles south of El Capitan, section 24, block 121, Public School Land. Total depth, 3,400 feet. Starts near top of Bone Spring limestone, and was probably drilled into Pennsylvanian rocks (pl. 8).

Anderson and Prichard, Borders No. 1. Located 14 miles south of El Capitan, section 34, block 69, Public School Land. Total depth, 4,728 feet. Starts 435 feet below top of Bone Spring limestone, and was probably drilled into Pennsylvanian rocks (pl. 8).

Pure Oil Co., Quaid No. 1. Located 20 miles east of El Capitan, section 12, block 63, township 2, Texas and Pacific Railroad survey. Total depth, 3,419 feet. Starts a little below top of Delaware Mountain group, and was drilled into Bone Spring limestone.

Niehaus et al., Caldwell No. 1. Located 35 miles east-southeast of El Capitan, section 15, block 109, Public School Land. Total depth, 5,008 feet. Starts in Castile formation, and was drilled through Delaware Mountain group into Bone Spring limestone (pl. 6).

In the region east of the Pecos River, oil and gas are produced from horizons in the Capitan and Carlsbad limestones, which there lie buried beneath several thousand feet of younger rocks. In the Guadalupe Mountains, these formations form the mountain summits, and any oil or gas that they once may have contained has long since escaped.

There is a possibility that oil may occur in the deeper formations, which lie beneath the surface of the mountains. As noted in the statigraphic descriptions, black limestones of the Bone Spring are impregnated by bituminous material, although chemical analyses show that this bituminous material forms less than one percent of the rock. Occasional small pockets in the limestone contain some free oil. Parts of the formation might therefore serve as source beds, and oil derived from them may have accumulated in interbedded sandstones in the Bone Spring, or in the overlying Delaware Mountain group. As the Delaware Mountain group, however, is predominantly a sandstone, any oil escaping into it from the Bone Spring limestone would likely be diffused and lost, unless local variations in porosity or structural conditions were such as to permit accumulation. There is a possibility that oil may be trapped in the northwestward tapering sandstone wedges of the Delaware Mountain group, where they are under a cover of younger rocks.

The possibilities of oil in the underlying, pre-Permian formations are largely unknown, as only their top has been reached by the Updike and the Anderson and Prichard wells. Beds of Middle Ordovician age produce oil east of the Pecos River, but exposures in the Sierra Diablo southwest of the Guadalupe Mountains show the Upper Ordovician resting on the Lower Ordovician with the producing beds absent. As the two wells in the Guadalupe Mountain region indicate that the Pennsylvanian series underlies the Permian, the Guadalupe Mountain region was probably much lower structurally in pre-Permian time than either the Sierra Diablo or the producing areas (fig. 16, *B*).

Most of the present tectonic features of the region are of Cenozoic age (pl. 21 and fig. 15, *A*). As a result of the Cenozoic movements, the region is broken into tilted fault blocks, some of which, along the crest of the uplift, might enclose sands that would serve as traps for oil and gas. Moreover, the easternmost faults, which form the terminus of a long westward rise of the strata, might seal off porous beds on their updip sides, and thus cause them to collect oil and gas that had been generated over an extensive area and had migrated up the dip. The wells listed above have been located on Cenozoic tectonic features.

Many petroleum geologists believe that oil and gas are likely to be generated shortly after the source rocks are deposited, and thus to accumulate mainly in such structural traps as are developed in them within a short time after deposition. If so, the tectonic features imposed on the region in Cenozoic time probably had little or no influence on petroleum accumulation in Permian or older source beds.

GROUND WATER

The ground-water resources of the region received little attention in this investigation. The best account of the water resources of the area is that of Richardson,[85] published in 1904. These resources deserve further study because, aside from water supplies that can be collected in surface storage tanks, ground waters constitute the only source of water for the inhabitants of the area.

[85] Richardson, G. B., Reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, pp. 86–92, 1904.

Ground water is fairly abundant along the southeast base of the Guadalupe Mountains, and comes to the surface in numerous springs. The largest and most numerous lie within a mile or so of the southeastern base of the Guadalupe Mountains and issue from sandstones of the Delaware Mountain group or the gravels that cover them. They include Pine Spring, Upper Pine Spring, Manzanita Spring, and many smaller ones. Their water is derived from the high Guadalupe Mountains to the northwest, where the rainfall is greater than in surrounding areas. Migration of the water from the mountains to the points where the springs issue is accomplished in several ways. Some of it probably moved down through joints in the limestone and sandstone, for the north-northwesterly joint set is prominently developed near the springs and extends toward them down the slope of the mountains.

Other springs some miles to the southeast of the Guadalupe Mountains issue from the base of the gravel sheet that overlies the sandstone, and their water may have traveled through the gravel from the foot of the Guadalupe Mountains. The largest of them is Independence Spring, about 5 miles east of the mountains and near the southeast edge of the gravel sheet. Only a few wells have been put down in this area, and it is not known whether additional supplies can be obtained by more wells.

Several springs issue from the west side of the Guadalupe Mountains, whose water is derived also from the mountains. The largest of them is Bone Spring, west of Guadalupe Peak. It issues from sandstone a little above the Bone Spring limestone, and its water is no doubt brought to the surface by following the top of this impervious limestone bed.

Ground water is relatively more abundant in the Salt Basin than in the mountains to the east but is of poor quality, most of it being rather strongly saline and gypseous. Over most of the basin floor it is reached at depths of 30 feet or less, and is being taken out in numerous wells. Many more wells probably can be sunk without depleting the supply. It is unlikely that water of better quality can be discovered in the basin, for the central part of the basin has doubtless been an area of concentration of mineral salts throughout its history as a topographic feature.

Water of better quality probably occurs in the fanglomerates that form bajada slopes along the edges of the basin, especially at the foot of the Guadalupe Mountains. The bajadas stand much higher than the basin floor, and water contained in the deposits is derived from nearby mountains; hence it is unlikely that much concentration of mineral salts has taken place. Abundant supplies of water of this type are found at Van Horn,[86] but they are probably derived from the broad drainage area of Ryan Flat to the south. Nothing comparable to this drainage area exists near the Guadalupe Mountains. Limited supplies might be obtained from the two large areas of alluvial fans at the north and south ends of the Patterson Hills, where rock ridges have caused the drainage to converge. In these areas the rock floor on which the fanglomerates rest is irregular. It is probable that on the mountainward side of the buried rock ridges water has accumulated in the fanglomerates in local reservoirs.

BUILDING STONE

The sedimentary rocks of the southern Guadalupe Mountains include several sorts of stone that are used locally for building purposes. Of them the most distinctive and useful are the even-bedded, flaggy limestones and sandstones that occur in the Delaware Mountain group. These rocks are used in building houses, and in making fences and other structures along the highway. The bed most extensively used is the flaggy limestone that lies between the Rader and Lamar limestone members of the Bell Canyon formation southeast of the mouth of McKittrick Canyon. This bed is about 10 feet thick and crops out over an extensive area. Numerous small quarries have been opened in it by the local residents. At Frijole some of the buildings have been constructed of cobbles of Capitan limestone obtained from the gravels washed out from the mountains.

ROAD METAL

Abundant supplies of road metal are available near the highway that crosses the region. In many places the highway extends across patches of older and younger gravel deposits, but some of them are too coarse to use as road metal and require much screening to remove the larger stones. In places the gravels and other alluvial deposits are strongly impregnated by caliche. The caliche also has been used for surfacing the highway.

SELECTED STRATIGRAPHIC SECTIONS

In the course of the field work, numerous stratigraphic sections were measured, and these sections were of great aid in working out the stratigraphy of the region. However, it appeared that giving any or all of the sections in the text of this report would confuse, rather than aid, the description of the stratigraphy. They were therefore omitted and the reader is referred to plates 6, 8, 13, and 15, on which most of the sections are shown graphically.

The sections are, however, of great value to geologists who might wish to study the stratigraphy in the field, or the fossil collections obtained from the region. It

[86] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Van Horn folio (No. 194), p. 9, 1914.

therefore seems desirable to include in this report some of the sections that are particularly well exposed or contain abundantly fossiliferous zones, or extend across the type localities of formations and members. Thirteen of these sections are given. As here presented, they are considerably revised and condensed from the original field notes.

SECTION 1

Measured on west slope of Cutoff Mountain, beds 1 to 5 on south side of canyon just north of Texas-New Mexico line, the higher beds in the embayment that slopes westward from the summit. Correction has been made for a fault that crosses the embayment. (See pl. 6.)

	Feet
Carlsbad limestone:	
16. Light-gray, fine-grained limestone, weathering white, in 6-inch to 1-foot beds. Forms receding ledges at top of mountain	45
15. Thin-bedded limestone and pinkish sandstone	20
14. Similar to bed 16, forming a cliff	45
13. Basal sandstone member: Buff, fine-grained sandstone in thick, rounded ledges, covered on surface with brown crust. Passes above into platy or pinkish limestone	55
Goat Seep limestone:	
12. Light-gray, fine-grained, dolomitic limestone, weathering white, in beds a few inches to more than a foot thick, with some thick ledges and cliffs, interbedded with fine-grained, pinkish sandstone	165
11. Light-gray, dolomitic limestone in 1-foot beds, in members 10 feet or more thick, interbedded with buff, medium-grained, calcareous sandstone like that below	147
10. Calcareous, medium-grained, buff sandstone, weathering brown, in 2- to 5-foot beds, in part cross-bedded, and with some layers containing molds of fusulinids. Some layers are more calcareous	250
Sandstone tongue of Cherry Canyon formation:	
9. Buff or pink, soft, fine-grained sandstone, in thin beds or blocky layers up to 2 feet thick. Some calcareous beds in upper part. Toward top contains irregular siliceous masses and silicified brachiopods	206
Bone Spring limestone:	
Cutoff shaly member: (type section):	
8. Prominent ledges of drab-gray, fine-grained or dense limestone in 1-foot beds. Some granular beds in lower part contain fragments of crinoid stems and brachiopods. Upper part contains pelecypod imprints. Near middle, soft, platy sandstone and siliceous shale is interbedded	113
7. Platy, black siliceous shale and black shaly limestone, interbedded with black, dense limestone. Shales contain small, spherical limestone concretions	109
6. Black, dense limestone in beds a few inches thick, weathering dove-gray, with some chert bands. Contains *Chonetes* and other brachiopods	11
Victorio Peak gray member:	
5. Upper division: Thin-bedded limestone, forming receding ledges packed with poorly preserved fusulinids and productids. Top forms an even bed	25
4. Gray, fine-grained limestone, in massive beds up to 7 feet thick, forming cliffs above and below, but with a slope near middle. Upper cliff contains chert nodules	217
3. Middle division: Pale buff, fine-grained sandstone in rounded 1-foot ledges, overlain by flaggy, porcelainlike, white limestone	20
2. White, evenly bedded, laminated limestone in 1-foot beds, some of which contain crinoid fragments and small pisolites, forming 10-foot members. Thinner members of buff, fine-grained, calcareous sandstone are interbedded	97
1. Lower division: Gray, fine-grained, somewhat dolomitic limestone in 1- to 6-foot beds. Contains rare, small chert concretions. Thinner beds weather hackly	184
Base concealed.	

SECTION 7

Measured on west slope of Bartlett Peak, ¾ mile north of Shirttail Canyon. Section begins at base of projecting promontory of escarpment. On this escarpment, the lower division of the Victorio Peak gray member could not be measured, as it stands in an inaccessible cliff. The description and thickness of the lower division are therefore taken from section 8, one-quarter of a mile to south. (See pls. 6, 8.)

	Feet
Goat Seep limestone:	
14. Massive, gray dolomite, standing in single cliff, not measured. Top was examined on north slope of Bartlett Peak, where it is a massive, sandy dolomite, containing casts of fossils (locality 7404). Thickness estimated	900
13. Gray, dolomitic limestone in 5-foot beds, interbedded with thick-bedded, sandy dolomite and thin-bedded sandstone. Beds in this part of formation considerably more sandy here than on adjacent ridges	254
Sandstone tongue of Cherry Canyon formation:	
12. Buff, brown, or reddish, fine-grained, thin-bedded sandstone, with some thicker-bedded sandstone and a few calcareous layers	321
Bone Spring limestone:	
Cutoff shaly member:	
11. Dark gray, fine-grained limestone in 6-inch to 1-foot beds, in part cherty, weathering into hackly fragments. Forms poor ledges and rounded slopes	133
10. Black, sandy shale and platy limestone	38
Victorio Peak gray member:	
9. Upper division: Gray limestone in thick, massive beds, standing in cliffs. Near middle is a bed of calcareous sandstone. Top limestone beds contain abundant fusulinids and some brachiopods	186
8. Middle division: Light gray to white calcitic limestone in beds several feet thick, forming slope	77

Bone Spring limestone—Continued *Feet*

Victorio Peak gray member—Continued

7. Lower division: Stands in inaccessible cliff along line of section 7, in steep ledges along line of section 8, where these observations were made. Gray to dark gray, fine-grained, dolomitic limestone in beds several feet thick, containing fossil fragments and widely spaced, large, gray, and buff chert masses. Weathers gray-brown and pitted. Bed of calcareous sandstone 40 feet above base---- 372

Black limestone beds:

6. Black, dense, laminated limestone, weathering gray-brown, in beds a few inches thick, with chert masses. Upper part changes to gray color ---------- 139
5. Light gray to dark gray, granular limestone in beds several feet thick, containing fragments of productids, corals, and crinoids, and occasional chert masses, forming ledges and narrow cliffs. Some interbedded, lenticular, massive, reeflike limestone beds, and occasional beds of black limestone (fossil locality 7689) ---------- 127
4. Dense black limestone in 1-foot beds, with some platy sandy limestone and granular limestone ---------- 147
3. Light gray, granular limestone, containing fragments of crinoids and other fossils, in 1-foot beds, standing in cliff---------- 37
2. Buff, calcareous, fine-grained sandstone in rounded ledges---------- 10
1. Black, fine-grained to dense limestone in 6-inch to 2-foot beds that form even, parallel layers. Weathers gray or gray-brown. Chert concretions in some beds---------- 435

Base concealed.

SECTION 10

Section on north wall of Shumard Canyon. Bed 1 measured on projecting spur on north side of canyon at entrance; beds 2 and 3 along goat trail a few hundred yards to east; bed 4 on west side of hill whose elevation is 6,402 feet; beds 5 and 6 east of hill. Section ends a short distance below top of Brushy Canyon formation. (See pl. 6).

Delawara Mountain group: *Feet*

Brushy Canyon formation:

6. Buff, medium-grained sandstone in 2-foot to 5-foot beds, in part cross-bedded, in part calcareous. Some layers rest on channeled surfaces. Thin-bedded sandstone in middle 112
5. Thin-bedded, buff, friable, fine-grained sandstone with 5-foot bed of medium-grained sandstone near middle. Lies unconformably on limestones below, which rise in a hill to west. Lower sandstones dip 30° off the hill, but dips flatten in higher beds to east------ 105

Bone Spring limestone:

Victorio Peak gray member:

4. Upper division: White to light gray, fine-grained, calcitic limestone, in beds several feet thick, with no chert. Weathers to blue-gray, slightly pitted surfaces. Some beds contain abundant brachiopods (locality 7690). Rests with sharp contact on beds beneath. Thickness on south side of ridge appears to be greater than that given, on account of low south dip---------- 165
3. Lower division: Gray-brown; fine-grained, dolomitic limestone, weathering to drab, pitted surfaces. Contains large spherical concretions and knotted masses of chert, which are less abundant above. Beds range in thickness from a few inches to 5 feet, the thicker beds forming ledges, cliffs, and serrated walls. Occasional fossils---------- 427

Black limestone beds:

2. Black, fine-grained to dense limestone in 3-inch to 1-foot beds, with irregular black and brown chert nodules and some interbedded platy layers. Somewhat thicker-bedded above. Beds are truncated at several horizons. Fossil locality 7712 is 300 feet above base---------- 385
1. Black, fine-grained to dense limestone, weathering gray or gray-brown, in 3-inch to 1-foot beds, with some knotted chert bands. Two members in lower half up to 30 feet thick of platy, shaly black limestone and sandy limestone. Rock is divided into slices 30 feet or more thick, each of which truncates underlying slice, and each with different dip, which in some slices reaches a maximum of 20°---------- 332

Base concealed.

SECTION 11

Measured up spur that projects southwestward from Shumard Peak, east of upper end of section 10. Only upper part (above Brushy Canyon formation) is given here; it begins on south side of spur, ½ mile south-southwest of summit of Shumard Peak. (See pl. 6.)

Capitan limestone: forming cliffs at top of section. *Feet*

Delaware Mountain group:

Bell Canyon formation:

Hegler limestone member:

18. Thin- to thick-bedded or massive, light gray or white limestone, with some chert, interbedded with calcareous sandstone ---------- 121
17. Thin-bedded to massive, buff, calcareous sandstone, with some limestone lenses- 36
16. Thin- to thick-bedded, gray or white limestone, with chert seams and some interbedded sandstone. Contains *Spirifer*, *Domopora*, and small productids. Forms cliff ---------- 45

Cherry Canyon formation:

15. Massive, buff sandstone---------- 15
14. Manzanita limestone member: Gray-buff, fine-grained limestone in beds a few inches thick, weathering yellow-brown. Contains irregular chert masses and geodic cavities. Pinches out a short distance to north----- 14

	Feet
Delaware Mountain group—Continued	
Cherry Canyon formation—Continued	
13. Soft, greenish-gray sandstone, weathering buff, in rounded ledges	42
Goat Seep limestone (marginal facies, transitional into Cherry Canyon formation):	
12. Buff, fine-grained limestone forming cap of projecting spur	15
11. Soft sandstone	10
10. Blue-gray to buff limestone, in 6-inch to 1-foot beds, containing a few small chert masses and a *Gastrioceras*	24
9. Buff, fine- to medium-grained, laminated sandstone in beds several inches thick, weathering brown. Interbedded in lower part with gray dolomitic limestone in 2-foot beds	120
8. Gray, fine-grained, dolomitic limestone, weathering to smooth, white surfaces, containing fusulinids, crinoid stems, and flat pebbles. Forms thick, lenticular beds, interbedded with sandstone. Several beds rest on channeled surfaces. Passes upward into interbedded, thin-bedded limestone and sandstone	115
7. Buff, brown-weathering, medium-grained sandstone in beds a few inches thick, with some interbedded limestone	59
6. Gray, fine-grained, dolomitic limestone, in lenticular massive beds, containing sandy streaks, breccia, and fusulinids	29
5. Medium- to fine-grained, laminated sandstone, weathering brown	13
4. Platy, dense, gray limestone, weathering white	8
3. Buff, thin-bedded, fine-grained sandstone, with some shaly sandstone below	142
2. Fine-grained, dolomitic limestone, weathering drab, in beds several feet thick, containing poorly preserved fusulinids and crinoid stems. Some thinner beds at top. Member thins out to north and south, but interfingers with main mass of Goat Seep limestone north of Shirttail Canyon	22
Cherry Canyon formation:	
1. Buff, thin-bedded, fine-grained sandstone, with 15-foot bed of hard, platy sandstone in lower part	203
Brushy Canyon formation: Thick ledges of medium-grained sandstone at base.	

SECTION 14

Measured along north side of Bone Canyon. Beds 1 and 2, constituting section 14–a, measured up north wall of canyon at its entrance; beds 3 to 11 measured up north wall of canyon one-quarter mile to east; higher beds measured on spur on north side of waste-covered embayment at head of canyon, starting at Bone Spring and ending on bench at foot of Capitan limestone cliff one-quarter mile west of Guadalupe Peak. (See pls. 6, 13.)

	Feet
Capitan limestone: Massive white limestone, extending in cliffs up to summit of Guadalupe Peak.	
Delaware Mountain group:	
Bell Canyon formation:	
Hegler limestone member:	
37. Thin-bedded, white limestone	40
36. Yellow-brown, massive sandstone	15
35. Blue-gray, dense limestone in 1-foot beds, with some chert nodules and bands, interbedded with thin layers of buff sandstone and calcareous sandstone	137
34. Thick-bedded, blue-gray, cherty limestone in prominent ledges and cliffs	56
Cherry Canyon formation:	
33. Massive, greenish-buff, fine-grained sandstone with faint laminations, weathering brown or reddish	52
32. Manzanita limestone member: Dense, calcarous sandstone in beds a few inches thick, weathering yellow, and standing in ledges and cliffs. Interbedded with thin-bedded, friable, greenish sandstone. Near middle, a 1-foot bed of green chert	99
31. Massive, greenish-gray, fine-grained sandstone	44
South Wells limestone member:	
30. Buff, sandy, cherty limestone in beds up to 1 foot thick, interbedded with buff sandstone	23
29. Buff, thin-bedded, fine-grained sandstone	28
28. Hard, dense, calcareous sandstone in beds a few inches thick, weathering buff. Contains geodic cavities, and molds of ammonoids	4
27. Buff, thin-bedded, fine-grained sandstone	66
26. Laminated, gray or buff, sandy limestone in 3-inch to 6-inch beds, interbedded with gray, platy, shaly sandstone. Forms ragged ledges	44
25. Buff, thin-bedded, fine-grained, laminated sandstone	148
Getaway limestone member:	
24. Drab, dense, flaggy limestone, interbedded with shaly sandstone	19
23. Buff to drab, sandy, dolomitic limestone in a single massive, lenticular bed. Contains pebbles in lower part, and poorly preserved fusulinids	11
22. Thin-bedded, buff, fine-grained sandstone	24
21. Gray, dense or fine-grained limestone, weathering drab, in beds a few inches to several feet thick	46
20. Buff, thin-bedded, laminated, fine-grained sandstone interbedded in upper part with dark shaly sandstone and flaggy, calcareous sandstone. Some channeling	170
Brushy Canyon formation:	
19. Buff, medium-grained, quartzitic sandstone, weathering brown and forming a prominent ledge. Rests on channeled surface	10
18. Thin-bedded, buff sandstone, with a layer of dark shaly sandstone near middle	314

	Feet
Delaware Mountain group—Continued	
Brushy Canyon formation—Continued	
17. Dark, shaly, platy sandstone, with some interbedded buff sandstone, forming prominent ledges	72
16. Buff, thin-bedded, fine-grained sandstone	72
15. Three ledge-making layers up to 10 feet thick, of dark, shaly, platy sandstone, separated by buff, thin-bedded, fine-grained laminated sandstone	115
14. Buff, thin-bedded, fine-grained, laminated sandstone, becoming a little thicker-bedded above	145
13. Dark, shaly, platy sandstone, interbedded with some buff sandstone, forming prominent bench	28
12. Buff, thin-bedded, fine-grained sandstone	50
11. Massive, buff, medium-grained sandstone, in part calcareous. Changes into platy sandstone to east, where it crops out near Bone Spring	6
10. Thin-bedded sandstone	5
9. Massive, buff, medium-grained sandstone, in part calcareous, containing fusulinid casts and ripple marks	22
8. Conglomerate of limestone pebbles in a calcareous sandstone matrix	6
7. Sandy, gray or gray-brown limestone in beds several feet thick, with some quite sandy layers and a conglomerate lens near middle	33
6. Buff, medium-grained, laminated sandstone in 3-inch to 2-foot beds	21
5. Conglomerate of limestone pebbles in a calcareous sandstone matrix	4
4. Buff, medium-grained sandstone in 6-inch to 1-foot beds; some cross bedding	12
3. Conglomerate of limestone pebbles and cobbles in a sandy limestone matrix. Some interbedded dolomitic sandy limestone that disappears into the conglomerate to northwest Rests unconformably on Bone Spring limestone, whose top bed is here a lens of massive gray limestone, resting on black limestone	16
Bone Spring limestone (type section):	
Black limestone beds:	
2. Ledges more prominent than below, of black limestone in 6-inch to 1-foot beds, with some chert. Near middle are lenticular beds of black, fine-grained limestone, containing crinoid stems and other fossil fragments	264
1. Black, dense limestone, weathering buff or gray, in well-laminated beds, in part platy, in part several inches thick. Some chert bands and some interbedded shaly or sandy limestone. Some irregular dips and truncation of beds. Forms irregular ledges and bluffs	257
Base concealed.	

SECTION 18

Measured up south slope of El Capitan. Bed 1 measured near outer edge of escarpment on south bank of next canyon north of Indian Cave, or 2 miles southwest of El Capitan; beds 2 to 10 up west slope of butte 1½ miles south of El Capitan; beds 11 to 20 farther north along same ridge, starting 1 mile south of El Capitan and proceeding up to great sandstone bench; higher beds on slope southeast of El Capitan, starting at top of sandstone bench and proceeding up to base of cliffs. (See pl. 6.).

	Feet
Capitan limestone:	
42. Massive limestone, with faint, inclined bedding planes, extending to top of cliff.	
43. Massive white limestone, interbedded with thin-bedded, white limestone, containing large limestone lenses	25
Delaware Mountain group:	
Bell Canyon formation:	
40. Thin-bedded white limestone	15
39. Soft, greenish-gray sandstone, parts of which weather red, with some interbedded white limestone	30
Pinery limestone member:	
38. Dark gray, fine-grained, somewhat lumpy, thin-bedded limestone. Some thicker layers	33
37. Light to dark gray, fine-grained or dense limestone in 3-inch to 1-foot beds. Stylolites prominent in places	49
36. Gray to dark gray, fine-grained limestone in 6-inch to 1-foot beds, in part cherty, interbedded with layers of massive, granular, gray, fossiliferous limestone up to 5 feet thick	52
35. Gray, granular limestone in massive beds, containing silicified fossils and some chert masses	32
34. Buff, thin-bedded sandstone, interbedded with dense, dark gray, flaggy limestone	36
33. Hegler limestone member: Gray, fine-grained, lumpy, slabby limestone, with some traces of fossils, in two ledges, separated by pale, greenish-gray sandstone	15
Cherry Canyon formation:	
32. Soft, pale greenish-gray, thin-bedded sandstone	65
31. Manzanita limestone member: Pale buff or gray sandstone and sandy limestone in blocky, rounded ledges, weathering orange-brown, part of it full of geodic cavities. Several layers of apple-green, siliceous shale and bentonitic clay	63
30. Massive, greenish-gray, fine-grained sandstone, without bedding planes	44
29. Buff, thin-bedded, fine-grained sandstone, with some 1-foot beds, and occasional thin, discontinuous layers of dark, platy, shaly sandstone	369
28. Black, dense, drab-weathering limestone in 6-inch to 1-foot beds, with some ammonoid imprints, interbedded with platy sandstone	27
27. Thin-bedded, buff, fine-grained sandstone with some 6-inch beds	70

	Feet
Delaware Mountain group—Continued	
Cherry Canyon formation—Continued	
Getaway limestone member (very poorly developed):	
26. Hard, platy, calcareous and quartzitic sandstone, forming bench	10
25. Buff, fine-grained, thin-bedded sandstone, with thin beds of black sandy limestone and gray, hard, platy sandstone	109
24. Black, dense, sandy limestone, weathering brown, and gray platy sandstone. Forms bench	6
23. Buff, thin-bedded, fine-grained sandstone, with some dark gray, platy, shaly sandstone	115
22. Two 6-inch beds of brown, sandy, flaggy limestone, separated by thin-bedded sandstone	23
21. Buff, fine-grained, thin-bedded sandstone, with some harder, platy beds	99
Brushy Canyon formation:	
20. Calcareous sandstone, similar to bed 19. Cross-bedded and lenticular, with thin zones of conglomerate and casts of fusulinids	36
19. Massive, very prominent ledge, forming projecting bench about halfway up mountainside toward El Capitan. Consists of medium-grained, buff sandstone, weathering brown, in beds several feet thick. Rests on channeled surface	85
18. Fine to medium-grained buff sandstone in beds a few inches to several feet thick, with some platy beds at base	96
17. Buff, fine-grained, thin-bedded sandstone, with some platy beds in lower part	272
16. Medium-grained, buff sandstone in beds several feet thick, weathering brown, forming prominent ledge	18
15. Buff, fine-grained, thin-bedded sandstone, with some thicker beds	65
14. Thick-bedded, medium-grained, brown sandstone and some platy sandstone, forming prominent ledges	9
13. Buff, thin-bedded, fine-grained sandstone, with some thicker beds, interbedded below with gray, platy or papery sandstone, which projects in ledges	34
12. Buff, thin-bedded, fine-grained sandstone	90
11. Buff, thin-bedded, fine-grained sandstone, interbedded with hard, gray, platy sandstone, which forms well-marked ledges at top	71
10. Fine-grained, hard, platy sandstone, weathering brown, with some quartzitic beds at top. Forms prominent ledges at top of bench. Changes into massive, medium-grained sandstone to south, on hill 5087	20
9. Dark-gray, platy, shaly sandstone, interbedded with buff, thin-bedded sandstone	81
8. Buff, thin-bedded, fine-grained sandstone	31
7. Medium-grained buff sandstone in beds several feet thick, with ripple marks. Forms ledge	17
6. Buff, thin-bedded, fine-grained sandstone, with some shaly sandstone below	54
5. Fine- to medium-grained buff sandstone, forming ledges above and below	38

	Feet
Bone Spring limestone:	
Cutoff shaly member:	
4. Thin-bedded, buff, fine-grained sandstone with a 1-foot bed of granular, fossiliferous limestone in middle	40
3. Medium-grained buff sandstone in beds several feet thick	5
2. Black, calcareous, papery shale, containing spherical limestone nodules an inch to a foot across	12
Black limestone beds:	
1. Black limestone, mostly thin-bedded, cropping out in irregular ledges and bluffs, separated by slopes. Most of beds are a few inches to a foot thick, part are evenly bedded and laminated, others are lumpy, knotted, or even markedly lenticular. Near middle are lenses a foot or more thick containing silicified bryozoans. Lower beds are papery or platy, and in part sandy. Some contortion of beds and slickensiding on bedding planes	242
Base concealed.	

SECTION 21

Measured on hillside above Pine Spring, starting at the level of the spring and proceeding up the slope to the base of the Capitan limestone. (See pls. 6, 15.)

	Feet
Capitan limestone:	
19. Massive white to gray dolomitic limestone, extending up to crest of Pine Top Mountain.	
18. Massive, white dolomitic limestone in pinching and swelling beds up to 8 feet thick, interbedded with white limestone in beds a few inches thick	25
Delaware Mountain group:	
Bell Canyon formation:	
17. Light-gray, granular limestone in beds several feet thick, containing some brachiopods (fossil locality 7702)	12
16. Buff, fine-grained, thin-bedded sandstone, interbedded with dark-gray, platy, shaly limestone, and with fine-grained, gray limestone. The last forms 1-inch to 6-inch beds, in part laminated, and contains chert and some fossils	50
15. Buff, fine-grained, thin-bedded sandstone	23
14. Gray, fine-grained limestone in beds several feet thick, containing chert lenses	12
13. Buff, fine-grained, thin-bedded sandstone, interbedded with dark-gray, fine-grained, slabby limestone	55
Pinery limestone member (type section):	
12. Soft, buff, sandstone, interbedded with 1-foot beds of gray fossiliferous limestone	10
11. Fine-grained, dark-gray limestone in beds a few inches thick, containing fossils in some beds	32
10. Light-gray, granular limestone in a single massive bed	10
9. Light-gray, coarse- to medium-grained limestone, with some cherty lenses, in beds 2 feet or more thick, interbedded with slabby limestone	26

Delaware Mountain group—Continued	*Feet*
Bell Canyon formation—Continued	
Pinery limestone member—Continued	
8. Dark-gray, fine-grained limestone in beds a few inches to a foot thick, in part laminated, containing chert nodules and bands. *Polydiexodina* and a few other fossils (fossil localities 7703 and 7917)	36
7. Light-gray, coarse-grained limestone in irregular, lenticular beds several feet thick, ending above in a very massive ledge. Contains small chert masses and numerous silicified fossils including *Coenocystis*, *Domopora*, and small brachiopods (localities 7477 and 7420)	22
6. Fine-grained, gray limestone in straight beds a few inches thick, containing small chert masses, interbedded with sandstone	15
5. Buff, fine-grained sandstone, with some thin layers of lumpy limestone	17
4. Hegler limestone member: Dark-gray, fine-grained limestone in lumpy or nodular beds a few inches thick, forming two sets of ledges, separated by sandstone that forms a a slope in middle. Winding trails on bedding surfaces and some poorly preserved ammonoids	15
Cherry Canyon formation:	
3. Friable, fine-grained, pale-buff sandstone	25
2. Manzanita limestone member: Pale-buff, calcareous sandstone and sandy limestone in 3-inch to 8-inch beds, weathering orange-brown and to blocky fragments; some beds contain geodic cavities. Contains two beds, each a foot or more thick, of apple-green chert or siliceous shale (altered volcanic ash), the first 18 feet above, and the second 30 feet above the base	55
1. Buff, fine-grained sandstone in beds a few inches thick, weathering into slabs. Contains faintly marked, dark laminations. Best exposed in middle third	111
Base of slope, at level of spring.	

SECTION 23

Measured at head of Rader Ridge. Beds 1 to 7 measured on south side of ridge 1¼ miles west of Hegler Ranch; beds 8 to 23 on south side of ridge ½ mile farther west, but with some additional notes from first locality; higher beds measured on top of ridge, proceeding northwestward up face of escarpment. All beds above 23, and notably the sandstones of beds 25 and 27, interfinger or intergrade northwestward with massive Capitan limestone, which is exposed throughout the interval in the adjacent ravines. (See pls. 6, 15.)

	Feet
Capitan limestone: Thick-bedded to massive dolomitic limestone, extending to top of escarpment.	
Delaware Mountain group:	
Bell Canyon formation:	
Lamar limestone member:	
29. Platy, gray, fine-grained limestone, in part laminated, containing numerous fossils in cross section. Dips 15 to 30 degrees southeastward, down the ridge. Corrected for dip	50
28. Massive dolomite, in part sandy, with dip of about 15 degrees down the ridge	75
27. Buff, medium-grained, friable sandstone, similar to bed 25. Sandy dolomite interbedded in middle	80
26. Dark gray, fine-grained, laminated, slabby limestone, and thick-bedded, sandy dolomite, in part pebbly	23
25. Buff, medium-grained, friable sandstone, in part cross-bedded, in rounded ledges, with a layer of brown, sandy dolomite in middle	68
24. Buff, massive dolomitic limestone, interbedded with platy limestone and sandstone	36
23. Dark gray, fine-grained, granular limestone in slabby beds, containing fusulinids and bryozoans, interbedded in middle with lighter gray, thicker-bedded limestone and dolomitic limestone (locality 7360)	64
Rader limestone member (type section):	
22. Fine-grained, gray limestone in 6-inch to 1-foot beds, with some interbedded massive layers of light-gray limestone	28
21. Light gray to white, granular to dense limestone, containing silicified bryozoans and some small chert masses, forming massive, lenticular beds which weather into two sets of rounded cliffs. Parts contain angular cobbles and pebbles of limestone. Some interbedded lenses of thin-bedded white limestone. Rests irregularly on bed below (locality 7668)	58
20. Light gray, fine-grained limestone in 6-inch to 1-foot beds, containing silicified fossils	4
19. Soft, platy sandstone, with some thin limestone beds	19
Pinery limestone member:	
18. Fine-grained, light-bray limestone, beds several feet thick, containing some chert, passing into thinner-bedded, darker-gray limestone toward top. Forms ledges	16
17. Dark gray, fine-grained limestone, in part laminated, in part lumpy, in 3-inch to 8-inch beds, with some chert. Near middle, a 5-foot bed of massive, light gray, granular limestone	50
16. Brown, fine-grained, platy sandstone, interbedded with dark gray, fine-grained, well-laminated limestone, in beds a few inches thick. Contains fossils at top of ridge 1¼ miles west of Hegler Ranch (locality 7705)	53
15. Light gray, granular limestone in beds up to 3 feet thick. Forms bench	15
14. Fine-grained, gray to dark-gray limestone in 3-inch to 1-foot beds, containing nodules and bands of chert	12

	Feet
Delaware Mountain group—Continued	
Bell Canyon formation—Continued	
13. Buff to greenish, fine-grained, soft sandstone, interbedded with dark-gray, laminated limestone in beds a few inches thick	32
12. Hegler limestone member: Dark gray, fine-grained limestone in lumpy, slabby beds a few inches thick, projecting in two ledges, separated by a slope of sandstone. Contains poorly preserved ammonoids at nearby localities on the ridge	16
Cherry Canyon formation:	
11. Buff, fine-grained, thin-bedded sandstone	33
Manzanita limestone member:	
10. In section to east, a buff calcareous sandstone like bed 8; in section to west, a lumpy gray limestone like bed 12	3
9. Buff, soft, fine-grained sandstone	9
8. Gray, fine-grained, sandy limestone, containing geodic cavities, in 2-inch to 6-inch beds. Some bedding planes are knobby. Weathers blocky and orange brown. Interbedded with soft, thin-bedded, fine-grained sandstone. In section to east, contains 1-foot bed of apple green chert 45 feet above base	61
7. Massive, pale greenish, fine-grained sandstone in rounded ledges, with some thin-bedded sandstone	38
6. Buff, thin-bedded, fine-grained, friable sandstone	21
5. Thin-bedded, fine-grained, calcareous buff sandstone, in part standing in rounded ledges, containing poorly preserved fusulinids in places	15
South Wells limestone member:	
4. Massive gray dolomite in thick beds, containing flat, angular pebbles and abundant, poorly preserved fossils. Weathers to gray-brown, jagged surfaces. Interbedded with flaggy, laminated gray, dolomitic limestone	22
3. Buff sandstone	5
2. Fine-grained, laminated, buff, sandy dolomite in 1-foot beds, overlain by massive ledge of sandy dolomite which weathers to jagged surfaces	7
1. Buff, thin-bedded, fine-grained sandstone	38
Base of slope.	

SECTION 28

Measured on south side of McKittrick Canyon at its entrance. Beds 1 to 3 measured along the stream channel; beds 4 to 5 up slope of projecting bench; beds 6 to 7 up slope above the bench toward Capitan limestone escarpment. (See pl. 6.)

	Feet
Capitan limestone:	
7. Light gray, somewhat dolomitic limestone, containing occasional *Squamularia* and *Composita*, with poorly developed bedding planes, forming rounded ledges. Beds rise northwestward up slope of peak. Probable maximum thickness is	100
Delaware Mountain group:	
Bell Canyon formation:	
Lamar limestone member:	
6. Light gray, fine-grained limestone in 1-foot to 3-foot beds, with some interbedded sandy limestone	40
5. Dark gray, fine-grained or dense limestone in beds a few inches thick, interbedded with some sandstone in lower part, and higher up with many beds 1 to 5 feet thick of lighter gray, granular limestone, containing abundant silicified and somewhat fragmented fossils. These are mostly brachiopods, nearly all of which are Capitan species (locality 7401). Upper few feet are slabby or nodular. Forms steep cliff, top of which is a flat bench that exposes some of fossiliferous layers. Changes into massive Capitan limestone a few hundred yards up the canyon to northwest	130
4. Pale brown or yellowish, fine- to medium-grained sandstone in thin to thick beds. A few thin limestone layers interbedded. This and bed 3 interfinger abruptly with massive Capitan limestone a few hundred yards up the canyon	140
3. Thin-bedded, laminated, dark-gray limestone, resting on channeled surface of sandstone below, so that it thickens and thins on the eroded surface. Some beds have thin trail marks on their upper surfaces. Some bedding surfaces are wavy. Several lenses of granular, fossiliferous limestone are interbedded, which contain brachiopods and bryozoans (locality 7608)	10
2. Brown, fine-grained sandstone in slabby beds, with ripple marks on many bedding surfaces. Bedding is irregular, with dips in various directions and some channeling	35
1. Gray, dolomitic limestone in lenticular, massive beds a few feet to 15 feet thick, forming bouldery ledges. Contains some brachiopods. Interbedded are layers of white or gray, laminated limestone in beds a few inches to several feet thick, and some darker-gray, more granular limestone, full of fossil fragments (locality 7708). Downstream, near where bed dips beneath channel, it becomes more regularly bedded, with fewer thick layers, and is interbedded with sandstone in upper part	50
Sandstone beneath, exposed farther northwest, up the canyon.	

SECTION 33

Section west of Guadalupe Summit radio station. Starts at base of Delaware Mountain escarpment in ravine on north side of projecting spur that is capped by a turretlike remnant of limestone. Proceeds up escarpment to radio station at top.

	Feet
Delaware Mountain group:	
Cherry Canyon formation:	
Getaway limestone member:	
25. Buff sandstone, with several layers of dark gray, granular limestone, containing fusulinids. Top limestone bed forms summit of escarpment	19
24. Dark gray, fine- to medium-grained limestone, in part well laminated, in beds up to 1 foot thick, with a 2-foot ledge of very granular, black, fossiliferous limestone in middle (fossil locality 7463). Forms ledges	52
23. Platy sandstone and limestone	5
22. Dark gray, irregularly bedded limestone, in part thinly laminated, in part massive, with some granular, fossiliferous lenses (locality 7474). Forms ledges	16
21. Platy sandstone, with 1-foot bed of conglomeratic limestone in middle	22
20. Dark gray to black, fine-grained to dense, well-laminated limestone, in 1-inch to 1-foot beds	15
19. Thin-bedded sandstone, in part papery and shaly, with 1-foot bed of fine-grained, dark gray limestone in middle	19
18. Several beds up to 5 feet thick of very massive, granular, dark gray, sandy limestone, containing pebbles, fusulinids, and other fossils. Weathers to rough, brown-colored surface. Interbedded with thicker layers of black, papery limestone and sandy limestone	29
17. Platy buff sandstone, containing thin limestone lenses	18
16. Medium-grained sandstone in 1- to 2-foot beds, weathering brown	6
15. Mostly buff, fine-grained sandstone, with some interbedded platy sandstone. In lower part are several beds up to 10 feet thick of sandy, friable limestone, crowded with fusulinids, but also containing crinoid stems and brachiopods, mostly somewhat water worn (locality 7423). Member rests on channeled surface of lower division, and thins northward and southward by overlap	100
Brushy Canyon formation:	
14. Medium-grained sandstone, forming brown, massive ledges, containing some fusulinids. Higher beds of this member are present nearby, beneath erosion surface	10
13. Dark gray, platy, shaly sandstone, with some thicker beds of ripple-marked sandstone	6
12. Buff, fine-grained sandstone in beds a few inches thick, forming rounded ledges or slopes, with some thin beds of platy, shaly sandstone, and a few layers containing fusulinids	66
11. Dark gray, platy, shaly sandstone	6
10. Buff, medium-grained sandstone in beds several feet thick, forming massive ledges, and weathering brown. Some beds contain fusulinids (locality 7920)	5
Delaware Mountain group—Continued	
Brushy Canyon formation—Continued	
9. Black, platy, shaly sandstone	4
8. Buff, fine-grained, thin-bedded, laminated sandstone	38
7. Dark gray to black, platy or papery, shaly sandstone, standing in ledges	6
6. Buff, fine-grained sandstone in beds a few inches to a foot thick, in part laminated, with ripple marks on some bedding surfaces, interbedded with black, shaly sandstone, especially toward top	36
5. Fine- to medium-grained buff sandstone in beds several feet thick, with some thinner partings, forming great rounded ledges in upper half which extend for long distances along escarpment. Some fusulinids in lower part	59
4. Buff, fine-grained, thin-bedded, laminated sandstone, with some calcareous beds in lower part	10
3. Massive sandstone in prominent ledges; buff, medium-grained, friable, weathering brown, in beds several feet thick. Top part is a calcareous sandstone, containing some sandstone pebbles, and crowded with calcareous tests of fusulinids	21
2. Dark gray, well laminated, shaly sandstone, passing upward into black, hard, papery, sandy shale	3
1. Gray, fine-grained, friable sandstone in 1-inch to 6-inch beds, weathering buff. Marked by light and dark laminae a few millimeters apart, suggestive of varves. Some thinner bedding in upper part	62
Base of section cut off by fault.	

SECTION 34

Section along and northeast of Lamar Canyon near old route of U. S. Highway 62. Beds 1 to 9, or section 34–a, measured on south side of Lamar Canyon 3 miles east of Hegler Ranch, ending on top of butte 1 mile east-northeast of B. M. 4923. Section of higher beds begins 1 mile to northeast, near crossing of highway over Bell and Lamar Canyons, and proceeds north-northeastward to top of limestone cuesta 1½ miles distant. (See pl. 6.)

	Feet
Castile formation:	
20. Dark gray, papery, very thinly laminated sandstone. Elsewhere passes up into laminated anhydrite, within a few feet. Here it is overlain by older Quaternary gravel	2
Delaware Mountain group:	
Bell Canyon formation:	
19. Platy, brown-weathering, fine-grained sandstone, forming scattered remnants at top of cuesta	26
18. Lamar limestone member: Gray to dark-gray, fine-grained limestone, mostly in beds a few inches thick, with some thicker layers. Weathers gray-brown and to rather rough surfaces. Some beds contain small chert nodules. Bedding planes undulatory, some	

	Feet
Delaware Mountain group—Continued	
Bell Canyon formation—Continued	
layers lenticular, and some appear to be contorted. Thin partings of platy sandstone in lower part. Forms rim of prominent line of cuestas	30
17. Massive, buff sandstone with some faint laminations. Bedding planes widely spaced and mostly very smooth. One, however, shows faint ripple marks, and in places the laminae are cross-bedded. Overlain with sharp contact by Lamar member. Crops out in prominent ledges and rocky buttes, bare of vegetation	138
16. Platy, brown-weathering sandstone, underlying broad valley and poorly exposed. Thickness corrected for dip	160
15. Flaggy limestone bed: Hard, fine-grained limestone, in part sandy, in straight, even beds a few inches thick, making four or five layers, interbedded with sandstone	10
14. Platy, brown-weathering sandstone	10
13. Buff, fine-grained sandstone, thin-bedded in lower half, in upper half standing in massive, rounded ledges several feet thick	90
Rader limestone member:	
12. Thin beds of gray limestone, interbedded with platy sandstone	5
11. Buff, fine-grained sandstone, thin-bedded below, passing upward into rounded ledges several feet thick	33
10. Thin-bedded, fine-grained limestone, overlain by thick ledge of light-gray, granular, conglomeratic limestone, containing fossil fragments (locality 7600 at top of section 34–a). At base, a bed of apple-green chert is locally developed	8
9. Buff, fine-grained, thin-bedded sandstone, forming thick, rounded ledges at top. Ripple marks in bed of Bell Canyon nearby	30
8. Pinery limestone member: Dark gray, laminated limestone in beds several inches thick, with some chert bands, interbedded with sandstone in upper part. Several ledges of lighter gray, more granular limestone up to 3 feet thick, containing fossils. In section to northeast, limestones are all thin bedded, and there is much more sandstone	47
7. Fine-grained, yellowish sandstone in thin or platy beds	54
6. Hegler limestone member: Dark gray, dense, laminated limestone in beds several inches thick, with some chert bands, interbedded with platy sandstone. Contains three beds up to 2 feet thick of gray, granular, cherty limestone, with pebbles and silicified fossils (locality 7601)	37
Cherry Canyon formation:	
5. Soft, pale buff, platy sandstone, weathering brown	14
Manzanita limestone member:	
4. Fine-grained, sandy limestone, weathering brown, in beds up to 1 foot thick, interbedded with sandstone	12
3. Fine-grained, pale-yellow sandstone in massive, rounded ledges with thinner-bedded sandstone below	35
Delaware Mountain group—Continued	
Cherry Canyon formation—Continued	
Manzanita limestone member—Continued	
2. Pale buff, compact, sandy limestone and calcareous sandstone in 2-inch to 1-foot beds, weathering brown, and containing geodic cavities. Some ammonoid casts. Interbedded with soft, buff sandstone, and with 3 or 4 thin beds of green, bentonitic clay	38
1. Fine-grained, pale-yellow sandstone in massive, rounded ledges. Below base of section is some interbedded dark shaly sandstone	32
Lower beds, exposed farther northwest up Lamar Canyon, not measured.	

SECTION 40

Getaway Gap section. Beds 1 and 2 measured in channel of Getaway Canyon, starting at fault at west end of gap. Higher beds measured up south wall of canyon a few hundred yards east of its western end. (See pl. 6.)

	Feet
Delaware Mountain group:	
Cherry Canyon formation:	
Getaway limestone member (type section):	
19. Platy gray limestone, forming rim of canyon	3
18. Platy buff sandstone, quartzitic above	10
17. Granular, conglomeratic, fossiliferous limestone, interbedded with sandstone	8
16. Buff, platy sandstone	14
15. Granular limestone, containing fusulinids, passing up into platy limestone	5
14. Platy sandstone in beds up to 5 feet thick, interbedded with three layers a foot or more thick of granular, somewhat conglomeratic limestone	25
13. Granular, dark gray to black limestone, full of fusulinids and other fossils, in lenticular, irregular ledges. Some beds contain limestone pebbles	18
12. Buff, platy sandstone with some thin limestone beds	8
11. Dark gray to black, granular to dense limestone, some of which contains abundant fossils, in lenticular beds up to several feet thick, but with platy beds between. Forms ledges	16
10. Platy or papery sandstone, containing sandy limestone nodules, and with two beds of granular, conglomeratic limestone	52
9. Gray, granular limestone, crowded with fusulinids and crinoid stems, with numerous limestone cobbles and pebbles in lower part. Rests on channeled surface. To southwest, around hill, thickens to ten feet (fossil locality 7632 at latter place)	4
8. Buff, thin-bedded, fine-grained sandstone in beds up to 4 feet thick, interbedded with dark gray, papery, shaly sandstone, and with 2 beds of nodular limestone	21
7. Buff, thin-bedded, fine-grained sandstone, with two beds of nodular limestone in upper part	23
6. Dark gray, sandy limestone, forming nodular bed	1

	Feet
Delaware Mountain group—Continued	
Cherry Canyon formation—Continued.	
5. Buff, fine-grained, thin-bedded sandstone, interbedded with dark gray, shaly sandstone in middle. Some channeling at base	22
4. Gray, thinly laminated limestone in nodular bed	1
3. Buff, fine-grained, friable sandstone in beds a few inches thick, marked by thin, dark laminae, with a bed of dark gray, platy, shaly sandstone in middle	26
2. Mostly covered in flood plain and lower slopes of valley. Some exposures of buff, fine-grained, platy sandstone, and of darker, shaly beds. Some beds ripple-marked	41
Brushy Canyon formation:	
1. Reddish-brown, quartzitic, medium-grained sandstone	6

Lowest beds exposed; cut off by fault to west.

SECTION 42

Section between Pinyon Canyon and Long Point. Parts were measured at several places, as follows: a) beds 1 to 9 on south side of Pinyon Canyon 2¾ miles south-southeast of Getaway Gap, and continuing to hilltops ½ mile to east; b) beds 10 to 16 on south side of Pinyon Canyon 1½ miles west of Long Point, and up slope of butte to south; c) beds 17 to 24 on west slope of Long Point, and beds 25 to 28 on higher hill ¾ mile east of end of point. (See pl. 6.)

	Feet
Delaware Mountain group:	
Bell Canyon formation:	
28. Hegler limestone member: Limestone in 3-inch to 1-foot beds, in part dense, in part finely granular, containing some silicified fossils and chert bands. Interbedded with platy sandstone	33
Cherry Canyon formation:	
27. Hard, platy, brown-weathering sandstone	4
Manzanita limestone member:	
26. Dark gray, lumpy limestone in beds a few inches thick	5
25. Greenish-buff, friable sandstone, forming massive, rounded ledges, but with some thinner beds	62
24. Limestones resembling typical facies of Hegler member as exposed in foothills of Guadalupe Mountains. Gray to dark gray, lumpy limestone, interbedded with greenish, marly sandstone, forming slabby beds a few inches to a foot or more thick. Contains numerous poorly preserved ammonoids. Forms prominent cliff at end of Long Point, but separates elsewhere into several groups of ledges	46
23. Fine-grained, pale-buff or greenish sandstone in massive, rounded ledges, with some thinner-bedded layers. Forms slopes of Long Point	117
22. Platy brown sandstone, poorly exposed above	74

	Feet
Delaware Mountain group—Continued	
Cherry Canyon formation—Continued	
South Wells limestone member:	
21. Dark gray, fine-grained limestone	3
20. Brown, fine-grained, platy sandstone	10
19. Dark gray, granular, sandy limestone, weathering light gray, containing small pebbles and numerous fossils (locality 7641 from this and nearby beds)	6
18. Buff, fine-grained sandstone in beds several inches thick, interbedded with dark shaly sandstone	18
17. Buff, fine-grained, sandy limestone in 1-foot to 2-foot beds, forming rounded ledges. Forms top of section (b) and base of section (c)	6
16. Thin-bedded, fine-grained, buff sandstone, with some interbedded limestone	58
15. Gray, fine-grained, in part sandy limestone, in 6-inch beds, forming a bench	3
14. Thin-bedded to platy, brown-weathering sandstone, with some lenticular beds of limestone, especially in upper part	32
13. Buff, fine-grained sandstone in thick, rounded ledges, bare of vegetation	42
12. Buff, calcareous sandstone in prominent, blocky ledge	3
11. Thin-bedded to platy, fine-grained, buff sandstone weathering brown	59
10. Fine-grained, gray limestone, with some more granular and fossiliferous parts, and some beds of reddish quartzite. Forms top of section (a), where it is mostly quartzite. In section (b), it crops out 67 feet above bed of Pinyon Canyon	6
9. Thin-bedded to platy, fine-grained, buff sandstone, with several thin limestone beds	39
8. Reddish quartzite and slabby, fine-grained limestone, with some lenses of granular limestone. Forms prominent bench	7
7. Thin-bedded, fine-grained buff sandstone, with some limestone in middle	57
Getaway limestone member:	
6. Gray, fine-grained limestone, with some granular seams that are crowded with fusulinids. In places, bed is much silicified. Forms prominent ledge	4
5. Buff, thin-bedded, fine-grained sandstone, with some interbedded limestone	32
4. Dark gray, granular limestone, containing numerous fusulinids and crinoid stems, and some other fossils, in 1-foot beds	5
3. Thin-bedded brown sandstone and gray sandy limestone	17
2. Thin-bedded, fine-grained, dark-gray limestone, and massive, granular, fossiliferous limestone, in irregular, lenticular beds, with some interbedded sandstone	31
1. Fine-grained, gray, brown-weathering, platy sandstone, standing in ragged ledges in lower half, interbedded with softer buff sandstone, and containing nodular beds of gray, fine-grained sandy limestone	88

Base of section; lower beds cut off by fault to west.

The accompanying list contains all papers through 1947 on the geology or geography of the southern Guadalupe Mountains, as well as a few on closely adjacent areas. Textbooks and other general works are omitted. Some publications in the list are labeled as compilations; they do not contain original observations and are based on the work of others. The bibliography is chronological, and within each year papers are listed alphabetically by authors.

1850. Report of Secretary of War, 31st Cong., 1st sess., S. Ex. Doc. 64, vol. 14, pp. 14–24.

Report of survey for a road from San Antonio to El Paso through Guadalupe Pass made in summer of 1849 by Lieut. F. T. Bryan, Corps of Topographical Engineers.

——— 31st Cong., 1st sess., S. Ex. Doc. 64, vol. 14, pp. 201–203.

Description of journey over same route a few months later by Capt. R. B. Marcy.

1854. Bartlett, J. R., Personal narrative of explorations and incidents in Texas, New Mexico, California, Sonora, and Chihuahua, connected with the United States and Mexican Boundary Commission, during the years 1850, 1851, 1852, and 1853, 2 vols., New York, D. Appleton & Co.

Excellent description of Guadalupe Mountains and of route from San Antonio to El Paso through Guadalupe Pass (pp. 117–121, vol. 1).

1855. Pope, John, Report of exploration of route for the Pacific Railroad near the 32d parallel of latitude from the Red River to the Rio Grande, in Report of the Secretary of War; 33d Cong., 1st sess., H. Ex. Doc. 129.

Description of country near Guadalupe Pass. Contains geologic report by Jules Marcou, based on notes and collections made by Capt. C. L. Taplin, rather than personal observation. It is suggested that the rocks of Guadalupe Mountains are of Triassic and Jurassic age.

——— Report of exploration of route for the Pacific Railroad near the 32d parallel of latitude from the Red River to the Rio Grande, in Reports of explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean, made under the direction of the Secretary of War in 1853 to 1854: 32d Cong., 2d sess., S. Ex. Doc. 78, vol. 2, pp. 1–95.

Revision of preceding report. Marcou's geologic report is replaced by one by W. P. Blake, likewise based on observations of others, in which it is suggested that rocks of the Guadalupe Mountains are of Carboniferous age, with a granitic axis.

1858. Shumard, G. G., Observations on the geological formations of the country between the Rio Pecos and the Rio Grande, in New Mexico, near the line of the 32d parallel, being an abstract of a portion of the geological report of the expedition under Capt. John Pope, Corps of Topographical Engineers, U. S. Army, in the year 1855: St. Louis Acad. Sci. Trans., vol. 1, pp. 273–289, 1858 [1860].

First geologic report on Guadalupe Mountains based on personal observations. Describes stratigraphy and structure along road through Guadalupe Pass and notes occurrence of fossils.

Shumard, B. F., Notice of new fossils from the Permian strata of New Mexico and Texas, collected by Dr. George G. Shumard, geologist for the United States government expedition for obtaining water by means of artesian wells along the 32d parallel, under the direction of Capt. John Pope, U. S. Top. Eng.: St. Louis Acad. Sci. Trans., vol 1, pp. 290–297, 1858 [1860].

1859. Pope, John, Reports of Capt. John Pope, Topographical Engineer, to Capt. A. A. Humphreys, Topographical Engineer, in charge of office of exploration and survey, War Department, in Report of Secretary of War: 35th Cong., 2d sess., S. Ex. Doc. 1, vol. 2, pp. 582, 590–608, maps and sections in vol. 5.

Describes drilling of well east of Pecos River in search of artesian water. Includes geologic cross section from Guadalupe Peak eastward to well, possibly prepared by Shumard.

Shumard, B. F., Notice of fossils from the Permian strata of New Mexico, obtained by the United States expedition under Capt. Pope for boring artesian wells along the 32d parallel, with descriptions of new species from these strata and the coal measures of that region: St. Louis Acad. Sci. Trans., vol. 1, pp. 387–403, 1859 [1860].

This paper and the one above by the same author give the first description of fossils from the Guadalupe Mountains; these are considered to be of Permian age.

1874. Jenney, W. P., Notes on the geology of western Texas near the 32d parallel: Am. Jour. Sci., 3d ser., vol. 7, pp. 25–28.

Gives results of geologic work done for Texas and Pacific Railroad, with brief mention of Guadalupe Mountains, whose rocks are said to be of Carboniferous age (p. 27).

1886. Shumard, G. G., A partial report on the geology of western Texas, consisting of a general geological report, and a journal of geological observations along the routes traveled by the expedition between Indianola, Texas, and the valley of the Mimbres, New Mexico, during the years 1855 and 1856, State of Texas, 145 pp.

Same as his publication of 1858, but giving further details. Gives description of Guadalupe Mountains (pp. 88–114).

1892. Tarr, R. S., Reconnaissance in the Guadalupe Mountains: Texas Geol. Survey Bull. 3, 39 pp.

Describes stratigraphy of Guadalupe Mountains and concludes that rocks are of Carboniferous (Pennsylvanian) age, as they are dissimilar to Permian rocks of central Texas. Contains notes on structure and geomorphology.

1900. Hill, R. T., The physical geography of the Texas region: U. S. Geol. Survey Topog. Folio 3, 12 pp.

Contains brief description of geomorphology and geology of Guadalupe Mountains (p. 4) and of Salt Basin, called Howard Bolson (p. 9). Based on author's personal observations.

1902. Girty, G. H., The upper Permian in western Texas: Am. Jour. Sci., 4th ser., vol. 14, pp. 363–368.

Preliminary description of stratigraphy and paleontology of southern Guadalupe Mountains.

1904. Richardson, G. B., Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, 119 pp.

Describes stratigraphy (pp. 38–45), structure (pp. 53–55), geomorphology (pp. 20–23), and ground-water resources (pp. 86–92) of Guadalupe and Delaware Mountains, and proposes the names Hueco, Delaware Mountain, Capitan, Castile, and Rustler formations.

1905. Girty, G. H., The relations of some Carboniferous faunas: Washington Acad. Sci. Proc., vol. 7, pp. 1–26.

Contains brief notes on paleontology of Guadalupe Mountains (pp. 14–15).

1908. Girty, G. H., The Guadalupian fauna: U. S. Geol. Survey Prof. Paper 58, 651 pp.

Describes fossils from Guadalupe Mountains in detail, and discusses correlation of strata. B. F. Shumard's contention that strata are of Permian age is upheld.

1909. Beede, J. W., Review of "The Guadalupian fauna": Jour. Geol., vol. 17, pp. 672–679.

Girty, G. H., The Guadalupian fauna and new stratigraphic evidence: New York Acad. Sci. Annals, vol. 19, pp. 137–138.

Discusses new fossil collections and stratigraphic observations, chiefly by Richardson, and their bearing on correlation of rocks of southern Guadalupe Mountains. Recognizes importance of environment in causing differences in faunas.

1910. Beede, J. W., The correlation of the Guadalupian and Kansas sections: Am. Jour. Sci., 4th ser., vol. 30, pp. 131–140.

Discusses correlation of rocks of Guadalupe Mountains with areas to east and northeast. Contains some notes on geology of northern Guadalupe Mountains.

Richardson, G. B., Stratigraphy of upper Carboniferous in west Texas and southeast New Mexico: Am. Jour. Sci., 4th ser., vol. 29, pp. 325–337.

Further observations on later Paleozoic rocks in west Texas and New Mexico, based on reconnaissance studies.

1914. Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Van Horn folio (No. 194), 9 pp.

Describes geology of an area not far south of the Guadalupe Mountains.

1915. Udden, J. A., The age of the Castile gypsum and Rustler Springs formation: Am. Jour. Sci., 4th ser., vol. 40, pp. 151–156.

Reports occurrence of Cretaceous Foraminifera in well cuttings from Castile gypsum. Includes a discussion by Richardson.

1917. Porch, E. L., Jr., The Rustler Springs sulphur deposits: Tex. Univ. Bull. 1722, 71 pp.

Describes some features of Delaware Mountain, Castile, and Rustler formations, with special reference to occurrence of sulfur.

1919. Böse, Emil, The Permo-Carboniferous ammonoids of the Glass Mountains and their stratigraphical significance: Texas Univ. Bull. 1762, 241 pp.

Discusses correlation of west Texas Permian formations, with incidental reference to Guadalupe Mountains.

Udden, J. A., Baker, C. L., and Böse, Emil, Review of geology of Texas: Texas Univ. Bull. 44, 178 pp., 1916, rev. ed.

Contains summary of stratigraphy of Guadalupe Mountains. Revised edition includes report of discovery of "Manzano group" (Bone Spring limestone) on west side of Guadalupe Mountains (pp. 59–61); compilation.

1920. Baker, C. L., Contributions to the stratigraphy of eastern New Mexico: Am. Jour. Sci., 4th ser., vol. 49, pp. 99–126.

Includes important new observations on Guadalupe Mountains. Unconformity at top of Bone Spring limestone and northward passage of Delaware Mountain group into Goat Seep limestone described for first time (pp. 112–117).

1922. Udden, J. A., Some cavern deposits in the Permian of west Texas: Geol. Soc. America Bull., vol. 33, pp. 153–155.

Occurrence of Cretaceous Foraminifera from within Castile gypsum, reported in 1915, and similar occurrences found afterward, now interpreted as cave deposits.

1924. Beede, J. W., Report on the oil and gas possibilities of the University block 46 in Culberson County: Texas Univ. Bull. 2346, 16 pp.

Contains two detailed sections of Bone Spring limestone and Delaware Mountain group in area south of Guadalupe Mountains.

Udden, J. A., Laminated anhydrite in Texas: Geol. Soc. America Bull., vol. 35, pp. 347–354.

Describes laminated anhydrite of Castile formation, found in cores in David Flood well, southeast of Delaware Mountains; suggests that laminations may be varves.

1925. Hoots, W. H., Geology of a part of western Texas and southeastern New Mexico, with special reference to salt and potash: U. S. Geol. Survey Bull. 780, pp. 33–126.

Includes observations on red beds of Pecos valley, and brief mention of rocks of Guadalupe Mountains (pp. 65–70), the latter a compilation.

Lee, W. T., Erosion by solution and fill: U. S. Geol. Survey Bull. 760, pp. 107–121.

Emphasizes the importance of removal of soluble rocks by ground-water as an erosion process in the region near the Pecos River, east of Guadalupe Mountains.

——— New discoveries in Carlsbad Cavern: Nat. Geol. Mag., vol. 48, pp. 301–320.

Description of Carlsbad Cavern, with illustrations and a map.

1926. Darton, N. H., The Permian of Arizona and New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 10, pp. 819–852.

Contains résumé of information in paper below (pp. 844–847).

Darton, N. H., and Reeside, J. B., Jr., Guadalupe group: Geol. Soc. America Bull., vol. 37, pp. 413–428.

Results of a study of stratigraphy and structure of Guadalupe Mountains, giving new information on fossils, confirming some older interpretations, and making some new ones. Name Carlsbad limestone proposed.

Meinzer, O. E., Renick, C. B., and Bryan, Kirk, Geology of No. 3 reservoir site of the Carlsbad irrigation project, New Mexico, with reference to water-tightness: U. S. Geol. Survey Water-Supply Paper 580–A, 39 pp.

Describes Carlsbad limestone and associated beds near Pecos River, at eastern edge of Guadalupe Mountains.

1927. Udden, J. A., Fossils from the Word formation of west Texas: Geol. Soc. America Bull., vol. 38, p. 159.

Note on ammonoids from cores described in 1924 paper; states that they have been determined to be of Word age.

1928. Baker, C. L., Desert-range tectonics of trans-Pecos Texas: Pan-American Geologist, vol. 50, pp. 341–371.

Contains observations on structure of Guadalupe Mountains (pp. 359–360).

Carter, W. T., and others, Soil survey (reconnaissance) of the trans-Pecos area, Texas: U. S. Dept. Agr., Soil Survey, ser. 1928, No. 35, 66 pp.

Map, which includes southern Guadalupe Mountains, shows distribution of soil types. Text contains descriptions of soils and vegetation.

Darton, N. H., "Red beds" and associated formations in New Mexico, with an account of the geology of the State: U. S. Geol. Survey Bull. 794, 356 pp.

Includes description of Guadalupe Mountains similar to that in 1926 paper of Darton and Reeside, but somewhat revised (pp. 220–227).

King, P. B., and King, R. E., The Pennsylvanian and Permian stratigraphy of the Glass Mountains: Texas Univ. Bull. 2801, pp. 109–145.

Contains paragraph by Ruedemann on reef origin of Capitan limestone of Guadalupe Mountains (p. 139).

Schuchert, Charles, Review of the late Paleozoic formations and faunas, with special reference to the ice-age of middle Permian time: Geol. Soc. America Bull., vol. 39, pp. 769–886.

Contains summary of stratigraphy and paleontology of Guadalupe Mountains (pp. 819–821); compilation.

Udden, J. A., Study of the laminated structure of certain drill cores obtained from the Permian rocks of Texas: Carnegie Inst. Washington Year Book, vol. 27, p. 363.

Summary of study of cores described in 1924 paper; mathematical analyses of laminations suggest imperfect cycles.

1929. Baker, C. L., Depositional history of the red beds and saline residues of the Texas Permian: Texas Univ. Bull. 2901, pp. 9–72.

Describes conditions of deposition of west Texas Permian, with incidental reference to Guadalupe Mountains.

——— Discussion of Permian symposium: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1057–1065.

Discussion of other papers published in same journal, with reference to conditions of deposition of Permian rocks, including origin of sandstones of Delaware Mountain group.

Blanchard, W. G., and Davis, M. J., Permian stratigraphy and structure of parts of southeastern New Mexico and southwestern Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 957–995.

Includes description and interpretation of rocks of Guadalupe Mountains. Proposes several stratigraphic names, including Bone Spring limestone and Queen sandstone.

Crandall, K. H., Permian stratigraphy of southeastern New Mexico and adjacent parts of western Texas: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 927–944.

Describes stratigraphy of rocks of Guadalupe Mountains and discusses their origin.

Keyes, C. R., Guadalupian reef theory: Pan-Am. Geologist, vol. 52, pp. 41–60.

This and later papers by same author are not based on field work, or even on an adequate study of published descriptions; interpretations made are at wide variance with established facts.

Keyte, I. A., Correlation of Pennsylvanian-Permian of Glass Mountains and Delaware Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp 903–906.

Brief notes on correlation, accompanied by chart.

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. 907–926.

Contains notes on stratigraphy of Guadalupe Mountains (p. 921); compilation.

Lloyd, E. R., Capitan limestone and associated formations in New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 645–657.

Capitan limestone interpreted as a reef deposit; discussion of stratigraphic implications of interpretation.

Mohr, C. L., Secondary gypsum in Delaware Mountain region: Am. Assoc. Petroleum Geologists Bull., vol. 13, p. 1395.

Observations on gypsum intercalated in limestone and sandstone along borders of Salt Basin; interpreted as secondary deposit.

Ruedemann, Rudolf, Coralline algae, Guadalupe Mountains: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1079–1080.

Notes on pisolites of Carlsbad limestone, which are interpreted as of algal origin.

Willis, Robin, Preliminary correlation of the Texas and New Mexico Permian: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 907–1031.

Contains notes on stratigraphy and correlation of rocks of Guadalupe Mountains (pp. 1017–1025); compilation.

——— Structural development and oil accumulation in Texas Permian: Am. Assoc. Petroleum Geologists Bull., vol. 13, pp. 1033–1043.

Contains incidental reference to limestone reefs and other features of Guadalupe Mountains; compilation.

1930. Cartwright, L. D., Jr., Transverse section of Permian basin, west Texas and southeast New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 14, pp. 969–981.

Contains cross sections showing stratigraphic relations at mouth of McKittrick Canyon, Guadalupe Mountains (p. 978).

Dobie, J. F., Coronado's children, tales of lost mines and buried treasures of the southwest, 367 pp., Dallas.

Chapter on "The secret of the Guadalupes" tells of lost Sublett mine, one of the many local legends of hidden treasure (pp. 256–268).

1931. 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.

Describes two species of new genus *Polydiexodina* from Guadalupe Mountains (pp. 263–268).

King, R. E., Geology of the Glass Mountains, part 2, faunal summary, with description of the brachiopoda: Texas Univ. Bull. 3042, 245 pp.

Summarizes stratigraphy, paleontology, and correlation of rocks of Guadalupe Mountains (pp. 11–13, 25–28); compilation.

Van der Gracht, W. A. J. M., The Permo-Carboniferous orogeny in the south-central United States: K. Akad. Wetensch. Amsterdam Verh., Afd. Natuurk., Deel 27, No. 3, 170 pp.

Includes discussion of conditions of deposition of Permian rocks of west Texas, with incidental reference to Guadalupe Mountains (pp. 79–85), accompanied by correlation charts (tables 7b and c); compilation.

1932. Roth, Robert, Evidence indicating the limits of Triassic in Kansas, Oklahoma, and Texas: Jour. Geology, vol. 40, pp. 688–725.

Discusses stratigraphy of Guadalupe Mountains and its bearing on the author's contention that some beds generally considered Permian are of Triassic age (pp. 702–706); compilation.

Sellards, E. H., The Valentine, Texas, earthquake: Texas Univ. Bull. 3201, pp. 113–138.

Contains reports on effect of earthquake on Guadalupe Mountain region (pp. 124–125); compilation.

1933. Darton, N. H., Guidebook of the western United States, part F, the Southern Pacific lines from New Orleans to Los Angeles: U. S. Geol. Survey Bull. 845, 304 pp.

Contains brief description of route through Guadalupe Mountains to Carlsbad Cavern (pp. 108–109).

Darton, N. H., and King, P. B., Western Texas and Carlsbad Caverns: 16th Internat. Geol. Cong., Guidebook 13, 38 pp.

Contains description by Darton of route through Guadalupe Mountains to Carlsbad Cavern (pp. 27–32).

Fiedler, A. G., and Nye, S. S., Geology and ground-water resources of the Roswell artesian basin, New Mexico: U. S. Geol. Survey Water-Supply Paper 639, 372 pp.

Contains description by Nye of stratigraphy, structure, and geomorphology of area north of Guadalupe Mountains (pp. 7–113).

Sellards, E. H., The pre-Paleozoic and Paleozoic systems in Texas, in The geology of Texas, vol. 1, Stratigraphy: Texas Univ. Bull. 3232, pp. 15–238.

Summarizes stratigraphy of Guadalupe and Delaware Mountains (pp. 156–161); compilation. Includes aerial photograph of south end of Guadalupe Mountains (pl. 1).

1934. King, P. B., Permian stratigraphy of trans-Pecos Texas: Geol. Soc. America Bull., vol. 45, pp. 697–798.

Summarizes stratigraphy of Guadalupe and Delaware Mountains (pp. 763–782); compilation, written before present field work was started.

1935. Baker, C. L., Structural geology of trans-Pecos Texas, in The geology of Texas, vol. 2: Texas Univ. Bull. 3401, pp. 137–211.

Contains descriptions of structure of Guadalupe and Delaware Mountains (pp. 159–161) and of Salt Basin (pp. 169–171); compilation.

Gardner, J. H., Origin and development of limestone caverns: Geol. Soc. America Bull., vol. 46, pp. 1255–1274.

Includes discussion of significant features of Carlsbad Cavern and its probable age (pp. 1268–1273).

Howard, E. B., Evidence of early man in North America: The Museum Journal, vol. 24, pp. 61–158.

Describes Burnet Cave in northern Guadalupe Mountains, which contains remains of Basket Maker Indians and possible older remains (pp. 62–79).

Lang, W. B., Upper Permian formations of Delaware Basin of Texas and New Mexico: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 962–970.

Proposes name Salado halite and Pierce Canyon redbeds for Permian stratigraphic units east of Guadalupe Mountains.

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