Geological studies of the Guadalupe Mountains area, New Mexico and West Texas, to 1928

Barry S. Kues

2006, pp. 127-144. https://doi.org/10.56577/FFC-57.127

in:

Caves and Karst of Southeastern New Mexico, Land, Lewis; Lueth, Virgil W.; Raatz, William; Boston, Penny; Love, David L. [eds.], New Mexico Geological Society 57th Annual Fall Field Conference Guidebook, 344 p. https://doi.org/10.56577/FFC-57

This page is intentionally left blank to maintain order of facing pages.

GEOLOGICAL STUDIES OF THE GUADALUPE MOUNTAINS AREA, NEW MEXICO AND WEST TEXAS, TO 1928

BARRY S. KUES
Department of Earth and Planetary Sciences, MSC03 2040, University of New Mexico, Albuquerque, NM 87131-0001

Abstract.—This paper traces observations and studies of the classic Permian sequence of the Guadalupe Mountains area through 1928. Early American expeditions in 1849 and 1850 provided the first descriptions of the southern Guadalupes, including a sketch of the southern end of the range by John R. Bartlett. Pope's 1854 32nd parallel Pacific Railroad expedition passed through Guadalupe Pass; geological reports by Blake (1856) and Hall (1857) included simple geological maps of the Guadalupe region. George Shumard, the first geologist to visit the range (1855), reported four stratigraphic units, including an "upper white limestone" that yielded fossils identified as Permian by B. F. Shumard (1858). Opinion shifted to a Carboniferous age based on reconnaissance surveys in the 1890s by Tarr, Cummins, and Hill. George Girty collected and studied Guadalupian fossils, which he originally considered Late Permian (1902), but by the time of publication of his monograph (1908) he had retreated from that view and by 1909 thought they were of late Carboniferous age. G. B. Richardson (1904) provided a moderately detailed geologic map, considered the Guadalupe Mountains an eastward dipping monocline with little faulting, and named the Capitan and Delaware Mountain formations, as well as the probably younger Castile and Rustler formations to the east. Later work by Girty and Richardson ascertained that Guadalupian strata passed northward into red beds and evaporites but precise correlations were not possible. Beede (1910) thought it likely that Guadalupian strata were an isolated equivalent of Lower Permian strata in the Midcontinent, but gave an age range of mid-Pennsylvanian to Late Permian for the Capitan and Delaware Mountain formations. Baker (1920) clarified aspects of the stratigraphy, by which time the age was again thought to be Permian. Studies by Darton and Reeside (1926) and Darton (1928) concluded that Permian Chupadera Formation (=Yeso and San Andres) strata graded into the Capitan and Delaware Mountains, while recognizing that the Castile and Rustler were of younger Permian age. Recognition of the reef complex nature of Guadalupian strata in 1929 provided a new paradigm for stratigraphic interpretation, one that has continued to be refined to the present.

INTRODUCTION

The Guadalupe Mountains of New Mexico and west Texas (Fig. 1) are composed of one of the most important Permian stratigraphic sequences in the world. This sequence includes the Capitan reef, the largest, best-preserved, most accessible and most intensively studied Paleozoic reef system in the world (Fig. 2). Two of the largest and deepest known cave systems, as well as dozens of other caves, are developed in the Permian strata of the Guadalupes. The facies exposed in the range extend into the subsurface, where they have been sampled by 250,000 wells, that have yielded enormous quantities of oil and gas. The reef and related marine strata contain incredibly diverse faunas, many of which have been found nowhere else. Aspects of the Permian rocks of the Guadalupe Mountains have been the subject of more than a dozen books (e.g., King, 1948; Newell et al., 1953; Hileman and Mazzullo, 1977; Reid et al., 1988; Hill, 1996; Saller et al., 1999), and more than a thousand papers; a recent bibliography of selected references to the Permian geology of this range and adjacent areas (Scholle, 2000) lists more than 1200 citations.

Early observations and studies of a geologic feature such as the Guadalupe Mountains form the foundation upon which later knowledge is constructed, yet with each passing generation the early work is less read and cited, and fades from the awareness of those studying the feature a century or more later. However, understanding how early explorers and geologists viewed and interpreted the Guadalupe Mountains is of fundamental historical interest and broadens appreciation of the development of modern knowledge about this range. Accounts of the early studies of the Guadalupes by modern authors are few and brief (King, 1948; Brezina in Cys et al., 1977; Hill, 1996). This paper considerably augments these works by providing a more detailed survey of studies and interpretations through 1928, outlining the historical context in which they were done, and providing some biographical information on the main contributors to early knowledge.

EARLY RECORDS

Before the Mexican War (1846-1848), the Guadalupe Mountains were largely unknown. Tribes of Indians, primarily Apaches and then Comanches, roamed the area, and petroglyphs suggest centuries of Indian use of salt from playa lakes west of the range (Adams, 1988). A few Spanish expeditions came within sight of the range, probably beginning with the expedition of Antonio

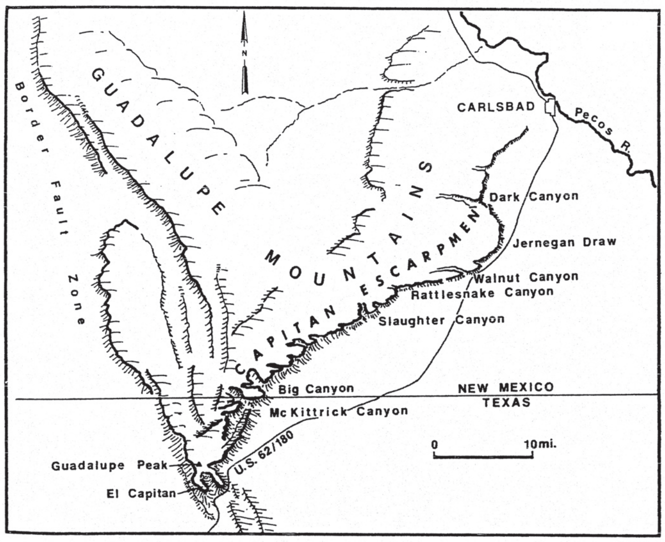


FIGURE 1. Location of Guadalupe Mountains area (after Babcock, 1977).

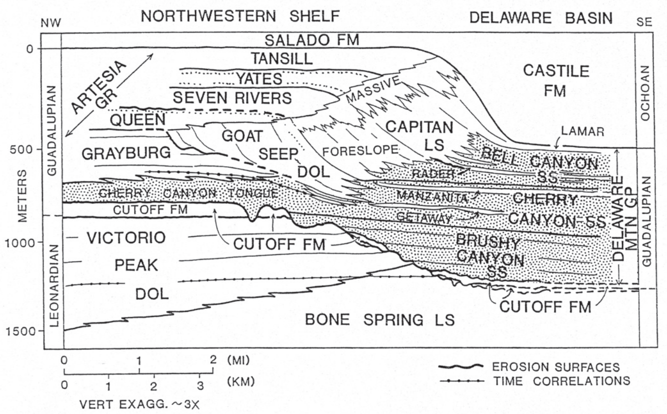


FIGURE 2. Modern interpretation of Guadalupe Mountains area Permian stratigraphy, showing backreef (shelf), reef (Capitan Ls), and Delaware basin facies relationships (after Pray, 1988).

Espejo in 1583 (McBride, 1957), and including Mendoza's expedition of 1684 and that of Amangual in 1808 (Goetzmann and Williams, 1992, p. 90-91, 138-139). Amangual's party crossed the Llano Estacado from the north before turning west towards El Paso, and on 13 November camped at the foot of the Sierra Guadalupe on its way back to San Antonio. Adams (1988) also noted that the Spanish of northern Mexico began mining salt from the area by 1750, but apparently no geological observations of the Guadalupes were made during the Spanish and Mexican periods.

The origin of the name Guadalupe as applied to these mountains is obscure. Julyan (1996) suggested that it was transferred from the Franciscan Mission Nuestra Senora de Guadalupe established in El Paso in 1668. The name was in use in the early 1800s, judging from the account of the Amangual expedition and its appearance on Zebulon Pike's 1810 map of the interior provinces of New Spain (see Martin and Martin, 1984, for this and other early maps), where it is portrayed as part of a continuous chain of mountains extending from the Sangre de Cristos through the Sacramentos and south into Texas. However, on most subsequent maps the range is not indicated, or if it is, the name Guadalupe is not used. For example, on Emory's 1844 "Map of Texas and the countries adjacent…", an early effort by the U. S. Army Corps of Engineers, the mountains are shown in approximately their correct location, but are unnamed. Seven years later, after New Mexico passed to American control and several expeditions had marched through the area, Emory's 1851 map of the western U. S. clearly shows the range identified as the Guadalupe Mountains. The earliest (1849) American expeditions past the range all refer to it as the Guadalupe Mountains or Sierra Guadalupe.

FIRST AMERICAN OBSERVATIONS

Although no American forces traversed the area of the Guadalupe Mountains during the Mexican-American War, military parties were sent through west Texas and southern New Mexico afterwards in order to explore and survey routes for wagon roads, both for military and supply purposes and to accommodate large numbers of travelers who were already beginning to surge westward to California in order to search for gold. The reports of these expeditions largely are limited to geographic description, such as topography, location of sources of water, grass and timber, and nature of the soil, which would be useful to travelers and eventual settlers. Three such expeditions passed by the southern end of the Guadalupes in 1849.

Lieutenant Francis J. Bryan, of the Army Corps of Topographical Engineers, led one expedition, beginning on 14 June, from San Antonio to El Paso (Bryan, 1850). By 20 July they crossed the Pecos River and were moving westward along Delaware Creek within sight of the Guadalupe Mountains: "Our general course is west to the southern point of Guadalupe. There are three high peaks of the Sierra Guadalupe which serve as landmarks from a great distance. The soil of the road is sometimes limestone and sometimes sand." (p. 21). Two days later they had passed Independence Spring and encamped at "a fine spring of pure cold water, at the foot of Guadalupe" (p. 21) and Bryan noted that the mountains were covered with forests. The party then continued westward past the Cornudas Mountains , "a mass of gigantic granitic rocks piled upon each other in every imaginable way" (p. 22), and "Waco" (Hueco) Mountain, arriving in El Paso on 29 July.

At about the same time an expedition under the command of Captain S. G. French was exploring the area west of San Antonio to the Rio Grande, and then north to El Paso. The party returned eastward, and in September traversed the rugged terrain south of the Guadalupe Mountains. French's (1850, p. 53) description was brief: "The Guadalupe Mountains arise abruptly from the plain…to their highest elevation, and in an unbroken chain stretch over the tableland in a northeasterly direction, until their tops sink below the horizon in the distance. From these mountains one vast, irregular, and slightly broken plain extends to the Pecos River…"

A more substantial military expedition was led by Colonel Randolph Marcy (Marcy, 1850; see also Goetzmann, 1959, p. 213-218). Marcy's large party left Ft. Smith, Arkansas, on 4 April, 1849, escorting a group of goldseekers bound for California, entered New Mexico east of Tucumcari about 15 June, and arrived in Santa Fe on 28 June, where it remained for several weeks. In mid-August, Marcy headed south along the Rio Grande, crossed the Jornada del Muerto, paused in Doña Ana for a few days, and then struck east through San Augustin Pass, crossed the Tularosa Valley, and continued south along the Sacramento Mountains to the Hueco Mountains. Continuing east past the Cornudas Mountains, roughly along the present New Mexico-Texas border, Marcy's party came within sight of "the southern peak of a high range of mountains called the "Sierra Guadalupe" (p. 64) on 8 September. The following day the party passed the southern end of the Guadalupes, which Marcy described as follows (p. 65):

> "The Guadalupe range of mountains terminates at this place in an immense perpendicular bluff of light-colored sandstone, which rises to the enormous height of nearly two thousand feet, and runs off to the northeast towards the Pecos. On the south side of the peak there is a range of bluffs about two hundred feet high, running from north to south across our course…"

This is the first recorded geological observation of the Guadalupe Mountains. Marcy's party was traveling on Permian sandstones along the base of the range, and he apparently mistook the massive limestones of Capitan Peak for sandstone. Marcy continued eastward across Texas, and the expedition ended at Fort Washita (Oklahoma) in November. An important result of Marcy's expedition was to ascertain that there were no significant geographic barriers to the construction of a road through this region, and Marcy believed this southern route to be a better and shorter route from the Mississippi River to California than any other.

THE BOUNDARY SURVEY

The Treaty of Guadalupe Hidalgo, ending the Mexican-American War, necessitated the establishment of a new boundary between the two countries, from the mouth of the Rio Grande north to El Paso and then westward to San Diego, California. The task of surveying and marking the boundary in the field fell to American and Mexican Boundary Commissioners and their surveying teams. President Polk appointed the first (of what was eventually to number six) American Boundary Commissioner in December, 1848. What followed was one of the most complex, disorganized, problem-plagued, expensive, and politically controversial exercises in the annals of American geography, which was not completed until 1856 (see James, 1969; Emory, 2000; and Rebert, 2001, for detailed information).

John Russell Bartlett, the fourth boundary commissioner, was a New York City bookseller and artist with interests in ethnology and linguistics. During his term of service (1850-1852) he was believed by many to have failed his duties, because he agreed to a boundary too far north (requiring the U. S. to pay $10 million to Mexico to secure a southern strip of territory believed essential for a railroad; the Gadsden Purchase), and for wasting funds by traveling extensively through the Southwest and northern Mexico on journeys that were only tenuously related to the boundary survey. However, Bartlett's account of his travels (1854), a two-volume "personal narrative" represents, in the words of one author (James, 1969, p. 55), "…a high point in southwestern literature. His geographic descriptions were vivid and communicated a sense of beauty and wonderment. The narratives were readable, reliable, and accurate."

Bartlett and his party, traveling from the Texas Gulf Coast to take up his duties in El Paso, crossed the Pecos River on 30 October, 1850, and approached the southern end of the Guadalupes from the east. On 9 November, Bartlett (1854, p. 117) recorded:

> "The road was quite tortuous, winding among and over hills, 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 all other objects, and terminating abruptly three thousand feet above the surrounding plain. The *sierra* or mountain range which ends with it, comes from the northeast. It is a dark, gloomy-looking range, with bold and forbidding sides, consisting of 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 other portions of the range, or with the azure blue of the sky beyond."

Bartlett's party negotiated the difficult terrain slowly (p. 120):

> "Winding and turning in every direction we followed the intricacies of the Guadalupe Pass for at least six hours; and whenever the prospect opened before us, there stood the majestic bluff in all its grandeur, solitary and alone. In one place the road runs along the mountain on a bare rocky shelf not wide enough for two wagons to pass, and the next moment passes down through an immense gorge, walled by mountains of limestone, regularly terraced."

Bartlett sketched a view of Guadalupe Pass (in pencil, with sepia wash, see Sweeney, 1996, p. 37); a wood-cut version of this view appears in his "Narratives" and is reproduced here (Fig. 3). Upon reaching the western side of the mountains the party viewed a broad plain, with the Sacramento and Cornudas Mountains rising in the distance, and arrived in El Paso on 13 November. The scientific results of the Boundary Survey, published in 1857, included little relating to the Guadalupe Mountains, but the geology of the range and the surrounding area was included on a map by Hall (1857).

JOHN POPE AND THE 32ND PARALLEL SURVEY

In the early 1850s, interest in building a transcontinental railroad across the new territories to the Pacific Ocean was great, and the federal government funded exploratory expeditions (the Pacific Railroad surveys) along several possible routes, including two that passed through New Mexico. These expeditions were led by members of the Corps of Topographical Engineers, but in contrast to earlier American expeditions typically included geologists and other scientists. The first of the New Mexico expeditions (1853), along the 35th parallel of latitude (roughly Tucumcari-Santa Fe-Albuquerque-Zuni) was commanded by Lt. Amiel

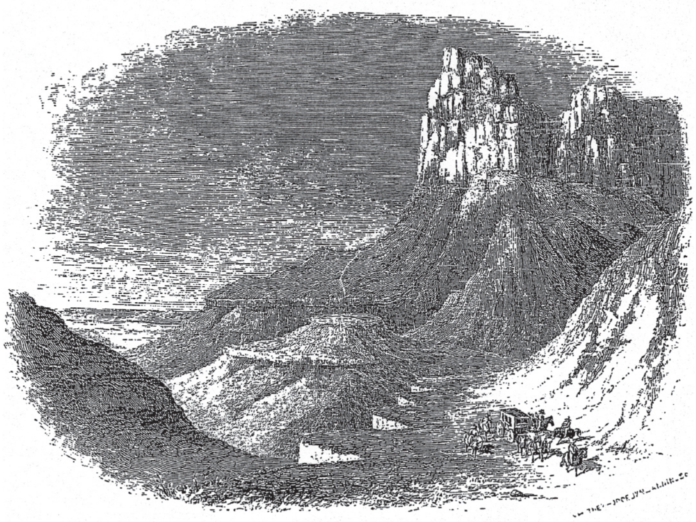


FIGURE 3. Bartlett's (1854) wood engraving of the southern end of the Guadalupe Mountains.

Whipple and included the Swiss-born geologist Jules Marcou (see Kues, 1985; Lucas, 2001). The second expedition, along the 32nd parallel, which included the Guadalupe Mountains, was commanded by Captain John Pope. No geologist accompanied this expedition, but Pope arranged with Marcou to examine specimens collected and to write the geologic part of the expedition report.

Captain Pope's previous service in the Corps of Topographical Engineers had been less than exemplary and he had become something of a problem (Goetzmann, 1959, p. 247). Pope arrived in New Mexico in 1853, and was assigned to lead the eastern part of the 32nd parallel survey. His party left Doña Ana on 12 February, 1854, traveled east through San Augustin Pass, then south to the Hueco and Cornudas Mountains, and arrived at the south end of the Guadalupes on 28 February. Pope's (1855) general account of the route and Byrne's (1855) daily journal contain little information about the Guadalupe Mountains, but the party was successful in finding a less difficult route through Guadalupe Pass and in exploring portions of the southern Llano Estacado. Marcou (1855), who had left for Europe shortly after completion of the Whipple expedition, did submit a short geological report. It contained little new information or interpretation, and Marcou seems to have merely been going through the motions of fulfilling his agreement with Pope. Because Pope's party collected few rock specimens and recorded few geologically relevant observations, and because Marcou had never been within 200 miles of the route, his report is of little value. He (p. 127-128) incorrectly interpreted the strata around the southern end of the range as being Triassic and Jurassic age because he thought them to be the same as he had actually seen along the northern edge of the Llano Estacado on the Whipple expedition. Marcou virtually ignored the Guadalupe Mountains, merely noting that they were composed of Carboniferous limestone, and very briefly mentioned the red sandstone and limestone [Late Permian Rustler Formation] around the junction of Delaware Creek and the Pecos River, as well as the "immense field of gypsum" [Castile Formation] reported by Pope extending eastward from the mountains, but without suggesting an age. He did conjure a Cretaceous age for the 'white sandstones' that he believed covered much of the area west of the Guadalupes, around the Hueco and Cornudas Mountains, but except for small Cretaceous outliers in the Cornudas Mountains discovered much later there are no Cretaceous strata exposed in this large area.

Marcou's geological report was so brief and unsatisfactory that William P. Blake was called upon to write a more authoritative report, just as he did for the Whipple expedition report in Marcou's absence. Blake's (1856) report was prefaced by an ungenerous disclaimer by Pope: "The mineralogical collections…were placed in the hands of M. Jules Marcou for examination, and carried by him to France. They were subsequently returned in a confused condition, and with many of the labels displaced. This fact will account for many errors in the report, map, and section prepared by Mr. Blake." In reality, Blake did the best he could with the information and specimens available, but the report clearly suffered from the fact that he had never seen the area he was attempting to characterize.

Of the general topography of the Guadalupe Mountains, Blake (p. 14) could only repeat a description by A. B. Gray, for a time surveyor of the Boundary Commission:

> "There is an abrupt and precipitous cliff of columnar rock upon vast limestone terraces, attaining a height of 1,000 to 1,500 feet above its base, with a general elevation of several thousand feet above the plain…The face of this stupendous structure is perpendicular, and looks as if it had been shaped by some sudden and powerful convulsion of nature into the form of a large edifice or church…Viewed from the deep gorge below, it is truly sublime and beautiful; its lofty peak towering to so great an altitude, and crowning the terminal point of an extensive range of mountains."

Blake's interpretation of the geology of the range was brief (p. 14): "The specimens from the Guadalupe Mountains are all of sandstone and limestone, and I do not find any of the erupted rocks represented. From the general topographical indications, I am led to regard this range as having a granitic axis, or as being on the crest of an uplift of granite and the allied rocks, although they may not appear upon the surface." Because neighboring ranges all seemed to have granitic cores, Blake considered it "highly probable that granite will ultimately be found in some parts of the range, north or south of the part explored." Based on this dubious assumption, Blake went on to speculate that granite was not far below the surface, and covered by only a thin layer of sediments, and that the area between the Guadalupe and Hueco Mountains was a broad "axis or summit" of granite and metamorphic rocks overlain by the sedimentary rocks. As for the age of these rocks, Blake commented that "[A]lthough there are no fossils in the specimens of limestone from the Guadalupe, and thus there is no evidence of the age of the rocks, I cannot but regard them as Carboniferous."

Blake also discussed the red sandstone and "great gypsum formation" exposed along Delaware Creek, which is (p. 19) "remarkable for its extent, and for the number and variety of gypseous [sic] beds of all degrees of transparency and of many colors." These strata extended eastward over a large area, into the Red River region of Oklahoma and north-central Texas, but Blake could not provide information on their age, although indicating that their stratigraphic position was below the Cretaceous.

Complementing his extremely speculative notions of the geology of southeastern New Mexico and west Texas, Blake also produced a simple geologic map of this region. The Guadalupe Mountains are portrayed as an elongate arc, composed of Carboniferous sandstones along its eastern side and Carboniferous limestones along its western side, in contrast to ranges to the west (Hueco, Organ/Franklin, and Doña Ana Mountains), which comprise Carboniferous limestone above granite and metamorphic rocks. The Tertiary intrusives of the Cornudas Mountains were also portrayed as the same granite unit, a reflection of the fact that early geologists could not differentiate Precambrian basement from Tertiary intrusive rocks. A "gypsum formation" was mapped along Delaware Creek and the Pecos River. The surrounding region covering the entire area between the Pecos River and Guadalupe Mountains, and across to the Hueco and Organ (+Franklin) Mountains, was portrayed as Cretaceous, despite the fact that there was no fossil evidence at all to indicate Cretaceous strata in this region. This was a considerable (and incorrect) extrapolation from the known presence of Cretaceous rocks far to the south in Texas, far to the north in Marcou's Tucumcari area, and in places along the Rio Grande near El Paso.

JAMES HALL'S MAP

The geologic reports of the Boundary Survey did not deal with the Guadalupe Mountains region because the Survey extended westward from El Paso. James Hall, the preeminent American paleontologist of the time, contributed a paper to the Boundary Survey volumes (Hall, 1857) that did include an ambitious geologic map of the entire western United States, based on information available from prior expeditions and surveys. This map included New Mexico and represents the first published geologic map of the entire territory. The Guadalupe Mountains were drawn as the northern end of a continuous range that extended sinuously south past Ft. Davis, Texas, to Presidio, on the Rio Grande nearly 200 mi south of El Paso. The central part of the Guadalupes was portrayed as Upper Carboniferous limestones surrounded on all sides by a band of "Triassic through Lower Cretaceous" strata. To the east, the area along Delaware Creek and the Pecos River was also assigned to this Triassic-Lower Cretaceous unit. Most of the remainder of southeastern New Mexico, including large areas to the east and north of the Guadalupes and the region between the mountain ranges westward to the Rio Grande, were considered "middle and upper Cretaceous". Large patches of Tertiary sediments were recognized on the Llano Estacado and north of Fort Sumner.

In the light of present knowledge of the geology of this area, Hall's map is incorrect in many details, and reflects the dangers of projecting stratigraphic data derived from a few locations across large areas where almost no direct information was available. The assignment of a Triassic-Early Cretaceous age to strata around the Guadalupe Mountains and along Delaware Creek and the Pecos River was apparently based on the (largely correct) observations of Marcou in the Tucumcari area, far to the north, and Cretaceous strata were assumed, following Blake, to surface most of the Llano as well as the intermontane regions west of the Guadalupes, in both cases without direct evidence. Further, the presence of Permian strata in this area, or anywhere in the western U. S., was not known or suspected (except by Marcou) when Hall produced his map. He probably considered the red-bed and gypsum lithologies documented near the Guadalupes to be of Triassic age, although, as Blake had pointed out, no evidence existed to assign a definite age to these strata. Ironically, the information required for a more accurate view of the geology of the range had already been assembled, although not published, at the time Hall constructed his map. This information resulted from the observations of the first geologist to actually examine the Guadalupe Mountains, George G. Shumard, in 1855-1856.

GEORGE G. SHUMARD'S OBSERVATIONS

Pope had been optimistic about the possibility of large quantities of ground water being present within the Llano Estacado of southeastern New Mexico. Accordingly, Congress voted $100,000 to "pursue experiments in sinking artesian wells on the Llano Estacado and Jornada del Muerto" (Goetzmann, 1959, p. 365) in order to provide water that would be needed by a possible railroad and for eventual settlement. Pope was ordered to conduct exploratory drilling in these areas and was assigned geologist George G. Shumard to supervise the drilling operations. Pope's party traveled from the Texas Gulf Coast to the mouth of Delaware Creek and in May, 1855, established camp there, near the New Mexico-Texas boundary and about 40 mi east of the Guadalupe Mountains, to begin drilling wells. Shumard had ample time to examine the local geology from this camp, and in September, when the party moved westward past the Guadalupe Mountains, he had several days to study the geology of the range.

The artesian well experiment dragged on for three more years before Pope admitted failure to produce significant amounts of water. Part of the problem was, as Goetzmann (1959, p. 366) noted, that the available pumps for bringing ground water to the surface were powered by steam engines that burned dried mesquite as fuel. In an arid region where fuel could be as scarce as water, these pumps were clearly not practical. Windmill water pumps, which solved that problem, were not manufactured and distributed widely until the 1870s.

Shumard's complete geological report was never published. A "partial report" was exhumed from the files of the Texas Geological Survey three decades later, and published by the state of Texas (Shumard, 1886), long after Shumard had died. He did, however, write a paper describing his observations of the Guadalupe Mountains area (Shumard, 1858), and this remained the most detailed source of geological information until the early 1900s. George Getz Shumard (1823-1867) was born in New Jersey and, like many geologists of his time, was trained in medicine, receiving his degree from the medical college in Louisville, Kentucky. He then moved to Ft. Smith, Arkansas, and in 1852 was attached as surgeon and naturalist to Marcy's expedition to explore the upper part of the Red River in Texas and Oklahoma. In 1854 he accompanied Marcy on a survey of the Big Wichita and Brazos Rivers in Texas. Following his service with Pope's artesian well expedition in 1855-1856, he was appointed by his brother, B. F. Shumard, as assistant geologist with the first Texas Geological Survey, and served in that capacity from 1858 to 1861, when the Survey was shut down because of the Civil War. In 1861 he moved to Cincinnati, Ohio, and served as Ohio State Surgeon General until his death (information from Ferguson, 1969 and R. Shumard, 2001).

Shumard (1858) included a wealth of detail on the geology of the area from the Pecos River west to El Paso, along the present New Mexico-Texas boundary. His daily journal (Shumard, 1858, 1886) includes details of terrain and landscape, soil, stratigraphy (including lithological description, fossils, dip and variations in thickness), and the relationships of the strata to the landscapes he observed. As he traveled he synthesized and interpreted structural features, sediment sources, effects of erosion on topography, and local geologic history. Here the focus will be on major observations of the geology of the Guadalupe Mountains and surrounding areas.

Pope's party moved westward from its first camp on 23 September, 1855, after more than three months of laboriously drilling a single well to a depth of 841 ft at a location about 15 mi east of the Pecos River. Shumard described Quaternary conglomerate and limestone breccia covering a limestone he thought was Cretaceous, and beneath it thick beds of red marly clay, sandstone and gypsum [Upper Permian Castile and Rustler Formations]. About 30 mi west, in the eastern foothills of the northern Delaware Mountains, these lithologies abruptly disappeared, to be replaced by a sequence containing "Upper Coal Measures" fossils and consisting, in ascending order (Shumard, 1858, p. 277) of 1) a basal "yellow quartzose sandstone, with thin seams of black, compact limestone interstratified at its upper portion"; 2) "dark-gray, thin bedded crystalline limestone" (50 ft); 3) "black, thinly laminated limestone" (100 ft) and 4) "heavy-bedded, compact, white and light-gray limestone." In most places the latter limestone was covered with thick deposits of Quaternary conglomerate and limestone breccia. The landscape was deeply dissected (p. 278): "The limestone is now only occasionally observed capping the summits of the highest elevations, and nowhere presents a thickness of more than one or two hundred feet. Immediately south of our route, the country is much cut up by deep valleys and rocky ravines; to the surface, although less broken, is nevertheless, rough, and thickly strewn with coarse, angular fragments of limestone."

At the head of Delaware Creek, approaching the pass between the Guadalupe and Delaware Mountains, Shumard observed "abrupt escarpments and hills of massive and thin-bedded sandstone, surmounted by heavy and finely laminated strata of limestone." Closer to the eastern base of the Guadalupes, "the sandstone is exposed, by denudation, to the height of six hundred feet. The overlying limestones are confined mostly to the hills, and, at some points, exhibit a thickness of nearly four hundred feet." (p. 279). King's (1948) map of this area indicates that most of the sandstones Shumard observed are the Cherry Canyon and Bell Canyon Formations, and the limestones are members of the Bell Canyon. Shumard also noted that "[n]o evidence appears of any sudden or violent disturbance, but the uplifting of the strata has evidently been the result of causes operating in a uniform and very gradual manner."

Passing Independence Spring, the party arrived at the southern base of the Guadalupes on 27 September, and Shumard (1858, p. 279-280) described the range as follows:

> "The main axis, or line of upheaval, trends somewhat irregularly northeast and southwest. [T]here is a gradual descent to the northeast, while, to the south, the range terminates abruptly in a frightful precipice upwards of 2,000 feet in height. Around the base of this precipice our road led, by a gradual descent, through a deep cañon, with rough and nearly vertical cliffs on either side. …It is only when observed from the west, however, 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 with the axis of upheaval of the mountains, which present the appearance of having been cleft vertically through their center, and the western halves removed."

One of the "vertical precipices" visible from the west, north of Guadalupe Peak, would eventually be named Shumard Peak.

Shumard divided the stratigraphic sequence he observed at the south end of the mountains into four units; in ascending order, 4) black, thin-bedded limestone (500 ft); 3) yellow, quartzose sandstone (1200-1500 ft); 2) dark, thinly laminated and foliated limestone (50-100 ft); and 1) upper or white limestone (1000 ft). The upper white limestone was found to be "remarkably rich in organic remains, a large portion of which are new to science; but others appear to be forms of the Coal Measures" (p. 280). Shumard collected fossils from all but the basal unit, noting numerous species, including (p. 281) "a slender *Fusulina*, upwards of an inch in length, which appears to be quite distinct" from those known from the upper Coal Measures of the Midwest, and a brachiopod "which possesses all of the external features" of a species from the Permian of Russia.

By the time this paper appeared in print, George's brother B. F. Shumard had announced the Permian age of the Guadalupe fauna, and a footnote (G. G. Shumard, 1858, p. 281) mentions that age. Studies beginning in the early 20th century (see below) would greatly refine the stratigraphy of this magnificent sequence of strata, and Shumard's four units would eventually be named (King, 1948) Bone Spring Limestone (unit 4), Delaware Mountain Group (unit 3), Pinery Member of the Bell Canyon Formation (unit 2), and Capitan Limestone (unit 1).

Shumard worked in the Guadalupe Mountains and vicinity, from September 25 to 28, 1855. Just to the west, beyond the foot of Guadalupe Canyon, Shumard also reported a line of hills about 500-800 ft high, which (p. 281-282) "presents a precipitous face towards the east, extending, irregularly, for several miles, in a direction nearly parallel with the mountains", with strata dipping 25 degrees WNW, "in a direction contrary to that observed in the Guadalupe Mountains. But the rocks are in all respects similar to those of the mountains, a portion of the western slope of which they, at one time, formed, although at present separated by a deep valley…" These are the Patterson Hills, and Shumard's observations of stratigraphy and dip are generally accurate.

Pope and Shumard continued westward past the Cornudas and Hueco Mountains, arriving in El Paso on 5 October, and moved to Doña Ana a few days later to begin a second artesian well drilling operation. Shumard spent several months studying the geology of southern New Mexico (e.g., G. G. Shumard, 1859), returned east late in 1856, and transferred the fossils he had collected to his older brother, B. F. Shumard (1820-1869). The elder Shumard at this time was assistant geologist and paleontologist of the Missouri Geological Survey. He had received a medical degree from the medical college in Louisville in 1842, but his practice soon gave way to a greater interest in paleontology. He served as assistant to David Owen in a geological survey of Iowa, Wisconsin and Michigan (1846-1850), spent 18 months (1850-1851) on a geological reconnaissance of Oregon, and was with the Missouri Geological Survey from 1853 to 1858. He served as head of the newly organized Geological Survey of Texas (1858-1860) until removed by Sam Houston in favor of a political appointee. Shumard then practiced medicine in St. Louis, and was a professor of obstetrics at the University of Missouri until his death (information from Anonymous, 1889; National Cyclopedia, 1900).

Upon examining the Guadalupe fossils his brother had given him, B. F. Shumard determined that they were not of "Coal Measures" age, but were Permian. He announced the Permian age of the Guadalupe strata on 8 March, 1858, at a meeting of the St. Louis Academy of Sciences. Interestingly, a short time before (at the 22 February meeting of the Academy) G. C. Swallow had announced the discovery of Permian fossils in Kansas, and this was quickly followed by a similar announcement in Philadelphia on 2 March, by F. B. Meek. Both Swallow and Meek had received their fossils from the same collector, and the nearly simultaneous announcement of "the first Permian fossils in North America" led to an acrimonious debate about priority (see Merrill, 1924; Branson, 1961). Shumard never claimed priority in this matter (after all, Swallow was his boss at the Missouri Geological Survey), although some later authors have claimed that the Guadalupe Mountains fossils were the first Permian fossils recognized in North America. It is true, however, that the Permian fossils in Kansas were collected from strata very close to the Pennsylvanian-Permian boundary, whereas the fossils from the Guadalupe Mountains are considerably younger and more distinctively Permian.

B. F. Shumard (1858, 1859) described the Guadalupe taxa, and Prout (1858) described one new bryozoan. In all, 54 taxa from the Guadalupe Mountains, most from the "upper white limestone" (=Capitan Limestone), were described, of which 26 were new species. More than half of these are brachiopods, but fusulinids, sponges, corals, trilobites, ostracods, bryozoans, bivalves, gastropods, nautiloids and fish scales were also present in the collections. Unfortunately, most of Shumard's new species are not recognizable today because their descriptions, while good for his time, are inadequate by modern standards. Moreover, most of the species were not illustrated (but see Fig. 4), and the type specimens in St. Louis were destroyed in a fire long ago (Cooper and Grant, 1972, p. 3). As we will see, the taxa described by Shumard represent only a small fraction of the total Permian faunas of the Guadalupe Mountains.

STUDIES TO 1900

After the work of the Shumard brothers, little additional geologic study of the Guadalupe range was done for several decades. Pope's artesian well camp on Delaware Creek was taken over by John Butterfield in August, 1858, and the Butterfield Overland Mail Route (Ft. Smith to San Francisco) operated until the Civil War began in 1861 (Adams, 1988). No doubt hundreds of travelers were awed by the view of the southern end of the mountains as they rode through Guadalupe Pass, but the only geological observations between the Shumards and the 1890s were made by Walter Jenney (1874), geologist for the Texas and Pacific Railroad. Jenney's short paper dealt mainly with the geology of the Franklin, Hueco, and Cornudas Mountains, and the Llano Estacado along the Pecos River in Texas. His only comment on the Guadalupe Mountains (p. 27) noted that "…at Guadaloupe [sic] Pass, about 800 feet of sandstone underlie a precipice nearly 600 feet high of Carboniferous limestone, above which the peaks of the mountains rise to perhaps an equal height."

In the 1890s two geologists working for the Third Texas Geological Survey, R. S. Tarr and W. F. Cummins, published observations on the Guadalupe Mountains area. Tarr (1892) visited the southern end of the Guadalupes and measured a stratigraphic section that differed little from that of Shumard; in ascending order his units were 4) black limestone, shale and slate (200 ft); yellow,

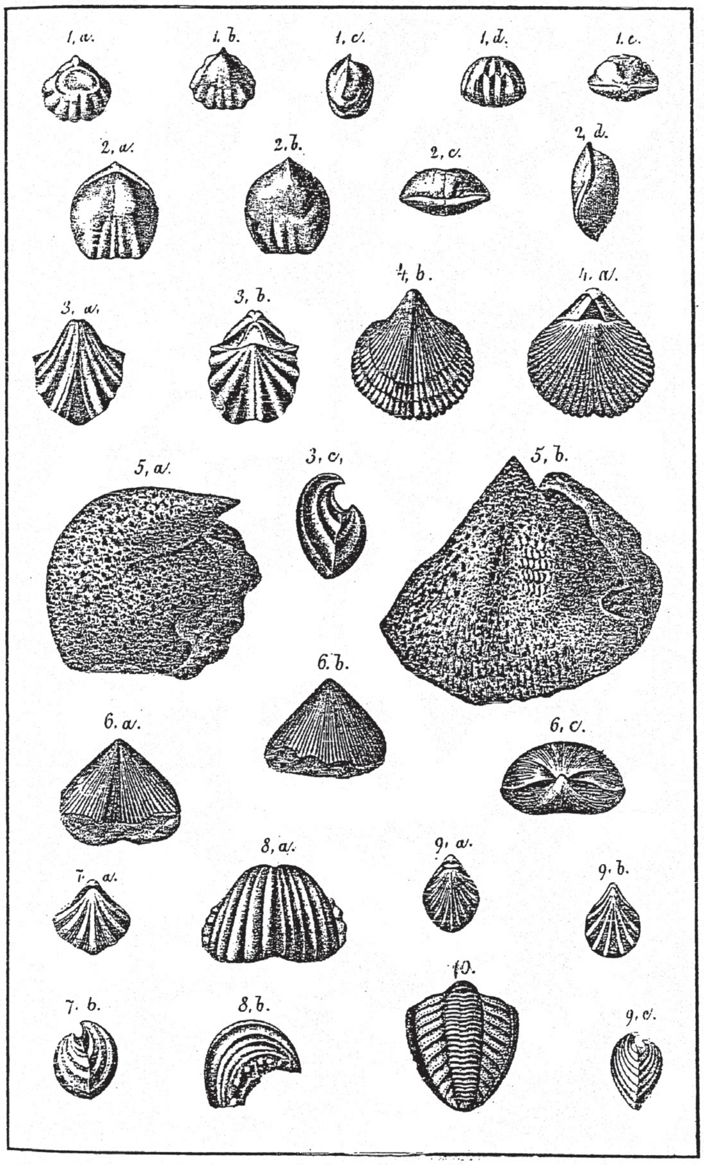


FIGURE 4. The single plate of Guadalupe Mountains Permian fossils illustrated by B.F. Shumard (1858, pl. 11). Original caption: 1, *Camerophoria* Swall.; 2, *Cam. bisulcata*; 3, *Spirifer sulcatus*; 4, *Spir. Mexicanus*; 5, *Strophalosia Guadalupensis*; 6, *Rhynchonella Guadalupae*; 7, *Retzia Meekiana*; 8, *Productus Popei*; 9, *Retzia papillata*; 10, *Phillipsia perannulata*.

clayey sandstone with numerous bands of black and white limestone (1200 ft); 2) dark-colored limestone (50 ft); and 1) upper or white limestone (1200-1500 ft). Tarr interpreted the structure of the range as an eastward dipping monocline, with its precipitous western face probably due to faulting. He considered the Guadalupe strata as "Upper Coal Measures" (Late Pennsylvanian) in age, because its fauna was quite different from that of marine (Lower) Permian beds discovered in the 1870s in north-central Texas, which correlated with the Kansas Permian, and which are associated with nonmarine strata bearing Early Permian vertebrate faunas. Tarr also believed, incorrectly, that the "upper white limestone" of the Guadalupe Mountains was stratigraphically below the limestones (now known to be Pennsylvanian and Early Permian in age) that compose many of the mountain ranges of southern New Mexico. Thus, he concluded that the Guadalupe sequence must be older than Permian.

Cummins extended his studies of the plains of western Texas into New Mexico, exploring the Llano Estacado from Tucumcari south along the Pecos River Valley. He apparently did not actually venture into the Guadalupe Mountains, as his comments on the range are very general. However, he did note (Cummins, 1892, p. 211), referring to the age of the Guadalupe strata, that the "fossils found would indicate that the horizon is about the middle of the Carboniferous formation, as seen along the eastern side of the plains. In the mountains there is a massive white limestone, first described by Dr. Shumard, in 1855, and supposed by him to be Permian, but none of the characteristic fossils were found in it, and its lithological characteristics are very different from the Permian which occur in the valley below and in the area east of the Staked Plains…"

Cummins did correctly identify the thick sequence of strata, "composed of sandstones, limestones, gypsum and beds of red and blue clay", occurring along the Pecos River Valley, from Fort Sumner southward, as Permian. No fossils were discovered; the determination was made "on lithological grounds as well as stratigraphic relations" (p. 212). He thus put to rest the idea, dating back to Blake, Hall, and Shumard, that this large area consists of Cretaceous exposures. Cummins also doubted that much artesian water would be obtained from the Llano Estacado, but devoted an unusual amount of attention to the soils, surface water and potential for irrigation in the Pecos valley, commenting enthusiastically on various canals and reservoirs then being constructed.

A third Texan, R. T. Hill, working for the U. S. Geological Survey (USGS), visited southeastern New Mexico in the 1890s in the course of preparing his monumental work on the physical geology, geography, and hydrogeology of the Texas region (Hill, 1900, 1901). There is little direct information on the geology of the Guadalupe Mountains in these publications, but he did include a geological map (Hill, 1900, fig. 14; Hill, 1901, pl. 2B; Fig. 5) of Texas and southeastern New Mexico that portrayed the views current at the turn of the 20th century. The Guadalupe and Sacramento Mountains were considered Carboniferous, bordered by a broad band of Permian strata to the east, around the Pecos Valley, and covered along the eastern New Mexico-west-central Texas boundary by nonmarine Tertiary deposits. By 1900, then, the prevailing view of the strata of the Guadalupe Mountains had shifted back to a Carboniferous age, rather than the Permian age advanced by B. F. Shumard more than 40 years before.

GIRTY, RICHARDSON, AND BEEDE, 1901-1910

During the opening years of the 20th century the USGS directed considerable attention to the geology of west Texas and adjacent areas of southeastern New Mexico, and it is with the work of G. H. Girty and G. B. Richardson that modern study of the stratigraphy and paleontology of the Guadalupe Mountains began. Girty focused mainly on the paleontology of the Guadalupian fauna, while Richardson studied the Guadalupe Mountains strata as part of a larger effort to understand the stratigraphy exposed throughout the region.

George H. Girty (1869-1939) was for several decades the USGS's primary expert on late Paleozoic fossils. He grew up in comfortable surroundings in Cleveland, Ohio, and received his B.

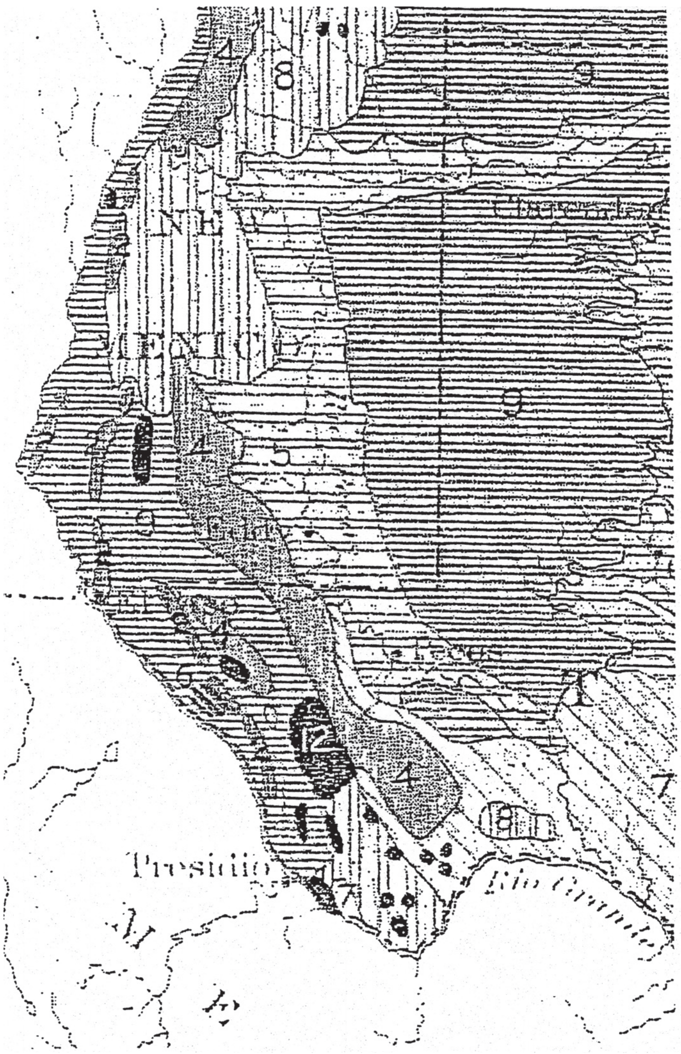


FIGURE 5. Portion of Hill's (1901, pl. 28) geologic map of eastern New Mexico and west Texas. Key: 2, Paleozoic and Mesozoic; 4, Carboniferous; 5, Permian; 7, Lower Cretaceous; 8, Upper Cretaceous; 9, nonmarine Tertiary; 12, later igneous.

A. degree in 1892 and Ph.D. degree in 1894, both from Yale. In 1895 he joined the Survey and shortly afterward embarked upon a highly productive career describing numerous entire invertebrate faunas, mainly from the western U. S., and producing taxonomic studies of various groups. His paleontological work on the faunas he studied, including several from New Mexico, remains the foundation on which subsequent studies are based. In addition, he contributed lists of identified taxa to dozens of papers written by others, based on specimens U.S.G.S. geologists would bring him from their field work for identification and age determination. A shy and formal man, responsible from an early age for caring for his widowed mother, he married late in life (age 56) and maintained strong artistic and musical interests. The last paragraph of Williams' (1940) memorial, too long to cite here, is an outstanding testament to Girty's qualities as a person and a scientist.

In September, 1901, Girty retraced Shumard's route (in reverse, from west to east) and spent 11 days collecting fossils and studying the stratigraphy of the southern end of the Guadalupes. In a preliminary report of his observations entitled "Upper Permian in western Texas", Girty (1902) repeated the stratigraphic section of Shumard (1858), but estimated the thickness of the upper white limestone at 1700 to 1800 ft, and of the middle yellow quartzose sandstone at 2000 to 2500 ft, both considerably greater than Shumard's estimates. Although he provided lists of taxa from each of the four units reported by Shumard, most were from the "upper white limestone" [Capitan Limestone], especially from a fossiliferous horizon about 1000 ft below the top of Capitan Peak. "The locality," Girty noted (p. 364) "was difficult of access, and could only be reached by hard climbing, so that the collections were less complete than might be wished." He reported also that this limestone "…is peculiarly massive and shows little evidence of bedding", but the significance of this aspect of the unit would not be apparent for another three decades. Girty stated that the faunas of the Guadalupe strata bore no resemblance to Carboniferous or Early Permian faunas of the Midwest, and were in fact (p. 368) "very different from any known in America elsewhere," being more closely related to Permian faunas of Europe and Asia. Girty proposed the term Guadalupian as a regional name of equal status to Mississippian and Pennsylvanian as then used in the U. S., and set about studying the fauna in detail.

In a subsequent paper, Girty (1905) further explored relationships of the Guadalupian faunas, as well as those of the underlying Hueco Formation, with faunas known from the Permian of Russia and elsewhere. He correctly correlated the Hueco with strata bearing the fusulinid *Schwagerina*, considering the Hueco approximately equivalent to the "Kansas Permian", although he doubted that the Kansas faunas were really Permian, stating that (p. 25) "[i]f the Capitan fauna is Permian, then certainly that of Kansas is not, for 2 Carboniferous faunas could scarcely have less in common." All things considered, Girty concluded that the Guadalupian fauna was distinctly younger than the "Kansas Permian."

Meanwhile, George B. Richardson began field work in the northern part of trans-Pecos Texas in 1903, and the following year published a lengthy and important paper (Richardson, 1904) on the geology of this region. Richardson (1872-1949) was born in New York City, received his B.S. and M.S. degrees from Harvard, and his Ph.D. degree in 1901 from Johns Hopkins. He began work with the USGS as an assistant geologist in 1896, and retired from the Survey in 1942. During his career with the USGS Richardson studied the areal, stratigraphic and structural geology of numerous states, and much of his work focused on the petroleum resources of the U. S. (Wood and Richards, 1951).

Richardson (1904) interpreted the Guadalupe Mountains as an eastward sloping monocline, and formally established the name Delaware Mountain Formation for the lower three of Shumard's units, and the name Capitan Limestone for the "upper white limestone." He also measured three relatively detailed stratigraphic sections for the Delaware Mountain Formation, consisting of as many as 17 units of interbedded sandstone and limestone totaling as much as 2300 ft in thickness, and presented extensive faunal lists. The Capitan Limestone, "a massive white rock…remarkably homogenous in physical appearance" (p. 41), was measured at 1700 ft thick. Both formations were definitely considered Permian in age. Richardson (1904, pl. 4A) also included one of the earliest photographs of the southern Guadalupe Mountains.

Richardson also named the Castile gypsum but was uncertain as to its stratigraphic relationship to the Capitan Limestone. He noted (p. 43-44) that it "appears that either the gypsum was deposited at or near the top of the Delaware Mountain formation as a lens which did not extend westward to intervene between the Delaware Mountain formation and the Capitan limestone in the Guadalupe Mountains, or that erosion removed [the Capitan]…before the deposition of the gypsum. Richardson tentatively concluded that "the Castile gypsum…[was] formed after the deposition and erosion of a part of the Capitan limestone." Richardson also named the Rustler Formation for the 200 ft-thick unit of limestone and sandstone above the Castile. A few fossils were not diagnostic of age, but he considered both formations to be Permian. Richardson's views on the relationship between the Capitan and Castile formations were perceptive for their time, and his 1904 paper marks a great advance in understanding the Permian stratigraphy of the Guadalupe Mountains region.

Richardson's structural interpretation of the Guadalupe Mountains, as a gently east-dipping monocline, was relatively simple. He observed, as had Shumard, that foothills west of Guadalupe Pass [Patterson Hills] included Delaware Mountain and Capitan strata dipping to the southwest, and his cross section (Fig. 6) indicates a broad anticline with its eroded axis within the valley between the Guadalupes and the western foothills. Richardson (1904, p. 53, 55) also noted that the high western escarpment of the southern Guadalupe and Delaware Mountains "suggests a fault", and that faulting "may be associated with this anticline, but if present, it is subordinate to the fold. There is need here for detailed work…" He pointed out that farther north, towards the New Mexico border, the foothills [Cutoff Mountain] are not separated by a valley from the main mass of the Guadalupe Mountains, and appeared to be faulted.

Richardson's geologic map and structural analyses, based on reconnaissance field studies in a large area of west Texas, are outstanding for their time, but of course have been modified by later work (e.g., King, 1948). King (p. 111) observed that although "one receives the impression at first that the rocks of the Dela-

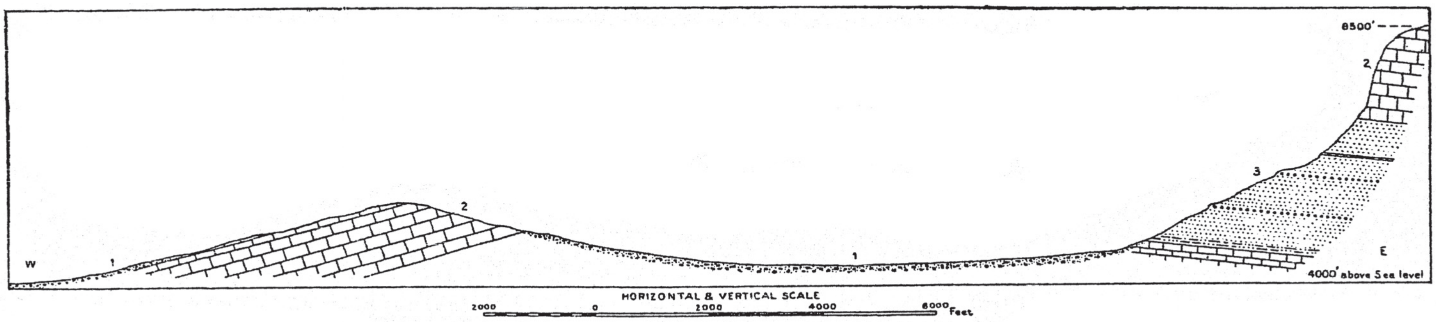


Fig. 1. **Section west from Guadalupe Peak.**
1. Pleistocene debris. 2. Capitan limestone.
3. Delaware Mountain formation.

FIGURE 6. "Section west from Guadalupe Peak" to Patterson Hills (Richardson, 1904, fig. 1).

ware and Guadalupe Mountains bend over to the west with little or no faulting", more detailed study reveals that faulting along the border fault zone along the western side of the Delaware and Guadalupe Mountains was by far the most significant process in elevating these mountains above the foothills and Salt Basin to the west, and that the structure of the foothills region likewise is complicated by extensive faults, which however are difficult to map because of alluvial cover.

Although not directly related to the Guadalupe Mountains, it is worth noting that Richardson (1904) also established, from exposures in the Franklin Mountains, the Bliss, El Paso and Hueco Formations. Later, Richardson (1908) added Montoya and Fusselman to the sequence of Paleozoic stratigraphic units exposed in trans-Pecos Texas. These units extend widely through southern New Mexico as well, and all are currently in use, forming major components of the southern New Mexico stratigraphic section. However, Richardson (1908, 1909) did not recognize Devonian or Mississippian strata within the sequence, and believed that the Hueco, which he thought to immediately underlie the Delaware Mountain Formation, was of Pennsylvanian age. Little new information on the stratigraphy of the Guadalupe Mountains was included in the 1908 and 1909 publications.

It took Girty seven years (among other projects) to complete his paleontological study of the Guadalupian faunas collected in 11 days in 1901. This study (Girty, 1908, but published early in 1909) is a 651-page volume that includes description of 326 species, more than half of them new. Nearly 40% of these are brachiopods, with bivalves, bryozoans, and gastropods each representing an additional 13 to 14% of the species diversity. He also noted (p. 13) that "sponges…are…unusually abundant and varied, developing novel and characteristic types of structures." Despite their abundance and diversity, Girty was well aware that he had sampled only a small portion of the Guadalupian faunas, for he explained (p. 12) that collections that "did justice to its richness and importance would greatly enhance the number in this report."

Girty made collections from the lower and upper parts of the Capitan Limestone, but by far the most diverse fauna was collected from about the middle of the formation. Additional material was obtained from several limestone and sandstone beds of the Delaware Mountain Formation, and from localities to the south of the Guadalupe Mountains as well. He reported that faunas from various levels of the two formations differed significantly and recognized (p. 23) four "rather well-marked faunas" from this sequence. He was impressed by how distinctive these faunas, taken together, were from all other late Paleozoic faunas in the U. S. While considering it possible that the Guadalupian faunas were an "extremely local development", Girty also suggested the possibilities that similar faunas were present elsewhere but had not yet been discovered, that the Guadalupian beds were represented elsewhere by strata, such as red beds, that lack fossils, or that Guadalupian deposits were once more extensive but had been removed by erosion.

In assessing the relationships of the Guadalupian faunas, Girty (1908) compared them extensively with known Carboniferous and Permian faunas from around the world, finding little similarity with any previously described faunas. He spent 11 pages on details relating to the age of the "Kansas Permian" and how it was related to the Permian of Russia, still doubting that Kansas Permian faunas could be within the same period as his vastly different Guadalupian fauna. He also wrestled with the task of explaining whether the distinctive nature of the Guadalupian fauna reflected a younger age than other Permian faunas, or represented a unique fauna in an unusual depositional environment that was possibly contemporaneous with known earlier Permian or even Carboniferous faunas. As a result of needlessly overanalyzing these possibilities, Girty retreated from his earlier [and correct] designation of the Guadalupian fauna as Late Permian (p. 41): "Subsequent studies have led me to believe that it was ill advised to call the Guadalupian fauna upper Permian…and that it would be unwise at present to correlate the Guadalupian series with any definite stage of the Russian section. …I no longer hold to the assignment of the Guadalupian to the upper Permian."

J. W. Beede (1909), an expert on late Paleozoic stratigraphy, especially of the Midwest, reviewed Girty's monograph and put his finger on a major defect of Girty's analysis (p. 679): "It is very difficult to determine what Dr. Girty's conclusion as to the relative age of the Guadalupian, Russian, and Kansas deposits is." Beede politely clarified some of the "Kansas Permian" age issues, pointed out that both the Kansas and Guadalupian faunas appeared to be Permian in age, and saw no reason why the distinctive Guadalupian fauna could not be later Permian in age.

Although the initial field work of Girty and Richardson had focused on the southern (Texas) part of the Guadalupe Mountains, both men quickly extended their stratigraphic observations into southeastern New Mexico in order to determine what became of the distinctive Guadalupian facies and fauna to the north and northeast. Girty (1909) provided "new stratigraphic evidence" relating to the Guadalupian fauna from personal observation and from a reconnaissance survey of the Sacramento Mountains and areas to the east conducted by Richardson. One key point of this paper is the following (p. 138):

> "In its northward extension the massive Capitan limestone merges along strike into thin-bedded limestone and sandstone, the limestone element finally disappearing altogether or being represented only by thin local beds. Still farther to the north, the strata take on a red color and become part of the "Red Beds" series. Northward from Guadalupe Point fossiliferous horizons become rare in the Capitan and…tend to show that with the change in lithology the fauna also changes character, so that practically nothing of the typical Guadalupian facies is left."

As a general statement, this is an accurate portrayal of the transition northward from the Capitan Limestone to the backreef deposits of the Artesia Group.

Girty stated that the limestone capping the Sacramento Mountains and exposed near Cloudcroft [San Andres Formation] was underlain by about 3000 ft of red beds [Abo and Yeso Formations], but miscorrelated this limestone with the upper part of the Hueco formation. He did recognize that part of the Hueco is represented by these red beds, which is correct; the Hueco and Abo Formations do interfinger in the Sacramento Mountains. Analysis of fossils from the limestone at Cloudcroft led Girty to suggest a close resemblance to the Manzano Group [an abandoned term] fauna of the Rio Grande valley. As the Manzano Group included the Abo, Yeso, and San Andres Formations, all units established by Lee and Girty (1909), this resemblance is not surprising. What is surprising is that Girty failed to recognize the San Andres Formation in the Sacramento Mountains.

Girty also reported sparse marine fossils from beds he considered to be above the limestone at Cloudcroft, at localities east of the Sacramento Mountains and in the northern Guadalupe Mountains, and believed these to represent the northern extension of the Guadalupian strata [actually these localities are from middle and upper portions of the San Andres]. Despite this miscorrelation, Girty's conclusion was accurate (p. 141): "…it is apparent that the Guadalupian fauna in a characteristic form is not indicated by our collections in the northward extension of the Guadalupian rocks…" Girty failed to recognize that there are actually two "red bed" sequences in the region north of the Guadalupe Mountains, one below the San Andres limestone, and one above, with only the latter [current Artesia Group] sequence representing the northern extent of Guadalupian strata. Given the large area, absence of detailed geologic knowledge, scattered outcrops, lithological similarity of different red-bed sequences, and too few fossils for reliable age dating, Girty's confusion is understandable.

More importantly, this view of the limited geographic extent of the typical Guadalupian fauna led Girty to surmise that (p. 144) "…it seems to render untenable the proposition that the peculiarities of the Guadalupian fauna are due to position in time, which I had employed as a working hypothesis, and of course to make it necessary to abandon the tentative correlations [that the Guadalupian is of Late Permian age] which developed from it." What, then, was the age of the Guadalupian fauna? Girty referred to a 1500 ft-thick sequence of marine strata near Alamogordo and La Luz [Holder and Laborcita Formations of present usage] as undeniably Pennsylvanian. The overlying red beds, with a fauna similar to that of the Manzano Group, and the apparently correlative Hueco Formation were also considered of late Carboniferous age, as were the overlying poorly fossiliferous strata supposed to represent the northward extension of the Guadalupian. Beede, on the other hand, insisted upon the Permian age of the "Kansas Permian" beds. Girty concluded (p. 145) therefore, that "the Guadalupian beds represent a horizon below the base of the Kansas "Permian" as determined by the Wreford Limestone" and were equivalent to the Gzelian of the Russian section [now, as then, recognized as latest Carboniferous]. He only hedged a bit by noting that the Guadalupian fauna is not much like that of the Gzelian, and that the Hueco-Guadalupian thickness, 10,000 ft, "is a rather great thickness to represent the Russian formation," thus implying that the Guadalupian section might be younger.

During the seven years from 1902 to 1909, then, Girty went from a definite Late Permian age assignment for the Guadalupian strata, to a belief that they were older than the Early Permian Kansas marine section, and possibly not even Permian in age at all! Incomplete knowledge of the late Paleozoic stratigraphy of southeastern New Mexico, inaccurate age determinations for Permian units such as the Hueco Formation and "Manzano Group", and incorrect assumptions in attempting to correlate the New Mexico strata with the Midcontinent section are partially responsible for the chain of reasoning that resulted in a progressively older, less accurate age for the strata of the southern Guadalupe Mountains. Equally important, however, is the flaw in logic that led Girty to believe that because the Guadalupian fauna was geographically and environmentally restricted, it must simply represent a facies of Lower Permian or earlier strata known to the north in New Mexico and in Kansas. He did not consider the possibility that the explanation for the distinctive nature of the Guadalupian fauna might be that this fauna was BOTH younger than any other Permian fauna in North America, AND represented an unusual depositional environment not present elsewhere on the continent.

Richardson (1910) contributed additional stratigraphic details of his reconnaissance survey of southeastern New Mexico, with special attention to the red beds of the Pecos Valley. His conclusions essentially parallel those of Girty (1909) and may be summarized as follows: 1) the Hueco Formation correlates with the Magdalena and Manzano Groups and all are Upper Carboniferous; and 2) the Guadalupian series lies between the Hueco and the red beds of the Pecos Valley, which at least in their upper strata are of Permian age. Both Girty and Richardson realized that the youngest red beds of the Pecos region probably correlated with strata of similar lithology in the Midcontinent that are of later Permian age, but believed that these strata were far above the level of the Guadalupian beds.

J. W. Beede also visited southeastern New Mexico in 1909 to view the Guadalupian beds and to try to correlate them with the Kansas section. Compared with the papers of Girty and Richardson discussed above, Beede's (1910) contribution is a model of clarity, but not much more enlightening in terms of conclusions about the age of the Guadalupian. Beede examined and described strata in the northern Guadalupe Mountains, in the Carlsbad and Lakewood areas, and elsewhere along the Pecos Valley. The Capitan Limestone, he reported, changes rapidly northward to a sequence of relatively thin limestone and dolomite, which gives way to yellowish sandstone and shale eastward, as these strata gently dip beneath red beds; near Carlsbad, gypsum also becomes significant in the red-bed sequence. Using sparse marine fossils from several red-bed intervals, especially near a locality first reported by Fisher (1906), Beede pointed out their general similarity to taxa he had studied in the Whitehorse and Quartermaster Formations, of Late Permian age, in Oklahoma and the Texas panhandle. Stratigraphically these fossils ranged from an interval equivalent to the top of the Capitan Limestone into the overlying red beds.

Beede's correlation chart (1910, fig. 1) and accompanying text show the upper Capitan as approximately equivalent to the Whitehorse [both are presently considered Guadalupian in age], and below a higher series of red beds correlated with the Quartermaster [now known to be post-Guadalupian, Ochoan strata]. These correlations are generally accurate. However, Beede believed the Capitan represented a much longer period of time than it actually does, and thus he correlated the middle Capitan with the Wellington red beds [Leonardian], and stated (p. 138) that "the base of the Capitan falls near the bottom of the Elmdale formation stratigraphically." The Elmdale is an obsolete term for the interval between the Americus and Neva Limestones in Kansas, and includes strata traditionally included in the "Kansas Permian" [this interval straddles the present Pennsylvanian-Permian boundary]. Thus, as Beede (p. 139) noted, the Guadalupian fauna "may well have been an early Permian fauna," and in fact he portrayed it on an early paleogeographic map (1910, fig. 2) essentially as an isolated southern marine area (thus accounting for the distinctive Guadalupian fauna) separated by mostly continental red beds from a larger area of Early Permian [now Wolfcampian] marine strata in Kansas (Fig. 7). Beede further portrayed the underlying Delaware Mountain Formation as extending down to the Cherokee Shales of Kansas, which are of Middle Pennsylvanian age. By assigning the Guadalupian strata a long age range that included each of the three specific ages that had been proposed – Late Carboniferous (Pennsylvanian), "Kansas Permian" (Early Permian), and Late Permian – Beede contributed little in determining the actual age of the Guadalupian strata.

STUDIES TO 1928

After 1909, Girty went on to other studies and authored no additional papers on the age of the Guadalupian strata. He did continue to identify fossils collected by others from the area (e.g., in Darton and Reeside, 1926), and contributed about 15 pages of commentary on the paleontology of various units ultimately described by King (1948). Richardson (1914, p. 5) expressed the view that evolved from the discussions mentioned above:

> "The Delaware Mountain formation and overlying Capitan limestone…constitute the Guadalupe group and contain the unique Guadalupian fauna…which is strikingly different from that of the underlying Hueco formation [considered Pennsylvanian]. For this reason and because of certain resemblances between its fauna and the late Paleozoic faunas of Asia and Europe, the Delaware Mountain formation [and Capitan limestone] is classified with the Permian."

The Guadalupian units were portrayed as being unconformably overlain by the Castile and Rustler Formations, "members of the group of Permian red beds that outcrop in the Pecos Valley," (p. 2), which were in turn overlain by younger Permian red beds. This general scheme was adopted by others working in Texas and New Mexico at the time (e.g., Baker, 1915). In addition, detailed study of the Glass Mountains, some 150 miles southeast of the Guadalupes, revealed an even thicker sequence of Late Paleozoic carbonates with Guadalupian fossils, which Udden (1917) believed to be in part equivalent to the Capitan Limestone and of Permian age.

One curious footnote to the general agreement on a Permian age for the Castile and Rustler Formations was a paper by Udden (1915) entitled "The age of the Castile Gypsum and Rustler Springs Formation." In it, Udden reported on cuttings from an oil test hole supposedly drilled in the Rustler Hills through the Castile, some of which yielded Cretaceous foraminiferans. He

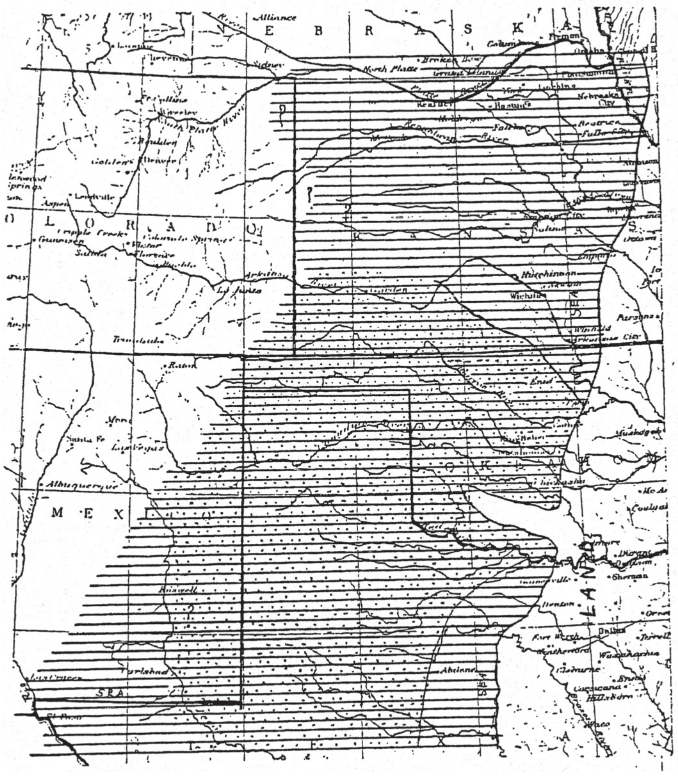


FIGURE 7. Beede's (1910, fig. 3) paleogeographic map showing his interpretation of the Guadalupian and "Kansas Permian" marine strata (horizontal lines) separated by red beds and evaporates (stippled area within horizontal lines).

concluded that the Castile and Rustler Formations were Mesozoic in age, probably Early Cretaceous. Later workers ignored this report, and it is clear from the stratigraphic units Udden described (which contain very little gypsum) that subsurface Cretaceous beds, not the Castile Formation, had been sampled.

As suggested earlier, part of the problem in arriving at an accurate age for the Guadalupian strata was Girty's (in Lee and Girty, 1909) identification of the "Manzano Group" (Abo, Yeso, San Andres) faunas as Pennsylvanian. Girty believed the upper part of the Manzano Group correlated with at least part of the Capitan Limestone, and that part of the Manzano Group interfingered in the Sacramento Mountains with the Hueco Formation, which underlay the Delaware Mountain Formation and which Girty also believed to be Pennsylvanian based on its fossils. This mindset made it appear most reasonable that the Guadalupian was of Late Pennsylvanian or Early Permian age. However, during the years 1915-1920 this view changed.

Willis Lee (1917), who had established the Manzano Group and named the Abo, Yeso, and San Andres Formations, emphasized the widespread unconformity in the western U. S. that often separates marine strata from overlying red-bed sequences, and suggested that this unconformity marked the boundary between the Pennsylvanian and Permian. In developing this idea further, Lee (1918) introduced the term Ancestral Rocky Mountains and attributed to their uplift both the unconformity at the top of marine Pennsylvanian strata and the influx of eroded continental red sediments across former marine environments at the beginning of the Permian. He thus regarded the "Manzano Group" as Permian. Lee (1920) further discussed this idea, and noted that the USGS had approved reference of the Manzano Group to the Permian in July, 1919. With the thick Abo-Yeso-San Andres sequence considered Permian, Guadalupian strata could only have been deposited well after the Permian began.

The only substantial work between 1910 and 1920 that provided new field observations of the Permian of southeastern New Mexico, including the Guadalupe Mountains, was a wide-ranging paper by Baker (1920). He traced Pennsylvanian and Permian strata from exposures along the Rio Grande Valley across eastern new Mexico and included detailed descriptions of the Abo, Yeso, San Andreas [sic], Delaware Mountain and Capitan formations. Baker made several important observations. First, he verified the Early Permian age of the Yeso, and by implication of the overlying San Andres. Second, he documented the northward thinning and wedge-out of the Delaware Mountain Formation (p. 114), "…the upper beds passing to the north into limestone only a little less massive than the overlying Capitan limestone [first recognition of the unit now called the Goat Seep Limestone]", or, at El Paso Gap, disappearing entirely so that the San Andres is directly overlain by the Capitan Limestone. Third, he observed the Capitan changing abruptly into a part of the "Pecos Valley red beds." Beginning at Rocky Arroyo, in the east-central Guadalupe Mountains, he documented (p. 115) a transition southward from strata consisting of "red clay, gray and red sandstone, light gray limestone, with many interbeds of gypsum", to thin-bedded limestone and brown sandstone, and then "the limestone becomes very heavy-bedded and represents typical Capitan" – a portion of the Artesia Group of present usage transitioning into the Capitan Limestone. Using well data, he also showed that salt and gypsum units of the red beds occurred above the San Andres Formation in the subsurface near Roswell, noting also (p. 117) that the deeper borings "penetrate both the upper red beds and the lower Manzano red beds [Abo and Yeso], the two series being separated by the intervening San Andreas [sic] limestone." These observations clarified important aspects of regional Permian stratigraphic relationships of the Pecos Valley and the mountains to the west, including the Guadalupe Mountains.

USGS work in southeastern New Mexico during the 1920s included studies of salt and potash resources as well as evaluation of petroleum prospects. In addition, N. H. Darton, prolific contributor to New Mexico geological knowledge, studied the Guadalupe Mountains region in preparing his treatise on the geology of the entire state (1928). Darton (1921) briefly discussed the salt deposits of southeastern New Mexico and west Texas, known mostly from subsurface data, and concluded that they represented a facies of the Manzano Group "of undoubted Permian age", and were part of a thick sequence of red shale, gypsum and anhydrite. A cross section (fig. 38) shows the salt bed [Salado Formation] underlain by a thicker anhydrite unit [Castile gypsum], and overlain by anhydrite, limestone and red beds [Rustler Formation]. The relationship of these strata with Guadalupian strata was not addressed. The following year, Darton (1922) considered the "Pecos Valley red beds" to comprise the upper part of his Chupadera Formation (a short-lived name coined by Darton for the combined Yeso and San Andres Formations in areas were they could not be differentiated), as well as beds overlying the Chupadera. He noted (p. 182) that he had traced [erroneously, see below] the Chupadera southward into the Delaware Mountain and Capitan formations of Texas. Hoots (1925), in studying the distribution of salt and potash in this area, recognized that the Rustler Formation in the Pecos Valley is (p. 73) "of younger Permian age than Darton's Chupadera formation", and suggested that both the Rustler and underlying Castile gypsum were likely of Late Permian age.

The definitive USGS interpretation of the structure, stratigraphy, and age of the strata of the Guadalupe Mountains region was published by Darton and Reeside (1926); a shorter version appears in Darton (1926). They cautiously noted (p. 414) that the Delaware Mountain and Capitan formations (Guadalupe Group) "carry the rich and very distinct Guadalupian (Permian) fauna which Girty has suggested may possibly be younger than any other Permian strata deposited under similar conditions in the United States." Opinions were shifting back to Girty's original Late Permian age assignment for the Guadalupian strata. Schuchert (1927) declared unequivocally that the Capitan Limestone and its equivalent strata in the Glass Mountains were of Late Permian age, and (Schuchert, 1928, fig. 6), for example, portrayed the Capitan and upper Delaware Mountain Formations as Upper Permian, and the lower part of the Delaware Mountain as upper Lower Permian.

The Delaware Mountain Formation was described essentially as Richardson (1904) had defined it, with a thick medial sandstone with thinner dark limestones below and above (Shumard's units 4 to 2). Darton and Reeside asserted that it and the Capitan limestone graded northward into the Chupadera Formation. In this transition, (p. 419) "the lower strata of the Capitan limestone and the thick dark and gray limestones of the lower part of the Delaware Mountain formation grade laterally into lower and medial members of the Chupadera formation, and Guadalupe fauna gives place to Manzano fauna." Further, Darton and Reeside described a "medial gypsum member" (formalized as the Seven Rivers gypsiferous member by Meinzer et al., 1926), and an overlying Carlsbad Limestone Member of the Chupadera Formation, which constituted a northward extension of less massive limestones from the upper part of the Capitan limestone. The Carlsbad Member was reported to thin and give way to red beds some distance north of Carlsbad. This supposed transition of the Guadalupe Group northward into the Chupadera Formation is shown in several cross sections (Fig. 8), and their geologic map of the region (fig. 1) conveniently shows the former unit ending at

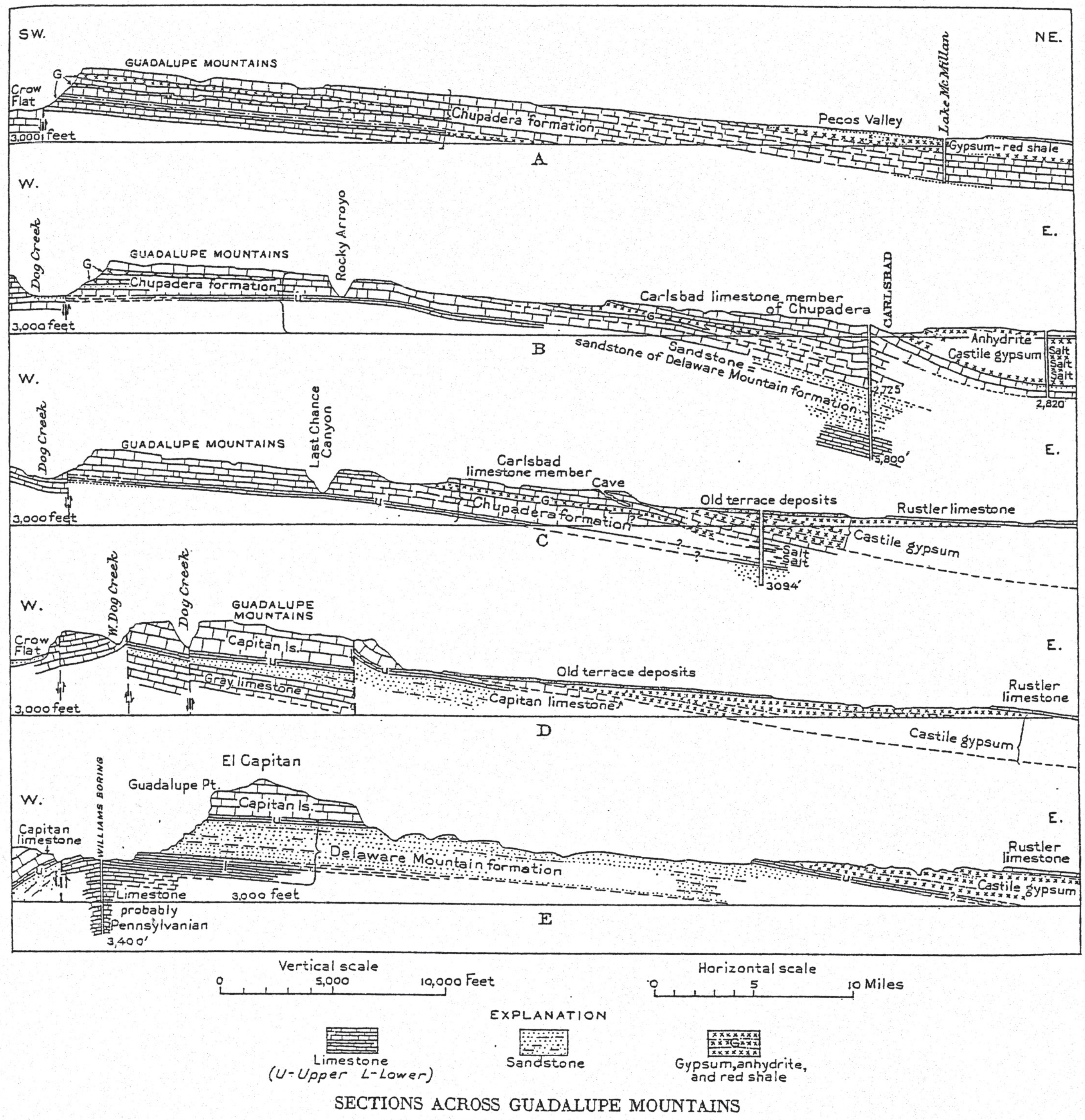
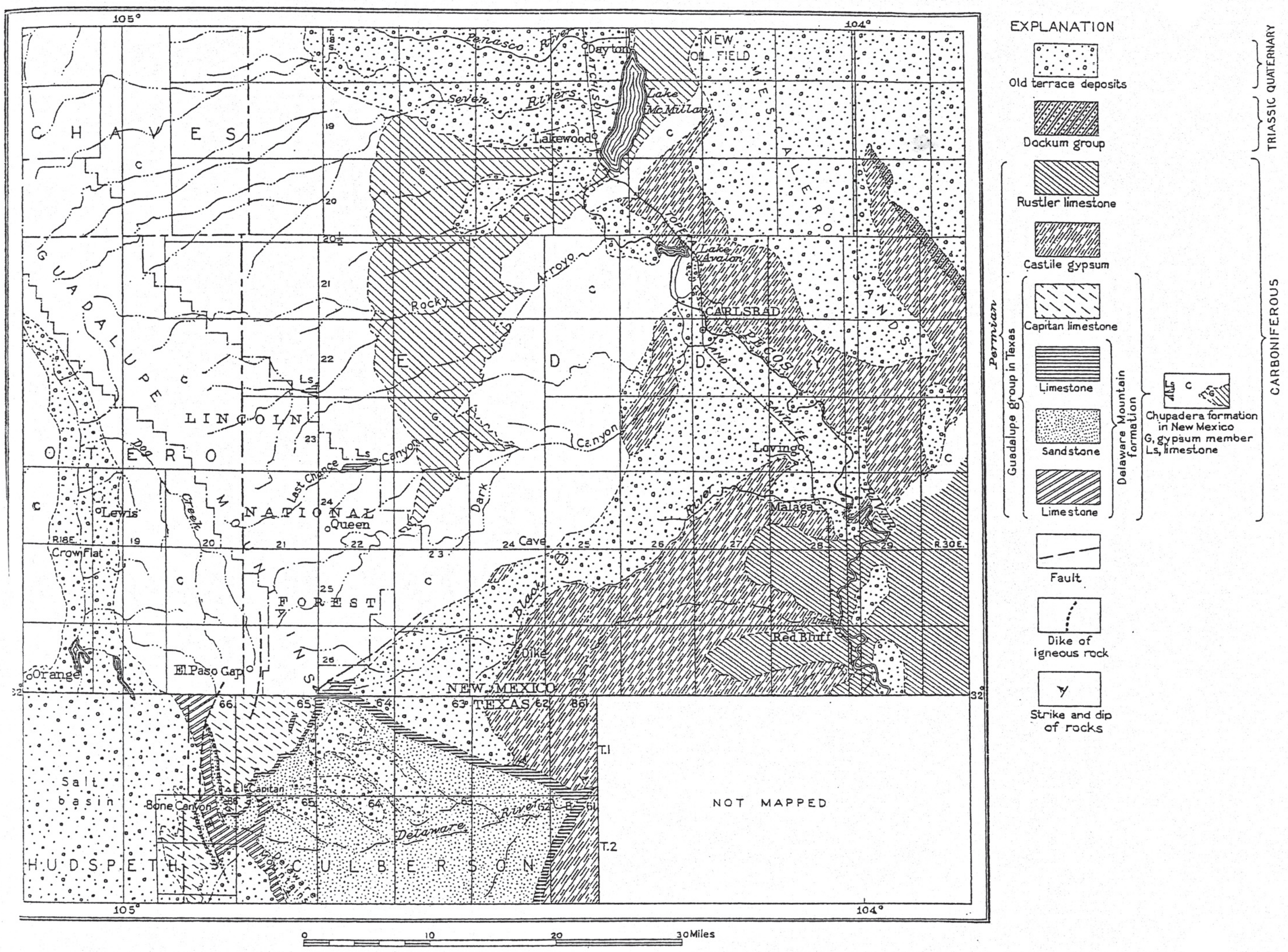


FIGURE 8. Cross sections through Guadalupe Mountains to Pecos Valley (Darton and Reeside, 1926, fig. 2; reproduced from Darton, 1928, pl. 50), showing their interpretation of the Permian stratigraphy, including the Chupadera Formation becoming the Capitan and Delaware Mountain formations to the south.



GEOLOGIC MAP OF GUADALUPE MOUNTAIN REGION

FIGURE 9. Darton and Reeside's (1926, fig. 1; reproduced from Darton, 1928, pl. 49) geologic map of the Guadalupe Mountains region. Note "boundary-line" contact between Guadalupian strata and Chupadera Formation.

the New Mexico-Texas boundary, with the Chupadera Formation composing all of the strata of the Guadalupe Mountains north of the boundary and northeastward through Carlsbad (Fig. 9).

The correlation of the Chupadera with Guadalupian strata is somewhat peculiar and was based on several misconceptions. As originally defined (Darton, 1922) the Chupadera included the Yeso and San Andres formations, which even at the time were known to be of Early Permian (Leonardian) age (see King and King, 1929). The Chupadera includes abundant red beds, evaporates, and carbonates; Darton and Reeside (1926) either miscorrelated these lithologies with the younger sequence of similar lithologies now recognized as the Artesia Group (the Guadalupian backreef facies of the Capitan Limestone), or they extended the Chupadera upward to include Artesia Group strata without explicitly stating (or perhaps realizing) that they were doing so. Part of the confusion was related to the contemporary view that the lower limestone unit of the Delaware Mountain Formation was of Guadalupian age (see below), when in fact it (now the Bone Spring and Victorio Peak formations) is of Leonardian age and does approximately correlate with the San Andres Formation. Correlation of the upper Chupadera (San Andres) with these lower Delaware Mountains limestones, supposed to be Guadalupian, may have encouraged Darton and Reeside (1926) to correlate the entire Chupadera with the entire Guadalupian in the Guadalupe Mountains.

Darton and Reeside attributed the change in faunas northward to (p. 416) "different conditions of deposition, possibly the presence in the waters of increased amounts of saline constituents [related to evaporite deposition farther north] inimical to the Guadalupian [fauna]", but as noted, failed to realize that the Yeso-San Andres ("Manzano") faunas were also older than the typical Guadalupian faunas of the upper Delaware Mountain and Capitan formations. Their term Carlsbad Limestone has faded from use in recent decades, and these limestones are now recognized as near-reef carbonate facies of the Yates and Tansill Formations of the upper Artesia Group. Darton and Reeside also recognized that the Carlsbad (upper Capitan) limestones dip beneath the Castile gypsum in New Mexico, but in Texas the Castile rests directly on Delaware Mountain strata. Finally, they discussed the relationships of the black "lower limestone member" of the Delaware Mountain Formation, as well as an overlying gray limestone member below the thick sandstone of this formation. Based on Girty's fossil identifications, these limestones were said to be Guadalupian, but later workers (see King and King, 1929; King, 1948) removed these units from the Delaware Mountain Formation, recognized their Leonardian rather than Guadalupian age, and named them the Bone Spring and Victorio Peak formations, respectively.

Darton (1928), in his "red beds" volume, a remarkable summation of the geology of New Mexico, repeated the interpretations of Darton (1926) and Darton and Reeside (1926) with little change. Ironically, as Darton's volume was rolling off the presses, data was being assembled that, when published the following year, would result in a paradigm shift in the interpretation of the structure and stratigraphy of the Guadalupe Mountains.

One other aspect of the study of Guadalupe Mountains geology during the 1920s deserves mention, although it will not be discussed in detail here. Carlsbad Cavern, which had been intermittently and very incompletely explored since the late 1800s, began to be scientifically explored and studied. USGS geologist Willis Lee first visited the caverns in 1923, spoke and wrote highly of its importance, and was instrumental in its designation as a National Monument in October, 1923. Lee took a leave of absence from the USGS to become temporary custodian of the Monument, and led an expedition the following year to better map and photograph the caverns (see Meyer and Halliday, 1991, for a detailed account of early explorations, and Hill, 1987 for later geologic studies).

EPILOGUE

Although relatively few publications on the geology of the Guadalupe Mountains appeared between 1910 and 1928, much information, especially subsurface data, was being accumulated as a result of exploration for petroleum in west Texas and southeastern New Mexico. Initially, this effort yielded little oil, but in May, 1923 the first major Permian basin field in west Texas (near Big Lake, south of Midland) was developed, followed in April, 1924 by the first large commercial well in southeastern New Mexico, near Artesia (Christiansen, 1989). Intensive production and exploration drilling stimulated renewed interest in the stratigraphy of Permian exposures in the Guadalupe Mountains area in order to better understand the stratigraphic complexities being encountered in the subsurface. Much of this information was brought together in the landmark "Symposium on Pennsylvanian and Permian stratigraphy of southwestern United States" published in the August, 1929 issue of the Bulletin of the American Association of Petroleum Geologists. Many of the papers were written by oil company geologists. That symposium followed by two months the seminal publication by Lloyd (1929) interpreting the Capitan Limestone as a gigantic barrier reef and recognizing backreef and basinal forereef facies. These papers provided a wealth of new stratigraphic detail, new facies interpretations, and new names that both rendered obsolete some of Darton and Reeside's (1926) interpretations and stimulated further studies that continue to the present. Discussion of this new chapter in the study and understanding of the Guadalupe Mountains is beyond the scope of this paper, but has been summarized by Brezina (in Cys et al., 1977) and Hill (1996).

Girty's (1908) comment that the number of species treated in his monograph on the Permian paleontology of the Guadalupe Mountains would be much enhanced by additional collecting proved prescient. Intensive collecting efforts, begun in 1939 in the Glass Mountains and later extended to the Guadalupes and other areas, produced many tons of limestone blocks that were then treated with acid at the Smithsonian Institution and American Museum of Natural History to remove exquisitely preserved silicified fossils. Resulting studies of the faunas have yielded monographs or series of papers on the brachiopods, sponges, fusulinids, cephalopods, gastropods, bivalves, fenestrate bryozoans, calcareous algae, and other groups. Nearly 1000 species of brachiopods alone have been recognized from the Permian of west Texas and southeastern New Mexico, and studies of the paleontology of the Guadalupe Mountains faunas continue to this day.

ACKNOWLEDGMENTS

I thank Carol Hill and Jim W. Adams for their thoughtful and enthusiastic reviews of the manuscript, and for their suggestions on improving it.

REFERENCES

Adams, J.W., 1988, Historic Guadalupe Pass; *in* Reid, S.T., Bass, R.O., and Welch, P., eds., Guadalupe Mountains revisited: West Texas Geological Society 1988 Field Seminar, Publication 88-84, p. 191-196.

Anonymous, 1889, Benjamin Franklin Shumard: The American Geologist, v. 4, p. 1-6.

Babcock, J.A., 1977, Calcareous algae, organic boundstones, and the genesis of the upper Capitan Limestone (Permian, Guadalupian), Guadalupe Mts., west Texas & New Mexico; *in* Hileman, M.E. and Mazzullo, S.J., eds., Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and west Texas: 1977 Field Conference Guidebook, Permian Basin Section, S.E.P.M., Publication 77-16, p. 3-44.

Baker, C.L., 1915, Geology and underground waters of the northern Llano Estacado: Texas University Bulletin no. 57, 225 p.

Baker, C.L., 1920, Contributions to the stratigraphy of eastern New Mexico: American Journal of Science, 4th series, v. 49, p. 99-126.

Bartlett, J.R., 1854, Personal narrative of explorations and incidents in Texas, New Mexico, California, Sonora, and Chihuahua…, vol. I: New York, D. Appleton & Co., 506 p.

Beede, J.W., 1909, [Review of] The Guadalupian fauna, by George Herbert Girty: Journal of Geology, v. 17, p. 672-679.

Beede, J.W., 1910, The correlation of the Guadalupian and Kansas sections: American Journal of Science, 4th series, v. 30, p. 131-140.

Blake, W.P., 1856, Report on the geology of the route near the thirty-second parallel; prepared from the collection and notes of Capt. Pope: Explorations and surveys for a railroad route from the Mississippi River to the Pacific Ocean, U.S. 33rd Congress, 2nd Session, Senate Executive Document 78 and House Executive Document 91, v. 2, 50 p.

Branson, C. C., 1961, Proposed American standard of Early Permian (?) rocks, a century-old controversy: Oklahoma Geology Notes, v. 20, p. 229-235.

Bryan, F.T., 1850, Report of Lieutenant F.B. Bryan; *in* Reports of Secretary of War with reconniassances of routes from San Antonio to El Paso: U.S. 31st Congress, 1st Session, Senate Executive Document 64, v. 14, p. 14-25.

Byrne, J.H., 1855, Appendix A. Diary of the expedition; *in* Pope, J., Report of exploration of a route for a Pacific Railroad near the thirty-second parallel of latitude from the Red River to the Rio Grande: Reports of Explorations and Surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean…, vol. 2: 33rd Congress, 2nd Session, Senate Executive Document 78, p. 51-95.
Christiansen, P.W., 1989, The story of oil in New Mexico: N.M. Bureau of Mines and Mineral Resources, Scenic Trips to the Geologic Past, no. 14, 112 p.
Cooper, G.A., and Grant, R.E., 1972, Permian brachiopods of west Texas, I: Smithsonian Contributions to Paleobiology, no. 14, p. 1-231.
Cummins, W.F., 1892, Report on the geography, topography, and geology of the Llano Estacado or staked plains with notes on the geology of the country west of the plains: Texas Geological Survey, Annual Report 3, p. 127-223.
Cys, J.M. and 10 others, 1977, Capitan reef – evolution of a concept; *in* Hileman, M.E., and Mazzullo, S.J., eds., Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and west Texas: 1977 Field Conference Guidebook, Permian Basin Section, S.E.P.M., publication no. 77-16, p. 201-322.
Darton, N.H., 1921, Permian salt deposits of the south-central United States: U.S. Geological Survey, Bulletin 715, p. 205-223.
Darton, N.H., 1922, Geologic structure of parts of New Mexico: U.S. Geological Survey, Bulletin 726, p. 173-275.
Darton, N.H., 1926, The Permian of Arizona and New Mexico: American Association of Petroleum Geologists Bulletin, v. 9, p. 819-852.
Darton, N.H., 1928, "Red beds" and associated formations in New Mexico; with an outline of the geology of the state: U.S. Geological Survey, Bulletin 794, 356 p.
Darton, N.H., and Reeside, J.B. Jr., 1926, Guadalupe Group: Geological Society of America Bulletin, v. 37, p. 413-428.
Emory, D.C., 2000, Running the Line: men, maps, science, and art of the United States and Mexico boundary survey, 1849-1856: New Mexico Historical Review, v. 75, p. 221-265.
Ferguson, W.K., 1959, Geology and politics in frontier Texas, 1845-1909: Austin, University of Texas Press, 233 p.
Fisher, C.A., 1906, Preliminary report on the geology and underground waters of the Roswell artesian area, New Mexico: U.S. Geological Survey, Water-supply Paper 158, 29 p.
French, S.G., 1850, Report of Captain S. G. French; *in* Reports of the Secretary of War with reconnaissances of routes from San Antonio to El Paso: U.S. 31st Congress, 1st Session, Senate Executive Document 64, v. 14, p. 40-54.
Girty, G.H., 1902, The upper Permian in western Texas: American Journal of Science, 4th series, v. 14, p. 363-368.
Girty, G.H., 1905, The relations of some Carboniferous faunas: Proceedings of the Washington Academy of Sciences, v. 7, p. 1-26.
Girty, G.H., 1908, The Guadalupian fauna: U.S. Geological Survey, Professional Paper 58, 651 p.
Girty, G.H., 1909, The Guadalupian fauna and new stratigraphic evidence: Annals of the New York Academy of Science, v. 19, no. 6, part I, p. 135-147.
Goetzmann, W.H., 1959, Army exploration in the American West, 1803-1863: Lincoln, University of Nebraska Press, 489 p.
Goetzmann, W.H., and Williams, G., 1992, The atlas of North American exploration: from the Norse voyages to the race to the pole: New York, Prentice Hall, 224 p.
Hall, J., 1857, Geology and paleontology of the boundary; *in* Emory, W.H., Report on the United States and Mexican boundary survey made under the direction of the Secretary of the Interior: U.S. 34th Congress, 1st Session, Senate Executive Document 108, v.1, pt. 2, p. 101-140.
Hileman, M.E., and Mazzullo, S.J., eds., 1977, Upper Guadalupian facies, Permian reef complex, Guadalupe Mountains, New Mexico and west Texas: 1977 Field Conference Guidebook, Permian Basin Section, S.E.P.M., publication no. 77-16, 508 p.
Hill, C.A., 1987, Geology of Carlsbad Cavern and other caves in the Guadalupe Mountains, New Mexico and west Texas: New Mexico Bureau of Mines and Mineral Resources, Bulletin 117, 150 p.
Hill, C.A., 1996, Geology of the Delaware Basin, Guadalupe, Apache, and Glass Mountains, New Mexico and west Texas: Permian Basin Section, S.E.P.M., publication 96-39, 480 p.
Hill, R.T., 1900, Physical geography of the Texas region: U.S. Geological Survey, Topographical Atlas, Folio 3, 12 p.
Hill, R.T., 1901, Geography and geology of the Black and Grand Prairies, Texas: U.S. Geological Survey, 21st Annual Report, pt. 7, 666 p.
Hoots, H.W., 1925, Geology of a part of western Texas and southeastern New Mexico, with special reference to salt and potash: U.S. Geological Survey, Bulletin 780, p. 33-126.
James, H.L., 1969, History of the United States-Mexico boundary survey – 1848-1855: New Mexico Geological Society, 20th Field Conference Guidebook, p. 41-55.
Jenney, W.P., 1874, Notes on the geology of western Texas, near the thirty second-parallel: American Journal of Science, 3rd series, v. 7, p. 25-29.
Julyan, R., 1996, The place names of New Mexico: Albuquerque, University of New Mexico Press, 385 p.
King, P.B., 1948, Geology of the southern Guadalupe Mountains, Texas: U.S. Geological Survey, Professional Paper 215, 183 p.
King, P.B., and King, R.E., 1929, Stratigraphy of outcropping Carboniferous and Permian rocks of trans-Pecos Texas: American Association of Petroleum Geologists Bulletin, v. 13, p. 907-926.
Kues, B.S., 1985, Early geological explorations in northeastern and east-central New Mexico: New Mexico Geological Society, 36th Field Conference Guidebook, p. 103-118.
Lee, W.T., 1917, General stratigraphic break between Pennsylvanian and Permian in western North America: Geological Society of America Bulletin, v. 28, p. 169-170.
Lee, W.T., 1918, Early Mesozoic physiography of the southern Rocky Mountains: Smithsonian Miscellaneous Collections, v. 69, no. 4, p. 1-41.
Lee, W.T., 1920, Notes on the Manzano Group, New Mexico: American Journal of Science, 4th series, v. 49, p. 323-326.
Lee, W.T., and Girty, G.H., 1909, The Manzano Group of the Rio Grande Valley, New Mexico: U.S. Geological Survey, Bulletin 389, 141 p.
Lloyd, E.R., 1929, Capitan limestone and associated formations of New Mexico and Texas: American Association of Petroleum Geologists Bulletin, v. 13, p. 645-658.
Lucas, S.G., 2001, The first geologic map of New Mexico: New Mexico Geology, v. 23, p. 84-88.
Marcou, J., 1855, Geological report; *in* Pope, J., Report of exploration of route for the Pacific Railroad near the 32d parallel of latitude from the Red River to the Rio Grande: U.S. 33rd Congress, 1st Session, House Executive Document 129, p. 124-128.
Marcy, R.B., 1850, Report of Captain R. B. Marcy: U.S. 31st Congress, 1st Session, Senate Executive Document 64, p. 169-227.
Martin, J.C., and Martin, R.S., 1984, Maps of Texas and the Southwest, 1513-1900: Albuquerque, University of New Mexico Press, 174 p.
McBride, G.B., 1957, A historical sketch of the trans-Pecos region; *in* Cooker, G.A., and King, P.B., eds., Glass Mountains: West Texas Geological Society Guidebook, p. 28-39.
Meinzer, O.E., Renick, B.C., and Bryan, K., 1926, Geology of Number 3 reservoir site of the Carlsbad irrigation project, New Mexico, with respect to water tightness: U.S. Geological Survey, Water Supply Paper 580-A, 39 p.
Merrill, G.P., 1924, The first one hundred years of American geology: New Haven, Yale University Press, 773 p.
Meyer, R., and Halliday, W.R., 1991, Carlsbad Cavern, the early years: Carlsbad, Guadalupe Mountains Association, 156 p.
National Cyclopedia of American Biography, 1900, Benjamin Franklin Shumard: New York, James T. White & Co., v. 8, p. 256-257.
Newell, N.D., Rigby, J.K., Fischer, A.G., Whiteman, A.J., Hickox, J.E., and Bradley, J.S., 1953, The Permian reef complex of the Guadalupe Mountains region, Texas and New Mexico: San Francisco, W.H. Freeman and Co., 236 p.
Pope, J., 1855, Report of exploration of a route for the Pacific Railroad, near the thirty-second parallel of north latitude, from the Red River to the Rio Grande: U.S. 33rd Congress, 2nd Session, Senate Executive Document 78, v. 2, p. 1-95.
Pray, L.C., 1988, The western escarpment of the Guadalupe Mountains, Texas, and day two of the field seminar; *in* Guadalupe Mountains revisited, Texas and New Mexico: West Texas Geological Society, publication 88-84, p. 23-31.
Prout, H.A., 1858, Description of new species of Bryozoa from Texas and New Mexico, collected by Dr. George G. Shumard, geologist of the U.S. expedition for boring artesian wells along the 32d parallel, under the direction of Capt. John Pope, U.S. Corps Top. Eng.: Transactions of the St. Louis Academy of Science, v. 1, p. 228-235.

Rebert, P., 2001, La Gran Linea, mapping the United States-Mexico boundary, 1849-1857: Austin, University of Texas Press, 259 p.

Reid, S.T., Bass, R.O., and Welch, P., 1988, Guadalupe Mountains revisited, Texas and New Mexico: West Texas Geological Society, publication 88-84, 202 p.

Richardson, G.B., 1904, Report of a reconnaissance in trans-Pecos Texas, north of the Texas and Pacific Railway: Texas University Mineral Survey Bulletin 9, 119 p.

Richardson, G.B., 1908, Paleozoic formations in trans-Pecos Texas: American Journal of Science, 4th series, v. 25, p. 474-484.

Richardson, G.B., 1909, Description of the El Paso district: U.S. Geological Survey, Geologic Atlas, Folio 166, 11 p.

Richardson, G.B., 1910, Stratigraphy of the upper Carboniferous in west Texas and southeast New Mexico: American Journal of Science, 4th series, v. 29, p. 325-337.

Richardson, G.B., 1914, Description of the Van Horn quadrangle, Texas: U.S. Geological Survey, Geologic Atlas, Folio 194, 9 p.

Saller, A.H., Harris, P.M., Kirkland, B.L., and Mazzullo, S.J., eds, 1999, Geologic framework of the Capitan reef: SEPM (Society for Sedimentary Geology), Special Publication 65, 224 p.

Scholle, P., 2000, Selected geologic bibliography of the Permian rocks of the Guadalupe Mountains, the Permian Basin, and adjacent areas of New Mexico and west Texas: <http://geoinfo.nmt.edu/staff/scholle/guadbiblio.html>, 99 p.

Schuchert, C., 1927, The Pennsylvanian-Permian Systems of west Texas: American Journal of Science, 5th series, v. 14, p. 382-401.

Schuchert, C., 1928, Review of the late Paleozoic formations and faunas, with special reference to the ice age of middle Permian time: Geological Society of America Bulletin, v. 39, p. 789-886.

Shumard, B.F., 1858, Notice of new fossils from the Permian strata of New Mexico and Texas: Transactions of the St. Louis Academy of Science, v. 1, p. 290-297.

Shumard, B.F., 1859, Notice of fossils from the Permian strata of Texas and New Mexico, obtained by the United States expedition under Capt. John Pope for boring artesian wells along the 32d parallel, with descriptions of new species from these strata and the Coal Measures of that region: Transactions of the St. Louis Academy of Science, v. 1, p. 387-403.

Shumard, G.G., 1858, 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 Top. Eng., U.S.A., in the year 1855: Transactions of the St. Louis Academy of Science, v. 1, p. 273-289.

Shumard, G.G., 1859, The geological structure of the “Jornada del Muerto,” New Mexico, being an abstract from the geological report of the expedition under Capt. John Pope, U.S. Top. Engrs., for boring artesian wells along the line of the 32d parallel: Transactions of the St. Louis Academy of Science, v. 1, p. 341-355.

Shumard, G.G., 1886, 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 p.

Shumard, R., 2001, Shumard, George Getz: Handbook of Texas Online, <http://www.tsha.utexas.edu/handbook/online/articles/SS/fsh57.html>.

Sweeney, G., 1996, Drawing borders: art and the cultural politics of the U.S.-Mexico boundary survey, 1850-1853; *in* Hall, D., ed., Drawing the borderline: artist-explorers of the U.S.-Mexico boundary survey: Albuquerque Museum, p. 23-77.

Tarr, R.S., 1892, Reconnaissance of the Guadalupe Mountains: Texas Geological Survey, Bulletin 3, 42 p.

Udden, J.A., 1915, The age of the Castile gypsum and Rustler Springs formation: American Journal of Science, 4th series, v. 40, p. 151-156.

Udden, J.A., 1917, Notes on the geology of the Glass Mountains: Texas University Bulletin 1753, p. 5-59.

Williams, J.S., 1940, Memorial to George Herbert Girty: Proceedings of the Geological Society of America for 1939, p. 195-205.

Wood, R.H., and Richards, R.W., 1951, George Burr Richardson (1872-1949): American Association of Petroleum Geologists Bulletin, v. 35, p. 2125-2127.