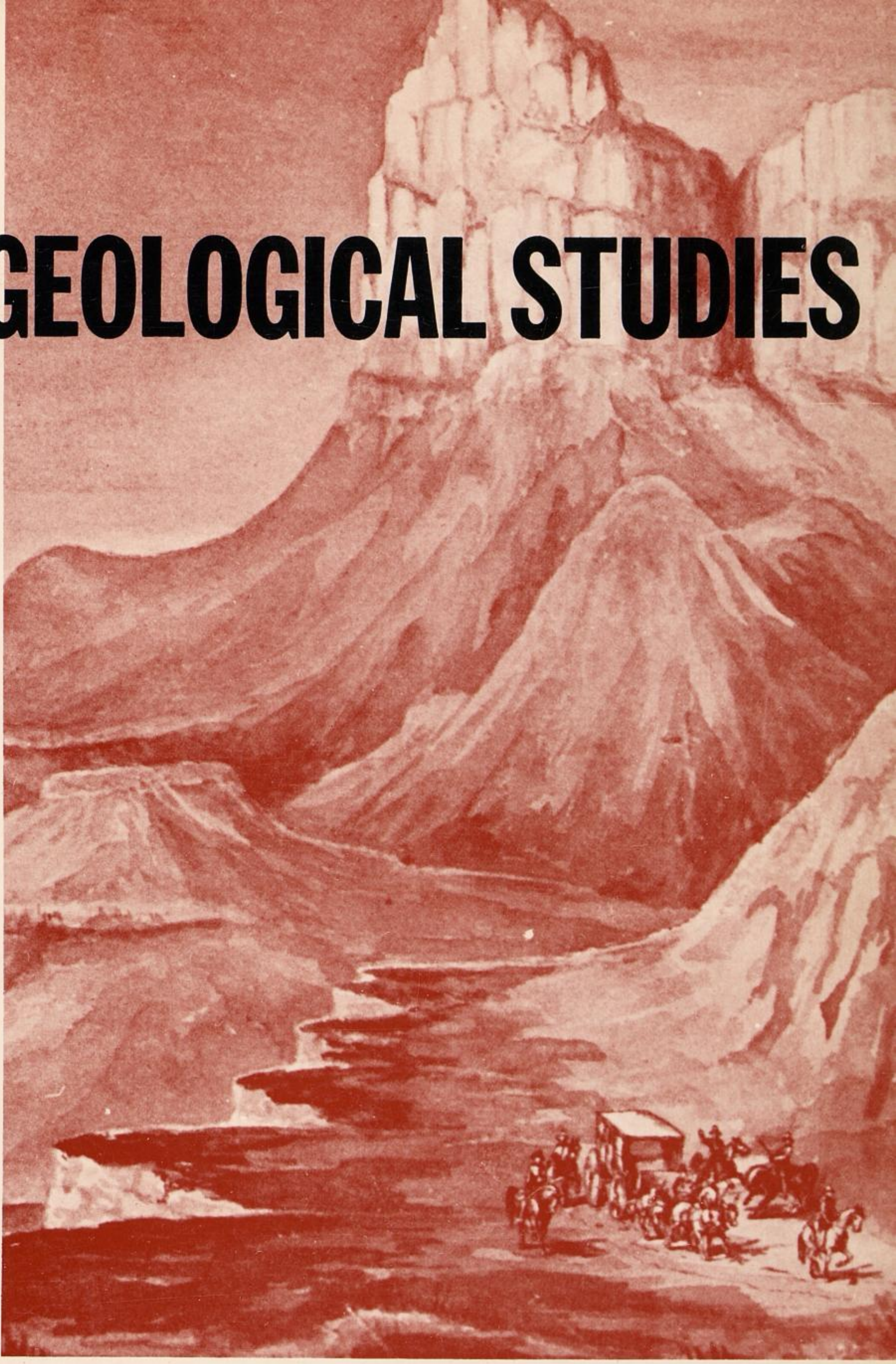
BAYLOR GEOLOGICAL STUDIES



SPRING 1986

Bulletin No. 43

Descriptive Geomorphology of the Guadalupe Mountains, South-Central New Mexico and West Texas

CLEAVY L. McKNIGHT

"Creative thinking is more important than elaborate equipment--"

Frank Carney, Ph.D.
Professor of Geology
Baylor University
1929-1934

Objectives of Geological Training at Baylor

The training of a geologist in a university covers but a few years; his education continues throughout his active life. The purposes of training geologists at Baylor University are to provide a sound basis of understanding and to foster a truly geological point of view, both of which are essential for continued professional growth. The staff considers geology to be unique among sciences since it is primarily a field science. All geologic research including that done in laboratories must be firmly supported by field observations. The student is encouraged to develop an inquiring objective attitude and to examine critically all geological concepts and principles. The development of a mature and professional attitude toward geology and geological research is a principal concern of the department.

Front cover. Bartlett's 1854 pencil and sepia wash *Guadalupe Mountain, Texas.* This southernmost peak of the Guadalupe Mountains is now known as El Capitan. Bartlett's vantage point appears to be in the area of Guadalupe Pass on the eastern side of the range. The ledge upon which the field party is standing marks the contact between the Cherry Canyon Formation above and the Brushy Canyon Formation below. From Hine, 1968, p. 99. Used with permission.

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Descriptive Geomorphology of the Guadalupe Mountains, South-Central New Mexico and West Texas

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BAYLOR UNIVERSITY
Department of Geology
Waco, Texas
Spring 1986

Baylor Geological Studies

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Descriptive Geomorphology of the Guadalupe Mountains South-Central New Mexico and West Texas

Cleavy L. McKnight

ABSTRACT

The Guadalupe Mountains of south-central New Mexico and west Texas occupy a unique position in the physiography of the United States. The range lies on the boundary between two major provinces: the block-faulted Basin and Range to the west and the relatively undisturbed Great Plains to the east.

The region surrounding the Guadalupe Mountains geomorphic province can be divided into five other geomorphic provinces: Pecos Valley-Gypsum Plain; Delaware Mountains; Salt Basin-Crow Flats; Diablo Plateau-Otero Platform; and Sacramento Mountains.

The Guadalupe Mountains geomorphic province can be divided into five subprovinces, each of which exhibits distinctive characteristics of physiography, structure, and stratigraphy. From east to west, these five geomorphic subprovinces are: Eastern Range, Seven Rivers Embayment, Western Range, Dog Canyon, and Brokeoff Mountains.

The Eastern Range is a deeply dissected, northeast-tilted, high pediment surface bounded on the east by the Barrera Fault and Reef Monocline. The Seven Rivers Embayment is a gently northeast-tilted, low pediment surface bounded by the two ranges of the Guadalupe Mountains. The Western Range is a northeast-dipping stripped structural plain bounded on the east by the Huapache Monocline and on the west by the Dog Canyon and Guadalupe Fault Zones. Dog Canyon is a synclinal graben located between the Western Range and the Brokeoff Mountains. The Brokeoff Mountains form a faulted anticlinal horst block bounded on the east by Dog Canyon and on the west by the Border Fault Zone.

The Guadalupe Mountains region has been subject to a complex sequence of depositional, tectonic, and erosional processes. Nine major stages in the geologic evolution of the region are recognized: Precambrian, early Paleozoic, Late Pennsylvanian, Permian, Cretaceous, Laramide, Early Oligocene, Mio-Pliocene, and Plio-Pleistocene to present.

By the end of Precambrian time, the region was differentiated into a structurally high western area, the Pedernal Positive Area or Pedernal Landmass (site of the future Diablo Plateau-Otero Platform) and a structurally low eastern area, the Tobosa Basin (site of the future Delaware Basin). During early Paleozoic time, sedimentation accompanying subsidence along monoclinal flexures and normal faults in the east marked the initiation of the Delaware Basin. During Late Pennsylvanian time, renewed uplift of the Pedernal Landmass in the west caused erosion of the overlying Paleozoic sedimentary rock. Compressional forces from the west caused thrusting to the east in the Huapache Thrust Zone. During Permiam time, carbonates, evaporites, and red beds of the Northwest Shelf prograded southeast toward the subsiding, clastic-filled Delaware Basin. Upper Permian evaporites filled the basin. In Cretaceous time, marine sediments were again deposited throughout the tectonically stable region. Laramide compressional forces reactivated the Huapache Thrust Zone, folding the overlying rocks into the Huapache Monocline. In the east, the rocks were folded into a series of anticlines and synclines, the Guadalupe Ridge Folds, Carlsbad Folds, and Waterhole Anticlinorium. During Oligocene time, igneous activity associated with the northern Trans-Pecos magmatic province resulted in the emplacement of a group of intrusions into the sedimentary rock in the central Diablo Plateau-Otero Platform. During Early Miocene erosion, Cretaceous rock was stripped away from most of the region. The Ogallala Formation was spread over the eastern side of the region to form the huge alluvial surface of the High Plains. During Pliocene and Pleistocene time, the Ogallala Formation was removed from the region by the downcutting action of the ancestral Pecos River. The Guadalupe Mountains rose as an anticlinal upwarp and were broken into a series of fault blocks by extensional forces associated with the Rio Grande rift to the west. As the water table fell during uplift, caves

formed in the soluble carbonates of the mountains. The Pleistocene climate fluctuated between wet/cold and dry/warm.

The Guadalupe Mountains are important to an interpretation of the geologic evolution of the Basin and Range physiographic/tectonic province both because they are located on the boundary of the province and because they provide information as to the age of Basin and Range faulting along this boundary. Evidence indicates that the faulting in the Guadalupe Mountains is Plio-Pleistocene or younger and may be active today. If the normal faulting present on the eastern side of the Guadalupe Mountains is basement involved (possibly reactivating the fault zone along which the Delaware Basin subsided), then the eastern boundary of the Basin and Range extends to the eastern escarpment of the Guadalupe Mountains, rather than coinciding with the Border-Guadalupe Fault Zone on the west side of the mountains.

INTRODUCTION*

PURPOSE

The Guadalupe Mountains of south-central New Mexico and west Texas occupy a unique position in the physiography of the United States. The range lies on the boundary between two major provinces: the block-faulted Basin and Range to the west and the relatively undisturbed Great Plains to the east.

The Guadalupe Mountains region has been subject to a complex sequence of depositional, tectonic, and erosional processes. Evidence of these processes is found in the physiographic and structural features of the region. The Permian stratigraphy of the mountains has been studied in great detail over the past 50 years and is considered a classic section of carbonate shelf-margin deposits. However, the geomorphology of the range has been largely ignored or has received only passing mention.

Because the Guadalupe Mountains present a number of important questions concerning both the development of arid landforms and the tectonics of the eastern Basin and Range province, a more specific geomorphic treatment seems justified. Therefore, the purpose of the present study is to describe the geomorphic features of the Guadalupe Mountains region critical to an interpretation of the development of the range. A secondary objective is to present a series of speculations, developed during the course of the study, concerning major episodes in the geomorphic evolution of the Guadalupe Mountains region.

LOCATION

The study area covers about 2500 sq mi in Eddy, Otero, and Chaves Counties, New Mexico and in Culberson and Hudspeth Counties, Texas (Figs. 1, 2). The range forms a V-shaped, uplifted block on the New Mexico border. The apex of the V and the highest peaks in the range lie south, in Texas (Fig. 3). The upland surface slopes northeast to merge with the Pecos Slope (Kelley, 1971, p. 1) near Carlsbad, New Mexico.

The Guadalupe Mountains form a transition from the island-mountain physiography of the Basin and Range province on the west to the flat-lying Great Plains province on the east (Figs. 4, 5). The Guadalupes are the easternmost range in the Sacramento Mountains Section of the Basin and Range (Hunt, 1974, p. 505).

Structurally, the mountains are an uplifted, gently tilted fault block. On the west, the block is bounded by down-to-the-west, southeast-northwest trending normal

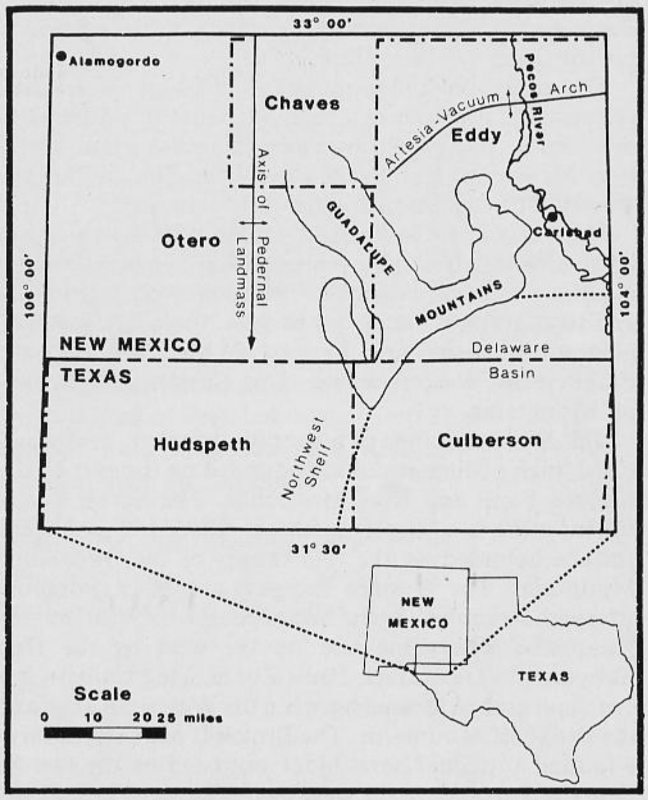

Fig. 1. Index map showing geographic location of the study area and relation of the Guadalupe Mountains to major tectonic features. The Pedernal Landmass, a basement high, was uplifted intermittently from Precambrian through Early Permian time. The eastern front of the Guadalupe Mountains marks the Permian Shelf Margin, which separated the deep Delaware Basin from the shallow Northwest Shelf. The Artesia-Vacuum Arch reflects the Early Permian Abo reef trend. After Kelley, 1971, p. 37, 52.

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* A thesis submitted in partial fulfillment of the requirements for the M.S. degree in Geology, Baylor University, 1983. Numerous geographic names mentioned in this study are shown on the USGS 1:250,000 series topographic map of the Carlsbad and Van Horn Quadrangles.

faults, and on the east by down-to-the-east, southwest-northeast trending normal faults and some southwest-northeast trending folds.

Stratigraphically, the bedrock of the mountains consists of Lower to Upper Permian (Leonardian to Ochoan) clastics, carbonates, and evaporites (Fig. 6). Both east and west of the range are Cretaceous and Tertiary sedimentary rocks and Tertiary volcanic features that give evidence useful in the interpretation of Guadalupe Mountains chronology. Quaternary alluvial and bolson deposits mantle much of the low-lying area around the mountains.

METHODS

The study consisted of five phases. First, extensive literature on geology of the Guadalupe Mountains was reviewed. Second, topographic maps, aerial photographs, and Landsat imagery were examined to locate anomalous areas requiring field investigation and to develop preliminary concepts concerning the evolution of the range. Third, field reconnaissance served to confirm or modify interpretations based on literature and remote sensing data and to generate questions previously unrecognized. Fourth, drillers' logs and borehole logs from oil, gas, and water wells in and around the mountains were used to map structure and to verify interpretations based upon surface geology and geomorphology. Finally, a geologic chronology based on all dated paleontologic and mineralogic localities in the region was used to generate a time frame into which events in the history of the range were fitted.

PREVIOUS WORKS

The geologic literature on the Guadalupe Mountains region is voluminous. Literally hundreds of works devoted to the stratigraphy of the area have been published. An exhaustive review of these works would be prohibitively long and is, in fact, unnecessary. Therefore,

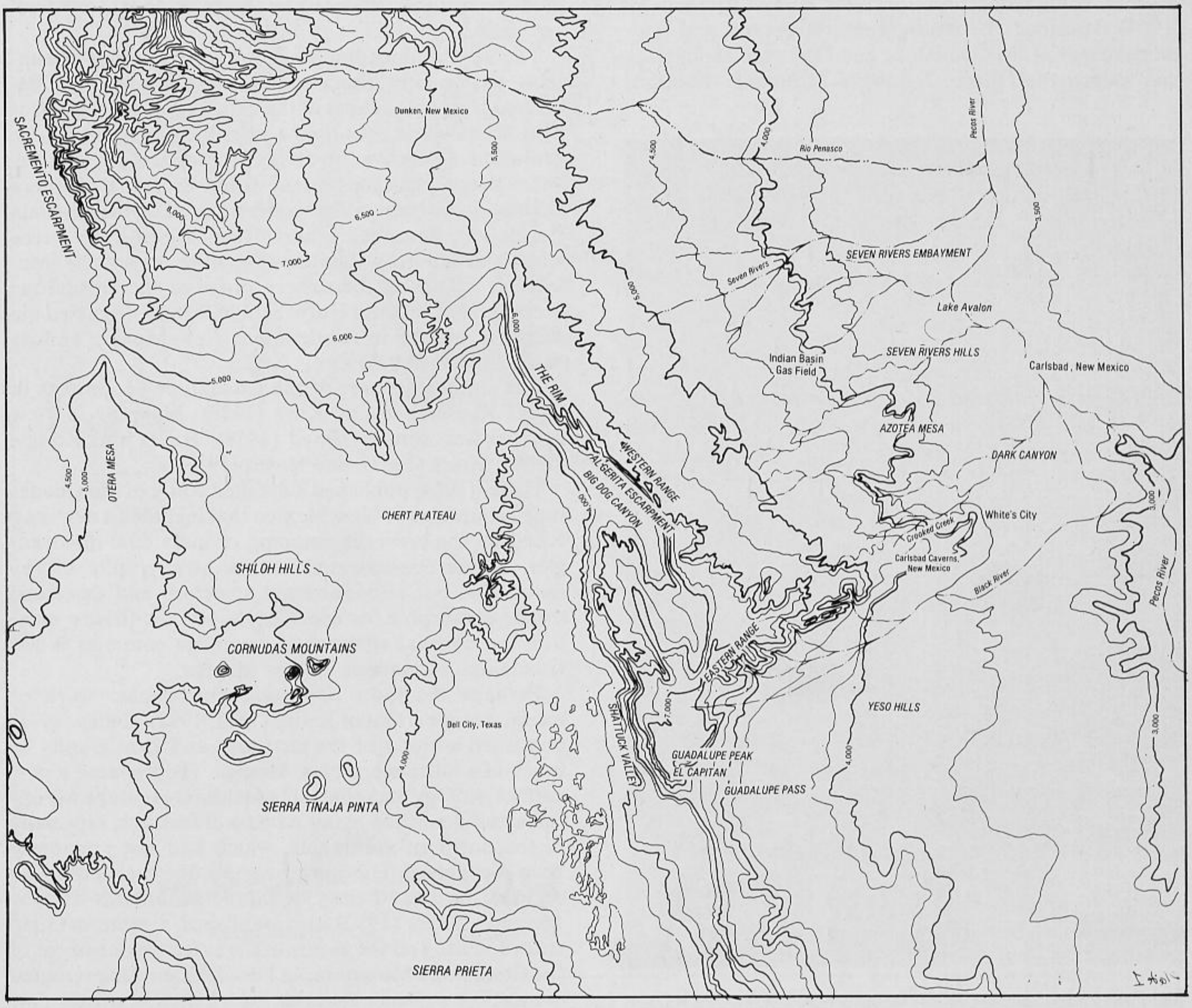


Fig. 2. Locality map.

only those works dealing with regional geology of the study area and with major concepts important to the study, including geomorphology and structural geology, are considered in this introductory section. Other works concerning important specifics of the geology will be discussed as those subjects are introduced.

The name "Guadalupe Mountains" was originally given to the hills of the Edwards Plateau around the upper Guadalupe River in central Texas. A careless eighteenth-century cartographer shifted the name 400 mi to the west (Tennant, 1980, p. 12).

Among the first published descriptions of the Guadalupe Mountains was that of Bartlett (1854), who traveled with the United States-Mexican Boundary Commission. Bartlett provided both a description of the geography of the area and probably the first published illustration from it—a pencil and sepia wash drawing of El Capitan from Guadalupe Pass (Cover).

The first geological work done in the mountains was that of G. G. Shumard (1858). He described the stratigraphy and structure of the Guadalupe Pass area and made a fossil collection for later study. Richardson (1904) described the stratigraphy, structure, and geomorphology of the Guadalupe and Delaware Mountains and named the Hueco, Delaware Mountain, Capitan, Castile, and Rustler Formations. From that time forward, there were numerous stratigraphic and paleontologic studies in the area.

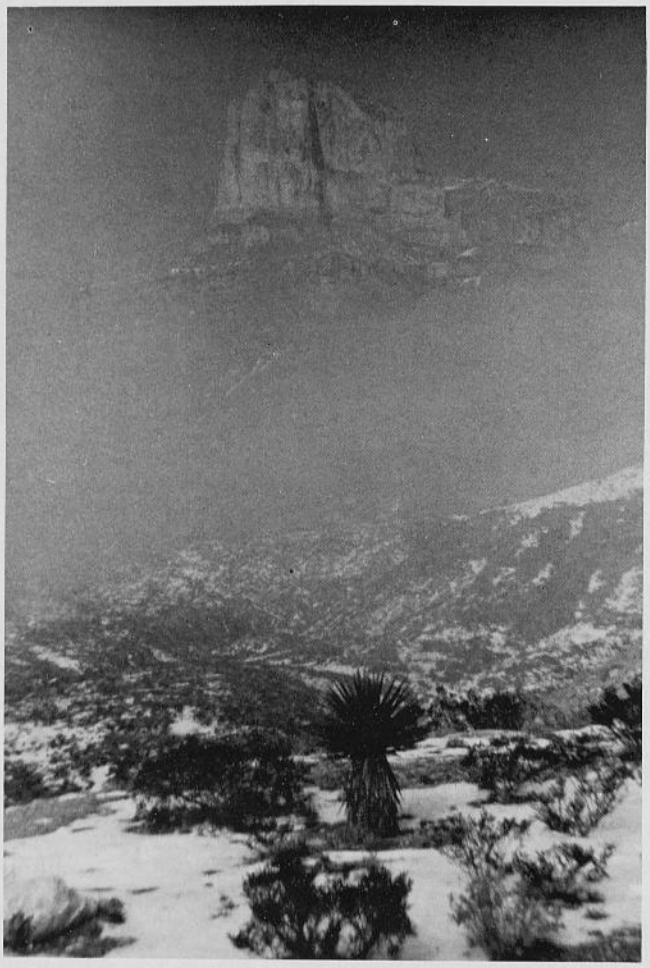


Fig. 3 El Capitan, southern point of the Guadalupe Mountains, framed by ice fog. Photograph taken from Locality 21.

Work to decipher the complex stratigraphy of the Guadalupe Mountains began in earnest in the late 1920's, with the beginning of petroleum exploration in the Permian Basin. One of the first studies to come out of this period was that of Lloyd (1929), who interpreted the Capitan Formation as a reef complex. In fact, several different geologists reached this conclusion independently at about the same time (King, 1977, p. 38).

The most important study (from a geomorphic standpoint) to come out of this period was the monumental work of King (1948). Not only did King describe and interpret the stratigraphy and structure of the Guadalupe Mountains of Texas in great detail, but he also provided the most complete description of the geomorphic features of the area yet published. In addition, King reviewed all of the literature on the Guadalupe Mountains region published up to 1948. King's work serves as a standard for all subsequent studies of the region, and his geomorphic descriptions and interpretations are vital to the present study.

The next geomorphic work in the Guadalupe Mountains was done by Bretz and Horberg. Bretz (1949) described features of caves in the Guadalupe Mountains of New Mexico and proposed a model for the geomorphic evolution of the caves involving an ancestral Pecos River valley deeper than the present valley. Bretz and Horberg (1949a), in a study of the western extent of the Ogallala Formation, described gravel deposits along the Pecos River and reported Ogallala-type siliceous gravels from fracture fillings in the eastern range of the Guadalupe Mountains. Bretz and Horberg (1949b) also discussed the origin of caliche in southeastern New Mexico and its paleoclimatic significance.

The surface geology of the Guadalupe Mountains in Texas was mapped by King (1948). Mapping in New Mexico was done by Boyd (1958), Hayes and Koogle (1958), Motts (1962), and Hayes (1977).

Hayes (1964) published a detailed study of the Guadalupe Mountains of New Mexico that included a new map based on the previous mapping of individual quadrangles. Hayes concentrated on the stratigraphy of the mountains but also discussed structure and described some geomorphic features. Hayes was the first to mention the unusual entrenched meanders common in the Guadalupe Mountains in New Mexico.

Perhaps the most important geomorphic work of recent vintage is that of Kelley (1971, 1972). Kelley (1971) published a study of the structure and stratigraphy of much of southeastern New Mexico. He prepared a new surface geology map that included the Guadalupe Mountains and described many structural features, especially in the northern mountains, which had not previously been recognized. His work provides the most complete regional picture of the Guadalupe Mountains of New Mexico. Kelley (1972) also published a more detailed study focusing on the nature of the eastern escarpment of the Guadalupe Mountains in New Mexico. He presented compelling evidence that this escarpment is at least partially fault controlled.

Fig. 4. Physiographic map showing location of the study area (outlined by solid lines) in relation to the Basin and Range and Great Plains physiographic provinces. The Basin and Range province is west of the dashed line; the Great Plains province is east of the line. After Raisz, 1957.

Thomas (1972), in a study of the Pecos River system, reported siliceous gravels atop the eastern range of the Guadalupe Mountains and suggested that the mountains had been uplifted relative to the High Plains surface to the east.

McKnight (1981) completed a preliminary description of the Guadalupe Mountains. McKnight (1982) also studied entrenched meanders in ephemeral streams in the New Mexican mountains and proposed some paleohydrologic and paleoclimatic parameters involved in their formation.

ACKNOWLEDGMENTS

Appreciation is expressed to a number of individuals and groups who aided in the completion of this study. Dr. O. T. Hayward, Department of Geology, Baylor University, suggested the problem and supervised the study, providing both field assistance and invaluable discussion and criticism. Dr. Don Parker, Department of Geology, Baylor University, critically reviewed the manuscript, aided in the field work, and provided information on the tectonics of Trans-Pecos Texas. Professor Lucille Brigham, Department of Mathematics, Baylor University, also reviewed the manuscript. Professor W. G. Brown, Department of Geology, Baylor University, aided in structural interpretation and analysis of aerial photographs.

Field assistance was rendered by the Fall 1981 Field Geomorphology class; by Valerie Adkins, Steve Krogh, Kurt Ritch, Clif Posey, and Ed Westergaard; and by the Spring 1983 Field Stratigraphy-Sedimentology class, all of Baylor University. Ann Marie Giarratana aided in the completion of the manuscript. The Cave Research Foundation of Carlsbad Caverns, New Mexico, provided use of its cabin in Carlsbad Caverns National Park during 1983 winter field work.

James Jasek of the Cave Research Foundation, Waco, Texas, kindly provided access to his library of speleological publications, which would have been otherwise unavailable. Base maps and well logs for the subsurface study were generously provided by Geomap Co. of Midland, Texas; Dr. Robert Bieberman of the New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico; and the Geologic Information Library of Dallas, Texas.

Louis J. Mazzullo, consulting geologist, Midland, Texas, discussed his study of faulting in the Indian Basin Gas Field with me.

Finally, I would like to express my deepest gratitude to my parents, Mr. and Mrs. Louis S. McKnight of Houston, Texas, for their spiritual and material support throughout my six years of education at Baylor University. This bulletin is dedicated to my mother, Mildred Lorraine Rogers McKnight.

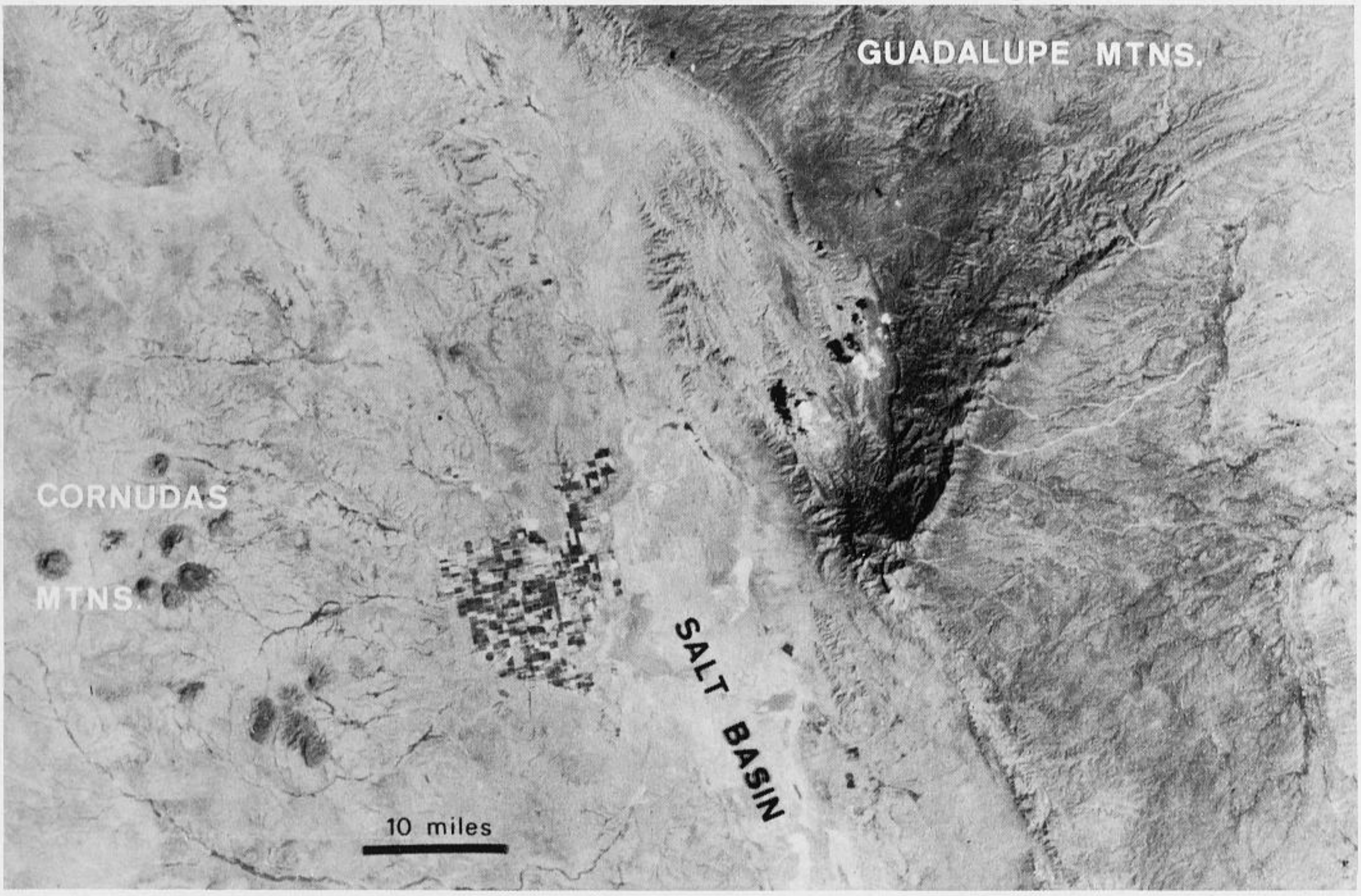


Fig. 5. Landsat image of the Guadalupe Mountains region. Note physiographic features and approximate scale. Compare with Figures 7 and 11. Landsat MSS; Scene ID: E-30567-16521; Exposure Date 9-23-79.

DESCRIPTIVE GEOMORPHOLOGY OF THE GUADALUPE MOUNTAINS REGION

REGIONAL GEOMORPHIC PROVINCES

In the study of any area that has been acted upon by forces of regional tectonism, erosion, and deposition, it is necessary to understand the geologic framework of the surrounding area. No interpretation of events in the geomorphic evolution of the Guadalupe Mountains can be considered viable if it ignores or contradicts this framework, which contains evidence critical to the interpretation.

The region surrounding the Guadalupe Mountains geomorphic province can be divided into five other geomorphic provinces: Pecos Valley-Gypsum Plain, Delaware Mountains, Salt Basin-Crow Flats, Diablo Plateau-Otero Platform, and Sacramento Mountains (Fig. 7).

PECOS VALLEY-GYPSUM PLAIN

The Pecos Valley-Gypsum Plain is a region of low relief formed by dissection by the Pecos River. It is bounded on the east by the Mescalero Escarpment and on the west by the Guadalupe and Delaware Mountains. Relief in this province is least in the north, where the Pecos Valley is floored with Quaternary sediments. Relief increases south of the Black River, where Upper Permian (Ochoan) evaporites are exposed to form the Gypsum Plain. The Yeso Hills in the west, the Rustler Hills in the east, and scattered "castiles" or limestone buttes are the only topographic features rising above the plain. A series of east-northeast trending lineations visible on aerial photographs and Landsat imagery (Fig. 5) are present along the western side of the plain. These small scarps, up to 50 ft high and 1 mi long, have been interpreted as solution-subsidence features localized by fractures parallel to regional dip. The presence of caves, sinks, and other solution features in the Gypsum Plain supports this hypothesis. The "castiles" of the plain are small buttes capped by limestone formed from the alteration of gypsum (Kirkland and Evans, 1980, p. 173).

Drainage in the Pecos Valley is asymmetrical, with long tributaries from the west draining the Sacramento, Guadalupe, and Delaware Mountains. Drainage from the east consists of short streams draining the High Plains. Playa lakes are common east of the Pecos River. All of the drainage is ephemeral, with the exception of the Black River and the Pecos itself. North of the Guadalupe Mountains, the Pecos River flows on the western side of its valley. At Carlsbad, it shifts to the eastern side of the valley.

The Pecos Valley-Gypsum Plain province is developed on the evaporites of the Castile Formation in the west, the Salado Formation in the center, and the Rustler Formation in the east. The youngest Permian strata present in the study area are the Dewey Lake Formation redbeds east of the Pecos River (Kelley, 1971, p. 24). These strata were deposited in the Permian Delaware Basin as it was filled. The Permian formations dip gently east as a result of probable Laramide tilting. Movement of thick Salado halites in the deep basin has caused some anticlinal folding in the subsurface in the east (Jones, 1982, p. 14). The solubility of the Permian evaporites, perhaps localized by fracturing, has caused large-scale solution-collapse features to form in the province and was probably important in the development of the Pecos River valley (Bachman, 1982, p. 15). Mesozoic rocks in the province include the Triassic Santa Rosa Sandstone of the Dockum Group east of the Pecos River and Lower Cretaceous (Trinity) Cox Sandstone east of the Rustler Hills (Kelley, 1971, p. 26; Barnes, 1975). Pebbles of limestone and sandstone containing Lower Cretaceous (Washita) marine fossils were reported near U.S. Highway 62-180 east of Slaughter Canyon by Lang (1947, p. 1472; Locality H). The pebbles were interpreted as a cavern or sink fill. No Cretaceous fossils were found in the area during field work (Locality 103).

Tertiary deposits in the province include, from presumed oldest to youngest, the widespread clastics of the Gatuna Formation (Kelley, 1980, p. 213); the "quartzose conglomerate" of Bretz and Horberg (1949a, p. 477), commonly found along the Pecos River; and the Ogallala Formation, which makes up the High Plains. Frye and Leonard (1957, 1964) dated the beginning of Ogallala deposition in southeast New Mexico and west Texas as Late Miocene to Early Pliocene. Bretz and Horberg (1949a, p. 477) suggested that the "quartzose conglomerate" along the Pecos River was a basal Ogallala equivalent, but Leonard and Frye (1975, p. 8) disagreed, citing dissimilarities in the stratigraphy of the two units; they dated the conglomerate as pre-Ogallala.

Igneous dikes near U.S. Highway 62-180 east of Slaughter Canyon (Locality D; Hayes, 1964, p. 39), identified as alkali trachyte (Pratt, 1954, p. 143), have not been age-dated but were presumed by Calzia and Hiss (1978, p. 39) to correlate with basaltic dikes of Oligocene age (32.2 to 33.9 m.y. BP) east of the Pecos River.

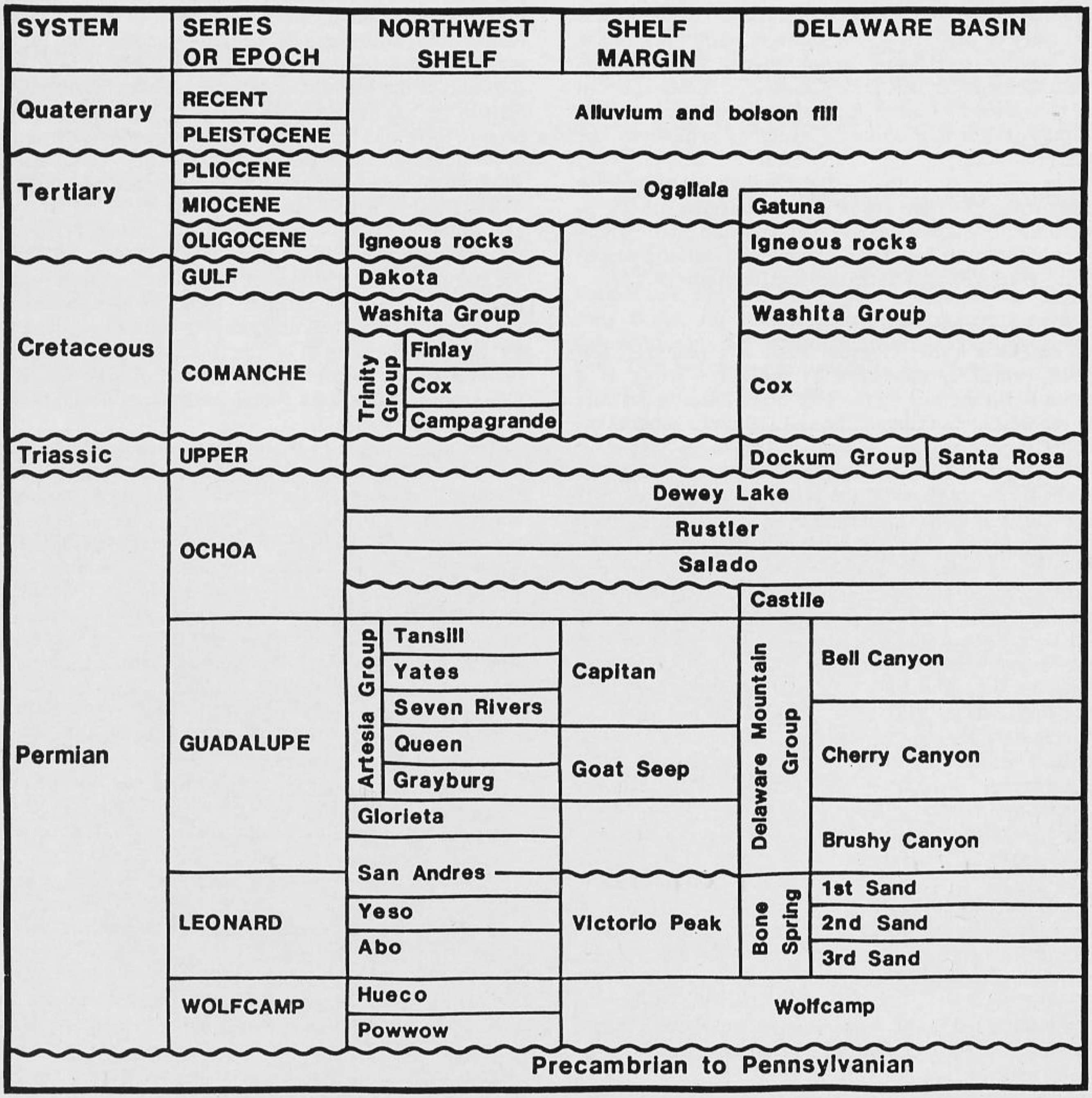
Two pediment surfaces are recognized in the Pecos Valley (Morgan and Sayre, 1942, p. 28). The Sacramento Plain or Pecos Slope (Kelley, 1971, p. 2) on the west is an erosional surface correlated with the constructional surface of the High Plains to the east. At a lower level, the Diamond-A Plain west of the river is correlated with the Mescalero Plain east of the river. Below these erosional surfaces are three terrace levels: from oldest to youngest, these are the Blackdom, Orchard Park, and Lakewood surfaces. The Lakewood terrace is essentially the modern alluvial bottoms of the river (Kelley, 1971. p. 32).

The Mescalero Plain east of the Pecos River is covered by a caliche layer that began to accumulate about 500,000 years BP; a younger soil of 300,000 years BP rests on the older one (Bachman, 1982, p. 15). Pleistocene terrace deposits of the Pecos in the study area contain material dated at 13,550 ± 170 years BP and 6420 ± 110 years BP (Leonard et al., 1975, p. 4); the terrace levels are not specified.

Delaware Mountains

The Delaware Mountains are a long north-south trending cuesta with a steep, faulted western face and a gentle eastern dip slope. The northern end of the fault escarpment is a series of parallel, linear escarpments trending north-northwest. The southern end of the scarp consists of arcuate faults or slump surfaces and is more dissected than the northern escarpment. In between, a large fault block, Bitterwell Mountain, projects west of the scarp into the Salt Basin.

The crest of the Delaware Mountains forms a divide



SYSTEM	SERIES OR EPOCH	NORTHWEST SHELF		SHELF MARGIN	DELAWARE BASIN	
Quaternary	RECENT	Alluvium and bolson fill				
	PLEISTOCENE					
Tertiary	PLIOCENE					
	MIOCENE	Ogallala			Gatuna	
	OLIGOCENE	Igneous rocks			Igneous rocks	
Cretaceous	GULF	Dakota				
	COMANCHE	Washita Group			Washita Group	
		Trinity Group	Finlay		Cox	
			Cox			
			Campagrande			
Triassic	UPPER				Dockum Group	Santa Rosa
Permian	OCHOA	Dewey Lake				
		Rustler				
		Salado				
					Castile	
	GUADALUPE	Artesia Group	Tansill	Capitan	Delaware Mountain Group	Bell Canyon
			Yates			
			Seven Rivers			
			Queen	Goat Seep		Cherry Canyon
			Grayburg			
		Glorieta				Brushy Canyon
		San Andres				
	LEONARD	Yeso		Victorio Peak	Bone Spring	1st Sand
						2nd Sand
		Abo				3rd Sand
	WOLFCAMP	Hueco		Wolfcamp		
		Powwow				
Precambrian to Pennsylvanian						

Fig. 6. Chart showing stratigraphy of the Guadalupe Mountains region. The terms at the tops of the three columns in the chart apply specifically to the Permian rocks of the region. Note the facies and nomenclature changes from the Northwest Shelf evaporite-carbonate platform to the massive Shelf Margin carbonate buildup and into the clastic-dominated Delaware Basin (compare with Fig. 1). For post-Permian rocks, the terms correspond to geographic areas as follows: Northwest Shelf = Diablo Plateau-Otero Platform and Sacramento Mountains, Shelf Margin = eastern edge of Guadalupe Mountains, Delaware Basin = Pecos Valley-Gypsum Plain (Fig. 7). After King, 1948, p. 101; Kelley, 1971, p. 6; Barnes, 1975; and petroleum industry terminology.

between short, westward drainage into the closed Salt Basin depression and long eastward drainage into the Pecos River. All of the drainage is ephemeral. The steep west-flowing streams have built a bajada at the base of the fault escarpment.

The black, cherty Bone Spring Limestone of Middle Permian (Leonardian) age, which was deposited in the deep Delaware Basin, is exposed at the base of the Delaware Mountains escarpment. The upper portion of the mountains is comprised of sandstones of the Delaware Mountain Group of Middle Permian (Guadalupian) age. From oldest to youngest the group consists of the Brushy Canyon, Cherry Canyon, and Bell Canyon Formations, which crop out progressively eastward in the mountains. Thin limestone units are interbedded with these thick sandstones, which were deposited in the Delaware Basin.

A small intrusive plug, probably a trachyte, was reported by King (1948, p. 103) in the northern Delaware Mountains. It has not been age dated but is assumed to be of Tertiary age.

Quaternary bajada sediments slope westward from the base of the fault scarp into the Salt Basin. Permian bedrock, which projects through this alluvial surface, suggests that the cover is relatively thin and that the major fault bounding the Salt Basin is on trend with the west side of the Patterson Hills, west of the Delaware Mountains escarpment.

SALT BASIN-CROW FLATS

The Salt Basin-Crow Flats geomorphic province is a long, narrow topographic depression formed over a north-south trending graben. The northern end of the basin in New Mexico is known as the Crow Flats, whereas the portion in Texas is called the Salt Basin. The

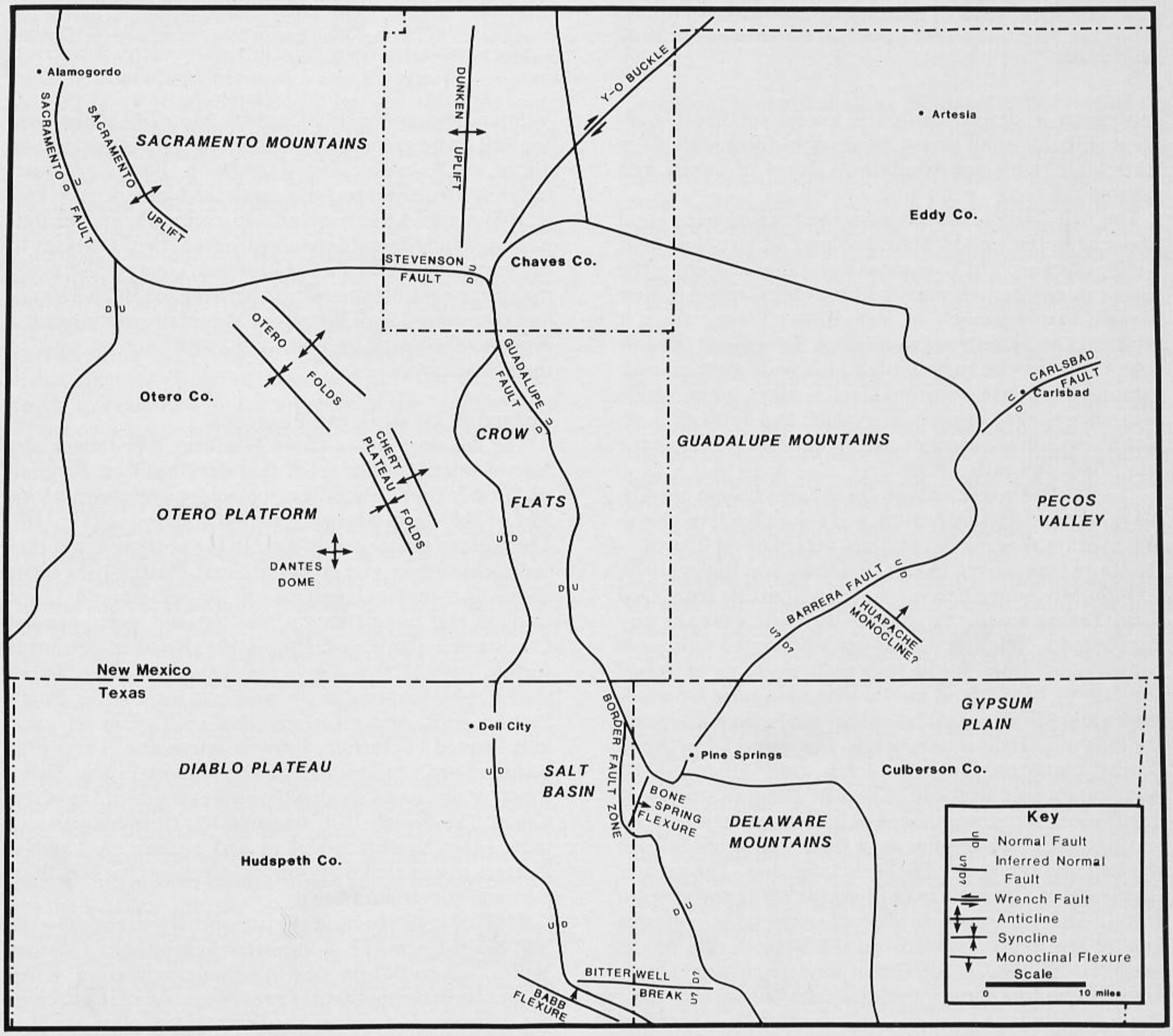


Fig. 7. Geomorphic provinces and structural elements of the Guadalupe Mountains region. Area shown is the same as that in Fig. 1. After Kelley, 1971, p. 37 and Black, 1976, p. 41.

Fig. 8. Inselberg projecting above coarse bajada sediments in the Crow Flats, Locality 44. Note the creosote bushes growing on the bajada sediments where thin soils have formed. Vegetation is essentially absent from the bedrock surface of the inselberg. In the center of the Salt Basin-Crow Flats, fine-grained playa lake sediments support short, hardy grasses.

Fig. 9. View east across the Salt Flats, Locality 50. The light-colored foreground is formed of modern evaporite deposits. During storms, rain water dissolves minerals from the rocks in the Guadalupe Mountains (visible in the background) and other surrounding highlands and flows into the Salt Basin, forming playa lakes. As the water evaporates, gypsum and halite are precipitated.

depression is almost featureless except for small inselbergs (Fig. 8), small closed depressions filled with playa lakes after rains, and windblown dunes of quartz and gypsum sand.

The Salt Basin is the second largest region of internal drainage in the United States, second only to the Great Basin (Parker, 1983, personal communication). The basin extends from the mouth of Big Dog Canyon in New Mexico to the vicinity of Van Horn, Texas, where it bifurcates and continues southward. Ephemeral streams flow from the the surrounding highlands after storms, forming in the basin various sizes of playa lakes, which evaporate leaving deposits of gypsum and halite (Fig. 9). Halite was mined near the town of Salt Flat, Texas, in the late 1800's and early 1900's.

The Salt Basin is filled with Quaternary bolson gravels, playa lake silts and evaporites, and eolian sands of quartz and gypsum. The maximum thickness of basin fill within the study area is over 1500 ft (Veldhuis and Keller, 1980, p. 148). Mr. Leroy Perry, a water-well driller from Dell City, Texas, noted that one of his wells near the city penetrated a 700-ft section of unconsolidated sediments consisting of from 30- to 50-ft units made up of gravel overlain by black, fetid mud overlain, in turn, by windblown silt. He also mentioned that the bolson sediments contain brackish water, while the underlying Bone Spring Limestone produces fresh water (Perry, 1981, personal communication). The Salt Basin is a series of north-south trending grabens or half-grabens. The trend is offset in dogleg fashion near Bitterwell Mountain on the east and the Sierra Diablo on the west. The greater frequency of Quaternary fault scarps along the western margin and the westward shift of playa lakes indicates greater modern subsidence on the western side of the basin (Goetz, 1980, p. 92). Gravity and magnetic anomaly maps reveal low density trends coincident with the Salt Basin (Veldhuis and Keller, 1980, p. 146-147). The thickness of Paleozoic sedimentary rocks preserved in the basin suggested a Paleozoic origin for the structure to Veldhuis and Keller (1980, p. 148). More likely, the present Salt Basin graben is coincident with the western margin of the Paleozoic Delaware Basin. Four northwest-trending structural features cross the basin. King (1948, p. 105) mapped the Babb and Victorio Flexures of Permian age and a feature running from south of Dell City to the south side of Bitterwell Mountain. Goetz (1980, p. 83) mapped a possible connection between the Babb Flexure and the south side of Bitterwell Mountain and suggested down-to-the-north normal fault movement on each of these structures.

DIABLO PLATEAU-OTERO PLATFORM

The Diablo Plateau-Otero Platform, a pediment surface of relatively low relief that developed on Permian and Lower Cretaceous rocks, coincides with the southern end of the Precambrian Pedernal Landmass (Fig. 10). The plateau slopes gently east. In the northeast, another pediment surface known as the Chert Plateau rises 400 ft above the regional surface in the vicinity of Lewis Canyon and Long Canyon. Still farther north, around Cornucopia Draw, a higher, more dissected pediment surface rises 1000 ft above the regional surface. Other topographic features in the province include the Pump Station Hills, where Precambrian rock crops out, and hills formed by Tertiary igneous intrusions. These hills include the Cornudas Mountains, Sierra Prieta, Sierra Tinaja Pinta, and a small hill on the east side of Dell City, Texas. The Shiloh Hills north of the Cornudas Mountains exhibit radial drainage and appear on Landsat imagery to be a shallowly buried intrusion (Parker, 1981, personal communication).

Most of the streams in the province drain east into the Salt Basin depression. Some drain west into the Tularosa Valley, Hueco Bolson, or Rio Grande depression. A few evaporate in the middle of Otero Mesa. All of the streams are ephemeral. A surprising thickness of alluvial silt is exposed in stream cuts on the east side of Otero Mesa.

Permian sedimentary rocks make up most of the surface strata of Otero Mesa. From west to east, the Lower Permian (Wolfcampian) Abo Formation, the Leonardian Yeso Formation, and the Middle Permian (Leonardian-Guadalupian) San Andres Formation are exposed (Black, 1975). In the Diablo Plateau to the south, the Wolfcampian Hueco Limestone and the Leonardian Victorio Peak and Bone Spring Formations are overlain by Lower Cretaceous clastics of the Campagrande and Finlay Formations (Barnes, 1975). The Cornudas Mountains are ringed by contact-metamorphosed Lower Cretaceous marls (Barker et al., 1977, p. 1438). Intrusions in the Diablo Plateau are all of Oligocene age, ranging from 36.8 ± 0.6 m.y. BP to 33.0 ± 1.4 m.y. BP (Table; Barker et al., 1977, p. 1440; Parker, 1983, personal communication).

Black (1976) mapped a complex series of structures in the northern and eastern Otero Platform, including east-west and north-south trending anticlines and synclines, some of which are bounded by high-angle normal faults. The AV Lineament crosses the area from southwest to northeast, interrupting the fold trends. Black suggested a possible connection between it and the Artesia-Vacuum Arch (Fig. 1), 30 mi to the northeast, and proposed some left-lateral offset along the lineament. The entire Diablo Plateau-Otero Platform geomorphic province coincides with the southern end of the Precambrian Pedernal Landmass, a positive element possibly bounded by deep-seated shear zones (Kelley, 1971, p. 58). The Pedernal Landmass was uplifted several times, and pre-Permian units dip away from its center to the east and west. Pennsylvanian uplift and erosion produced an unconformity surface, so that Lower Permian (Wolfcampian) rocks rest on units ranging in age from Precambrian to Pennsylvanian. Erosion continued into the Early Permian, as evidenced by the presence of the Wolfcampian Powwow Conglomerate Member of the Hueco Formation.

SACRAMENTO MOUNTAINS

The Sacramento Mountains form a large, north-south trending cuesta with a steep, faulted western scarp face and a gentle east-dipping backslope. The backslope, termed the Pecos Slope or Sacramento Plain, slopes 100 mi to the Pecos River. This upper surface is a dissected pediment surface that has been tilted east (Pray, 1961, p. 5). The eastward slope is broken by the Dunken Uplift, a north-south trending anticline between Dunken, New Mexico, and the Otero-Chaves County line (Kelley, 1971, p. 40).

Rio Penasco and its tributaries drain eastward down the Sacramento backslope into the Pecos River. Short ephemeral streams drain westward into the Tularosa Valley, a closed depression, from the Sacramento Escarpment. The Dunken Uplift forms a minor drainage divide on the Pecos Slope.

Rocks ranging in age from Precambrian to Pennsylvanian are exposed in the Sacramento Escarpment. Permian strata include the Wolfcampian Bursum and Abo Formations and the Leonardian Yeso Formation in the western part of the range. The Sacramento crest and backslope are developed on the Guadalupian San Andres Formation. A small outlier of Upper Cretaceous Dakota Sandstone is exposed along the Sacramento crest in the north (Pray, 1961, p. 1-4). Tertiary igneous dikes and sills are exposed in the western scarp face. A lamprophyre sill intruded into the Pennsylvanian Gobbler Formation has been K-Ar dated at 44.2 ± 2.2 m.y. BP (Late Eocene) (Locality A; Asquith, 1973, p. 537). Quaternary pediment gravels, terrace gravels, and alluvium also occur in the mountains. Pray (1961. p. 5) noted fault scarps in the recent alluvium at the base of the Sacramento Escarpment.

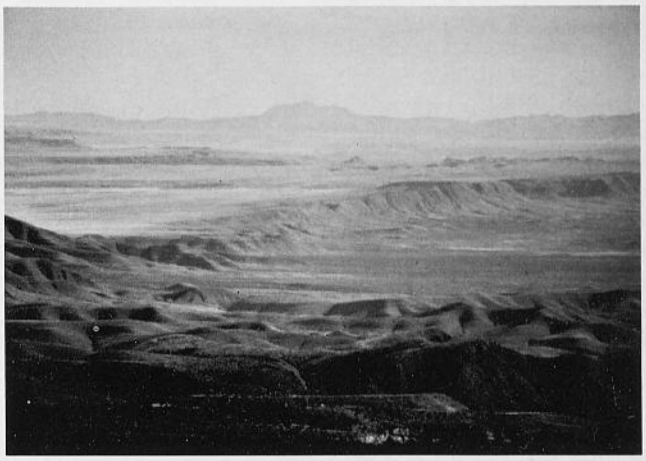


Fig. 10. Western edge of Otero Mesa, viewed from Hornbuckle Hill, the southern tip of the Sacramento Mountains (Locality 51). Note the flat pediment surface of Otero Mesa, which slopes gently eastward. The foothills of the Sacramento Mountains are in the foreground, and the Hueco Mountains are in the background.

In the south, the Sacramento Mountains step down to the Otero Platform along a series of southeastward plunging monoclines (Kelley, 1971, p. 38). The Pecos Slope merges with the northern Guadalupe Mountains in the east. The down-to-the-south, east-west trending Stevenson Fault bounding the Sacramento Mountains intersects the down-to-the-west, north-south trending Guadalupe Fault bounding the Guadalupe Mountains in an unclear angular relationship. The Y-O Buckle, a northeast-trending curving feature interpreted as a zone of strike-slip movement, also extends from this fault junction (Kelley, 1971, p. 44). Kelley (1971, p. 39) reported a fault scarp in Quaternary alluvium at the base of the Guadalupe scarp in this area.

GEOMORPHIC SUBPROVINCES OF THE GUADALUPE MOUNTAINS

The Guadalupe Mountains geomorphic province can be divided into five subprovinces, each of which exhibits distinctive characteristics of physiography, structure, and stratigraphy. From east to west, these five geomorphic subprovinces are: Eastern Range, Seven Rivers Embayment, Western Range, Dog Canyon, and Brokeoff Mountains (Fig. 11).

EASTERN RANGE

The Eastern Range is the largest and most varied subprovince of the Guadalupe Mountains, in terms of both physiography and geology. The highest peaks in the Guadalupe Mountains are located at the southern tip of the Eastern Range. From Guadalupe Peak, Texas, at 8751 ft elevation, the range slopes northeast to elevations around 3300 ft near Lake Avalon, 55 mi away.

The southern end of the Eastern Range is the most rugged physiographically. The high surface at the crest of the range is a deeply dissected pediment surface characterized by high relief and high drainage density. Remnants of the pediment surface are oriented east-west, and slope to the northeast. The west side of the range is bounded by down-to-the-west normal faults of the Border Fault Zone (King, 1948, p. 110), which drop strata from 2000 to 4000 ft. Trunk streams are oriented northwest-southeast, perpendicular to the eastern scarp face known as the Reef Escarpment, and are deeply incised. High-gradient tributaries feed the trunk streams in the canyon floors. The floor of McKittrick Canyon (Locality 87) consists of scoured Permian bedrock and Quaternary tufa-cemented cobbles and boulders.

To the northeast, the upland surfaces are oriented more southwest-northeast and are more rounded, reflecting the structure of three folds paralleling the scarp face. The high pediment grades into a dip slope in this area. The Guadalupe Ridge Folds consist of the Guadalupe Ridge Anticline on the west, the Walnut Canyon

Table. Age dated intrusions in the Diablo Plateau.

LOCALITY	REFERENCE	DESCRIPTION	AGE(S)
A	Asquith, 1973, p. 537.	Lamprophyre sill intruded into Pennsylvanian Gobbler Formation at base of Sacramento Mountains escarpment.	44.2 ± 2.2 m. y. BP (late Eocene); K-Ar date
B	Barker et al., 1977; ages recalculated using new decay constants (Parker, personal communication, 1983).	Hypabyssal intrusives injected into Permian and Cretaceous sedimentary rocks in Diablo Plateau, northern Trans-Pecos magmatic province.	All ages are middle Oligocene; K-Ar dates from biotites. **Cornudas Group** 36.8 ± 0.6 m. y. BP; Alamo Mountain discordant sheet; phonolite. 36.8 ± 0.6 m. y. BP; Augite syenite plug; nepheline-bearing augite syenite. 34.6 ± 1.5 m. y. BP; Cornudas Mountain plug; quartz-bearing syenite. 33.0 ± 1.4 m. y. BP; Deer Mountain plug; nepheline syenite. **Sierra Tinaja Pinta Group** 36.1 ± 0.6 m. y. BP; 35.1 ± 0.6 m. y. BP; 34.9 ± 0.6 m. y. BP; } all Mayfield Valley dome; syenite.
C	Bretz and Horberg, 1949a, p. 486; Thomas, 1972, p. 37.	Rounded siliceous gravels (vein quartz, metaquartzite, black chert, and jasper; schist reported at locality in Western Range) occurring as fracture fillings and scattered over upland surfaces in Eastern Range.	Ogallala Formation remnants (Mio-Pliocene)? Possibly Cretaceous.
D	Calzia and Hiss, 1978, p. 39.	Alkali trachyte (Pratt, 1954, p. 143) dikes intruded into Ochoan Castile Formation; Gypsum Plain.	33.9 to 32.2 m. y. BP (middle Oligocene). Dikes have not been dated; Calzia and Hiss assume that they are similar in age to K-Ar dated basaltic dikes intruded into Ochoan evaporites east of the Pecos River.
E	Harmon and Curl, 1978, p. 26.	Broken stalagmite found on floor of Ogle Cave, north wall of Slaughter Canyon, Eastern Range.	207,000 +64,000 or -40,000 years BP (Illinoisian); basal layers; Th-U date. 126,000 ± 26,000 years BP (Illinoisian); top layers; Th-U date.
F	Harris, 1978; Harris and Porter, 1980	Vertebrate bones (mollusks, small reptiles, birds, small mammals, and horses) from two levels in Dry Cave, McKittrick Hill, Eastern Range.	33,590 ± 1500 years BP to 25,160 years BP (post-Sangamon, pre-Kansan); lower level; radiocarbon date. 15,030 ± 210 years BP to 10,730 ± 150 years BP (Kansan); upper level; radiocarbon date.
G	Hester, 1960, p. 60.	Vertebrate bones from Hermit Cave, Western Range.	12,900 ± 350 years BP (Kansan); radiocarbon date.
H	Lang, 1974	Washita-age marine fossils found on the Ochoan Castile Formation, Gypsum Plain; believed trapped in a sink and preserved while surrounding rock was eroded.	Cretaceous.
I	Leonard et al., 1975, p. 4.	Organic material from Pleistocene terrace deposits along Pecos River; terrace levels not specified; Pecos Valley.	13,550 ± 170 years BP (Kansan); north (below Lake Avalon); radiocarbon date. 6,420 ± 110 years BP (Kansan); south (below Herradura Bend); radiocarbon date.
J	Exhibit at Living Desert State Park, Carlsbad, New Mexico (Locality 75).	Nautiloid found in White Oak Canyon by Bob Wilkinson, Carlsbad, New Mexico.	Cretaceous.

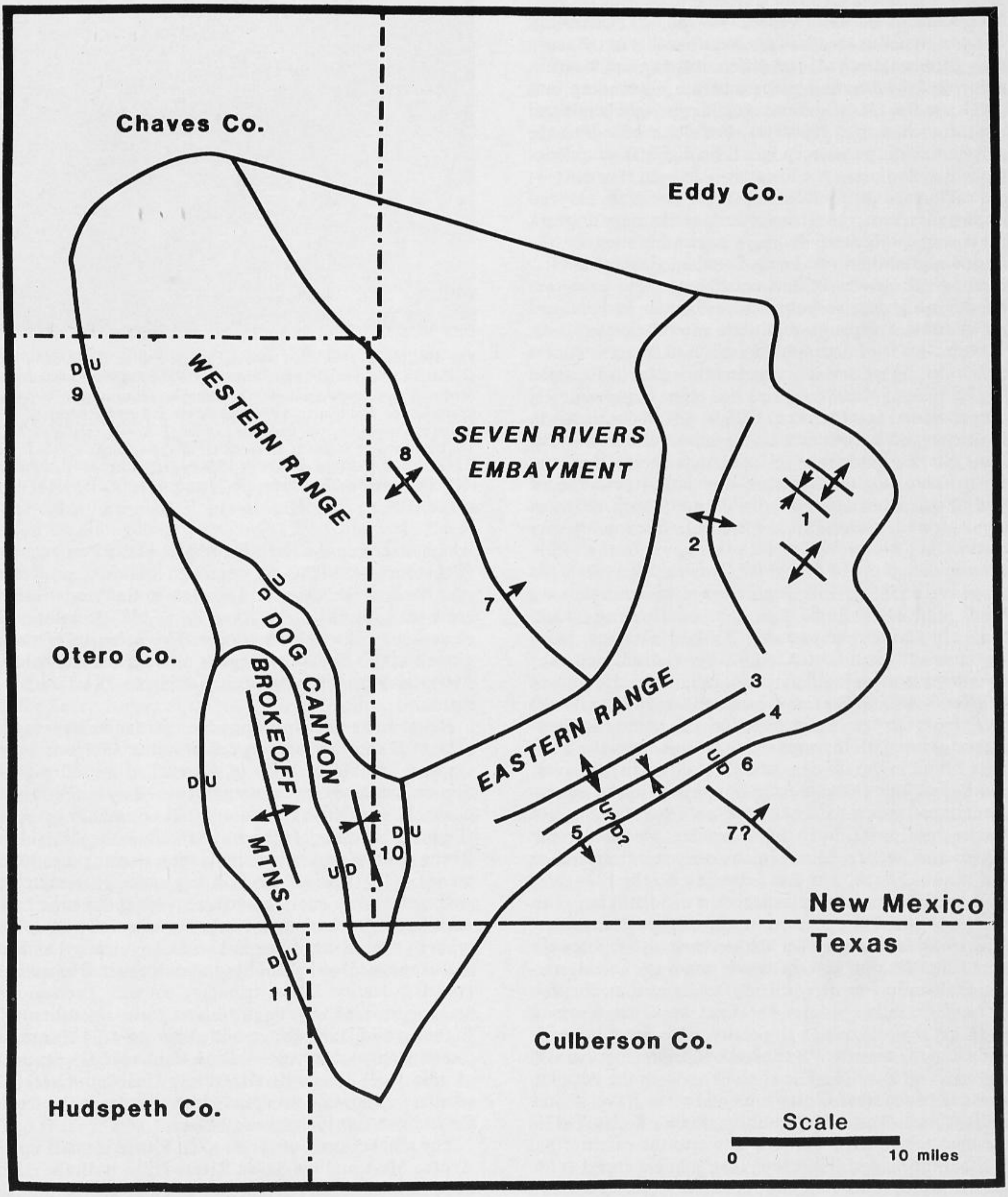


Fig. 11. Geomorphic subprovinces and structural elements of the Guadalupe Mountains geomorphic province. See Fig. 7 for location of Guadalupe Mountains geomorphic province and key to map symbols. Structural elements: 1—Carlsbad Folds, 2—Waterhole Anticlinorium, 3—Guadalupe Ridge Anticline, 4—Walnut Canyon Syncline, 5—Reef Monocline, 6—Barrera Fault, 7—Huapache Monocline, 8—Texas Hill Dome, 9—Guadalupe Fault, 10—Dog Canyon Fault Zone, 11—Border Fault Zone.

Syncline in the center, and the Reef Anticline or Reef Monocline on the east (Kelley, 1971, p. 40). The Walnut Canyon Syncline localizes drainage parallel to the scarp face. Streams drain several different topographic levels, controlled by bedding planes, before descending into trunk streams. Most streams meander in tight bends and are entrenched up to 1000 ft into bedrock. Some drainage perpendicular to the scarp face is probably fracture controlled, as shown by the linearity of stream segments.

Fractures and soluble carbonate bedrock play an important role in the large subsurface drainage network present in the Eastern Range. Caves are abundant, the largest and best known being Carlsbad Caverns in New Mexico. The caves of the Guadalupe Mountains are anomalously deep in comparison to their lengths, and many contain gypsum, a mineral rare in caves (Davis, 1980, p. 42). The horizontal directions of cave growth are controlled by two intersecting fracture sets, one parallel to the eastern scarp face and the other approximately perpendicular to it (Jagnow, 1978, p. 12). Vertical growth is determined by the elevation of the water table. The most active solution takes place at or just below the water table, where groundwater circulation is most pronounced and humic acids derived from the soil above are most concentrated (Gale, 1977). Carlsbad Caverns has five distinct known levels. Several other caves to the south, around the mouth of Slaughter Canyon, have two levels (Jagnow, 1978, p. 16). The presence of multiple cave levels indicates periodic stillstands of a lowering water table. In the deeper part of Carlsbad Caverns, some fluvial activity is indicated by 20-ft banks of silt incised by a younger stream that deposited locally derived limestone pebbles (Gale, 1977). The stream appears to have flowed away from the present Pecos River. The bones of a Pleistocene ground sloth, apparently washed into the cave, were found in the silt deposits 750 ft down in the cave.

Alluvial fans at the mouths of canyons in the escarpment are of wide areal extent and low relief; fans formed by streams flowing down the escarpment are smaller, but higher and steeper. Most fan-streams are entrenched at the heads of fans; however, streams on the Slaughter Canyon fan are more entrenched in the distal fan. This increased incision appears abrupt, as though at waterfalls. A lineament parallel to the scarp also crosses the fan. These data suggest that some down-to-the-east normal faulting has occurred during fan deposition, and that streams on either side of the fault have cut down to bedrock, the bedrock on the eastern side lying deeper.

East of the mouth of Rattlesnake Canyon, dark gravel deposits cap low hills. The contact between the Permian bedrock of the Reef Escarpment and these gravel deposits is abrupt and conspicuously linear. Kelley (1971) mapped the Barrera Fault, a down-to-the-east normal fault, at the base of this scarp. The fault is mapped at the surface from White's City south to Slaughter Canyon.

On the upland surfaces on either side of Slaughter Canyon and on the upland near the entrance to Carlsbad Caverns, Bretz and Horberg (1949a, p. 486) and Thomas (1972, p. 37) reported rounded siliceous gravels filling fractures and scattered on the surface (Locality C). Rounded gravels found at Locality 104 (Fig. 12) are interpreted as remnants of the Ogallala Formation, which makes up the High Plains east of the Pecos River. If the surface of the present High Plains is projected westward to the vicinity of Slaughter Canyon, it intersects the ground at the scarp base, 1300 ft below the elevation of the upland gravels. The presence of these gravels at this elevation suggests uplift of the Guadalupe Mountains by normal faulting along the Reef Escarpment.

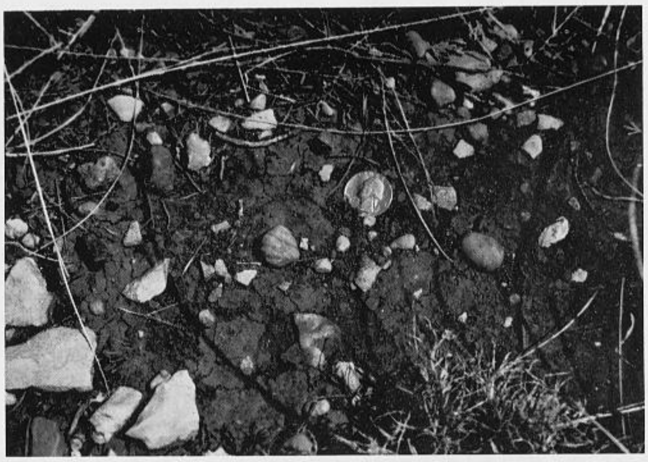


Fig. 12. Rounded siliceous pebbles, believed to be remnants of the Ogallala Formation, found on the crest of the Eastern Range at the head of Yucca Canyon, Locality 104. Pebbles consist mostly of metaquartzite and vein quartz, with some jasper and black chert, and are scattered abundantly over the upland surface below the crest of the hill. The pebbles were found at an elevation of approximately 5900 ft, or about 1300 ft above the elevation found by projecting the High Plains surface westward to this locality.

Relief in the Eastern Range decreases somewhat in the area of Dark Canyon and Last Chance Canyon. Dark Canyon exhibits a series of entrenched meanders, the Serpentine Bends, which are entrenched up to 600 ft into bedrock, and which have amplitudes up to almost 1 mi (Figs. 13, 14). Many of the canyon walls in the Serpentine Bends are almost vertical, indicating that the meanders are incised by vertical downcutting, rather than ingrown as the meanders migrated laterally. No terraces or bedrock benches are found along the canyon walls. The modern stream that flows in Dark Canyon is ephemeral and carries bedload of cobble- to boulder-sized limestone gravel (Locality 35). A tributary canyon, Lechuguilla Canyon, is filled with thick alluvial gravel (Locality 34). In the area of Dark Canyon, the bedrock dips in various directions at various angles. Dark Canyon is independent of this local structure. However, Crooked Creek, a smaller meandering stream at a higher topographic level, flows down an asymmetric syncline.

The northern end of the Eastern Range is made up of Azotea Mesa and the Seven Rivers Hills. Both the relief and drainage density in this northern area are less than in the south, and the uplands are dip slopes reflecting numerous small structures. The Carlsbad Folds are a group of small domes and synclines in the vicinity of McGruder Hill and Carnero Peak. The Waterhole Anticlinorium is a longer, arcuate series of narrow anticlines and synclines farther west. The Carlsbad Fault is a down-to-the-south normal fault beginning along the Cueva

Escarpment (Kelley, 1971, p. 50-51).

Most of the drainage in the north is controlled by Last Chance Canyon and Rocky Arroyo. Streams are not deeply entrenched and flow in gentle, open meanders. Streams north of Rocky Arroyo have cut back to the cliff-edge divide and are lowering the southern side of the Seven Rivers Hills.

The stratigraphy of the southern Eastern Range is considered a classic example of a shelf-margin carbonate buildup. The upland surfaces are horizontally bedded lagoonal dolomites, siltstones, and sandstones of the Yates and Tansill Formations. The canyon walls consist of massive Capitan Limestone, representing a carbonate bank buildup. To the west, the Capitan is replaced by Seven Rivers Formation dolomites and siltstones through facies changes. The underlying dolomites and sandstones of the Grayburg and Queen Formations are exposed in areas of maximum dissection. The face of the Reef Escarpment is made up of east-dipping forereef talus deposits of the Capitan Limestone. The northeast wall of Slaughter Canyon (Fig. 15) provides an excellent view of the shelf margin stratigraphy. Here (Locality 85), the forereef talus deposits dip eastward at around 20°. The scarp face itself slopes at angles up to 30°, based upon measurements from the U.S. Geological Survey Grapevine Draw 1:24,000 scale topographical sheet.

Azotea Mesa and the Seven Rivers Hills are held up by the resistant Azotea dolomite tongue of the Seven Rivers Formation (Kelley, 1971, p. 32). The transition from the Eastern Range to the Seven Rivers Embayment seems to be controlled by the disappearance of this dolomite tongue and a westward increase in gypsum and anhydrite in the Seven Rivers Formation. Some features, however, suggest that faulting or fracturing controls the western margin of the Eastern Range. From north to south, Rizado Point, Old Ranch Knoll, Cone Butte, Lookout Point, and Bandanna Point align and mark the western edge of the range. Just west of Old Ranch Knoll, a right-angle stream offset and a parallel cliff face suggest fault or fracture control. Limited subsurface data (Fig. 16) do not suggest major faulting in this area. However, Mazzullo (1984, personal communication) noted that Pennsylvanian strata in the Indian Basin Gas Field just west of Rocky Arroyo are complexly faulted into a series of blocks that are hydrodynamically independent of one another.

Two caves in the Eastern Range have yielded age-dated materials (Table). A broken stalagmite from Ogle Cave (Locality E) was dated at from 200,000 to 125,000 years BP (Harmon and Curl, 1978). Vertebrate bones from two levels of Dry Cave (Locality F) have been dated at from 34,000 to 25,000 years BP and from 15,000 to 10,000 years BP (Harris, 1978; Harris and Porter, 1980).

SEVEN RIVERS EMBAYMENT

The Seven Rivers Embayment is a triangular lowland between the Eastern and Western Ranges of the Guadalupe Mountains (Fig. 17). To the north, the area merges with the Pecos Slope. The surface of the Seven Rivers Embayment appears to dip less steeply than the bedrock exposed at the surface, making it a pediment surface. This relationship is only apparent on the western side of the area, where beds dip east from the Western Range. Elsewhere, Quaternary alluvium and bolson deposits obscure the attitude of the bedrock.

The Seven Rivers Embayment is developed on gypsum, mudstone, siltstone, and dolomite of the San Andres, Grayburg, and Queen Formations (Kelley, 1971, p. 6). The bedrock is relatively flat lying, except for small local folds (Locality 59) and the Huapache Monocline (Fig. 11), which defines the western margin of the Seven Rivers Embayment. There, flat-lying beds of the Western Range plunge eastward from a higher structural position and flatten out into the Seven Rivers Embayment.

Three ephemeral stream systems drain the Seven Rivers Embayment. Box Canyon and the Seven Rivers drain the northern end, Rocky Arroyo the central portion, and Last Chance Canyon the southern end. Only the headwaters of Box Canyon and some of its tributaries are entrenched. These streams meander slightly. Some streams follow straight reaches, indicating possible fault or fracture control. Thick alluvial deposits at the northern end of the Seven Rivers Embayment include both unconsolidated sand, silt, and channel-lag gravel (Locality 54) as well as caliche-cemented cobbles (Locality 53). All of the gravel examined appears to be locally derived limestone, dolomite, and sandstone gravel.

WESTERN RANGE

The Western Range is a moderately dissected upland dip slope developed primarily on the dolomite, limestone, mudstone, and Glorieta Sandstone of the Leonardian-Guadalupian San Andres Formation. The southern end of the range is capped by dolomite and sandstone of the Guadalupian Grayburg Formation. Sandstone, siltstone, and dolomite of the Leonardian Yeso Formation are exposed in the fault scarp north of Dog Canyon on the western margin of the Western Range. The Western Range is bounded on the west by the Dog Canyon and Guadalupe Fault Zones (Fig. 18; Kelley, 1971) and on the east by the Huapache Monocline. The upland surface trends southeast-northwest and slopes eastward from the fault escarpment known as The Rim. A minor anticlinal crest parallels The Rim just east of the escarpment.

East-flowing streams in the Western Range meander, even in their headwaters, but do not become appreciably entrenched until they reach the eastern margin of the range, where grade increases greatly. Last Chance Canyon and Rocky Arroyo are deeply entrenched at this margin. Rocky Arroyo displays a large cutoff meander. Caves are not as common in the Western Range as in the Eastern Range, but there is at least one, Hermit Cave (Locality G). Vertebrate bones from this cave have been dated at about 13,000 years BP (Table; Hester, 1960, p. 60).

The eastern margin of the Western Range is defined by the Huapache Monocline, where beds step down to the east into the Seven Rivers Embayment. This relationship is evident both in the field, as in Sitting Bull Canyon (Locality 73), and in subsurface data (Fig. 16). The Humble Oil and Refining Co. No. 1 Huapache Unit drilled through a thrust fault in the Pennsylvanian section beneath the monocline. Hayes (1964, p. 40) interpreted data from surrounding wells to indicate that the west side of the fault is upthrown and that the thrust zone was intermittently active throughout most of Pennsylvanian and possibly Early Permian time. The Texas Hill Dome, a small structure mapped by Kelley (1971, p. 40), appears on Landsat imagery as an area of semiradial drainage.

The western margin of the Western Range is defined by down-to-the-west normal faulting. The southern end of The Rim, adjacent to Dog Canyon, is known as the Algerita Escarpment. This portion of The Rim is linear and undissected (Fig. 19). Near the north end of Dog Canyon, the escarpment consists of a series of small folds and faults. Beds dip west from the upland surface, flatten, then dip west again and either flatten into the floor of Dog Canyon or are cut by faulting obscured by alluvium. In this area on The Rim, reverse drag can be seen along one fault in aerial photographs. A steeply west-dipping slump block rests against the Algerita Escarpment at the southern end of Shattuck Valley. Another complexly folded and faulted area is located on The Rim immediately north of the Brokeoff Mountains. North of this area The Rim is called the Buckhorn Escarpment and is more dissected than the Algerita Escarpment in the south (Fig. 20). En echelon fault segments are visible at the top of the scarp, but west-draining streams have cut farther east into the scarp, perhaps indicating that the crest of the Western Range lies farther east of The Rim along the Buckhorn Escarpment in the north than it is along the Algerita Escarpment in the south. Large, gently east-tilted (rotated) slump blocks are common at the base of the Buckhorn Escarpment. Kelley (1971, p. 39) noted a fault scarp in Quaternary alluvium at the base of the scarp. The north-trending Guadalupe Fault Zone is indistinct in the vicinity of Fourmile Canyon. Just to the north, the Y-O Buckle, a right-lateral wrench feature (Kelley, 1971, p. 44-45) appears almost on trend with the fault zone before curving northeast. The fault zone apparently terminates against this buckle (Kelley, 1971, p. 45). Along Pinon Draw, the west-trending Stevenson Fault marks the southern edge of the Sacramento Mountains (Kelley, 1971, p. 60). Its relation to the Guadalupe Fault Zone is not apparent in the field or on remote sensing data.

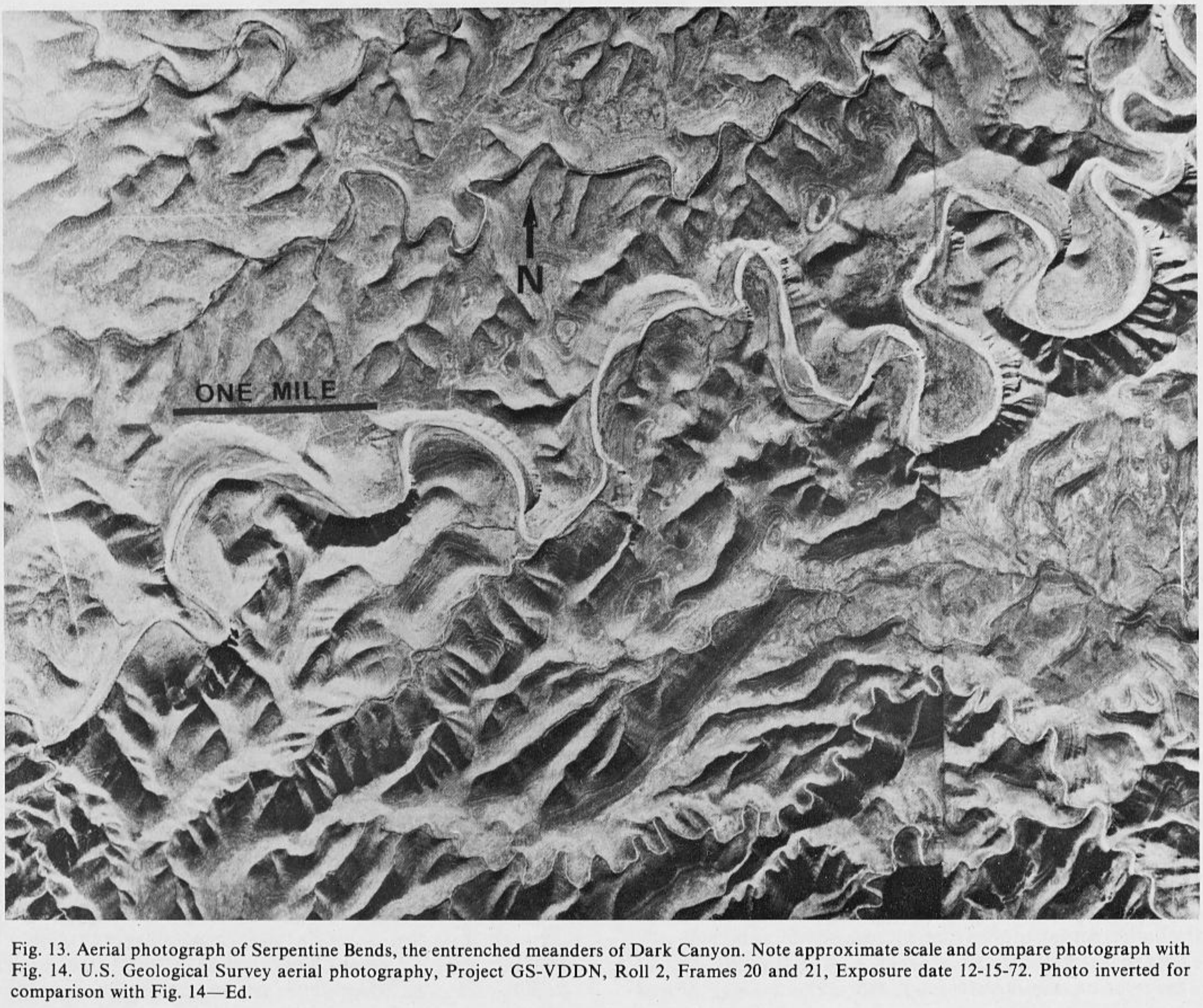


Fig. 13. Aerial photograph of Serpentine Bends, the entrenched meanders of Dark Canyon. Note approximate scale and compare photograph with Fig. 14. U.S. Geological Survey aerial photography, Project GS-VDDN, Roll 2, Frames 20 and 21, Exposure date 12-15-72. Photo inverted for comparison with Fig. 14—Ed.

Fig. 14. Serpentine Bends as they appear on U.S. Geological Survey Carlsbad Caverns West topographic sheet, scale 1:62,500. Contour interval is 50 ft.

DOG CANYON

Dog Canyon is a north-south trending, synclinal graben floored with Quaternary alluvium. The canyon slopes north from its head in the southern peaks of the Eastern Range to empty into the Crow Flats at the north end of the Brokeoff Mountains (Fig. 21). Two horsts parallel to the canyon axis project from the canyon floor. Martine Ridge is fault bounded on both sides, whereas El Paso Ridge appears to be a cuesta with a western fault face and a gentle eastern backslope. The faulting that forms El Paso Ridge and Shattuck Valley appears to die out into folding at the north end of the ridge. Because of the folding evident in the faulted ridges, it appears that folding occurred both before and during faulting. The dip of some beds may be due to rotation of blocks on listric fault planes.

Boyd (1958, p. 57) reported a flint spearhead buried in alluvium near the southern end of El Paso Ridge. Beneath the alluvial cover, most of the floor of Dog Canyon is probably San Andres Formation. Martine Ridge is mostly Grayburg Formation, capped at its southern end by the Queen Formation. The southern half of El Paso Ridge is capped by dolomite and siltstone of the Seven Rivers Formation (Kelley, 1971, p. 6).

Dog Canyon is bounded on the west by down-to-the-east normal faults along the flank of the Brokeoff Mountains. Ephemeral streams have built alluvial fans and bajadas along both walls of the valley. Streams are entrenched at the head of these fans. Some streams are entrenched into bedrock. El Paso Ridge is cut through by small streams at its north end and at El Paso Gap in its center. Streams flowing west from the Algerita Escarpment enter small closed depressions in Shattuck Valley and evaporate before reaching the axis of Dog Canyon.

BROKEOFF MOUNTAINS

The Brokeoff Mountains are an anticlinal horst feature trending north from the southern end of the Eastern Range. The mountains are broken by numerous north-south trending normal faults of varying throw direction. The upper surface of the Brokeoff Mountains is a gentle dip slope; beds on the flanks are tilted and faulted down away from the axis of the mountains (Fig. 22).

Fig. 16. (right) Generalized structure contour map on top of Bone Spring Limestone. This horizon was chosen for contouring because it is the easiest to correlate over a large portion of the study area, and as a basinal deposit it should reflect post-depositional structure. Fault shown is the Barrera Fault, solid where mapped at the surface (Kelley, 1971, Plate 4), dashed where inferred. Note Huapache Monocline in west and lack of significant structure along eastern margin of Seven Rivers Embayment. Patterned area within index map in corner shows area covered by this contour map within the study area.

The stratigraphy of the Brokeoff Mountains was mapped by Boyd (1958). The upper surface consists of dolomite and sandstone of the Grayburg and Queen Formations. The lower slopes expose San Andres Formation dolomites, limestones, and sandstones in the north (Kelley, 1971, p. 6). At their southern end, where the Brokeoff Mountains grade into the Eastern Range, the beds grade into basinal clastic facies including the Cutoff Shale and Cherry Canyon Sandstone. Below these units are small exposures of shelf-margin Victorio Peak Limestone.

All of the ephemeral streams flowing from the Brokeoff Mountains enter closed basins, Dog Canyon on the east and the Salt Basin-Crow Flats on the west. Streams in the mountains are relatively straight, and many are probably contolled by faults and fractures. The escarpments of the Brokeoff Mountains have been eroded deeply into faceted scarps.

The undissected upper surface of the Brokeoff Mountains curves upward to the south to merge into the flat surface of PX Flat, a block in the Eastern Range faulted down to the west from the elevation of Guadalupe Peak (King, 1948).

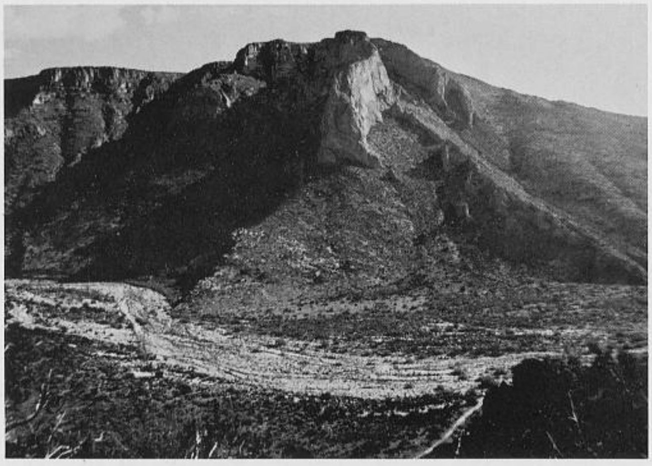
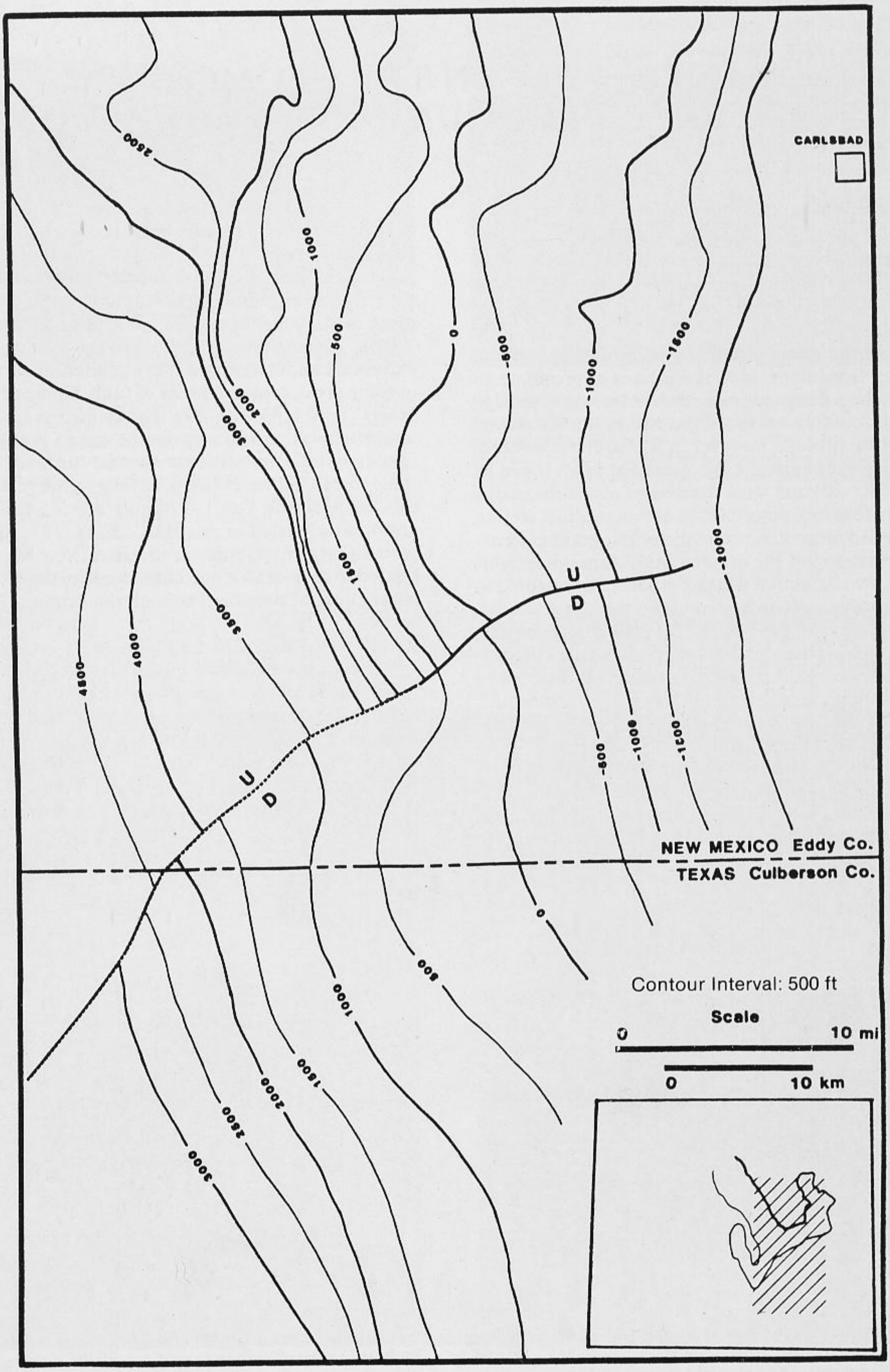


Fig. 15. North wall of Slaughter Canyon, from Locality 85. The Reef Escarpment on the right faces east. The three reef-related facies of Permian rocks in the Eastern Range are exposed in the canyon wall. On the west are horizontally stratified backreef or lagoonal rocks. The wall-like feature in the center is the massive, structureless "reef" core. On the right, forereef talus dips eastward into the Delaware Basin at 20° to 25°.

Fig. 17. Eastern margin of the Seven Rivers Embayment. Photograph taken from Locality 31 looking north. Note low, relatively flat Seven Rivers Embayment on the west and flat upper surface (dip slope) of northern Eastern Range on the east. The physiographic boundary between these two geomorphic subprovinces is controlled by a facies change from resistant dolomite beds in the Eastern Range to soft, easily eroded evaporites in the Seven Rivers Embayment.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NEW MEXICO Eddy Co.
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SPECULATIONS ON THE GEOMORPHIC EVOLUTION OF THE GUADALUPE MOUNTAINS

INTRODUCTION

While the purpose of this study is to describe the geomorphology of the Guadalupe Mountains, the data gathered present numerous opportunities for speculation on the relationships among the geomorphic features of the region.

In describing major episodes in the geomorphic evolution of the Guadalupe Mountains, it is appropriate to begin with the oldest event recorded and work forward to the present configuration of the range. In the actual interpretation process, however, it is instructive to begin with the present landscape (because that is what can be directly observed) and work backward chronologically. The major features described in the preceding section were compiled into a diagrammatic physiographic-structural cross section of the present Guadalupe Mountains region. This cross section was palinspastically restored to previous configurations by removing the effects of tectonism, erosion, and deposition for various time periods. The eight time periods chosen were dictated by isotopically dated events, information from the literature, and suppositions based upon knowledge of regional tectonic history. The time periods chosen were: Late Precambrian, Early Pennsylvanian, Late Pennsylvanian, Late Permian, Late Cretaceous (pre-Laramide), post-Laramide (Late Eocene), Middle Oligocene, and Pliocene (post-Ogallala). Each period is described and illustrated in a diagrammatic physiographic-structural cross section (Figs. 23-31).

PRECAMBRIAN EVENTS

The Precambrian history of the southern New Mexico/Trans-Pecos Texas region is complex. Flawn (1956, p. 34) interpreted the Precambrian rocks of west Texas as part of a geosyncline, the Van Horn mobile belt. The geosyncline was later succeeded by the Pedernal Landmass in the west (Kelley, 1971, p. 59), in the area of the present Diablo Plateau-Otero Platform, and by the Tobosa Basin in the east (Hills, 1984, p. 253; Fig. 23). The Pedernal Landmass appears as a gentle anticlinal upwarp in some areas, and as a series of fault-bounded blocks in others (Kelley, 1971, p. 59). The transition from high to low structural position across the region is apparently a fundamental zone of weakness that localized later tectonic forces. Flawn (1956, p. 24) suggested that the junction between the Van Horn mobile belt and the Texas craton was located in this area. Kelley (1971, p. 57) suggested that the tectonics of southern New Mexico were related to deep-seated northeast- and northwest-trending shear zones of possible Precambrian origin.

EARLY PALEOZOIC EVENTS

During early Paleozoic time, sediments were shed into the Tobosa Basin from the Pedernal Landmass and other surrounding highlands. The basin began to subside along down-to-the-east monoclinal flexures and normal faults. The Pedernal Landmass was intermittently active during this time, at times overlapped by sediments and at other times uplifted and eroded, providing a source of sediment (Kelley, 1971, p. 55-57). Beginning in Late Mississippian time, the Central Basin Platform rose, dividing the Tobosa Basin into the Midland Basin to the east and the

Fig. 18. Fault gouge in roadcut along the crest of the Algerita Escarpment, Locality 5. Calcite occurs in slickensides of the fault plane, which appears to dip steeply eastward.

Fig. 19. The Algerita Escarpment, southern portion of The Rim, which forms the eastern side of Dog Canyon. Photograph taken from Locality 88. Note how straight and steep (undissected) the escarpment appears. Also note the large fault block near the foot of the escarpment. The beds in the fault block dip steeply westward, whereas those exposed in the scarp face are almost horizontal.

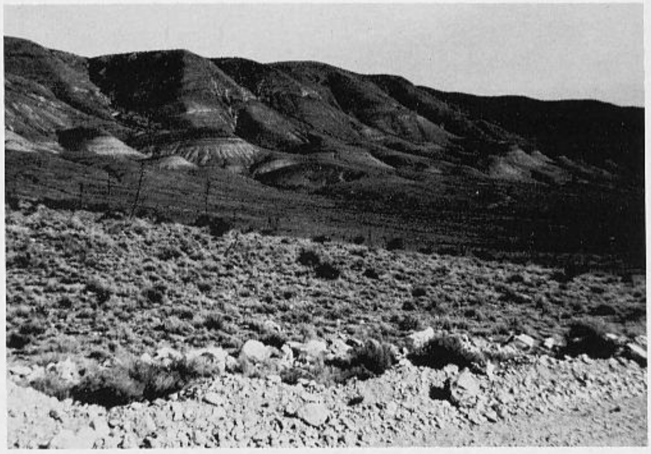

Fig. 20. The Buckhorn Escarpment, portion of The Rim north of the mouth of Dog Canyon, Locality 42. Note extensive dissection by headward-eroding streams resulting in reduced linearity of the escarpment. Ledge along foot of slope appears to be a rotated fault block; beds dip gently eastward. The beds exposed in the escarpment dip gently westward, indicating that the anticlinal crest of the Guadalupe Mountains Uplift lies somewhat east of the escarpment.

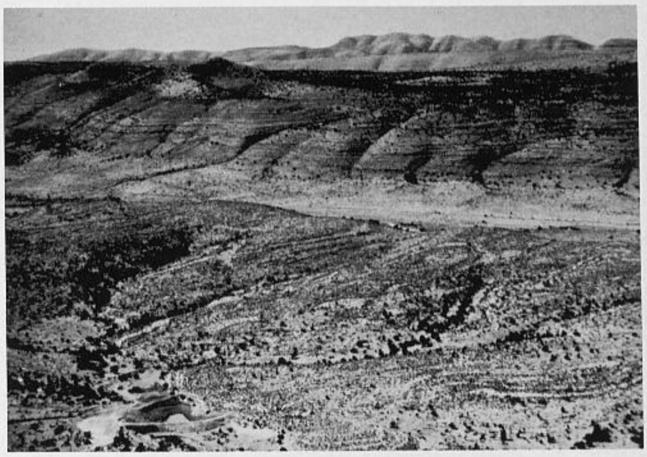

Fig. 22. The Brokeoff Mountains, looking west from Locality 26. Note flat, vegetated crest of Plowman Ridge in center of photograph. Beds on east side of the ridge, as well as beds in El Paso Ridge (foreground), dip east. Beds on the west side of the mountains, beginning at the high ridge in the background, dip west. The Brokeoff Mountains are an anticlinal horst.

Fig. 21. Dog Canyon, looking south from Locality 88. Beds along the east side of the canyon (left) dip west, and those on the west side of the canyon dip east from the Brokeoff Mountains. The canyon is a synclinal graben. Note east dip of beds in El Paso Ridge, which projects above the canyon floor just west of the road in the center of the photograph. The high southern peaks of the Eastern Range in Texas appear in the background.

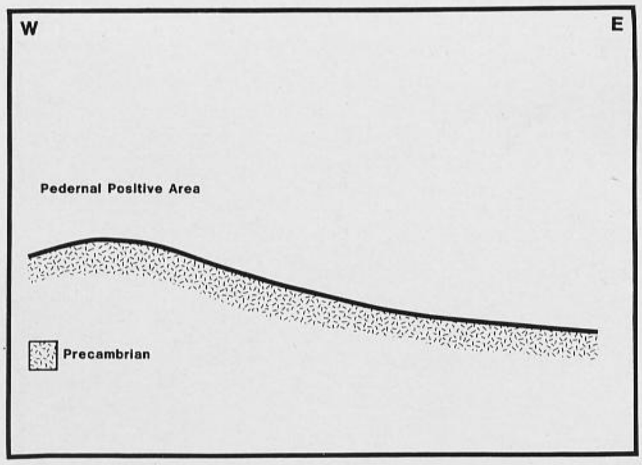

Fig. 23. Structural configuration of the Guadalupe Mountains region in late Precambrian time. The region was differentiated into a structurally high western area, the Pedernal Positive Area or Pedernal Landmass, site of the future Diablo Plateau-Otero Platform, and a structurally low eastern area, site of the future Delaware Basin.

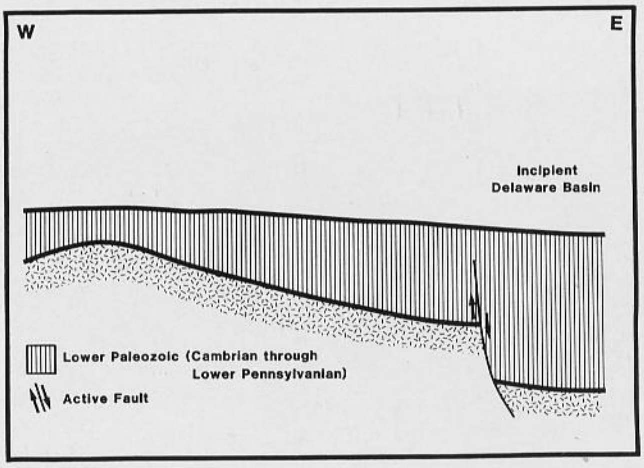

Fig. 24. Structural configuration of the Guadalupe Mountains region at the end of Early Pennsylvanian time. Sedimentation accompanying subsidence along monoclinal flexures and normal faults in the east marked the initiation of the Delaware Basin. Note that in each diagram only new rock units are identified. Unidentified units are carried over from the preceding diagram(s).

Delaware Basin to the west (Hills, 1984, p. 253). The Pedernal Landmass rose during Early Pennsylvanian time, as indicated by an unconformity between the Mississippian and Pennsylvanian rocks preserved in the Diablo Plateau-Otero Platform (Black, 1976, p. 44). By the end of Early Pennsylvanian time, the structural style of the eastern Guadalupe Mountains region was essentially established for the remainder of the Paleozoic Era (Fig. 24).

LATE PENNSYLVANIAN EVENTS

During Late Pennsylvanian time, the Delaware Basin received abundant sediment, which overlapped the Pedernal Landmass (Black, 1976, p. 44). Renewed uplift in the west allowed the Pedernal Landmass to attain its maximum relief and vigor of erosion (Kelley, 1971, p. 59) and created compressional forces which caused eastward thrusting in the Huapache Thrust Zone, the location of the present Western Range (Fig. 25).

PERMIAN EVENTS

Uplift of the Pedernal Landmass and concomitant erosion continued into Early Permian time, as Pennsylvanian and older rocks were stripped off of the Precambrian base (Kelley, 1971, p. 59) and the thrust surface was beveled. The Wolfcampian Powwow Conglomerate is the youngest deposit reflecting major uplift and erosion in the west.

Subsidence continued in the east, beginning along the Victorio, Babb, and Bone Spring Flexures (King, 1948, p. 105). The Northwest Shelf became a prograding carbonate platform separated by shelf margin carbonate buildups from the deep Delaware Basin, which was receiving clastic sediments. In early Leonardian time, the Abo reef trend ringed the basin, creating lagoons where backreef muds and carbonates accumulated in the shelf area. During later Leonardian time, the threefold facies relationship was represented by Yeso gypsum, mud, and sand on the shelf; Victorio Peak carbonate banks on the shelf margin; and black Bone Spring Limestone in the basin.

In early Guadalupian time, San Andres carbonate banks prograded basinward, while sand and minor limestones and muds of the Brushy Canyon and lower Cherry Canyon Formations accumulated in great thicknesses in the basin. Renewed flexing occurred along the Bone Spring Flexure. In later Guadalupian time, the shelf area experienced evaporitic conditions, as gypsum, mud, dolomite, and sand of the Artesia Group were deposited. The shelf margin carbonate buildups reached a maximum at this time, first with the Goat Seep bank, and then with the much thicker Capitan bank. In the basin, Cherry Canyon and Bell Canyon fine sands and dark limestones accumulated at a rate sufficient to keep up with carbonate bank growth. There was perhaps several hundred feet

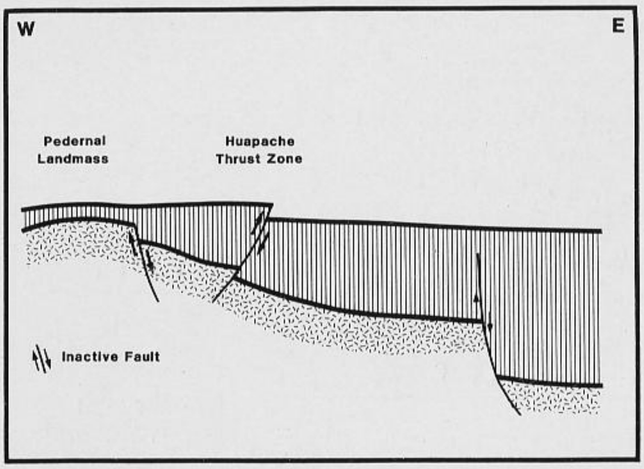

Fig. 25. Structural configuration of the Guadalupe Mountains region at the end of Late Pennsylvanian time. Renewed uplift of the Pedernal Landmass in the west caused erosion of the overlying Paleozoic sedimentary rock. The present updip limit of the Pennsylvanian in the subsurface is near the eastern edge of the Diablo Plateau-Otero Platform (Pedernal Landmass). Compressional forces from the west caused thrust faulting to the east in the Huapache Thrust Zone. Note that bold arrows indicate active faulting, whereas light arrows indicate inactive fault zones.

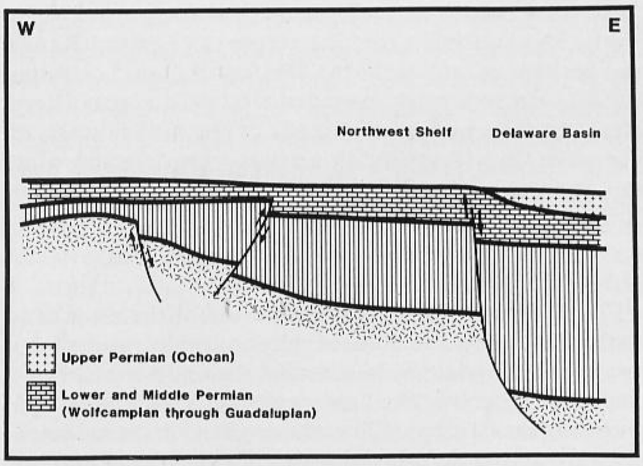

Fig. 26. Structural configuration of the Guadalupe Mountains region at the end of Permian time. Renewed subsidence and sedimentation in the Delaware Basin and the growth of the Northwest Shelf carbonate platform were the culmination of Paleozoic tectonic and sedimentary activity in the region. The Lower and Middle Permian rocks of the Northwest Shelf area are carbonates and red beds, whereas those in the Delaware Basin are fine clastics. The Upper Permian rocks filling the basin are evaporites.

of relief between shelf and basin at this time (Kelley, 1971). Finally, in Ochoan time, the Delaware Basin ceased to receive adequate water circulation, and the evaporites of the Castile, Salado, and Rustler Formations were deposited in the quiet basin water, gradually overlapping the shelf (Fig. 26). Dewey Lake red bed sediments were then deposited throughout the region (Kelley, 1971, p. 59-60).

MESOZOIC EVENTS

During Early Triassic time, erosion occurred throughout the Guadalupe Mountains region, producing a widespread peneplain (Kelley, 1971, p. 60). During the Late Triassic, the Santa Rosa Sandstone of the Dockum Group was deposited subaerially, perhaps in response to the rise of northern source areas (Kelley, 1971, p. 60).

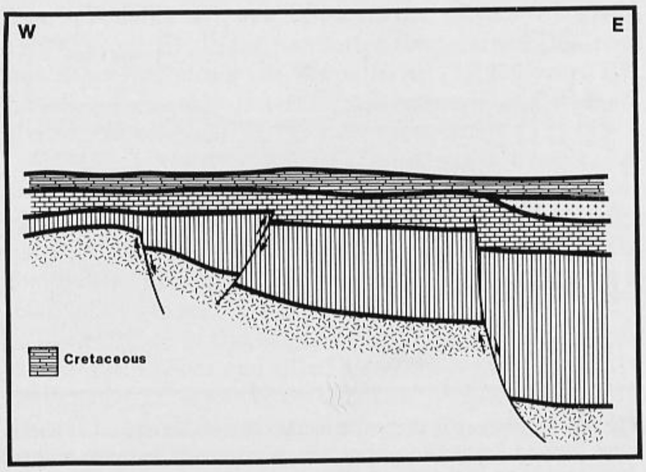

Fig. 27. Structural configuration of the Guadalupe Mountains region in Late Cretaceous time, before the Laramide Orogeny. Cretaceous marine sediments were deposited throughout the tectonically stable region.

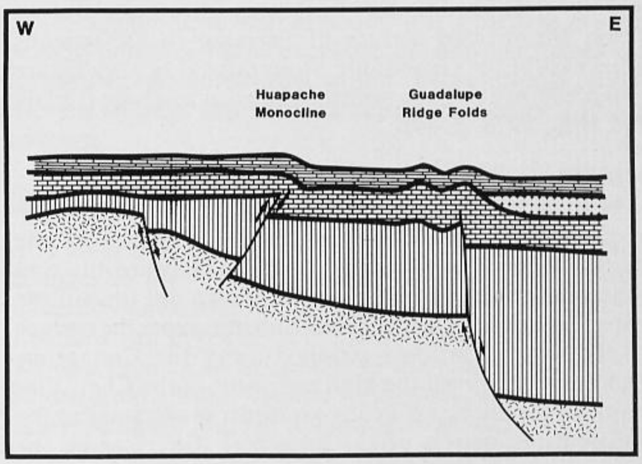

Fig. 28. Structural configuration of the Guadalupe Mountains region after the Laramide Orogeny, in Late Eocene time. Compressional forces reactivated the Pennsylvanian Huapache Thrust Zone, folding the overlying Permian and Cretaceous rocks into the Huapache Monocline. In the east, the rocks were folded into a series of anticlines and synclines, the Guadalupe Ridge Folds, Carlsbad Folds, and Waterhole Anticlinorium.

No Jurassic rocks are present within the area of study, suggesting continued erosion. Kelley (1971, p. 60) interpreted slight northward tilting during this time.

Later, Early Cretaceous marine clastics and carbonates were deposited across southeastern New Mexico and west Texas (Fig. 27).

LARAMIDE OROGENY

Because essentially all rocks younger than Permian have been stripped off of the Guadalupe Mountains, it is impossible to precisely date some of the structures present in the range. Regional deformation of Laramide (Late Cretaceous to Eocene) age is documented in surrounding areas (Kelley, 1971, p. 60). Thus, Laramide compressional forces probably were responsible for the formation of several features observed in the Guadalupe Mountains and the folds in the Otero Platform area (Black, 1976, p. 43). Compression from the west probably reactivated the Pennsylvanian Huapache Thrust Zone beneath the western Guadalupe Mountains, forming the Huapache Monocline by drape-folding of the overlying rocks. Similar stresses warped the eastern side of the range into the Guadalupe Ridge Folds, Carlsbad Folds, and Waterhole Anticlinorium (Fig. 28). Fractures parallel and perpendicular to the Reef Escarpment also probably originated at this time.

OLIGOCENE EVENTS

During Oligocene time, the Trans-Pecos magmatic province, an intracontinental rift zone was active (Barker, 1977). West of the Guadalupe Mountains, the igneous rocks of the Cornudas Mountains and Sierra Tinaja Pinta were injected into overlying Permian and Cretaceous sedimentary rocks, doming them (Fig. 29). Some of these shallow intrusives may have breached the surface, resulting in volcanism (Parker, 1983, personal communication). Based on the present relief between the summit of Wind Mountain and the surrounding plain, up to 2000 ft of sedimentary rock may have been present above the present surface of Permian rocks. Igneous dikes east of the Guadalupe Mountains (Locality D) are also presumed to have been emplaced at this time (Calzia and Hiss, 1978, p. 39).

MIO-PLIOCENE EVENTS

Most of Miocene time was a period of renewed erosion in the Guadalupe Mountains region. The rise of the Rocky Mountains produced a gentle eastward tilt, and consequent streams began to flow down dip toward the ancestral Pecos River. Streams flowing across the surface of the Otero Platform stripped away the Cretaceous rocks and produced the high pediment of the Chert Plateau. As the ancestral Pecos cut down in response to the downcutting action of the ancestral Rio Grande, the streams of the Chert Plateau cut down to the level of Otero Mesa and began to form a younger, lower pediment surface. The Cretaceous cover was removed from the Guadalupe Mountains, and the surface of the Western Range became a stripped structural plain or dip slope, as did the Seven Rivers Embayment and the northern end of the Eastern Range. The surface of the southern Eastern Range was slightly truncated, perhaps due to some early epeirogenic uplift, and fractures along the Reef Escarpment widened. As the ancestral Pecos River cut into soft, soluble Permian evaporites and formed a valley, siliceous sediments from the Rocky Mountains were carried south to form the "quartzose conglomerate" of Bretz and Horberg (1949a, p. 477). During Late Miocene to Early Pliocene time (Frye and Leonard, 1957, 1964), the gravels of the Ogallala Formation spread across the eastern half of the region as a huge bajada or series of coalescent alluvial fans (Fig. 30). The Ogallala filled the ancestral Pecos Valley to a depth of perhaps 1100 ft (based on projection of the High Plains surface across the Pecos Valley in the Malaga area, where "quartzose conglomerate" occurs near the present river level). The Ogallala extended across the Eastern Range and perhaps as far west as the Western Range (Localities C). Alluvial sediments extended westward across Otero Mesa. In the southern highlands of the Guadalupes, at Klondike Gap (Locality 4), an east-west oriented wind gap exposes up to 5 ft of sandy soil above a caliche horizon.

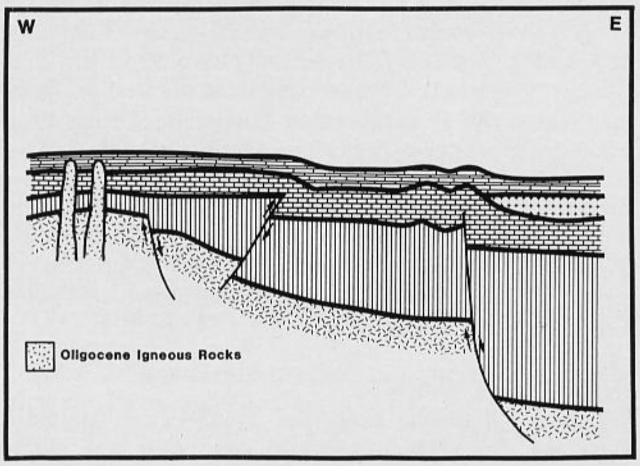

Fig. 29. Structural configuration of the Guadalupe Mountains region in Middle Oligocene time. Igneous activity associated with the northern Trans-Pecos magmatic province resulted in the emplacement of a group of intrusions in the central Diablo Plateau-Otero Platform, the area of the present Cornudas Mountains. The thickness of country rock above the intrusions is diagrammatic, but it may have been as much as 2000 ft. Most of the Cretaceous rock had probably not yet been removed from the region by erosion. The country rock was domed up and may have been breached, resulting in volcanism.

PLIO-PLEISTOCENE EVENTS

Plio-Pleistocene time was the period of the most dramatic changes in the climate, physiography, and structure of the Guadalupe Mountains region. At the beginning of this period, the area exhibited low relief and a gentle northeast slope. Slow-moving streams meandered eastward across the alluvial plains of Otero Mesa and the Guadalupe Mountains and onto the High Plains surface in the east. Perhaps eastward tilting associated with early uplift of the Sacramento Mountains provided the gradient for these streams.

The ancestral Pecos River began to remove Ogallala gravel and re-excavate a valley east of the Guadalupe Mountains (Thomas, 1972, p. 35). As Pecos downcutting lowered local base level, the steams to the west cut down, and the water table was lowered. Groundwater movement, localized along fractures, began to dissolve the Permian limestones to form a series of caves.

As the Rio Grande rift became active to the west (Ramberg et al., 1978), the Guadalupe Mountains began to rise as a north-south trending anticlinal arch with a crest that essentially followed the present Rim (King, 1948, p. 109). Perhaps the uplift was a response to mantle upwelling. As uplift continued, meandering streams cut down through their alluvial sediments and began to incise into bedrock while maintaining their meandering habit. For this to occur, the climate must have been much wetter than at present. Extensional forces became more important, and the Guadalupe Mountains Uplift broke along

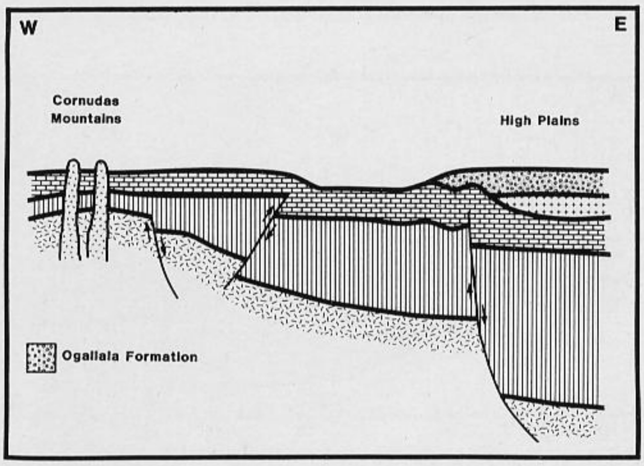

Fig. 30. Physiography of the Guadalupe Mountains region in Pliocene time. During Early Miocene erosion, Cretaceous rock was stripped away from most of the region, exposing the intrusions in the Cornudas Mountains area. During Late Miocene and Early Pliocene time, the Ogallala Formation was shed off the Rocky Mountains to the north and formed a huge bajada surface, the High Plains, on the east side of the region.

normal faults on the west and east to become a large horst. Streams on Otero Mesa, now deprived of an outlet for their sediment loads, began to alluviate rapidly. The east-flowing streams in the Guadalupes, although beheaded, continued to incise. The streams maintained their meandering habit in the resistant bedrock of the Western and Eastern Ranges. However, in the soft evaporitic rocks exposed in the Seven Rivers Embayment, the streams were able to freely erode laterally and assume a straight course more appropriate to their increased gradient. As the southern end of the mountains rose, the northeastern gradient increased, and the streams of the southern Eastern Range stripped away the remaining Ogallala cover from the uplands. These streams became consequent on the Guadalupe Ridge Folds and began to incise, controlled in some places by fractures.

Uplift of the Guadalupe Mountains appears to have been episodic, as evidenced by the several levels of the Eastern Range caves. Vertical solution is controlled by the elevation of the water table; each time this elevation stabilized for a prolonged period of time, solution produced a distinct cave level. A stalagmite from Ogle Cave (Locality E; cave level not specified) has been dated as having been deposited during the interval from about 200,000 years BP to 125,000 years BP. During this time in the Pleistocene, correlated with the Illinoisian epoch (Harmon and Curl, 1978, p. 26), Ogle Cave was in the vadose zone, above the water table, where precipitation of cave formation occurs. To account for the presence of varved gypsum in Ogle Cave, Jagnow (1978, p. 7) proposed that pyrite in the Yates Formation, exposed along the crest of the Eastern Range, was leached by groundwater and traveled down into the Capitan Formation (where the cave is located), adding sulfuric acid to the carbonic and humic acids normally found in groundwater. After aiding in the solution of the cave, the sulfuric acid contributed its sulfate to ponded waters high in calcium. The evaporation of these waters precipitated the gypsum found in the cave.

Downcutting by surface streams eventually breached the caves in the Guadalupe Mountains. Dry Cave (Locality F) had an entrance by about 34,000 years BP. Hermit Cave (Locality G) was open to the surface by about 13,000 years BP. Near this latter time, terrace material was deposited along the Pecos River (13,500 years BP; Locality I north). Later terrace material dates from around 6400 years BP (Locality I south).

On the western side of the Guadalupe Mountains, erosion proceeded along The Rim. Renewed faulting caused the Dog Canyon graben to subside. The Algerita Escarpment (the southern Rim) is less dissected than the Buckhorn Escarpment (the northern Rim) because it is relatively younger.

The bedrock of the Brokeoff Mountains was split into several fault slices and tilted away from the crest of the range as Dog Canyon to the east and the Salt Basin-Crow Flats to the west subsided around the range. As the subsidence of the Salt Basin graben lowered local base level, streams on Otero Mesa cut down through their alluvium and carried it into the Salt Basin. The presence of repeated intervals of fining-upward graded sediments in the Salt Basin indicates that uplift on the western side of the Guadalupes was periodic, just as it was on the eastern side. No evidence for episodic downcutting exists in the entrenched streams within the mountains, however, as terraces and bedrock benches are lacking in the canyons.

The present physiography and structure of the Guadalupe Mountains region is illustrated in Figure 31.

A final point of interest is the Pleistocene climatic changes in the region, a factor that had an important influence upon erosion in the Guadalupe Mountains. Leonard and Frye (1975, p. 5) interpreted the climate in Kansan time as xeric, similar to the modern climate in southeastern New Mexico. The presence of caliche horizons on the Mescalero Plain dating from 500,000 and 300,000 years BP (Bachman, 1982, p. 15) indicates that the climate was also arid at these times, during the late Yarmouthian and early Illinoisian. These caliche horizons also indicate that the Pecos River had cut down through much of the Ogallala gravel in its valley by this time. Later during the Illinoisian, cave formation was deposited in Ogle Cave. During wet periods, streams in the Guadalupe Mountains incised into the surface bedrock, while groundwater dissolved the subterranean rock. Eventually, surface erosion caught up with the underground solution, and caves were opened to the surface permitting animals to enter. The oldest bones found in Dry Cave are about 33,000 to 25,000 years old; younger bones from another cave level date from about 15,000 to 10,000 years ago. Bones from Hermit Cave are about 13,000 years old. All of these ages are middle and late Wisconsinan. Leonard and Frye (1975, p. 5), on the basis of studies of terrestrial and freshwater molluscan faunas from stream terraces and lake deposits, suggested that a long, perhaps intermittent, pluvial period lasted

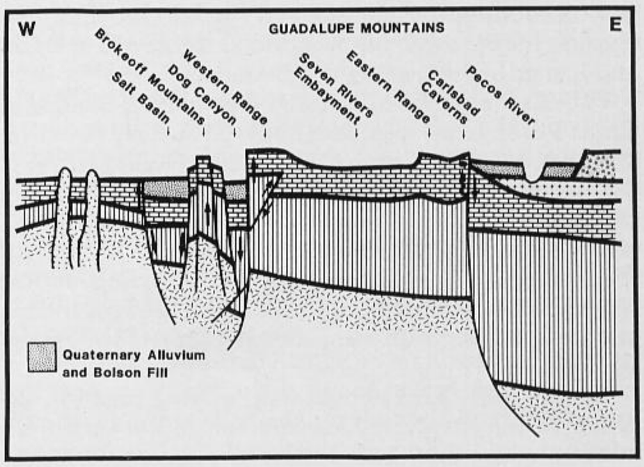

Fig. 31. Present physiographic/structural configuration of the Guadalupe Mountains region. Extensional forces associated with the Rio Grande rift to the west have broken the region into several fault blocks, including the Salt Basin graben, Brokeoff Mountains horst, Dog Canyon graben, and Guadalupe Mountains horst. During uplift, erosion removed the Ogallala Formation from most of the region. The difference in resistance between soft evaporites on the west and hard dolomites on the east resulted in the erosional relief between the Seven Rivers Embayment and the Eastern Range. As the water table was lowered by uplift and Pecos downcutting, caves formed in the soluble carbonates of the mountains.

from 18,000 to 13,000 years BP. King (1948, p. 156-157) interpreted the former existence of a lake 40 ft deep in the Salt Basin, and suggested that it was created during a pluvial period. However, the character of the sediments found in the Salt Basin suggests that much of the erosion of nearby highlands and filling of the basin took place under arid conditions.

Harris (1970, p. 14-25), in a study of Pleistocene vertebrates from caves in the Guadalupe Mountains, compared the climate indicated by the fossils to that of the Transition Life Zone in modern Wyoming. Rather than a simple lowering in elevation and southward migration of cold conditions, Harris envisioned a more complex climatic zone at low elevations. The most important characteristic of the Transition Life Zone is not an increase in total precipitation, but a decrease in the seasonality of precipitation. In present-day southeastern New Mexico and west Texas, it is the spring droughts that limit plants and animals to the highlands where evaporation is less. Harris also pointed out that insolation values in the Pleistocene must have been similar to those of today, so that there were great differences in vegetation and animal life on north- and south-facing slopes. North-facing slopes supported sagebrush intermixed with grasses, junipers, and possibly scattered conifers. South-facing slopes were characterized by grassland and occasional ponderosa pine, with local sagebrush and juniper. Riparian trees, shrubs, and forbs grew along waterways. Soil profiles were deeper, as shown by the presence of prairie dogs and large pocket gophers. The upper mountain slopes were probably in the lower Canadian Life Zone, down to elevations of perhaps 6000 ft (at least on north-facing slopes). Relict forests of Douglas fir, ponderosa pine, and even aspen are found today in the highest peaks of the Guadalupes (Barnett, no date, p. 12); ponderosa pine were observed in the field down to 5900 ft in stream valleys. The Transition Life Zone extended down to about 4000 ft, and the Upper Sonoran Life Zone occurred below (Harris, 1970, p. 25). Only 100 mi north of the Guadalupe highlands is Sierra Blanca (12,003 ft elevation), site of the southernmost Pleistocene glaciation in the United States. Leonard and Frye (1975, p. 5) stated that the present semi-arid climate of the Guadalupe Mountains region was established by 5000 years ago.

SIGNIFICANCE OF THE GUADALUPE MOUNTAINS IN THE BASIN AND RANGE

The Guadalupe Mountains are important to an interpretation of the geologic evolution of the Basin and Range physiographic-tectonic province both because they are located on the boundary of the province and because they provide information as to the age of Basin and Range faulting along this boundary.

The onset of Basin-and-Range type normal faulting in Trans-Pecos Texas is dated at about 23 m.y. BP (Dasch et al., 1969, p. 1819), during Miocene time. Kelley (1977, p. 50) suggested that faulting in the Albuquerque Basin began during the Miocene, and Seager and Morgan (1979, p. 100) suggested an age of from 28 to 26 m.y. BP (beginning of the Miocene) for the initiation of Rio Grande rifting. The origin of the rift is thought to be a mantle upwelling with associated thinning of the overlying crust.

Kelley (1971, p. 51) noted that faulting began in the center of the rift depression and spread outward from there to either side. This feature is consistent with the presence of a mantle upwelling, which might rise as a relatively narrow plume and then spread laterally upon reaching the lithosphere (Brown, 1981, personal communication). Thus, the farther away from the center of the rift a fault occurs, the younger it should be (in general). Since the faults in the Guadalupe Mountains mark the eastern edge of the Basin and Range, they should be among the youngest faults associated with the Rio Grande rift, if indeed they are assocated with it at all. Seager and Morgan (1979, p. 90-91) suggested that the Salt Basin graben might be a developing arm of the rift that has not yet "matured" to the stage of high heat flow and volcanism characteristic elsewhere.

If the rounded siliceous gravels found atop the Eastern Range are Ogallala remnants, then the faulting that raised these gravels at least 1300 ft is certainly post-Middle Pliocene. The presence of Quaternary fault scarps thoughout the Salt Basin (Goetz, 1980) and at the foot of the Buckhorn Escarpment of the Western Range (Kelley, 1971, p. 39) suggests that extensional faulting may be continuing even today. In addition, the linear, relatively undissected appearance of many fault scarps in the Guadalupe Mountains suggests an overall youthful age for the faulting in the region. Kelley (1977, p. 55) proposed that some major faulting in the Albuquerque Basin may be of Recent age, and stated that much of the Basin-and-Range structure of southeastern New Mexico is probably younger than is generally supposed.

Despite their lack of volcanism and high heat flow, the Guadalupe Mountains fit the structural style of the Rio Grande rift. Along The Rim, fault blocks, which are produced by rotation on a curved fault plane, display various degrees of tilting, including reverse drag. Recent work (Cape et al., 1983, p. 3) suggests that such listric normal faulting is the dominant structural style in the Rio Grande rift near Socorro, New Mexico. Kelley (1977, p. 51) proposed that Cenozoic normal faults in the Albuquerque Basin might sole out into old Laramide thrust planes at depth. This pattern is typical of the Basin and

Range in western Wyoming, where it intersects and overprints the Cordilleran overthrust belt (Brown, 1981, personal communication). Since the Guadalupe Mountains are a Basin-and-Range structure and the Rio Grande rift essentially composes the Basin and Range in southern New Mexico, the Guadalupe Mountains should be considered a part of the Rio Grande rift.

The presence of major down-to-the-east normal faulting on the eastern side of the Guadalupe Mountains is problematic. Major facies changes at the shelf margin-to-basin transition make it difficult to distinguish structural displacement from original depositional topography. Faulting has not been proven, yet it appears necessary for several reasons. First is the uplift of the presumed Ogallala remnants. Second, it is required to allow simple, relatively vertical uplift of the mountain block as a whole. The upper surface of the Guadalupes is not tilted eastward to the extent it should be if only the western side of the mountains rose along a normal fault zone. Third, the structure contour map of the area (Fig. 17) strongly suggests faulting in the south, at least to the depth of the Bone Spring Limestone. The Bone Spring in the map area is essentially a basinal deposit down dip from the Bone Spring Flexure, so original depositional topography and Permian monoclinal subsidence have had little effect on it. Finally, the Reef Escarpment exhibits the features of a relatively young fault-line scarp, including linearity, faceted scarps, and abrupt contacts with the rocks at its base. Furthermore, the displacement on the escarpment dies out to the northeast, although the "reef" itself does not (it continues into the subsurface). Thus, it appears that the Guadalupe Mountains are a single fault-bounded block that has been uplifted and tilted in relation to the areas on either side. Uplift of a relatively small block is much easier to reconcile than is the downdropping on either side of extensive stable areas, the Diablo Plateau-Otero Platform and especially the Great Plains.

The transition from the Basin and Range province to the Great Plains is interpreted from geophysical data as a transition from thin crust with shallow mantle beneath the former to thick crust with deep mantle beneath the latter (Ramberg et al., 1978, p. 119). This transition evidently occurs beneath or immediately adjacent to the Guadalupe Mountains. The western fault escarpment of the Guadalupes has been considered the eastern border of the Basin and Range. If the faulting present on the eastern side of the Guadalupe Mountains is basement involved (possibly reactivating the fault zone along which the Delaware Basin subsided), as postulated in Figure 32, then the eastern boundary of the Basin and Range coincides with the eastern escarpment of the Guadalupe Mountains.

CONCLUSIONS

(1) The Guadalupe Mountains of south-central New Mexico and west Texas occupy a unique position in the physiography of the United States, as they lie on the boundary between the Basin and Range province on the west and the Great Plains on the east.

(2) The Guadalupe Mountains are surrounded by five geomorphic provinces: Pecos Valley-Gypsum Plain, Delaware Mountains, Salt Basin-Crow Flats, Diablo Plateau-Otero Platform, and Sacramento Mountains.

(3) The Pecos Valley-Gypsum Plain is an area of low relief and gentle eastern dip developed principally on Permian (Ochoan) evaporites and Quaternary alluvium.

(4) The Delaware Mountains are a west-facing, faulted cuesta developed on the Permian (Guadalupian) sandstones of the Delaware Mountain Group.

(5) The Salt Basin-Crow Flats is a north-south trending graben filled with Quaternary bolson and playa deposits.

(6) The Diablo Plateau-Otero Platform is a stable region of low relief developed principally on Permian rocks. Intrusive igneous rocks of Oligocene age occur in several places in the province. The province coincides with the southern end of the buried Precambrian Pedernal Landmass.

(7) The Sacramento Mountains are a large, faulted, west-facing cuesta developed on Permian (Leonardian) limestones and dolomites. The east-dipping backslope of the Sacramento Mountains merges with the northern Guadalupe Mountains to the east.

(8) The Guadalupe Mountains geomorphic province can be divided into five geomorphic subprovinces: Eastern Range, Seven Rivers Embayment, Western Range, Dog Canyon, and Brokeoff Mountains.

(9) The Eastern Range is a deeply dissected, northeast tilted pediment surface developed on Permian (Guadalupian) limestones. It is bounded on the east by a fault-line scarp that follows the trend of the Permian Reef Escarpment.

(10) The Seven Rivers Embayment is a central lowland bounded by the two ranges of the Guadalupe Mountains. It is developed on Permian (Guadalupian) evaporites and is characterized by low relief.

(11) The Western Range is a northeast-dipping stripped structural plain bounded on the east by the Huapache Monocline and on the west by down-to-the-west normal faults. It is developed on Permian (Leonardian and Guadalupian) carbonates and sandstones.

(12) Dog Canyon is a synclinal graben between the Western Range and the Brokeoff Mountains, developed on Permian (Guadalupian) carbonates and sandstones and Quaternary alluvium.

(13) The Brokeoff Mountains are an anticlinal horst split by north-south trending normal faults and developed on Permian (Leonardian and Guadalupian) dolomites and sandstones.

(14) Nine stages in the geomorphic evolution of the

Guadalupe Mountains region have been recognized: Precambrian, early Paleozoic, Late Pennsylvanian, Permian, Cretaceous (pre-Laramide), Laramide, Oligocene, Mio-Pliocene, and Plio-Pleistocene to present.

(15) By the end of Precambrian time, the region had been differentiated into the Pedernal Landmass in the west and the Tobosa Basin in the east.

(16) During early Paleozoic time, the Tobosa Basin subsided along monoclinal flexures and normal faults and was divided into the Midland Basin on the east and the Delaware Basin on the west by the rise of the Central Basin Platform.

(17) During Late Pennsylvanian time, the Pedernal Landmass rose, producing a sediment source for the Delaware Basin and causing eastward thrusting in the Huapache Thrust Zone.

(18) During Permian time, carbonates, evaporites, and red beds of the Northwest Shelf prograded southeast toward the Delaware Basin, which was ringed by the Capitan "reef" complex. Upper Permian (Ochoan) evaporites filled the basin and overlapped the shelf.

(19) During Cretaceous time, marine sediments again spread across the region.

(20) During the Laramide Orogeny, the Huapache Thrust Zone was reactivated, folding the overlying rocks into the Huapache Monocline in the west, and a separate series of folds developed in the east.

(21) During Early Oligocene time, the Trans-Pecos magmatic province was active, and intrusive igneous rock was injected into the overlying sedimentary rock of the Diablo Plateau-Otero Platform.

(22) During Miocene and Pliocene time, Cretaceous rocks were removed from the region by erosion, and the Ogallala Formation gravels were deposited in the east as a huge alluvial surface, the High Plains.

(23) During Pliocene and Pleistocene time, the Ogallala Formation was removed from the region as the ancestral Pecos River re-excavated its valley. The Guadalupe Mountains rose as an anticlinal upwarp, then broke to become a fault-bounded block.

(24) The Pleistocene climate of the region fluctuated between cool-wet and warm-dry.

(25) The Guadalupe Mountains provide important information about the youthfulness of the Basin-and-Range faulting associated with the Rio Grande rift.

(26) If the normal faulting on the eastern side of the Guadalupe Mountains is basement involved, then the eastern boundary of the Basin and Range province is coincident with the eastern escarpment of the mountains, not with the western escarpment.

APPENDIX I

FIELD LOCALITIES

Locality

1. Eddy Co., New Mexico; 22-24S-22E. Dirt road south to Turkey Creek Canyon, just off State Highway 137 (Queen Road), near Red Lake. Overview of Eastern Range, Seven Rivers Embayment, and Western Range. Upper surface tilted gently east. Possible terrace or bench in Serpentine Bends just to the east.
2. Eddy Co., New Mexico; 22-24S-22E. Forest Service road 68E north to Guadalupe Work Center (U. S. Forest Service), just off State Highway 137 (Queen Road). View of western scarp of Eastern Range.
3. Eddy Co., New Mexico; 22-24S-22E. Dirt road south off State Highway 137 (Queen Road), just west of Forest Service road 68E. Upper surface of southern Eastern Range. Beds appear truncated, so that surface is a pediment, not a dip slope. Beds dip northeast.
4. Eddy Co., New Mexico; 23-25S-21E. Forest Service road 540 (South Rim Road) at Klondike Gap. Accordant summits in southern Eastern Range. Surface truncates dipping beds. Apparent wind gap with thick soil profile exposed in roadcut. Caliche horizon at base, overlain by up to 5 ft of brown, sandy soil. Wind gap oriented east-west, with cut bank on north side. Modern drainage from this high point is north-south. Sierra Blanca in the Jicarilla Range, the southernmost glaciated point in the United States, is visible on the horizon to the north.
5. Eddy Co., New Mexico; 28-25S-21E. Forest Service road 540 (South Rim Road). First view of The Rim (Algerita Escarpment). Overview of Dog Canyon and Brokeoff Mountains. El Paso Ridge is tilted eastward, as are eastern slopes of Brokeoff Mountains. Upper surface of Brokeoffs is a flat structural surface. Large west-tilted fault block at the base of the escarpment. Fault gouge zone in roadcut. Calcite formed along slickensides. Fault is almost vertical. Cornudas Mountains visible beyond Brokeoffs on western horizon. To northwest and north, Hornbuckle Hill (southern tip of Sacramento Mountains), Capitan Range, and Sierra Blanca are visible.
6. Eddy Co., New Mexico; 8-25S-21E. State Highway 137 (El Paso Gap Road), descending from The Rim into Dog Canyon. Beds step down to west along monoclinal folds rather than along normal faults.
7. Eddy Co., New Mexico; 18-26S-21E. Small gully east of State Highway 137 (El Paso Gap Road), at southern end of El Paso Ridge. Gully of Devil's Den Draw, southern Shattuck Valley. Deep alluvium in floor of Dog Canyon.
8. Culberson Co., Texas. Southern end of New Mexico State Highway 137. Dog Canyon Ranger Station, Upper Dog Canyon. Ascending from floor of Dog Canyon into forested area of Guadalupe Mountains National Park. Alluvium along sides of road.
9. Otero Co., New Mexico; 13-24S-20E. Forest Service road 67 (North Rim Road), at intersection with Forest Service road 277. Overview of Otero Mesa and Sacramento Mountains to west and north. Junction of Guadalupe Mountains with Sacramento Mountains is unclear. Upper surface of Sacramentos is probably a pediment. Otero Mesa is probably a pediment surface, graded from a western highland (Hueco Mountains?) to some drainage above the present Salt Basin. No gravels reported from Otero Mesa surface.
10. Otero Co., New Mexico; 3-24S-20E. Forest Service road 67 (North Rim Road) at Rawhide Triangulation Station. Closed depressions visible in floor of Dog Canyon. Streams flowing west from The Rim end before reaching Dog Canyon Draw.
11. Otero Co., New Mexico; 26-22S-19E. Forest Service road 67 (North Rim Road) at Wildhorse Triangulation Station. Change from Algerita Escarpment in the south to Buckhorn Escarpment in the north. Dissection of The Rim increases at Little Dog

Canyon; appears to be another folded area along Rim.

12. Otero Co., New Mexico; 8-21S-19E. Forest Service road 67 (North Rim Road) at Bates Triangulation Station. Buckhorn Escarpment deeply dissected at Pup Canyon, largest west-draining canyon along The Rim. Upper surface of Western Range slopes gently to the east.
13. Otero Co., New Mexico; 2-21S-19E. Forest Service road 518 just outside Lincoln National Forest. View of eastern slope of Western Range.
14. Eddy Co., New Mexico; 24-23S-25E. County Road 408 (Dark Canyon Road) west of U. S. Highway 62-180. Mouth of Dark Canyon. Beds dip gently eastward; dip steepens at canyon mouth. Large east-tilted fault block (?) in alluvium east of canyon mouth. Canyon walls appear to be recrystallized fusulinid-pellet packstones.
15. Eddy Co., New Mexico; 34-24S-25E. Dirt road west from U. S. Highway 62-180, just south of State Highway 7 (Carlsbad Caverns Road) at White's City. View of Reef Escarpment from north end. Apparent "flatirons" or vertical beds visible.
16. Eddy Co., New Mexico; 4-26S-24E. County Road 418 west of U. S. Highway 62-180, at intersection with County Road 422 (Slaughter Canyon Road). View of Reef Escarpment. Massive beds at top of cliff.
17. Eddy Co., New Mexico; 36-25S-24E. Entrance to Carlsbad Caverns National Park property on County Road 422 (Slaughter Canyon Road). View of Reef Escarpment at mouth of Slaughter Canyon. Horizontal beds visible above massive cliff-forming beds.
18. Eddy Co., New Mexico; 25-25S-24E. Crossing of Black River on County Road 418. Tilted sand and pebble to cobble-sized gravel along Black River; approximately 10 ft exposed in roadcut.
19. Culberson Co., Texas. U. S. Highway 62-180, about 10 mi southwest of Texas-New Mexico line. Thin-bedded black limestone exposed in roadcut about 1 mi south of roadside park. Smells of H_2S. Basinal limestone member of Bell Canyon Formation.
20. Culberson Co., Texas. U. S. Highway 62-180, about 2 mi south of entrance to Pine Spring Canyon, Guadalupe Mountains National Park. Roadcut exposure of large exotic blocks of gray "reef" detritus in thin-bedded yellow siltstones of Cherry Canyon Formation.
21. Culberson Co., Texas. Roadside park on U. S. Highway 62-180 immediately south of Guadalupe Pass. Panoramic view of Patterson Hills to west, El Capitan immediately to north, and Delaware Mountains to south. Vertical upper slopes of El Capitan are developed on resistant Capitan limestone, whereas gentle lower slopes are developed on Cherry Canyon sandstones. Prominent bench marks contact between Cherry Canyon Formation above and Brushy Canyon Formation below.
22. Hudspeth Co., Texas. Farm Road 1437 north from U. S. Highway 62-180, at intersection with Farm Road 2249 in Dell City, Texas. Panoramic view of Cornudas Mountains to west and Salt Flats, Brokeoff Mountains, and Guadalupe Mountains to east.
23. Otero Co., New Mexico; 27-25S-16E. Near County Road 4215 (Pinon Road), 22 mi north of Dell City. Western side of Otero Mesa. Thin, rocky, brown soil supports creosote bushes. View of Cornudas Mountains to west, Sierra Tinaja Pinta to south, and Guadalupe Mountains to east.
24. Otero Co., New Mexico; 29-22S-16E. Highway 506 (Pinon Road) near Cornucopia Diversion Dam in Cornucopia Draw, approximately 20 mi south of Pinon, New Mexico. Tilted and gently folded limestone bedrock exposed in walls of Cornucopia Draw.
25. Chaves Co., New Mexico; 25-16S-18E. U. S. Highway 82, approximately 2 mi east of State Highway 24 intersection. Panoramic view of northern end of Guadalupe Mountains to south and eastern Sacramento Mountains to west.
26. Eddy Co., New Mexico; 33-25S-21E. Forest Service road 540 (South Rim Road) at Deer Hill Overlook. Panoramic view of Dog Canyon and Brokeoff Mountains; Organ Mountains on western horizon. Vegetation contours follow bedding planes. Beds in Martine Ridge and Manzanita Ridge dip east to northeast. Some streams flowing west off Algerita Escarpment end in closed depressions at toe of slope. Alluvial fan material at toe of slope supports small bushes, whereas fine-grained playa-like sediment in canyon floor supports short, hardy grass.
27. Eddy Co., New Mexico; 27-25S-21E. Forest Service road 540 (South Rim Road) at intersection with Forest Service road 70. View north of dip slope-pediment (?) surface of Western Range from high pediment surface of Eastern Range. High pediment surface with good sandy soil development is older than lower surface. High surface supports pinon pine and juniper, with ponderosa pine beginning at 5900-ft elevation in stream valleys.
28. Eddy Co., New Mexico; 26-25S-21E. Forest Service road 69 near intersection with Forest Service road 307. Headwaters of Dark Canyon. Deeply entrenched. Bedload is cobbles to large boulders of limestone and pebbles to large cobbles of sandstone; all locally derived. No exotics (igneous rocks) found. Stream floor is covered by abundant bedload in some places and scoured to smooth bedrock in others. Stream meanders even in headwaters.
29. Eddy Co., New Mexico; 25-25S-21E. Forest Service road 69 at intersection with Forest Service road 69A (Dark Canyon Lookout Road). Floor of Dark Canyon. Deeply entrenched meanders. Boulder bedload. No exotic gravels found. Good soil supports ponderosa pine forest. Elevation 6100 ft.
30. Eddy Co., New Mexico; 17-25S-22E. Forest Service road 69 at intersection with Forest Service road 527. Entrenched meandering stream with boulder bedload.
31. Eddy Co., New Mexico; 23-24S-22E. State Highway 137 (Queen Road) 1 mi east of Guadalupe Work Center (U. S. Forest Service). Panoramic view of Seven Rivers Embayment. Western side defined by smooth descent from Western Range along Huapache Monocline. Center relatively flat and featureless. Eastern side defined by western escarpment of northern Eastern Range. Headlands along west-facing escarpment are alined.
32. Eddy Co., New Mexico; 20-24S-23E. State Highway 137 (Queen Road) near intersection with Forest Service road 527 (Serpentine Bends Road). Eastern Range slopes smoothly north to merge with southern Seven Rivers Embayment. Gypsiferous rocks in roadcuts.
33. Eddy Co., New Mexico; 4-24S-24E. Dirt road to Serpentine Bends, about 1.5 mi south of County Road 408 (Dark Canyon Road). Road follows Dark Canyon upstream from its junction with Last Chance Canyon. High, steep canyon walls. Possible collapsed solution feature in south canyon wall.
34. Eddy Co., New Mexico; 4-24S-24E. Dirt road to Serpentine Bends, about 2 mi south of County Road 408 (Dark Canyon Road). Alluvial fan-type sediments at mouth of Lechuguilla Canyon. Sand to boulder-sized sediments cut through by Dark Canyon.
35. Eddy Co., New Mexico; 9-24S-24E. Dirt road to Serpentine Bends, about 3 mi south of County Road 408 (Dark Canyon Road). Narrow meander neck 160 ft high. Large boulder bedload forms longitudinal gravel bars in steam bed. Stream bedload is both thickest and topographically highest in center of stream (center of bar).
36. Eddy Co., New Mexico; 17-19S-26E. County Road 21, just west of intersection with U. S. Highway 285. North end of Seven Rivers Hills. Flat upper surface slopes east. Dips appear steeper than surface slope.
37. Eddy Co., New Mexico; 24-17S-22E. U. S. Highway 82, about 0.5 mi west of Hope, New Mexico. High pediment surface of southern Eastern Range visible above surface of Western Range. High point is apparently Guadalupe Peak.
38. Chaves Co., New Mexico; 6-17S-20E. State Highway 13, 0.5 mi north from intersection with U. S. Highway 82. Sierra Blanca and Capitan Range project above Sacramento Plain (Pecos Slope) to north.
39. Chaves Co., New Mexico; 22-19S-16E. 2 mi east on dirt road from intersection with State Highway 24, about 13 mi south of Dunken, New Mexico. Panoramic view of The Rim from northwest.
40. Chaves Co., New Mexico; 5-20S-17E. 6 mi east on dirt road from intersection with State Highway 24. Rillwash on south-facing escarpment bounded by Stevenson Fault (southern boundary of Sacramento Mountains).
41. Chaves Co., New Mexico; 14-20S-17E. 3.5 mi north of Chaves-Otero Co. line on County Road 4210, which intersects dirt road from State Highway 24. Buckhorn Escarpment (northern end of The Rim) is deeply notched by headward-eroding streams that flow west into Pinon Creek (Lewis Canyon). Massive beds at top of cliff. Possible fault planes visible in cliff.
42. Chaves Co., New Mexico; 24-20S-17E. 2 mi north of Chaves-Otero Co. line on County Road 4210. Beds at top of cliff dip west because crest of Guadalupe Mountains Uplift is east of escarp-

ment. Beds in bench at base of cliff dip east because of rotation on curved fault plane.

43. Otero Co., New Mexico; 2-21S-17E. 1 mi south of Chaves-Otero Co. line on County Road 4210. Guadalupe Peak and Sierra Diablo visible to south.

44. Otero Co., New Mexico; 25-22S-17E. Near Templeton Ranch Landing Strip on County Road 4210. Inselberg (bedrock remnant) projects through coarse bolson sediments on east side of Crow Flats. Thin, rocky soil developed on bolson sediments supports creosote bushes (greasewood). Inselberg is essentially barren of vegetation and soil.

45. Otero Co., New Mexico; 26-23S-19E. Just south of County Road 415 (4209) at northern end of Brokeoff Mountains. Ridges of west-tilted bedrock on western face, northern end of Brokeoff Mountains. Bedrock appears to be algal-laminated dolomite or limestone. Cornudas Mountains visible above Chert Plateau on western horizon. Vegetation indicative of bolson and playa sediments (greasewood and grasses) extends up canyons cut back into Chert Plateau (e.g., Cornucopia Draw, Long Canyon, Lewis Canyon).

46. Otero Co., New Mexico; 34-25S-18E. Highway 506, 6 mi north of New Mexico-Texas state line. Panoramic view of connection between Brokeoff Mountains and southern end of Eastern Range. Flat crest of Brokeoff Mountains curves smoothly up to the south to merge with Eastern Range. Where Eastern Range is continuous with Brokeoff Mountains, it appears to be faulted down to the west from high surface of Eastern Range (elevation of Guadalupe Peak). West-dipping western face of Brokeoff Mountains also appears continuous with west-dipping beds forming lower slopes of southern Eastern Range. Fine-grained playa sediments support relatively thick soil, which supports short, hardy grasses.

47. Hudspeth Co., Texas. Intersection of Farm Road 2249 and Farm Road 1576, east side of Dell City, Texas. Small (167-ft high) domal intrusion of intermediate composition. Identified by Barker et al. (1977, p. 1439) as nepheline-bearing trachyte. Parker (1983, personal communication) suggests that it might be mugearite with plagioclase and biotite phenocrysts. Syenite pegmatite dike runs through upper part of intrusion. Intrusion is rounded by erosion. Surface is extensively spheroidally weathered. Intrusion appears to have been intruded at shallow depth (small crystal size of groundmass), exposed, eroded, downfaulted to east into Salt Basin graben, and surrounded by younger playa sediments.

48. Hudspeth Co., Texas. Corner of Farm Road 1576, 5 mi north of U. S. Highway 62-180. Panoramic view of Salt Flats and southern Guadalupe Mountains to east. Dell City intrusion and Cornudas Mountains visible to west.

49. Hudspeth Co., Texas. Farm Road 1437, 2 mi north of U. S. Highway 62-180. Panoramic view of southern Guadalupe Mountains to east. Sierra Prieta visible to south, Sierra Tinaja Pinta to west.

50. Hudspeth Co., Texas. U. S. Highway 62-180, 1.5 mi east of Salt Flat, Texas. Salt Flats. Sediment is gray mud with small crystals of halite and gypsum. Some eolian gypsum sand on surface.

51. Otero Co., New Mexico; 30-18S-12E. 13 mi south of U. S. Highway 82 at Cloudcroft, New Mexico on Forest Service road 64, to Sunspot Solar Observatory; then 7 mi farther south on Forest Service road 537 to just beyond intersection with Forest Service road 90. Crest of Hornbuckle Hill, southern tip of Sacramento Mountains. Western escarpment of Guadalupe Mountains visible on eastern horizon. To south are foothills of Sacramento Mountains and western edge of Otero Mesa. Surface of Otero Mesa is planar, and western escarpment is little dissected. Surface slopes gently east toward Crow Flats. Cornudas Mountains visible to southeast, projecting above Otero Mesa surface. Hueco Mountains are due south and appear relatively low and rounded. To west is Tularosa Basin, with San Andres Mountains and Organ Mountains beyond. Sacramento Mountains are more heavily vegetated with ponderosa pine and fir trees than are Guadalupe Mountains, probably because of more abundant winter precipitation. Sacramento Mountains, San Andres Mountains, and Organ Mountains are the closest orographic barriers west of the Guadalupe Mountains.

52. Culberson Co., Texas. U. S. Highway 62-180, 3.5 mi south of Texas-New Mexico state line. View of southern Reef Escarpment. Scarp is more extensively dissected here than farther north (Localities 15, 16, 17). Upper surface is also more rugged.

53. Eddy Co., New Mexico; 23-19S-25E. County Road 21, 3.3. mi west of U. S. Highway 285. Gravel pit on south side of road. Coarse sand cemented by caliche. Boulders of caliche-cemented conglomerate containing pebble- to cobble-size limestone, dolomite, chert, and sandstone.

54. Eddy Co., New Mexico; 20-19S-25E. County Road 21, 6.8 mi west of U. S. Highway 285. Gravel pit on north side of road. 10 ft of unconsolidated, crossbedded pebbles and cobbles in sandy caliche matrix exposed. Channel-lag gravel deposit in one wall of pit.

55. Eddy Co., New Mexico; 16-19S-24E. County Road 21, 11.6 mi west of U. S. Highway 285. Bedrock exposed in hills along Gardner Draw. Beds dip east.

56. Eddy Co., New Mexico; 16-19S-23E. County Road 12, 2.4 mi south of intersection with County Road 21. Pebbles to small boulders of limestone, dolomite, sandstone, and chert in Gardner Draw. No exotics (igneous rocks) found. Draw is cut 2 ft down into terrace of sand, silt, and gravel.

57. Eddy Co., New Mexico; 4-20S-23E. County Road 23A, 0.8 mi east of intersection with County Road 12. Flat upper surface of hill north of road appears to be a dip slope. No gravels found atop hill.

58. Eddy Co., New Mexico; 19-20S-23E. County Road 12, 3 mi south of intersection with County Road 23A. Bedrock exposed in Segrest Draw.

59. Eddy Co., New Mexico; 3-21S-21E. County Road 12, 8.8 mi south of intersection with County Road 23A. Beds along east bank of Segrest Draw are warped into several small folds.

60 Eddy Co., New Mexico; 14-21S-21E. County Road 400, 1.8 mi east of intersection with County Road 12. Box Canyon has wide, flat floor with trees along dry stream course. Beds on east bank are warped into small folds.

61. Eddy Co., New Mexico; 2-21S-22E. 3.7 mi north of County Road 400 on dirt road along Box Canyon, then 6.4 mi east along dirt road running southeast. Terrace and bedrock in floor of Box Canyon.

62. Eddy Co., New Mexico; 1-21S-22E. 1.5 mi southeast from Locality 61 on same dirt road. Panoramic view of west-facing escarpment of northern Eastern Range from hilltop.

63. Eddy Co., New Mexico; 18-21S-23E. 1.5 mi north of County Road 401 on County Road 402, which joins dirt road leading from Locality 62. Panoramic view of west-facing scarp of northern Eastern Range. Promontories are, from north to south, Seven Rivers Hills, Old Ranch Knoll, Cone Butte, Lookout Point, and Bandanna Point.

64. Eddy Co., New Mexico; 23-21S-23E. County Road 401, 2.1 mi east of intersection with County Road 402. Marathon Oil Corporation's Indian Basin Gas Plant.

65. Eddy Co., New Mexico; 19-21S-24E. County Road 401, 1.7 mi west of intersection with County Road 405. Seven Rivers Hills to north, Old Ranch Knoll to south.

66. Eddy Co., New Mexico; 28-21S-24E. County Road 401 at intersection with County Road 405. County Road 405 leads south to State Highway 137 (Queen Road).

67. Eddy Co., New Mexico; 24-21S-24E. County Road 401, about 2.5 mi east of intersection with County Road 405. High cliff on south side of Rocky Arroyo meander. Large, cultivated terrace at base of cliff.

68. Eddy Co., New Mexico; 30-21S-23E. County Road 401, 8.1 mi west of intersection with County Road 405. Panoramic view of eastern slope of Western Range (Huapache Monocline).

69. Eddy Co., New Mexico; 29-21S-22E. County Road 400, 3.8 mi northwest of intersection with County Road 401. East-dipping bedrock forms slopes of Western Range foothills.

70. Eddy Co., New Mexico; 30-21S-22E. County Road 400, 5 mi west of intersection with County Road 401. View to south of Seven Rivers Embayment and surrounding areas from hilltop. No gravels found atop hill.

71. Eddy Co., New Mexico; 29-21S-24E. State Highway 137 (Queen Road), 1.1 mi south of intersection with County Road 401. Apparent angular unconformity in small hill in front of scarp. Sandstone beds forming lower hillslopes are arched into a small anticline, and dip east more steeply than undisturbed limestone beds above.

72. Eddy Co., New Mexico; 10-23S-23E. State Highway 137 (Queen Road), 12.1 mi south of intersection with County Road 401. Panoramic view down Last Chance Canyon to east, toward southern Eastern Range to south, and toward Western Range to west.

73. Eddy Co., New Mexico; 34-23S-22E. County Road 409 (Sitting Bull Falls Road), 4.7 mi west of intersection with State Highway 137. Sitting Bull Canyon. Huapache Monocline exposed in canyon walls. Beds are in high structural position, dipping gently east, at west end of canyon. Eastward dip abruptly steepens to form monoclinal structure, then flattens again so that beds exposed in arroyo in Seven Rivers Embayment are dipping gently east in low structural postion. Judging from topographic relief, structural relief is almost 1000 ft. An unconformity is also apparent in canyon walls. Sample from top of south side of canyon is a chert nodule in limestone; silica has replaced both matrix and fusulinid fossils.
74. Eddy Co., New Mexico; 3-24S-22E. End of County Road 409 (Sitting Bull Falls Road), 7.2 mi west of State Highway 137. Sitting Bull Falls Picnic Area, Lincoln National Forest. Water of falls comes from upper surface of Western Range. Water flows down canyon, which is a humid microenvironment with numerous phreatophytes, tall grasses, and small animals. As water flows east into Seven Rivers Embayment, it sinks into gravel floor and becomes east-flowing groundwater. Water around falls has deposited tufa containing fossilized plants. Tufa on west wall of canyon overlies coarse conglomerate. No exotics (igneous rocks) noted in pools below falls. Cemented conglomerate in stream bed below falls. Possible terrace deposit of pebble- to boulder-sized conglomerate along stream banks farther downstream. No exotics found in terrace.
75. Eddy Co., New Mexico; 24-22S-23E. State Highway 137 (Queen Road), 7.3 mi north of intersection with County Road 409 (Sitting Bull Falls Road). Road below Lookout Point. Eastern side of Seven Rivers Embayment. Seven Rivers Embayment is more dissected than is first apparent. Hills have little or no alluvial cover, and draws are fairly deep.
76. Eddy Co., New Mexico; 17-21S-24E. 1.3 mi north of County Road 401 on County Road 28, then 1.9 mi east on dirt road leading to wellsite. Upper surface of Seven Rivers Hills and Azotea Mesa (northern end of Eastern Range) slope gently east. Surface is a dip slope. Beds are locally warped in several places. No rounded locally derived gravels found on surface; no exotics (igneous rocks) found. Draws in hills are filled with over 1 ft of fine-grained alluvium. Grassy area at base of escarpment marks alluvial fan. Alluvium of northern Seven Rivers Embayment appears to be thick only in areas of alluvial fans. Fans cover any evidence of faulting along base of escarpment.
77. Eddy Co., New Mexico; 32-20S-25E. County Road 28, 2 mi north of intersection with County Road 401. Wadcutter Draw cuts through from 6 to 8 ft of alluvial fan sediment.
78. Eddy Co., New Mexico; 7-20S-26E. County Road 28, 0.5 mi west of intersection with U. S. Highway 285. View of Seven Rivers Hills from north.
79. Eddy Co., New Mexico; 26-23S-25E. County Road 408 (Dark Canyon Road), 16 mi west of U. S. Highway 62-180. Beds in east wall of Mosley Canyon are warped into several folds.
80. Eddy Co., New Mexico; 27-22S-25E. 5.8 mi north of County Road 408 (Dark Canyon Road) on County Road 672 along Cueva Escarpment; then 6.2 mi west on County Road 429 up McKittrick Draw. Tilted beds of Carlsbad Folds near Carnero Peak. Draws are filled with cobble- to small boulder-sized bedload. Bedrock is exposed in stream beds in some places.
81. Eddy Co., New Mexico; 6-22S-26E. 3.5 mi west on County Road 427 from Highway 524 in Carlsbad, New Mexico. Crest of Hackberry Hills. Beds are relatively horizontal on ridge crest, and dip east toward Pecos valley on eastern side of ridge.
82. Eddy Co., New Mexico; 30-24S-25E. State Highway 7 (Carlsbad Caverns Road), about 5 mi west of U. S. Highway 62-180 at White's City, New Mexico. Floor of Walnut Canyon is bedrock thinly mantled with alluvium. Bedrock exposed in stream bed. Bedload is pebble- to boulder-sized limestone, angular to subrounded. Vadose pisolites in some cobbles collected in stream bed. Walnut Canyon is located in the center of the Walnut Canyon Syncline. Beds on west side dip east, and beds on east side dip west. Small caves visible in bedrock exposed in canyon walls.
83. Eddy Co., New Mexico; 36-24S-24E. End of Highway 7 (Carlsbad Caverns Road), 7 mi west of U. S. Highway 62-180 at White's City, New Mexico. Carlsbad Caverns National Park Visitor Center and entrance to caverns. In upper level of cave, roof is horizontal because it follows bedding planes of Tansill and Yates Formations. Deeper in cave, roof is arched where cave is dissolved in massive, unstratified Capitan Formation “reef” rock. Caverns have five known levels.
84. Eddy Co., New Mexico; 4-25S-24E. About 3 mi west on Scenic Loop Drive from State Highway 7 in Carlsbad Caverns National Park. Bedrock on crest of ridge is horizontal. Beds exposed in Rattlesnake Canyon to northwest are tilted (continuation of Walnut Canyon Syncline). No gravels (locally derived or exotic igneous rocks) found on crest of ridge. Ogallala-type siliceous gravels are reported from this vicinity by Bretz and Horberg (1949a, p. 486).
85. Eddy Co., New Mexico; 23-25S-23E. 5.8 mi southwest on County Road 418 (Slaughter Canyon Road) from intersection with U. S. Highway 62-180; then 4.5 mi northwest on County Road 422 to end of road. Mouth of Slaughter Canyon. Canyon floor is covered with rounded, pebble- to boulder-sized limestone fragments. No exotic gravels found. Stream bed is 3-4 ft below main floor of canyon. Most limestone beds in northern wall of canyon are massive, with no visible sedimentary structures. Rock at base of southern canyon wall is conglomerate of angular limestone fragments (“reef” detritus facies). From New Cave trail on south wall of canyon, three “reef”-related facies are visible in northern wall. Beds on east are “reef” detritus facies, dipping steeply east into Delaware Basin. Massive rocks in center of wall are “reef” core facies. Horizontally bedded rocks to west and overlying massive facies are backreef or lagoonal facies. Sediments of Slaughter Canyon Draw and alluvial fans from escarpment on either side of canyon obscure any surface evidence of faulting at base of scarp.
86. Eddy Co., New Mexico; 14-25S-23E. In Slaughter Canyon (upstream from Locality 85). Measured strikes and dips for “reef” detritus beds at base of north canyon wall: N67°E strike, 11°SE dip; N69°E strike, 19°40′SE dip; N75°E strike, 9°30′SE dip. Apparent dip from south side of canyon: 25°30′SE. Christmas Tree Cave near top of south canyon wall is a dry cave. The largest room is perhaps 40 ft in each dimension (length, width and height). The cave apparently has only one level.
87. Culberson Co., Texas. About 5 mi west on National Park road from intersection with U. S. Highway 62-180, 11 mi south of Texas-New Mexico state line; then 2.7 mi into McKittrick Canyon to Pratt Lodge. Floor of McKittrick Canyon is Permian bedrock (limestone and sandstone) in some places, tufa-cemented cobbles and boulders in other places, and unconsolidated pebble- to boulder-sized sediment in still others. McKittrick Canyon has a humid micro-climate, with abundant madrone trees, phreatophytes, maple trees, grasses, and animals. Several caves are visible in canyon walls. Bedrock exposed in walls is horizontal to east dipping. Near Pratt Lodge, beds strike N30°E and dip southeast at 12°30′.
88. Eddy Co., New Mexico; 5-25S-21E. About 1 mi north of State Highway 137 (El Paso Gap Road) on Forest Service road 67 (North Rim Road). View south into Dog Canyon from base of Pickett Hill. Streams flow south from upper surface of Western Range across folded zone near Locality 6 and into Dog Canyon.
89. Eddy Co., New Mexico; 18-25S-21E. State Highway 137 (El Paso Gap Road), about 2 mi south of intersection with Forest Service road 67 (North Rim Road). Bedding in roadcut dips steeply west. Beds in surrounding hills are folded, and dip east, south, and west.
90. Eddy Co., New Mexico; 17-25S-21E. State Highway 137 (El Paso Gap Road), about 3 mi south of intersection with Forest Service road 67 (North Rim Road). Stone Canyon is a 380-ft deep east-west canyon cut through the north end of El Paso Ridge by ephemeral stream draining off the Algerita Escarpment immediately to east.
91. Eddy Co., New Mexico; 30-25S-21E. County Road 415 (4209A), about 1 mi north of El Paso Gap. Beds on east side of Martine Ridge dip steeply east. Dip steepens to east (downdip).
92. Otero Co., New Mexico; 24-25S-20E. County Road 415 (4209A), about 2 mi north of El Paso Gap. West (downstream) end of Stone Canyon, seen at Locality 90. Dissected alluvial fan on west side of road at base of east face of Martine Ridge.
93. Otero Co., New Mexico; 11-25S-20E. County Road 415 (4209A), about 4.5 mi north of El Paso Gap. North end of Martine Ridge. Alluvial fan at mouth of Cistern Canyon, eastern face of Big Ridge, Brokeoff Mountains.
94. Otero Co., New Mexico; 2-25S-20E. County Road 415 (4209A), about 5 mi north of El Paso Gap. Graded bedding in sides of Big

Dog Canyon Draw on east side of road.

95. Otero Co., New Mexico; 31-23S-20E. County Road 415 (4209), about 12 mi north of El Paso Gap. Faulted and slumped zone of The Rim (transition from Algerita Escarpment in south to Buckhorn Escarpment in north) makes up north wall of Dog Canyon at canyon mouth (directly north of north end of Brokeoff Mountains). Little Dog Canyon flows south over this zone and is dissecting it.

96. Otero Co., New Mexico; 1-24S-18E. County Road 4209, 2.5 mi east of intersection with Highway 506. Inselberg (bedrock remnant) projecting above bolson sediments on west side of Crow Flats. Beds in Otero Mesa dip east toward Crow Flats; surface truncates bedding.

97. Otero Co., New Mexico; 11-26S-14E. County Road 4212, 1 mi east of intersection with County Road 4264. Cornudas Mountains. Wind Mountain laccolith and Black Mountain sill (Barker et al., 1977, p. 1439) to south. Guadalupe Mountains on eastern horizon.

98. Otero Co., New Mexico; 4-26S-14E. County Road 4212, 1 mi northwest of intersection with County Road 4264. Cornudas Mountain on north side of road. Cornudas Mountain differs in appearance from all other intrusions in area. It weathers into large boulders and is fractured. It appears to be more coarsely crystalline than the surrounding intrusions and is evidently a trap-door laccolith, which domed up the Permian sedimentary rocks on its west side and rose along a fault on its east side (Parker, 1983, personal communication). Barker et al. (1977, p. 1439) classify it as a plug, but this description does not fit the evidence observed in the field.

99. Otero Co., New Mexico; 30-25S-14E. County Road 4212, 4 mi northeast of intersection with County Road 4264. View of Cornudas Mountains. Flat Top sill and Deer Mountain plug (Barker et al., 1977, p. 1439) to south. The magma that formed the Cornudas Mountains intrusions could have been derived (further evolved) from the magma that formed the Dell City intrusion (Parker, 1983, personal communication).

100. Otero Co., New Mexico; 23-25S-13E. County Road 4267, 0.5 mi north of intersection with County Road 4212. Deep silt in tributary of New Tank Draw. Soil supports short grass, small deciduous bushes, and cactus.

101. Otero Co., New Mexico; 7-26S-15E. County Road 4212, 2.5 mi east of intersection with County Road 4264. Wind Mountain, to southwest, appears to have some remnants of domed-up Permian and Cretaceous sedimentary rock making up its lower slopes. The magma that formed it was probably more viscous than the magma that formed the nearby sills (Parker, 1983, personal communication). Some of the intrusions in the Cornudas Mountains area may have breached the surface, producing volcanism (Ibid.).

102. Otero Co., New Mexico; 16-26S-15E. County Road 4214, 2 mi southeast of intersection with County Road 4212. Arroyo (tributary of Wind Mountain Draw) with at least 10 ft of silt exposed in banks. Igneous cobbles found in dry stream bed. Surface of Otero Mesa is veneered with much thicker soil than is first apparent.

103. Eddy Co., New Mexico; 31-25S-25E. 1000 ft southeast of U. S. Highway 62-180 on dirt road about 1.2 mi south of County Road 418 (Slaughter Canyon Road). Cretaceous fossils reported from this vicinity by Lang (1947, p. 1472). No Cretaceous fossils found. Basalt fragments scattered over surface throughout area indicate presence of a dike covered by thin soil. Euhedral, doubly terminated quartz crystals (hexagonal dipyramids) brought to surface by ants to form anthill. A few rounded, siliceous pebbles (Ogallala?) found.

104. Eddy Co., New Mexico; 28-25S-23E. 5.8 mi southwest on County Road 418 (Slaughter Canyon Road) from intersection with U. S. Highway 62-180; then about 2.4 mi west on County Road 422; then 0.2 mi west on dirt road; then about 2 mi northwest on dirt road to end of road. Hiking trail beginning at mouth of Yucca Canyon. Trail follows canyon for 2 mi to crest of Eastern Range. Just below head of canyon, fracture in limestone is filled with sandstone and small, subangular to subrounded, quartzose pebbles. Possibly Ogallala gravel; possibly Cretaceous sediments. On crest of Eastern Range, around eastern brow of hill, abundant well-rounded, large pebbles of vein quartz, metaquartzite, jasper, and black chert are scattered over surface. Bedrock at top of hill is coarse-grained red sandstone. Hill is covered with abundant alligator juniper and some pondersoa pine and madrones. Madrones are more abundant within Yucca Canyon.

105. Eddy Co., New Mexico; 34-21S-26E. 2.5 mi southwest of U. S. Highway 285 on park road just north of Carlsbad, New Mexico. Living Desert State Park, crest of Ocotillo Hills. Bedrock dips east under Pecos valley alluvium to form eastern face of Eastern Range. In park museum is fossil Cretaceous nautiloid found in White Oak Canyon in Guadalupe Mountains (Locality J, Fig. 2 and Appendix 2). Fossil indicates former presence of Cretaceous sediments overlying Guadalupe Mountains.

106. Culberson Co., Texas. About 20 mi south of Texas-New Mexico state line on U. S. Highway 62-180. Hiking trail beginning at Pine Springs campground, Guadalupe Mountains National Park. 4.4 mi hiking trail to Guadalupe Peak, highest point in Texas and in Guadalupe Mountains (8751-ft elevation). Panoramic view of entire study area from peak. Pecos Valley-Gypsum Plain, Delaware Mountains, Salt Basin-Crow Flats, Diablo Plateau-Otero Platform, Sacramento Mountains, and Guadalupe Mountains visible. Fault scarps in Delaware Mountains, Sierra Diablo, and Patterson Hills especially noticeable. Guadalupe Peak Campsite is located on a pediment surface; beds dip east and are truncated by surface. Steeply dipping "reef" sediments visible in canyon walls. Beds in Delaware Mountain Group sandstones below dip steeply at base of mountains, then flatten out basinward. Large (1-in long) fusulinids and vadose pisolites common in rocks near peak.

APPENDIX 2

LITERATURE LOCALITIES

LOCALITY

A. Asquith, 1973, p. 537.
Lamprophyre sill intruded into Pennsylvanian Gobbler Formation at base of Sacramento Mountains escarpment.
44.2 ± 2.2 m.y. BP (Late Eocene); K-Ar date.

B. Barker et al., 1977; ages recalculated using new decay constants (Parker, personal communication, 1983).
Hypabyssal intrusives injected into Permian and Cretaceous sedimentary rocks in Diablo Plateau, northern Trans-Pecos magmatic province.
All ages are middle Oligocene; K-Ar dates from biotites.

Cornudas Group
36.8 ± 0.6 m.y. BP; Alamo Mountain discordant sheet; phonolite.
36.8 ± 0.6 m.y. BP; Augite syenite plug; nepheline-bearing augite syenite.
34.6 ± 1.5 m.y. BP; Cornudas Mountain plug; quartz-bearing syenite.
33.0 ± 1.4 m.y. BP; Deer Mountain plug; nepheline syenite.

Sierra Tinaja Pinta Group
36.1 ± 0.6 m.y. BP }
35.1 ± 0.6 m.y. BP } all Mayfield Valley dome; syenite
34.9 ± 0.6 m.y. BP }

C. Bretz and Horberg, 1949a, p. 486; Thomas, 1972, p. 37.
Rounded siliceous gravels (vein quartz, metaquartzite, black chert, and jasper; schist reported at locality in Western Range) occurring as fracture fillings and scattered over upland surfaces in Eastern Range.
Ogallala Formation remnants (Mio-Pliocene)? Possibly Cretaceous.

D. Calzia and Hiss, 1978, p. 39
Alkali trachyte (Pratt, 1954, p. 143) dikes intruded into Ochoan Castile Formation; Gypsum Plain.
33.9 to 32.2 m.y. BP (middle Oligocene). Dikes have *not* been dated; Calzia and Hiss assume that they are similar in age to K-Ar dated basaltic dikes intruded into Ochoan evaporites east of the Pecos River.

E. Harmon and Curl, 1978, p. 26.
Broken stalagmite found on floor of Ogle Cave, north wall of Slaughter Canyon, Eastern Range.
207,000 + 64,000 or -40,000 yr BP (Illinoisian); basal layers; Th-U date.
126,000 ± 26,000 yr BP (Illinoisian); top layers; Th-U date.

F. Harris, 1978; Harris and Porter, 1980.
Vertebrate bones (mollusks, small reptiles, birds, small mammals, and horses) from two levels in Dry Cave, McKittrick Hill, Eastern Range.
33,590 ± 1500 to 25,160 yr BP (post-Sangamon, pre-Kansan); lower level; radiocarbon date.
15,030 ± 210 to 10,730 ± 150 yr BP (Kansan); upper level; radiocarbon date.

G. Hester, 1960, p. 60.
Vertebrate bones from Hermit Cave, Western Range.
12,900 ± 350 yr BP (Kansan); radiocarbon date.

H. Lang, 1947.
Washita-aged marine fossils found on the Ochoan Castile Formation, Gypsum Plain; believed trapped in a sink and preserved while surrounding rock was eroded.

I. Leonard et al., 1975, p. 4.
Organic material from Pleistocene terrace deposits along Pecos River; terrace levels not specified; Pecos Valley.
13,550 ± 170 yr BP (Kansan); north (below Lake Avalon); radiocarbon date.
6,420 ± 110 yr BP (Kansan); south (below Herradura Bend); radiocarbon date.

J. Exhibit at Living Desert State Park, Carlsbad, New Mexico (Locality 75, Fig. 2).
Nautiloid found in White Oak Canyon by Bob Wilkinson, Carlsbad, New Mexico.
Cretaceous.

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