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GEOLOGIC HISTORY AND THE EXPLORATION FOR OIL IN THE BORDER REGION

by

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ABSTRACT

Oil exploration in the Border region of southwestern New Mexico and northern Chihuahua is in its infancy. Bounded by and containing mountain ranges of the Basin and Range province, this Mexican Highlands physiographic province is comprised in great part of bolson plains, ancient lake basins with associated beach terraces, some river terraces, valley fill, stabilized to active sand dunes, and some lava cover. The Border region is mainly one of interior drainage, excepting the Rio Grande on the northeast.

Three marine regimes, the pre-Pennsylvanian, Pennsylvanian-Permian, and the Cretaceous, have given the Border region a stratigraphic setting of high potential for oil and gas discovery. However, petroleum exploration is made difficult by results of late Cretaceous and post-Cretaceous tectonic and volcan-intrusive events, and by widespread cover of Cenozoic and Holocene sediments.

Four areas of maximum wildcat potential in the entire region are: the Potrillo shelf on the northeast, the Florida shelf on the northwest, the Alamo Hueco shelf slope, and parts of the Pedregosa basin on the southwest, and elements of all of these several paleogeologic provinces present in northern Chihuahua.

A logical exploration program leading to drilling of many deep tests must involve detailed photogeology, measurement and collection of stratal sections exposed in the mountains, careful field mapping, analysis of the subsurface via the few deep wells that have been drilled, gravity mapping, reflection seismic shooting, and synthesis of all data by capable exploration-oriented petroleum geologists.

RESUMEN

La exploración petrolera en la region limitrofe entre el suroeste de Nuevo Mexico y de los estados del Norte de Chihuahua, está en sus principios. La provincia fisiográfica mexicana de tierras altas está bordeada y contiene cadenas montanosas de la Provincia de Cuencas y Sierras. Esta montanosa región consiste en su mayoria en bolsones, cuencas lacustres antiguas con terrazas de playas y de algunos de rio, rellenos de valle, médanos de arena estables o activos con algunos derrames de lava. La region limitrofe se caracteriza principalmente por drenaje endorreico, exceptuando al Rio Bravo en el noreste.

Los tres regimenes marinos, el pre-Pensilvánico, Pensilvánico-Permico y el Cretácico, ban proporcionado a la región limitrofe una situation estratigráfica muy favorable para descubrimientos de petróleo y gas. Sin embargo, la exploración del petróleo se ha visto obstraculizada por el tectonismo y actividad plutónica-volcinica del cretácico tardio y post-cretácico, asi como por la extensa cubierta sedimentaria Cenozoica y holocénica.

Las cuatro areas más favorables para la exploración de la region son: la Plataforma de Potrillo en el norete, la plataforma de Florida en el noroeste, la pendiente de la Plataforma Alamo Hueco y partes de la cuenca de Pedregosa hacia el suroeste cuyos elementos están presentes en el norte de Chihuahua.

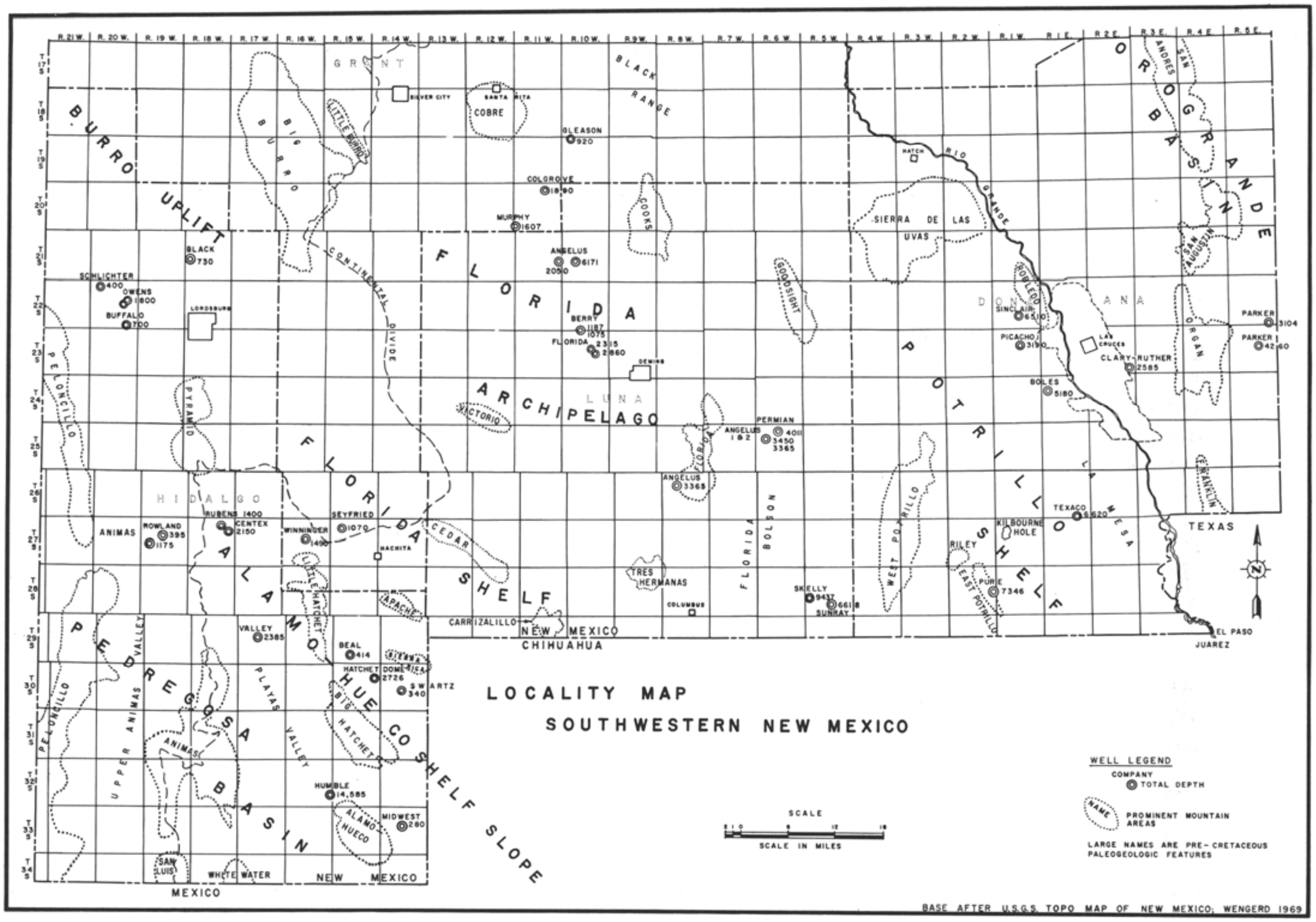
Un programa de exploración bien disenado tendiente a la perforación de varios pozos profundos debe incluir f fotogeologia de detalle, medición y colección en secciones estratigráficas expuestas en las sierras, cartografia geológica precisa y análisis del subsuelo utilizando los datos de los pocos pozos profundos ya perforados, gravimetrias, sismologia de reflection y sintesis de todos los datos por geólogos petroleros capaces en exploración.

INTRODUCTION

About 10,000 square miles of southwestern New Mexico involving parts of Dona Ana, Luna, Grant, and Hidalgo Counties constitute the United States part of the Border region under consideration in this guidebook. Northern Chihuahua constitutes the Mexican part. This region is bounded on the east by the San Augustin-Organ-Franklin tectonic alignment, on the west by the Peloncillo Mountains, on the north by a line joining the Big Burro Mountains—the Sierra de las Uvas—Cooks Peak, and on the south by the Mexico-United States boundary (Fig. 1) .

A part of the Mexican Highlands in the Basin and Range province, this region may also be considered to be a part of the Mexican Mesa Central between the Sierra Madre Occidental and Oriental. Tectonically it falls into the Sonoran-Chihuahuan part of the Basin and Range system and is the locale of intersection of the north-trending Cordilleran Mountain system and the older west-trending Ouachitan-Sonoran tectogenic system. As such, its geologic history is interestingly complex as a future petroleum province.

A not-quite chronological, highly over-simplified sequence of geologic events involves these elements in the



geologic history: (A) peneplanation of Precambrian sedimentary, metamorphic, and igneous rocks during a relatively short Lipalian interval; (B) deposition of Cambrian to Morrowan-Atokan strata on the irregular north flank of the Sonoran geosyncline and its several gentle pre-Pennsylvanian basinal sags, such as the Pedregosa basin; (C) widespread intra- and intersystemic disconformities in pre-Pennsylvanian rocks; (D) partial segmentation of the irregular Sonoran shelf into Pennsylvanian and Permian positive areas, islands, tectonic sags and spurs, and accessways having northerly to northwesterly trends across New Mexico during Desmoinesian, Missourian, Virgilian, Wolfcampian, and part of Leonardian time; (F) the localized uplifts of the Burro-Florida arch of islands and barriers between the Pedregosa basin on the southwest, and an unnamed accessway of Desmoinesian age and the Virgilian Orogrande basin on the east; (F) important regional disconformities between Desmoinesian and Missourian strata, and on top of middle Leonardian strata, with disconformities merging into angular unconformities around ancient uplifts; (G) subsidence and southward tilting in early Cretaceous time when the region was on the northern flank and shelf slope of the Mexican geosyncline; (H) episodic tectonism from latest Triassic to early Tertiary time; relatively gentle pre-Cretaceous deformation, late Cretaceous to Tertiary (Laramide) deformation marked by folding, thrusting, and wrench faulting that is more intense toward the southwest; (I) local intrusion of monzonitic stocks, particularly on the northeast, the southwest, and the far west in late Cretaceous time, accompanied and followed by volcanism which lasted into the Miocene; (J) thin late Tertiary to Pleistocene lava flows, most common in the east-central part of the region; (K) mid-Tertiary to Quaternary block faulting to create the Rio Grande depression and other basins filled with coarse detritals, lake sediments, and alluvial wash from the rising north to northwest trending mountain ranges.

The Border region has its highest oil and gas potential in the following strata: Lower Cretaceous carbonate reefs, biostromes, and quartzrose sandstones; Permian reefs, biostromes, and dolomite (Concha-Epitaph-Colina-Upper Horquilla, and Hueco); Pennsylvanian Desmoinesian (Horquilla, Magdalena), and Virgilian (Panther Seep) carbonate reefs, disconformities, and dolomite; Mississippian to Ordovician limestone, dolomite, disconformities, stray sandstones, and some reefs; and Cambrian Bliss sandstone. The traps to search for are in northeast and northwest trending anticlines, along northwest-trending normal faults, barrier carbonate reefs, and wedge sandstone trends.

This region presents to the exploratory geologist several major difficulties and problems in the search for oil and gas which may be resolved by making full use of the very highest type of geologic imagination coupled with full cooperation of geologists and geophysicist in exploration. (See Kottlowski et al, and Wilson et al, this guidebook) .

For purposes of exploration, the United States part of the region may be divided into two major areas, an east one and a west one, divided by a north-south line through Cooks Peak, Florida Mountains, Tres Hermanas Mountains, and Palomas, Mexico. About 40 percent of the whole region appears to be favorable for petroleum accumulation and preservation. Over half of the 40 percent, scattered in several localized sectors, both in Mexico and the United States, is good wildcat country, albeit somewhat difficult to explore. Utilization of every possible means of exploration, including the dauntless drilling of deep tests, may result in the discovery of major oil and gas fields in southwestern New Mexico and northern Chihuahua.

BY WAY OF EXPLANATION

This rather philosophical and understandably generalized summary is based on numerous field trips, field mapping for a number of companies between 1956 and 1968, analysis of the abundant but generalized literature on the region, more than a few exploratory flights, examination of air photographs, and the more detailed investigation by a number of my associates as well as members of the New Mexico Bureau of Mines and Mineral Resources, particularly Roy Foster and Frank Kottlowski. This summary is purposely limited to the United States part of the region in view of the excellent but largely confidential work by the competent geologists of Petróleos Mexicanos. Nonetheless, in the body of this paper, I can make certain cursory projections of trends into Mexico which the alert reader could make for himself. I am indebted to Florence M. Wengerd for typing the manuscript and to Joseph Nelms for drafting Figure 1.

The reader will note absence of detailed bibliography which can be found appended to other articles in this Guidebook. I am indebted to Kottlowski, Zeller, Lasky, Jicha, Needham, Thompson, Callaghan, Darton, Dunham, Elston, Flower, Foster, Lochman-Balk, Richardson, Sandeen, and others for their published works which have set the stage for petroleum exploration in the Border region.

POTRILLO SHELF

GEOGRAPHY

The Potrillo shelf lies between the Orogrande basin on the northeast and the Florida archepelago on the west and may make an arcuate connection with the Florida shelf via northern Chihuahua. Bounded by the San Andres-Franklin alignment on the east and the Mexican Highland volcanic and desert plains on the west and southwest, this vast area extending into northern Chihuahua is a part of the Basin and Range physiographic province.

The Potrillo sedimentational shelf is overlain by the broad Laguna bolsons of Chihuahua, the Florida bolson, and a broad plain, La Mesa, whose surface is made up of Tertiary to Recent alluvial and windblown sediments, cali che, and thin lava flows in the central part. La Mesa extends from the East Potrillo Mountains (elevation 5359 feet) on the southwest, almost to the Franklin Mountains (elevation 6908 feet) on the east. The United States part of La Mesa is bounded by Sierra de las Uvas and Robledo Mountains on the north, the Organ Mountains on the northeast, the Juarez Mountains of Cretaceous reef limestone and shale and Tertiary volcanics on the southeast. The broad northern plains of Chihuahua are a southward continuation of La Mesa into Mexico. The average elevation of the La Mesa surface over the Potrillo shelf is 4200 feet; topographic range is about 100 feet on the huisache-mesquite-yucca-chamisa-grass-covered surface.

STRATIGRAPHIC HISTORY

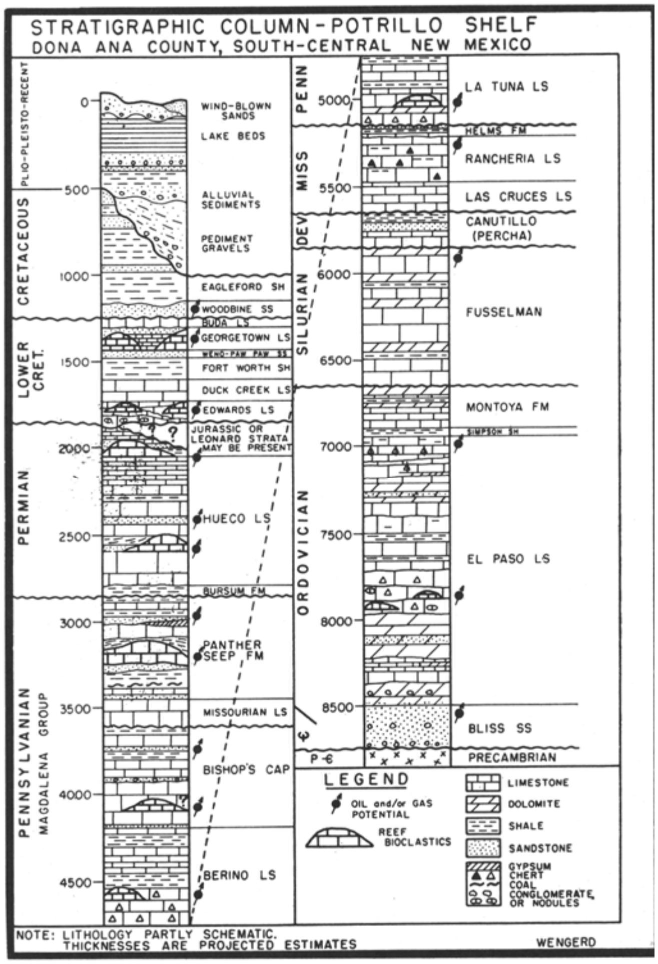
The stratigraphy of the Potrillo shelf as projected into the area from all sides is summarized in the figure entitled "Stratigraphic Column, Potrillo Shelf, Dona Ana County, South-Central New Mexico." Inasmuch as few tests have penetrated below the top of the Lower Cretaceous limestone in southern Dona Ana County, such projection must be based on good geologic practice, judgment, and the recognition of stratigraphic trends controlled by ancient uplifts and subsidences. Despite the distances involved, such projection from wide areas can be remarkably reliable in the reconnaissance sense. This writer is reasonably certain that an optimum thickness of pre-Pennsylvanian strata is present under most of the Potrillo shelf; that between 500 and 3000 feet of Pennsylvanian strata are present representing all series, between the Florida Positive on the west and the Orogrande basin on the east, across the Potrillo shelf; that over 1000 feet of Permian carbonates are present over the south half of the shelf; that well over 500 feet of Lower Cretaceous strata may be present in the subsurface over parts of the Potrillo shelf; and that Upper Cretaceous strata with Texas affinities may be found under 500 to 2000 feet of Santa Fe and Recent alluvial and lake sediments which cap the stratigraphic column under La Mesa (see Fig. 2).

The optimum thickness of the oil-potential marine section is thus about 7500 feet, divisible for discussion into four parts:

Pre-Pennsylvanian.—These strata are mainly carbonates and, oldest to youngest, consist of the Cambro-Ordovician Bliss sandstone; the Ordovician El Paso dolomite and Montoya limestone, dolomite, and shale; the Silurian Fusselman carbonates; the Devonian Percha, and Canutillo gray shale, sandstone, and limestone; and the Mississippian Las Cruces, Rancheria, and Helms limestone, shale, and sandstone.

These strata are shelf to shelf break-in-slope strata controlled in their deposition by the tectonic activities of the north flank of the Sonoran geosyncline which may have been an east-west connection between the Ouachita-Llanorian geosyncline in Texas, Oklahoma, and Arkansas, and the Cordilleran geosyncline in Arizona and Nevada. Numerous disconformities punctuate the section, and the marine strata are suitable as source and reservoir rocks for oil and gas.

Pennsylvanian.—Strata of all series from Morrowan to



Virgilian are probably present and consist of limestone, gray shale, and some sandstone embracing biostromal and biohermal sections of high oil and gas potential. These strata were controlled in their deposition by the north sedimentational shelf of the Sonoran geosyncline until mid-Des Moines time when the Orogrande basin began a strong subsidence on the east and northeast. Thin but persistent Missourian carbonates showed a momentary halt in subsidence of the Orogrande basin, but in Virgilian time a strong movement (uplift) in the Florida positive to the west was coupled with a strong negative movement (subsidence) in the Orogrande basin. During this time a strong shelf-break formed with elastic sediments coming westward across parts of the basin from the Pedernal positive of central New Mexico, and some elastics from the Florida archipelago. Between these two elastic sources, stratigraphically and geographically, the biostromal-biohermal carbonates were generated in relation to areas of high organic growth, to form the Virgilian Panther Seep formation. The Potrillo shelf is believed to be the locale of these maximum facies gradations which are typical of petroleum provinces.

Permian.—Widespread uplift and some southeast tilting took place in late Virgilian and early Wolfcampian time, and then the Permian Hueco (Wolfcamp to earliest Leonard) limestone was deposited on the Potrillo shelf as this entire region subsided on the north flank of the Sonoran geosyncline. Equivalent but basinal fine-grained strata are found in the Placer de Guadalupe area northeast of Ciudad Chihuahua, far to the south-southeast of this area. The Hueco strata contain limestone reefs, and time-equivalent reefs are present as very thick porous sections in the upper Horquilla limestone in Hidalgo County on the west; correlative strata, called Abo reefs, are productive of oil and gas in westernmost Eddy County, to the east. During late Leonardian, Guadalupian, and Ochoan time, a vast subsidence took place in the Permian basin, but much of this area probably stood above, but near, sea level.

Cretaceous.—Jurassic marine invasions took place farther to the south in the newly formed Mesozoic geosyncline. A thick section of Comanchean rocks (Lower Cretaceous) was deposited as interbedded reefing limestone, shale, sandstone, and shelf limestone. These Cretaceous rocks may be as thick as 2000 feet in southernmost Dona Ana County, but the optimum thickness across the Potrillo shelf is probably more nearly 1000 feet, as represented in outcrops near the Franklin and in the East Potrillo Mountains. Equivalent strata in the Juarez Mountains contain large reefs (see Córdoba, this guidebook) .

After widespread but not deep erosion which succeeded an epeirogenic uplift, the area again subsided to receive the transgressive Woodbine (Dakota) sandstone and Eagle (Colorado) shale with some upper sandstones and shales having Mesaverde affinities. These strata represent momentary high shelf merging of the Mexican and Rocky Mountain geosynclines through narrow accessways across central New Mexico.

STRUCTURE

The Potrillo shelf area is a vast but shallow graben between the tilted uplifted Franklin Mountains on the east and the normal-faulted East Potrillo Mountains on the southwest. The west tilt of the Franklin Mountain section is partly occasioned by the major fault on the east side of the Franklins, downthrown to the east, to form the west edge of the Hueco bolson. Perhaps it may be suggested that a similar normal fault of much lesser throw is present on the west side of the Franklin Mountains, although this is not a new concept.

The East Potrillo Mountain fault, downthrown to the east on the east side of the mountain, actually dies out north and south into anticlinal noses. There is a slight thrust overturn, to the east, on the crestal area of the nose at the north end of the East Potrillo Mountains. Thus these mountains are actually part of a faulted anticline.

The geologic structure west of a line between the West Potrillo Mountains to the Robledo Mountains (involving the West Potrillos, the Adens, Picacho, and the Sierra de las Uvas) is not known, but the surface evidence and volcanic alignments suggest a northeast-trending normal fault crossing the north-central part of the Potrillo shelf. This fault has the northwestern block downthrown perhaps as much as 2500 feet as indicated by the Picacho No. 1 Armstrong drilled to 3190 feet in 1941 from an elevation of 3600 feet. This test reportedly penetrated Santa Fe gravels, alluvial sediments, and volcanic rocks. Foster and Kottlowski have reported Hueco and possibly older limestones in the lowermost cuttings from the Picacho test, but only limited samples are available (personal communication, July, 1969). Such a sequence may be expected from its location on the Picacho volcanic-fault trend north of the area of the La Mesa plain and 8 miles west of Las Cruces.

The localized structures that might be inferred from the surface characteristics of La Mesa are as follows:

A. Anticlinal nature of the East Potrillo Mountains.
B. The fault zone from the West Potrillo Mountains to the Robledo and Dona Ana Mountains.
C. The subsidence sinks of the Kilbourne, Hunt, and Phillips holes by the leaching of soluble salts from Tertiary lake strata, rather than by leaching of deeper oil-potential strata or by major volcanic explosions.
D Northwest-trending synclines directly east of the east-facing fault-line scarp of the East Potrillo Mountains.
E. A possible eastward-curved anticlinal trend from T 24 S, R 2 W, through T 27 S, R 1 E, to T 29 S, R W, with a spur extending southeastward to the Juarez Mountains.

GEOLOGIC HISTORY

The general geologic history of the Potrillo shelf area may to he tabulated as follows:

AGE	REGIONAL MOVEMENT	PROBABLE LOCAL STRUCTURE
Pre-Pennsylvanian	South tilt with gentle uplifts and subsidences	Unknown
Pennsylvanian	Southwest tilt then east tilt, with sags and spurs	North-south structures parallel to facies strike, and possible reefs
Permian	Southeast tilt by uplift of Florida positive	Drape structure parallel to shoreline
Jurassic-Triassic	South tilt and uplift to erosion	Broad regional folding related to Nevadan orogeny in the far west
Early Cretaceous	South tilt, then uplift	Early east-west folds
Late Cretaceous	Laramide folding, some thrust-faulting and uplift	Northwest-southeast folds of some amplitude
Early Tertiary	Uplift and erosion	Continuation of Laramide folding
Late Tertiary into Pleistocene	Graben faulting with vast lake and stream alluviation	Intrusion of dacites and some rhyolites in west and northeast
Pleistocene to Recent	Regional uplift and erosion, subsidence of "holes"	Late basaltic volcanoes and thin lava flows

This summary suggests that the critical folding for first-phase oil and gas accumulation accompanied Pennsylvanian and Permian basinal subsidence during the deposition of marine sediments on the Potrillo shelf, followed by accentuation of these folds to facilitate second-phase oil migration in Jurassic, Early Cretaceous, and particularly Late Cretaceous Laramide time. Subsequent deformation was in the nature of normal faulting which formed the broad but shallow La Mesa graben over the site of the Potrillo shelf. There is no published information that the graben area is other than normally folded in depth. However, in 1960 Pan American drilled two slim-hole stratigraphic tests less than 1800 feet deep northwest of El Paso to check thickness of the valley-fill beneath La Mesa, and encountered some anomalous dips in unidentified strata. Grabens of this type have been locales of the preservation of major oil fields in the Mid-continent area. Whether structural traps within the La Mesa graben are reflected through the Santa Fe sedimentary cover is dependent upon the thinness of that cover and the recency of structural growth. That question cannot be answered without detailed photogeologic mapping and geophysical investigation followed by deep drilling.

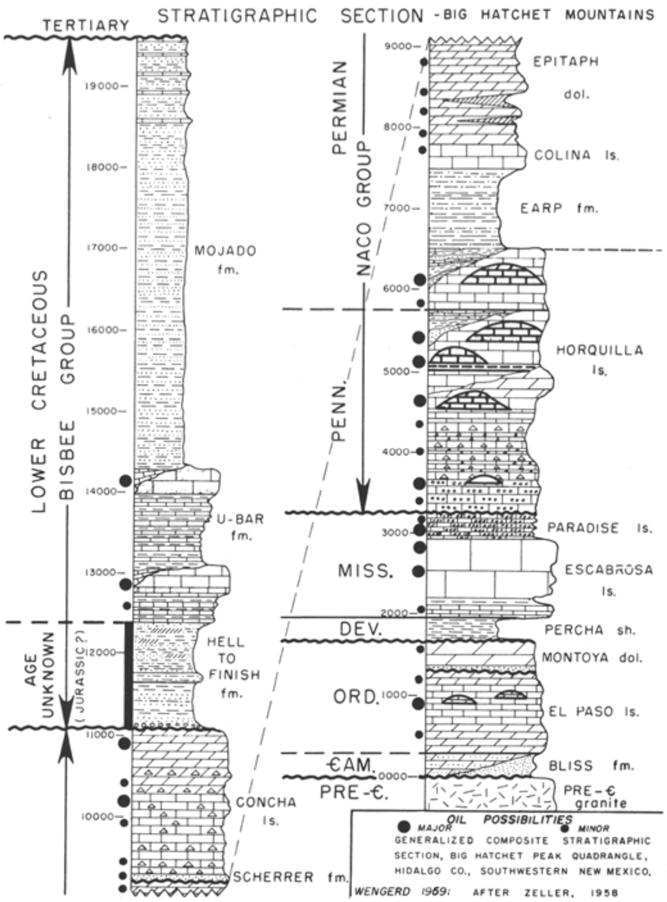
FLORIDA SHELF-ALAMO HUECO SHELF SLOPE

GEOLOGIC HISTORY

This region lies on the north flank of the Sonoran geosyncline (pre-Pennsylvanian), south and southwest of the Florida-Burro uplift, on the northeast flank of the Pedregosa basin (Pennsylvanian and Permian), on the north flank of the Mexican geosyncline (early Cretaceous), and within the late Cretaceous-Cenozoic intrusive-extrusive province of the southwestern United States and northern Mexico.

Pre-Pennsylvanian.—Rocks of Cambrian, Ordovician, questionable Silurian, Devonian, and Mississippian ages record a long history of gentle southward tilting and subsidence as a north shelf of the Ouachita-Sonoran geosyncline, of epeirogenic uplift to create regional disconformities, and of eventual uplift to wide erosion prior to Pennsylvanian time. Significantly, the geosynclinal subsidences to the south left the area open to shelf and shelf-slope deposition of limestone with some high- to low-shelf conversion of lime muds to dolomite in the lower El Paso and Montoya Formations of Ordovician age. Three quartzose sandstones of minor thickness but major extent are present in this early Paleozoic section; namely, the Cambrian Bliss at the base, the Cable Canyon in the Ordovician, and the sporadic sand lenses at the top of the Mississippian Paradise Formation. Small stromatolitic reefs are present in the upper part of the El Paso Group. (See Fig. 3).

Aside from the regional submarine and subaerial disconformities, the most important tectonic feature in these pre-Pennsylvanian rocks is the change from a southerly tilt of the shelf into the Sonoran geosyncline on the south during Escabrosa time, to the southwesterly and westerly tilt into the Cordilleran geosyncline on the west, represented by the



thin-bedded oolitic Paradise carbonate strata. The only near-basinal deposits are the dark brown, massive, fine-grained, fetid limestones of the Escabrosa, although their relative thinness as a unit belies basinal affinities.

Sedimentary patterns in these pre-Pennsylvanian formations suggest that they are mainly of shelf origin, with no localized tectonism, and that they are almost wholly composed of carbonates generated in situ on this sedimentary shelf and shelf-slope.

Pennsylvanian.—The advent of Pennsylvanian time saw the genesis of the Alamo Hueco shelf-slope and the Florida shelf extending from the axis of the deepening Pedregosa basin on the south, northward to the Florida archipelago. The Pedregosa basin was a northwest-trending, sedimentational sag on the north flank of the Sonoran geosyncline, itself probably a westward extension of the great Ouachita geosyncline. Early Horquilla carbonates in the Big Hatchet Mountains are Atokan to early Des Moines oolitic shelf deposits with some reefs of Chaetetes sp. and Syringopora sp. The seas deepened on the south as regional tilting and greater subsidence took place during late Desmoinesian and early Missourian times. As the break-in-shelf slope migrated northward, basinal deposits of dark, marine, fetid limestones were deposited in the expanding basin on the south, while high-shelf sediments were deposited intermittently in and around the Florida archipelago. Between these two sedimentary regimes, the migrating break-in-shelf slope supported linear reefs, beautifully exposed in the Big Hatchet Mountains, whose extent and trends are not well known because of lack of deep drilling. During latest Desmoinesian, Missourian, and Virgilian times, the Burro-Florida positive rose above sea level, seas migrated southward as did the break-in-slope, and large middle Horquilla bioherms grew across south-central Hidalgo County extending into Chihuahua, southeast of the Big Hatchet and Alamo Hueco Mountains. Thus while black shale and dense limestone were being deposited in the Pedregosa basin, bioherms formed across the medial part on the Alamo-Hueco shelf-slope, and gray-green shale and coarse sandstone were deposited with high-shelf carbonates and some dolomite on the highest part of the Florida shelf off the Burro-Florida positive.

Far to the north lay the Zuni uplift from which were shed fine, red, elastic sediments and which may have been joined intermittently with the Burro-Florida positive; to the northeast, the mid-New Mexico seaway connected the Sonoran geosyncline to the Cordilleran geosyncline across New Mexico, Colorado, and Utah via the Orogrande trough, the Socorro-San Mateo trough, the Lucero basin, the Cabezon accessway, the San Juan sag, the Barker dome constriction, the Paradox geosyncline, and the Fremont and Oquirrh sag and basin. To the southwest and southeast, the Pedregosa basin opened into the Sonoran-Ouachita geosyncline.

Across much of this region, the Pennsylvanian section is almost wholly carbonates with fine, dark gray shale; however, northward and eastward, coarser quartzose elastics increase in amount as the section becomes markedly thinner. Intra-Pennsylvanian subaerial erosion and high-shelf nondeposition and post-Pennsylvanian erosion have combined to cause stripping of Pennsylvanian strata in the north and northeast parts of Hidalgo County and central Luna County. To the northwest and west, Supai-Earp red elastics interfinger downward in the section so that in Arizona the Pennsylvanian Naco carbonates are equivalent to only about the lower one third to one half of the Pennsylvanian Horquilla carbonates of New Mexico. Perhaps the northwest end of the Burro-Florida uplift was also connected by islands northwestward to the Zuni uplift in western New Mexico, and the Kaibab uplift in north-central Arizona.

Permian.—Sedimentation continued in the Pedregosa basin and around the Burro-Florida shelf across the Pennsylvanian-Permian temporal boundary to form the upper Horquilla bioherms and associated fore-reef and back-reef limestones. At the end of Wolfcamp time, floods of silt and clay from northerly and northwesterly directions were deposited to form a part of the Earp Formation, composed mainly of continental beds. The Earp is probably a lithologic correlative with the Abo tongue in the Hueco limestone to the northeast and with the medial part of the Supai Formation in Arizona. The seas were thus driven southward and southeastward into the Sonoran geosyncline where, by early Leonardian time, the subsidence continued as the Permian marine Pedregosa basin. Thick carbonate sequences of the Colina, Epitaph, and Concha formations were deposited on the Alamo-Hueco shelf-slope, and thick dark siltstones were deposited in the deeper water of the Pedregosa basin in northern Chihuahua.

Post-Permian.—The absence of late Guadalupian and Ochoan Permian strata in this region suggests strongly that tectonism somewhat more localized than simple epeirogeny took place in the Burro-Florida positive area in late Permian time. However, the absence of Triassic and Jurassic rocks from the whole region also suggests that a widespread regional uplift brought most of the region above sea level until early Cretaceous time. In the Burro Mountains southwest of Silver City, Cretaceous Beartooth strata lie unconformably on Abo down to Precambrian rocks. (Kottlowski, personal communication, July, 1969). Thick sections of marine Jurassic limestones were deposited in the Sonoran-Mexican geosyncline far to the southwest in northern Mexico, whereas, in the western United States, thick sections of marine Triassic limestones prove the existence of earlier Mesozoic seas in the Cordilleran geosyncline.

Erosion during late Permian, Triassic, and Jurassic times is recorded by the cavernous upper surface of the Concha limestone in the Big Hatchet Mountains and the presence of thick, basal conglomerates in the Hell-to-Finish and lithologically correlative formations, whose ages are somewhat in doubt because of lack of fossils. Elsewhere, Lower Cretaceous strata lie on strata as old as the Earp Formation.

During early Cretaceous time, the Mexican geosyncline again subsided strongly on the south, and marine, biohermal, (Broken Jug, Howells Ridge, U-Bar) carbonates were formed, interbedded with thin-bedded limestone and gray shale. This formation and the Mojado terrestrial beds above record a strong, localized subsidence of a sag across the northern shelf of the Mexican geosyncline. Toward the end of Mojado continental deposition, very shallow seas waxed and waned across the region to form thin limestones and shales that seem to typify Late Cretaceous marine sedimentation, the results of which are found on the surface in the El Paso area to the east.

Inasmuch as Late Cretaceous marine sedimentary rocks have not been identified in southern Hidalgo County, it might be concluded that the rather sharp epeirogeny graded into the localized orogenic tectonism of the Laramide to form the first strong folds and faults in the region.

Late Cretaceous and Cenozoic times saw considerable tectonic disintegration of the region by thrusting, folding, and Basin-and-Range normal faulting, as well as intrusion and extrusion of igneous rocks.

PETROLEUM POSSIBILITIES

Commercial oil and gas potential exists in this part of the Border region as indicated by the thick section of Paleozoic and Mesozoic sedimentary rocks, the shows of petroleum in the tests drilled to date, and by the several favorable structures known to exist. Although the location of commercial quantities of oil and gas is a difficult problem and exploration is limited by several overlapping complexities such as igneous intrusion and thrust and normal faulting, the excellent stratigraphic setting warrants thorough geological and geophysical analysis prior to selection of drill sites.

Formations, Reservoirs, *and Traps.—The* formations embracing potentially productive reservoir beds in this part of the Border region are listed in the paper by Kottlowski, Foster, and Wengerd elsewhere in this Guidebook. (also see Fig. 3) .

Erosion Surfaces.—The erosion surfaces which recognizably punctuate the stratigraphic column exposed in the mountain areas are almost wholly those formed by epeirogenic uplift to subaerial erosion after a cycle of carbonate deposition. The general northward gradation of the Pennsylvanian carbonates into medium-grained quartzose and arkosic elastics with southward gradation into fine-grained bituminous limestone and dark gray shale is notable, and these lithologies clearly exerted a control on the dissolution effects while the area stood up to subaerial erosion. Also, there is no doubt that many submarine disconformities were formed, and these presumably may have increased the intercrystalline and intergranular porosity created during, or closely subsequent to, deposition.

Because of the general lack of thick, elastic, detrital, terrestrially-derived lentils in the section prior to Hell-to-Finish time, it may be surmised that this much of this area and its provenances never stood much more than a few hundred feet above sea level until latest Cretaceous time. Because ground water has major dissolutionary effects to and somewhat below sea level and the relief was low, only in the Ordovician carbonate sequences can we expect to note that ground water related to an upper erosion surface notably affected strata below a subjacent disconformity. This probably was the situation until the post-Hueco uplift and southward tilting in the Burro-Florida positive prior to early Cretaceous marine invasion from the south. However, ground water may have affected some of the reservoirs in folds, reefs, and facies-gradation traps during and subsequent to the Laramide orogeny. This potentially destructive ground-water incursion, combined with volcanism and intense block faulting preceded by thrust faulting, makes the search for unbreached oil-filled traps arduous in this Border region of the Basin and Range structural province, specifically in the western one third and northern half of Hidalgo County.

The reader will recognize the conspicuous absence of thick marine shale above all but the erosion surface on top of the Montoya. The Percha shale, itself representative of a suitable source environment, may have made possible the generation of petroleum for emplacement in the solution and intercrystalline openings of the Montoya Dolomite. However, the continental elastics of the Mojado, Hell-to-Finish, and Earp Formations can hardly be considered to have been the most favorable representatives of source environments. This somewhat academic conclusion thus leads one to believe that petroleum generated in this region must be intraformational of an almost in situ origin, genetically related to thin marine shale or the carbonates themselves.

Following is a tabulation of the widespread, known, erosion surfaces, from youngest to oldest.

BETWEEN FORMATIONS	LITHOLOGY BELOW	LITHOLOGY ABOVE
Mojado/U-Bar	limestone	continental clastics
Hell-to-Finish/Concha	dolomite	continental conglomerate and sandstone
Concha/Epitaph	dolomite	limestone*
Earp/Horquilla	limestone	red deltaic clastics
Horquilla/Paradise	oolitic limestone	oolitic limestone
Escabrosa/Percha	shale	limestone
Percha/Montoya	dolomite	marine shale
Montoya/El Paso**	dolomite	dolomite
Bliss/Precambrian	igneous & metamorphic	sandstone & dolomite

* In places, the Scherrer quartzose sandstone is present and may be a thin reservoir similar to the Misener sandstone of Oklahoma. The Scherrer is a basal Conca sandstone.

** In places, the Cable Canyon quartzose sandstone is present as a thin potential reservoir at the base of the Montoya Group.

Regional Tilts and *Fluid* Movements.—Because of two important factors, a summary of fluid movements in relation to regional tilts is not possible for most areas in the Basin and Range country:

1. Too few deep oil tests have been drilled, and very scanty data are available for quality of deep water or pressures in this part of the Border region.
2. The orogenic activities of mid-Tertiary Basin-and-Range normal faulting combined with intense Tertiary and Quaternary volcanism created an unknown amount of derangement of pre-Tertiary fluid systems. Most certainly, these early "rock-and-roll" regional tilts combined with the known but moderate compactional drives in fluids encased in carbonate sequences led to migration and entrapment of any oil and gas present in marine reservoirs. However, these earlier accumulations may have been partially altered in location by inter- and intrasystemic fresh-water incursions as disconformities were created and undoubtedly, in some areas, were deranged by Tertiary, Pleistocene, and Recent fresh-water movements facilitated by faults. Thus only in certain hidden tectonic units in the valley segments of the Border region may one expect to find relatively unbroken reservoirs and unflushed traps where petroleum is entrapped by pressures related to structural and stratigraphic blocking.

Detrimental Factors.—Factors detrimental to exploration must be clearly separated from those detrimental to the preservation of oil and gas in traps which no doubt are present in the region.

Petroleum exploration is made more difficult by localized lava cover, Cretaceous and Tertiary intrusives, low-angle thrust faults which have ridden over sub-fault anticlines, gravel cover of the valley fill, and horizontal and strike-slip movements along the larger normal faults which may have displaced projections of mappable mountain structures.

Preservation of oil in traps may have been negated, in part, by post-Permian intrusives and their accompanying earth heat, excessive shearing, and mylonization along major normal and thrust faults, fresh-water incursion during many erosion inetrvals, including the present, as well as the partial erosion of traps later to be covered by continental strata.

Area of Maximum Oil and Gas *Potential.—With* the exception of the higher parts of the mountain blocks (Big Hatchet, Little Hatchet, Sierra Rica, Cedar, Carrizalillo, Apache, Tres Hermanas, and Alamo Hueco), the area of maximum oil and gas potential in this western part of the Border region embraces the south half of Hidalgo County, the south quarter of Luna County, and a broad area projecting southeasterly into the State of Chihuahua. Methods of petroleum exploration that should be used in combination to discover logical drill sites are photo-geology, surface mapping, mapping of gravity anomalies, and seismic reflection shooting. Detailed sedimentational and stratigraphic analysis of the type represented by the article by Wilson et al., in this Guidebook, are a "must" for the location of broad trends of porosity in which major oil fields could be found by additional dauntless drilling of the Border region.