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Oil, natural gas and helium potential of the Chupadera Mesa area, Lincoln and Socorro Counties, New Mexico

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OIL, NATURAL GAS AND HELIUM POTENTIAL OF THE CHUPADERA MESA AREA, LINCOLN AND SOCORRO COUNTIES, NEW MEXICO

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Abstract—The Chupadera Mesa region encompasses 3900 mi^2 in eastern Socorro and western Lincoln counties, central New Mexico. The area includes varied geological elements including the broad Jornada del Muerto Basin in the west, and the Oscura Mountains and Chupadera Mesa in the medial area. The Laramide-age Sierra Blanca basin and several isolated mountain ranges formed principally by Tertiary-age igneous intrusive bodies occupy the eastern third of the region.

The Chupadera Mesa area has been sparsely drilled. A total of 47 wells have been drilled within the project area. This is a density of approximately one well for every 85 mi^2. Many of the wells are shallow and reached total depth in Permian strata. Only 20 wells have been drilled to Precambrian basement. This is a density of one well per 200 mi^2, or 5.5 townships. Neither oil, natural gas nor helium production have been established. Nevertheless, several of the wells have encountered promising shows of oil, natural gas, and helium.

The geology of the Chupadera Mesa area indicates favorable potential for oil and natural gas. Petroleum source rock facies are concentrated in marine Pennsylvanian strata that blanket the western two-thirds of the area and attain a maximum thickness of 2200 ft. Dark-gray to black Pennsylvanian shales contain both gas-prone and oil-prone kerogen populations and are thermally mature to the east and west, but marginally mature in the medial area. Maturation into the oil window is caused primarily by heating associated with igneous events during the Tertiary. Favorable reservoirs are Pennsylvanian marine to marginal marine sandstones, continental sandstones of the Abo Formation (Permian: Wolfcampian), and marine to marginal marine sandstones of the Yeso Formation (Permian: Leonardian). Untested plays include speculated but undrilled late Paleozoic basins that may underlie synclines, truncation traps in Pennsylvanian sandstones under a basal Permian unconformity at the eastern pinchout of Pennsylvanian strata, and northward pinchout of Ordovician carbonate rocks in the southern part of the region. There is also a very limited coalbed methane potential in Cretaceous strata in the Jornada del Muerto and Sierra Blanca basins.

The Chupadera Mesa project area also has favorable potential for helium. Uranium-bearing granitic rocks favorable for the formation of radiogenic helium are present within Precambrian basement. In addition, high-angle fracture and fault systems and Tertiary-age igneous thermal events characterize the area and are favorable not only to the release of radiogenic helium from the Precambrian basement into the overlying Paleozoic sedimentary column but also to transport of primordial helium from the mantle. Pennsylvanian and Permian shales and Permian anhydrites and salt beds are favorable seals for helium. Analyses of gases recovered from exploratory wells drilled on Chupadera Mesa indicate the presence of helium in substantial amounts. Nonburnable gases recovered from other wells may also contain helium. Isotopic analyses indicate that the helium has a mixed crustal-mantle origin.

INTRODUCTION

The Chupadera Mesa area lies in central New Mexico in eastern Socorro and western Lincoln Counties (Figure 1). Aerial extent is approximately 3900 mi^2. The project area encompasses several diverse geomorphic elements including the broad Jornada del Muerto Basin in the west, the Oscura Mountains and Chupadera Mesa in the medial area, and several isolated mountain ranges formed principally by Tertiary-age igneous intrusive bodies in the eastern third of the area (Figure 2). The area is sparsely populated. There are two major towns in the area, Carrizozo (population approximately 1200) and Capitan (population approximately 760). Land ownership is interspersed state, federal and private. Most of the area from the Oscura Mountains to the western boundary of the project area and south of U.S. Highway 380 is within White Sands Missile Range, and access for oil and gas leasing is restricted. Several natural gas pipelines traverse the area, including two northwest-southeast interstate pipelines in the northeastern part of the region. There are smaller pipelines that supply the towns of Capitan and Carrizozo.

No oil or natural gas production has been established in the Chupadera Mesa project area. Forty-seven exploration wells have been drilled within the area, including deep water wells (Table 1, Figure 3). These have targeted mainly oil or natural gas prospects based on mapping of anticlines at the surface. In recent years helium gas has also become an attractive exploratory target.

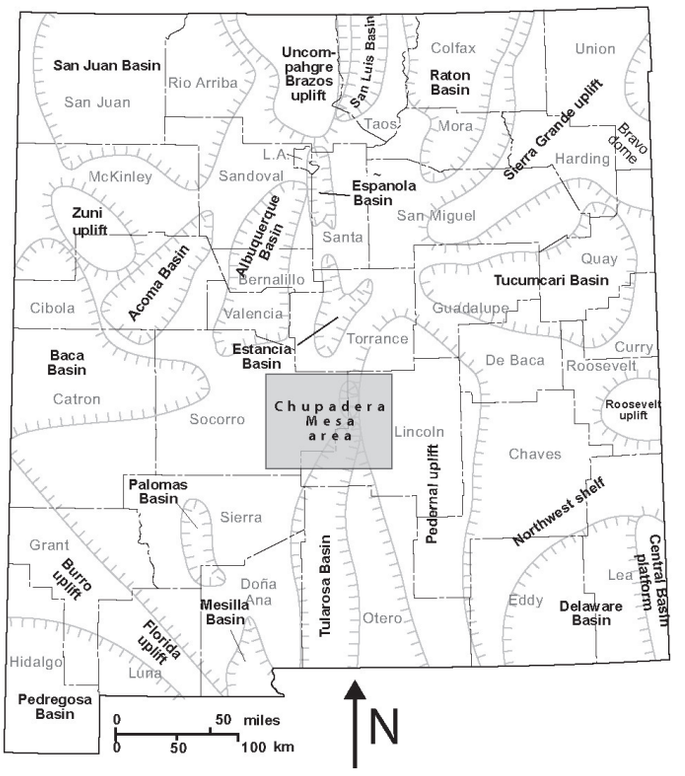


FIGURE 1. Location of the Chupadera Mesa project region (gray) and principal geologic basins and uplifts of New Mexico.

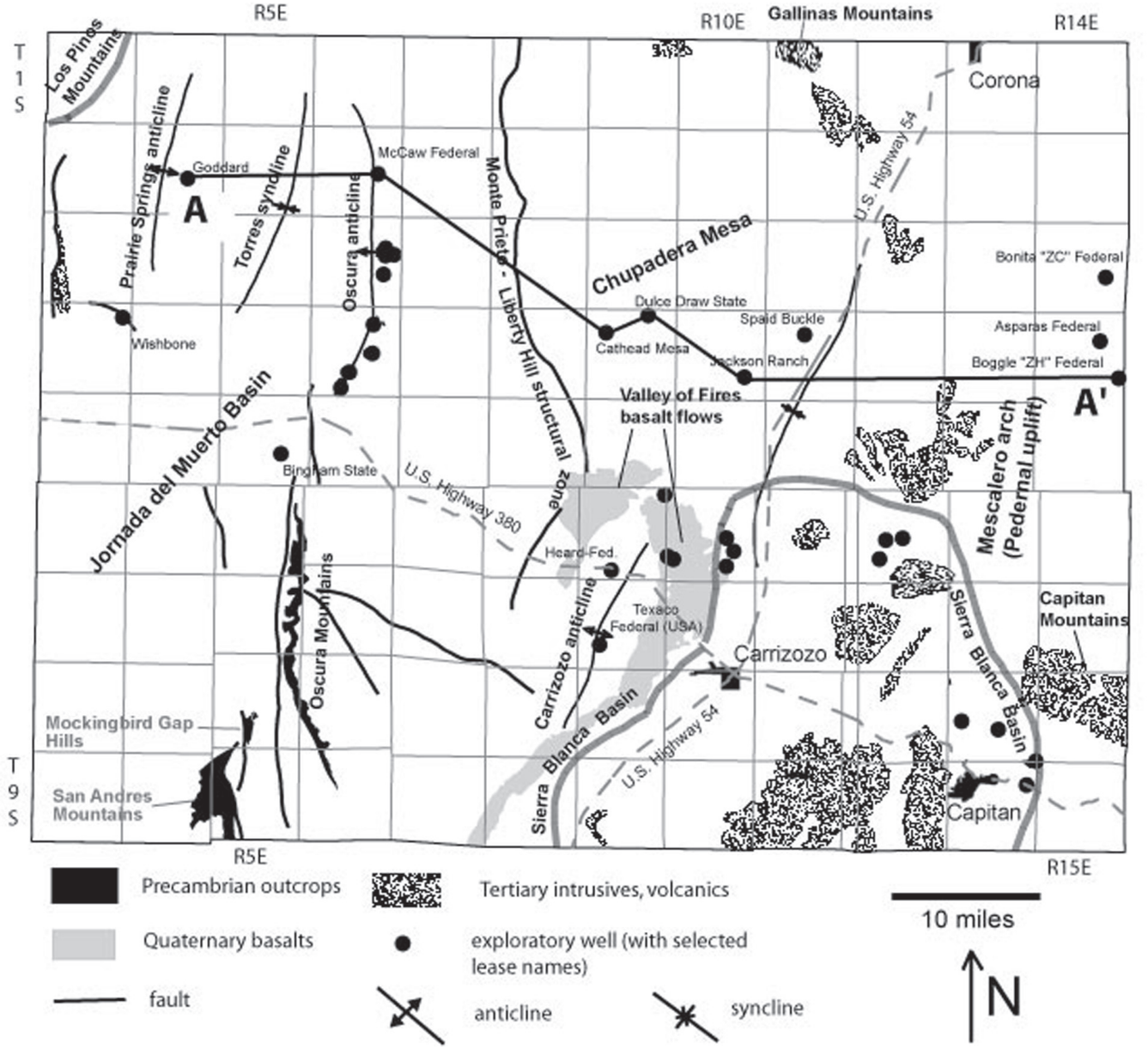


FIGURE 2. Location of major geologic elements, major structures mapped at the surface, and Tertiary and Quaternary igneous and volcanic centers in the Chupadera Mesa region. See Figure 5 for cross section A-A'.

Paleozoic strata in the region range in age from Cambrian to Permian (Figure 4). Mesozoic strata include Triassic red beds and Cretaceous shales, sandstones, and coals. Principal stratigraphic units of interest to oil, gas and helium explorationists include Ordovician dolostones, Pennsylvanian sandstones and limestones, and Lower Permian sandstones.

STRUCTURE

Oscura Mountains uplift

The central part of the Chupadera Mesa area is dominated by the Oscura Mountains. The Oscura Mountains are formed by a series of north-south trending, east-dipping asymmetrical fault blocks (Bachman, 1968) that rise from an elevation of approximately 5000 ft on the east side to more than 8500 ft at the summit of the mountain range. The western boundary of the mountain range is formed by a high-angle fault that extends north-south for approximately 22 miles and offsets Precambrian basement rocks at altitudes of more than 8500 ft on the summit of the range against Pennsylvanian and Permian strata at altitudes of less than 6000 ft to the west of the fault. Surface expression of the western boundary fault dies out northward as the crest of the Oscura Mountains plunges into the subsurface and forms the north-south trending Oscura anticline.

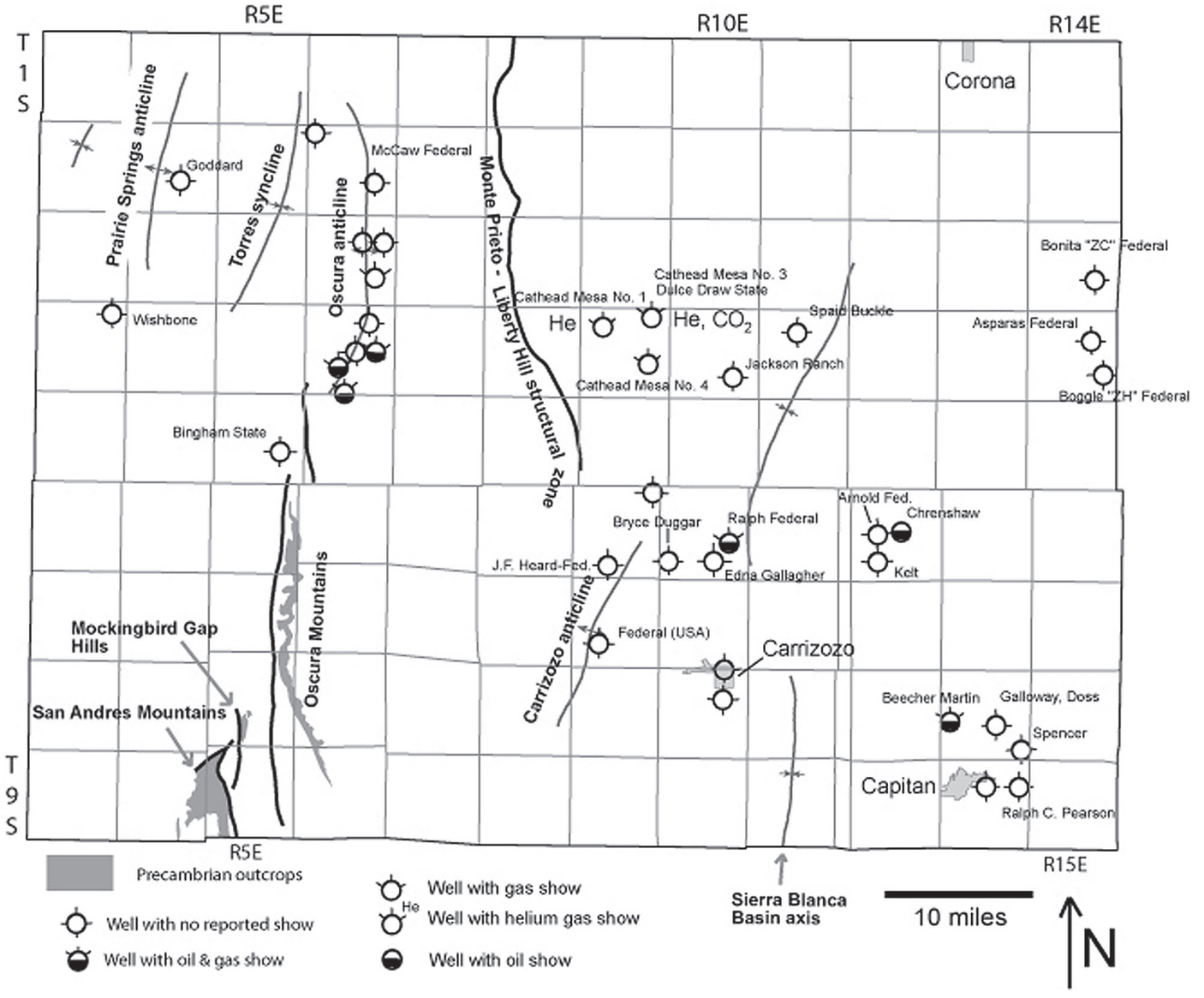


FIGURE 3. Exploration wells in the Chupadera Mesa region. See Table 1 for a description of individual wells. Some well symbols represent multiple wells drilled close to each other.

Oscura anticline

The Oscura anticline is a broad, gentle, north-plunging structure 20 miles long and five miles wide. It is a northward extension of the Oscura Mountains uplift. Strata of the Yeso Formation (Permian: Leonardian) are exposed along its crest. Younger strata of the Glorieta Sandstone and San Andres Formation (Permian: Leonardian) are exposed on the flanks but have been eroded from the crest of the anticline. Osburn (1984) indicates that strata dip away from the crest of the anticline at angles of generally less than 10° on its eastern and western flanks. Several wells drilled on the Oscura anticline revealed that Pennsylvanian strata rest unconformably on Precambrian basement.

San Andres Mountains and Mockingbird Gap Hills

The northernmost part of the San Andres Mountains and Mockingbird Gap Hills lie to the southwest of the Oscura Mountains. These prominent topographic features are formed by uplifted fault blocks of Precambrian basement and Ordovician, Pennsylvanian, and Lower Permian strata. The Mockingbird Gap Hills are bounded on the west by high-angle faults that are exposed at the surface. The faults separate the uplifts on the east from the Jornada del Muerto Basin on the west.

Jornada del Muerto Basin

The Jornada del Muerto Basin forms the wide valley that occupies the region from the Oscura Mountains and Oscura anticline

TABLE 1. Exploratory wells drilled in the Chupadera Mesa region and reported fluid recoveries. See Figure 3 for locations. D&A, dry and abandoned.

Well	Location S-T-R	Comp Date (year)	Total Depth (feet)	Elevation (feet)	Completed status	Shows (stratigraphic unit & fluid recovery)
Skelly Oil No. 1 Goddard	22-2S-4E	1948	3386	5619	D&A	
Chupadero Oil	06-2S-6E	unknown		5770	D&A	
Yates Petroleum No. 1 McCaw Fed.	23-2S-6E	1963	4450	6371	D&A	
Sealey No. 1	13-3S-6E	unknown	705	5922	D&A	
Abo Oil Co. No. 1 Government Permit	14-3S-6E	1927	584	5850	D&A	Yeso (water)
Abo Oil Co. No. 1 Powell-Stackhouse	14-3S-6E	1927	614	6300	water well	Yeso (water)
Abo Oil Co. No. 1A Powell-Stackhouse	14-3S-6E	unknown	750	6300	D&A	
Lockhart & Companies No. 3 Powell Stackhouse	14-3S-6E	1930	2772	5920	D&A	
Mountain States No. 1 Chupadera	23-3S-6E	1993	4379	5910	D&A	Pennsylvanian (gas @ 50 MCFD)
Yates Petroleum No. 1 Bonita ZC Fed.	23-3S-14E	1984	2101	6225	D&A	
James K. Anderson No. 1 Wishbone Fed.	01-4S-3E	1989	4997	5485	D&A	
Mountain States No. ST-1 Lacy Hattie	11-4S-6E	1991	3065	6013	D&A	
Lockhart, J.E. No. 1 Lockhart Fed.	28-4S-6E	1953	2990	5744	D&A	Abo (oil & water)
Reeves Brothers No. 1 Morrison Fed.	22-4S-6E	1976	2937	5785	D&A	
Reeves Brothers No. 2 Morrison Fed.	22-4S-6E	1976	689	5781	water well	
Virgle Landreth No. 1 Virgle Landreth Fed. (also known as No. 1 Panhandle)	23-4S-6E	1973	3445	5805	D&A	Pennsylvanian (oil, gas, saltwater)
Virgle Landreth No. 1 Panhandle A	28-4S-6E	1973	3240	5782	D&A	Yeso (fluorescence & cut); Abo (fluores cence);Pennsylvanian (bleeding gas and gilsonite in core)
J.R. Lockhart J.R. No. 2 Lockhart	33-4S-6E	1954	3037	5697	D&A	Pennsylvanian (distillate)
J.R. Lockhart No. 3 Lockhart	33-4S-6E	1955	2665	5709	D&A	Pennsylvanian (oil & gas)
Primero Operating No. 1 Dulce Draw State (re-entered by Chaparral Energy)	02-4S-9E	2001 (2008)	4030	5972	D&A	Abo (nonburnable gas & salt water)
Primero Operating No. 3 Cathead Mesa (re-entered by Chaparral Energy)	03-4S-9E	2006 (2008)	3491	5974	Shut-in CO_2 (D&A after re-entry)	Abo (CO_2 gas @ 972 MCFD + 15 BWPD)
Chaparral Energy No. 4 Cathead Mesa	23-4S-9E	2008	4300	5935	D&A	Yeso (slight gas show) Abo (tested water)
Manzano Oil No. 1 Cathead Mesa	08-4S-9E	1996	6190	6278	D&A	Yeso (fluorescence & cut);Abo (fluorescence); Pennsylvanian (gas); Precambrian (gas)
Primero Operating No. 1 Jackson Ranch Fed.	26-4S-10E	1999	4948	5840	D&A	
Manzano Oil No. 1 Spaid Buckle	09-4S-11E	1996	4871	6066	D&A	
Mesa Petroleum No. 1 Asparas Fed.	11-4S-14E	1982	2218	6181.5	D&A	
Yates Petroleum No. 1 Boggle ZH Fed.	25-4S-14E	1984	2662	6022	D&A	
Sun Oil No. 1 Bingham State	23-5S-5E	1955	3141	5423	water well	Yeso (water)
Loveless	01-6S-9E	1952	1005	5465	water well	
Standard Oil Of Texas No. 1 J.F. Heard Fed.	33-6S-9E	1951	8050	5893	D&A	Yeso (salt water)
Bryce Duggar No. 1 Helen Fed.	23-6S-10E	1975	1250	5579	D&A	Triassic (oil)
Ralph Nix No. 1 Ralph Fed.	23-6S-10E	1981	2468	5449	D&A	San Andres (oil & gas)
Bryce Dugger No. 1 Edna Gallagher	26-6S-10E	1969	2059	5400	D&A	
Bryce Dugger No. 4 Bryce Duggar	30-6S-10E	1962	900	5450	water well?	
Bryce Dugger No. 1 Federal	30-6S-10E	1963	1500	5500	D&A	

TABLE 1. Cont.

Well	Location S-T-R	Comp Date (year)	Total Depth (feet)	Elevation (feet)	Completed status	Shows (stratigraphic unit & fluid recovery)
Dalton Kincheloe No. 1 Arnold Fed.	20-6S-13E	1985	3572	6802	D&A	
Mark Vaughan No. 1 Chrenshaw	21-6S-13E	1959	400	6795	water well	Cretaceous (oil)
Roy Sipple No. 1 H.E. Kelt	29-6S-13E	1949	1027	6550	D&A	
Texaco No. 1D Federal (USA)	29-7S-9E	1969	7616	5412	D&A	
Southern Pacific RR. No. 1 Carrizozo	02-8S-10E	1901	895	5460	water well	
EP & SW RR. No. 1	11-8S-10E	1924	1125	5510	water well	
Western Ranchers Oil Co. No. 1 Beecher Martin	19-8S-14E	1959	1342	6960	D&A	Artesia (oil & gas)
Western Ranchers Oil Co. No. 1 Galloway Doss	22-8S-14E	1959	unknown	6760	D&A	
Capoco Corp. No. 1 Spencer	36-8S-14E	1959	2181	6275	D&A	
Layne-Texas Co. Capitan water well	10-9S-14E	1959	1261	6350	water well	
J.D. Cone No. 1 Ralph Pearson	12-9S-14E	1959	1005	6270	D&A	San Andres (water)
Lockhart et al. No. 1 Powell Stackhouse	14-3S-6E	1930	2772	5870	D&A	Abo (water)

on the east to the western boundary of the project area. South of U.S. Highway 380, bedrock in the Jornada del Muerto Basin is covered by eolian, alluvial and playa deposits of Quaternary age that obscure basin structure and stratigraphy. North of Highway 380, the bedrock rises upward out of the subsurface and forms the northern, eastern and western flanks of the basin. Elevation of the land surface in the Jornada del Muerto Basin ranges from 5400 ft in the south where a blanket of Quaternary sediments is present to 6200 ft in the north where bedrock is exposed.

There are two principal structures within the Jornada del Muerto Basin, the Torres syncline and the Prairie Springs anticline (Figures 2, 5; Wilpolt and Wanek, 1951). Both structures plunge to the south. The Yeso Formation is exposed along the crest of the Prairie Springs anticline, and younger strata crop out on its flanks. Scattered, small exposures of Triassic and Cretaceous strata are exposed along the axial part of the Torres syncline, which is covered mostly by unconsolidated Quaternary sediments. The Oscura anticline borders the Torres syncline on the east. On the Prairie Springs anticline, as on the Oscura anticline, drilling has revealed that Pennsylvanian strata rest unconformably on Precambrian basement. The Torres syncline has not been drilled.

Many Laramide structural features in New Mexico are thought to have developed by reactivation of late Paleozoic ancestral Rocky Mountains structures (Cather, 2002; Broadhead et al., 2002; Broadhead, 2002). Although there is no direct evidence from either seismic lines or drill holes, it is possible that the anticlines and synclines mapped at the surface overlie Pennsylvanian to Permian-age fault-bounded blocks of the ancestral Rockies that were reactivated during Laramide compression. The anticlines would have developed over ancestral Rocky Mountain horst blocks, and the intervening synclines would have developed over Ancestral Rocky Mountain grabens or elevator basins. If this is the case, then thickened sections of Pennsylvanian and Lower Permian strata are present under the synclines (Figure 6A). Alternatively, the flanks of the anticlines and synclines may be underlain by a series of step faults of Laramide age with no thickened upper Paleozoic section (Figure 6B).

Los Pinos Mountains

The eastern slope of the Los Pinos Mountains occupies the very northwestern part of the project area. Elevation of the crest of this mountain range exceeds 7000 ft. That portion of the Los Pinos Mountains covered by the project area is formed by Pennsylvanian, Bursum, and Abo strata with a gentle southeast dip of 1° to 3° (Wilpolt and Wanek, 1951).

Chupadera Mesa

Chupadera Mesa lies east of the Oscura anticline (Figures 2, 5). The mesa is a wide uplifted area whose surface is formed by limestones of the San Andres Formation. Topography consists of rolling hummocky hills and mesas cut by arroyos. Elevation of the land surface varies from 6000 to 7000 ft.

The Monte Prieto–Liberty Hill structural zone of Hawley (1986) lies within the western part of Chupadera Mesa. This north-south trending feature manifests itself at the surface as the east-facing Monte Prieto Bluff of Bates et al. (1947), which attains a maximum relief of more than 250 ft. Hawley (1986) concluded that the Monte Prieto–Liberty Hill structural zone is a high-angle fault zone with down-to-the-east vertical throw. Vertical displacement at the ground surface must be less than 300 ft because the San Andres Formation (Permian: Leonardian) crops out on both sides of the bluff. Cather (1999) and Cather and Harrison (2002) labeled this feature as the Chupadera fault and mapped it as a Laramide-age strike slip fault with dextral movement.

A broad, poorly understood synclinorium straddles the Monte Prieto–Liberty Hill structural zone. West of the structural zone, strata dip eastward off of the Oscura anticline. East of the struc-

AGE		ROCK UNITS	THICKNESS (feet)	DESCRIPTION
Quaternary		unconsolidated sediments	0-thin	alluvial and playa sands and silts; basalt flows in Valley of Fires
Tertiary		intrusives, volcanics, continental	0-2000	extrusive andesitic and rhyolitic volcanics and volcaniclastic sediments; intrusive diabase and monzonite stocks, dikes and sills; continental seds.
Cretaceous		Mesaverde	0-800	gray to tan shale; lenticular sandstones; coal
		Mancos	0-1000	shale, marine, gray to black; marine sandstone
		Dakota	0-200	sandstones, lenticular, nonmarine to coastal; siltstone; gray to black shale
Triassic		Chinle	0-1000	shale, maroon, silty; sandstone, fine to medium grained, maroon to orange
		Santa Rosa		sandstone, fine to medium grained, maroon to orange
Permian	Ochoan	absent	0	
	Guadalupian	Artesia	0-325	sandstone, fine to very fine grained, red to light gray
	Leonardian	San Andres	0-975	limestone, dark gray, finely crystalline, dolostone, dark gray finely crystalline; anhydrite
		Glorieta	0-400	sandstone, very fine to coarse grained, white to light gray, quartzose
		Yeso	1000-4300	sandstone, orange to white, marine to marginal marine; orange shale; limestone; dolostone; gypsum; anhydrite; salt
	Wolfcampian	Abo	230-1700	shales, red, nonmarine; sandstones, red, very fine to coarse grained, arkosic, fluvial
		Bursum	0-390	shales, red; sandstones, fine to coarse grained, arkosic; limestones, marine
Pennsylvanian	Virgilian	Madera	0-2200	shale, gray to black; limestone, marine, lime mudstones and bioclastic wackestones; sandstone, fine to medium grained, quartzose to arkosic
	Missourian			
	Des Moinesian			
	Atokan			
		Sandia		sandstone, arkosic to lithic to quartzose, fine to coarse grained; shale, gray to black
	Morrowan	absent	0	
Mississippian		Lake Valley	0-15	limestone, dark gray, cherty
Devonian		undivided	0-30	yellowish-brown mudstone; fine-grained sandstone
Silurian		absent	0	
Ordovician		Montoya	0-43	dolostone, dark-olive gray microcrystalline to cryptocrystalline
		El Paso	0-128	dolostone, light-medium gray, sandy
Cambrian		Bliss	0-19	sandstone, medium grained, quartzose, glauconitic
Precambrian				granodiorite,diorite,diabase, monzonite, meta-quartzite, schist, meta-arkose, meta-rhyolite

FIGURE 4. Stratigraphic chart of Phanerozoic sedimentary units in the Chupadera Mesa region.

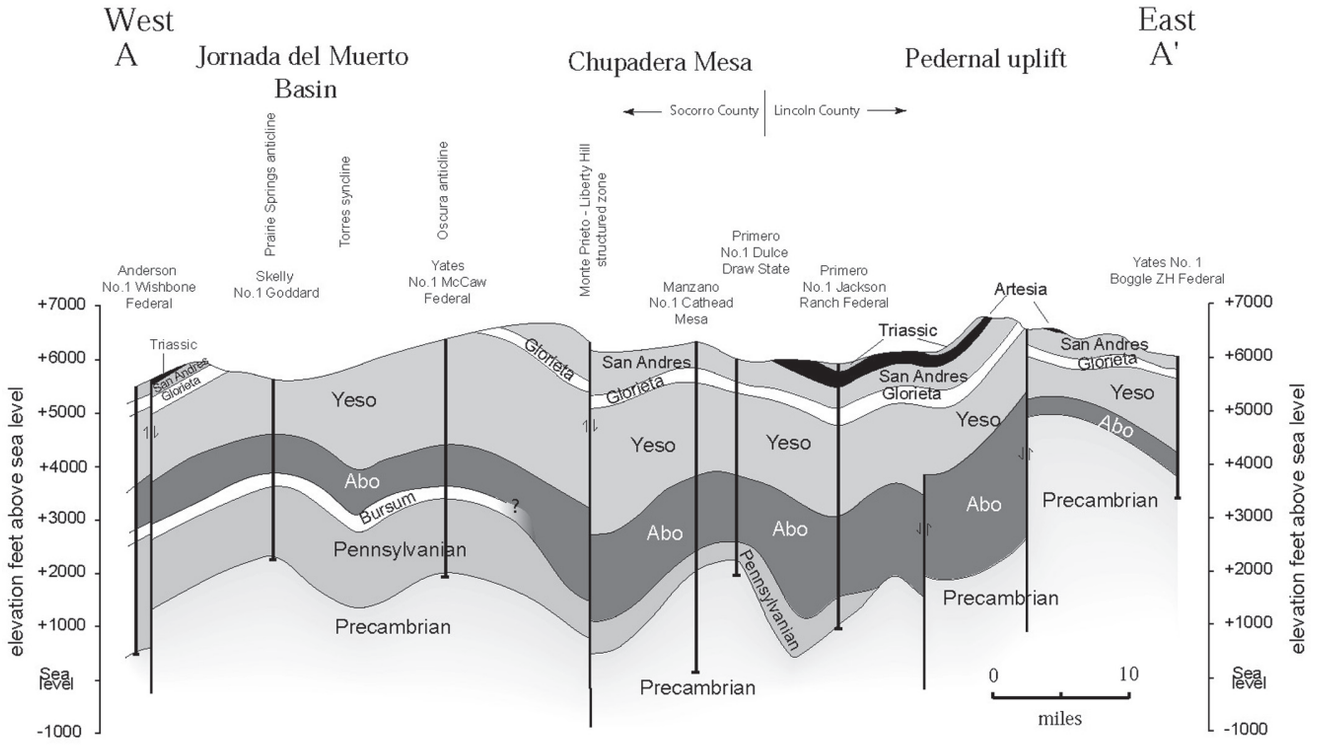


FIGURE 5. West-east structural cross section across the Chupadera Mesa region. See Figure 2 for location.

tural zone, pre-San Andres strata in the subsurface dip generally westward.

The Precambrian structure east of the Monte Prieto–Liberty Hill structural zone and underneath Chupadera Mesa has been demonstrated by drilling to be complex. Four exploratory wells (Primero No. 1 Dulce Draw State, Manzano No. 1 Cathead Mesa, Primero No. 1 Jackson Ranch Federal, Manzano No. 1 Spaid Buckle; Figure 2) were drilled in the area between 1996 and 2001. The Precambrian surface has a structural relief of at least 1200 ft across the 70 mi^2 covered by these four wells (Figure 5). As is the case with the Precambrian under the Jornada del Muerto Basin, it is likely that the brittle basement in this area was deformed through brittle failure (faulting) rather than by ductile folding; structural relief is formed by downdropped, upthrown and tilted fault blocks bounded by high-angle faults of Pennsylvanian to Early Permian age. Subsurface control is inadequate to portray the exact locations of the faults.

Carrizozo Anticline and Carrizozo Basin

East of the Oscura Mountains strata dip gently east toward Carrizozo. The eastward slope is punctuated by several southeast-trending high-angle faults. East of the Valley of Fires basalt flows, Triassic and Cretaceous strata form an eastward-dipping sequence at the surface. Just west of the lava flow, Kelley and Thompson (1964) mapped the Carrizozo anticline at the surface (Figure 2). This feature trends northeast-southwest and is doubly plunging. The Yeso Formation is exposed along its axis, and the San Andres Formation and Glorieta sandstone are exposed along the flanks. Kelley and Thompson mapped an estimated 400 ft of structural closure at the surface.

A deep graben (the Carrizozo basin of Ben Donegan) is present under the Carrizozo anticline. The Carrizozo basin has been penetrated at depth by two wells, the Standard of Texas No. 1 Heard (sec. 33 T6S R9E) and the Texaco No. 1D Federal (sec. 29 T7S R9E). Structural elevation of the Precambrian surface is below –2000 ft MSL in the deepest parts of the basin. There is at least 4000 ft of structural relief between this basin and structurally higher areas to the north, west, and east. The western boundary of the basin appears to be a high-angle fault. Fill in the basin consists primarily of pre-San Andres Permian and Pennsylvanian strata.

Sierra Blanca Basin

East of the Carrizozo anticline, strata dip into the Sierra Blanca Basin (Figure 2). The Sierra Blanca basin (Cather, 2002) is an elliptical structural depression that extends from Carrizozo on the west to Capitan on the east. Its northern limit is approximately 12 miles north of Carrizozo in T6S, R10-11E and it stretches 40 miles to the south to T12S, R10-11E. The basin is defined by Triassic and Cretaceous strata that dip inward on all sides. The Cretaceous section has been removed by erosion outside of the basin boundaries. The basin is asymmetrical about its northerly trending axis, with a gently dipping western limb and a steeply dipping eastern limb. The Sierra Blanca Basin is late Laramide in age, having formed from easterly directed regional compression (Cather, 2002).

Numerous late Eocene to early Miocene (Tertiary) intrusive stocks and associated volcanic rocks are present in the Sierra

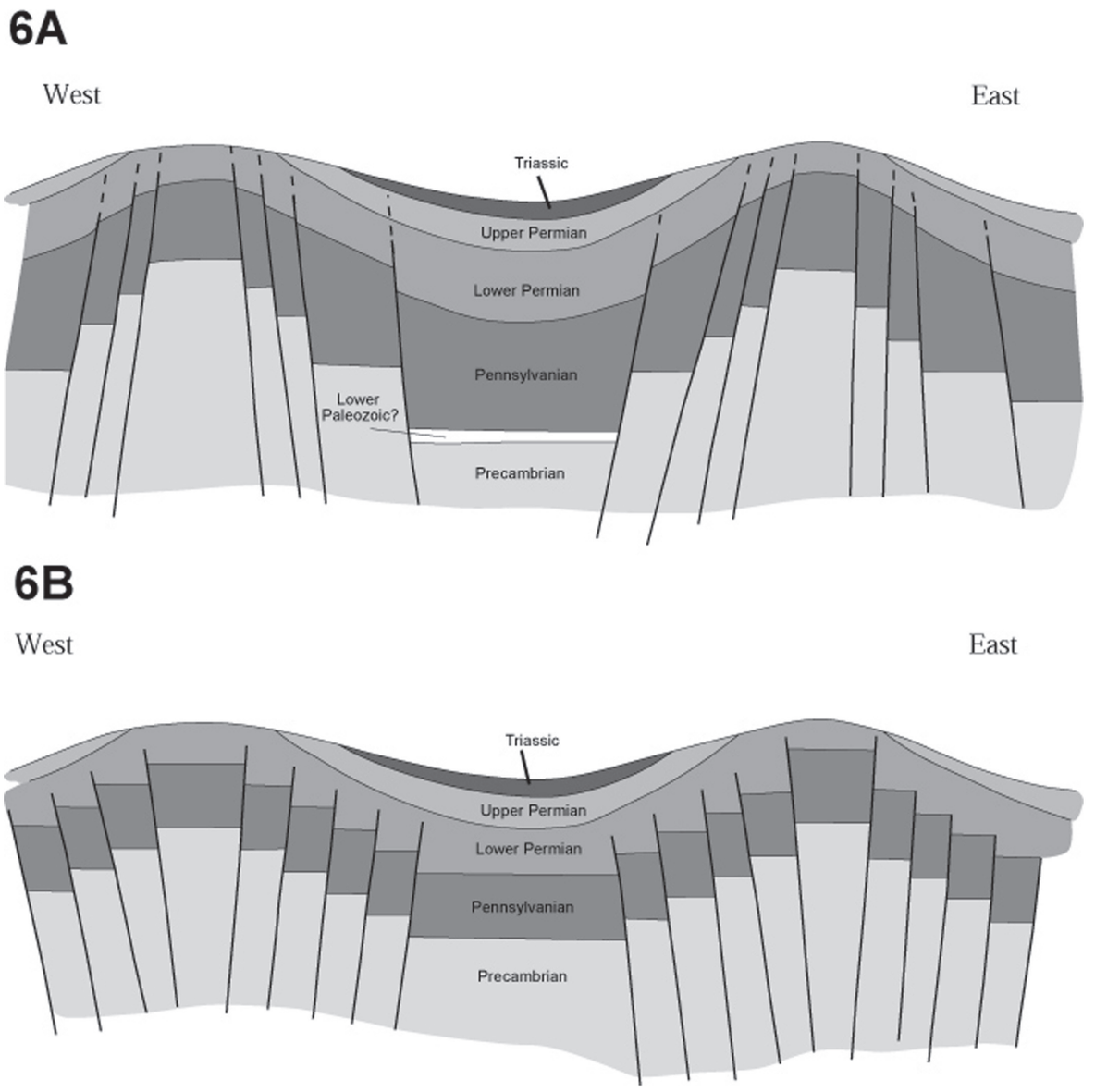


FIGURE 6. Possible structural and stratigraphic configuration of Precambrian basement and Pennsylvanian strata underneath the synclines and anticlines in the western part of the Chupadera Mesa region. **A**, assumes Laramide reactivation of Ancestral Rocky Mountain structures. **B**. assumes no Ancestral Rocky Mountain tectonic ancestry.

Blanca Basin. These intrusive bodies form prominent mountains.

Mescalero Arch and Pedernal Uplift

The Mescalero arch lies to the east of the Sierra Blanca Basin (Kelley and Thompson, 1964; Kelley, 1971). The Mescalero arch is a broad, uplifted structural divide that separates the Sierra Blanca basin on the west from the Pecos slope of the Permian Basin on the east. It is complexly folded and faulted (Kelley, 1971). Folds and faults have a dominant northeast-southwest trend. The Mescalero arch plunges northward and is terminated by the east-west trending Tertiary intrusive that forms the Capitan Mountains. North of the Capitan Mountains, the arch is only a vague feature that appears to be offset to the west. Outcrops over the arch are formed mostly by San Andres limestones with the underlying Yeso Formation exposed in the more deeply incised stream valleys. Cather (2002) stated that the Mescalero arch is late Laramide in age. However, it appears to overlie the spine of the late Paleozoic Pedernal uplift that separated the Permian Basin from late Paleozoic basin and shelf areas to the west. The nonmarine, redbed sandstones, shales, and conglomerates of the Abo Formation (Permian) rest unconformably on Precambrian basement at the northern end of the Mescalero arch (Figure 5). Therefore, this tectonic feature has a late Paleozoic ancestry and was reactivated during the Laramide.

STRATIGRAPHY

Precambrian

Precambrian rocks of the Chupadera Mesa region are granites, granodiorites, diorites, metarhyolites, and metasediments. Granitic igneous rocks are present in the Los Pinos, Oscura, and San Andres Mountains (Bachman, 1968; Beers, 1976; Condie and Budding, 1979) as well as in most of the deep exploratory wells that have penetrated the Precambrian. Diorites are present in outcrops of the Oscura Mountains and at Mockingbird Gap (Bachman, 1968), as well as in exploratory wells drilled in the central and south-central parts of the area. Precambrian diabases, metaquartzites, and schists have also been penetrated by exploratory wells in the region.

Cambrian and Ordovician Systems

Strata of Cambrian and Ordovician age consist of the Bliss, El Paso, and Montoya formations (Figure 4). These strata are not present in the wells drilled within the project area. However, Bachman (1968) has mapped and described Bliss, El Paso, and Montoya strata in the Mockingbird Gap Hills and in the southern part of the Oscura Mountains. These strata are erosionally truncated beneath a regional angular unconformity in a northward direction and are not present in the northernmost parts of the Oscura Mountains (Figure 7).

Devonian System

Devonian strata (Figure 4) have been preserved over a limited area in the southernmost part of the project area where they crop out in the southern Oscura Mountains and have a maximum thickness of 30 ft (Bachman, 1968). Devonian strata are truncated to the north by erosion at the base of the Pennsylvanian System.

Mississippian System

A dark-gray, thin-bedded cherty limestone is present beneath the Sandia Formation (Pennsylvanian) in the northernmost San Andres Mountains (Figure 4). Bachman (1968) correlated this limestone with the Alamogordo Limestone Member of the Lake Valley Formation (Lower Mississippian). It is truncated to the north by the unconformity at the base of the Pennsylvanian System

Pennsylvanian System

Pennsylvanian strata are composed of 0 to 2200 ft of interbedded marine limestones, sandstones, and shales (Figures 4, 8). Most of the sandstones are arkosic arenites, although some lithic arenites and quartz arenites are present. Pennsylvanian strata are not present over the Pedernal uplift in the eastern part of the project area. Pedernal was an emergent highland during a significant part of Pennsylvanian time, and detritus eroded from its exposed Precambrian core was transported into adjacent basinal areas and deposited as fluvial, alluvial, and marine sands and shales.

The Pennsylvanian section is 1300 to 1400 ft thick throughout most of the central part of the project area and also to the south in the Carrizozo Basin. From these central areas, the section thins eastward to zero on the flank of the Pedernal uplift. Pennsylvanian strata thicken to 2200 ft in the Oscura Mountains and thicken westward to more than 1500 ft at the western boundary of the project area.

The regional eastward thinning of the Pennsylvanian (Figure 5) is caused by erosional truncation at the base of Permian strata. Sue Reid examined cuttings of the Wishbone Federal well for fusulinids. She identified *Triticites* of Missourian or Virgilian age 310 ft below the top of the Pennsylvanian, indicating that Upper Pennsylvanian strata are present in the western part of the project area. The Pennsylvanian section thins to 920 ft in the northern Oscura Mountains where lower Virgilian strata are present but upper Virgilian strata were removed by erosion prior to deposition of the Permian (Thompson, 1942). Further to the north, Pennsylvanian strata thin to less than 500 ft in the Manzano Cathead Mesa well, the Primero Dulce Draw State well, and the Primero Jackson Ranch Federal well. In these three wells, Pennsylvanian strata are overlain by the Abo Formation (Permian: Wolfcampian). Unpublished fusulinid determinations by the late Garner Wilde indicate that the Pennsylvanian in the Cathead Mesa well is early Atokan in age. The Desmoinesian (Middle Pennsylvanian) and Missourian and Virgilian (Upper Pennsylvanian) sections are missing. Farther east, Pennsylvanian strata are absent entirely.

Permian System

Strata of Permian age consist of the following lithostratigraphic units (Figure 4, ascending): Bursum Formation, Abo Formation, Yeso Formation, Glorieta Sandstone, San Andres Formation, and Artesia Group. The Bursum and Abo are Wolfcampian in age, although some workers believe that the upper Abo may be Leonardian. New work involving conodont biostratigraphy questions whether the Bursum should be placed in the latest Pennsylvanian or the earliest Permian (Wahlman, 2001). The Yeso Formation, Glorieta Sandstone, and San Andres Formation are Leonardian. The Artesia Group is Guadalupian.

The Bursum Formation is the lowermost Permian unit within the project area. It is composed of marine limestones, red shales, and fine- to coarse-grained arkosic sandstones and conglomerates. The Bursum has long been regarded as a transitional facies between the dominantly marine limestones, shales and sandstones of the Madera Formation and the overlying dominantly nonmarine red beds of the Abo Formation. The type section of the Bursum Formation is located within the project area in Sec. 1 T6S, R4E (Wilpolt et al., 1946). The Bursum pinches out along a north-south trend in the central part of the Chupadera Mesa area (Figure 7). It is uncertain whether the pinchout results from lateral gradation of the Bursum into lowermost Abo strata or whether it results from erosional truncation of the Bursum at the base of the Abo section.

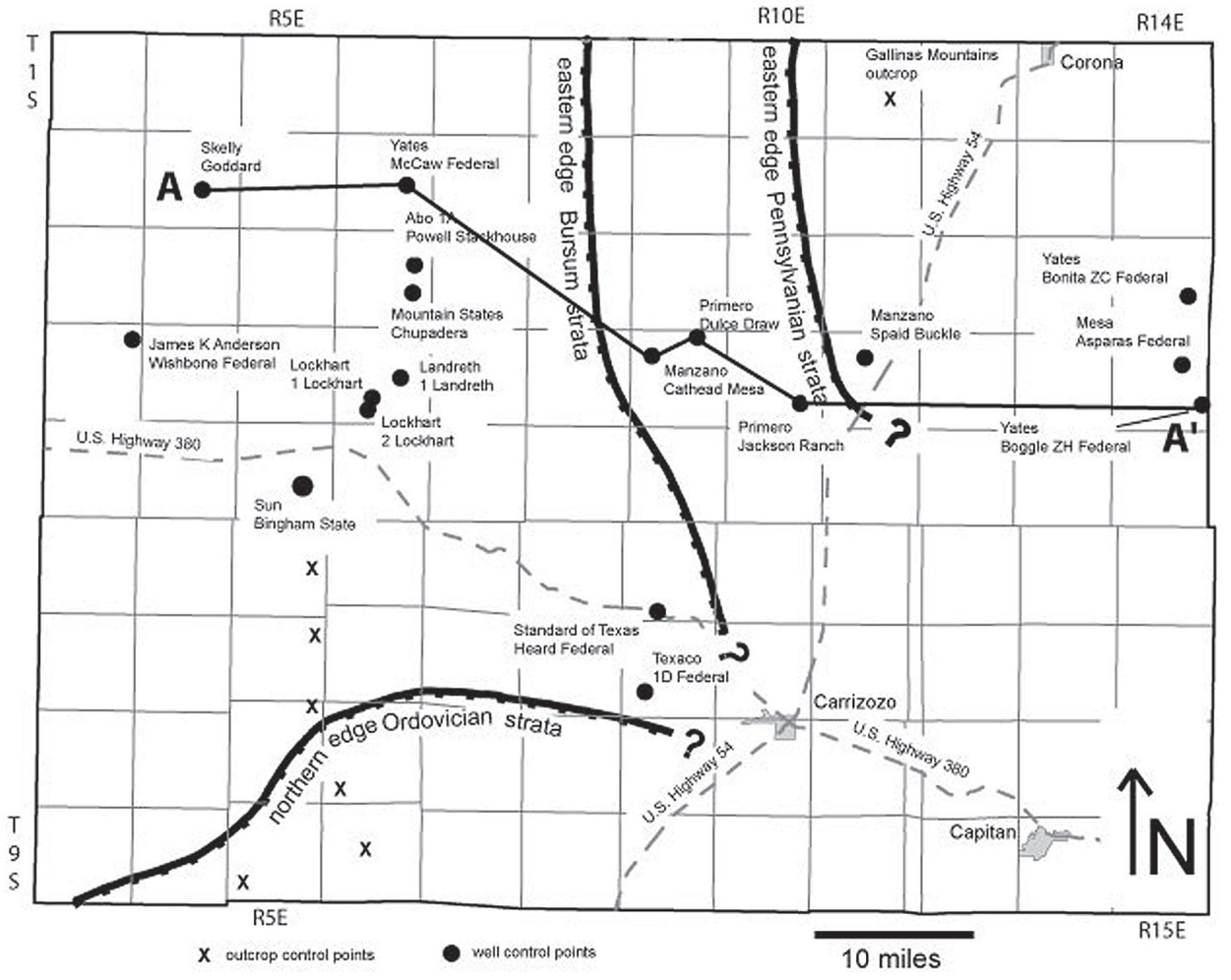


FIGURE 7. Zero isopach lines of Ordovician and Pennsylvanian strata and the Bursum Formation. Hachures indicate the side of the pinchout line where strata are present. Outcrop control points from Bachman (1968).

The Abo Formation rests conformably and gradationally on the Bursum Formation in the western half of the project area and in the Carrizozo basin. It is composed of fine-to coarse-grained red fluvial sandstones, red nonmarine shales, and very minor limestones and dark-gray to black shales. To the east of the Bursum zero isopach line (Figure 7), the Abo rests unconformably on Lower Pennsylvanian strata. Farther to the east, the Abo rests on Precambrian basement over the Pedernal uplift. The Abo Formation is 230 to 1700 ft thick within the project area. It is thinnest over the Pedernal uplift (Figure 5).

The Yeso Formation rests on the Abo Formation throughout the project area except where it has been removed by Tertiary or Recent erosion from topographically high areas. It crops out over large parts of the region. The Yeso Formation is composed of 1000 to 4300 ft of marginal marine to marine orange to white sandstone, orange shale, limestone, dolostone, anhydrite, and salt. Many of the sandstones are poorly cemented, friable and permeable. The anhydrites have been hydrated to gypsum where they are at or near the surface. The lower contact with the Abo varies from sharp to gradational.

The Yeso Formation is thinnest on top of the Pedernal uplift in the eastern part of the project area. From the spine of the Pedernal uplift, the Yeso thickens to the east and to the west. Thickness increases westward to more than 2000 ft over the Oscura anticline except where it has been removed by Cenozoic erosion along the axis of the southern part of the anticline. Farther west, the Yeso is only 1030 ft thick in the Skelly No. 1 Goddard well where it is exposed at the surface and the upper parts have been removed by erosion (Figure 5).

The Yeso attains a maximum thickness of 4200 ft in wells drilled within the Carrizozo basin. Dipmeter logs indicate part of this thickness appears to be caused by steep chaotic dips within the Yeso Formation (Broadhead and Jones, 2004). The steep, random dips appear to be associated with thick evaporite-rich sections, although other rock types such as sandstones are involved. The steep dips may have several origins, including ductile deformation in response to Laramide compression or intraformational collapse due to salt solution. The presence of thick evaporites in the Yeso in the Carrizozo basin indicates that the basin may have existed as a restricted bathymetric depression during the Leonardian. Some salt extends as far northward as the Manzano Oil No. 1 Cathead Mesa well in T4S R9E. It is possible that salt was once more widely distributed than it now is. The chaotic nature of Yeso bedding in many outcrops throughout the region suggests

the possibility that salt has been dissolved where it is close to the surface. Steve Cather (personal communication; this volume) suggests intraformational folding in the Yeso has been caused by lateral movement along a regional detachment surface.

The Glorieta Sandstone is comprised of 30 to 400 ft of white to light-gray, quartzose, marginal marine to shallow marine sandstone in outcrops of the Chupadera Mesa region (Wilpolt and Wanek, 1951). The limited data available indicate thickness distribution is irregular across the region, possibly because of an intertonguing relationship with the San Andres Formation. Wilpolt and Wanek (1951) indicate and the lower contact with the Yeso Formation is also an intertonguing relationship. The Glorieta has been eroded from topographically higher areas including the Oscura Mountains and the Oscura and Pinon Springs anticlines.

The San Andres Formation is comprised of 240 to 975 ft of marine limestone, dolostone, and anhydrite. The San Andres has been removed by erosion from many of the topographically higher areas, including the Oscura Mountains and the Oscura and Prairie Springs anticlines. It crops out over large parts of Chupadera Mesa as well as the region north of the Sierra Blanca basin. It is present in the subsurface of the Sierra Blanca basin. Where the formation is present west of the Oscura anticline, it is usually at the surface and thin. Elsewhere it has been removed by erosion altogether.

Lateral facies changes characterize the San Andres. Northwest of Capitan, the San Andres consists of an evaporite facies of gypsum and thinly bedded to massive limestone (Kottlowski, 1969). In the Chupadera Mesa area, Wilpolt and Wanek (1951) described the San Andres as 240 to 400 ft of limestone interbedded with gypsum and gray sandstone. The limestones are thin to medium bedded, dark gray, and slightly petroliferous. In wells east of the Oscura anticline, the San Andres consists of interbedded thin, dark microcrystalline dolostones, fine-grained red to white sandstones and siltstones, gypsum and anhydrite.

The Artesia Group is composed of 0 to 325 ft of fine- to very fine-grained, orange to white sandstones with minor thin beds of dark-gray limestone. It is present south and west of T3S R9E where it unconformably overlies the San Andres Formation and is unconformably overlain by Triassic red beds. The Artesia Group has been removed by pre-Triassic and Cenozoic erosion from large parts of the Chupadera Mesa area.

Triassic System

The Triassic section has been eroded from large parts of the region and is generally present within structurally or topographically low areas that are protected from erosion. Triassic strata attain a maximum thickness of approximately 1000 ft within the Sierra Blanca basin. Erosional remnants are also present underneath a thin cover of Quaternary sediments in the Jornada del Muerto Basin. The Triassic section consists of maroon shales and maroon to orange-red sandstones. The lower Santa Rosa Formation is mostly sandstone and the upper Chinle Group is dominantly shale. In general, Triassic strata of west Texas and eastern New Mexico region are fluvial and fresh-water lake deposits (McGowen et al., 1979).

Cretaceous System

Cretaceous strata unconformably overlie Triassic strata. Jurassic strata are absent. Cretaceous strata are present only in structurally low areas. The Sierra Blanca basin and the Jornada del Muerto basin and have been removed by post-Cretaceous erosion elsewhere. Cretaceous strata consist of marine to marginal marine sandstones, tan to gray to black shales, and coal. In general the coals are thin, generally less than 2 ft thick, and laterally discontinuous. In the past they were mined in small-scale operations in both the Sierra Blanca and Jornada del Muerto basins (Bodine, 1956; Tabet, 1979; Hoffman, 1996, 2002). Within the Sierra Blanca basin, the Cretaceous section is approximately 2000 thick (Arkell, 1986). Thickness within the Jornada del Muerto Basin is not well established because of poor outcrops and sparse drilling, but appears to be approximately 2000 ft where not removed by Tertiary erosion (Tabet, 1979).

Tertiary System

Tertiary rocks within the Chupadera Mesa project area include continental sedimentary units, extrusive volcanic rocks and associated volcaniclastic sediments, and intrusive stocks, dikes, and sills. Sedimentary and volcanic rocks are present in the Jornada del Muerto and Sierra Blanca basins. Intrusive rocks are present mainly in the eastern half of the project area. Within the Jornada del Muerto Basin continental sediments of Tertiary age have been assigned to the Baca Formation (Tabet, 1979) and attain a maximum thickness of approximately 1000 ft (Gardner, 1910). Andesitic, rhyolitic and associated volcaniclastic sediments are also present locally within the Jornada del Muerto Basin (Tabet, 1979) with a maximum thickness of 2000 ft (Wilpolt and Wanek, 1951). Sedimentary rocks within the Sierra Blanca Basin are assigned to the Cub Mountain Formation and the Sanders Canyon Formation (Cather, 2002). The Cub Mountain Formation of Eocene age unconformably overlies Cretaceous strata and consists of 2500 ft of red sandstones, mudstones and conglomerates. The Sanders Canyon Formation overlies the Cub Mountain Formation and consists of volcaniclastic sandstone and mudstone. Flows, tuffs and volcaniclastic breccias, sandstones and conglomerates of the Sierra Blanca volcanics gradationally overlie the Sanders Canyon Formation.

Tertiary igneous intrusive rocks form numerous stocks, dikes, and sills in the eastern half of the project area (Figure 2). The stocks form prominent mountains in the region. East-to-northeast-trending dikes and sills have been mapped at the surface on Chupadera Mesa and areas to the east of Chupadera Mesa and also have been cut by exploratory wells drilled in the region. Composition of the igneous intrusive rocks is varied and includes diabases, monzonites, and rhyolites.

Quaternary System

Alluvial and eolian sands and silts cover much of the Jornada del Muerto Basin and the topographically low Valley of Fires area

west of Carrizozo. Thickness is not well established but is probably less than 100 ft in most places. The Quaternary basalt flows present west of Carrizozo in the Valley of Fires are 5200 years old (Dunbar, 1999).

PETROLEUM GEOLOGY

Petroleum Source Rocks

Three gross stratigraphic intervals, the Pennsylvanian section, the San Andres Formation (Permian), and the Upper Cretaceous section contain the major organic-rich source facies within the region (Broadhead and Jones, 2004). Cretaceous strata are preserved only within the Jornada del Muerto and Sierra Blanca basins. The San Andres Formation crops out and is present only at shallow depths or has been eroded from most of the region and is therefore of minor interest as a source unit.

Pennsylvanian strata, with thick sections of dark-gray to black organic-rich shales, are present over a large part of the region at depth (Figure 8). In most places, shales in the lower part of the Pennsylvanian section contain 1 to 2 percent total organic carbon (TOC), sufficient for hydrocarbon generation and some individual shale beds contain more than 2 percent TOC (Broadhead and Jones, 2004). Organic matter is approximately equally divided among kerogens that are oil and gas prone (amorphous and herbaceous types), gas prone (woody types), and nongenerative (inertinite).

Thermal maturity patterns exhibit a spatial relationship to Tertiary-age heat sources. A roughly north-south aligned trend of lower thermal maturity is centered approximately on the Oscura anticline (Figure 9). Along this trend, shales in the lower part of the Pennsylvanian section are moderately mature with Thermal Alteration Index (TAI) values ranging from 2.2 to 2.5. These maturity levels indicate generation of perhaps some heavier, immature oils.

Maturity increases both east and west of the central low-maturity trend. This increase appears to be largely independent of present or past burial depths. TAI increases to 2.8 in the west around the Anderson Wishbone Federal well; this places the source facies in the mature, upper half of the oil window. The same west-increasing trend in maturity was seen to the north of the project area in the Estancia Basin where it was ascribed to an Early Tertiary heating event associated with volcanism in the Rio Grande rift (Broadhead, 1997). The eastward increase in thermal maturity from the central low-maturity trend appears to be independent of burial depth. Pennsylvanian shales have similar maturity in both shallow areas in the north and in the deep Carrizozo Basin in the south. This thermal maturity trend can be explained by higher paleo-heatflow associated with the large igneous intrusive bodies of Tertiary age that occur in the eastern third of the region (Figure 9). TAI values of Pennsylvanian strata increase eastward to a known maximum of 3.5 in the Primero Jackson Ranch well; this is at the base of the oil window, past the stage of maximum oil generation and at the point where light oils begin to break down into condensates and associated wet gases. Rock-Eval TMAX values and Productivity Index values confirm the levels of maturity that the TAI values indicate (Broadhead and Jones, 2004).

Oil and Gas Possibilities

Several of the wells drilled in the Chupadera Mesa region have encountered oil and gas shows (Figure 3; Table 1). Although production has not been established, these shows indicate that at least some oil and gas is present within the region or has migrated though the region.

Most of the exploratory wells have been drilled on the Oscura anticline and more recently on Chupadera Mesa. Several wells drilled on the Oscura anticline encountered oil, condensate and gas shows in Pennsylvanian and Abo sandstones. The condensate and oil shows encountered in the wells drilled on the Oscura anticline may have originated in more mature Pennsylvanian strata located east and west of the anticline and migrated up-structure into the anticline. The Oscura anticline has been breached along its crest, and Precambrian basement is exposed to the south in the Oscura Mountains. Unless lateral stratigraphic barriers to migration are present, a large portion of the oil and gas that migrated into this positive structural element may have been lost to surface seepage.

The composition of gases encountered by wells drilled on the Oscura anticline is not known. However, the wells recently drilled to the east on Chupadera Mesa encountered non-burnable gases in both Pennsylvanian and Abo sandstones. These gases mostly contain varying amounts of nitrogen and carbon dioxide as well as lesser amounts of helium and other inert gases. Hydrocarbon content is less than 5 percent.

Other wells have sparsely tested the region with few oil and gas shows. The two wells drilled within the Carrizozo basin did not have mudlog or other reported shows, and wells drilled to the lower Pennsylvanian and Precambrian on the Prairie Springs anticline also had no reported shows. The Ralph Nix No. 1 Ralph Federal well, drilled in the Sierra Blanca Basin in T6S, R10E had several oil and gas shows in the San Andres, and the Layne Texas Capitan water well in T9S, R14E had a small reported gas show, also in the San Andres. These shows indicate at least some oil and gas potential for the San Andres within the Sierra Blanca Basin.

Most wells in the region have been drilled to test structures mapped at the ground surface. Despite the relative paucity of oil and gas shows, there is hydrocarbon potential in at least three untested plays that are summarized below. In addition, there may be a very modest coalbed methane potential within the Cretaceous section.

Synclinal basin play

This play covers the Torres syncline and the synclinorium that straddles the Monte Prieto-Liberty Hill structural zone. The play is predicated on the possibility that these structurally low areas have an ancestral Rocky Mountains ancestry (Figure 6A). If this hypothesis is true, then thickened sections of Pennsylvanian strata underlie the synclinal areas and are separated from the adjacent

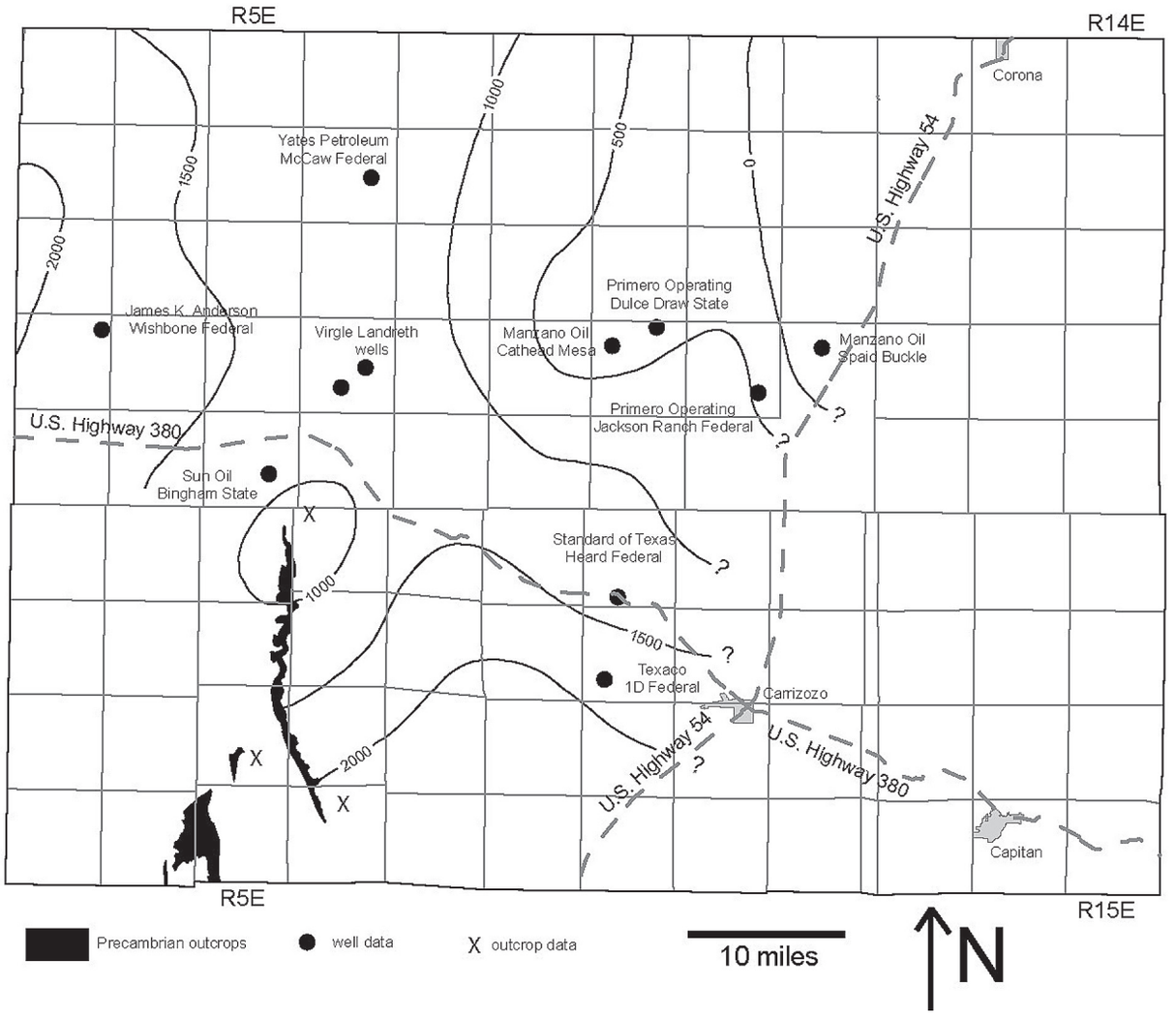


FIGURE 8. Isopach map of Pennsylvanian strata. Contours in feet.

anticlines by late Paleozoic faults that die out upward. The thickened Pennsylvanian will not only have additional reservoirs in possible basinal facies, but also thicker sections of source rocks and seals. Having been buried more deeply than the anticlinal areas, thermal maturity will be enhanced under the synclines. The kerogen populations within the Pennsylvanian indicate that this play has the potential for oil as well as gas.

Eastern Pennsylvanian boundary play

The zero isopach line of the Pennsylvanian System trends roughly north-south in R10-11E (Figure 7). The location of the zero isopach line in the southern half of the project area is uncertain and could lie anywhere from R10E to R13E. The eastward thinning of the Pennsylvanian underneath Chupadera Mesa is accompanied by increasing thermal maturity of source rocks. The Pennsylvanian section in R10-11E is thermally mature and within the oil window, whereas Pennsylvanian strata to the west are only marginally mature. Hydrocarbons generated within the mature area may have migrated eastward in an updip direction onto the western flank of the Pedernal uplift. Because maturation (and therefore petroleum generation) are hypothesized to have been associated with Tertiary-age igneous activity, migration pathways would have followed structural trends in existence at the time the igneous bodies were emplaced, and these pathways would closely approximate the current structure of the area. Potential traps include Pennsylvanian sandstones truncated under the basal Permian unconformity.

Lower Paleozoic pinchout play

Outcrop maps in the Oscura Mountains demonstrate that lower Paleozoic strata are truncated northward under the unconformity at the base of the Pennsylvanian section (Fig. 7). This truncation raises the possibility that hydrocarbons could be trapped in favorable updip locations under the unconformity. Although the sparse available information does not provide firm evidence for good reservoir quality within the Ordovician dolostones and sandstones, it is possible that fracturing and karsting of Ordovician dolostones could have occurred during formation of the major unconformity at the top of the lower Paleozoic section.

The Oscura Mountains bisect the northward pinchout into a

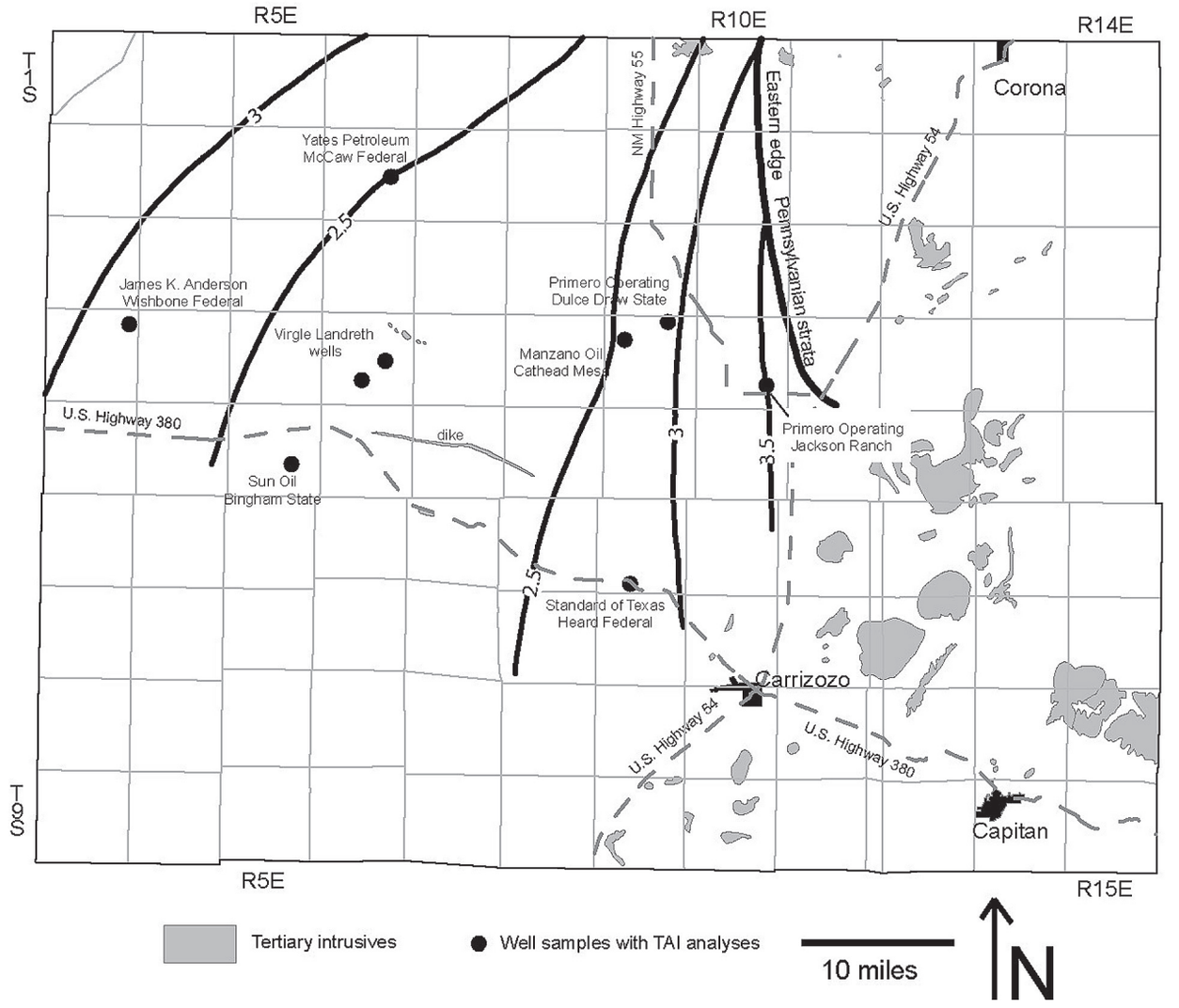


FIGURE 9. Contours of the Thermal Alteration Index (TAI) of kerogen in Lower Pennsylvanian shales. TAI is an indicator of thermal maturity of a source rock.

western part and an eastern part. Potential areas for trap formation and petroleum accumulation include the southern part of the Jornada del Muerto Basin west of the Oscura Mountains. Limited areas east of the Oscura Mountains may also be favorable for hydrocarbon entrapment. Strata dip east from outcrops in the Oscura Mountains. This geometry would have led to updip leakage of hydrocarbons to outcrops in the mountains. However, if Ordovician strata are present within the Carrizozo basin, then the western boundary fault of the Carrizozo basin may have acted in concert with the northern pinchout to form a trap. Overlying Pennsylvanian shales are possible source rocks.

Coalbed Methane Potential

The presence of coals in Cretaceous strata of the Jornada del Muerto and the Sierra Blanca basins raises the possibility of coalbed methane potential in these areas. In general, the thin discontinuous nature of the coals limits the coalbed methane potential (Broadhead and Jones, 2004). Low rank of the coals also limits potential as well and suggests that any coal gas that may be present in the region may have been generated primarily through biogenic processes. Sidwell (1946) thought that coal rank, and therefore thermal maturity, increased near igneous intrusive bodies in the Capitan coal field within the Sierra Blanca Basin. Areas of thermogenic gas generation may be present in the subsurface near the larger intrusive bodies.

HELIUM POTENTIAL

Helium has two isotopes, He^3 and He^4. He^3 is derived primarily from the mantle; mantle derived helium is rare in reservoir gases (Hunt, 1996). He^4, on the other hand, is derived primarily from the radioactive decay of uranium, thorium and radium in the earth's crust (Hunt, 1996; Selley, 1998; Maione, 2004). It is thought that the common sources of helium are the uranium, thorium and radium-bearing minerals in granitic basement rocks and in sedimentary uranium ore deposits. High helium flux in the crust is associated with faults, lineaments and natural springs (Hunt, 1996; Maione, 2004). Thermal activity or tectonic events

that create or enhance fracture permeability facilitate release of helium gas from granitic basement into overlying sedimentary rocks (Selley, 1998; Maione, 2004).

Helium diffuses upward though the sedimentary section more rapidly and readily than other natural gases. The helium atom has an effective diameter of 0.2 nm, significantly less than CO_2 (0.33 nm), CH_4 (0.38 nm), and N_2 (0.34 nm), allowing helium to diffuse through seals that are effective barriers to larger molecules (Hunt, 1996). Sedimentary rocks of low permeability and with fine pore sizes such as salt, anhydrite or Paleozoic shales make the best seals for helium and slow its upward diffusion through the crust (Maione, 2004). Helium may leak upward through other types of seals that will retain hydrocarbons and CO_2.

The geology of the Chupadera Mesa project area is favorable to helium generation, migration, and entrapment. The region is underlain by Precambrian granitic rocks in most places that gamma-ray logs indicate are significantly more radioactive than the overlying sedimentary section. Deep, high-angle faults penetrate the basement in many places. Although many of these faults have a late Paleozoic ancestry, they were reactivated during Laramide and post-Laramide Basin and Range tectonism. The latter event was characterized by extension that would enhance fracture permeability in the Precambrian. In addition, Tertiary igneous activity was apparently accompanied by widespread heating that would have facilitated the release of helium into the Paleozoic sedimentary sequence. Pennsylvanian stratal units immediately overlie the Precambrian and contain shales that may act as effective seals for helium. In addition, basal Pennsylvanian sandstones overlie basement in most places and would make ideal migration pathways through which helium, liberated from the basement, could migrate updip within the basal sandstones until trapped. The overlying Abo Formation contains abundant thick shales and the Yeso Formation contains widespread anhydrite beds that would make good seals. In the area extending from the Carrizozo basin northward to the Manzano Cathead Mesa well, the Yeso Formation contains salt beds that make ideal seals for helium. Other favorable targets include basal Pennsylvanian sandstones located updip of major basement involved faults where they are in trap configuration.

There are direct indications of elevated helium levels in the area. Nonburnable gas recovered from the Manzano Cathead Mesa well, located in T4S R9E, had 2.56 percent helium (Figure 3). Nonburnable gas recovered from an Abo sandstone in the Primero Dulce Draw State well, located in T4S R9E, just 3 miles northeast of the Cathead Mesa well had a helium content of 3.2 percent. Two gas samples recovered from an Abo sandstone reservoir in the Primero No. 3 Cathead Mesa well, also located in T4S R9E, had helium contents of 2.9 and 3.4 percent, with the remainder of the gas primarily carbon dioxide and nitrogen.

Isotopic analyses indicate that the helium encountered in the reservoirs on Cathead Mesa is a mixture of crustal-derived radiogenic helium and mantle-derived helium. The ratio of $^3He/^4He$ in a gas sample can be normalized to the $^3He/^4He$ ratio in the atmosphere (1.41×10^{-6}; Oxburgh et al., 1986). This value is expressed as the variable R. Mantle-derived helium has R values between 6 and 10; the maximum R value for most crustal-derived helium is 0.08 and the average R value for crustal-derived helium is less than or equal to 0.04 (Oxburgh et al., 1986). The R value for helium recovered from the Primero No. 3 Cathead Mesa well is 0.515, significantly more than the upper limit of 0.08 for crustal-derived helium but less than minimum value of 6 for mantle-derived helium. This is strongly suggestive of a mixed crustal-mantle origin for the helium recovered from reservoirs in the Cathead Mesa area. The granitic Precambrian rocks that underlie the region may be logically assumed to be the source of the crustal-derived fraction. The transport-mechanism for the mantle-derived fraction is enigmatic, however. One possible migration pathway is the Monte Prieto–Liberty Hill structural zone, which lies 5 miles west of the Cathead Mesa wells. Alternatively, the helium may have been transported to the near surface by the magmas that formed the Tertiary-age igneous rocks in the region. Igneous activity in general has been shown to be an effective mechanism for the transport of mantle helium to the surface (Oxburgh et al., 1986).

CONCLUSIONS

The Chupadera Mesa region has been sparsely drilled. A total of 45 wells have been drilled within the region. This is a density of approximately one well for every 85 mi^2. Many of the wells are shallow and reached total depth in Permian strata. Only 20 wells have been drilled to Precambrian basement. This is a density of one well per 200 mi^2, or 5.5 townships. Areal distribution of the wells has not been even, with most of the deeper wells concentrated on the Oscura anticline and in the Cathead Mesa area. Neither oil, natural gas nor helium production have been established. Nevertheless, several of the wells have encountered promising shows of oil, natural gas, and helium.

The geology of the Chupadera Mesa area indicates favorable potential for oil and natural gas. Petroleum source rock facies are concentrated in marine Pennsylvanian strata that blanket the western two-thirds of the project area and attain a maximum thickness of 2200 ft. Dark-gray to black Pennsylvanian shales that contain both gas-prone and oil-prone kerogen populations are thermally mature to the east and west of a central, less mature area. Maturation into the oil window appears to have been caused primarily by heating associated with igneous events during the Tertiary. Favorable reservoirs are marine Pennsylvanian sandstones, continental sandstones of the Abo Formation (Permian: Wolfcampian), and marine to marginal marine sandstones of the Yeso Formation (Permian: Leonardian). Most exploratory wells have been drilled on anticlines mapped at the surface. Untested plays include speculated but undrilled late Paleozoic basins that underlie Laramide-age synclines, truncation traps in Pennsylvanian sandstones under a basal Permian unconformity at the eastern pinchout of Pennsylvanian strata, and northward pinchout of Ordovician carbonate rocks in the southern part of the project area. There is also limited coalbed methane potential in Cretaceous strata in the Jornada del Muerto and Sierra Blanca basins.

The Chupadera Mesa project area also has favorable potential for helium. Isotopic analyses indicate helium recovered from reservoirs in the Cathead Mesa area has a mixed crustal-mantle

provenance. Uranium-bearing basement rocks favorable for the formation of radiogenic helium are present. In addition, high-angle fracture and fault systems and Tertiary-age igneous events characterize the area and are favorable not only to the release of radiogenic helium from the Precambrian basement into the overlying Paleozoic sedimentary column but also for the transport of helium from the mantle. Pennsylvanian and Permian shales and Permian anhydrites and salt beds are favorable seals for helium. Analyses of gases recovered from wells drilled on Chupadera Mesa indicate the presence of helium in substantial amounts. Nonburnable gases recovered from other wells may also contain helium.

ACKNOWLEDGMENTS

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