OIL AND GAS EXPLORATION WELLS IN SOUTHWESTERN NEW MEXICO

SAM THOMPSON III[1]

ABSTRACT

In Hidalgo, Grant, Luna, and Doña Ana Counties of southwestern New Mexico, 64 oil and gas exploration wells have been drilled through 1980. In the 22 key wells drilled to Mesozoic, Paleozoic, or Precambrian rocks, shows of oil or gas have been reported in 11, but no commercial production has been established as yet. Several favorable source and reservoir units are indicated in the Paleozoic section, which is analogous to that of the productive Permian basin, and in the Mesozoic section, which is analogous to that of the western Gulf basin.

Lithostratigraphic and biostratigraphic studies of the subsurface sections in the key wells provide significant data for both local and regional interpretations. In the Humble No. 1 State BA, Ordovician conodonts were identified in the bottom of the well, negating a previous thrust interpretation. In the Grimm No. 1 Mobil 32, lower Tertiary palynomorphs were identified below the Lobo(?), providing a critical maximum age for that formation; Lower Cretaceous and Jurassic index fossils document a northward extension of the Chihuahua trough.

A regional isopach map of the Paleozoic shows thickening up to 15,000 ft in the Pedregosa basin area, thinning to less than 4,000 ft in the Burro-Moyotes uplift area, and thickening to over 8,000 ft in the Orogrande basin area. A map of the Mesozoic shows southward thickening of the Bisbee Group (Lower Cretaceous) to over 15,000 ft, northward onlap, and possible continuity of the upper part with the Sarten. Upper Cretaceous strata are less than 2,000 ft thick and exhibit southwestward onlap.

Laramide uplift and erosion stripped Mesozoic and older rocks from much of the Burro and other positive areas. Upon the Laramide unconformity, conglomerates and redbeds were deposited, followed by andesitic volcanic rocks; their decreasing ages to the northeast reflect the migration of the Cordilleran magmatic arc. Some Laramide thrusts may have formed by upward and outward movement from wrench zones. In the lower plate of a major thrust, thermal alteration of kerogens has exceeded the limit of oil preservation, and gas may not be preserved in older units.

INTRODUCTION

Oil and gas exploration wells drilled to Paleozoic or Precambrian rocks in the Pedregosa basin area of southeastern Arizona, southwestern New Mexico, and northern Mexico were discussed by Thompson and others (1978). The present investigation focuses on the wells in southwestern New Mexico and it: (1) includes those drilled to Mesozoic, Paleozoic, or Precambrian rocks; (2) provides an update of formation tops and other basic well information; and (3) presents isopach maps of Paleozoic and Mesozoic strata. Those strata contain the significant petroleum source and reservoir rocks of the region.

Figure 1 shows the locations, names, total depths, and oldest formations penetrated by exploration wells drilled to documented Mesozoic or older rocks in southwestern New Mexico prior to 1982. The map area covers about 156 miles from west to east and about 100 miles north to south, including all of Hidalgo and Luna Counties and the southern parts of Grant, Sierra, and Doña Ana Counties in New Mexico. The northern part of Chihuahua, Mexico, and the western part of El Paso County, Texas, also are included in the map rectangle.

Table 1 is a generalized correlation chart of stratigraphic units in southwestern New Mexico. Separate columns of formation names are listed for the Pedregosa basin (after Zeller, 1965 and 1970), Burro uplift (after Jicha, 1954), and the Orogrande basin (after Kottlowski and others, 1956). These basins are areas of subsidence where Pennsylvanian rocks are 2000 ft thick or more (Kottlowski, 1960a). Only wells which reached units beneath the Laramide unconformity are discussed in this paper. Main rock types and depositional environments are grossly generalized. Petroleum source and reservoir evaluations are based on current work in the Hidalgo County area (Thompson, 1981) that is being extended to other parts of the region.

Lying within the Basin and Range province, this area is one of the active frontiers of petroleum exploration. Because of the stratigraphic similarities of the Paleozoic section with that of the Permian basin, and of the Lower Cretaceous section with that of the western Gulf basin, this area has a high potential (Greenwood and others, 1977). Projections of the Cordilleran fold and thrust belt have encouraged structural exploration (Corbitt and Woodward, 1973; Drewes, 1978); however, several contrasts are noted in comparison with the productive overthrust belt of Wyoming and Utah (Woodward, 1980; Thompson, 1980; Woodward and DuChene, 1981). Tectonic and igneous complexities, including Tertiary volcanism, local metamorphism, and extensive Basin and Range faulting, add to the risks of frontier exploration (Thompson, 1976, 1980).

EXPLORATION WELLS

Table 2 presents the basic data on the 22 wells drilled to pre-Laramide stratigraphic units in Hidalgo, Grant, Luna, and Doña Ana Counties, New Mexico (Fig. 1). These data generally were taken or derived from scout tickets, cuttings, logs, and other information available in the New Mexico Library of Subsurface Data, supervised by R.A. Bieberman at the New Mexico Bureau of Mines and Mineral Resources. Locations, names, and completion dates were taken directly from the scout tickets or re-

[1] New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801.

In addition to specific acknowledgements mentioned in the main body of the text, I wish to express my thanks to the reviewers of the manuscript, R.E. Clemons and A.C. Selby, who have made several suggestions for improvement. This paper is published with permission of F.E. Kottlowski, Director of the New Mexico Bureau of Mines and Mineral Resources.

Table 1. Stratigraphic units of southwestern New Mexico (modified from Thompson and others, 1978, Table 1).

Chronostratigraphic units		Pedregosa basin Hidalgo-Grant Counties	Burro uplift Luna County	Orogrande basin Doña Ana County	Main rock type	Depositional environment	Petroleum evaluation source	Petroleum evaluation reservoir
Quaternary		---bolson, fluvial, and other deposits---			sand	nonmarine	none	poor
Quaternary-Upper Tertiary		Gila	Gila	Santa Fe	conglomerate	nonmarine	none	fair
Middle Tertiary		---volcanic and local intrusive rocks---			rhyolite, etc.	nonmarine	none	none
Lower Tertiary-Uppermost Cretaceous		Hidalgo	Rubio Peak	Palm Park	andesite, etc.	nonmarine	none	none
		Ringbone	Lobo	Love Ranch	cgl., redbeds	nonmarine	none	poor
		absent	absent	unnamed	sandst.,mudst.	nonmarine	poor	poor
---Laramide unconformity---								
Upper Cretaceous		absent	upper Colorado	absent	sandst.,mudst.	nonmarine	poor	poor
		absent	lower Colorado	Mancos	mudstone	shallow marine	good	very poor
		absent	Beartooth	Dakota	sandstone	deltaic	poor	fair
Lower Cretaceous		Bisbee: Mojado	Sarten	Sarten	sandst.,mudst.	deltaic	poor,fair	fair,poor
		Bisbee: U-Bar	absent	absent	limestone	shallow marine	fair	fair
		Bisbee: Hell-to-Finish	absent	absent	cgl., redbeds	nonmarine	none	very poor
Jurassic		absent	absent	unnamed	sandst.,mudst.	marine	poor,fair	fair,poor
Triassic		absent	absent	absent	--	--	--	--
---basal Mesozoic unconformity---								
Permian	Guadalupian	Concha	absent	San Andres	limest.,dolost.	shallow marine	fair	poor,fair
		Scherrer	absent	Glorieta	sandstone	shallow marine	very poor	poor
	Leonardian	Epitaph	absent	Yeso (Hueco?)	dolostone	shallow marine	fair-good	fair
		Colina	absent		limestone	shallow marine	fair	very poor
	Wolfcampian	Earp	Abo	Abo-Hueco	redbeds-limest.	non.-shall.mar.	poor-fair	poor-fair
Pennsylvanian	Virgilian	upper Horquilla limestone-shelf dolostone-margin mudstone-basin	absent	Magdalena: Bursum	limest. dolost. mudst. / limest.	shallow to deep marine	fair to good	fair to good
	Missourian		absent	Magdalena: Panther Seep	sandst.			
	Desmoinesian		Magdalena	Magdalena: Lead Camp	limest.			
	Derryan	lower Horquilla	absent		limestone	shallow marine	fair	poor
	Morrowan		absent					
Mississippian	Chesterian	Paradise	absent	Helms	limest.,mudst.	shallow marine	fair-good	poor
	Meramecian,etc.	Escabrosa	Lake Valley	Lake Valley-Rancheria	limest.,chert	shall.-deep mar.	fair	poor
Devonian		Percha	Percha	Percha	dark mudstone	shallow marine	poor-fair	poor
Silurian		Fusselman	Fusselman	Fusselman	dolostone	shallow marine	poor	fair-good
Upper Ordovician		Montoya	Montoya	Montoya	dolost.,sandst.	shallow marine	fair,poor	fair,poor
Middle Ordovician		absent	Simpson	absent	mudst.,sandst.	shallow marine	fair	poor
Lower Ordovician		El Paso	El Paso	El Paso	limest.,dolost.	shallow marine	fair	poor,fair
Lowermost Ordovician-Upper Cambrian		Bliss	Bliss	Bliss	sandstone	shallow marine	poor	poor
Middle and Lower Cambrian		absent	absent	absent	--	--	--	--
---basal Paleozoic unconformity---								
Precambrian		---basement complex---			granite,met.	nonmarine	none	none

Table 2. Basic data on exploration wells drilled to Mesozoic, Paleozoic, or Precambrian rocks in southwestern New Mexico (see text for sources of information).

Location	Well name	Completion date	Elevation	Formation tops (Ti = Tertiary intrusive rock)	Total depth	Oil, gas shows
HIDALGO COUNTY:						
24S-19W-31 1,980'N; 660'E	Cockrell No. 1 Pyramid Fed.	9-30-69	4,244' KB	Surface-Quaternary; 385'-Gila?;1,890'-Tertiary volcanic rocks (Ti); 5,795'-Escabrosa (Ti); 6,680'-Percha (Ti); 6,860'-Montoya (Ti); 6,980'-El Paso (Ti); 7,130'-Bliss (Ti); 7,340'-Precambrian	7,404' Precambrian	None
26S-17W-4 330'S; 1,980'E	Powers No. 1 State	12-3-72	4,377' KB	Surface-Quaternary; above 920'-Tertiary (or Cretaceous) volcanic rocks; 1,190'-Mojado; 3,930'-Tertiary intrusive rocks	4,007' Tert. intrus. (Mojado)	None
28S-17W-18 1,980'N; 1,980'E	KCM No. 1 Cochise St. A	3-22-75	4,416' KB	Surface-Quaternary; above 70'-Gila; 2,370'-Mojado	5,916' Mojado	Gas: 2,050'; 2,220';2,650'
30S-15W-12 1,655'S; 2,012'W	Hachita Dome No. 1 Tidball-Berry Fed.	5-23-57	4,349' DF	Surface-Quaternary; 224'-Escabrosa; 800'-Percha (Ti); 1,395'-Montoya; 1,653'-El Paso; 2,590'-Bliss; 2,723'-Precambrian	2,726' Precambrian	Gas: 1,500'; 2,310';2,430'; oil: 2,590'
30S-15W-12 1,980'S; 660'W	Graham No. 1 Hatchet Fed.	11-21-78	4,331' GL	Surface-Quaternary; 540'-Escabrosa (Ti); 960'-Percha; 1,240'-Montoya; 1,710'-El Paso	2,455' El Paso	None
30S-17W-14 600'N; 1,980'E	Cockrell No. 1 Playas State	6-11-70	4,455' KB	Surface-Quaternary; 100'-Gila; 2,480'-Horquilla; 3,836'-Paradise; 4,127'-Escabrosa; 5,192'-Percha; 5,568'-Montoya; 5,890'-El Paso; 6,764'-Bliss; 7,030'-Precambrian?	7,086' Precambrian?	Dead oil: 5,780'
31S-17W-12 1,980'N; 660'E	Cockrell No. 1 State-1,225	11-24-70	4,480' KB	Surface-Quaternary; 150'-Gila; 2,465'-Tertiary volcanic (and sedimentary?) rocks; 2,595'-Epitaph; 3,770'-Colina	4,005' Colina	None
31S-18W-3 1,494'N; 1,753'E	KCM No. 1 Forest Fed.	1-22-75	5,156' KB	Surface-Earp (Ti); 255'-Horquilla (Ti); 2,225'-metamorphosed Horquilla and Tertiary intrusive rocks.	4,464' Tert. intrus. (Horquilla)	None
32S-16W-25 990'N; 1,980'E	Humble No. 1 State BA	12-24-58	4,587' KB	Surface-Quaternary; 230'-U-Bar; 648'-Hell-to Finish; 995'-Concha; 1,522'-Scherrer; 1,532'-Epitaph; 3,310'-reverse fault, Epitaph repeated; 4,450'-Colina; 5,258'-Earp; 6,265'-Horquilla; 10,995'-Paradise; 11,425'-Escabrosa; 12,500'-Percha; 12,830'-Montoya; 13,214'-El Paso	14,585' El Paso	Gas: 4,190'-4,219'
GRANT COUNTY:						
25S-16W-14 700'S; 700'W	Cockrell No. 1 Coyote State	8-24-69	4,354' KB	Surface-Quaternary; above 360'-Tertiary (or Cretaceous) volcanic rocks; 1,790-Mojado (Ti); 6,400'-U-Bar (Ti); 7,100'-Hell-to-Finish; 7,240'-Montoya; 7,720'-El Paso; 8,360'-Bliss; 8,580'-Precambrian	9,282' Precambrian	Oil: 4,140'
27S-16W-16 1,600'S; 850'E	Wininger and Berry No. 1 State	9-13-43	4,675' GL	Surface-Quaternary; 28'-Ringbone?; 580'-Mojado?	1,500' Mojado?	Oil: 610'-620'; oil,gas: 1,270'-1,330'; gas: 1,415'-1,430'

Location	Well Name	Completion date	Elevation	Formation tops (Ti = Tertiary intrusive rock)	Total depth	Oil, gas shows
DOÑA ANA COUNTY (cont)						
25S-1E-32 1,315N; 1,315'W	Grimm et al No. 1 Mobil 32	10-12-73	4,220' GL	Surface-Quaternary; above 310'-Santa Fe; 1,940'-Tertiary volcanic rocks; 5,880'-Lobo?; 12,100'-Lower Tertiary (Paleocene-Eocene) sedimentary rocks; 13,300'-Sarten; 14,100'-Jurassic sedimentary rocks (Ti); 15,550'-Hueco (Ti); 19,080'-Magdalena (Ti); 20,560'-Rancheria?; 20,710'-Percha; 20,880'-Fusselman; 21,560'-Montoya	21,759' Montoya	Gas and oil: 12,340'-12,600'; gas: 19,015'-19,240'; 20,620'-20,690'; oil: 21,600'-21,710'
28S-2W-24 1,060'N; 2,297'E	Pure No. 1 Federal H	2-8-62	4,404' SC	Surface: Lower Cretaceous sedimentary rocks (Ti); 625'-Permian? to Mississippian? sedimentary rocks (Ti); 3,850'-Percha; 4,060'-Fusselman; 4,405'-reverse fault?, Permian? to Mississippian? sedimentary rocks; 6,240'-marble?; 6,815'-Tertiary intrusive rock	7,346' Tert. intrus. (Paleoz.?)	None

ity at that depth, only lower Paleozoic strata are preserved. A slight show of oil was found in Mojado sandstones by the mudlogger; however, on two drill stem tests only fresh water (chloride contents 150 and 120 ppm) was recovered, indicating flushing by meteoric water from the Burro uplift area to the north.

Only a driller's log is available on the Wininger and Berry well. Previous reports of Mississippian rocks at the surface and Ordovician rocks at the total depth of only 1,500 ft are considered erroneous. Near that location in the Little Hatchet Mountains the Ringbone Formation (uppermost Cretaceous) crops out. The reported shows of oil and gas are probably in the Mojado.

LUNA COUNTY

Of the 17 wells drilled in Luna County, five definitely have reached pre-Laramide units, and one recent well may have. Others which have been drilled to 2,000 ft or more in the northern and eastern part of the county appear to have reached red beds of the Lobo Formation (uppermost Cretaceous to lowermost Tertiary), which overlies the Laramide unconformity.

All five of the key wells were checked in an earlier study (Thompson and others, 1978). In the present investigation, formation tops were rechecked with available cuttings and logs and some revisions were made. Further revisions may be necessary after each well is studied in detail and biostratigraphic control is added.

In the Mimbres Valley area northwest of Deming, the Cockrell, Sycor Newton, and Guest and Wolfson wells encountered lower Paleozoic strata beneath the Laramide unconformity. Individual units should be documented with conodonts or other index fossils. Nevertheless, the lithostratigraphic evidence confirms the fact that younger Paleozoic and Mesozoic strata have been eroded off this subsurface portion of the Burro uplift. Above the unconformity, the Lobo is about 4,000-5,000 ft thick and may be filling a narrow Laramide trough trending northwest-southeast (parallel to the San Vicente Arroyo). The Lobo is only 500 ft thick in the Florida Mountains southeast of Deming (R.E. Clemons, personal communication, 1982).

Near Deming, two recent wells were drilled by the Seville Trident Corp. Their No. 1 City of Deming (24S-8W-6) was drilled in 1981 to a total depth of 4,225 ft and probably did not reach pre-Laramide units. Their No. 1 McSherry (24S-8W-4) was drilled in 1981-1982 to a total depth of 12,495 ft and probably went into Precambrian. Because these wells were drilled tight, no cuttings or logs were available for use in the present investigation. Shows of gas have been tested in both wells.

North of Camel Mountain, in the southeastern part of the county, the other two key wells also encountered lower Paleozoic strata beneath the unconformity on that portion of the Burro uplift. Cuttings in the Skelly well are of poor quality; however, a normal fault with at least 1,675 ft of stratigraphic throw appears to have been crossed at the El Paso/Precambrian contact. The total throw may be nearly 4,000 ft because the top of the El Paso is 3,960 ft higher in the Sunray well (3 mi to the southeast). A red-bed section between 3,900-5,130 ft in the Skelly well is correlated tentatively with the Lobo Formation. It overlies an andesitic-volcanic section which may be as old as uppermost Cretaceous Normally, the Lobo and its correlatives underlie a Cretaceous or Tertiary volcanic section.

DONA ANA COUNTY

The 14 wells drilled in Doña Ana County were discussed by Thompson and Bieberman (1975). That work was based on reported information. Other references on these wells include:

3,850-4,060 ft are inferred to be Percha, and the light, coarsely crystalline dolostones between 4,060-4,405 ft are inferred to be Fusselman. Both determinations should be checked with biostratigraphic evidence.

A reverse fault is inferred as 4,405 ft where circulation was lost in a possible fractured zone, and where the dipmeter shows an abrupt reversal from southeast above to northward below. Cuttings again are poor below 4,600 ft, but the dominant carbonate section appears to be a repetition of the Permian? to Mississippian? undifferentiated unit. The abundance of clear calcite crystals beginning at 6,240 ft indicates that the lower part of the sedimentary section has been marbelized in contact with the Tertiary intrusive diorite below 6,815 ft.

A slight show of gas in the drilling mud was recorded between 4,380-4,400 ft. A drill-stem test from 4,354-4,412 ft recovered 3,480 ft of mud-cut water with a chloride content of 4,000 ppm. The spontaneous-potential curve shows a pronounced positive deflection through this interval, indicating invasion of meteoric water into the fault zone. This Pure well is another case illustrating the point that, in the Basin and Range province, uplifted areas tend to be flushed with fresh water.

REGIONAL ISOPACH MAPS

Kottlowski (1963) presented a series of regional isopach maps showing thicknesses of individual Paleozoic and Mesozoic units across southwestern and south-central New Mexico. Greenwood and others (1977) presented a similar series of maps covering southeastern Arizona, southern New Mexico, western Texas, and northern Mexico. Such overviews of stratigraphic units, especially if combined with delineations of depositional facies, are useful in regional projections of petroleum source and reservoir objectives.

In this short paper, only two isopach maps of southwestern New Mexico are presented — one each for the Paleozoic and Mesozoic. They provide the most basic step in analysis of the two most general stratigraphic units containing the significant petroleum source and reservoir objectives in the region. Exploration geologists may find them useful for gross estimates of: 1) burial history of source units, 2) distribution of source and reservoir units, and 3) drilling depths to test complete sections. They also reflect generally the cumulative effects of tectonic uplift and subsidence.

Thicknesses of the Paleozoic and Mesozoic at the well locations in southwestern New Mexico were determined directly from the drilled intervals given in Table 2. True stratigraphic thicknesses of these gross units may be considerably less, especially where dips are appreciable. However, such corrections would be feasible in only those few wells where dipmeter surveys are available. Thicknesses of sills or other minor Tertiary intrusions generally were not discounted. Values shown at locations of Pemex wells in Chihuahua, Mexico, were calculated from data in Thompson and others (1978, Table 4). Small areas of erosion sketched around wellsties are rough estimates in most cases and are shown to emphasize the fact that the unit is only locally thin or absent at that control point.

Thicknesses at surface sections were determined from publications and other sources listed under the Paleozoic and Mesozoic headings Data range in quality from precise measurements to gross field estimates as reported by different workers. Most are totals of composite sections located in separate parts of a given mountain range. In some cases, such stacking of even precisely measured sections may result in a composite thickness that is not as representative of a single location as the uncorrected drilled interval in a well bore. Where a range of thicknesses was reported for a given unit, the maximum was chosen as long as it appeared reasonable in comparison with nearby control. Locations were placed at the top of the Paleozoic or Mesozoic sections to indicate where the reported thicknesses should be present in the subsurface. Some of the previously published sections contain errors of omission or duplication resulting from low-angle thrusts, which have been discovered in recent mapping (H. Drewes, personal commun., 1982).

The extent of local Quaternary erosion around the surface locations was not shown to avoid a cluttering effect on these small-scale maps, but it may be observed at the outcrops of Precambrian, Paleozoic, and Mesozoic rocks indicated on the geologic map of New Mexico by Dane and Bachman (1965). This map and others were used for regional control to determine key surface locations where the Paleozoic or Mesozoic are present or absent by non-deposition or erosion prior to Quaternary time.

Thickness data from other wells and surface sections immediately surrounding the map area were used to control the contour trends. The contour interval of 1,000 ft is considered small enough to show significant regional features and large enough to smooth over minor local variations.

PALEOZOIC

Figure 2 is a regional isopach map of Paleozoic strata in southwestern New Mexico. It confirms many of the regional thickness trends shown in the earlier version by Kottlowski (1963, Fig. 2). With the addition of several subsurface sections from more recently drilled wells, and of additional or better documented surface sections, the major features are more sharply delineated.

This isopach map includes all the units shown on Table 1 between the basal Paleozoic unconformity and the basal Mesozoic unconformity. At most places, both boundaries are considered to be accurately determined within 100 ft of section. In undisturbed sections, the only problems with the lower boundary are at locations where the basal Bliss sandstones are arkosic and differentiation with underlying Precambrian granite is difficult, especially in well cuttings. In the southeastern part of the map area, the upper boundary was determined with some difficulty within 200-300 ft of section because dark carbonates or mudstones of the Jurassic are superposed on similar rocks of the Permian.

Thicknesses shown at surface locations on this isopach map were determined from several sources. In Hidalgo County, they are Zeller (1965; measured 11,489 ft). Soule (1972; reported incomplete section of 3,465 ft), and Gillerman (1958; measured 5,643 ft). In Grant County, they are Cunningham (1974; measured 1,945 ft) and Pratt (1967 measured and estimated 3,269 ft). In Luna County, they are Jicha (1954; measured 2,274 ft), Kottlowski (1960a Pl. 13; measured incomplete section of 1,735 ft), Thorman and Drewes (1981, estimated 2,430 ft), and R.E. Clemons (current study; measured 1,565 ft and 3,720 ft). In southern Sierra County, the one is Jicha (1954; measured and estimated 1,824 ft). In Doña Ana County, they are Kelley and Silver (1952; measured 4,300 ft), Seager and others (1971; measured 425 ft), Kottlowski and others (1956; measured 7,130 ft), Kottlowski (1960b; measured and estimated 4,300 ft), and Seager (1973; measured incomplete section of 3,075 ft). In El Paso County, Texas, the one is Harbour (1972; measured 8,426 ft). In Chihuahua, Mexico, the one is Diaz and Navarro (1964; measured and estimated 10,675 ft). Estimated thicknesses are of nearly complete sections with additions from the nearest control.

Most of the formations in the Paleozoic are shallow-marine carbonate deposits. They generally were deposited over the entire region and are missing in most cases as a result of subsequent erosion. Unconformities within the Paleozoic are recognized at the bases of the Montoya, Percha, Horquilla-Magdalena, Earp-Abo-Hueco, and Scherrer-Glorieta. In this area, most exhibit low relief, and the hiatuses normally include only parts of the underlying units. However, at the basal unconformity of the Earp-Abo-Huceo, the entire Horquilla-Magdalena and older units locally have been eroded. Nevertheless, the depositional extent and preservation are documented by the fact that each key well drilled below the Mesozoic has encountered at least some part of the Paleozoic.

Where the Paleozoic thickness is greater than 5,000 ft, more complete Pennsylvanian-Permian sections are preserved. In the southern part of the map area, the Paleozoic attains a thickness of 15,000 ft, and the Pennsylvanian-Permian part is over 12,000 ft. Part of that thickening is attributed to the Pedregosa basin, a Pennsylvanian basin of subsidence (Kottlowski, 1960a). Similarly, in the eastern part of the map area, the Orogrande basin, another Pennsylvanian basin of subsidence, contributed to the thickening of the total Paleozoic to over 8,000 ft.

On the Moyotes Ridge, uplift and erosion in mid-Wolfcampian time formed a boundary between these two Pennsylvanian basins. In the southeastern part of the Florida Mountains, Hueco rests unconformably on Lake Valley, and in the Pemex No. 1 Moyotes, Abo-Hueco rests unconformably on Precambrian. On the Burro uplift, in the northwestern part of the map area, the Paleozoic was completely eroded in Mesozoic time, as Beartooth (Cretaceous) rests unconformably on Precambrian (Elston, 1958). Laramide uplift and erosion, possibly along Precambrian shear zones, appears to be responsible for linear thinning of the Paleozoic on the San Vincente (to Moyotes) and Robledo ridges, as Lobo (or Love Ranch) rests unconformably on rocks as old as Lower Paleozoic. On the complex Florida uplift, at the intersection of the ridges, Lobo rests unconformably on Precambrian (R.E. Clemons, current study). On the San Diego uplift, Love Ranch rests unconformably on Lower Paleozoic rocks (Seager and others, 1971); it appears to be a local anomaly. On the Lake Valley uplift, Tertiary volcanic rocks rest unconformably on Lake Valley (Mississippian) (Jicha, 1954).

An isopach of the Bliss by Thompson and Potter (1981, Fig. 1) shows the paleotopography on top of the Precambrian. The most striking feature is the northeast-southwest trending crest of the ancestral continental divide extending across southwestern New Mexico (passing through the Hatch-Florida area). It also may follow a Precambrian shear zone. Because this feature is not evident on the total Paleozoic isopach, it apparently was not rejuvenated in post-Bliss time.

MESOZOIC

Figure 3 is a regional isopach map of Mesozoic strata in southwestern New Mexico. It includes all the units on Table 1 between the basal Mesozoic unconformity and the Laramide unconformity. It excludes some nonmarine sedimentary rocks and volcanic rocks of the uppermost Cretaceous.

Thicknesses shown at surface locations on this isopach map were determined from several references. In Hidalgo County, they are Zeller (1965; measured 9,969 ft), Zeller and Alper (1965; measured 7,619 ft), Gillerman (1958; measured and estimated 2,500 ft), and Elston (1960; measured 860 ft). In Grant County, they are Zeller (1970; measured and estimated 15,000 ft), Hewitt (1959; measured 1,160 ft), Edwards in Gillerman (1964, measured incomplete section of 273 ft), Cunningham (1974; measured 1,555 ft), and Pratt (1967; measured 1,755 ft). In Luna County, they are Jicha (1954, estimated 600 ft), and Kottlowski (1960a, Pl. 13; measured incomplete section of 800 ft). In Doña Ana County, they are Kottlowski and others (1956; measured 707 ft), Bowers (1960; measured incomplete section of 1,585 ft), and Lovejoy (1976; measured incomplete section of 1,361 ft). In Chihuahua, Mexico, the one is Lovejoy and others (1980; measured incomplete section of 5,665 ft).

Note that Mesozoic rocks are shown as absent at the locality in the Tres Hermanas Mountains (northwest of Columbus). Kottlowski and Foster (1962) measured an incomplete section of 1,530 ft which they designated as Lower Cretaceous on the basis of a few poorly preserved pelecypods. At that stop on the 1981 field trip of the El Paso Geological Society, some of us observed that the dolostones, limestones, and cherts resembled the Epitaph (Permian). A.C. Selby of ARCO Exploration Co. collected a sample and sent it to T.R. Carr who identified conodonts of Early Leonardian age. Appreciation is expressed to ARCO and the individuals involved for clearance to publish this important information.

Inferred depositional limits of the undifferentiated Jurassic, Bisbee Group (Lower Cretaceous), Sarten (Lower Cretaceous), and undifferentiated Upper Cretaceous are shown on the isopach. These limits provide explanations for some of the regional thickness patterns.

In the southeastern part of the map area, the depositional limit of the Jurassic lies within the Chihuahua trough of Navarro and Tovar (1975). In this trough, subsidence probably was more rapid than sedimentation, as the Jurassic black mudstones, dark limestones, and sandstones appear to have been deposited in a deep-marine environment. These basin-filling strata may onlap the bottom of the trough. The Jurassic ranges in thickness from 1,400 ft in the Grimm well to at least 4,800 ft in the Pemex No. 1 Sapallo, and possibly over 13,500 ft in the Pemex No. 1 Presidio.

The northern limit of the Bisbee Group trends nearly east-west across the middle of the map area. As described by Zeller (1965) in the Big Hatchet Mountains of Hidalgo County, the Bisbee is 9,969 ft thick and consists of three units: 1) Hell-to-Finish conglomerates and redbeds, 2) U-Bar limestones containing the distinctive orbitolinid foraminifers and rudist pelecypods in the upper part, and 3) Mojado sandstones and mudstones. These units generally are recognizable from the type area of the Bisbee Group in southeastern Arizona to western Texas where the succession corresponds approximately to the Trinity, Fredericksburg, and Washita of the Comanchean. A regional unconformity is evident at the base, but none has been documented within the Bisbee.

In the Hidalgo County area, the 10,000 ft or more in the Bisbee basin is projected from control in southeastern Arizona, as is the thin section on the Chiricahua ridge. The Little Hatchet basin may not contain the entire 15,000 ft estimated by Zeller (1965), but at least 10,000 ft are present. Regional thinning to the north appears to be mainly at the expense of the U-Bar, although the entire Bisbee appears to onlap an earlier Mesozoic highland.

In southern Doña Ana County and northern Chihuahua, different nomenclatures are applied to the Bisbee equivalents described by Bowers (1960) in the East Potrillo Mountains, by Lovejoy (1976) in the Cerro de Cristo Rey, and by Lovejoy and others (1980) in the Sierra de Juárez. This Lower Cretaceous section thickens to over 12,000 ft in the Pemex No. 1 Sapallo, after which the Sapallo basin is named.

The southern limit of the Sarten appears to trend northwest-southeast across the northern part of the map area (Fig. 3). At the type section in the Cooke's Range, the Sarten is about 300 ft thick and consists mostly of sandstone (Jicha, 1954, p. 26). It is late Albian to early Cenomanian in age (S.C. Hook, personal communication, 1982). The Sarten has been recognized also in the southern part of the San Andres Mountains (Kottlowski and others, 1956, p. 62-66; Seager, 1981, p. 33) and in the lower part of the Beartooth (unrestricted) in the Silver City area (Pratt, 1967, p. 42-44; S.C. Hook, personal communication, 1982).

The southern limit of the Sarten may represent onlap on the northern side of an earlier Mesozoic highland trending west-northwest to east-southeast through the Deming area. Alternatively, the Sarten may be a northern extension of the upper Mojado; they are similar in lithofacies and both contain the diagnostic foraminifer *Haplostiche texana* (Zeller, 1965, p. 68, and S.C. Hook, personal communication, 1982). As such, the Sarten would represent the last unit in a northward onlapping Lower Cretaceous succession of Hell-to-Finish, U-Bar, and lower Mojado. The northern limit of the Sarten lies around the northern boundary of the map area (Fig. 3). Its absence in the Deming area would then be explained as a result of subsequent erosion.

Recognition of Sarten in the Grimm well extends its previous usage to the south and lends support to the alternative interpretation of an upper Mojado extension. If later evidence confirms this relationship, the southern limit of the Sarten would not be a depositional limit but only an arbitrary cutoff between Sarten and Mojado (Bisbee Group).

The southern limit of undifferentiated Upper Cretaceous also tends generally northwest-southeast across the northern part of the map area (Fig. 3). Included are deltaic-marine, sandstone-mudstone units called Beartooth (restricted) - Colorado (Pratt, 1967, p. 42-44) or Dakota-Mancos (Kottlowski and others, 1956, p. 66-68; Seager, 1981, p. 33-34); they are equivalent to the Woodbine- Eagle Ford of Texas (Hayes, 1970, Fig. 5). The upper part of the Colorado contains nonmarine sandstones and mudstones which probably are equivalent to the Mesaverde. The unconformity between the Sarten and Beartooth (or Dakota) occurs within the Cenomanian; other unconformities are documented within the Turonian part of the Colorado (Hook and Cobban, 1981; and S.C. Hook, personal communication, 1982). Together, the Sarten and the Upper Cretaceous units are less than 2,000 ft thick in the northern part of the map area.

The Upper Cretaceous limit curves southward as a result of absence in the Grimm well and presence in the Cerro de Cristo Rey and Sierra de Juárez. In those two surface sections, the Upper Cretaceous is called Boquillas Formation and consists of 360 ft of dark mudstones and thin limestones; it is Cenomanian to probably Turonian in age (Lovejoy, 1976, p. 20; Lovejoy and others, 1980, p. 27).

These Upper Cretaceous rocks are absent over a large area covering southwestern New Mexico, southeastern Arizona, and northern Mexico (Hayes, 1970, Fig. 5). The southern limit shown on Figure 3 may represent a depositional boundary with southwestward onlap onto a low-relief land area. Alternatively, this limit may represent an erosional boundary with the onlap boundary lying originally an unknown distance to the southwest; however, it is likely that such a distance was less than 100 mi, because at least one remnant section should have been preserved if the distance had been greater.

In any case, between the time of U-Bar deposition (Aptian-early Albian) and that of the upper Cretaceous units (late Cenomanian-Turonian), positions reversed from land on the north and sea on the south to land on the southwest and sea on the northeast. The uplift of the southwestern area probably was associated with the northeastward migration of the Cordilleran magmatic arc (Damon and others, 1981). During continued migration in Laramide time, the sea finally withdrew from the region.

Laramide uplift and erosion stripped Mesozoic and older rocks from much of the Burro and other uplifts shown on Figure 3. The remainder was eroded in Cenozoic time. Upon the Laramide unconformity, conglomerates and redbeds were deposited, followed by andesitic volcanic rocks. The Ringbone-Hidalgo succession in Hidalgo-Grant Counties is uppermost Cretaceous (Campanian-Maestrictian) in age (Hayes, 1970, Fig. 5; Marvin and others, 1978, Table 1, sample A); the Lobo-Rubio Peak and Love Ranch-Palm Park successions in Luna-Doña Counties are lower Tertiary (Paleocene-Eocene) in age (this paper, Grimm well; Seager and others, 1975, Table 1; and R.E. Clemons, personal communication, 1982). These relationships of decreasing age to the northeast also reflect the migration of the Cordilleran magmatic arc in Laramide time (Damon and others. 1981).

CONCLUSIONS AND RECOMMENDATIONS

Paleozoic and Mesozoic strata of southwestern New Mexico and adjoining areas contain several petroleum source and reservoir units. In Hidalgo-Grant Counties, the source units appear to have generated abundant gas and moderate amounts of oil (Thompson, 1981). The best reservoir objective in that area is the upper Horquilla (Pennsylvanian-Permian), which contains thick porous dolostones at the margin of the Alamo Hueco basin, a deepmarine basin lying within the Pedregosa basin (Thompson and Jacka, 1981). Documentation of source and reservoir units is continuing in that area and adjacent parts of southwestern New Mexico. Projection of these objectives into subsurface prospects is directly dependent upon the accuracy of the stratigraphic-sedimentologic framework.

Documentation of lithostratigraphic and biostratigraphic boundaries in the Paleozoic and Mesozoic has progressed well, but some surface sections and many subsurface sections need additional control before detailed isopach-facies maps of individual units can be made with a high level of confidence. Continuing studies of biostratigraphy, paleoecology, and microfacies by D.V. LeMone and his students, at the University of Texas at El Paso, are adding much of the needed control.

In the Paleozoic, the Cambrian-Ordovician-Silurian units were deposited over a broad shelf, so their regional facies problems are minimal. Some changes are evident in the Devonian, but the Mississippian shows major differentiation into shelf, margin, and basin facies which need accurate delineation. Similar major facies changes are evident in the upper Pennsylvanian-lower Permian; their regional delineation has important economic significance regarding projection of the porous dolostones in the margin facies. Additional documentation of the deep-marine deposits in the Pedregosa and Orogrande basins is needed; the southern terminations of these basins may form a rift-rift-rift triple-junction relationship with the Marfa basin, similar to that shown by Elam (1982) for the Marfa-Delaware-Val Verde basins in western Texas.

In the Mesozoic, the recently discovered Jurassic unit in the Grimm well prompts re-examination of other sections in the region which contain the Paleozoic-Mesozoic boundary to see if equivalent units are present elsewhere. The concept that the Jurassic is confined to deep-marine deposits in the Chihuahua trough should be examined critically. The Lower Cretaceous of the Little Hatchet Mountains (discussed by Zeller, 1970) needs to be measured and described in detail, but the problem is complicated by multiple thrusting. Northward onlap of the Bisbee Group should be documented with seismic sections. Especially important is the relationship between the upper Mojado and Sarten; were they separated by a barrier, or were they a continuous part of the northward onlap? Analyses of depositional environments and paleocurrents may help resolve this question. Similar studies may document the southwestward onlap of the Upper Cretaceous. Results of these studies will be useful to exploration by delineating unconformity traps along the onlapping edges of these sandstones. Stratigraphic-sedimentologic

Gillerman, Elliot, 1958, Geology of the central Peloncillo Mountains, Hidalgo County, New Mexico, and Cochise County, Arizona: New Mexico Bureau of Mines and Mineral Resources, Bull. 57, 152 p.

Gillerman, Elliot, 1964, Mineral deposits of western Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 83, 213 p.

Greenwood, Eugene, Kottlowski, F.E., and Thompson, Sam III, 1977, Petroleum potential and stratigraphy of Pedregosa Basin: comparison with Permian and Orogrande Basins: American Association of Petroleum Geologists, Bull., v. 61, no. 9, p.1448-1469.

Harbour, R.L., 1972, Geology of the northern Franklin Mountains, Texas and New Mexico: U.S. Geological Survey, Bull. 1298, 129 p.

Hayes, P.T., 1970, Cretaceous paleogeography of southeastern Arizona and adjacent areas: U.S. Geological Survey, Prof. Paper 658-B, 42 p.

Hewitt, C.H., 1959, Geology and mineral deposits of the northern Big Burro Mountains-Redrock area, Grant County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 60, 151 p.

Hook, S.C., and Cobban, W.A., 1981, Late Greenhorn (mid-Cretaceous) discontinuity surfaces, southwest New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 180, p. 5-21.

Jicha, H.L., Jr., 1954, Geology and mineral deposits of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 37, 93 p.

Kelley, V.C., and Silver, Caswell, 1952, Geology of the Caballo Mountains: Univ. of New Mexico, Publications in Geology, no. 4, 286 p.

King, W.E., and Kelley, R.E., 1980, Geology and paleontology of Tortugas Mountain, Doña County, New Mexico: New Mexico Geology, v. 2, no. 3, p. 33-35.

Kottlowski, F.E., 1960a, Summary of Pennsylvanian sections in southwestern New Mexico and southeastern Arizona: New Mexico Bureau of Mines and Mineral Resources, Bull. 66, 187 p.

Kottlowski, F.E., 1960b, Reconnaissance geologic map of Las Cruces thirty-minute quadrangle: New Mexico Bureau of Mines and Mineral Resources, Geol. Map 14, scale 1:126,720.

Kottlowski, F.E., 1963, Paleozoic and Mesozoic strata of southwestern and south-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 79, 100 p.

Kottlowski, F.E., 1973, Pre-Pliocene rocks in La Mesa region, southern Doña Ana County, New Mexico: El Paso Geological Society, Guidebook 7th annual field trip, p. 37-46.

Kottlowski, F.E., Flower, R.H., Thompson, M.L., and Foster, R.W., 1956, Stratigraphic studies of the San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Mem. 1, 132 p.

Kottlowski, F.E., and Foster, R.W., 1962, Pre-Tertiary strata of Tres Hermanas Mountains, Luna County, New Mexico: American Association of Petroleum Geologists, Bull., v. 46, p. 2090-2098.

Kottlowski, F.E., Foster, R.W., and Wengerd, S.A., 1969, Key oil tests and stratigraphic sections in southwestern New Mexico: New Mexico Geological Society, Guidebook 20th field conference, p. 186-196.

Lovejoy, E.M.P., 1976, Geology of Cerro de Cristo Rey uplift, Chihuahua and New Mexico: New Mexico Bureau of Mines and Mineral Resources, Mem. 31, 84 p.

Lovejoy, E.M.P., Campuzano, Jorge, Nodeland, S.K., Swift, D.B. Uphoff, T.L., and Wacker, H.J., 1980, Sierra de Juárez, Chihuahua, Mexico, structure and stratigraphy: El Paso Geological Society, Guidebook, 59 p.

Marvin, R.F., Naeser, C.W., and Mehnert, H.W., 1978, Tabulation of radiometric ages for rocks in southeastern Arizona and southwestern New Mexico: New Mexico Geological Society, Guidebook 29th field conference, p. 243-252.

Navarro, G., Arsenio, and Tovar R., Jorge, 1975, Stratigraphy and tectonics of the State of Chihuahua, Mexico *in* Exploration from the mountains to the basin: El Paso Geological Society, p. 23-27.

Pearson, B.T., 1980, General survey of the oil and gas prospects of Trans-Pecos Texas: New Mexico Geological Society, Guidebook 31st field conference, p. 271-275.

Pearson, B.T., and Underwood, J.R., Jr., 1975, Oil and gas prospects of western Trans-Pecos Texas and northern Chihuahua: Society of Economic Paleontologists and Mineralogists, Permian Basin Section, Guidebook, Pub. no. 75-15, p. 148-154.

Pratt, W.P., 1967, Geology of the Hurley West quadrangle, Grant County, New Mexico: U.S. Geological Survey, Bull. 1241-E, 91 p.

Seager, W.R., 1973, Geologic map and sections of Bishop Cap-Organ Mountains area, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geol. Map 29, scale 1:24,000.

Seager, W.R., 1981, Geology of Organ Mountains and southern San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Mem. 36, 97 p.

Seager, W.R., Clemons, R.E., and Hawley, J.W., 1975, Geology of Sierra Alta Quadrangle, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 102, 56 p.

Seager, W.R., Hawley, J.W., and Clemons, R.E., 1971, Geology of San Diego Mountain area, Doña Ana County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 97, 38 p.

Soule, J.M., 1972, Structural geology of northern part of Animas Mountains, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 125, 15 p.

Thompson, Sam III, 1976, Tectonic and igneous effects on petroleum accumulations in southwestern New Mexico: New Mexico Geological Society, Spec. Pub. no. 6, p. 122-126.

Thompson, Sam III, 1980, Pedregosa Basin's main exploration target is Pennsylvanian dolostone: Oil and Gas Journal, v. 78, no. 42, p. 202, 207, 210, 215.

Thompson, Sam III, 1981, Petroleum source rocks in exploration wells drilled to Paleozoic or Mesozoic units, Hidalgo and Grant Counties, New Mexico: New Mexico Energy Research and Development Institute, report no. EMD 2-66-3306, 126 p.

Thompson, Sam III, Behnken, F.H., Budding, A.J., Broadhead, R.F., Cernock, P.J., Bayliss, G.S., Ewing, R.C., Elston, W.E., Erb, E.E., 1977, Geology, petroleum source rocks, and thermal metamorphism in KCM No. 1 Forest Federal well, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 152, 62 p.

Thompson, Sam III, and Bieberman, R.A., 1975, Oil and gas exploration wells in Doña Ana County, New Mexico: New Mexico Geological Society, Guidebook 26th field conference, p. 171-174.

Thompson, Sam III and Jacka, A.D., 1981, Pennsylvanian stratigraphy, petrography, and petroleum geology of Big Hatchet Peak section, Hidalgo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 176, 125 p.

Thompson, Sam III and Potter, P.E., 1981, Paleocurrents of Bliss Sandstone (Cambrian-Ordovician), southwestern New Mexico and western Texas: New Mexico Bureau of Mines and Mineral Resources, Annual Report 1979-1980, p. 36-51.

Thompson, Sam III, Tovar R., J.C., and Conley, J.N., 1978, Oil and gas exploration wells in the Pedregosa Basin: New Mexico Geological Society, Guidebook 29th field conference, p. 331-342.

Thorman, C.H., 1977, Geologic map of the Coyote Peak and Brockman quadrangles, Hidalgo and Grant Counties New Mexico: U.S. Geological Survey, Miscellaneous Field Studies Map MF-924, scale 1:24,000.

Thorman, C.H. and Drewes, Harald, 1981, Geologic map of the Gage SW quadrangle, Grant and Luna Counties, New Mexico: U.S. Geological Survey, Miscellaneous Investigations Series Map I-1231, scale 1:24,000.

Uphoff, T.L., 1978, Subsurface stratigraphy and structure of the Mesilla and Hueco Bolsons, El Paso region, Texas and New Mexico: M.S. Thesis, Univ. of Texas at El Paso, 66 p.

Woodward, L.A., 1980, A hard look at overthrust-belt prospects in southwest New Mexico: Oil and Gas Journal, v. 78, no. 16, p. 114-116.

Woodward, L.A. and DuChene, H.R., 1981, Overthrust belt of southwestern New Mexico: comparison with Wyoming-Utah overthrust belt: American Association of Petroleum Geologists Bull., v. 65, no. 4, p. 722-729.

Zeller, R.A., 1965, Stratigraphy of the Big Hatchet Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Mem. 16, 128 p.