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# OIL AND GAS EXPLORATION WELLS IN THE PEDREGOSA BASIN

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## INTRODUCTION

The area of interest for this paper covers about 110,70C km$^2$ (49,500 mi$^2$) in the Basin and Range province from Tuc. son, Arizona, to El Paso, Texas (fig. 1). Figure 2 shows 3E petroleum-exploration wells which have penetrated Paleozoic or Precambrian rocks or both in the Pedregosa basic, on the Burro and associated uplifts, and in the southwestern part of the Orogrande basin. Five additional wells which penetrated only Mesozoic rocks are shown in Mexico.

This region may be called the *Cuatro Fronteras,* as it in. cludes four major political boundaries—the international boundary between the United States and Mexico, and three boundaries between states, Arizona-New Mexico, New Mexico-Texas, and Sonora-Chihuahua. Any regional study of stratigraphic or structural geology, and especially an evaluation of petroleum potential, requires an exchange of surface and subsurface data across these boundaries. We are indebted to many workers in these areas for supplying us with essential information; only some of them are acknowledged specifically in this brief paper.

The inter-regional relationships of the Pedregosa, Orogrande and Permian basins during the Paleozoic are discussed by Greenwood and others (1977). For each major stratigraphic unit an isopach map was given, and the general source and reservoir quality in the frontier basins was compared to that of the correlative unit in the productive Permian basin of southeastern New Mexico and western Texas.

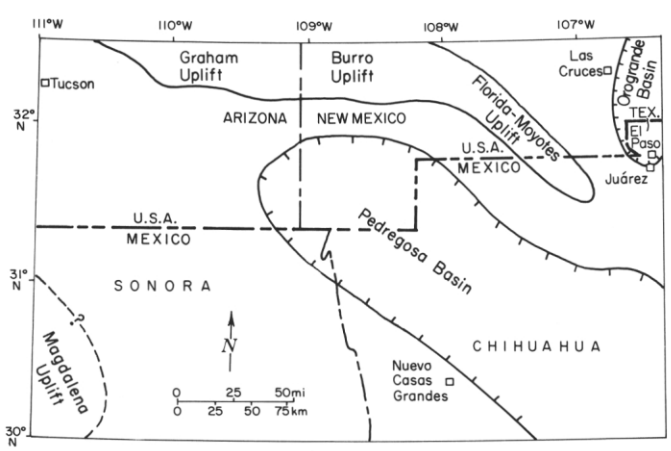


*Figure 1. Index map of Cuatro Fronteras region.*

Table 1 presents a generalized correlation of stratigraphic units in the Pedregosa basin and adjoining areas, an updated but still preliminary evaluation of the petroleum source and reservoir qualities, and the current ranking of exploration objectives. Most of the major objectives are in the Paleozoic, which is characterized by shallow-marine carbonate deposits. The best reservoirs observed so far are in the shelf-margin dolostones of the upper Horquilla (Hidalgo Co., N.M.), the shelf dolostones of the Fusselman (Luna Co., N.M.), the shelf dolostones and sandstones of the Martin and equivalents (Cochise Co., Ariz.), and the shelf dolostones of the El Paso, Concha and Epitaph (New Mexico and Chihuahua). The best source rocks documented so far are in the dark mudstones of the Percha, Paradise and upper Horquilla (basin facies).

Triassic rocks are found in the extreme western part of the Pedregosa area, and Jurassic rocks are found in the eastern part (Chihuahua trough), but both generally are absent over the central part. The Lower Cretaceous Bisbee Group is thick and widespread over most of the area, yet it is absent on the Burro and related uplifts and is not found to the north. Rudist-limestone buildups of the Mura1=U-Bar have the best reservoir potential in the Mesozoic of the Pedregosa area; however, good permeability has not been observed, and the relatively small size of the buildups make them difficult exploration targets. In some areas the Cintura=Mojado sandstones locally exhibit good permeability, but an effective seal and associated source facies are lacking. The Upper (to Lower?) Cretaceous Beartooth sandstones and the overlying Colorado shales have similar reservoir-to-source and seal relationships as the productive Dakota-Mancos units of the San Juan Basin; however, marine Upper Cretaceous rocks have not been found south of the Burro and related uplifts in this region.

Laramide and later tectonic and igneous events have had both positive and negative effects on possible accumulations of petrolum in the older rocks (Thompson, 1976). Thermal-alteration indices (based on kerogen and conodont studies) are in the overmature to metamorphosed range near plutonic intrusive complexes but are in the mature range (where oil may be preserved) a few thousand feet away (Thompson and others, 1977). However, these indications of higher paleotemperatures, and the measurements of high heat-flow at many localities by Reiter and others (1975), suggest that the potential for dry gas is better than that for oil in the Pedregosa basin. Basin and Range deformation was the most negative event, as extensional faulting disrupted regional traps and caused segments to be uplifted into horsts where flushing by fresh meteoric water is evident (Thompson and Bieberman,

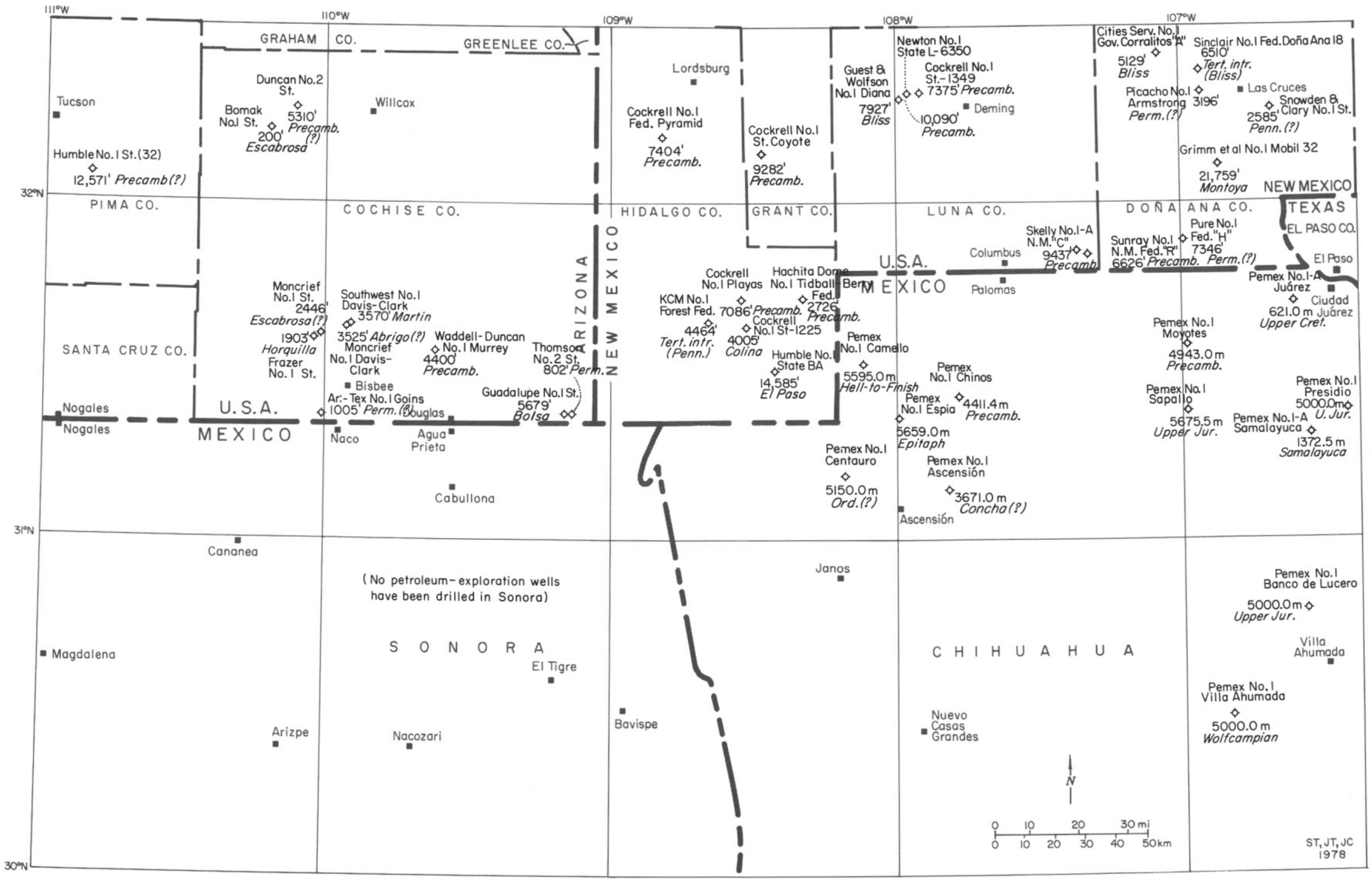


*Figure 2. Regional map of key petroleum-exploration wells drilled in southeastern Arizona, southwestern New Mexico and northwestern Chihuahua. (At each location, the name, total depth in feet or meters, and the stratigraphic unit at the bottom of the well are given.)*

*Table 1. Preliminary evaluation of petroleum potential for stratigraphic units in the Pedregosa basin and adjoining areas.*

| Chronostratigraphic Units | Lithostratigraphic Units: Pedregosa basin, Ariz.-Sonora | Pedregosa basin, New Mex.-Chih. | Burro and related uplifts | Orogrande basin (southern part) | Main Rock Type | General Depositional Environment | Source Quality | Reservoir Quality | Ranking of Exploration Objectives |
|---|---|---|---|---|---|---|---|---|---|
| Quaternary | bolson and other deposits | | | | sand | nonmarine | very poor | fair | |
| Quat.-Tertiary | Gila | | | Santa Fe | conglomerate | | | | |
| Tertiary to Cretaceous | volcanic (and intrusive) rocks | | | | igneous | | | poor | |
| | Ft. Crittenden | Ringbone | Lobo | Love Ranch | conglomerate | | | | |
| Upper to Lower(?) Cretaceous | (absent) | | Colorado | Mancos | dark mudstone | shallow mar. | good | very poor | |
| | | | Beartooth | Dakota | sandstone | shallow mar. to nonmarine | very poor | fair | 11 |
| | | | Sarten | | sandstone | | | | |
| Lower Cretaceous | Bisbee: Cintura | Mojado | (absent) (present in Chihuahua trough) | (absent) | sandstone | | | fair to good | 12 |
| | Mural | U-Bar | | | limestone | shallow mar. | fair | fair | 9 |
| | Morita | Hell-to-Finish | | | red mudstone | nonmarine | very poor | very poor | |
| | Glance | | | | conglomerate | | | | |
| Jurassic | intrusive rocks | (absent) | | (absent) | ign. — ls.,ss. | — shallow mar. | — fair | — fair | 10 (limest., sandst.) |
| Triassic | volcanic rocks | (absent) | | | igneous | nonmarine | very poor | very poor | |
| Permian: Guadalupian | (absent) | Santa Rita | (absent) | (absent) | sandstone | shallow marine | very poor | fair | |
| | Rainvalley | (absent) | | San Andres | limestone, dolostone | | fair (limest.) to poor | fair to good (dol.) | 5 (dolostone) |
| Permian: Leonardian | Concha | | | | | | | | |
| | Scherrer | | | Glorieta | sandstone | | very poor | poor | |
| | Epitaph | | | Yeso | dolostone | | poor | fair | 6 |
| | Colina | | | | limestone | | fair | very poor | |
| Permian: Wolfcampian | Earp ? | Earp | Abo-Hueco | | red mudst., ls. | non., shall. mar. | very poor, fair | poor, fair | 7 (limestone) |
| | Earp | Horquilla | (absent) | Magdalena: Bursum | limest., dolost., mudst. / limest. | shallow to deep marine / shallow marine | fair to good (deep marine mudst., limest.) | fair to good (shall. marine dolostone) | 1 (dolostone at shelf margin) |
| Pennsylvanian: Virgilian | | | | Panther Seep | / sandst. | | | | |
| Missourian | Horquilla | | | Bishops Cap | / limest. | | | | |
| Desmoinesian | | | | | | | | | |
| Atokan | | | | Berino | limestone, sandstone | shallow marine | fair | poor | |
| Morrowan | Black Prince | | | La Tuna | | | | | |
| Mississippian | Paradise | | | Helms | limest., mudst. | | fair to good | poor | |
| | Escabrosa | | Lake Valley — Rancheria | | limest., chert | | fair | poor | |
| Devonian | Percha | | | | dark mudstone | | fair to good | very poor | |
| | Martin | (absent) | | Canutillo | dolost. / dol., cht. | | poor | good (dol.) to poor | 3 (dolostone) |
| Silurian | (absent) | | Fusselman | | dolostone | | very poor | good | 2 |
| Ordovician | (absent) | Montoya | | | dolostone | | poor | fair to poor | 8 |
| | | El Paso | | | limest., dolo. | | fair, poor | poor, fair | 4 (dolostone) |
| Ord.-Cambrian | Coronado | Bliss | | | sandstone | shall. mar. to non. | very poor | poor | |
| Cambrian | Abrigo | (absent) | | | limest., dolo. | shallow marine | fair, poor | fair | 13 (dolostone) |
| | Bolsa | | | | sandstone | shall. mar. to non. | poor | poor | |
| Precambrian | basement rocks | | | | ign., metamorphic | — | — | — | |

1975). Therefore, the best potential for petroleum exploration lies in the deep grabens beneath the bolson (intermontane) valleys where preservation of oil and gas is more likely.

## EXPLORATION WELLS

In this section we examine the records of key wells drilled in search of crude oil and natural gas in the Pedregosa basin and adjoining areas. Although some encouraging shows have been encountered, no commercial production has been found to date.

Only brief summaries of the wells are given. Additional basic data are available in the references cited, and more detailed analyses are planned for future publications on selected wells.

Depths of wells drilled in the United States are recorded in feet, and those in Mexico are recorded in meters, relative to a surface-elevation datum (KB = kelly bushing, DF = derrick floor, GL = ground level). To allow direct reference to well data, and to avoid conversion errors, the depths are given in their respective original units.

### Southeastern Arizona

Over 40 petroleum-exploration wells have been drilled in the southeastern part of Arizona shown on Figure 2. The latest report and map containing the most accurate information on well names, locations, elevations and total depth, are presented by Conley and Stacey (1977). Previous reports which have important information on formation tops and results of drill-stem tests were prepared by Peirce and Scurlock (1972) and Scurlock (1973). A summary report on the oil and gas potential of southeastern Arizona, including geophysical maps and cross sections, is given by Aiken and Sumner (1974).

Table 2 lists 11 wells which have been drilled to Paleozoic (or Precambrian) rocks. (About 9 additional wells are reported to have reached Cretaceous rocks.) Formation tops are based on the best available data in the well files of the Arizona Oil and Gas Conservation Commission. Sources include reports by operators and consulting wellsite geologists (L. I. Buck, H. D. Hand and others), sample logs and descriptions by the American Stratigraphic Company, reports by the Paleontological Laboratory (R. V. Hollingsworth), and hydrocarbon logs and wire-line logs by several service companies. Tops reported by previous workers were checked and revised where necessary. Improvements could be made with a detailed subsurface study of the drill cuttings and logs, and with additional age determinations by micropaleontology and geochronometry.

In the Humble No. 1 State (32) stratigraphic test, a limestone with crinoids and fusulinids was described from 2816 to 2897 m (9,240 to 9,505 ft). This interval appears to encompass a block of Pennsylvanian or Permian rock that was emplaced structurally within a Miocene to Pliocene section dated by palynology. The quartz-monzonite basement was dated as Eocene (46 m.y.) by potassium-argon and Jurassic to Cretaceous (120 ± 60 m.y.) by rubidium-strontium geochronometric determinations. We tentatively assign it a Precambrian (?) age following the interpretation of Drewes (1977), who considered the younger ages to reflect the complex history of intrusion seen in the basement rocks of the nearby mountains. He shows the Tertiary-Precambrian basement contact as a low-angle fault surface. Eberly and Stanley (1978) discuss the Cenozoic geology of this well and others in southwestern Arizona.

Precambrian (?) basement was reported in the Duncan No. 2 State by Conley and Stacey (1977, p. 13). Most of the well appears to have been in Cenozoic rock, but the increasing gamma radiation and resistivity on the logs suggest the possibility of Precambrian at the bottom. This well lies along the southwestern margin of the Graham uplift, where Tertiary volcanic rocks are seen to rest unconformably on Precambrian.

The other wells confirm the presence of Paleozoic rocks in the subsurface of southern Cochise County. Several shows of oil and gas have been reported in sample descriptions, hydrocarbon logs, drill-stem tests and production tests.

In the Waddell-Duncan No. 1 Murrey, a section of Tertiary volcanic rocks (probably reworked at least in the upper part into the Gila Formation) is interpreted from the sample description by R. E. Geer. These rocks rest directly on lower Horquilla (Atokan). The contact may be an unconformity; alternatively, it may be a Basin-and-Range fault considering the location between a positive gravity anomaly to the east and a negative anomaly to the west.

None of the wells have tested the deeper parts of the intermontane valleys in Cochise County where thick sections of Paleozoic rocks should be encountered at depths below 3,000 m (10,000 ft). Future exploration should also evaluate the potential of the Lower Cretaceous objectives in favorable locations.

### Southwestern New Mexico

Over 50 petroleum-exploration wells have been drilled in the southwestern part of New Mexico shown on Figure 2. Basic data, cuttings, and logs are available at the New Mexico Bureau of Mines and Mineral Resources, New Mexico Library of Subsurface Data, supervised by R. A. Bieberman. Kottlowski and others (1969) listed the wells drilled to that date, and R. W. Foster discussed the deep ones in that reference. Some additional information on older wells may be found in Sandeen (1953) and Dixon and others (1954).

Table 3 lists 12 wells which have been drilled to Paleozoic rocks in Hidalgo, Grant and Luna counties. (Only 2 additional wells have reached Lower Cretaceous rocks.) Some additional older wells were reported, apparently erroneously, to have encountered Paleozoic rocks. The 6 wells in Dona Ana County were discussed by Thompson and Bieberman (1975). In preparation of the table, a procedure was followed similar to that used in the Arizona study. W. C. Miley kindly released data and logs on the tight holes drilled by the Cockrell Corporation, and R. W. Foster and E. Greenwood provided notes on the formation tops. Lithologic descriptions and plotted strip logs for several wells are available from the Permian Basin Sample Laboratory. Formation tops on the Hachita dome and Humble wells were taken from Zeller (1965, p. 116-120), and those on the KCM well were taken from Thompson and others (1977). Tops on the other wells in the table were checked and revised where necessary based on a preliminary study of drill cuttings mounted on strip logs in the Bureau files. A detailed study of the wells in southwestern New Mexico is in progress.

Several subsurface sections of Paleozoic rocks have been intruded by Tertiary igneous rocks (designated Ti in Table 3). The only date available is 30 m.y. for the intrusion at the bottom of the KCM well. These rocks generally are light colored, quartz monzonites or granodiorites that are highly radioactive according to the gamma-ray curves. The most extreme metamorphism observed was in the KCM well, but even in that case the extent was limited to a few thousand feet.

*Table 2. Exploration wells drilled to Paleozoic (or Precambrian) rocks in southeastern Arizona (Pima and Cochise counties).*

| Location | Name | Completion Date | Elev. | Formation Tops (Ti = Tertiary intrusive rock) | Total Depth | Oil, Gas Shows |
|---|---|---|---|---|---|---|
| PIMA COUNTY: | | | | | | |
| Sec. 5,T16S,R15E 2210'FSL, 2210'FWL | Humble No. 1 St.(32) (strat.) | 12-18-72 | 2886' KB | Surf.-Quat., 1143'-Tert. sed. rock (incl. evaporites), 6168'-Tert. vol. and sed. rock, 11,987'-fault-Precamb.(?) (Ti) | 12,571' Precamb.(?) | None rept. |
| COCHISE COUNTY: | | | | | | |
| Sec. 33,T13S,R22E 1920'FSL, 960'FEL | Duncan No. 2(1-X) St. | 12-20-60 | 4965' DF | Surf.-Quat., 520'(?)-Tert. sed. rock, 2160'-Tert.(?) vol. and sed. rock, 5220'-Precamb.(?) | 5310' Precamb.(?) | None rept. |
| Sec. 22,T14S,R21E 1865'FNL, 2262'FWL | Bomak No. 1 St. | 10-15-60 | 4765' GL | Surf.-Escabrosa | 200' Escabrosa | None rept. |
| Sec. 17,T21S,R23E 770'FSL, 550'FEL | Moncrief No. 1 St. | 2-7-63 | 4755' GL | Surf.-Colina, 592'-Earp, 1216'-Horquilla, 2440'-Escabrosa(?) | 2446' Escabrosa(?) | Gas: 1600'-1640' 1840'-1884' |
| Sec. 19,T21S,R23E 2010'FSL, 1120'FEL | Fraser No. 1 St | 10-30-68 | 4479' KB | Surf.-Quat., 50'-Colina, 410' Earp, 1230'-Horquilla | 1903' Horquilla | Gas, Oil: 1409'-1449' |
| Sec. 5,T21S,R24E 2710'FNL, 2310'FEL | Moncrief No. 1 Davis-Clark | 2-7-63 | 4594' KB | Surf.-Quat., above 300'-Morita, 1135'-Horquilla(?), 2480'-Escabrosa, 3026'-Martin, 3335'-Abrigo(?) | 3525' Abrigo(?) | Oil: 1950'-1970' |
| Sec. 5,T21S,R24E 884'FNL, 660'FEL | Southwest No. I Davis-Clark | 10-17-67 | 4595' GL | Surf.-Quat., 200'-Morita, 1150'-Earp, 1575'-Horquilla, 2670'-Escabrosa, 3290'-Martin | 3570' Martin | Oil: 2570'-2590' |
| Sec. 5,T22S,R27E 1980'FNL, 1980'FWL | Waddell-Duncan No. 1 Murrey | 5-16-52 | 4238' KB | Surf.-Quat., 515'-Gila, Tert. vol. rocks, 1755'-fault(?)-lower Horquilla (Atoka), 2245'-Paradise(?), 2305'-Escabrosa (Ti), 2570'-Martin (Ti), 2885'-Abrigo, 3525'-Bolsa, 3995'-Precamb. | 4400' Precamb. | Oil: 1950'-1960', 2980'-2990' 3345'-3350' |
| Sec. 4,T24S,R23E NW¼NW¼ | Ari-Tex No. 1 Goins | 5- -45 | 4480' GL | Surf.-Quat., above 1005'-Permian(?) | 1005' Perm.(?) | None rept. |
| Sec. 2,T24S,R31E 630'FNL, 530'FEL | Thomson No. 2 St. | 12-28-61 | 4186' KB | Surf.-Quat., above 458'-Permian(?) (Epitaph-Colina?) | 802' Perm. | Gas: 458' |
| Sec. 2,T24S,R31E 2200'FSL, 2500'FWL | Guadalupe No. 1 St. | 12-26-71 | 4363' KB | Surf.-Colina, 100'-Earp, 1296' (no spls.)-Horquilla, 2760'-Paradise(?), 2840'-Escabrosa, 4260'-Dev. (Pedregosa), 4555'-Montoya(?), 4712'-Abrigo, 5545'-Bolsa | 5679' Bolsa | None |

*Table 3. Exploration wells drilled to Paleozoic rocks in southwestern New Mexico (Hidalgo, Grant and Luna counties).*

| Location | Name | Completion Date | Elev. | Formation Tops (Ti = Tertiary intrusive rock) | Total Depth | Oil, Gas Shows |
|---|---|---|---|---|---|---|
| HIDALGO COUNTY: | | | | | | |
| Sec. 31,T24S,R19W 1980'FNL, 660'FEL | Cockrell No. 1 Fed. Pyramid | 9-30-69 | 4244' KB | Surf.-Quat., 385'-Gila(?), 1890'-Tert. vol. rock (Ti), 5795'-Escabrosa(Ti), 6680'-Percha (Ti), 6860'-Montoya (Ti), 6980'-El Paso (Ti), 7130'-Bliss (Ti), 7340'-Precamb. | 7404' Precamb. | None |
| Sec. 12,T30S,R15W 1655'FSL, 2012'FWL | Hachita Dome No. 1 Tidball-Berry Fed. | 5-23-57 | 4349' DF | Surf.-Quat., 21'-Escabrosa, 800'-Percha (Ti), 1395'-Montoya, 1653'-El Paso, 2590'-Bliss, 2723'-Precamb. | 2726' Precamb. | Gas: 1500', 2310', 2430, Oil: 2590' |
| Sec. 14,T30S,R17W 660'FNL, 1980'FEL | Cockrell No. 1 Playas | 6-11-70 | 4455' KB | Surf.-Quat., 100'-Gila, 2480'-Horquilla (Wolfcampian), 2820'-Penn., 3700'-Paradise, 4120'-Escabrosa, 5200'-Percha, 5570'-Montoya, 5890'-El Paso, 6900'-Bliss, 7030'-Precamb.(?) | 7086' Precamb.(?) | Dead Oil: 5780' |
| Sec. 12, T31S,R17W 1980'FNL, 660'FEL | Cockrell No. 1 State-1225 | 11-24-70 | 4480' KB | Surf.-Quat., 150'-Gila, 2465'-Tert. vol. (and sed.?) rock, 2595'-Epitaph, 3770'-Colina | 4005' Colina | None rept. |
| Sec. 3,T31S,R18W 1494'FNL, 1753'FEL | KCM Co. No. 1 Forest Fed. | 1-22-75 | 5156' KB | Surf.-Earp (Ti), 255'-Horquilla (Wolfcampian), 1526'-Penn. (Ti), 2225' metamorphosed Penn. (Ti) | 4464' Ti (Penn.) | None |
| Sec. 25,T32S,R16W 990'FNL, 1980'FEL | Humble No. 1 State "BA" | 12-24-58 | 4587' KB | Surf.-Quat., 230'-U-Bar, 648'-Hell-to-Finish, 995'-Concha, 1522'-Scherrer, 1532'-Epitaph (repeated by reverse fault), 4450'-Colina, 5258'-Earp, 6265'-Horquilla (Wolfcampian), 8755'-Penn., 10,995'-Paradise, 11,425'-Escabrosa, 12,500'-Percha, 12,830'-Montoya, 13,214'-El Paso | 14,585' El Paso | Gas: 4190'-4219' |
| GRANT COUNTY: | | | | | | |
| Sec. 14,T25S,R16W 700'FSL, 700'FWL | Cockrell No. 1 State Coyote | 8-24-69 | 4354' KB | Surf.-Quat., above 360'-Tert. (or Cret.) vol., 1790'-Mojado (Ti), 6400'-U-Bar (Ti), 7100'-Hell-to-Finish, 7240'-Montoya, 7720'-El Paso, 8360'-Bliss, 8580'-Precamb.. | 9282' Precamb. | Oil: 4140' |
| LUNA COUNTY: | | | | | | |
| Sec. 7,T23S,R10W 1500'FNL, 700'FWL | Cockrell No. 1 State-1349 | 11-6-69 | 4534' KB | Surf.-Quat., 230'-Tert. vol. and sed. rocks, 1300'-Lobo, 6550'-El Paso, 7095'-Bliss, 7240'-Precamb. | 7375' Precamb. | None |
| Sec. 10,T23S,R11W 660'FSL, 330'FWL | Newton No. 1 State L-6350 | 10-22-74 | 4556' KB | Surf.-Quat., 200'(?)-Tert.(?), above 2000'-Lobo, 6530'-Montoya, 7160'-El Paso, 7630'-Bliss, 7775'-Precamb. | 10,090' Precamb. | Oil: 6670'-6720' 7612:-7632' |
| Sec. 16,T23S,R11W 1980'FNL, 1980'FWL | Guest & Wolfson No. 1 Diana | 3-21-73 | 4548' KB | Surf.-Quat., 90'-Tert. vol. and sed. rocks, 2740'-Lobo, 6705'-El Paso, 7835'-Bliss | 7927' Bliss | None rept. |
| Sec. 19,T28S,R5W 560'FSL, 1980'FEL | Skelly No. 1-A N.M. "C" | 1-13-64 | 4029' KB | Surf.-Quat., 140'-Gila, 5130' Tert. (to Cret.) vol. rocks, 8390'-Fusselman, 8430'-Montoya, 8800'-fault-Precamb. | 9437' Precamb. | None rept. |
| Sec. 27,T28S,R5W 1980'FNL, 1980'FWL | Sunray-Mid-Cont. No. 1 NM Fed. "R" | 3-24-62 | 4097' KB | Surf.-Quat., 500'-Tert. vol. rock, 2990'-Fusselman (Ti), 4015'-Montoya, 4355'-Simpson(?), 4870'-El Paso (Ti), 6395'-Bliss, 6570'-Precamb. | 6626' Precamb. | Gas: 5582'-5619' |

No dates are available for the Precambrian rocks encountered in the subsurface; however, in nearly every case these rocks are overlain by recognizable Cambrian-Ordovician units. In the Skelly No. 1-A New Mexico "C," a fault contact is interpreted between the Precambrian and overlying Montoya. A dark mudstone, sandstone and limestone section in the Sunray No. 1 N.M. Federal "R" that lies between Montoya and El Paso at a total depth of 4,446 m (14,585 ft) in the Humble No. 1 State "BA," as there is some doubt about the lower reverse fault suggested by Thompson in Zeller (1965 , p. 116); however, the upper reverse fault repeating much of the Epitaph can be demonstrated with several stratigraphic markers.

Deeper and more complete sections of Paleozoic rocks have been found in the exploratory wells of southwestern New Mexico in contrast to those of southeastern Arizona. But here also the prospective Paleozoic and Lower Cretaceous units in the deeper parts of the bolson valleys remain untested. The several shows of oil and gas lend encouragement for further exploration.

### Northwestern Chihuahua

In the northwestern part of Chihuahua shown on Figure 2, 12 wells have been drilled by PetrOleos Mexicanos (Pemex). Wells drilled in northeastern Chihuahua and Trans-Pecos Texas are listed by Pearson and Underwood (1975). The significance of several Pemex wells in relationship to the stratigraphic-tectonic framework of the Chihuahua trough was discussed by Navarro and Tovar (1975). No petroleum-exploration wells have been drilled in Sonora.

Table 4 lists all 12 wells, 7 of which penetrated Paleozoic rocks. We are very grateful to PetrOleos Mexicanos for releasing this information for publication. The formation tops are the most accurate ones in this paper because the Pemex geologists have made detailed studies of the cuttings, cores and logs, and have had stratigraphic, paleontologic, and geochronometric determinations made by experts.

Of the 5 wells drilled in the AscensiOn area, only the No. 1 Chinos reached Precambrian basement. The granite gneiss was dated by the rubidium-strontium method as 1327 ± 242 m.y. old. A complete succession of Paleozoic formations from Bliss to Concha was encountered in this well, including a dolostone and chert unit correlated with the Devonian Canutillo. The Santa Rita Formation (Tovar, 1969) has not been found in the subsurface.

Lower Cretaceous rocks were found overlying the Paleozoic in the No. 1 Espia and the No. 1 AscensiOn. In the former well, andesite-basal rocks, dated generally 25 to 31 m.y. old by the potassium-argon method, are interpreted as shallow Tertiary intrusives within the Lower Cretaceous section. In the No. 1 Ascension, no intrusive rocks were found, but the Paleozoic (Concha?) and much of the Lower Cretaceous section was metamorphosed, probably by Tertiary igneous activity. Probable Tertiary igneous rocks were found in the No. 1 Camello intruding the Hell-to-Finish Formation below a reverse fault repeating the Lower Cretaceous section. Some Tertiary volcanic rocks are present in the Cenozoic bolson fill.

Of the 7 wells drilled in the Ciudad Juarez-Villa Ahumada area, only the No. 1 Moyotes reached Precambrian basement. The granite gneiss was dated by the rubidium-strontium method as 890 ± 32 m.y. old. The entire pre-Permian Paleozoic section is absent by erosion at the unconformity of Abo (Wolfcampian) on Precambrian. Based on this evidence, a Wolfcam plan or older uplift is indicated at least in the Moyotes area, and may extend northwestward to the Florida uplift where Hueco rests unconformably on Mississippian. Hueco limestone (with Wolfcampian fusulinids) overlies the Abo clastic section in the No. 1 Moyotes, similar to the intertongued succession in the Robledo Mountains. At the top of the Permian in this well is a unit with some evaporites that may be correlative with the Yeso Formation of the San Andres Mountains.

The thick section of fine-grained clastic rocks in the Permian of No. 1 Villa Ahumada suggests the presence of a deep-marine basin in the Pedregosa area south of the Florida-Moyotes uplifts. Conglomerates, quartzites and phyllites of possible Paleozoic age comprise the Samalayuca Formation (recognized only in the type area), which is seen to underlie Upper Jurassic (La Casita Formation) on the surface.

Thick Upper Jurassic-Lower Cretaceous sections of limestone, evaporites, mudstone and sandstone were found in several wells that confirm the indications of relatively rapid subsidence in the Chihuahua trough. The No. 1-A Juarez encountered an Upper Cretaceous section of sandstone and mudstone beneath a reverse fault with the overlying Lower Cretaceous.

A show of gas in the Epitaph was found in the No. 1 Espia and may be an equivalent of the gas zone in the Humble No. 1 State "BA"; however, the show could not be tested because of mechanical difficulties. Other indications of petroleum on electric logs and in samples are being evaluated as part of a regional study to be completed before additional drilling is considered in Chihuahua. Many of the Pemex wells were drilled on the uplifts to minimize the depths to Paleozoic and Mesozoic objectives. The few wells drilled in the bolson valleys have reached only Mesozoic and Upper Paleozoic rocks. Thus the Middle and Lower Paleozoic objectives lying at great depths would be some of the best targets for future exploration.

## PENNSYLVANIAN ROCKS

Exploration for oil and gas in the Paleozoic rocks of this region generally has been concentrated in the Pedregosa basin. Kottlowski (1960, p. 152) defined the Pedregosa as a basin of subsidence in which a thick sequence of Pennsylvanian rocks was deposited. Greenwood and others (1977, p. 1449) suggested that the limit be drawn where Pennsylvanian rocks are 600 m (2000 ft) or more thick.

Zeller (1965, p. 42) defined the Alamo Hueco basin as a deep-marine basin of Upper Pennsylvanian-Lower Permian (Upper Desmoinesian-Lower Wolfcampian) rocks bounded by reefs at the shelf margin. The Alamo Hueco basin lying within the Pedregosa basin is analogous to the deep-marine Delaware basin lying within the regional Permian basin of southeastern New Mexico and western Texas. The margin of the Alamo Hueco basin is ranked as the top exploration objective because the thick units of porous dolostone observed along the margin are in close proximity to the organically rich, deep-marine limestones and mudstones of the basin facies in which source rocks of petroleum are indicated (P. J. Cernock and others, current study).

Figure 3 is a regional isopach map showing the present thickness of Pennsylvanian rocks and the margin of the Alamo Hueco basin as determined with available control. The thicknesses are given in feet to minimize the number of conversions. At this scale, local erosion is not shown in mountain ranges

*Table 4. Exploration wells in northwestern Chihuahua.*

| Location | Name: | Completion Date | Elev. | Formation Tops | Total Depth | Oil, Gas Shows |
|---|---|---|---|---|---|---|
| 47.5 km NNW of Ascensión | Pemex No. 1 Camello | 8-27-73 | 1246.8 mKB | Surf.-Quat., Tert., 2113.0 m-U-Bar, 2795.0 m-Hell-to-Finish, 3180.0 m-reverse fault-U-Bar, 4295.0 m-Hell-to-Finish | 5595.0 m Hell-to-Finish | None |
| 32 km N of Ascensión | Pemex No. 1 Espia | 5-24-72 | 1269.3 mKB | Surf.-Quat., Tert., 1950.0 m-Lower Cret., 5068.0 m-Concha, 5405.0 m-Scherrer, 5425.0 m-Epitaph | 5659.0 m Epitaph | Gas: 5650.0 m |
| 43.5 km NE of Ascensión | Pemex No. 1 Chinos | 1-19-71 | 1309.7 m KB | Surf.-Concha, 82.0 m-Scherrer, 86.0 m-Epitaph, 396.0 m-Colina, 842.0 m-Earp, 1034.0 m-Horquilla, 1170.0 m-Penn., 1925.0 m-Paradise, 2134.0 m-Escabrosa, 2671.0 m-Percha, 2853.0 m-Canutillo, 3425.0 m-Montoya, 4150.0 m-El Paso, 4349.0 m-Bliss, 4381.0 m-Precamb. | 4411.4 m Precamb. | None |
| 20.5 km NW of Ascensión | Pemex No. 1 Centauro | 2-12-78 | 1353.6 mKB | Surf.-Quat., Tert., 460.0 m-Perm., 3750.0 m-Penn., 4190.0 m-Miss., 4710.0 m-Dev., 4833.0 m-Ord(?) | 5150.0 m Ord.(?) | None |
| 14 km NE of Ascensión | Pemex No. 1 Ascensión | 6-28-74 | 1325.6 mKB | Surf.-Quat., Tert., 165.0 m-Mojado, 370.0 m-U-Bar, 2545.0 m-metamorphosed U-Bar, 2825.0 m-metamorphosed Hell-to-Finish, 3418.0 m-metamorphosed Concha(?) | 3671.0 m Concha(?) | None |
| 12 km WSW of Cd. Juárez | Pemex No. 1-A Juárez | 5-23-70 | 1286.0 mKB | Surf.-Quat., Tert., 86.0 m-Lower Cret., 293.0 m-reverse fault-Upper Cret. | 621.0 m Upper Cret. | None |
| 49 km SW of Cd. Juárez | Pemex No. 1 Moyotes | 5-14-72 | 1240.8 mKB | Surf.-Quat., Tert., 685.0 m-Lower Cret., 2365.0 m-Upper Jur., 3395.0 m-Yeso, 3740.0 m-Hueco, 4754.0 m-Abo, 4810.0 m-Precamb. | 4943.0 m Precamb. | None |
| 60 km SW of Cd. Juárez | Pemex No. 1-A Sapallo | 1-27-77 | 1221.9 mKB | Surf.-Quat., Tert., 514.0 m-Lower Cret., 4200.0 m-Upper Jur. | 5675.5 m Upper Jur. | None |
| 5.4 km SW of Samalayuca | Pemex No. 1-A Samalayuca | 9-17-69 | 1365.0 mKB | Surf.-Samalayuca (Paleozoic ?) | 1372.5 m Samalayuca | None |
| 42 km S of Cd. Juárez | Pemex No. 1 Presidio | 6-8-72 | 1285.8 m KB | Surf.-Quat., Tert., 70.0 m-Lower Cret., 870.0 m-Upper Jur. | 5000.0 m Upper Jur.(?) | None |
| 20.5 km NNW of Villa Ahumada | Pemex No. 1 Banco de Lucero | 4-5-71 | 1200.0 mKB | Surf.-Quat., Tert., 2010.0 m-Lower Cret., 4675.0 m-Upper Jur. | 5000.0 m Upper Jur. | None |
| 33.7 km SW of Villa Ahumada | Pemex No. 1 Villa Ahumada | 5-24-69 | 1296.0 mKB | Surf.-Lower Cret., 2375.0 m-Upper Jur., 3085.0 m-Permian-Leonardian, 4200.0 m-Wolfcampian | 5000.0 m Wolfcampian | None |

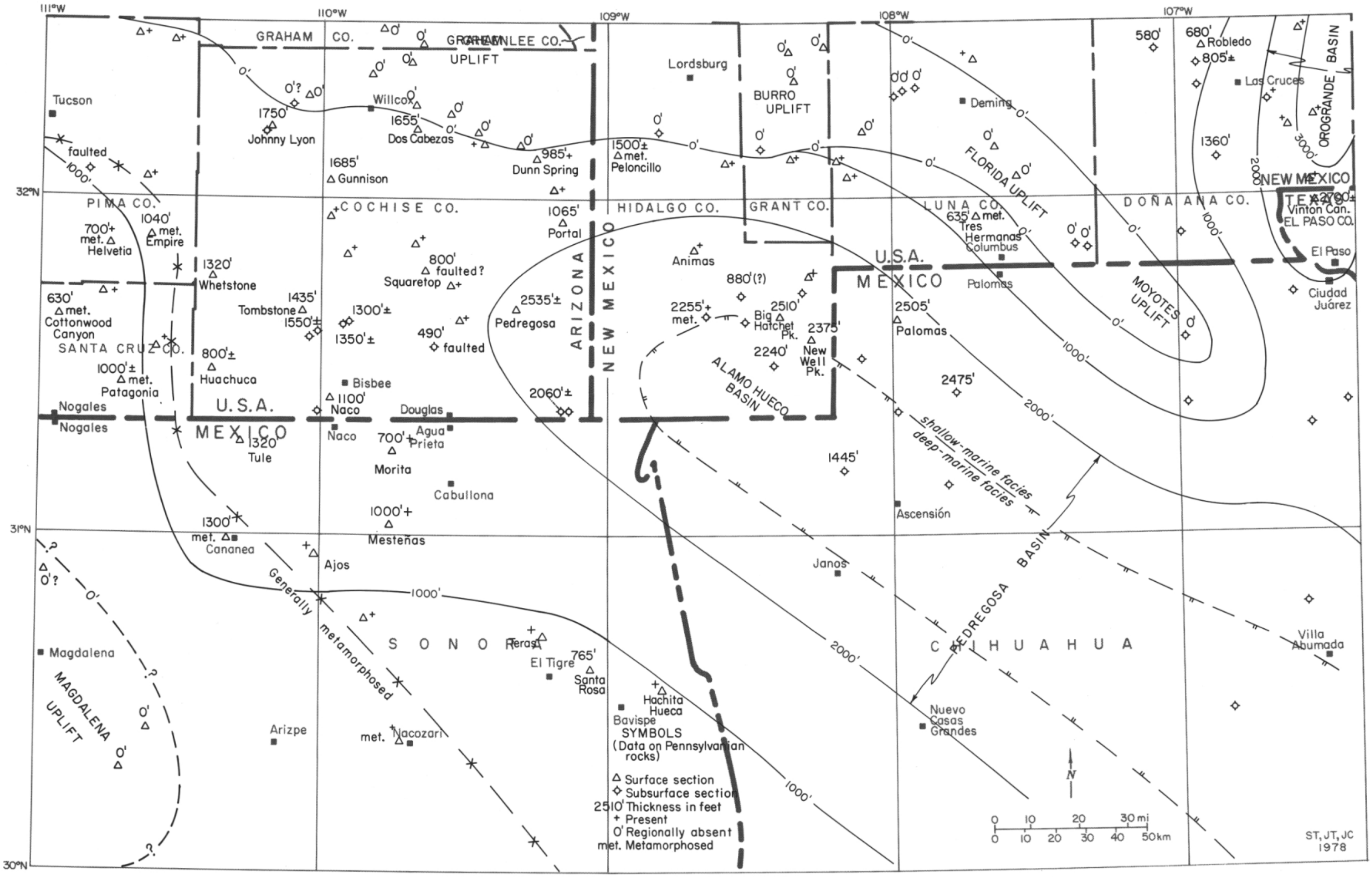


*Figure 3. Regional isopach and facies map of Pennsylvanian rocks in the Pedregosa basin and adjoining areas. Thicknesses of surface sections are taken from several sources discussed in text. Those of subsurface sections are taken from wells shown in Figure 2 and tabulated in this paper.*

where older rocks are exposed. Drilled thicknesses in wells have not been corrected for dips, but such errors appear to be minimal. Structural complications produced by Laramide thrusting, wrench faulting, and other diastrophic processes cause some local variations; however, no regional displacements of thickness or facies trends are evident across the basin and shelf area.

Pennsylvanian rocks generally are absent on the Graham-Burro-Florida-Moyotes uplifts to the north and northeast of the Pedregosa basin, and on the Magdalena uplift to the southwest. Pennsylvanian rocks probably once covered these uplifts, although some depositional thinning may have been produced by onlap and decreasing amounts of subsidence away from the basin axis. In late Pennsylvanian or early Permian time, uplift and erosion occurred along the northwesterly trend of the Florida-Moyotes axis, where Wolfcampian rocks now rest unconformably on pre-Pennsylvanian ones. Later episodes involved these and the other uplifts as Lower Cretaceous (Bisbee), Upper(?) Cretaceous (Beartooth), uppermost Cretaceous (Lobo) sedimentary rocks, and uppermost Cretaceous to Tertiary volcanic rocks rest on pre-Pennsylvanian rocks at various localities. Mesozoic to Cenozoic igneous intrusions have metamorphosed Pennsylvanian rocks locally within the basin area and more extensively to the southwest according to available reports.

## Southeastern Arizona

Total thicknesses of the Pennsylvanian sections in southeastern Arizona are determined by adding thicknesses of the Black Prince, Horquilla and the lower part of the Earp. Most of the thicknesses from surface sections in Cochise County were calculated from the excellent work of Ross (1973), who subdivided the Pennsylvanian-Lower Permian into 14 depositional units (formats) bounded by regional unconformities, dated the units with fusulinids and correlated them across the region in detailed measured sections (see Ross, this guidebook).

Abrupt changes in thickness near the shelf-basin margin are interpreted by Ross to be the result of Pennsylvanian-age faulting with thinning on horsts and thickening in grabens. Detailed mapping would be needed to locate such structures. Some thickness anomalies may be the result of subtle Laramide or later faults which locally disrupt many sequences exposed in the Basin and Range uplifts. For example, the anomalously thin 245 m (800 ft) given for the Squaretop Hills area may be the result of such younger faulting, which so complexly deformed the succession in the nearby Swisshelm Mountains (to the southeast).

As discussed previously, the 150 m (490 ft) in the Waddell-Duncan well is explained by an unconformable or fault contact of Tertiary volcanic rocks on lower Pennsylvanian (Atokan). Subsurface sections northwest of Bisbee have more normal thicknesses, but the Pennsylvanian-Permian boundary within the Earp is roughly estimated without fusulinid control.

In southwestern Cochise County, an approximate thickness of 250 m (800 ft) is based on the work of Hayes and Raup (1968) in the Huachuca Mountains. In eastern Santa Cruz and Pima counties, the approximate thicknesses of metamorphosed, surface sections are taken from Kottlowski (1960). In the Humble well, the absence of Pennsylvanian at the Tertiary-Precam brian(?) contact is attributed to faulting.

All of the Pennsylvanian sections in southeastern Arizona appear to be of shallow-marine deposits. The Guadalupe No. 1 State was drilled in a critical location and could have provided key facies control for the southwestern shelf of the Alamo Hueco basin. Unfortunately, this well was drilled with air and mist so the samples generally are of poor quality; moreover, no samples at all were recovered from 198 to 542 m (650 to 1780 ft) in the important Lower Permian-Upper Pennsylvanian section.

## Southwestern New Mexico

Total thicknesses of Pennsylvanian sections in the Pedregosa area of southwestern New Mexico are determined within the Horquilla. Following the lithostratigraphic succession defined by Zeller (1965) in the Big Hatchet Mountains, the Horquilla in this area includes equivalents of the Black Prince in the lower part and of the lower Earp (as defined in Arizona) in the upper part. Depositional units, probably equivalent to those of Ross (1973), are recognized within the Horquilla. The Virgilian-Wolfcampian contact occurs at the unconformable boundary of such units, but age determinations with fusulinids are needed to designate the contact with confidence.

Thicknesses of surface sections are from New Well Peak (Zeller, 1965), Big Hatchet Peak (Thompson, current study), Peloncillo Mountains (Armstrong and others, 1978, in press), and the Tres Hermanas Mountains (Kottlowski, 1960). The margin of the deep-marine Alamo Hueco basin is defined by surface control in the Big Hatchet Mountains and by subsurface control in the Humble No. 1 State "BA," KCM No. 1 Forest Federal, and the Cockrell No. 1 Playas (Zeller, 1965; M. A. Schiipbach and C. F. Jordan with Wilson, 1975, p. 179-185; Thompson and others, 1977; and current studies by Thompson and A. D. Jacka).

Northeast of the Florida-Moyotes uplifts, in the Orogrande basin area, total thicknesses of the Pennsylvanian are determined within the Magdalena Group (below the Bursum), including the La Tuna, Berino, Bishops Cap, and Panther Seep Formations. Thicknesses of surface sections in the Robledo Mountains and Vinton Canyon (Franklin Mountains) are taken from Kottlowski (1960). Dark mudstones and carbonates in the Panther Seep indicate a restricted, quiescent depositional environment; however, shallow-marine conditions are evident throughout the Orogrande basin.

## Northwestern Chihuahua

Thicknesses of Pennsylvanian sections in northwestern Chihuahua are determined within the Horquilla as in southwestern New Mexico (following Zeller, 1965). The only surface section is in the Sierra de Palomas; it consists of mainly shallow-marine limestones with some sandstones in the basal part (Diaz and Navarro, 1964; Tovar, 1969). Absence of Pennsylvanian rocks in Pemex No. 1 Moyotes along the northwesterly trend with the Florida uplift provides subsurface control of the boundary between the Orogrande and Pedregosa basins.

The thickness and facies in No. 1 Chinos add key control to the shallow-marine shelf area northeast of the Alamo-Hueco basin. The relatively thin section assigned to the Pennsylvanian in the recently drilled No. 1 Centauro may indicate a deficient sediment supply in the deep-marine ("starved") basin. The basin probably extends southeastward to underlie the deep-marine Wolfcampian rocks in No. 1 Villa Ahumada, and then trends southward toward the flysch-type deposits in the Sierra del Cuervo located northeast of Chihuahua City (Tovar and Valencia, 1974; Wilson and others, 1969).

### Northeastern Sonora

Pennsylvanian rocks of northeastern Sonora were included with Permian rocks in the Naco Group of some early references. At least the northernmost Pennsylvanian sections are correlated with the Black Prince, Horquilla and lower Earp units of southeastern Arizona.

Tovar (1969) measured the section at Canon Santa Rosa (see also Imlay, 1939, p. 1730-1732). This locality provides key control for the shallow-marine shelf area on the southwestern side of the Alamo Hueco basin (fig. 3). Other localities in the Bavispe-Nacozari area are described by Imlay (1939), Fries (1962) and LOpez-Ramos (1969), including some sections that have been metamorphosed.

F. Rangin (1978, and per. comm.) kindly provided thicknesses of Pennsylvanian rocks in the Morita, Mestenas, Cananea and Tule sections. She is making a biostratigraphic study of Paleozoic rocks in Sonora for the Institute de Geologia, Universidad Nacional AutOnoma de Mexico.

The Magdalena uplift is defined here as a Mesozoic positive element where Pennsylvanian and other Paleozoic rocks are absent, probably as a result of erosion. It replaces the "Hermosillo uplift" of Greenwood and others (1977). Although the limits of the uplift are not yet determined precisely, current studies are narrowing the possible range of areal extent. At two key localities southeast of Magdalena (Cucurpe and Cerro Prieto), Jurassic rocks rest unconformably on Precambrian as determined by C. Rangin and T. H. Anderson (per. comm.). At localities southwest and north of Magdalena, Lower Cretaceous and Tertiary rocks, respectively, rest unconformably on Precambrian(?) basement (Rangin and Roldan, 1978; and G. A. Solos, per. comm.).

The Magdalena uplift appears to be a relatively small feature developed on the eastern flank of a Jurassic magmatic arc (C. Rangin, 1978). Extensive igneous intrusions along the arc probably account for the general metamorphism of the Pennsylvanian sections northeast of the uplift (fig. 3).

## CONCLUSIONS AND RECOMMENDATIONS

A significant number of key exploration wells have been drilled in the Pedregosa basin and adjoining areas. Although the reports of several shows of oil and gas are encouraging, the fact that no commercial production has been developed is discouraging. Many of the wells have been drilled on Basin and Range uplifts (horsts) where reservoirs tend to be flushed by meteoric waters. Some structural anomalies have been found to be the result of Tertiary igneous intrusions, and the sedimentary sections locally are metamorphosed. The best remaining prospects lie below the deeper parts of bolson (intermontane) valleys where chances are greater for preservation of oil and gas. The thermal history of the region suggests that dry gas may be more abundant than oil.

To maximize the probability of success, petroleum source and reservoir rocks should be documented in surface and subsurface stratigraphic sections, especially in those of the Paleozoic and Mesozoic objectives, as a fundamental step in outlining the favorable areas. Some source and reservoir analyses have been completed and others are in progress in particular localities, but for comprehensive evaluation, the results need to be plotted with respect to regional thicknesses and facies patterns of individual units.

The Pennsylvanian was selected for mapping in this paper because it includes the top-ranking exploration objective in the region, and as a consequence it tends to be studied more thoroughly and drilled more extensively than other units. The quality and quantity of stratigraphic control now available is adequate for an accurate regional framework. However, additional documentation is needed for many individual sections, and on correlations between sections, before source and reservoir data can be evaluated and projected with complete confidence on a regional basis. Furthermore, maps of thinner depositional units within the Pennsylvanian and Lower Permian, such as those used by Ross (1973), probably will be needed for the most precise evaluations and projections.

A complete series of regional stratigraphic maps showing key control unit-by-unit in the Paleozoic, Mesozoic and Cenozoic is needed for a better understanding of the depositional history. Regional structure-contour maps on top of Precambrian basement and on selected horizons in the Phanerozoic are needed to show the interrelationships of tectonics and sedimentation. Combined with maps of plutonic, metamorphic and volcanic activity, such studies should provide a sound geologic basis for the exploration and development of petroleum and other mineral resources.

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