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Lower and Middle Pennsylvanian strata in the Orogrande and Pedregosa Basins, New Mexico

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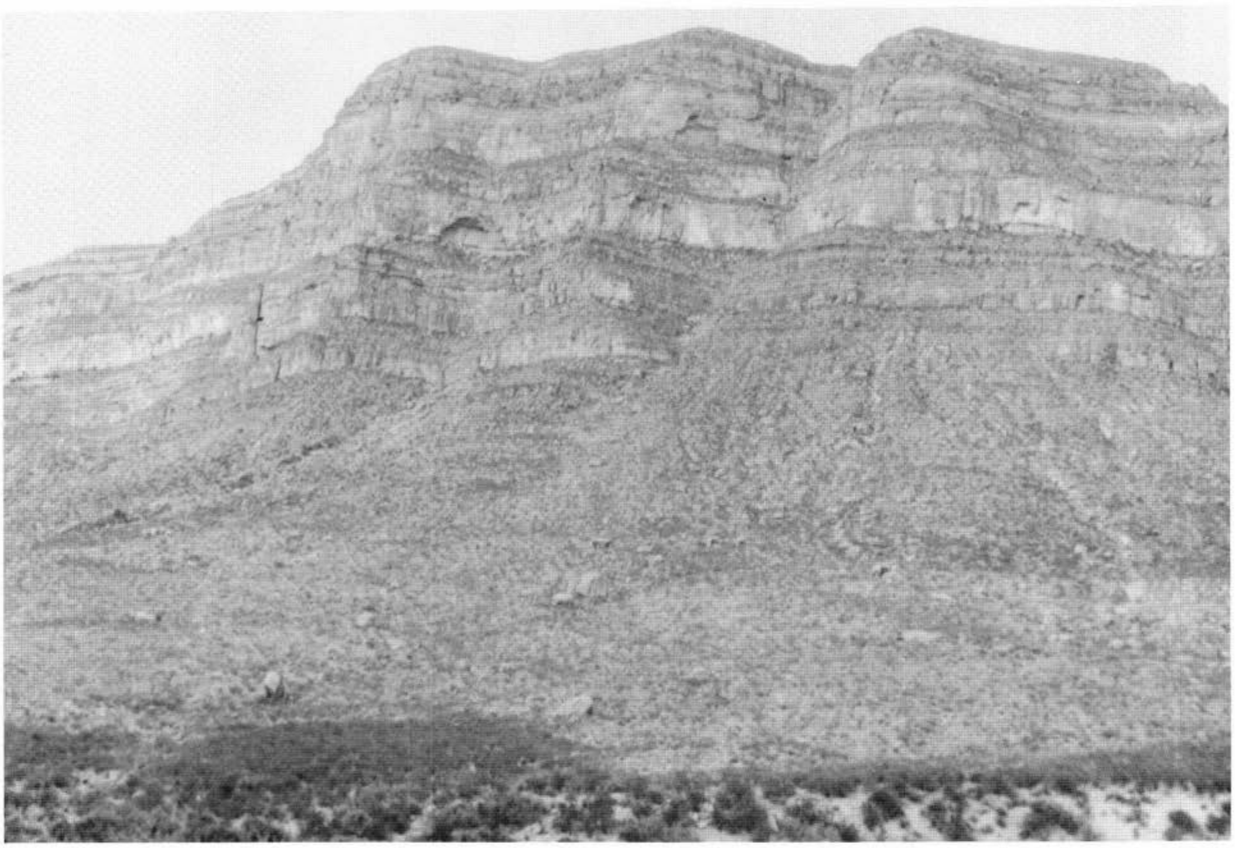

Well-developed ledges of limestone about 1,400 ft (425 m) thick constitute the Middle Pennsylvanian Bug Scuffle Limestone Member of the Gobbler Formation. North wall of Negro Ed Canyon, southern Sacramento Mountains, Otero County, New Mexico.

Abstract—Continued field work from 1955 to the present shows that Lower and Middle Pennsylvanian limestones crop out in various mountain ranges over most of southwestern New Mexico and northern Chihuahua, representing a once continuous sheet from 100 to 600 m thick. A regional NE–SW cross section from the Sacramento to the Big Hatchet Mountains shows detailed microfacies and fusulinid control and demonstrates that cyclic Lower Pennsylvanian (Morrowan) oolitic strata pinch out northward across southern New Mexico. The cross section also shows that Middle Pennsylvanian (Derryan and Desmoinesian) strata are widely represented by limestones with upward-shoaling cyclothems (generally upward-coarsening sequences) that number about a dozen at each location. Although the cyclothems are not correlative from section to section, they are generally present in all localities.

Petrologic studies show that the limestones are exclusively open marine and dominantly bioclastic lime wackestones and packstones. Tectonic stability during Early Pennsylvanian time caused the deposition of shallow-marine carbonates over wide shelves east and west of the Pedernal Uplift. In the Delaware Basin and on the west flank of the Pedernal Uplift terrigenous clastics are present. Small channels on the carbonate shelves, far west of the Pedernal Uplift, contain polymictic limestone–chert conglomerates. Quartzose sandstones at the base of the Pennsylvanian contain variable amounts of matrix, are often channeled, and may contain abundant terrestrial-plant fossils.

An isopach map of Lower and Middle Pennsylvanian strata shows that the Orogrande Basin is asymmetric in shape with marked subsidence along its eastern margin adjacent to the Pedernal Uplift. An anomalously thin area in the west-central part of the basin makes the basin narrower during Early and Middle Pennsylvanian time than in Late Pennsylvanian time. The Florida Uplift appears to transect thickness contours of the Lower and Middle Pennsylvanian, suggesting that uplift postdated development of the extensive carbonate sheet. The extent of carbonate deposition on the positive area, and the timing of the uplift, is difficult to prove since all Pennsylvanian and lowermost Permian (lower Wolfcampian) strata have been removed. The great thickness of Lower and Middle Pennsylvanian carbonates present in southwestern New Mexico and Arizona diminishes southward into Mexico (Chihuahua and Sonora). Two widely separated outcrops near Minas Plomosas, Chihuahua, and Bavispe, Sonora, contain only about 150 m of fusulinid-bearing shelf carbonates. Presumably these areas are located on opposite sides of the Pedregosa Basin. With sparse control at present, it is difficult to show whether or not the Pedregosa Basin, which should be between these localities, actually existed this early in Pennsylvanian time.

Introduction

Lower Pennsylvanian (Morrowan) and Middle Pennsylvanian (Derryan and Desmoinesian) strata are mostly carbonate in the southwest, unlike the dominantly terrigenous Lower and Middle Pennsylvanian in the midcontinent and eastern United States. Thick sheets of Lower and Middle Pennsylvanian limestones covered most of the region from Oklahoma to New Mexico, Arizona, and the southern Great Basin, and were present within the Ouachita—Marathon geosyncline. Studies of the region show that these limestones were part of a widespread carbonate platform that developed adjacent to the southwestern boundary of the late Paleozoic North American craton during Early and Middle Pennsylvanian time. The southwestern portion of the craton had remained relatively stable in early and medial Paleozoic time but near the end of Mississippian time it began to warp and break up. The platform was more intensely fragmented by Late Pennsylvanian (MissourianVirgilian) and Early Permian (Wolfcampian) rifting. The whole Paleozoic tectonic history, its causes and effects, are most recently discussed by Goetz and Dickerson (1985), Wilson (1987), and Wilson and Jordan (1988).

In southern New Mexico, Tertiary basin-and-range faulting uplifted large areas and exposed fragmented sheets of Lower and Middle Pennsylvanian limestones throughout scattered mountain ranges. From the Sacramento to the Big Hatchet Mountains, east and west of the Florida and Pedernal Uplifts, virtually complete sections of Lower and Middle Pennsylvanian strata crop out (Fig. 1).

The lithofacies and thickness relations of these exposures demonstrate the presence of two Pennsylvanian—Wolfcampian basins of subsidence in the region: the Orogrande and Pedregosa. Kottlowski (1960) defined the basins as areas where 2,000 ft (600 m) or more of sediments were deposited and where facies indicated only slightly deeper or more persistent water. The Orogrande Basin was named by Pray (1959: pp. 110, 116) as extending from Rhodes Canyon in the San Andres Mountains southward to the northern Franklin Mountains and eastward to the Sacramento Mountains, encompassing mostly Otero and Dona Ana Counties of New Mexico. The Pedregosa Basin (Kottlowski, 1960: p. 152) was defined as extending from the Gunnison Hills of Arizona southeastward to the Pedregosa Mountains of southeastern Arizona and Big Hatchet Mountains of southwestern New Mexico and southward into northern Sonora. The Pedregosa Basin is now known to have formed a rather long, narrow flysch-filled trough during Early Permian time extending far southeast into Chihuahua. The Lower and Middle Pennsylvanian sections both in and around these basins are mostly carbonate except where clastics have been locally introduced.

This report presents a detailed stratigraphic cross section and an isopach and facies map, describes the distribution of carbonate and terrigenous depositional facies in relation to the orientation of the carbonate platform, and appraises potential reservoir development in Pennsylvanian strata in the Orogrande and Pedregosa Basins of southern New Mexico and northern Chihuahua.

The distribution of Lower and Middle Pennsylvanian facies in the Orogrande and Pedregosa Basins was studied and measured at eight outcrops in the Sacramento and Big Hatchet Mountains of New Mexico, the Hueco and Franklin Mountains of Texas, and the Sierra de Palomas (Sierra Alta of other recent work) of Mexico. At these outcrops, samples were collected every few meters for petrologic analyses. The samples were cut, polished, and etched for rock-slab examination and for preparation of acetate peels. Some were

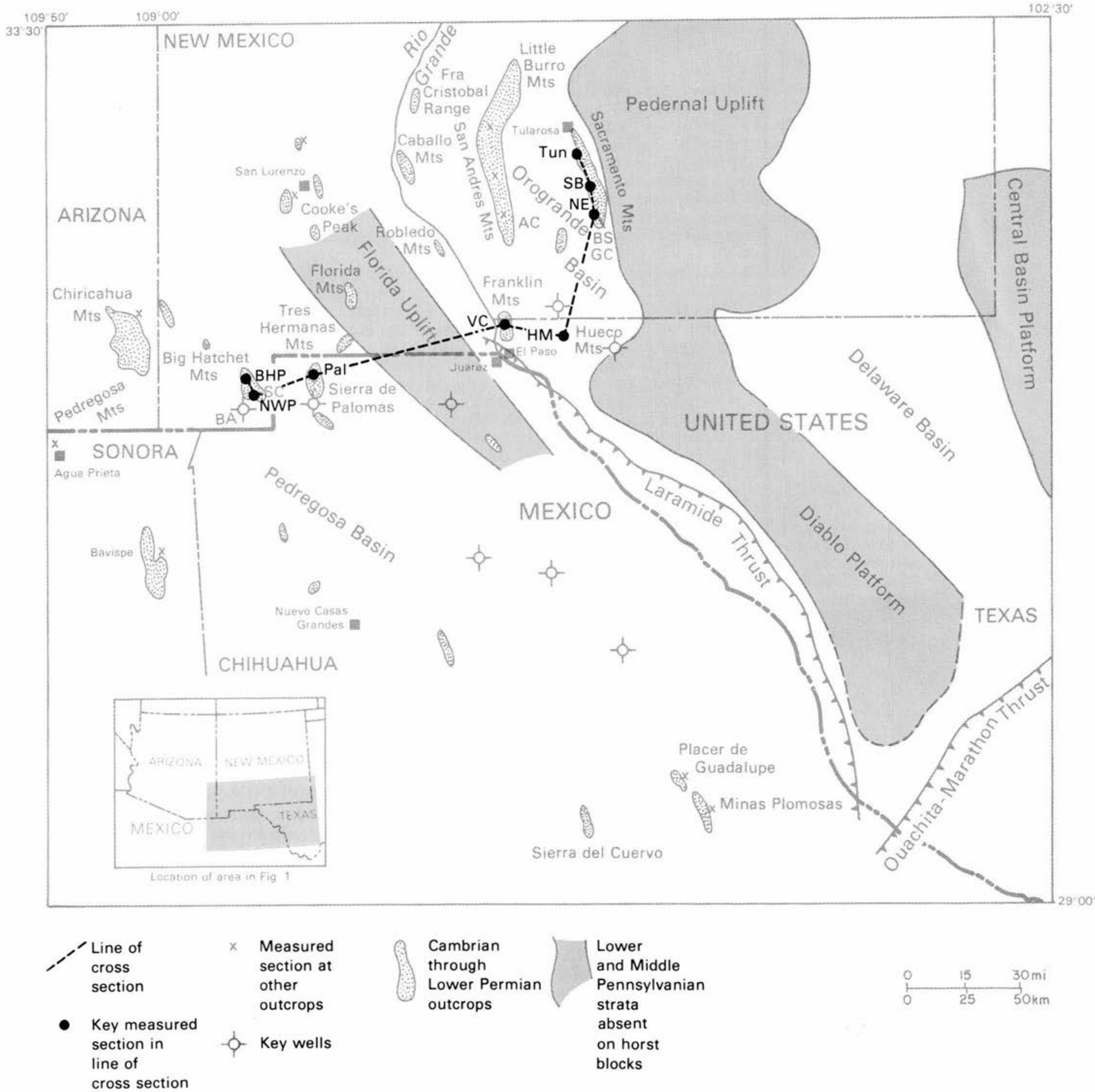

FIGURE 1—Regional setting of study area and location of cross section from Tun to BHP (Figs. 2A, 2B). See Table 1 for locations and references to measured sections in line of cross section: **Tun**, tunnel at High Rolls; **SB**, Steamboat; **NE**, Negro Ed Canyon; **HM**, Pow Wow Canyon in Hueco Mountains; **VC**, Vinton Canyon; **Pal**, Sierra de Palomas; **NWP**, New Well Peak; **BHP**, Big Hatchet Peak. Other areas (and references with maps showing locations): **BS**, Bug Scuffle Canyon (Pray, 1961: plate 2); **GC**, Grapevine Canyon (Pray, 1961: plate 2); **AC**, Ash Canyon (Kottlowski et al., 1956: fig. 7); **SC**, Sheridan Canyon (Zeller, 1975: sheet 1); **BA**, Humble Oil & Refining Company No. 1 State BA well (Zeller, 1975: sheet 1).

cut into thin sections for petrographic study. From this detailed petrographic work, a cross section (Figs. 2A, 2B) from the Sacramento to the Big Hatchet Mountains was drawn.

The cross section (Figs. 2A, 2B) extends through the eight sections of Lower and Middle Pennsylvanian outcrops and covers a distance of more than 200 miles from the Sacramento to the Big Hatchet Mountains (Fig. 1). Detailed locations and references to the eight sections are given in Table 1. From the northern Sacramento Mountains at the tunnel at High Rolls on the Alamogordo-Cloudcroft highway (Tun), just north of the major area of Lower and Middle Pennsylvanian terrigenous clastics, the cross section trends southward along the western escarpment of the Sacramento Mountains past Steamboat (SB) and Negro Ed Canyon (NE)—previously known as Negro Ed Canyon—to Pow Wow Can-yon at the western front of the Hueco Mountains (HM) of Texas, and then westward to Vinton Canyon (VC) in the northern Franklin Mountains (Fig. 2B). From Vinton Can-

TABLE 1—Locations and references to measured sections in line of cross section. See Fig. 1 for the regional setting and location of the cross section and Figs. 2A and 2B for the cross section.

Notation	Section	Location	Reference
Tun	Tunnel at High Rolls on Alamogordo–Cloudcroft highway	On upthrown side of Fresnal Fault of Pray (1961), on both sides of US–82, north and east of major area of Lower and Middle Pennsylvanian terrigenous clastics (Van Wagoner, 1977a: fig. 4).	Petrographic study by Van Wagoner (1977a, b). Fusulinid identifications by the writer. Fresnal Fault does not permit measurement to base of Pennsylvanian. Truncated by Abo red beds—small amount of Upper Pennsylvanian (Missourian) lies above Gobbler Formation and below the unconformity at base of Abo Formation.
SB	Steamboat	On northern side of prominent tilted ridge of Steamboat, just south of major area of Lower and Middle Pennsylvanian terrigenous clastics, southeast of Alamogordo, New Mexico (Van Wagoner, 1977a: fig. 8; Pray, 1961: plate 1).	Described by Van Wagoner (1977a).
NE	Negro Ed Canyon	On western front near southern end of Sacramento Mountains, north wall of canyon (Pray, 1961: plate 2).	From work in the 1950s by Shell Oil Company geologists. Fusulinid genera on column determined by Shell Oil Company paleontologists and C. A. Ross.
HM	Pow Wow Canyon in Hueco Mountains	At western front of Hueco Mountains, in Pow Wow Canyon, at north side of cut by US–180 and US–62, 25 miles east of El Paso, Texas (Seewald, 1968: stop 5 on map and section in pocket).	Originally described by Shell Oil Company geologists and in part by McGlasson and Seewald (1968) and Seewald (1968); later studied by C. Caldwell and M. G. Meyer, University of Michigan, 1978–79 and 1984, respectively. Truncated by Powwow conglomerate of Early Permian (Abo) age, but Lower and Middle Pennsylvanian are virtually complete. A small amount of Upper Pennsylvanian lies above Gobbler equivalent and below the erosional unconformity marked by Powwow conglomerate. This unconformity is caused by Early Permian uplift of Diablo Platform. Morrowan portion described by J. M. Spaw (1977) and Connolly and Stanton (1983) south of highway. Fusulinid genera on column determined by Shell Oil Company paleontologists and C. A. Ross.
VC	Vinton Canyon	On western side of northern end of Franklin Mountains (Jordan and Wilson, 1971: fig. 1, plate 1).	Originally described by Nelson (1940); fusulinids studied by Stewart (1958); measured and petrographically described by the writer and numerous students at Rice University (Jordan and Wilson, 1971). Names of fusulinids and identifications by Nelson and Stewart referenced on column. The notations 118 and 98 Nelson, and Stewart, refer to position of fusulinid-bearing strata collected by these geologists.
Pal	Sierra de Palomas	At eastern side of northern end of Sierra de Palomas on the *ejido*, 15 miles west of Palomas, Chihuahua, Mexico (Diaz and Navarro, 1964b: fig. 2).	Originally described by Diaz and Navarro (1964a, b); reviewed by J. C. Tovar R., Petroleos Mexicanos; partly measured by C. Caldwell, University of Michigan, 1978.
NWP	New Well Peak	In the southern part of Big Hatchet Mountains (Zeller, 1965: plate 1).	Originally measured by Zeller (1965); sampled by C. Caldwell, University of Michigan, 1978; lowest part studied by D. Johnson and students, New Mexico Institute of Mining and Technology; being restudied by S. Thompson III, New Mexico Bureau of Mines and Mineral Resources.
BHP	Big Hatchet Peak	In the northern part of Big Hatchet Mountains (Thompson and Jacka, 1981: fig. 3).	Described by Thompson and Jacka (1981).

yon, the cross section trends southwestward 60 miles across the Florida Uplift to the Sierra de Palomas (Pal) of northern Mexico, to New Well Peak (NWP), and then northwestward to Big Hatchet Peak (BHP) in the Big Hatchet Mountains of extreme southwestern New Mexico (Fig. 2A).

Although not in the line of cross section, other areas have been investigated by the writer and associates since 1955. These areas of investigation include measured sections of outcrops in the San Andres Mountains (see earlier work by Bachman and Myers, 1969; Kottlowski et al., 1956), the Caballo and Robledo Mountains, the Bug Scuffle Canyon and Fresnal Canyon areas in the Sacramento Mountains, and the Sheridan Canyon and Borrego areas in the Big Hatchet Mountains (Zeller, 1965). In Mexico, sections of outcrops were studied by the writer in areas near Placer de Guadalupe and Minas Plomosas, Nuevo Casas Grandes, and Bavispe. Subsurface strata were also examined in the Humble Oil & Refining Company No. 1 State BA well near the Big Hatchet Mountains.

The cross section (Figs. 2A, 2B) and the isopach and facies map (Fig. 3) are based in part on field observations recorded by Shell Oil Company in the 1950s during work headed by J. E. Galley and M. D. Wilson of the Midland area office. This report is also based on later work in the Sacramento

Mountains by Benne (1975) and Van Wagoner (1977a, b) and on field work in the Sacramento and Hueco Mountains by the author's students at the University of Michigan (C. D. Caldwell, M. G. Meyer, and T. **J.** Algeo, 1978-1988). Study of the section in the Sierra de Palomas is based on field work done by Diaz and Navarro (1964a, b) and refined by J. C. Tovar R. of Petroleos Mexicans, as well as by the writer. Study of the section at Big Hatchet Peak is based on work done by Thompson and Jacka (1981).

Acknowledgments—I am very grateful to Frank E. Kottlowski and Sam Thompson III of the New Mexico Bureau of Mines and Mineral Resources. They helped materially by adding information and sharpening stratigraphic concepts. Thompson reviewed the paper with unusual care. I also thank Don F. Toomey of Conoco, Inc. Research Laboratory, Ponca City, Oklahoma, whose editorial skills and wide knowledge of the Pennsylvanian also considerably improved the paper. I am also indebted to Jennifer Boryta who carefully edited the work for the Bureau of Mines and Mineral Resources. I am also grateful to my wife, Della, who did the word processing for me.

Biostratigraphy

Major lithic units and sedimentary cyclothems are correlated with great confidence because of the biostratigraphic control furnished by abundant fusulinids in the Lower and Middle Pennsylvanian strata of this region. Most fusulinid identifications for this study were done by G. Sanderson and the late P. Fickman, both formerly of Shell Oil Company, and by the late W. J. Stewart of Texaco. C. A. Ross also identified fusulinids from the Hueco and southern Sacramento Mountains.

The base of the first occurrence of *Profusulinella* is used as the Morrowan-Derryan contact. Morrowan strata (i. e. beds below *Profusulinella)* in the Hueco and Franklin Mountains, and in the western sections in the Sierra de Palomas and Big Hatchet Mountains, are from 75 to 100 m thick (Figs. 2A, 2B). They are easily correlated by their oolitecapped cycles. Morrowan strata are possibly present in the southern San Andres Mountains (Bachman and Myers, 1969).

There is disagreement, however, concerning conodont and fusulinid ranges within the Morrowan section in the Sacramento Mountains. In the writer's opinion, it is doubtful that Morrowan strata exist in this area. Derryan to Desmoinesian fusulinids appear at the base of the Pennsylvanian in Negro Ed Canyon and near the base of the Pennsylvanian in Grapevine Canyon. Discrepancy with Benne's (1975) age determination of Morrowan beds, which was based on conodont and brachiopod identifications, needs to be reconciled for the southern Sacramento Mountains. No fusulinid determinations have been published in the northern part of the Sacramento escarpment, but Middle Pennsylvanian (Derryan to lower Desmoinesian) fusulinids occur near the base of the Gobbler Formation in the sections at Steamboat and the tunnel at High Rolls (Van Wagoner, 1977a).

Derryan strata include the ranges of *Profusulinella* and *Fusulinella. Fusulina* (now *Beedeina)* and *Wedekindellina* are present with *Fusulinella* in lower Desmoinesian strata, which are 150-200 m thick in the western sections, 100 m thick at Vinton Canyon in the Franklin Mountains, and 75-150 m thick in the Hueco and Sacramento Mountains.

The stratigraphic range of *Komia* is plotted on various sections (Figs. 2A, 2B). The tiny branching problematical form is essentially of Middle Pennsylvanian (Desmoinesian) age, but the zone in which it occurs extends as far down as the uppermost Derryan in one section in the San Andres Mountains, at Steamboat in the Sacramento Mountains, and in the sections in the Sierra de Palomas and at New Well Peak.

The problematical sponge/coral *Chaetetes* has a long vertical stratigraphic range throughout Lower and Middle Pennsylvanian strata in the western sections (Fig. 2A). At Vinton Canyon in the Franklin Mountains and at Pow Wow Canyon in the Hueco Mountains (Fig. 2B), the occurrence of *Chaetetes* is confined to the lower half of the sections (lower Desmoinesian ranging down into the Morrowan). *Chaetetes* is present in Desmoinesian strata in the San Andres Mountains north of Ash Canyon. Despite much investigation, *Chaetetes* has not been seen in the Sacramento Mountains; the apparent absence is inexplicable at this time.

Upper Desmoinesian strata contain the strongly fluted *Fusulina* (now *Beedeina). Fusulinella* is absent. Upper Desmoinesian strata vary more in thickness than lower Desmoinesian strata. The upper Desmoinesian reaches a maximum thickness of 235 m at Vinton Canyon and 175 m at Negro Ed Canyon. In other places the top of the upper Desmoinesian may be partly eroded.

Lithostratigraphy

Lower Pennsylvanian (Morrowan) and Middle Pennsylvanian (Derryan and Desmoinesian) strata in and around the Orogrande and Pedregosa Basins correspond to regional lithostratigraphic units that include the Wapanucka Formation of Oklahoma, the Bend and Strawn Groups of the Llano Uplift, and the Dimple Limestone of the Marathon area.

Lower Pennsylvanian (Morrowan) and Middle Pennsylvanian (Derryan and Desmoinesian) carbonates are present across nearly all of southern New Mexico (Fig. 3). Lower and Middle Pennsylvanian terrigenous clastics, as well as carbonates, occur in the Orogrande Basin. A similar facies relationship occurs in the Delaware Basin. Lower and Middle Pennsylvanian strata are absent on the Florida and Pedernal Uplifts and Lower Pennsylvanian (Morrowan) strata are absent in the Sacramento Mountains. Lower and Middle Pennsylvanian strata are 500-600 m thick in the Big Hatchet Mountains and Sierra de Palomas and about 135 m thick in the Robledo Mountains. Middle Pennsylvanian (Derryan and Desmoinesian) strata are as much as 450 m thick in the Sacramento Mountains. No notable unconformities are known at these localities. The crest of the thin area in the Robledo Mountains is shown in Fig. 3 at the 100 m contour, but the orientation is poorly controlled. A more northwesterly trend is possible and would align the area with the strike of the Diablo Platform. Such an orientation might be construed to indicate Early to Middle Pennsylvanian northwest faulting across the Orogrande Basin, but minimal evidence exists at present.

In the San Andres Mountains, Lower and Middle Pennsylvanian strata are termed the Lead Camp Limestone (Bachman and Myers, 1969). In the Sacramento Mountains, Pray (1961) adopted the term Gobbler Formation for Lower and Middle Pennsylvanian strata. He termed the massive

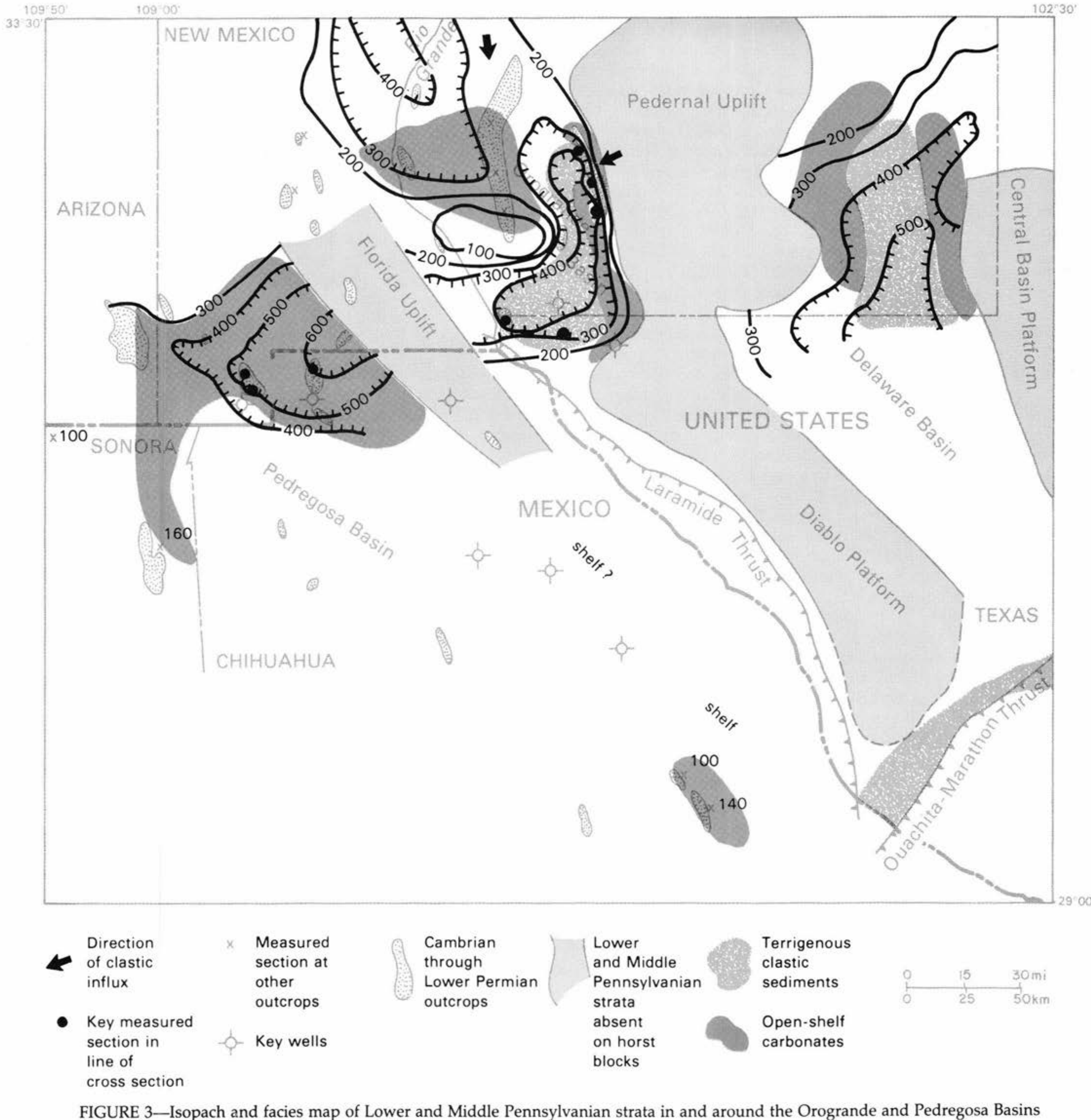

FIGURE 3—Isopach and facies map of Lower and Middle Pennsylvanian strata in and around the Orogrande and Pedregosa Basins (after Wilson, 1987). Contour interval = 100 m.

carbonate portion of the Gobbler Formation the Bug Scuffle Limestone to differentiate the limestone from areas in which terrigenous clastics from the Pedernal Uplift are dominant (Van Wagoner, 1977a, b).

The La Tuna, Berino, and Bishop Cap Formations of the Magdalena Group of the El Paso region are present in the Hueco and Franklin Mountains (Nelson, 1940). In the Sierra de Palomas and the Big Hatchet Mountains, the entire Pennsylvanian and lowermost Permian (lower Wolfcampian) are included in the thick Horquilla Formation (Zeller, 1965). At Minas Plomosas, Chihuahua, Mexico, the Pennsylvanian is termed the Pastor Formation (Bridges, 1964).

Nearly all the Lower and Middle Pennsylvanian strata in and around the Orogrande and Pedregosa Basins consist of shallow-marine, open-shelf limestones. Clastic influx is represented by both sandstones and shales. Conglomerates occur rarely in channels, and are associated with some fossil wood (mainly conifers). In the San Andres and Caballo Mountains, the lowermost Pennsylvanian contains chert conglomerates. There are no red beds or coals, but some carbonaceous shales occur. Microfacies present in the Sacramento Mountains are illustrated in Figs. 4A, 4B, and 5.

About 250 miles to the southeast at Minas Plomosas, Chihuahua, Mexico, Middle Pennsylvanian strata are exposed on the southeastern side of the Pedregosa Basin. At the base of the Middle Pennsylvanian, the Pastor Formation is a 100-140-m-thick, micritic shelf limestone that contains abundant fusulinids. On the western side of the Pedregosa Basin, just west of Nuevo Casas Grandes in Chihuahua, Mexico, shelf biota occur in limestones (Perez et al., 1984). The limestones are possibly Lower to Middle Pennsylvanian bioclastic shelf debris reworked into Permian (Leonardian) turbidite slope deposits. Near Bavispe in Sonora, Mexico, in situ shelf limestones, which contain Middle Pennsylvanian fusulinids, occur throughout at least 160 m of the lower portion of an outcrop (unpublished Pemex data).

Deep-marine deposits may be as old as latest Desmoinesian in the Pedregosa Basin. In the Sheridan Canyon area of the central Big Hatchet Mountains, Upper Pennsylvanian and Lower Permian (Wolfcampian) strata change to the basin fades (termed Alamo Hueco Basin by Zeller, 1965, and Thompson, 1980). In this area, Upper Pennsylvanian isolated phylloid-algal bioherms occur, which are characteristic of shelf margins. The shelf-margin carbonates change to a basin facies that consists of dark limestones, shales, and thick debris-flow deposits. Older Pennsylvanian sequences are not exposed in the area, but may contain sediments of a shelf facies because such strata are observed in the sections to the north at Big Hatchet Peak (Thompson and Jacka, 1981) and to the southeast at New Well Peak (Zeller, 1965). Near Sheridan Canyon at the base of the Borrego section described by Zeller (1965), the lowest beds exposed consist of dark limestones and black, laminated, fine-grained dolomites, which are characteristic of a slope facies. These beds are either Middle or Late Pennsylvanian (Desmoinesian or Missourian) in age.

There is a question about whether a Pedregosa basin facies is developed in Middle Pennsylvanian strata. As much as 600 m of older Pennsylvanian has been identified in the Humble Oil & Refining Company No. 1 State BA well, a few miles southwest of the Big Hatchet Mountains (Zeller, 1965; Schüpbach, 1973). According to Schüpbach, the interval from 9,000 to 11,000 ft consists mostly of dark, cherry limestones and mudstones, and also includes some sandstones. Thompson (1980) indicated dark mudstones and limestones from 6,265 to 9,425 ft to be deep-marine basin deposits of the upper Horquilla (Missourian–Wolfcampian) and limestones and cherts from 9,425 to 10,995 ft to be shelf deposits of the lower Horquilla (Morrowan(?)–Desmoinesian).

Major rock types

The major rock types in Lower and Middle Pennsylvanian strata in and around the Orogrande and Pedregosa Basins are indicated on the cross section (Figs. 2A, 2B). Each type has distinct characteristics related to its environment of deposition.

Carbonates

The Lower Pennsylvanian (Morrowan) and Middle Pennsylvanian (Derr yan and Desmoinesian) limestones may generally be described as bioclastic wackestones and packstones (Dunham, 1962; Wilson, 1975: pp. 12, 13). They contain "normal" Pennsylvanian biota that consists of brachiopods, bryozoans, echinoderms, platy algae, fusulinids, tubular and globular foraminifera, bivalves, gastropods, impressive beds of rugose corals, *Syringopora*, and the problematical *Komia* and *Chaetetes* in the western sections. The diversity in biota indicates water deep enough for open-marine circulation. Dasycladacean algae are conspicuously absent. Also absent are evaporites and tidal-flat sedimentary structures; dolomite is rare.

Grainstones—Most lime grainstone–packstone units are difficult to correlate over distances of tens of km between the stratigraphic sections in the line of cross section (Figs. 2A, 2B). Grain-rich units occur mostly in the lower 200 m. Grain-rich units also occur at the tops of the sections. The units are generally extensively crossbedded and have channels filled with large-scale foresets. Most grainstones consist

FIGURE 4A—Typical phylloid-algal lime packstone–wackestone of Middle Pennsylvanian (Desmoinesian) shelf facies. Note small, fragmented algal plates and mollusk (?) pieces with void-filling calcite. The pattern of centripetally enlarging crystals shows solution and later cementation of fossil moldic porosity. Bryozoan (**B**) in lower right corner. From road cut on US–82 at the tunnel at High Rolls, Sacramento Mountains, New Mexico. Thin section UDC–3, plane light × 13.

of worn and superficially coated peloids, foraminifera, or bioclasts.

The Lower Pennsylvanian (Morrowan) portion of the Pennsylvanian has three clearly defined and correlative cycles capped by well-developed oolites, as illustrated in Figs. 2A and 2B (see section on cyclic sedimentation). These capping beds have the best developed oolite occurrences within the area represented by the cross section. True oolites are rare in the Middle Pennsylvanian.

A Middle Pennsylvanian somewhat oolitic lime grainstone-packstone interval correlates from the section at Negro Ed Canyon in the southern Sacramento Mountains to the section at Vinton Canyon in the Franklin Mountains, where the unit lies almost at the top of the La Tuna Formation. To the west, the sections in the Sierra de Palomas and at Big Hatchet Peak are more grain-rich. The lower Horquilla Formation at Big Hatchet Peak is the most grain-rich unit in the line of cross section.

Encrinites—Pure crinoidal beds of moderately crossbedded lime packstones and grainstones are present at intervals in almost all sections, as illustrated in Figs. 2A and 2B, but are not correlative from section to section. They are prominent in the sections at Big Hatchet Peak and New Well Peak, are less abundant in the section in the Sierra de Palomas, and are absent in the section at Vinton Canyon in the Franklin Mountains and most of the section at Pow Wow Canyon in the Hueco Mountains. Thin-bedded encrinites are present in all three sections within the Sacramento Mountains.

Clinothems—In a 1986 field study in the northern San Andres Mountains, T. J. Algeo noted large-scale clinothems (10-20 m high) that consist of micritic limestones prograding down paleoslopes. It is not known whether such strata represent fillings of large channels or deposits off flanks of mounds.

Mounds—Lenticular carbonate-mound buildups, which contain phylloid algae and much micrite and which have a relief of 10-20 m, occur along the Middle-Upper Pennsylvanian (Desmoinesian-Missourian) boundary at shelf-margin sections in the Big Hatchet Mountains (New Well Peak). Elsewhere, they occur in the Lower Pennsylvanian (Morrowan) beds on the south side of Pow Wow Canyon in the Hueco Mountains (not found in HM section in the line of cross section, Fig. 2B). They also occur in Desmoinesian beds at Bug Scuffle Canyon in the southern Sacramento Mountains. In this section, the middle portion of the Bug Scuffle Limestone contains a 25-m-thick massive ledge made up of six north-south-oriented algal-plate mounds. These mounds were mentioned by Bowsher (1986: **p. 59)** at nearby Grapevine Canyon. Generally, however, mounds are rare in Lower and Middle Pennsylvanian strata in the Orogrande and Pedgregosa Basins as compared with those found in Upper Pennsylvanian strata.

Cherry limestones—Chert occurs as ropy, crudely tabular masses in limestones, as abundant, discrete silicified fossils, and as large nodules in more massive limestones. Wispy seams of silicification are common throughout thick-bedded carbonates. Individual cher t bodies are too localized to be correlated over tens of km between sections. In the Sacramento Mountains, the Middle Pennsylvanian (Desmoinesian) part of the section becomes much more cherty to the south in Negro Ed and Bug Scuffle Canyons. The Desmoinesian is also cherty in the Hueco and Franklin Mountains. This diagenetic facies change does not seem to exist within the San Andres Mountains.

Other carbonate rock types—Van Wagoner (1977a, b) contributed a detailed description of Middle Pennsylvanian carbonate rock types. From his petrographic work in the

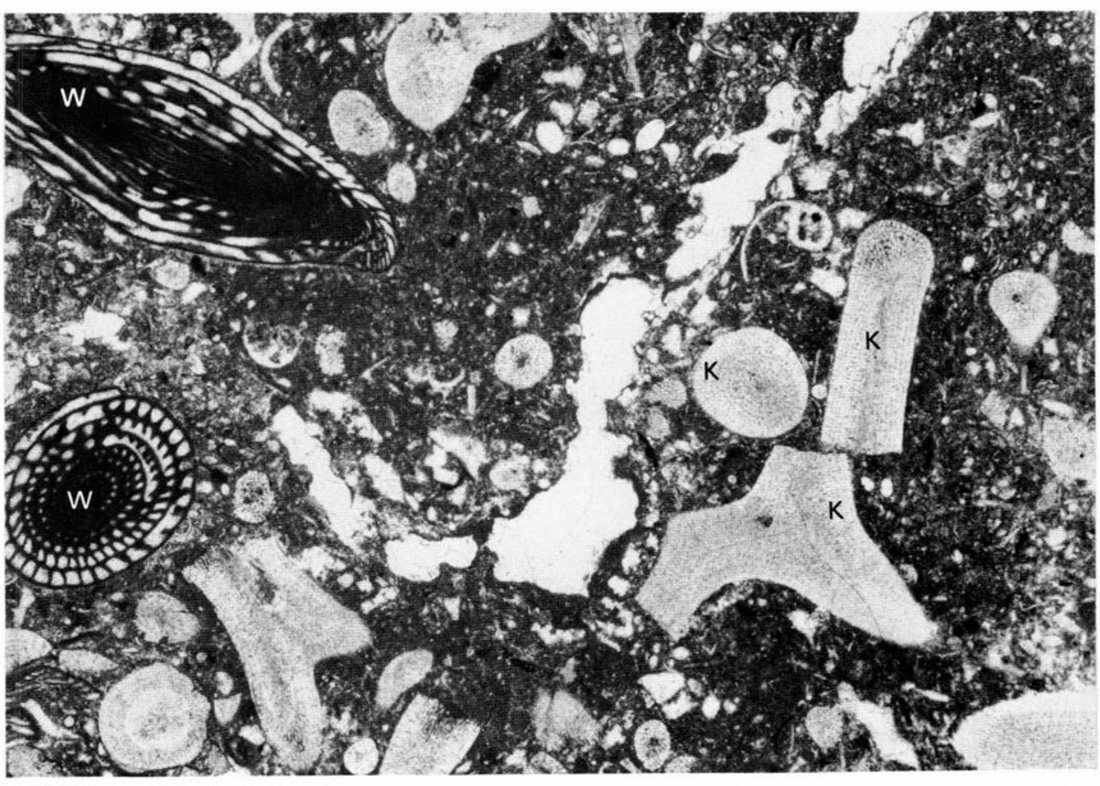

FIGURE 4B—Typical *Komia* lime packstone–wackestone of Middle Pennsylvanian (lower Desmoinesian) shelf facies. Note *Wedekindellina* (**W**) and *Komia* (**K**). From middle Gobbler Formation in road cut on US–82 at the tunnel at High Rolls, Sacramento Mountains, New Mexico. Thin section UDCW–20, plane light × 13.

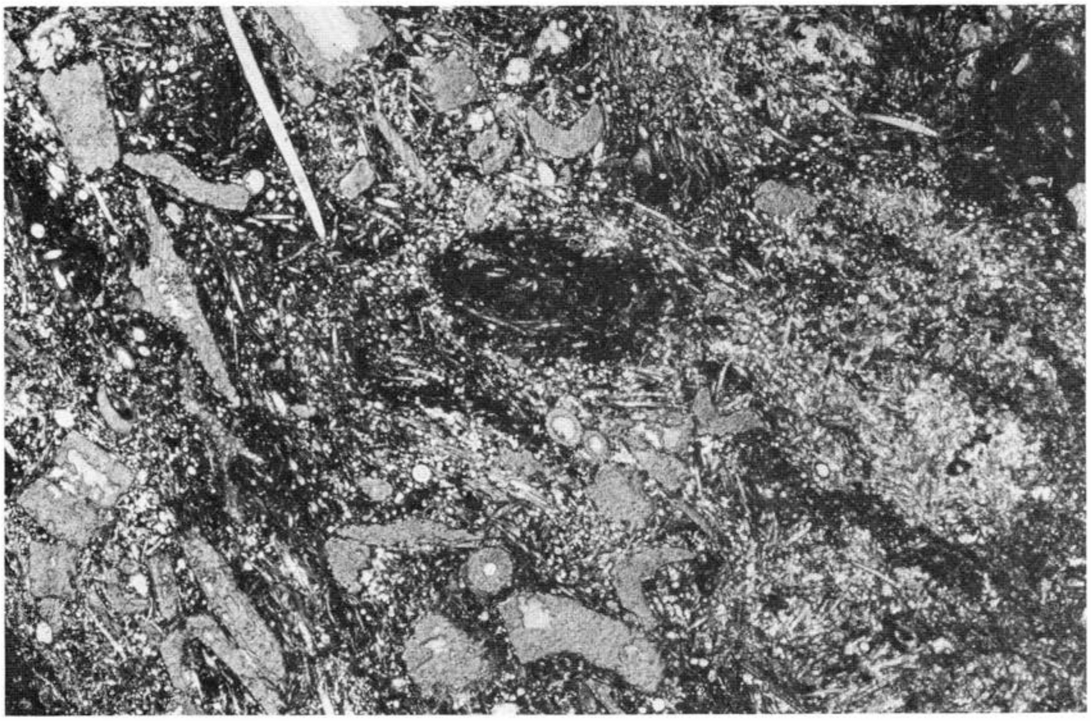

FIGURE 5—Spiculitic lime packstone with abundant, siliceous, monaxon sponge spicules (now mostly calcite) and partly silicified echinoderm debris. Fabric burrowed and bioturbated. Offshore facies of Middle Pennsylvanian age. Common in lower part of upward-shoaling cyclothems. From road cut on US–82 at the tunnel at High Rolls, Sacramento Mountains, New Mexico. Thin section EDCE–2, plane light × 13.

northern Sacramento Mountains, he described the cyclicity of these strata and recognized the following ten microfacies based on faunal content, depositional texture, bedding and sedimentary structures, and small-scale stratigraphic relationships:

1) Bioclastic, burrowed lime wackestones that contain "normal" marine fauna;
2) Bioclastic lime packstones (essentially similar to the above);
3) Spiculitic, bioclastic, dark, pyritic limestones formed in deeper, quiet water below storm wave base, but not quite euxinic (Fig. 5);
4) Abraded bioclastic lime grainstones that are trough crossbedded and that contain ooids and coated particles of *Osagia;*
5) Crinoidal lime grainstones that are trough crossbedded;
6) Platy phylloid-algal lime wackestones in tabular beds (Fig. 4A);
7) Intraclastic lime mudstones and wackestones associated with algal-plate micrites (these are brecciated beds commonly seen within mounds in Upper Pennsylvanian strata);
8) Foraminiferal lime packstones–grainstones;
9) *Komia* lime packstones commonly associated with platy-algal facies (Fig. 4B);
10) Rare dolomitic lime mudstones associated with shallow-water strata and characterized by a paucity of fauna.

Many of these microfacies were illustrated by Wilson et al. (1969) for Lower, Middle, and Upper Pennsylvanian sections in Mexico and New Mexico, by Toomey et al. (1977) for the Yucca Mound section in the Sacramento Mountains, and by Toomey and Babcock (1983) for the Hueco Mountains.

Terrigenous clastic influx

Sandstones—In the section in the Sierra de Palomas, cross-bedded clean sandstones, about 50 m thick, are present at the base; another sandstone bed occurs somewhat higher in the Lower Pennsylvanian (Morrowan). Chert-pebble conglomerates and some sandstones have also been observed at the base of the Pennsylvanian in the San Andres and Caballo Mountains. To the west, in the Big Hatchet Mountains, sandstones are rare to absent in the shelf facies.

In the Sacramento Mountains, the basal Pennsylvanian consists of transgressive sandstones generally present in channels and associated with fossil-plant remains. A persistent sandstone unit above the base of the Pennsylvanian but still in the lower part of the Middle Pennsylvanian (Derryan) was studied by Benne (1975) and Van Wagoner (1977a, b). In the northern Sacramento Mountains, at Steamboat, this sandstone is similar to the sandstones at the base of the Pennsylvanian in the San Andres and Caballo Mountains and in the Sierra de Palomas.

The channel sandstones near the base of the Pennsylvanian are of variable maturity and grain size. Some are relatively pure quartzose sands, whereas others contain plants, rock fragments, and feldspars. Conglomerates also occur. The widespread occurrence of the sandstones indicates an important period of tectonic adjustment and upland erosion during Late Mississippian to Early Pennsylvanian time. Uppermost Mississippian strata, the Helms Formation (Chesterian), are shales and are confined to the southernmost area of New Mexico, just west of the Diablo Platform; thus, they probably were deposited a significant distance to the south of the eroded highland. The sandstones in the Lower Pennsylvanian probably were deposited closer to the highland.

In the northern Sacramento Mountains, a deltaic complex, 8 km wide, occurs in the upper part of Middle Pennsylvanian (Desmoinesian) strata (Van Wagoner, 1977a, b) and differs from the basal sandstones. Van Wagoner described nine sections in the 10-km^2 area that outlines this deltaic complex. Within the area of clastic influx, several upward-coarsening, asymmetric cycles occur in each section; these cycles are thought to represent deltaic progradation. The cycles consist of three units. The lowest unit has wavy, laminated claystones to very fine-grained sandstones that contain some burrowing structures and rare fossils. Black, macerated plant fragments may also be present. Upward-coarsening sandstones of the middle unit normally exhibit load casts, flutes, other sole markings, organic trails, slumps, convolute beds, and ball-and-pillow and cut-and-fill structures. Marine fossils are rare, whereas plant fragments are common. The upper unit consists of trough-crossbedded sandstones that occur in sets 1-2 m thick. Large plant fragments and pieces of fossil wood may also be included. The base of the succeeding cycle may be represented by spiculitic lime mudstones-wackestones, claystones, or fine-grained sandstones.

This terrigenous deltaic facies is not shown on the cross section (Fig. 2B), but it lies between the Bug Scuffle Limestone Member in the section at the tunnel at High Rolls and the Bug Scuffle Limestone Member in the section at Steamboat. Van Wagoner (1977a) showed that the deltaic complex consists of elongated deltaic lobes. These lobes are directed northwesterly into the Orogrande Basin and were fed by braided streams that flowed westward off the Pedernal Uplift. Apparently the deltaic complex interrupted construction of the regional carbonate shelf.

Middle Pennsylvanian sandstones produce gas near the town of Tularosa, about 25 km north of the deltaic occurrence (Greenwood et al., 1977: p. 1457).

Sporadic channels—There are sporadic channels in the dominantly carbonate sections at New Well Peak, in the Sierra de Palomas, and at Anthony Gap near Vinton Canyon. These channels are 1-5 m deep. They are filled with polymictic limestones and chert conglomerates, fossil wood, and sandstones, and some can be correlated from section to section. In some places, the channels are represented by thin-bedded shale and siltstone units (see below). The sporadic channels, filled with coarse clastics, are located on the broad carbonate shelf, far west of the obvious source of terrigenous debris in the Pedernal-Diablo uplifted areas. They may indicate periodic downcutting during substantial falls of sea level and subsequent infilling during later marine transgressions. They may have also been cut during episodic storms that crossed the shallow shelf.

Shaly units—A pronounced, thick (75-100 m), shaly carbonate unit of Middle Pennsylvanian (early Desmoinesian) age is seen in the sections in the Sacramento Mountains and at Pow Wow Canyon in the Hueco Mountains (Fig. 2B). The shaly unit apparently correlates with strata of the major clastic deltaic influx mentioned above and mapped by Van Wagoner (1977a, b) in the northern Sacramento Mountains.

Present within this lower Desmoinesian shaly unit are dark lime mudstones. They form a key bed in the northern Sacramento Mountains and are located 95-120 m above the base of the Gobbler Formation at Steamboat (Van Wagoner, 1977a, b). Benne (1975) showed this interval, which constitutes his 1-38, to be 88-100 m above the base of the section at Mule Canyon on the south side of the ridge at Steamboat. Van Wagoner used this lime mudstone bed as a key marker unit for detailed correlation between nine sections in the northern Sacramento Mountains. The lime mudstone interval constitutes part of his depositional episode I. The lime mudstone interval is situated below the major northwest-directed tongue of terrigenous clastics, and is thought to be equivalent to the bulk of the lower Desmoinesian shaly unit of the cross section in the present report. This clastic incursion is not well represented in the section in the Sierra de Palomas nor in the section at Big Hatchet Peak to the west.

The cross section (Fig. 2A) indicates another thinner shaly unit in the section at Vinton Canyon in the Franklin Mountains. This argillaceous unit is in the Berino Formation about 25 m below the white marker bed and is of Derryan age. It is shown to correlate with an erosional channel and covered interval in the sections in the Sierra de Palomas and at New Well Peak. Ross (1973) indicated a persistent silt zone in upper Desmoinesian beds in southeastern Arizona. It seems obvious that various periods of terrigenous influx occurred across the shelf at different times and from different source areas.

Cyclic sedimentation

Thin cyclothems (15-40 m thick) with upward-coarsening and increasing grain percentage occur in all sections (Figs. 2A, 2B). Ideally, the cyclothems begin with argillaceous wackestones or lime mudstones and grade upward through fossiliferous lime wackestones-packstones to grainstones, which in some places may be oolitic. These grain-rich units are commonly thicker bedded than the lower strata of the cyclothems, and generally form distinct capping ledges. In some localities, burrowed, black, mottled beds (some with black lithoclasts) appear in the upper strata of the cycles (Fig. 6), but their significance is not clear. The cyclothems are interpreted to represent upward-shoaling sequences.

The Derryan and Desmoinesian cyclothems recorded in Figs. 2A and 2B appear internally consistent but are not clearly correlative over tens of km from section to section. Although the cyclothems are not clearly correlative between sections, they occur persistently and are recognizable. The approximate number of cyclothems (including Morrowan) observed at each locality are as follows: Big Hatchet Peak, 12; New Well Peak, 12; Sierra de Palomas, 15; Vinton Canyon, 6 (in lower part, some in Berino and Bishop Cap Formations but poorly developed); and Pow Wow Canyon in the Hueco Mountains, 11. Although the Morrowan is absent in the sections in the Sacramento Mountains, the number of cyclothems observed are as follows: Negro Ed Canyon, 10; Steamboat, about 25 thin cycles at the top (see Van Wagoner, 1977a); and the tunnel at High Rolls, 6 (irregular). A similar number of cyclothems (a dozen or so) capped by massive limestone ledges is seen in the San Andres Mountains on the cross section of Kottlowski et al. (1956). T. J. Algeo (pers. comm., 1987) noted about 17 couplets of thin to thicker bedded limestones in a section in the Little Burro Mountains north of Mockingbird Gap.

The most obvious correlative cyclothems are those present in the Lower Pennsylvanian (Morrowan). They consist of three contiguous upward-shoaling units, each ending with beds of well-developed oolite. They have been correlated through all Morrowan outcrops studied from the Big Hatchet Mountains to the Hueco Mountains.

Lower and Middle Pennsylvanian upward-coarsening (upward-shoaling) cyclothems occur through 14 to 15 million years of time. Since the cyclothems are not all contiguous in sequence, each one probably represents less than 1 million years. This estimate can be compared with the work of Ross (1973). In southeastern Arizona, he recognized

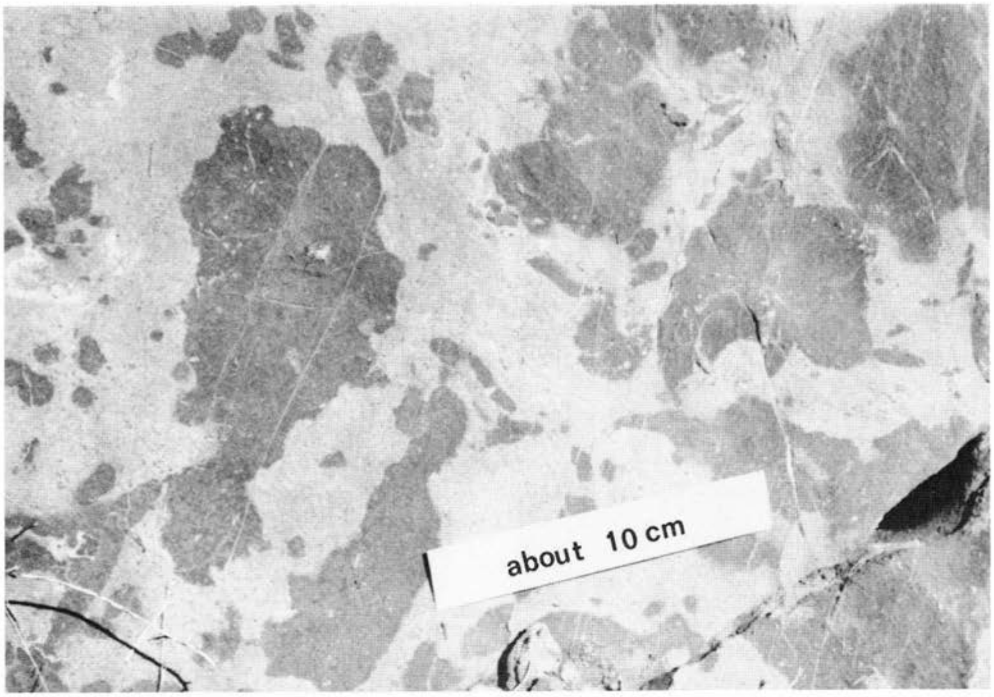

FIGURE 6—Outcrop of a peculiar, dark, mottled, lithoclastic bed in upper part of coarsening cycle. Origin not clear but probably results from in situ pull-apart of lime mud under marine conditions. The bed may represent a still-stand in sedimentation. Such features are common in Middle Pennsylvanian strata of southern New Mexico and northern Mexico (Chihuahua). From Horquilla Formation, Sierra de Palomas, northwestern Chihuahua, Mexico.

7 "formats" (units A—G) in the Lower and Middle Pennsylvanian (Black Prince and Horquilla Formations). The estimated duration of each of these "format" units would be about 1.5 to 2 million years.

Summary of geologic history

Lower and Middle Pennsylvanian carbonates were deposited in the southern New Mexico and Arizona parts of the Pedregosa Basin, in much of the Orogrande Basin, and probably across the area of the Florida Uplift. Terrigenous clastics, as well as carbonates, were deposited in the southern Orogrande Basin (Fig. 3). The parallelism of the isopach contours along the western boundary of the Pedernal Uplift suggests the uplift formed during development of the Orogrande Basin. The pre-Pennsylvanian history of the Pedernal Uplift is unclear because most of the Paleozoic section was removed before and during Early Permian time. Carbonates and evaporites covered the eroded Pedernal Uplift in mid-Permian time; carbonates covered the Diablo Platform in middle to late Wolfcampian time (Wilson, 1971; Greenwood et al., 1977).

The Florida Uplift apparently formed after mid-Pennsylvanian time because the uplifted block appears to transect perpendicularly the isopach contours. Late Pennsylvanian uplift presumably resulted in erosion of Lower and Middle Pennsylvanian carbonate strata, but evidence for this is inconclusive. Lower and Middle Pennsylvanian strata are probably thin at the Tres Hermanas locality due to erosion and are certainly not present in the Florida Mountains nor at Cooke's Peak.

In general, the Early Pennsylvanian seas transgressed northward from the Pedregosa Basin. Lower Pennsylvanian (Morrowan) strata were confined to the southern area (Hueco and Franklin Mountains, Sierra de Palomas, and Big Hatchet Mountains); such strata were not deposited in the area of the Sacramento Mountains. This transgression continued into the Middle Pennsylvanian (Derryan). By the close of Middle Pennsylvanian (Derryan) time, open-marine carbonate-producing seas had covered the entire region of southern New Mexico, except possibly the Pedernal Uplift. In Middle Pennsylvanian (Desmoinesian) time, carbonate deposition reached maximum thickness. Except in the Sierra de Palomas, Desmoinesian strata are thicker than either Derryan or Morrowan. Development of this carbonate sheet continued over the entire area.

Influx of quartz sand occurred only locally in the Sacramento Mountains and in the northern San Andres Mountains. Upper Pennsylvanian (Missourian) strata in these areas are more argillaceous than Middle Pennsylvanian beds, and represent a renewed transgression preceding the great terrigenous influx of latest Pennsylvanian and Early Permian time. Major subsidence of the Orogrande Basin appears to have been a Late Pennsylvanian event; at this time it filled with cyclically deposited clastics and carbonates (Wilson, 1967; Kottlowski et al., 1956). Whether the Orogrande Basin was present in earlier Pennsylvanian time is not clear, although isopach maps of various intervals suggest its partial development. Thicker and more shaly beds are found in the eastern and southern parts of the basin.

Limited data indicate the Pedregosa Basin was not present much before Late Pennsylvanian time (Wilson, 1987; Wilson and Jordan, 1988). The sparse Lower and Middle Pennsylvanian outcrops and subsurface data in Chihuahua do not furnish much information on this question.

Oil and gas prospects

Opinions differ about general hydrocarbon prospects in the Orogrande and Pedregosa Basins. Greenwood et al. (1977) pointed out that during Pennsylvanian-Permian time the proximity of porous shelf-margin carbonates to basin-facies source rocks was favorable. They also made an encouraging analogy with the west Texas Permian Basin and its northern shelf, and presented a map (Greenwood et al., 1977: fig. 13) of numerous oil and gas shows in the area. In Chihuahua, in the several wells drilled by Pemex into Lower Permian (Leonardian-Wolfcampian) dolomites, only gas shows were found. On the east side of the Orogrande Basin near the town of Tularosa, gas was discovered by Houston Oil and Minerals Company in Middle Pennsylvanian sandstones (Greenwood et al., 1977: p. 1457).

Bridges (1984) as well as others, however, believed that a combination of hydrothermal mineralization, subsurface solution, flushing by meteoric waters during the major unconformity between Permian and Late Jurassic-Cretaceous time, and extensive normal faulting during the Tertiary may have essentially ruined prospects for the development of hydrocarbons in the Pedregosa Basin. Thompson (1976) disagreed.

Generally, dolomite reservoirs are scarce in Lower to Middle Pennsylvanian strata. However, thick porous dolomites are found in Middle Pennsylvanian to Lower Permian (upper Desmoinesian to Wolfcampian) strata in the section at Big Hatchet Peak (Thompson and Jacka, 1981). Although the original matrix porosity of these dolomites is low, their total porosity and effective permeability have been enhanced by solution channels.

Phylloid-algal bioherms produce widely around the Permian Basin in both Pennsylvanian and Permian strata (e.g. Townsend-Kemnitz and Anderson Ranch fields in Lea County, New Mexico, and Nena Lucia in Nolan County, Texas). Similar small, phylloid-algal mounds are seen in latest Pennsylvanian and Wolfcampian strata in southern New Mexico. These buildups may be reservoir objectives, but so far no significant porosity has been reported in them. The Lower and Middle Pennsylvanian *Chaetetes* and rugose coral thickets, which form mounds and reservoirs in Desmoinesian strata of the Paradox Basin of Utah, exist chiefly as prominent biostromes on the shelves around the Orogrande and Pedregosa Basins. On a more positive note, the presence of a wide carbonate shelf on the northeast flank of the narrow Pedregosa Basin offers ample opportunity for potential reservoir development if the proper combination of depositional facies and diagenesis has occurred.

Source beds may exist in the shaly-silty deep-marine(?) facies of the Orogrande and Pedregosa (Alamo Hueco) Basins. The slope facies of Desmoinesian-Missourian age, exposed in the Sheridan Canyon area of the Big Hatchet Mountains, contains a thin unit (6 m) of dark, smelly, very fine grained, laminated dolomite, but its total organic carbon (TOC) content averages only 0.3%. Thompson and Jacka (1981) found some moderately rich hydrocarbon source units in the outcropping Horquilla Formation at Big Hatchet Peak (0.3-0.5% TOC). Organic geochemical analyses indicate that the preserved kerogens were derived from woody plants, not marine algae, and therefore indicate that any source beds will produce only gas. Also deep burial under the thick Permian to Cretaceous strata would have produced a moderately high thermal alteration color index of 3+ in the Big Hatchet Peak area (Thompson and Jacka, 1981: p. 70).

Subsequent orogenic history of the region is somewhat discouraging:

1) Laramide (Late Cretaceous-early Tertiary) compressive folding and low-angle thrusting may have disrupted some Pennsylvanian-Permian reservoirs, but may have formed traps on others;

2) Extensive basin-and-range faulting in late Tertiary time probably disrupted many older reservoirs;

3) Deep burial during Mesozoic time and local igneous intrusions in Tertiary time heated organic matter past the oil window in some parts in and around the Orogrande and Pedregosa Basins. The most significant volume of gas found so far in the region flows at 200 Mcf (thousand ft^3)/day and is in a sandstone of Early and Middle Pennsylvanian age in the Orogrande Basin (Greenwood et al., 1977); the conjectured source beds may be the local shales.

References

Bachman, G. 0., and Myers, D. A., 1969, Geology of the Bear Peak area, Dona Ana County, New Mexico: U.S. Geological Survey, Bulletin 1271-C, pp. C1-C30.

Benne, R. E., 1975, The stratigraphy of the lower Gobbler Formation, Sacramento Mountains, New Mexico: Unpublished MA thesis, University of Oklahoma, Norman, 141 pp.

Bowsher, A. L., 1986, Late Paleozoic reef complexes of the northern Sacramento Mountains; *in* Southwest section of American Association of Petroleum Geologists Transactions and Guidebook of 1986 Convention: New Mexico Bureau of Mines and Mineral Resources Publication, pp. 49-72.

Bridges, L. W., 1964, Stratigraphy of Minas Plomosas-Placer de Guadalupe area; in Geology of Minas Plomosas-Placer de Guadalupe area, Chihuahua, Mexico: West Texas Geological Society Guidebook, Publication 64-50, pp. 50-64.

Bridges, L. W., 1984, Hydrocarbon potential of Chihuahua; *in* Geology and petroleum potential of Chihuahua, Mexico: West Texas Geological Society, Publication 84-80, pp. 124-125.

Connolly, W. M., and Stanton, R. J., 1983, Sedimentation and paleoenvironment of Morrowan strata in the Hueco Mountains, west Texas; in Geology of the Sierra Diablo and southern Hueco Mountains, west Texas: Society of Economic Paleontologists and Mineralogists, Permian Basin section, Publication 83-22, pp. 3664.

Diaz, G. T., and Navarro, G. A., 1964a, Lithology and stratigraphic correlation of the upper Paleozoic in the region of Palomas, Chihuahua; in Geology of Minas Plomosas-Placer de Guadalupe area, Chihuahua, Mexico: West Texas Geological Society, Publication 64-50, pp. 65-84.

Diaz, G. T., and Navarro, G. A., 1964b, Litologia y correlation estratigrafica del Paleozoica superior en la region de Palomas, Chihuahua, Mexico: Boletin de la Asociacion Mexicana de Geologos Petroleros, v. 16, pp. 107-120.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture; *in* Classification of carbonate rocks: American Association of Petroleum Geologists, Memoir 1, pp. 108-121.

Goetz, L. K., and Dickerson, P. W., 1985, A Paleozoic transform margin in Arizona, New Mexico, west Texas, and northern Mexico; *in* Structure and tectonics of Trans-Pecos Texas: West Texas Geological Society, Publication 85-81, pp. 173-184.

Greenwood, E., Kottlowski, F. E.,t and Thompson, S., III, 1977, Petroleum potential and stratigraphy of Pedregosa Basin—comparison with Permian and Orogrande Basins: American Association of Petroleum Geologists, Bulletin, v. 61, no. 9, pp. 1448-1469.

Jordan, C. F., and Wilson, J. L., 1971, The late Paleozoic section of the Franklin Mountains; in Robledo Mountains, New Mexico-

Franklin Mountains, Texas: Society of Economic Paleontologists and Mineralogists, Permian Basin section, Guidebook, pp. 7785.
Kottlowski, F. E., 1960, Summary of Pennsylvanian sections in southwestern New Mexico and southeastern Arizona: New Mexico Bureau of Mines and Mineral Resources, Bulletin 66, 187 pp.
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, Memoir 1, 132 pp.
McGlasson, E. H., and Seewald, K. 0., 1968, El Paso to Hueco Mountains; *in* Delaware Basin exploration: West Texas Geological Society, Publication 68-55, pp. 24-34.
Nelson, L. A., 1940, Paleozoic stratigraphy of Franklin Mountains, west Texas: American Association of Petroleum Geologists, Bulletin, v. 24, no. 1, pp. 157-172.
Perez, C., Charleston, S., and Malpica, R., 1984, Una Nueva localidad del Paleozoico en Mexico: Memorias VII Convencion Nadonal Sociedad Geologica Mexicana, pp. 11-26.
Pray, L. C., 1959, Stratigraphic and structural features of the Sacramento Mountains escarpment, New Mexico; in Sacramento Mountains: Roswell Geological Society and Society of Economic Paleontologists and Mineralogists, Permian Basin section, Guidebook, pp. 86-130.
Pray, L. C., 1961, Geology of the Sacramento Mountains escarpment, Otero County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 35, 144 pp.
Ross, C. A., 1973, Pennsylvanian and Early Permian depositional history, southeastern Arizona: American Association of Petroleum Geologists, Bulletin, v. 57, no. 5, pp. 887-912.
Schüpbach, M. A., 1973, Comparison of slope and basinal sediments of a marginal cratonic basin (Pedregosa Basin, New Mexico) and a marginal geosynclinal basin (southern border of Piemontais geosyncline, Bernina Nappe, Switzerland): Unpublished PhD dissertation, Rice University, Houston, Texas, 135 pp.
Seewald, K. 0., 1968, Pennsylvanian and Lower Permian stratigraphy, Hueco Mountains, Texas; in Delaware Basin exploration: West Texas Geological Society, Publication 68-55, pp. 45-49.
Spaw, J. M., 1977, Paleoenvironments of Middle Pennsylvanian *Chaetetes* lithotopes, Texas and New Mexico: Unpublished MA thesis, Rice University, Houston, Texas, 81 pp.
Stewart, W. J., 1958, Some fusulinids from the upper Strawn, Pennsylvanian of Texas: Journal of Paleontology, v. 32, pp. 1051-1070.
Thompson, S., III, 1976, Tectonics and igneous effects on petroleum accumulations in southwestern New Mexico; *in* Woodward, L. A., and Northrop, S. A. (eds.), Tectonics and mineral resources of southwestern North America: New Mexico Geological Society, Special Publication 6, pp. 122-126.
Thompson, S., III, 1980, Pedregosa Basin's main exploration target is Pennsylvanian dolostone: Oil and Gas Journal, v. 78, no. 42, pp. 202, 207, 210, and 215.
Thompson, S., 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, Circular 176, 125 pp.
Toomey, D. F., Wilson, J. L., and Rezak, R., 1977, Evolution of Yucca Mound complex, Late Pennsylvanian phylloid-algal buildup, Sacramento Mountains, New Mexico: American Association of Petroleum Geologists, Bulletin, v. 61, no. 12, pp. 2115-2133.
Toomey, D. F., and Babcock, J. A., 1983, Precambrian and Paleozoic algal carbonates, west Texas-southern New Mexico: Colorado School of Mines, Professional Contributions, no. 11, pp. 1-50.
Van Wagoner, J. C., 1977a, Lower and Middle Pennsylvanian rocks of the northern Sacramento Mountains-a study of contemporaneous carbonate and siliciclastic deposition in an active tectonic setting: Unpublished PhD dissertation, Rice University, Houston, Texas, 179 pp.
Van Wagoner, J. C., 1977b, Carbonate and siliciclastic fades of the Gobbler Formation; *in* Geology of the Sacramento Mountains, Otero County, New Mexico: West Texas Geological Society, Publication 77-68, pp. 53-66.
Wilson, J. L., 1967, Cyclic and reciprocal sedimentation in Virgilian strata of southern New Mexico: Geological Society of America, Bulletin, v. 78, pp. 805-818.
Wilson, J. L., 1971, Upper Paleozoic history of the western Diablo Platform, west Texas and south-central New Mexico; *in* The geologic framework of the Chihuahua tectonic belt: West Texas Geological Society, Symposium for R. K. DeFord, Publication 71-59, pp. 57-64.
Wilson, J. L., 1975, Carbonate facies in geologic history: SpringerVerlag, New York, 471 pp.
Wilson, J. L., 1987, The late Paleozoic geological history of southern New Mexico and Chihuahua: Geological Society of Mexico, Chihuahua section, Field Conference Guidebook, pp. 36-53.
Wilson, J. L., Madrid, A., and Malpica, R., 1969, Microfacies of Pennsylvanian and Wolfcampian strata in southwestern U.S.A. and Chihuahua, Mexico: New Mexico Geological Society, Guidebook to 20th Field Conference, pp. 80-90.
Wilson, J. L., and Jordan, C. F., 1988, The late Paleozoic geologic history of southern New Mexico and Chihuahua: Society of Economic Paleontologists and Mineralogists, Permian Basin section, Guidebook, Publication 88-28, pp. 79-88.
Zeller, R. A., Jr., 1965, Stratigraphy of the Big Hatchet Mountains area, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 16, 128 pp.
Zeller, R. A., Jr., 1975, Structural geology of Big Hatchet Peak Quadrangle, Hidalgo County, New Mexico (with commentary by S. Thompson, III): New Mexico Bureau of Mines and Mineral Resources, Circular 146, 23 pp.

Selected conversion factors*

TO CONVERT	MULTIPLY BY	TO OBTAIN
Length		
inches, in	2.540	centimeters, cm
feet, ft	3.048×10^{-1}	meters, m
yards, yds	9.144×10^{-1}	m
statute miles, mi	1.609	kilometers, km
fathoms	1.829	m
angstroms, Å	1.0×10^{-8}	cm
Å	1.0×10^{-4}	micrometers, µm
Area		
in^2	6.452	cm^2
ft^2	9.29×10^{-2}	m^2
yds^2	8.361×10^{-1}	m^2
mi^2	2.590	km^2
acres	4.047×10^{3}	m^2
acres	4.047×10^{-1}	hectares, ha
Volume (wet and dry)		
in^3	1.639×10^{1}	cm^3
ft^3	2.832×10^{-2}	m^3
yds^3	7.646×10^{-1}	m^3
fluid ounces	2.957×10^{-2}	liters, l *or* L
quarts	9.463×10^{-1}	l
U.S. gallons, gal	3.785	l
U.S. gal	3.785×10^{-3}	m^3
acre-ft	1.234×10^{3}	m^3
barrels (oil), bbl	1.589×10^{-1}	m^3
Weight, mass		
ounces avoirdupois, avdp	2.8349×10^{1}	grams, gr
troy ounces, oz	3.1103×10^{1}	gr
pounds, lb	4.536×10^{-1}	kilograms, kg
long tons	1.016	metric tons, mt
short tons	9.078×10^{-1}	mt
oz mt^{-1}	3.43×10^{1}	parts per million, ppm
Velocity		
ft sec^{-1} (= ft/sec)	3.048×10^{-1}	m sec^{-1} (= m/sec)
mi hr^{-1}	1.6093	km hr^{-1}
mi hr^{-1}	4.470×10^{-1}	m sec^{-1}

TO CONVERT	MULTIPLY BY	TO OBTAIN
Pressure, stress		
lb in^{-2} (= lb/in^2), psi	7.03×10^{-2}	kg cm^{-2} (= kg/cm^2)
lb in^{-2}	6.804×10^{-2}	atmospheres, atm
lb in^{-2}	6.895×10^{3}	newtons (N)/m^2, N m^{-2}
atm	1.0333	kg cm^{-2}
atm	7.6×10^{2}	mm of Hg (at 0° C)
inches of Hg (at 0° C)	3.453×10^{-2}	kg cm^{-2}
bars, b	1.020	kg cm^{-2}
b	1.0×10^{6}	dynes cm^{-2}
b	9.869×10^{-1}	atm
b	1.0×10^{-1}	megapascals, MPa
Density		
lb in^{-3} (= lb/in^3)	2.768×10^{1}	gr cm^{-3} (= gr/cm^3)
Viscosity		
poises	1.0	gr cm^{-1} sec^{-1} *or* dynes cm^{-2}
Discharge		
U.S. gal min^{-1}, gpm	6.308×10^{-2}	l sec^{-1}
gpm	6.308×10^{-5}	m^3 sec^{-1}
ft^3 sec^{-1}	2.832×10^{-2}	m^3 sec^{-1}
Hydraulic conductivity		
U.S. gal day^{-1} ft^{-2}	4.720×10^{-7}	m sec^{-1}
Permeability		
darcies	9.870×10^{-13}	m^2
Transmissivity		
U.S. gal day^{-1} ft^{-1}	1.438×10^{-7}	m^2 sec^{-1}
U.S. gal min^{-1} ft^{-1}	2.072×10^{-1}	l sec^{-1} m^{-1}
Magnetic field intensity		
gausses	1.0×10^{5}	gammas
Energy, heat		
British thermal units, BTU	2.52×10^{-1}	calories, cal
BTU	1.0758×10^{2}	kilogram-meters, kgm
BTU lb^{-1}	5.56×10^{-1}	cal kg^{-1}
Temperature		
°C + 273	1.0	°K (Kelvin)
°C + 17.78	1.8	°F (Fahrenheit)
°F − 32	5/9	°C (Celsius)

**Divide by* the factor number to reverse conversions.
Exponents: for example 4.047×10^{3} (see acres) = 4,047; 9.29×10^{-2} (see ft^2) = 0.0929.

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FIGURE 2A—Cross section of Lower and Middle Pennsylvanian strata southwest to northeast across southern New Mexico from Big Hatchet Peak, Big Hatchet Mountains, to Vinton Canyon, Franklin Mountains. Based on limestone petrography. Datum is top of Desmoinesian fusulinids. See Fig. 1 and Table 1 for locations and references to measured sections.

FIGURE 2B—Cross section of Lower and Middle Pennsylvanian strata south to north across south-central New Mexico from Vinton Canyon, Franklin Mountains, to the tunnel at High Rolls, Sacramento Mountains. Based on limestone petrography. Datum is top of Desmoinesian fusulinids. See Fig. 1 and Table 1 for locations and references to measured sections.


SW
NE
Big Hatchet Peak
New Well Peak
Big Hatchet Mountains
Sierra de Palomas
Vinton Canyon
Franklin Mountains
upper Desmoinesian
lower Desmoinesian
Desmoinesian ?
Derryan ?
Derryan
Morrowan
Horquilla Fm
Bishop Cap Fm
Berino Fm
La Tuna Fm
Fusulina
Fusulinella
Profusulinella
(118 Nelson)
(Stewart)
(98 Nelson)
mound
channel
shaly
sandst
congl
wmb
ool
grnst
CH
Kom
F
ft 325 — 100 m
160 — 50
0 — 0
vertical scale
Length of cross section about 100 mi (160 km)
Cycle
No chert
Shaly unit
Encrinite
Minor disconformity; shale or channel
Kom Range of Komia
CH Range of Chaetetes
F Fusulinids
Rugose corals
ool Oolite lime grainstone, some bioclastic – peloidal lime grainstone
grnst Bioclastic – peloidal lime grainstone
sandst Sandstone
congl Conglomerate
wmb White marker bed — a distinctive lime mudstone unit
mound Phylloid-algal buildups
Crinoid debris
CH Chaetetes, reefy
Colonial corals, reefy
Horn corals
Gastropods
Brachiopods
Bivalves
Bryozoans
Platy algae
Ooids
Peloids
Fusulinids
Foraminifera
Tubular foraminifera
Bioclastic
Chert
Microbioclastic debris, spicules
Shaly
Lithoclasts and intraclasts
Silty
Calcareous
V Igneous rock
W Lime wackestone (Dunham, 1962)
M Lime mudstone
P Lime packstone
G,g Lime grainstone
cov Covered interval


S
N
Vinton Canyon
Franklin Mountains
Pow Wow Canyon
Hueco Mountains
Negro Ed Canyon
Steamboat
Tunnel
Sacramento Mountains
Top of section is now known to be lower Desmoinesion (H-95)
upper Desmoinesian
Bishop Cap Fm
lower Desmoinesian
Berino Fm
Derryan
Morrowan
La Tuna Fm
Desmoinesian
Gobbler Fm
shaly unit
grainstone unit
bentonitic shale
sandst
sill
grnst
Fusulina insolita
Lowest exposed at fault
The basal sandy portion of the Gobbler Formation with Tertiary sills may be thicker than shown here—as much as 140 m, rather than 75 m
It is possible that the basal strata are lower Desmoinesian
Helms Sh.
(118 Nelson)
(Stewart)
(98 Nelson)
wmb
congl
ool
Fusulina
Fusulina-Wedekindellina (reworked)
Fusulinella (reworked)
Profusulinella (reworked)
Wedekindellina - Fusulina
Fusulinella-Fusulina
Millerella
Profusulinella
Triticites
ft 325 — 100 m
160 — 50
0 — 0
vertical scale
Length of cross section about 100 mi (160 km)
Cycle
No chert
Shaly unit
Encrinite
Minor disconformity; shale or channel
Kom Range of Komia
CH Range of Chaetetes
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Rugose corals
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congl Conglomerate
wmb White marker bed — a distinctive lime mudstone unit
mound Phylloid-algal buildups
Crinoid debris
CH Chaetetes, reefy
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Horn corals
Gastropods
Brachiopods
Bivalves
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Platy algae
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Peloids
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Tubular foraminifera
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