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LOWER PERMIAN (WOLFCAMPIAN) SEDIMENTATION IN THE OROGRANDE BASIN, NEW MEXICO*

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INTRODUCTION

Middle Mississippian time marked the beginning of the Orogrande Basin of south central New Mexico. Pennsylvanian sediments account for the bulk of the basinal deposits, and Lower Permian Wolfcampian sediments completed the basin filling. By the time the Middle Permian Yeso Formation was deposited, the identity of the Orogrande Basin had passed. In all, late Paleozoic sediments are more than 6,000 feet thick in this part of New Mexico.

Wolfcampian stratigraphy clearly illustrates the final filling of a fairly large marginal cratonic basin in south central New Mexico. Eight measured sections of Wolfcampian rocks here (Fig. 1) form the basis for this report; detailed petrographic analyses were made of these rocks with nearly 2,000 thin-sections, each with a corresponding polished slab of rock. Much of the following discussion of pre-Wolfcampian geology is based on studies by Kottlowski (1958, 1960, 1963, and 1965) and Wilson (1967).

MISSISSIPPIAN

Fine-grained calcareous clastics of the Caballero Formation (Kinderhook) were deposited along an east-west trend limited to Otero, Dona Ana, and southwestern Sierra County, in what was later to become the northern part of the Orogrande Basin. This formation attained a maximum thickness of 110 ft, and the facies indicate inner shelf environments.

Above this was deposited the much more widespread Lake Valley Limestone (Osage), which extends across most of southern New Mexico and all but the southwestern part of the Orogrande Basin. Crinoid-rich limestone and biohermal build-ups characterize this formation and indicate shelf conditions. Maximum thickness of the Lake Valley Formation (388 ft) occurs in the center of the basin in the San Andres Mountains and represents the initial subsidence of the Orogrande Basin.

The first truly basinal facies occurs in the overlying Rancheria Formation (youngest Osage? and Meramec), which is a black cherty limestone laid down in the central and southern part of the basin. At most, the Rancheria is 340 ft thick in west central Otero County. Rhythmic layering and a high siliceous content suggest quiet-water deposition.

The overlying Helms Formation (Chester) has nearly the same areal distribution as the Rancheria and consists of green calcareous shale, fossiliferous sandstone, and crinoidal or oolitic limestone. In view of these shallow-water Helms facies, the underlying Rancheria Formation was most likely deposited in no more than a few hundred feet of water. The Helms reaches its greatest thickness (315 ft) on the southeastern margin of the Orogrande Basin in Hudspeth County, Texas.

In general, all Mississippian formations in south-central New Mexico show a first order thickening to the south (a combination of depositional thickening to the south and of erosion to the north) and a second order thickening toward the basin center. In Late Mississippian and Early Pennsylvanian times, erosion of regional extent occurred on the margins of the Orogrande Basin, especially on the north and east sides. Sedimentation in the basin center was most likely continuous from the Mississippian into the Pennsylvanian.

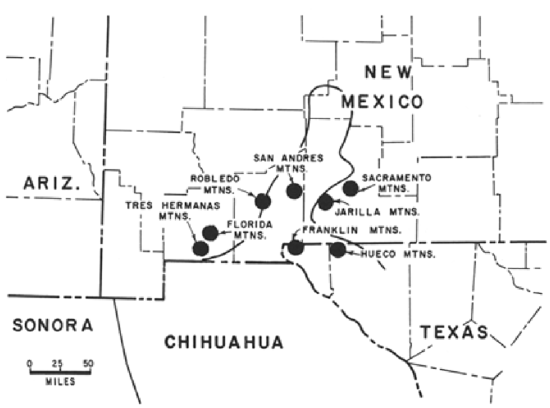

Figure 1. Index map of the Orogrande Basin showing the locations of measured sections discussed in this report; outline of the basin is shown by the 2,000 ft isopach (as shown in Figure 8).

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PENNSYLVANIAN

Rock units of this age in the Orogrande Basin include the Panther Seep Formation (San Andres Mountains), the lower part of the Laborcita Formation (Jarilla and Sacramento Mountains), the Holder, Beeman, and Gobbler Formations (Sacramento Mountains), and the Red House, Nakaye, and Bar B Formations (Caballo Mountains). Several unnamed units in this area (e.g., those in the southern San Andres Mountains) are probably Middle(?) Pennsylvanian.

More than 3,000 ft of Pennsylvanian rocks were deposited in the Orogrande Basin. Most of these were clastics shed from the Pedernal landmass on the east side of the basin. Evidently, this positive area rose intermittently to provide discrete units of clastic material. Wilson (1967) described the reciprocal nature of sedimentation on the narrow shelf west of the Pedernal landmass and in the Orogrande Basin itself. Distinct cycles of clastic and carbonate sediments indicate significant changes in Pennsylvanian sea level (up to 165 ft) with the limestone representing regressive conditions with little or no clastic influx. Such conditions favored the development of northtrending biohermal buildups at the edge of the narrow shelf on the eastern side of the Orogrande Basin.

To the southwest in the Florida Mountains, where Permian strata rest unconformably on Mississippian, a small uplift was emergent during the Pennsylvanian and acted as a secondary source for clastic material. This positive area separated the Orogrande Basin from the late Paleozoic Pedregosa Basin of southwestern New Mexico and Arizona. Kottlowski (1958) interpreted the Pennsylvanian Florida Islands as a precursor of the Mesozoic Burro uplift of southwestern New Mexico.

The thickest deposits in the Orogrande Basin are Late Pennsylvanian in age; in fact, approximately two-thirds of the Pennsylvanian section is Virgilian. Along with the great bulk of clastic material, these sediments include gypsum laid down in the southern part of the basin. The influence of tectonics upon sedimentation is exemplified by these deposits, in that the rising Pedernal landmass contributed most of the Orogrande Basin sediment when it was most emergent in Late Pennsylvanian time. The interpretation that the basin then had very shallow water and poor circulation is based on sedimentary structures observed in the basin center, which include flat-pebble conglomerate, algal laminations, caliche deposits, and mud cracks.

Throughout the Pennsylvanian, a shallow seaway at the northwest end of the Orogrande Basin led northward to connect the Orogrande with the San Mateo and Lucero Basins. By Early Permian, these smaller basins to the north had filled, leaving the rather isolated Orogrande Basin with its only open-water connection to the south.

Generally, the Permo-Pennsylvanian boundary is obscured by a gradational type of sedimentation in the Orogrande Basin, as clastic beds yield transitionally to the overlying carbonates. Late Paleozoic series in this area have been most successfully zoned with fusulinids; the basic zonation for Wolfcampian fusulinids is presented in Figure 2 (Jordan, 1971). Recently,

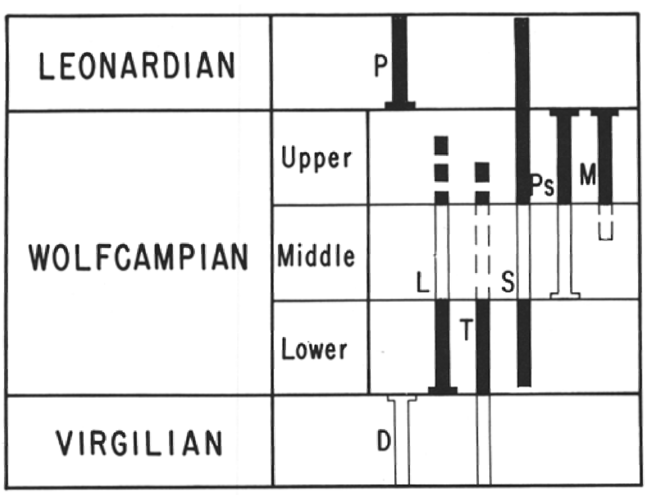

Figure 2. Fusulinid zonation of the Wolfcampian of west Texas and southern New Mexico. D = **Dunbarinella,** *L =* **Leptotriticites,** *T =* **Triticites,** *S =* **Schwagerina,** *Ps =* **Pseudoschwagerina,** *M =* **Monodiexodina,** *and P =* **Parafusulina.** *Lower Wolfcampian is defined by the* **Triticites-Schwagerina-Leptotriticites** *subzone, middle Wolfcampian by the* **Pseudoschwagerina-Leptotriticites** *subzone, and upper Wolfcampian by the* **Pseudoschwagerina-Monodiexodina** *subzone.*

conodont zonations have been used to subdivide the Mississippian, Pennsylvanian, and Permian in the Pedregosa Basin of southwestern New Mexico and Arizona (Butler, 1972 and Lane, 1974). It seems likely that these could also be used in the Orogrande Basin, especially in zones barren of fusulinids.

LOWER PERMIAN (WOLFCAMPIAN)

Both the Virgilian-Wolfcampian and the Wolfcampian Leonardian boundaries are difficult to determine in the Orogrande Basin. Formations assigned a Wolfcampian age include the upper part of the Panther Seep and Laborcita Formations, the Bursum Formation, the Hueco Limestone (the Hueco Group of the Franklin and Hueco Mountains), and the Abo Formation. The age of the Yeso Formation is generally considered to be Leonardian, although admittedly the time boundary has not been clearly determined. Wolfcampian paleogeographic features referred to below are shown in Figure 3.

Laborcita Formation

Otte (1959) proposed the name Laborcita for Lower Permian strata in the northern Sacramento Mountains that consist of rapidly changing facies of mudstone, limestone, sandstone, and conglomerate. The boundaries of the type section in Laborcita Canyon are the conformably underlying Holder Formation and the highest limestone in the Laborcita below the overlying Abo Formation. Sedimentary units of the type Laborcita are thin and quite variable, both laterally and vertically. Otte measured more than thirty sections of Pennsylvanian-Permian strata in the Sacramentos and recognized a southward thinning of the Laborcita. The thickest section in the northern area included over 750 ft of Laborcita; the thinnest complete southern section was 535 ft. Immediately south of here, Oppel (1959) measured ten stratigraphic sections within a total range of 2.5 mi to show that the formation is bounded at its top and bottom by unconformities. Above the upper unconformity are about 50 ft of conglomerate that may be the local equivalent of the Powwow Conglomerate in the Hueco Mountains. The lower unconformity is of regional extent and continues southward into Texas.

The Laborcita is also recognized in the Jarilla Mountains (Schmidt and Craddock, 1964). The basal part of the section here, however, has been rather thoroughly metamorphosed by intrusives of probable Tertiary age, and consequently the 1,526 ft of measured section is a minimum thickness. The lower half of the section contains conspicuously cross-bedded clastic metasediments (sandstone and siltstone) and metamorphosed limestone. The upper half consists of a very large covered area (Monte Carlo Gap) overlain by about 150 ft of dark gray unmetamorphosed limestone with minor amounts of siltstone. Both rock types are cross-bedded, fine grained, and low in bioclastic content. Carbonate rocks are either mudstone or wackestone with a low percentage of grains. Ostracods are most abundant in the sparse fauna; a few crinoids and shell fragments were also observed.

Extensive development of cross-bedding throughout the Laborcita and the great sedimentary thickness here suggest shallow-water conditions in a rapidly subsiding depocenter with the nearby Pedernal landmass shedding great volumes o sediment westward into the basin (Fig. 4). Schmidt and Craddock (1964) reported fusulinids from beds near the center o the formation; this, plus a few crinoids present near the top

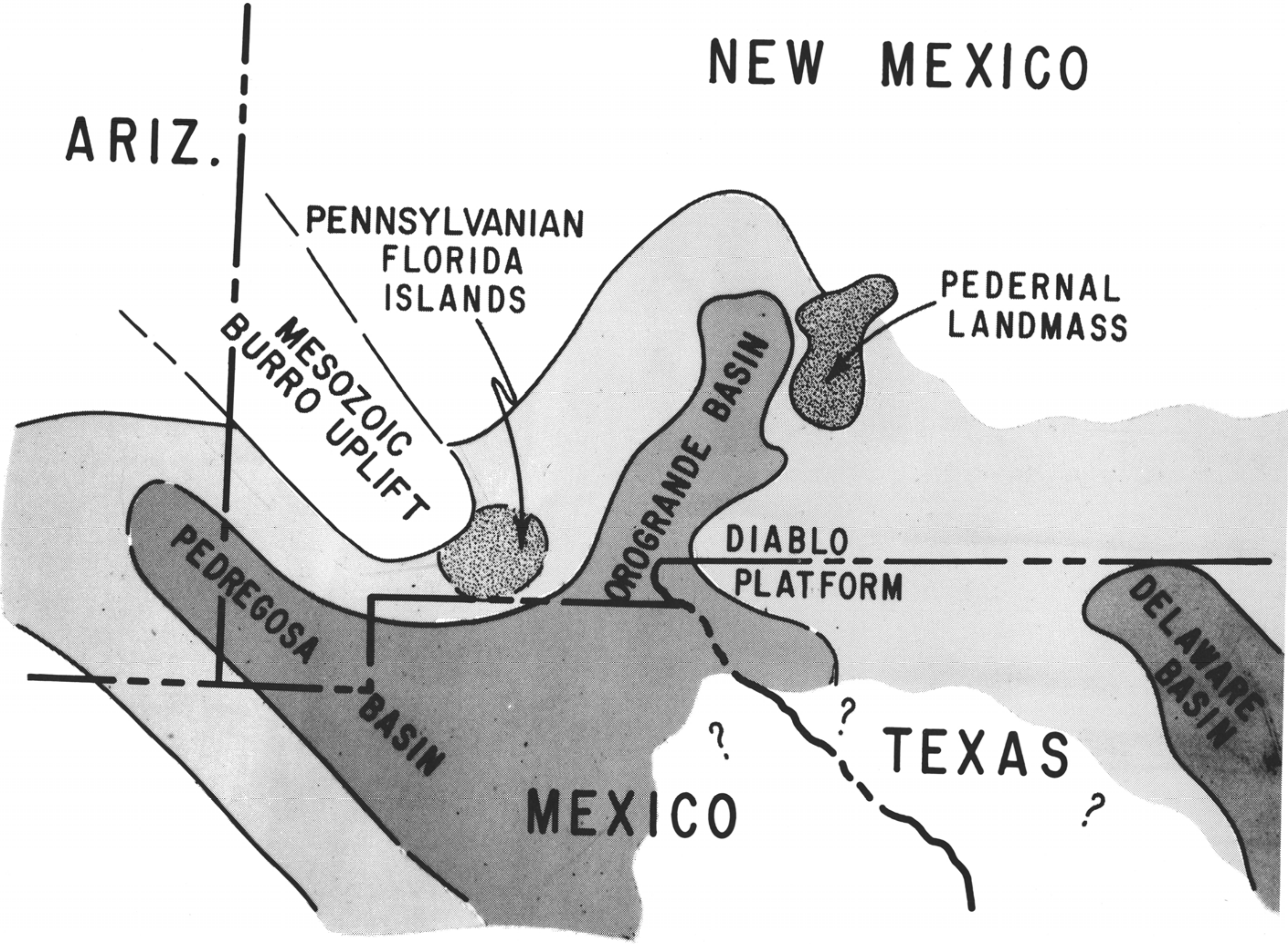

Figure 3. Wolfcampian paleogeographic map.

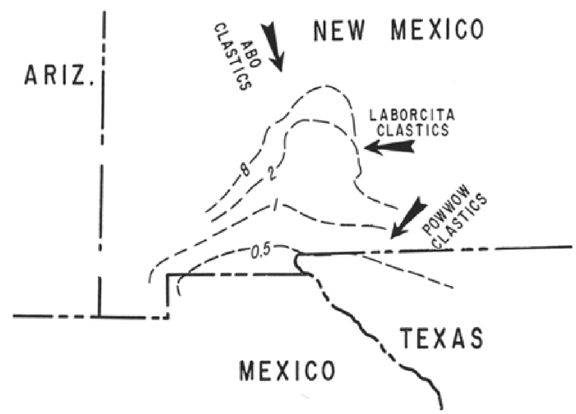

Figure 4. Clastic ratio map of Wolfcampian sediments; arrows indicate the direction of sediment transport.

indicate normal marine conditions for at least part of the formation. The fusulinids belong to the *Triticites-Schwagerina* Subzone and indicate an early Wolfcampian age for the Laborcita. This establishes correlation of the Laborcita with eastern outcrops of the Bursum, which it very much resembles lithologically (Steiner and Williams, 1968).

Bursum Formation

The type section of this formation, near the Oscura Mountains (Wilpolt, and others, 1946), is an interbedded sequence of marine limestone and red beds (arkosic sandstone, conglomerate, siltstone, and shale). The Bursum has been recognized in parts of south central New Mexico generally in very Lower Permian strata: in Mockingbird Gap, north of the San Andres range (Kottlowski, 1963); in Abo Canyon of the Manzano Mountains (Thompson, 1954); and in the Joyita Hills (Kottlowski and Stewart, 1970). Generally, an erosional unconformity bounds the base of the Bursum; locally, as in the Oscura Mountains, apparently conformable relationships are observed. The Abo Formation gradationally overlies the Bursum, the contact being placed at the top of the highest limestone in the Bursum interbeds. Thickness variations of the Bursum range from thin incomplete sections in eastern Socorro County, to 75 ft in Abo Canyon, 120 to 135 ft in the Oscura Mountains, and 325 ft in Mockingbird Gap. Generally the Bursum becomes thicker to the southeast; to the north and northwest, it apparently pinches out under the Abo Formation (Kottlowski and Stewart, 1970).

Limestone units of the Bursum thicken southward, where they are recognized as the Hueco Limestone. Thus, the Bursum Formation occupies a zone of transition between marine limestone of the Hueco and terrestrial sediments of the Abo. The presence of the Bursum marks the northernmost encroachment of Early Permian seas. Such transgressions were intermittent and of shorter duration to the north; the best interpretation of the Bursum is to consider it a basal Abo facies that reflects oscillations between marine and continental conditions.

The Bursum Formation, although essentially lower Wolfcampian, is not a synchronous unit, despite the common subsurface use of the term in the Delaware Basin for earliest Permian *pre-Pseudoschwagerina* beds. From westernmost outcrops of the Bursum, Jahns (1955) reported Virgilian fusulinids, whereas to the north and east, lower Wolfcampian fusulinids were identified from the Bursum by Thompson (1954). As discussed above, the Bursum Formation is correlated with the Laborcita Formation in the Sacramento and Jarilla Mountains, where similar fusulinid faunas have been found.

Hueco Limestone

The Hueco Limestone is present throughout the Orogrande Basin except in the north, where red bed sequences of the Abo and Bursum Formations form continental equivalents. Thick, almost entirely carbonate sections of the Hueco Limestone are present in west Texas and continue westward as far as the Florida and Tres Hermanas Mountains; the equivalents of the Hueco Limestone in southwestern New Mexico and south central Arizona include parts of the Horquilla Limestone, the Earp Formation, and probably the Colina Limestone.

Hueco Mountains

The type section of the Hueco Limestone is in the Hueco Mountains of west Texas. Williams (1963) here referred the following formations and members to the Hueco Group (from youngest to oldest): the Alacran Mountain Formation with the Deer Mountain Red Shale Member, the Cerro Alto Limestone, and the Hueco Canyon Formation with its basal Powwow Member. The total thickness of these units is about 1,600 ft. Youngest Paleozoic exposures available in this area are the top beds of the Alacran Mountain Formation. The bottom contact of the Hueco Group is a regional angular unconformity on which the Powwow conglomerate rests. The Hueco Group here is predominantly late Wolfcampian and late-middle Wolfcampian in age (Fig. 5).

The Powwow Member is overlain by the remainder of the Hueco Canyon Formation with about 500 ft of alternating packstone-grainstone couplets with thick to medium bedding. The Hueco Canyon Formation is basically a blanket of well rounded and worn foraminiferal detritus deposited in a shoaling environment on the western side of the Diablo Platform and is the best example of shoal-water facies encountered on the margins of the Orogrande Basin.

The overlying Cerro Alto Limestone crops out mainly in medium to thin beds which consist of much more micritic limestone and differ faunally from the underlying shoal-water facies. Two basic carbonate facies occur in this unit: 1) beds of platy algae (biostromal deposits) with codiacean and dasycladacean algae, foraminifera, *Tubiphytes,* bivalves, crinoids, bryozoa, and some corals, and 2) algal-foraminiferal limestone of shallow-water shelf facies.

Above this lies the thick- and medium-bedded Alacran Mountain Formation, with a diverse fauna of abundant algae and *Tubiphytes* in textures that are mainly wackestone and lime mudstone. Mudstone breccias occur and, together with mound development, indicate a period of biohermal buildup.

In summary, the type Hueco section begins with a basal conglomerate deposited on an unconformable surface; these rocks are followed by a thick sequence of interbedded biostromal and shallow-water shelf limestones. Above this is the Deer Mountain Red Shale Member which is overlain by biohermal and shallow-water shelf limestone.

Franklin Mountains

The Hueco section in the Franklin Mountains (Jordan and Wilson, 1971) totals 2,100 ft and, except for the lack of the

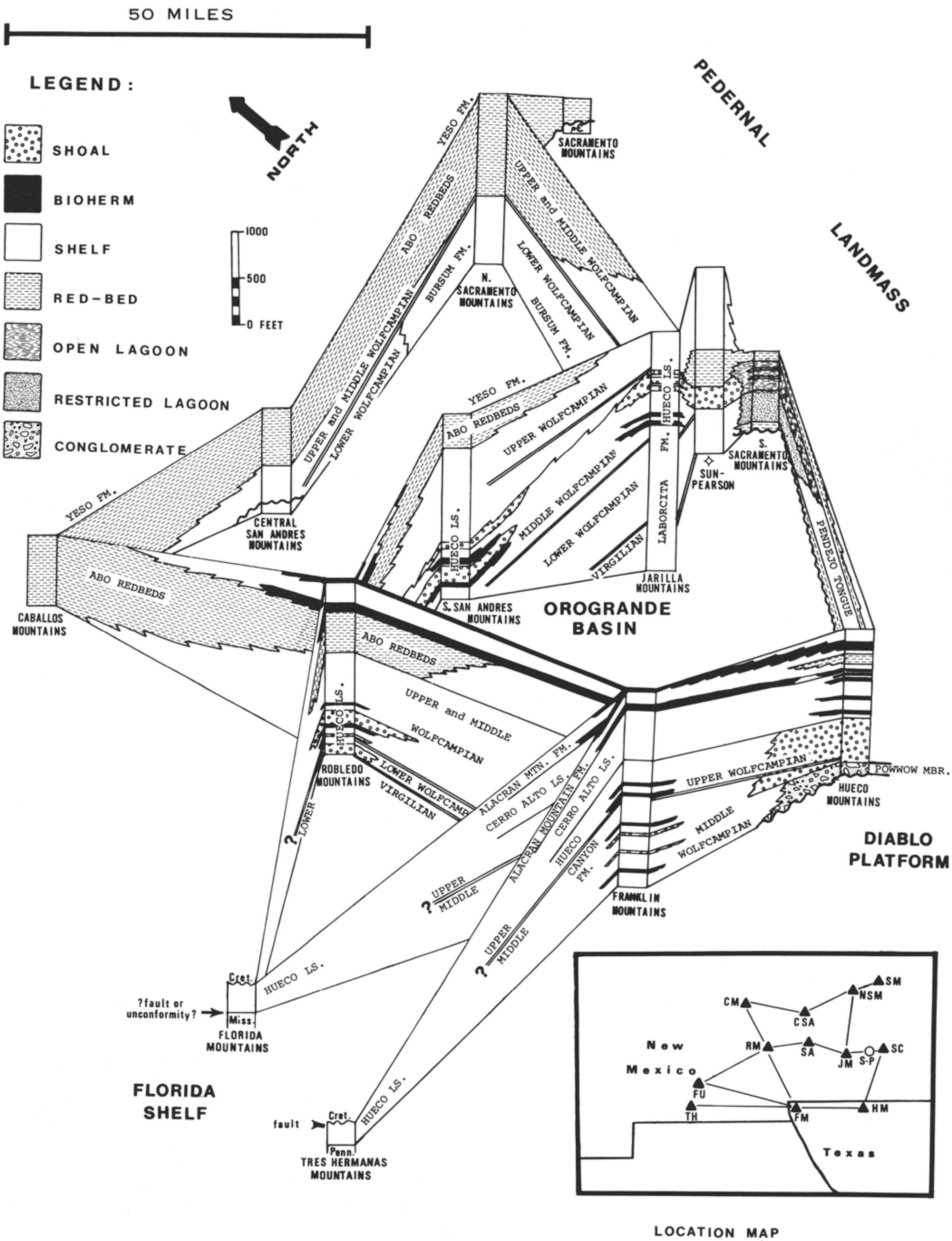

Figure 5. Wolfcampian fence diagram of the Orogrande Basin; view is to the northeast.

Deer Mountain Red Shale and Powwow Members, consists of the same formations recognized in the type section. The Hueco Limestone in the Franklin Mountains is chiefly upper and middle Wolfcampian (Fig. 5), and the lack of unconformities indicates that continuous sedimentation persisted through Late Pennsylvanian and Early Permian.

Throughout the section measured here, shallow-water shelf facies dominate over lesser amounts of biohermal and shoal-water facies. In the Hueco Canyon Formation, 1,350 ft of normal marine wackestones and packstones contain thin interbeds of algal plate biostromes (0 to 350 ft interval), grainstones of the shoal-water facies (350 to 650 ft), and more biostromal units (650 to 1,100 ft). Uppermost beds of this formation consist of shallow-water shelf limestone (1,100 to 1,350 ft).

In the overlying Cerro Alto Formation, medium-bedded shallow-water shelf carbonates are separated by siltstone and shale that become thicker toward the top of the formation. An increase in clastic influx is believed to account for the following changes in faunal composition between the Hueco Canyon Formation and the Cerro Alto Limestone: in the Cerro Alto, 1) brachiopods and *Tubiphytes* are considerably less abundant; 2) general abundance of foraminifera is the same, but tubular foraminifera dominate; and 3) a smaller number of smaller, long-ranging, more robust fusulinids (e.g., *Staffella)* replace the diverse *Schwagerina* and *Pseudoschwagerina* fauna of the Hueco Canyon Formation. Crinoids and dasycladacean algae, common in the Cerro Alto, indicate shallow, normal marine conditions.

The Alacran Mountain Formation in the Franklin Mountains begins with a thick, cherty, platy algal biostrome in the lower 50 ft of the formation. Above this occur about 175 ft of shallow-water shelf wackestones and packstones with a few thin beds of platy algae in the highest exposures. The Deer Mountain Red Shale Member (described here by Williams, 1966) was not observed in the Alacran Mountain Formation.

The Hueco section of the Franklin Mountains thus represents continuous Wolfcampian deposition, beginning with a thick cyclic sequence of shallow-water shelf limestone that becomes more clastic upward, ending with platy algal biostromal deposits. As observed in the Hueco Mountains, a general increase in lime mud occurs upward throughout the section, and a basal shoaling sequence is present.

Southern Sacramento Mountains

The Hueco section here (Fig. 5) shows about 625 ft of the Pendejo Tongue of the Hueco Limestone (Pray, 1961) resting conformably between the upper and lower tongues of the Abo. Fusulinids and ammonites were used by Pray in correlating the Pendejo Tongue with the Hueco Formation to the south.

Three subunits within the Hueco are recognized on the basis of lithologic and faunal characteristics. From bottom to top, they are 1) interbedded shale, siltstone, and mudstone or wackestone (occurring in the lower 300 ft) with gastropods, bivalves, ostracods, and tubular foraminifera; 2) 100 ft of limestone similar to that below but with abundant crinoids and with a much more diverse foraminiferal assemblage; and 3) about 200 ft of shale with thin limestone interbeds, some of which are similar in texture and composition to crinoid-rich beds lower in the section, and some similar to basal strata barren of crinoids.

Cyclic sedimentation here is reflected in thin clastic-carbonate couplets, of which there are probably more than 35 in this section. The environment of deposition is interpreted to have changed from restricted to open lagoonal conditions and finally to intermittent oscillations between the two.

Jarilla Mountains

In the Hueco section of the Jarilla Mountains (Fig. 5), about 900 ft of Hueco Limestone were measured, but as much as 130 ft more are exposed farther to the northwest where the section of Schmidt and Craddock (1964) was taken. The top of the Hueco is concealed by an igneous intrusion, and the total thickness is related to the amount of assimilation by intrusives rather than to depositional thickness; the lower contact of the Hueco is conformable upon the underlying Laborcita Formation. Fusulinids in the Hueco here date it as middle and upper Wolfcampian.

Basically, the rocks consist of alternating clastic and carbonate units; covered intervals and shale and siltstone saddles are common in the weathering profile between resistant limestone beds. Normal marine faunas persist throughout limestone sequences which consist primarily of fossiliferous packstones and wackestones with minor amounts of grainstone and mudstone. These rocks are predominantly dark to very dark gray, a characteristic found only in this and the Hueco section in the San Andres Mountains, both of which lie in the center of the Orogrande Basin.

A 33 ft thick unit of platy algae packstone marks the base of the Hueco Limestone in the Jarilla Mountains. Above this lie about 350 ft of shallow-water shelf sediment with a thin upper bioherm 160 to 180 ft above the base of the Hueco. Indications of shallow-water deposition include limestone pebble and granule conglomerate, cross-bedding, wavy laminations, scour marks, and the presence of *Tubiphytes* and dasycladacean algae. Above this occur about 200 ft of shoal-water facies. Grainstone, although relatively rare in the Jarilla section of the Hueco Limestone, is common in this interval; seven grainstone units were found interbedded with cross-bedded siltstone or shallow-water shelf carbonate. Algal plates and *Tubiphytes* are abundant in the beds above these shoaling units and again attest to the shallow-water shelf conditions for the Hueco Limestone deposited in the center of the Orogrande Basin.

San Andres Mountains

About 1,450 ft of Hueco Limestone were sampled in the San Andres range (Fig. 5). The Hueco overlies the Panther Seep Formation and is upper and middle Wolfcampian. The upper contact of the Hueco is transitional with the Abo Formation, as interbedded siltstone becomes dominant over interbedded limestone.

The lower Hueco Limestone consists of thick alternations of biohermal and shoal-water limestone. The section begins with a thick-bedded, cliff-forming, algal plate unit about 60 ft thick; in addition to codiacean algae, *Tubiphytes* and *Tetrataxis* are particularly abundant in these beds. Overlying this are about 150 ft of shoal-water carbonate, as indicated by oolitic grainstones. Next occur 150 ft of bioherm and bioherm flank deposits, very rich in *Tubiphytes* and *Tetrataxis;* another oolitic sequence of about 125 ft follows.

The upper two-thirds of the Hueco Limestone consist of interbedded shelf carbonate and cross-bedded siltstone. Limestones are generally dark to very dark gray and display wackestone and packstone textures with normal marine faunas. Although no significant amounts of *Tubiphytes* or algal plates occur in these beds, shallow-water deposition is indicated by sedimentary structures such as oscillation ripples and cross-bedding; the latter is common throughout the entire sequence.

Robledo Mountains

In the Robledo Mountains a comparatively thin Pennsylvanian carbonate section (Atokan through Virgilian) conformably underlies the Wolfcampian. Upper strata of the Hueco are unconformably overlain by Tertiary clastic and volcanic rocks (Kottlowski, 1963). A lack of continuous Wolfcampian exposures necessitated the assembling of a composite section based on nine components. Location of these sections was based on aerial photo interpretations and preliminary field studies by Frank Kottlowski (personal communication). The Hueco Limestone here contains a 414 ft thick medial Abo tongue, with about 1,050 ft of limestone below it and 400 ft above (Fig. 5).

The pre-Abo section of the Hueco contains two major subunits. The lower half represents shoal-water deposition of oolitic grainstone and calcirudite with some cross-bedded siltstone and sandstone; two thin intervals of bioherm or biostrome development also occur here. In the upper half of this Hueco subunit, shallow-water shelf environments are interpreted for interbedded limestone and fine clastics. Carbonate units are chiefly mudstone, with less common packstone and grainstone. Hueco strata below the Abo are generally unfossiliferous, but indications of normal marine faunas persist throughout the section; the scarcity of green algae and *Tubiphytes* is attributed to the large amount of clastics present. In the limited number of grainstones in this interval occur coated grains and even a few oolites. Thus, textural evidence, rather than faunal, indicates very shallow-water shelf conditions below the Abo.

About 400 ft of Hueco Limestone overlie the nearshore to terrestrial facies of the Abo tongue. The lowest Hueco beds above the Abo contain a series of algal plate beds, a total thickness of about 75 ft. Shallow-water shelf limestone with interbedded siltstone then continue upward to a 30 ft thick unit of thin biostromes near the highest exposures in the section.

In summary, the following shallow-water facies are observed in the Hueco Limestone of the Robledo Mountains: from the base upward, 1) shoaling facies, with medial and upper biostromes; 2) shallow-water shelf facies; 3) nearshore to terrestrial facies of the Abo; and 4) shallow-water facies with basal and capping algal plate beds.

Florida Mountains

The FU Section in the southern Florida Mountains (Fig. 5) lies on the western flank of the Orogrande Basin and indicates a partial thickness of the Hueco Limestone of about 350 ft. The basal contact of the Hueco Limestone here is either a fault contact or an unconformity. Despite the unresolved nature of the contact, it is apparent from the absence of Pennsylvanian rocks anywhere in the Floridas that the Hueco here is resting upon Mississippian strata. The upper contact of the Hueco is an unconformity, with Cretaceous sedimentary rocks resting on Permian.

The Pennsylvanian Florida Islands were submerged in the Wolfcampian as shelf sediments were deposited in this area. Thin-section studies indicate shallow-water normal marine conditions prevailed throughout the Florida Mountains' Hueco section, as evidenced by moderate amounts of crinoids, dasycladacean algae, and foraminifera. Two interesting features distinguish this Hueco Limestone section from those farther east: 1) the rocks have a very dark gray color and 2) large *Omphalotrochus* gastropods, common in the Wolfcampian-Leonardian Colina Limestone of southeastern Arizona, occur in the lower half of the Florida Mountain section.

Since this area and the Tres Hermanas Mountains to the south form a transition zone between the late Paleozoic stratigraphic units (and nomenclature) of the Pedregosa Basin and the Orogrande Basin, it is unfortunate that no diagnostic fossils were observed in the FU section to establish biostratigraphic zones.

Tres Hermanas Mountains

Approximately 250 ft of Hueco Limestone were measured in the Tres Hermanas Mountains. The lower 170 ft consists of metamorphosed carbonate; the upper 80 ft are dark gray normal marine shelf limestone with numerous crinoids and foraminifera. These carbonate units also contain *Omphalotrochus* gastropods, similar to those found in the Florida Mountains. Likewise, no age-significant fossils were found in the Tres Hermanas section.

Kottlowski and Foster (1962) obtained a more complete section and measured about 525 ft of Hueco Limestone in the Tres Hermanas. A basal chert pebble conglomerate of the Hueco rests unconformably on Pennsylvanian carbonates; a fault occurs at the top of the section. The presence here of cross-bedding, abundant conglomerate, algal plate limestone, and oolites indicates shallow-water, inner shelf conditions. Their mention of *Schwagerina* species from these rocks indicates only that the age of the Hueco is either Wolfcampian or Leonardian.

Abo Formation

The type section for the Abo Formation was described by Needham and Bates (1943) from Abo Canyon in the Manzano Mountains as 915 ft of red beds with about 60 percent red shale and 40 percent sandstone, arkose, and conglomerate; they note that no limestone is included in the type section. The Abo Formation was encountered in measured sections of the San Andres Mountains, Robledo Mountains, southern Sacramento Mountains, and the Hueco Mountains where its equivalents are recognized. In places, the lower contact of the Abo is unconformable (e.g., in the southern Sacramento Mountains); the upper contact is gradational in central New Mexico where it intertongues with the overlying Yeso Formation. From its source area in the north (Fig. 4), the Abo thins southward from 1,100 ft in the northern Sacramentos to zero in the Franklin Mountains (Jordan and Wilson, 1971). Conformable relationships exist where it intertongues with Hueco Limestone. This southward intertonguing is complex: Abo tongues occur both as medial or upper units in thick Hueco sections, and northward projecting tongues of the Hueco occur both as basal or medial units in thick Abo sections (Fig. 5). There are no obvious correlations of discrete red bed or limestone tongues.

Abo sections in the southern San Andres and Robledo Mountains are generally similar sequences of red shale and red

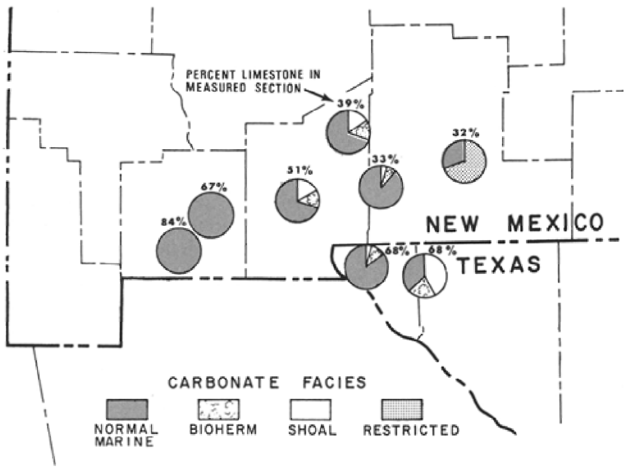

Figure 6. Distribution of Wolfcampian carbonate facies.

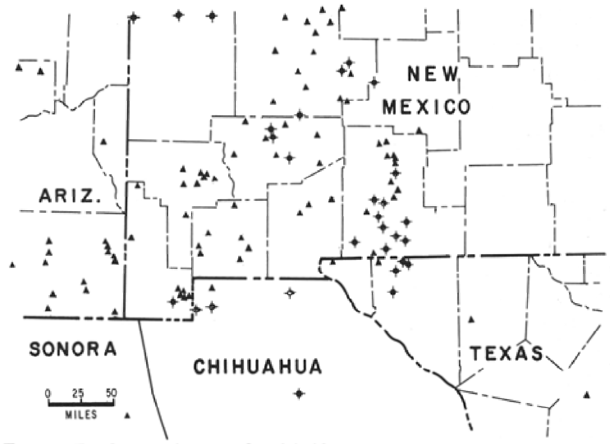

Figure 7. Control map for Wolfcampian isopach map of Figure 8; 110 control points shown, with triangles indicating outcrop sections. Additional points in the Delaware Basin are from Galley (1958) and are too numerous to show.

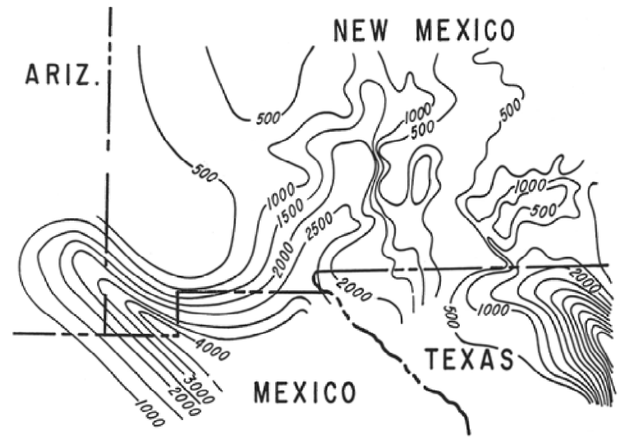

Figure 8. Regional isopach map of Wolfcampian sediments; contours in the Delaware Basin are from Galley (1958).

and yellow-brown, cross-bedded siltstone; less commonly, interbedded thin limestone units occur. In the San Andres Mountains, the Abo section is interpreted as an upward transition from the normal marine environment of the Hueco Limestone through an interval representing somewhat restricted conditions, finally to predominantly terrigenous sedimentation. Thin limestone units near the base of the Abo are wackestones with crinoids, pelecypods, and foraminifera; calcareous interbeds in the middle of the Abo are silty, argillaceous mudstone with a sparse ostracod fauna; no limestone was observed in upper Abo beds. In contrast, limestone units in the Abo of the Robledo Mountains are consistently normal marine interbeds throughout. Fossiliferous packstone here indicates shallow normal marine conditions by the presence of dasycladacean algae, crinoids, ostracods, coral, and foraminifera. Thickness relationships and the general fineness of the Abo clastics in these areas suggest a distant northern source.

In the southern Sacramento Mountains, the Abo is recognized as upper and lower tongues that enclose the Pendejo Tongue of the Hueco Limestone. Type sections for each were described from this area by Bachman and Hayes (1958). Otte (1959) and Pray (1961) demonstrated precisely how the medial Pendejo Tongue correlates with the Hueco Limestone in the Hueco Mountains. Below the lower tongue exists an unconformity of regional extent. Otte and Pray have clearly shown that coarse clastics of the lower Abo tongue in the Sacramentos came from the nearby Pedernal landmass. No fossils have been found in the lower tongue (Danley Ranch Tongue) by the writer or by Bachman and Hayes (1958). From the upper Abo tongue (Lee Ranch Tongue) the latter report fossil plants that have been interpreted as an indication of Leonardian age by Read (1957). Kottlowski (1963) and the writer, among others, doubt this interpretation and correlate the Lee Ranch Tongue with the Deer Mountain Red Shale Member of the Wolfcampian Alacran Mountain Formation in the Hueco Mountains (Fig. 5).

Equivalents of the Abo Formation in the Hueco Mountains consist of this red shale and of a basal conglomerate, the Powwow Member of the Hueco Canyon Formation. Middle Wolfcampian cobble and pebble conglomerate of the Powwow contain chert and highly fossiliferous limestone clasts.

SUMMARY

Initial subsidence of the Orogrande Basin began in Early to Middle Mississippian time. Siliceous limestone and arenaceous calcarenite, some of the first sediments to be deposited in the basin, suggest an initially "starved" situation; certainly, at this time, the Pedernal landmass had not been uplifted to serve as a ready sediment source.

In the Pennsylvanian, the Pedernal landmass began rising and shed large volumes of clastics into the basin. The greatest influx of material (the Laborcita and Panther Seep Formations) came in Virgilian time with the Pedernal at its highest.

At first, early Wolfcampian sedimentation continued in the same style as the underlying Virgilian clastics; it later gave way to interbedded clastic and carbonate sedimentation of the Bur-sum Formation which signaled the final influence of the Pedernal landmass in the northern part of the Orogrande Basin.

In the southern part, however, clastics of the Powwow Member were shed from the Pedernal in middle Wolfcampian time. Deposition of the Hueco Limestone then proceeded throughout the basin. Details of the Hueco facies distribution (Fig. 6) show the following features: 1) significant amounts of shallow-water carbonate in the basin center; 2) the largest percentage of shoal-water facies (i.e., in the Hueco Mountains) occurring on the western edge of the Diablo Platform; 3) large amounts of restricted facies deposited in coastal lagoons on a narrow shelf on the edge of the Pedernal landmass; and 4) the problematical shelf carbonate of the Florida and Tres Hermanas Mountains sections which serve mainly to separate the Orogrande sediments from those of the Pedregosa Basin.

Subsidence of the basin continued even after the Pedernal no longer supplied sediment to the basin. Abo red beds coming from the north kept up with subsidence and were laid down in shallow-water environments in the northern half of the basin, while Hueco carbonates were continually deposited in the southern half. By this time, the Pedernal was sufficiently eroded to allow it to be buried by Abo clastics.

In later Wolfcampian time, regressive carbonate built out across the southern part of the basin with biohermal and shallow-water shelf facies to complete the filling of the basin. In the north, Abo clastics flooded the nearly filled Orogrande Basin.

In Leonardian time, gypsum and anhydrite of the Yeso Formation were laid down across south central New Mexico in a northward thickening trend that was independent of any traces of the former Orogrande Basin; maximum thickness of the Yeso is 2,000+ ft in southwestern Lincoln County.

Thicknesses of Wolfcampian sediments of the Orogrande Basin are much less than those of the adjacent Pedregosa and Delaware Basins (Figs. 7 and 8). Moreover, deep-water environments certainly existed in parts of these basins, whereas the Orogrande Basin was always a shallow-water depocenter.

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