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PENNSYLVANIAN AND EARLY PERMIAN DEPOSITIONAL FRAMEWORK, SOUTHEASTERN ARIZONA

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INTRODUCTION

This summary of the Pennsylvanian and Early Permian depositional framework in southeastern Arizona and adjacent regions is based in large part on the data and conclusions presented earlier in more detail by Ross (1973, 1978). The general stratigraphy of the Pedregosa, Orogrande and Permian basins and much of the literature has recently been summarized by Greenwood and others (1977).

In southeastern Arizona, Pennsylvanian and Permian strata are well exposed in many of the Basin and Range uplifts, where they may be studied in considerable detail. Mesozoic and Cenozoic structures, including local thrust faulting, and the attendant possibility of considerable lateral displacement of some Paleozoic stratigraphic sections, tend to obscure the late Paleozoic tectonic and depositional framework in part of this region. Also much of the Pennsylvanian and Early Permian (Wolfcampian) strata are lithologically similar, being generally well-bedded, medium to light gray limestone and shale with minor amounts of sandstone and conglomerate that locally may reach a combined thickness of 1200 m (4000 ft). This combination of similar lithologic units that extend through considerable thickness of section and the overprint of major Mesozoic and Cenozoic structural disturbances have caused difficulty in recognizing stratigraphic position within this part of the section.

Studies of the biostratigraphy of this succession started with aid and encouragement from Floyd F. Sabins, Willis W. Tyrrell and others because of the abundance of fusulinaceans in several sections in the area (Sabins and Ross, 1963, 1965; Ross and Sabins, 1965; Ross and Tyrrell, 1965; Ross, 1969a). The results of these studies indicated that the different series and stages of the Pennsylvanian and Early Permian, as identified by fusulinacean zones, were represented by markedly different thicknesses in relatively nearby sections. Clearly additional field work and data was needed. In the succeeding three years the author measured and collected from many stratigraphic sections in southeastern Arizona (fig. 1) to form as complete a coverage as seemed possible. Many sections were restudied several times. A total of more than 800 fusulinacean-bearing rocks were collected and assigned ages in these stratigraphic sections.

STRATIGRAPHIC FRAMEWORK

The general stratigraphic framework (fig. 2) became apparent as data were processed (Ross, 1972, 1973). The lowest Pennsylvanian unit is of Morrowan age (fig: 3). In some sections this unit had previously been identified as the Black Prince Limestone, while in other sections these beds were included in the lower part of the Horquilla Limestone. The base of the Black Prince commonly is separated from older strata of Mississippian age by an accumulation of red shale, siltstone, chert pebbles and limestone conglomerate which marks an important unconformity in this region and also in other regions in the southwestern United States. The top of the Black Prince is separated from the overlying Horquilla in many sections by a similar accumulation of red shale, siltstone, chert pebbles and limestone conglomerate. This stratigraphic repetition of red clastic units is deceptive, because both red clastic units may not always be well developed in a particular section; in some sections only the lower one is exposed and in others only the upper one is apparent.

The Horquilla Limestone (figs. 4, 5, 6) includes a sequence of fusulinacean zones of Atokan (Derryan), Desmoinesian, Missourian, and, in some parts of the region, Virgilian and Wolfcampian age. Limestones of the Virgilian and Wolfcampian part of the Horquilia intertongue with clastic beds of the lower part of the Earp Formation. Within the Horquilla Limestone a number of unconformities are apparent from stratigraphic data, and these separate stratigraphic units each of which contain consistent fusulinacean zones. Thus, based on their fusulinacean content, it is possible to recognize within the Horquilla Limestone (fig. 2) 9 to 11 thin stratigraphic units that are bounded by unconformities. These units are of the type which Forgotson (1957) called formats—informal stratigraphic units that have marker-defined upper and lower boundaries; in these cases each is bounded by unconformities. The formats within the Horquilla are interpreted as transgressive and regressive, predominantly limestone, deposits that are similar in origin to cyclothems of the Mid-continent region, but were farther from major sources of clastic material. These transgressive-regressive sequences are considered to be the result of fluctuations in world sea levels that were caused by the storage of water as ice during glaciation of Gondwana during this time. This is comparable to the repeated lowering of sea level during the Pleistocene. Various lines of evidence suggest sea level fluctuations during the Pennsylvanian were commonly in the range of 65 m (200 ft) and perhaps as much as 200 m (650 ft) (Ross, 1970).

The lower formats of the Horquilla Limestone (fig. 4), B, C and D, are preserved in an overstep pattern in which each reached progressively farther to the north. Their depositional patterns suggest successively more complete inundation of the old continental shelf in Atokan (Derryan) and early Desmoinesian time. Formats D, E and F are widely distributed across most of the region. One of the few lithologically identifiable beds of regional distribution is a siltstone bed that appears within format F. Format G is truncated at its top and erosion at unconformity 8 has reduced the areal distribution of this format to the central part of the region.

Unconformity 8 separates Desmoinesian strata from Missourian strata throughout the region. As in other parts of the southwestern United States, this unconformity represents erosion of a longer duration and marks the introduction of changes in depositional patterns from those found within the

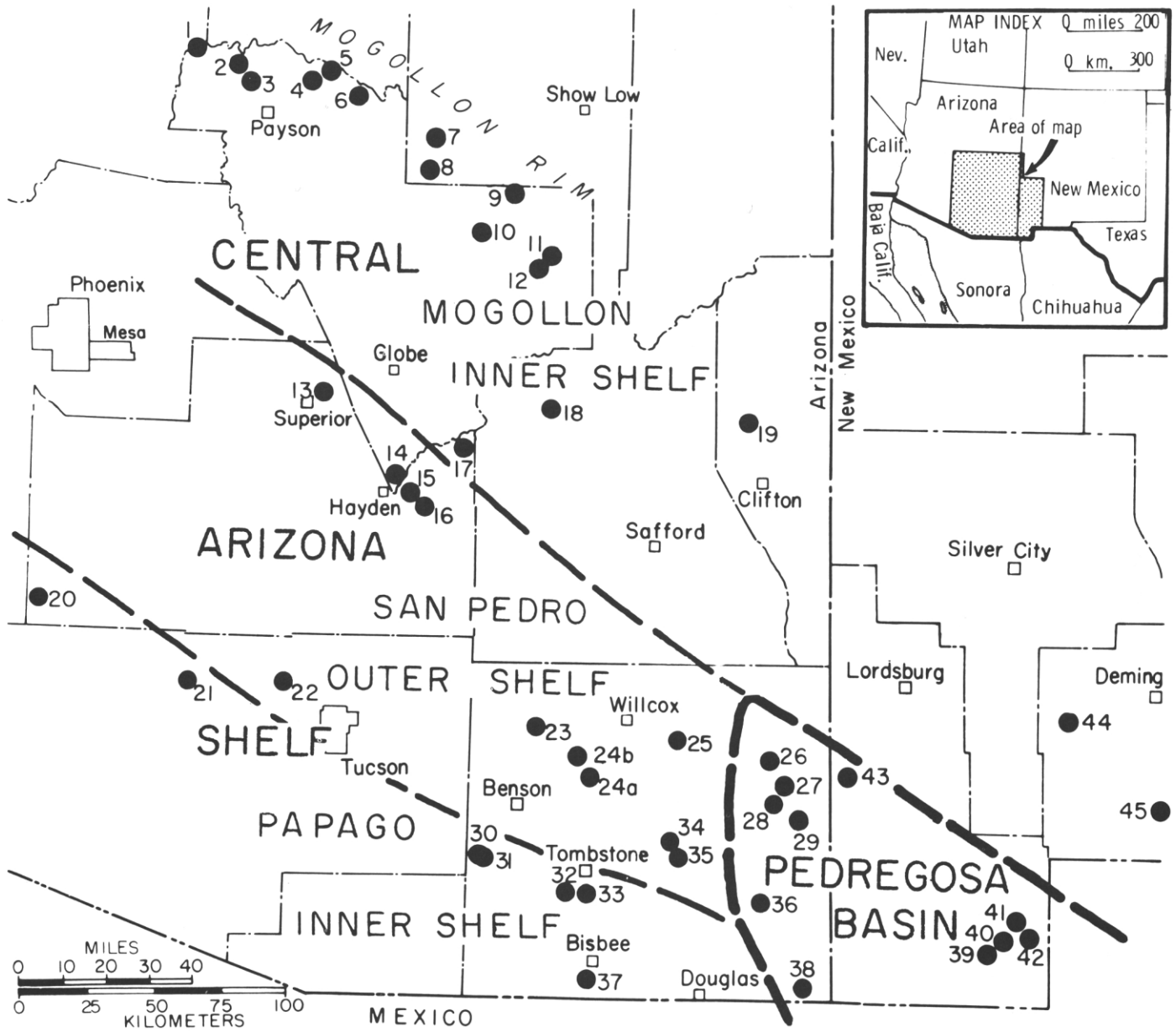


Figure 1. Location of measured sections used in compiling data for this study. Detailed descriptions of locations for each numbered locality are given in Ross (1973). Paleogeographic subdivisions are modified from Ross (1973).

Desmoinesian formats. In southeastern Arizona formats H, I, J and K (fig. 5) have thin reddish shale between limestone beds and the limestones are generally lighter gray and finer grained. These lithologic trends are more pronounced in both the northern and southwestern parts of the Central Arizona shelf (fig. 1).

The base of the Earp Formation is taken as the position "... where the thin shalt' limestones and reddish shales become dominant over the more massive limestone characteristic of the Horquilla" (Gilluly and others, 1954). This facies change usually occurs earlier, in format K, to the north along the Mogollon shelf and later, in format L, across the Central Arizona shelf and on the Arizona margin of the Pedregosa basin. However, on the eastern shelf of the Pedregosa basin, as in the Big Hatchet Mountains of southwestern New Mexico (Zeller, 1965), Horquilla Limestone lithologies continue through formats M and N (fig. 6), that is well into Wolfcampian time. In the north the Earp lithologies pass within short distances into red beds of the Supai Formation deposited in deltas, tidal flats, evaporitic lagoons, beaches, dunes, soil zones and other non-marine or marginal marine sediments.

Changes in Late Pennsylvanian sedimentary patterns are common elsewhere in the southwestern United States during the later part of the Virgilian, in deposits equivalent in age to formats K and L, and during early Wolfcampian, in deposits equivalent in age to formats M and N (Ross, 1975). Also of interest is the apparent general lack of evidence for rapid, short-lived, widespread transgressions and regressions in southeastern Arizona, and in the southwestern United States in general, in strata younger than format N. This appears to coincide with evidence from Gondwanan continents that shows glaciation ceased there shortly after the beginning of Permian time.

Miss.	Redwall Ls.	Escabrosa	Helms Fm.	Tesnus Fm.

Figure 2. Comparison of Pennsylvanian-Early Permian stratigraphic nomenclature for parts of southern Arizona, southern New Mexico and west Texas. See text for explanation of format column.

The upper part of the Earp passes through transitional beds into the dark gray Colina Limestone. In general these beds and younger Permian beds contain specialized facies faunas or are poorly fossiliferous in southeastern Arizona. As they have only a few fusulinacean-bearing beds (in the Concha Limestone; see Ross and Tyrrell, 1965), detailed correlations using fusulinaceans can not be established.

Large variations in thickness of many formats are also apparent from these measured sections. The Black Prince (fig. 3) increases gradually in thickness from northwest on the Central Arizona shelf toward the southeast into the Pedregosa basin, except for section 29 where it is nearly 80 m (260 ft) thinner than the regional trend. As all limestones in the Black Prince appear to have been deposited in shallow water, these local marked differences in thicknesses imply local contemporaneous uplift during Morrowan time. In the Horquilla, formats B through F (fig. 4) gradually increase in thickness from the southern part of the Mogollon shelf southeastward to the Pedregosa basin with only a few sections not fitting well into the regional trend. Section 29 is again conspicuous because it lacks format B, and format C is extremely thin. Also a thin erosional remnant of format G is preserved in Section 29, which is beyond the generally preserved areal extent of that format.

More marked variations in format thickness appear in formats H, I and J (fig. 5). Although each is fairly consistent in thickness in the central part of the Central Arizona shelf, they contain additional unconformities to the north in the Mogollon shelf area, some of which have eroded 50 m (165 ft) or more into the underlying stratigraphic succession. These formats thin near the northwestern end of the Pedregosa basin (Sections 29, 34 and 35) and then thicken abruptly on the basin flank (Section 36). Formats K and L have a more consistent thickness along the Mogollon shelf and central part of the Central Arizona shelf; however, they also thin markedly at the northwestern end of the Pedregosa basin (Sections 29, 34 and 35) and then thicken abruptly on the basin flank.

The greatest variations in thickness occur in formats M and N (fig. 6). Although some thickening of format N occurs on the Mogollon shelf adjacent to the Kaibab-Defiance-Zuni uplift because of an increased supply of clastic materials, the most pronounced anomalies again occur at the northwestern end of the Pedregosa basin. During deposition of these two formats, sections 28 and 29 (which previously had had unusually thin formats) became the sites of thick deposition and during these times the northwestern end of the Pedregosa basin became enlarged to include these sections.

Relation to Other Areas

The Pennsylvanian and Early Permian depositional history of southeastern Arizona (and probably most of southern New Mexico and west Texas) appears to be related to vertical adjustments which took place in the underlying continental crust during this time. Paleogeographic reconstruction for late Paleozoic time based on the theories of sea-floor spreading and plate tectonics suggests that northwestern Gondwana (South America) (fig. 7) approached the southern and southeastern edges of western Laurasia (North America) rapidly during Mississippian, Pennsylvanian and Early Permian time. Data from the folded and thrust-faulted Marathon geosyncline and the Glass Mountains of west Texas show this collision was accomplished in a series of steps (Ross, 1978). These general relationships can also be inferred from the sedimentary features of the Tesnus, Dimple and Haymond Formations in the Marathon fold belt (McBride and Thompson, 1964; Thomson and Thomasson, 1964, 1969; McBride, 1964, 1969).

Details of the structural and depositional history of the Marathon area suggest that during Chesterian and Morrowan time, thick sequences of graded-bedded clastics accumulated in a deep trough between the Gondwanan and Laurasian cratons. These clastics had their origins from the south. During late Morrowan and early Atokan time limestone accumulated on shelves, slopes and basins (Dimple Limestone), and the apparent origin of this carbonate material was from a northern shelf (i.e., Laurasia). During late Atokan and most of Desmoinesian time, graded-bedded clastic material again arrived from a southern source.

A major thrust faulting episode folded and crumpled these thick shelf, slope and basinal deposits to form a shallow marine shelf (Ross, 1967, 1969b) along the northern edge of Gondwana. These thrusted sediments were also shoved northward onto the southern edge of the Laurasian craton. This resulted in a depression of a narrow, but deep, forebasin and caused differential movement on older fault lineaments. The strong contrast in depositional facies between the Central Basin platform and the Midland and Delaware basins imme-

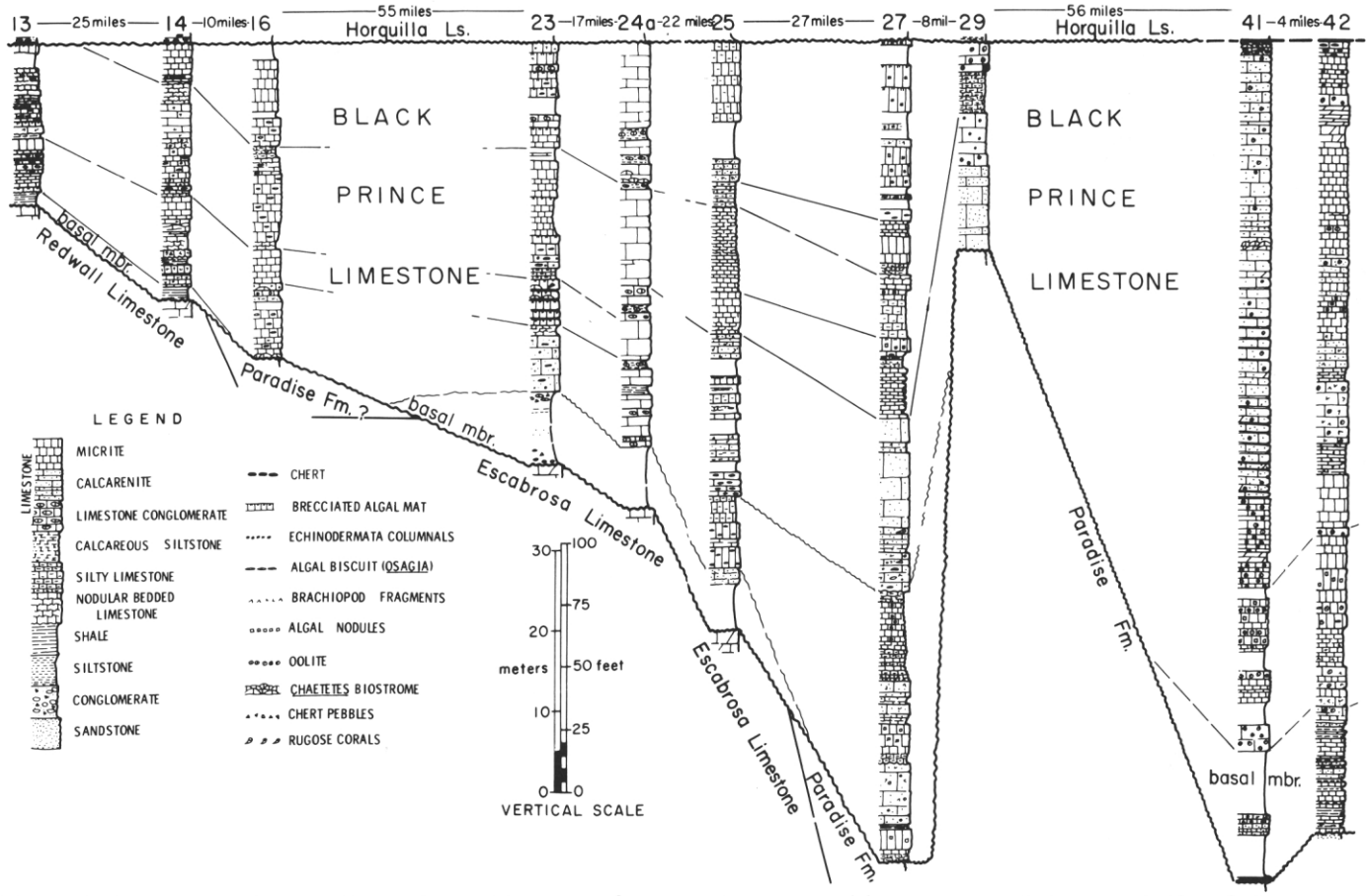


Figure 3. Measured sections of Black Prince Limestone from near its erosional limit on central Arizona shelf to Pedregosa basin (from Ross, 1973; copyrighted by Am. Assoc. Petroleum Geologists, reprinted with permission). See Figure 6 for location of line of section.

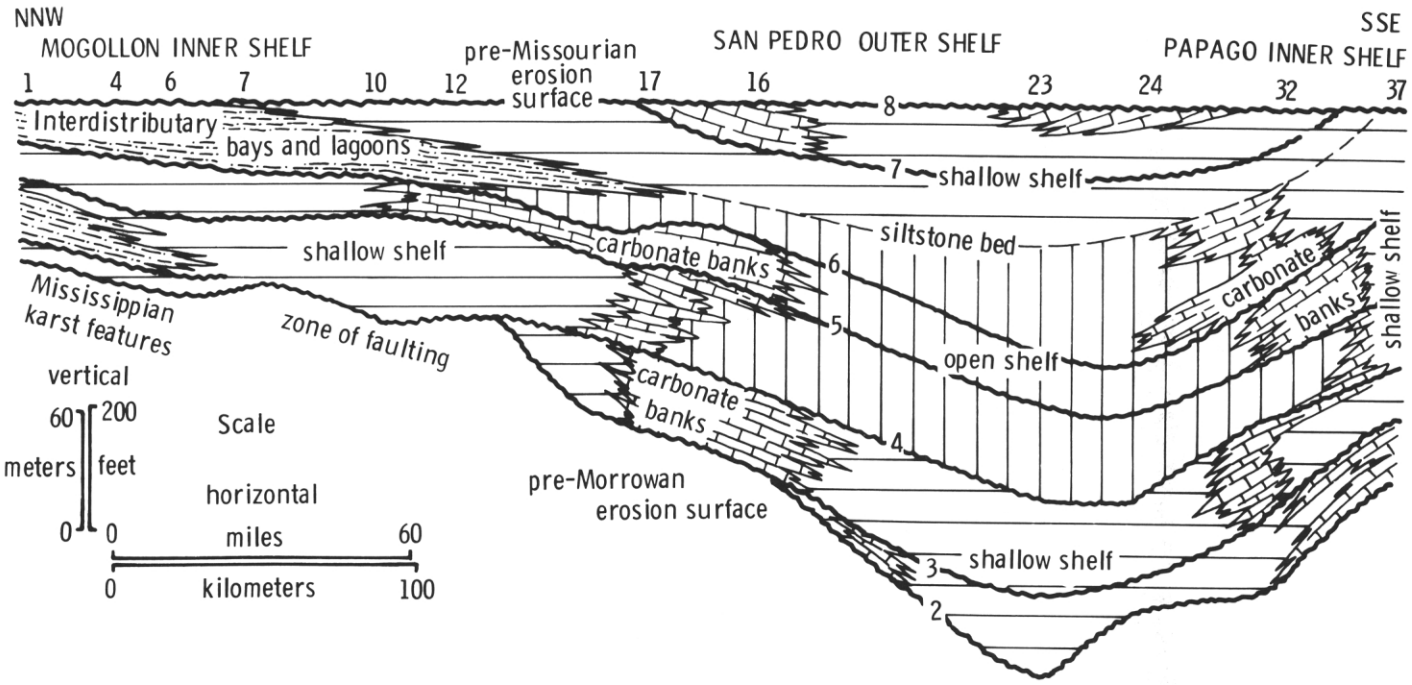


Figure 4. Reconstructed cross section of lower part (Atokan and Desmoinesian) of Horquilla Limestone from Mogollon inner shelf on north to Papago inner shelf on south (from Ross, 1973; copyrighted by Am. Assoc. Petroleum Geologists, reprinted with permission). See Figure 6 for location of line of section.

diately postdates this set of events. To the south shallow-water sediments of late Pennsylvanian age (Gaptank Formation) were deposited on this newly formed north-facing shelf. Starting near the end of late Pennsylvanian time and extending into the middle part of the Wolfcampian Epoch (Permian, i.e., Neal Ranch Formation), folding and finally major thrust faulting (Ross, 1963, 1978) again thrust the southern craton (and its accumulated wedge of deformed sediments) farther northwestward on the southwestern edge of the Laurasian craton. Although some relatively minor warping and structural adjustments occurred on the northern edge of the Marathon geosyncline in post-middle Wolfcampian time, this final thrusting completed the collision between the two cratonic masses.

Farther northwest on the Laurasian craton in southeastern and east central Arizona and southern New Mexico a number of major tectonic events also appear to be related to steps in this collision. Across most of southeastern and east-central Arizona and southern and central New Mexico, Morrowan strata are generally thin, shallow-water deposits and are separated from both underlying and overlying strata by regional unconformities. Atokan (Derryan) and Desmoinesian strata initially show progressive overlap of their repeated transgressions and regressions. Several tectonic interpretations are possible to explain this trend; however, I prefer the non-tectonic explanation which relates the extent of these transgressions and regressions to rise and fall of sea level caused by gradual decreasing amounts of ice remaining during "interglacials" in the Gondwanan ice fields.

The major stratigraphic break and unconformity at the end of the Desmoinesian, and associated changes in depositional patterns that mark the Missourian in much of this area, are associated by their timing with the major episode of folding and faulting that occurs in the Marathon orogenic belt. In southeastern Arizona this is shown by extensive erosion of late Desmoinesian strata (fig. 4), which left format G preserved in only the central part of the Central Arizona shelf and in the Pedregosa basin. Associated with the basal beds of Missourian age are reddish shales and siltstones indicating one or more nearby, low, erosional, elastic source areas. Several uplifts in the region were initiated or reactivated at this time. The Florida, Pedernal, Diablo, Central Basin platform and Matador structures began uplifting and the Pedregosa, Orogrande, Delaware and Midland basins began subsiding as pointed out by Greenwood and others (1977).

Several of these basins subsided more rapidly than sedimentation could keep pace, such as the Midland, Pedregosa and Orogrande basins that have well developed deep-water facies. By Virgilian time several of the uplifts, such as the Florida and Diablo uplifts, were largely covered by marine sediments. In southeastern Arizona, the southwestern side of the Pedregosa basin (fig. 5) was adjacent to a shallow carbonate shelf during Missourian and Virgilian time. Both shelf and basin were tectonically active, but opposite in their vertical movements.

During the later part of Virgilian time and in early Wolfcampian time, the cratonic uplifts and basins in this broad region from southeastern Arizona, southern New Mexico and west Texas showed increasing activity. Differences in lithologic facies became more pronounced. Sources and amounts of elastic deposits increased significantly at the beginning of Wolfcampian time and most of the uplifts were elevated rap-

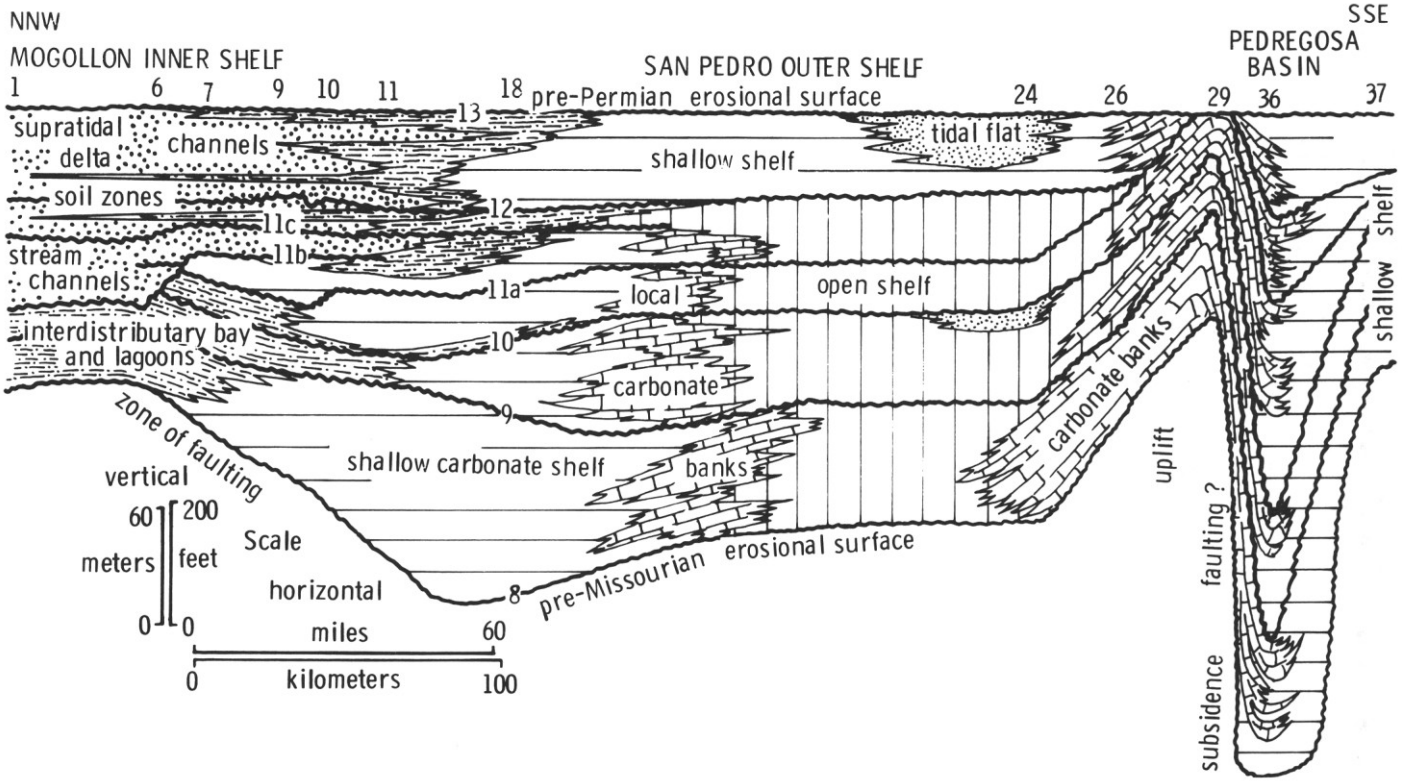


Figure 5. Reconstructed cross section of upper parts (Missourian and Virgilian) of Horquilla Limestone from Mogollon inner shelf on north to the Pedregosa basin on southeast (from Ross, 1973; copyrighted by Am. Assoc. Petroleum Geologists, reprinted with permission). See Figure 6 for location of line of section.

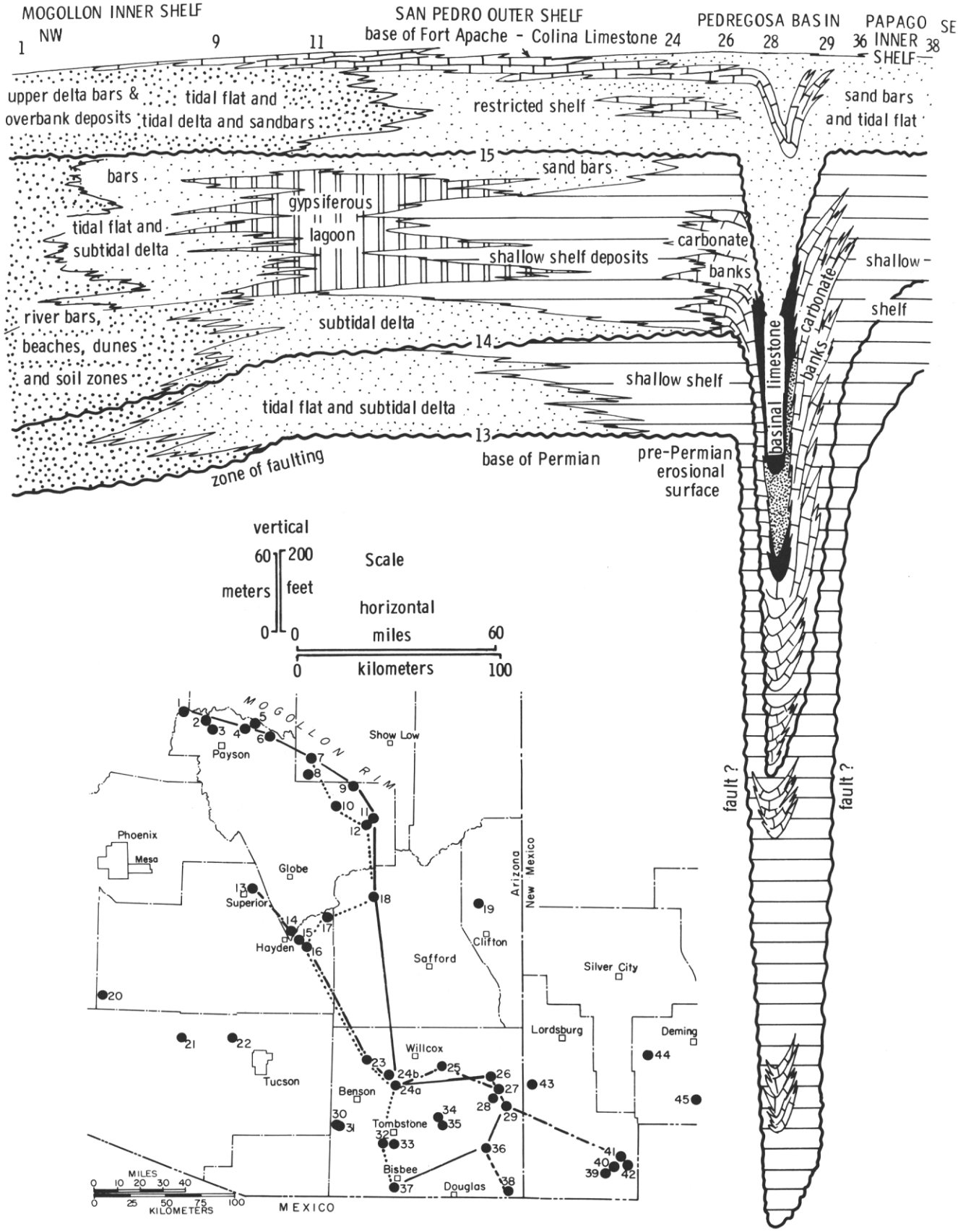


Figure 6. Reconstructed cross section of most of Earp Formation, locally part of Horquilla Limestone, and part of Supai Formation from Mogollon inner shelf on north to Pedregosa basin and Papago inner shelf to southeast and south (from Ross, 1973; copyrigted by Am. Assoc. Petroleum Geologists, reprinted with permission). See inset map for location of line of this section and also sections shown in Figures 3, 4 and 5.



Figure 7. Location of structures influencing depositional history in southeastern Arizona, southern New Mexico and west Texas and their relation to the collision of Laurasia and northwestern Gondwana during the Pennsylvanian and Early Permian.

idly. The increased amount of clastic sediment was transported across the shelves and eventually almost filled a number of rapidly subsiding deep basins that were nearby (fig. 6). These general tectonic relations are seen in the larger uplifted blocks, such as in the Florida, Hueco and Otero uplifts, where middle to late Wolfcampian strata commonly rest unconformably on much older strata.

Most of these basins remained centers of thick deposition, including the Val Verde fore-basin just north of the Marathon orogenic belt and the Pedregosa basin, although several others, such as the Orogrande basin, showed no apparent rapid increase in subsidence. The southwestern edge of the Pedregosa basin appears to have been controlled by the position of a block which had been positive during most of Virgilian time. During the early part of Wolfcampian time, the movement on this particular block reversed and the block became strongly subsiding and was included in an expanded Pedregosa basin.

By late Wolfcampian time, tectonic activity in these uplifts and basins was abruptly and greatly diminished, as was the tectonic activity in the Marathon orogenic belt. Former uplifts generally became sites of erosion and gradual depositional onlap. Late middle to late Wolfcampian strata are comparably uniform in thickness and lack the abrupt and strongly contrasting changes in thickness and lithofacies between areas of former uplift and basins. In the Glass Mountains this time period is represented by deposition of the Lenox Hills Formation, which rests unconformably on the last and possibly most important thrust sequences of the Marathon orogenic belt, which are dated as middle Wolfcampian (Ross, 1963). Most, if not all, of the Hueco Limestone on the Diablo platform and in southern New Mexico was deposited after this cessation of tectonic activity. In southeastern Arizona and southwestern New Mexico that part of the Earp Formation that is younger than unconformity 15 belongs to this interval. In southeastern Arizona and southwestern New Mexico only in the deepest part of the Pedregosa basin is there a significant local thickening of this part of the succession, and there basinal limestones are covered by shallower water deposits.

CONCLUSIONS

Many questions remain about the relationships between the depositional history of southeastern Arizona, local tectonic events and the structural mechanisms associated with the collision of northwestern Gondwana and southwestern Laurasia. However, it is possible, with considerable confidence, to reconstruct and to compare in considerable detail the age relations of most of the Pennsylvanian and Early Permian strata and tectonic events in this region and those in the Marathon orogenic belt. Much remains to be done, particularly in Chihuahua, Sonora and Coahuila, in tracing the southern extent of the Marathon orogenic belt, the ages of its thrusting episodes, and in establishing a comparable history of Pennsylvanian and Early Permian uplifts and basins. Although much of that region is covered by thick sequences of Jurassic and Cretaceous deposits, some Pennsylvanian and Permian sediments are exposed farther to the south. It is also possible that more detailed analyses of the southeastern highlands of Venezuela with its Wolfcampian and early Leonardian faunas (Thompson and Miller, 1949) may help in these interpretations.

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