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PALEOTECTONICS OF THE LATE PALEOZOIC PEÑASCO UPLIFT, NACIMIENTO REGION, NORTHERN NEW MEXICO

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Abstract—The late Paleozoic Peñasco uplift was a north-trending basement block that approximately coincides with the present Sierra Nacimiento. Rise of the uplift began after deposition of the Lower Pennsylvanian (Morrowan) Osha Canyon Formation and possibly during deposition of the Middle Pennsylvanian (Atokan) Sandia Formation, which appears to thin depositionally toward and is absent along the axis of the uplift. Principal orogenic rise of the uplift is recorded in coarse clasts of Precambrian rocks in the Middle and Upper Pennsylvanian Madera Formation. A growth fault, inferred to have been active along the southwest part of the uplift during Madera time, may have bounded the entire west side of the uplift. Clastic debris eroded from Precambrian rocks of the uplift during this time was shed into adjacent marine, carbonate basins. Lower Permian (Wolfcampian) strata of the terrestrial Abo Formation appear to thin locally across the uplift, suggesting that the uplift retained positive tendencies despite being buried by continental deposits. Limited thickness data for the Lower Permian (Leonardian) Yeso Formation may indicate that the north end of the uplift was slightly positive at this time. Rise of the uplift ceased prior to deposition of the Upper Triassic Chinle Group.

INTRODUCTION

Late Paleozoic uplifts of New Mexico, Colorado and northeastern Arizona (Fig. 1), commonly referred to as the Ancestral Rocky Mountains (Lee, 1918, 1923; Eardley, 1951), were recognized by many of the early field geologists in this region (Melton, 1925; VerWiebe, 1930; Heaton, 1933; Thompson, 1942). These uplifts shed coarse arkose and other terrigenous clastics into adjoining marine basins (Read and Wood, 1947). Wood and Northrop (1946) showed in their mapping of the Sierra Nacimiento that although Pennsylvanian strata are present surrounding these mountains, they are absent from the crest of the range at two localities where Permian Abo Formation is present on Precambrian rocks. These two localities are near the northern and southern ends of the range, leading Wood and Northrop (1946) to infer that Pennsylvanian rocks were absent along the entire uplift prior to deposition of Permian strata (Wood and Northrop, 1946, fig. 6). They also indicated that the Permian System thins stratigraphically across the top of the range (Wood and Northrop, 1946, fig. 7). Read and Wood (1947) named this late Paleozoic uplift the Peñasco axis; it is here called the Peñasco uplift.

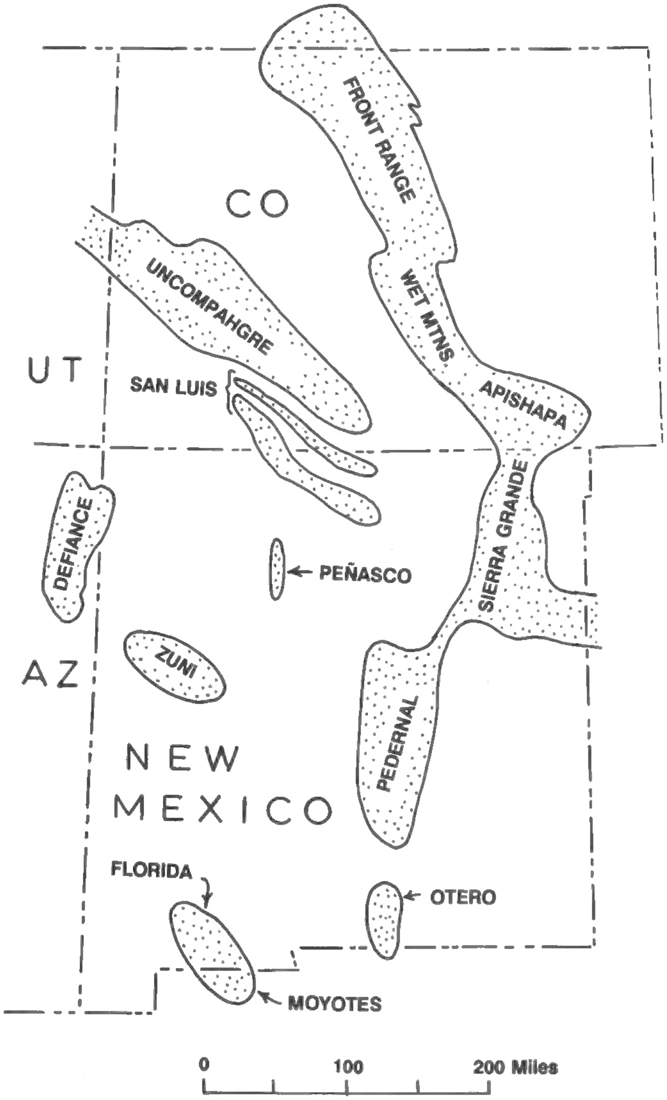

FIGURE 1. Late Paleozoic uplifts of New Mexico and adjacent areas. Modified from Woodward (1988).

Using drill-hole data from Shell Oil Company wells, Baars (1982) showed that Pennsylvanian strata are thin near the center of the Albuquerque basin of the Rio Grande rift and inferred that a north-trending positive structure of Pennsylvanian age in the subsurface of the basin extends southward from the Peñasco uplift to the Joyita Hills near Socorro.

Geologic mapping and stratigraphic studies by the author and graduate students at the University of New Mexico during the 1970s have provided additional data for a more detailed interpretation of the late Paleozoic tectonics of the Nacimiento region. Further studies of the lithofacies and biostratigraphy of the Madera Formation would allow a more detailed analysis of the rise of the Peñasco uplift and determination of the provenance of the clastic component of the Madera Formation. The following discussion presents the current data and paleotectonic interpretation.

ROCK UNITS

Rocks ranging in age from Precambrian through Tertiary are present in the Nacimiento region. Precambrian crystalline igneous and metamorphic rocks are overlain unconformably by Mississippian, Pennsylvanian, and Permian strata (Fig. 2). Inasmuch as only the Paleozoic rocks reflect the late Paleozoic deformation, the younger strata are not discussed in detail.

Two principal exposures of Precambrian rocks are present, in the northern and southern Nacimiento uplift, where 30 rock units have been mapped (Woodward, 1987). Although there are marked differences between the Precambrian rocks in these two areas, they both are characterized by the presence of metavolcanic and metasedimentary inclusions within gneissic rocks that were emplaced as plutons and by non-foliated granitoid plutons emplaced after regional, synkinematic metamorphism.

The Precambrian rocks are overlain locally and nonconformably by the Arroyo Peñasco Formation (Mississippian). This formation is preserved only in small blocks that were downwarped prior to extensive erosion that removed the Arroyo Peñasco from the higher intervening areas before deposition of Pennsylvanian strata. In the southern Nacimiento uplift at Los Piños and Peñasco Canyons, the type section

Triassic	Upper	Chinle Group	700-1,250
	Middle	Moenkopi Formation	0-80
Permian	Leonardian	Glorieta Sandstone	0-100
		Yeso Formation	10(?)-525
	Wolfcampian	Abo Formation	100(?)-2,900(?)
Pennsylvanian	Virgilian	Madera Formation	0-1,775
	Missourian		
	DesMoinesian		
	Atokan	Sandia Formation	0-225
	Morrowan	Osha Canyon Fm.	0-71
Mississippian	Chesterian	Log Springs Fm.	0-50
	Meramecian	Arroyo Peñasco Formation	0-120
	Osagean		
Cambro-Ordovician	Syenite, irregular dike-like bodies		
Precambrian	Metamorphic and igneous rocks		

FIGURE 2. Stratigraphic units of Paleozoic and Triassic age in the Nacimiento region. Thicknesses in feet.

for the Arroyo Peñasco Formation, the unit is about 120 ft thick and consists of 2-5 ft of sandstone to pebble conglomerate at the base overlain by limestone with locally abundant nodular chert (Armstrong and Mamet, 1974, 1979).

The Log Springs Formation (Mississippian) is locally present where it unconformably rests on the Arroyo Peñasco Formation. At the type section in Peñasco Canyon the Log Springs consists of 8-10 ft of red, hematitic shale overlain by 30-40 ft of dusky-red to orange, arkosic to conglomeratic sandstone. The basal part is interpreted as a residual soil and the upper part appears to be terrestrial clastic deposits derived from Precambrian crystalline rocks and Mississippian carbonates (Armstrong, 1967).

The Osha Canyon Formation is a Pennsylvanian (Morrowan) unit consisting of marine limestone and shale (DuChene et al., 1977). This unit, present at only a few localities in the Nacimiento uplift, rests unconformably on the Log Springs Formation, the Arroyo Peñasco Formation, or on Precambrian crystalline rocks (DuChene, 1973). This unit has a maximum thickness of 71 ft near the Guadalupe Box where it is unconformably overlain by the Sandia Formation.

In the Nacimiento region the Sandia Formation has a maximum thickness of 225 ft near Guadalupe Box. The Sandia thins by sedimentary onlap to a zero edge about 2.5 mi to the west and to the north, approaching the crest of the Nacimiento uplift. At most localities other than Guadalupe Box the Sandia Formation is nonconformable on Precambrian rocks. This unit is composed of coarse-grained sandstone, shale, silty sandstone, and argillaceous limestone of Atokan age (Wood and Northrop, 1946). The Sandia grades into the overlying Madera Formation.

Wood and Northrop (1946) divided the Madera Formation into a lower gray limestone member and an upper arkosic limestone member in the Sierra Nacimiento. The Madera is up to 1775 ft thick in the Nacimiento region (Fig. 3). The lower member consists of thick-bedded, dense, fossiliferous limestones with a few interbeds of arkosic sandstone and calcareous shale. The upper member is composed of arkosic limestone and arkose with interbedded calcareous shale. Feldspar and granitic clasts are locally abundant in a matrix of crinoidal micrite. Arkose becomes increasingly abundant upward until it predominates near the top of the Madera. The upper contact of the Madera with the Abo Formation (Permian) is conformable and is placed at the top of the stratigraphically highest,thick bed of fossiliferous marine limestone. The Madera rests conformably on the Sandia Formation at Guadalupe Box, but elsewhere in the Nacimiento region it is unconformable on older units ranging from the Osha Canyon Formation to Precambrian rocks (Fig. 4). Locations of measured sections and other critical localities for the Pennsylvanian in the Nacimiento region are listed in Appendix 1.

The Abo Formation (Permian) consists of brownish-red to maroon shale and lenticular beds of dark reddish-brown, coarse-grained, arkosic sandstone. Pebble- and cobble-conglomerates are locally abundant in this unit in the northern part of the Nacimiento uplift. The Abo ranges in thickness from about 100(?) ft (Woodward, 1987) to 2,900(?) ft (Gibson, 1975) (Fig. 5). Where the Madera Formation is absent the Abo Formation is nonconformable on Precambrian rocks.

The Yeso Formation (Permian) is conformable on the Abo Formation and was divided into two members by Wood and Northrop (1946). The lower Meseta Blanca Member is composed of reddish-orange, well-sorted, fine- to medium-grained, quartzose sandstone in beds 2 to 25 ft thick. The overlying San Ysidro Member consists of reddish-brown and dark red, fine-grained sandstone and interbedded siltstone in beds up to 3 ft thick. Thickness of the Yeso ranges from 525 ft near Guadalupe Box (DuChene, 1973) to 10(?) ft near the northern end of the Nacimiento uplift (Gibson, 1975) (Fig. 6).

The Glorieta Sandstone is present only in the southern part of the Nacimiento uplift, being cut out northward by an unconformity at the base of the Chinle Group (Triassic). The Glorieta, conformable on the Yeso Formation, consists of up to 100 ft of whitish to pale-yellow-gray, fine- to medium-grained quartz arenite.

The Triassic Moenkopi Formation is concordant with the Glorieta Sandstone and is absent in the northern Nacimiento uplift because of the unconformity at the base of the Chinle Group. The Moenkopi Formation was mapped as the Bernal Formation (Permian) by numerous workers in the Nacimiento uplift (Wood and Northrop, 1946; Woodward, 1987), but Lucas and Hayden (1989) correlated the Bernal with the Moenkopi Formation of Middle Triassic age. In the Nacimiento uplift, the Moenkopi is up to 80 ft thick and is made up of fine- to medium-grained, thin-bedded, reddish brown to purplish brown, poorly sorted sandstone with subordinate gray-tan, medium-grained sandstone.

The Chinle Group (Upper Triassic) is marked by a basal unconformity that cuts stratigraphically lower northward. In the southern Nacimiento uplift the Chinle rests on the Moenkopi Formation and at the north end it overlies the Yeso Formation.

PALEOTECTONICS

Thicknesses and lithologies of the Madera Formation provide the bulk of the data for interpreting the paleotectonic evolution of the Peñasco uplift (Figs. 3, 4). Prior to rise of this uplift, northern New Mexico during Mississippian time was a shallow, carbonate, marine shelf where the Arroyo Peñasco Formation was deposited on a peneplained Precambrian craton. In Late Mississippian time, broad epeirogenic uplift exposed the

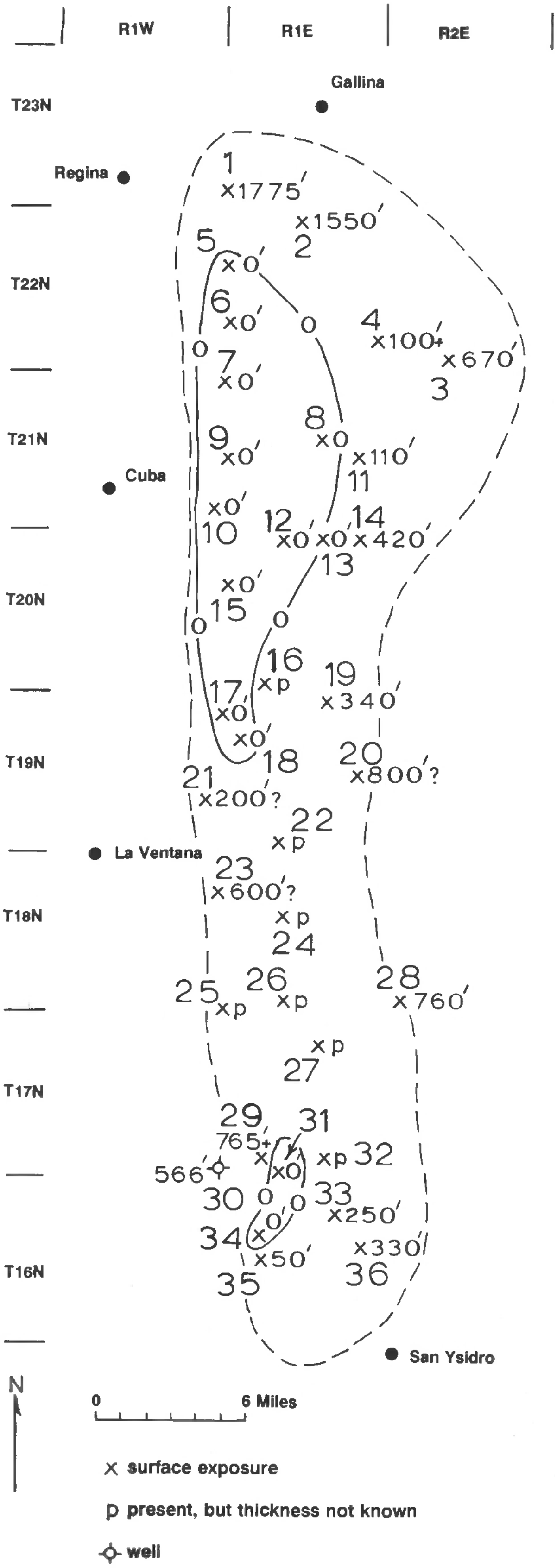

FIGURE 3. Localities of measured sections showing thickness (in feet) of the Madera Formation and localities where the Madera was absent prior to deposition of Permian rocks in Sierra Nacimiento. Dashed line indicates outline of present Nacimiento uplift. Modified from Woodward (1987).

Arroyo Peñasco Formation to erosion and weathering, resulting in removal of this unit from large areas of northern New Mexico (Armstrong and Mamet, 1979). The overlying Log Springs Formation appears to be totally terrestrial (Armstrong, 1967). The basal hematitic shale is a residual soil developed on the Arroyo Peñasco Formation, and the upper part of the Log Springs consists of coarse-grained detritus derived from the Arroyo Peñasco and from Precambrian igneous and metamorphic rocks (Armstrong, 1967).

The Osha Canyon Formation probably was deposited on a shallow, marine shelf during a time of tectonic quiescence by a transgression onto an erosion surface at the top of the Log Springs Formation and on Precambrian rocks. Uplift and erosion of the Osha Canyon Formation took place during late Morrowan or early Atokan rise of the Peñasco uplift, leaving only a few erosional remnants to be covered by younger Pennsylvanian strata (DuChene et al., 1977). No other major orogenic uplift occurred in New Mexico during Morrowan time (Bachman, 1975).

The Sandia and Madera Formations, both unconformable on the Osha Canyon Formation, onlap Precambrian rocks northward and westward from Guadalupe Box (Fig. 4). Thinning and eventual disappearance of the Sandia Formation to the north and west appears to be depositional (DuChene, 1973), suggesting that rise of the Peñasco uplift began during Sandia time. The absence of coarse-grained feldspar along with igneous and metamorphic clasts indicates that the uplift did not attain significant elevation above sea level at this time.

Principal rise of the Peñasco uplift occurred during deposition of the Madera Formation, with pulses of uplift marked by arkosic beds, becoming more frequent and stronger, until the uplift was locally emergent. Intercalated with limestones of the lower part of the Madera are thin, arkosic sandstone beds. Upward, the limestone locally becomes arkosic with angular feldspar clasts up to 1 in. across, and locally, angular granitic fragments as much as 10 in. in diameter. Arkose beds become thicker and more abundant upward, dominating the upper part of the formation. The uppermost part of the Madera also has interbeds of reddish-brown sandstone, mudstone, and shale, lithologies typical of the gradationally overlying Abo Formation.

Three stratigraphic sections (locations 29, 30 and 31, Fig. 4) in the southern part of the Nacimiento uplift are especially important to paleotectonic interpretations and are briefly described below. In Los Piños Canyon on the west side of the uplift (location 29) the Madera is at least 745 ft thick, with the upper contact being a fault. The formation consists of massive, poorly sorted, angular to subangular, coarse-grained arkose containing Precambrian crystalline fragments up to 10 in. across. Interbeds of massive, arkosic limestone and green to maroon, arkosic mudstone are present. The lower 300 ft of this section is Atokan to Desmoinesian, based on paleontologic evidence (Wood and Northrop, 1946). Approximately 3 mi to the east (location 33, Fig. 4) a complete section of the Madera consists of 255 ft of interbedded maroon to green mudstone, massive limestone, and minor coarse-grained arkose.

Martinez (1974) suggested that the Peñasco uplift was an east-tilted block bounded by a fault on the west side during Madera time; the conglomeratic section at Los Piños Canyon (location 29, Fig. 4) appears to have been derived from the fault scarp and the finer grained section to the east (location 33) was derived from the gentle slope on the east side of the uplift. This inferred fault is within the present Nacimiento uplift, about 0.3-0.7 mi east of the fault that bounds the west side of the Sierra Nacimiento (Woodward et al., 1977). The trend and extent of this inferred growth fault is not known precisely, but it may have coincided with the northwest-striking fault that bounds the Madera Formation at this locality (Fig. 7). Alternatively, the growth fault may have been east of the Madera outcrop and is now bounded by Precambrian rocks, but has not been recognized. The fault was probably no farther east of the Madera outcrops (locations 29 and 30, Fig. 4) than 1 mi because at that distance (location 31, Fig. 4) the Abo Formation rests directly on Precambrian rocks (Woodward et al., 1977). The absence of other Madera outcrops with a conglomeratic facies may indicate that the fault was of limited extent or perhaps such outcrops were eroded or are not exposed.

Large, angular feldspar and quartz clasts are found in the Madera at the north end of the uplift (Gallina quadrangle) but are absent in correla-

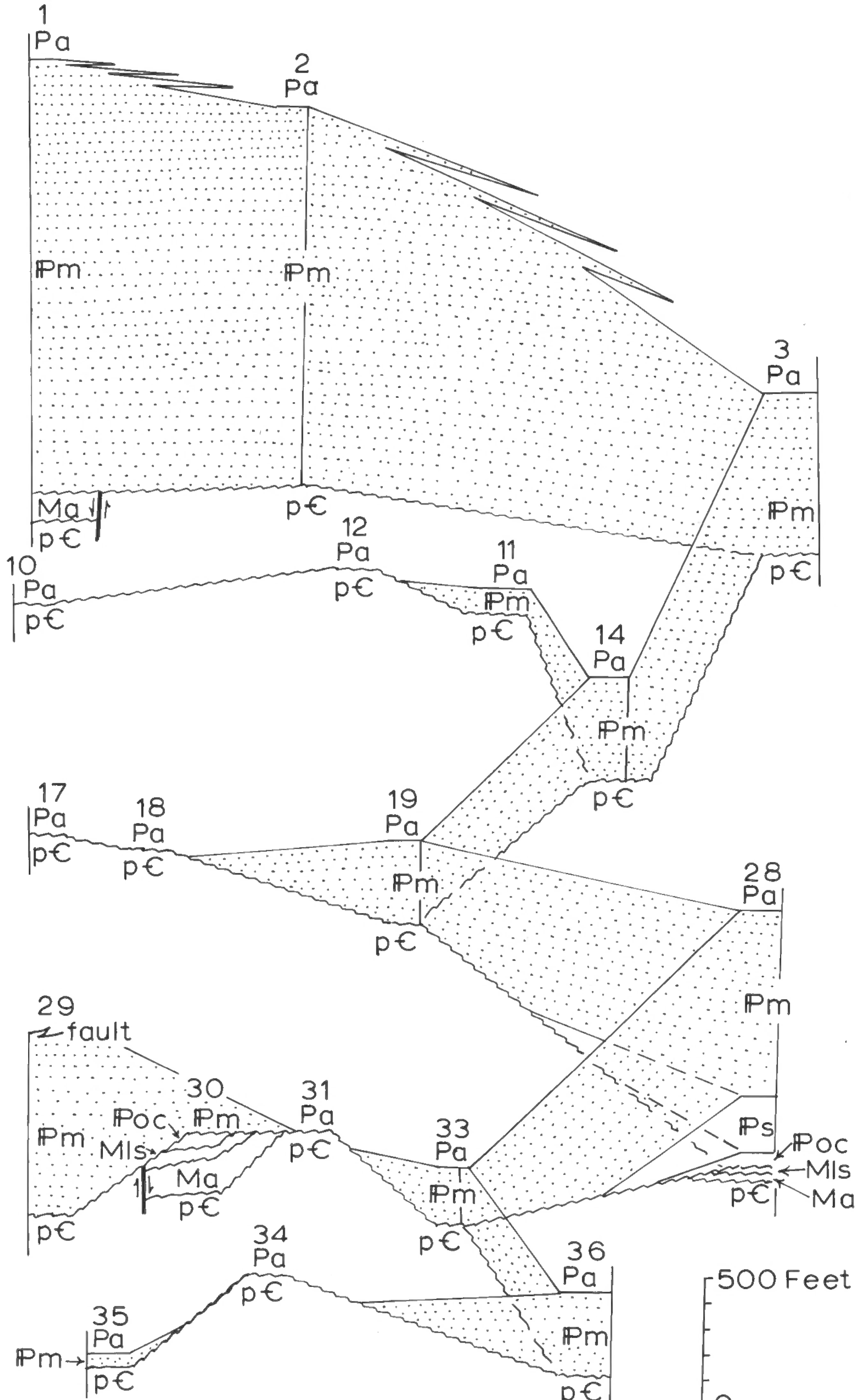

FIGURE 4. Fence diagram showing Pennsylvanian formations in Sierra Nacimiento. Sections are keyed to localities in Figure 3. Rock units are pꞒ = Precambrian rocks, Map = Arroyo Peñasco Formation, Mls = Log Springs Formation, Poc = Osha Canyon Formation, Ps = Sandia Formation, Pm = Madera Formation, and Pa = Abo Formation. Modified from Woodward (1987).

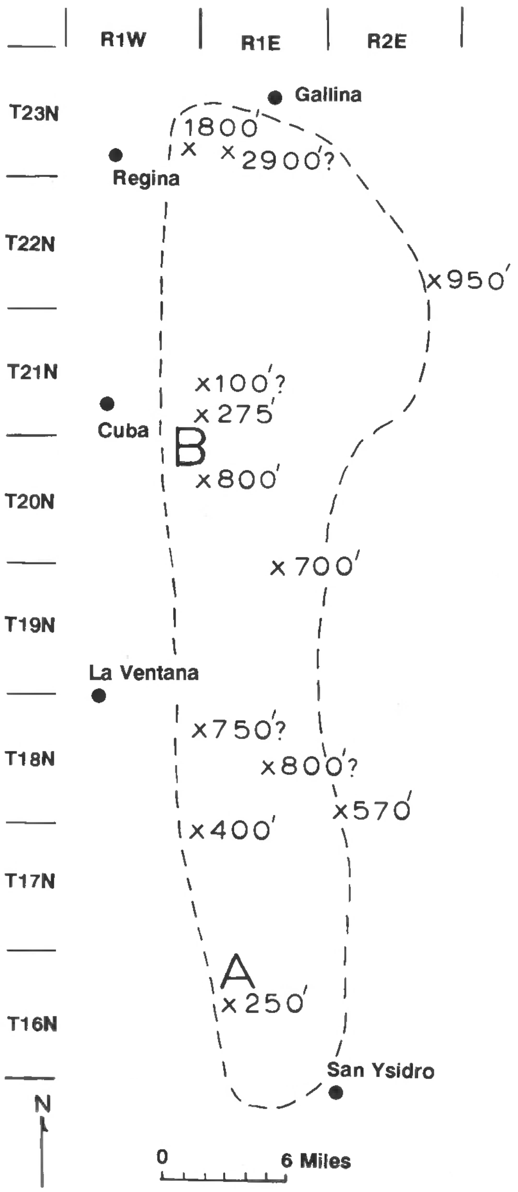

FIGURE 5. Thickness (in feet) of Abo Formation of various localities in the Nacimiento region. Dashed line indicates outline of present Nacimiento uplift. Modified from Woodward (1987).

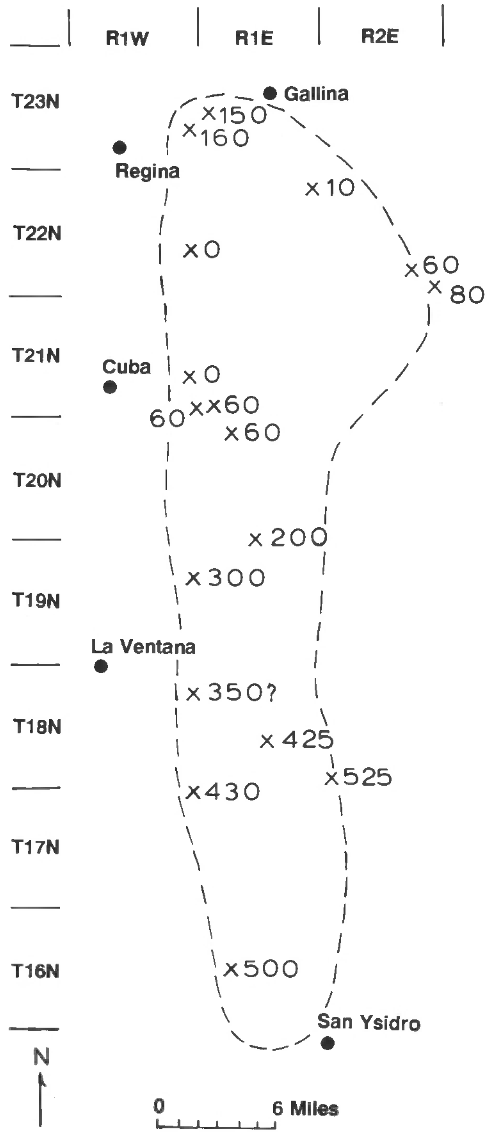

FIGURE 6. Thickness (in feet) of Yeso Formation at various localities in the Nacimiento region. Dashed line indicates outline of present Nacimiento uplift. Modified from Woodward (1987).

tive strata to the north, leading Gibson (1975) to infer that these clasts were derived locally and not transported from late Paleozoic uplifts to the north. Gibson (1975) also suggested that in the Gallina quadrangle the Madera either transgressed onto a high area to the west or was tilted eastward during deposition.

The thicknesses of the Abo Formation (Fig. 5) suggest that the Peñasco uplift was entirely buried by this unit. However, relatively thin stratigraphic sections at locations A and B (Fig. 5) may indicate continued positive tendencies for the uplift, with lesser subsidence at these locations than for the surrounding region.

The Yeso Formation is stratigraphically thin and locally absent in the northern part of the Sierra Nacimiento (Fig. 6), indicating that in this area the Peñasco uplift may have had positive tendencies well into the Permian. A regional disconformity at the base of the overlying Chinle Group (Triassic) limits the usefulness of interpreting the thickness of the Yeso Formation in terms of paleotectonics.

SUMMARY AND DISCUSSION

The Sierra Nacimiento is superimposed on the north-trending Peñasco uplift that began to develop early in Pennsylvanian (late Morrowan or early Atokan) time and rose episodically, with maximum tectonic activity in later Pennsylvanian (Desmoinesian, Missourian, and Virgilian) time. These episodes of uplift are recorded by an influx of coarse-grained, angular clasts of feldspar and granitic rocks in beds of the marine Madera Formation. A conglomeratic facies of the Madera, with boulders of Precambrian crystalline rocks up to 10 in. across, near the southwestern margin of the Sierra Nacimiento, may indicate the presence of a steep fault scarp on the west side of the Peñasco uplift. The distribution of the boulders in the Madera section indicate episodic uplift along a growth fault. About 3 mi east of this locality the Madera is markedly finer grained, suggesting that the Peñasco uplift was asymmetric, with a gentler slope on the east side, indicative of a tilted fault block.

Strata of the Sandia and Madera Formations onlap the Precambrian rocks toward the axis of the Peñasco uplift. The northern and southern ends of the uplift were emergent until the end of Madera time, but were ultimately buried by continental detrital rocks of the Abo Formation (Permian). Limited thickness data suggest that the positive tendency of the Peñasco uplift continued into Abo time inasmuch as this unit tends to be slightly thinner near the southern and northern ends of the uplift (Fig. 5).

Woodward and Ingersoll (1979) noted that the late Paleozoic uplifts of New Mexico appear to be contemporaneous with the Ouachita-Marathon orogeny that resulted from the collision of North America with South

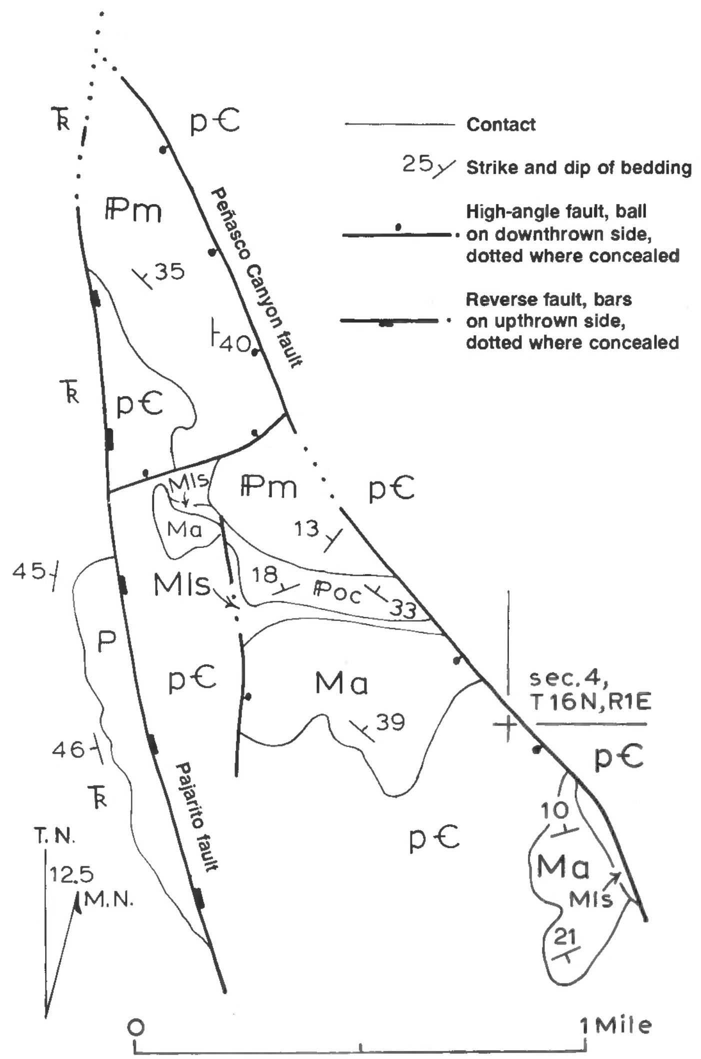

FIGURE 7. Generalized geologic map of Los Piños and Peñasco Canyons, Sierra Nacimiento (modified from Woodward et al., 1977). Pajarito fault bounds west side of present Nacimiento uplift and the Peñasco Canyon fault bounds the conglomeratic Madera section.

America-Africa. They suggested that a plate tectonic origin for the late Paleozoic uplifts was likely, but pointed out that the precise mechanisms by which stresses and strains are transmitted through hundreds of miles of continental lithosphere were poorly understood. Kluth and Coney (1981) proposed that the late Paleozoic uplifts of the southwestern U.S. were part of a complex intraplate response to the collision when the craton was pushed northwestward with wrenching and translation caused by distributive shear of a large area of the craton. They inferred a large component of vertical movement with a strike-slip component on many of the bounding faults. Northeast-trending magnetic anomalies have right-lateral offset along the western boundary of the Sierra Nacimiento (Zietz, 1982). The amount of right offset exceeds the strike-slip that can be attributed to Laramide (Late Cretaceous-early Tertiary) deformation (Woodward, 1994), suggesting that the western edge of the Peñasco uplift may have undergone right slip in the late Paleozoic. Baars and Stevenson (1984) attributed the late Paleozoic uplifts and basins to east-west extension. They inferred that north-south maximum compression resulted in right-lateral movement along the Olympic-Wichita lineament, a transcontinental, northwest-trending feature with rejuvenation of a strong Precambrian basement fabric. Resultant uplifts and basins thus had northerly trends.

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APPENDIX

Locations of measured sections and critical outcrops of the Madera and other formations in Sierra Nacimiento, New Mexico.

1. sec. 6, T22N, R1E; secs. 30 and 31, T23N, R1E, Regina quadrangle
2. secs. 28 and 33, T23N, R1E; Gallina quadrangle
3. secs. 28 and 33, T22N, R2E; Jarosa quadrangle
4. unsurv. sec. 25, T22N, R1E; sec. 30, T22N, R2E; Nacimiento Peak quadrangle
5. N. ½ sec 12, T22N, R1W; Regina quadrangle
6. NW ¼ sec 25, T21N, R1W; Cuba quadrangle
7. sec. 2, T21N, R1W; Cuba quadrangle
8. unsurv. sec. 14, T21N, R1E; Nacimiento Peak quadrangle
9. sec. 13, T21N, R1W; Cuba quadrangle
10. sec. 36, T21N, R1W; Cuba quadrangle
11. sec. 30, T21N, R2E; Nacimiento Peak quadrangle
12. sec. 3, T20N, R1E; Rancho del Chaparral quadrangle
13. unsurv. sec. 34, T21N, R1E; Rancho del Chaparral quadrangle
14. sec. 2, T20N, R1W; Rancho del Chaparral quadrangle
15. sec. 12, T20N, R1W; San Pablo quadrangle
16. sec. 29, T20N, R1E; Rancho del Chaparral quadrangle
17. sec. 12, T19N, R1W; San Pablo quadrangle
18. sec. 7, T19N, R1E; Rancho del Chaparral quadrangle
19. sec. 2, T19N, R1E; Rancho del Chaparral quadrangle
20. unsurv. secs. 23 and 24, T19N, R1E; San Miguel Mountain quadrangle
21. sec. 13, T19N, R1W; LaVentana quadrangle
22. unsurv. sec. 4, T18N, R1E; San Miguel Mountain quadrangle
23. unsurv. sec. 12, T18N, R1W; unsurv. sec. 7, T18N, R1E; LaVentana quadrangle
24. unsurv. sec. 16, T18N, R1E; San Miguel Mountain quadrangle
25. unsurv. sec. 6, T17N, R1E; Holy Ghost Spring quadrangle
26. unsurv. sec. 32, T18N, R1E; Gilman quadrangle
27. unsurv. sec. 10, T17N, R1E; Gilman quadrangle
28. unsurv. sec. 31, T18N, R2E; Gilman quadrangle
29. unsurv. sec. 5, T16N, R1E; Gilman quadrangle
30. sec. 5, T16N, R1E; Gilman quadrangle
31. sec. 4, T16N, R1E; Gilman quadrangle
32. unsurv. sec. 26, T17N, R1E; Gilman quadrangle
33. sec. 11, T16N, R1E; Gilman quadrangle
34. sec. 9, T16N, R1E; Gilman quadrangle
35. sec. 20, T16N, R1E; San Ysidro quadrangle
36. sec. 13, T16N, R1E; San Ysidro quadrangle