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L. L. Corbitt, 1988, pp. 67-70

in:

Cretaceous and Laramide Tectonic Evolution of Southwestern New Mexico, Mack, G. H.; Lawton, T. F.; Lucas, S. G.; [eds.], New Mexico Geological Society 39th Annual Fall Field Conference Guidebook, 216 p.

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TECTONICS OF THRUST AND FOLD BELT OF NORTHWESTERN CHIHUAHUA

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Abstract—The Cordilleran thrust and fold belt of northwestern Chihuahua is characterized by flat-lying thrusts and closely compressed folds. These structures are of Laramide age (late Cretaceous-early Tertiary) and are well exposed in northwestern Chihuahua in the Sierras Rica, Palomas (Alta), Boca Grande, Chinos, Santa Rita and Salada. Rocks deposited prior to and during Laramide deformation are exposed as small patches surrounded by younger post-orogenic volcanic rocks of mid-Tertiary age and late Cenozoic clastic sediments and basalt. Yielding on the thrust faults and folds is northeastward toward the foreland with displacements as much as several km. Basin and Range extensional block faulting occurred in late Cenozoic time, and range marginal faults truncate some of the Laramide structures.

INTRODUCTION

The thrust and fold belt of northwestern Chihuahua (Alvarez, 1949; Fig. 1) is well exposed in the Sierras Rica, Palomas, Boca Grande, Chinos, Santa Rita, Salada, Monumento, Cartucho, Borregos, Barrial and Nariz. Major overthrusts are exposed in the Sierras Rica and Salada. The other ranges are characterized by flat-lying thrusts of lesser displacement and closely compressed folds. Surface, subsurface, seismic (Harvey Sales) and magnetic data indicate that Paleozoic rocks have been thrust to the northeast over Cretaceous strata in the northern Animas Mountains, the Big Hatchet Mountains and Sierra Rica in the U.S., and in the Sierras Rica and Salada, in Mexico, along the Sierra Rica overthrust.

Drewes (1982) includes the area between the southern Florida Mountains (Fig. 1) and the Tres Hermanas Mountains in southwestern New Mexico in his para-autochthonous zone of minor thrusting. Brown and Clemons (1983) and Seager and Mack (1986) interpret the chief mode of Laramide deformation in southwestern New Mexico to be uplift of relatively simple basement blocks and subsidence of complementary basins.

S. Thompson, III (written commun. 1984) pointed out that seismic data (Harvey Sales) and well data show a 1500 m (5000 ft) deep Paleocene-Eocene molasse trough trending southeastward north of the Victorio Mountains, Snake Hills, Florida Mountains and East Potrillo Mountains.

STRATIGRAPHY

Precambrian basement does not crop out in northwestern Chihuahua but was penetrated in two Pemex wells. Granite gneiss in the Chinos No. 1 was dated by the rubidium-strontium method as 1327 ± 242 my and as 890 ± 32 my in the Moyotes No. 1 (Thompson et al., 1978).

Paleozoic strata are about 4270 m (14,000 ft) thick and consist mostly of platform limestone and dolomite (Fig. 2, thicknesses from Zeller, 1965). Mississippian through Permian strata are exposed in the Sierra Palomas (Sivils and Phillips, 1986). Lower Paleozoic rocks crop out

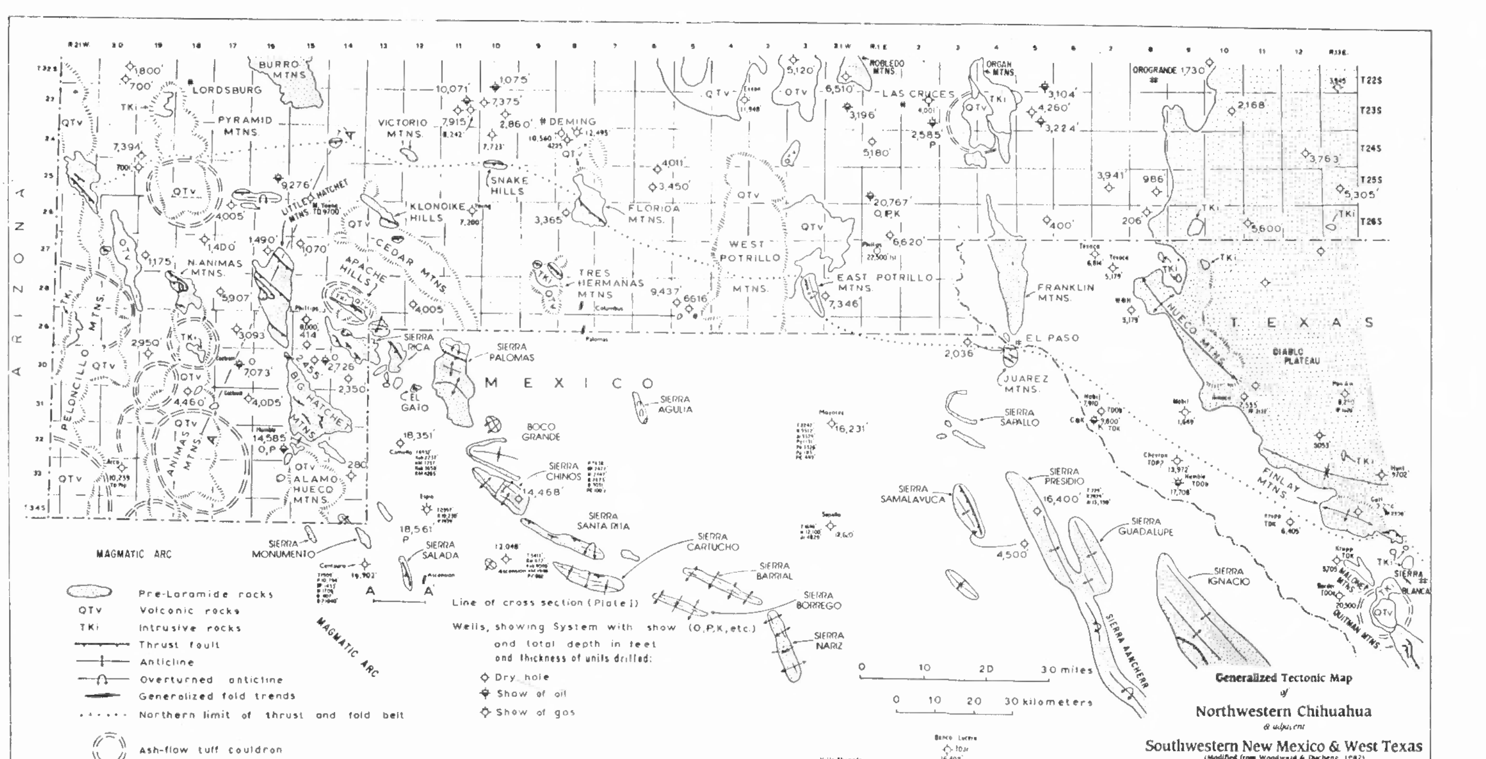

FIGURE 1. Generalized tectonic map of northwestern Chihuahua and southwestern New Mexico and west Texas, modified from Woodward and DuChene (1982).

Era	Period	Group	Formation	Thickness	Symbol
Cenozoic	Tertiary		Clastic basin-fill		Ts
			Rhyolitic-latitic volcanics		Tv
			Hidalgo Volcanics	5,500 ft	Th
			Ringbone Formation	7,500 ft	TKr
Mesozoic	Cretaceous		Mojado Formation	5,000 ft	Km
			U-Bar Formation	4,000 ft	Ku
			Hell-to-Finish Formation	6,000 ft	Kh
Paleozoic	Permian	Naco Group	Concha Limestone	1,375 ft	Pc
			Scherrer Formation	20 ft	Ps
			Epitaph Dolomite	1,500 ft	Pe
			Colina Limestone	500 ft	Pcl
			Earp Formation	1,000 ft	Per
	Pennsylvanian		Horquilla Limestone	3,500 ft	₱h
	Mississippian		Paradise Formation	320 ft	Mp
		Escabrosa Group 1,260 ft	Hatchita Formation		Mh
			Keating Formation		Mk
	Devonian		Percha Shale	280 ft	Dp
	Silurian		Fusselman Dolomite	900 ft	Sf
	Ordovician		Montoya Formation	385 ft	Om
			El Paso Formation	1,070 ft	Oep
	Cambrian		Bliss Formation	327 ft	O€b
Precambrian			Granitic and Metamorphic Rocks		p€

FIGURE 2. Composite stratigraphic sequence in southwestern New Mexico and northwestern Chihuahua, Mexico, adapted from Woodward and DuChene (1982).

in the Sierras Rica, Salada and Monumento. Permian rocks crop out in the Sierras Chinos and Santa Rita.

Triassic rocks are absent in northwestern Chihuahua. Jurassic rocks are reported in the Pemex Moyotes and Sapallo tests (Fig. 1), and are mapped in the Sierra Aguila south of Palomas (Reyeros de Castillo, 1974; Rodriquez, 1975). The unnamed evaporites underlying the Hell-to-Finish Formation in the Little Hatchet Mountains (Zeller, 1970) and the intrusive gypsum pods reported by Drewes (1982) in the Animas Mountains, also may be Jurassic in age.

Lower Cretaceous strata in northwestern Chihuahua have a maximum thickness of about 3050 m (10,000 ft) and include clastic red beds (Hell-to-Finish) and limestone with rudistids (U-Bar). These formations are best exposed in the Sierras Boca Grande and Cartucho.

Lower Tertiary rocks are of volcanic and continental clastic origin and probably accumulated contemporaneously with development of Laramide thrusts and folds. Mid-Tertiary (Oligocene and younger) volcanic rocks are widespread. Coarse clastic sediments of late Cenozoic age fill the basins between the present mountain ranges. Late Cenozoic basaltic rocks are locally present (Frantes, 1981).

PALEOTECTONIC SETTING

From Cambrian through Mississippian time, northwestern Chihuahua was part of a stable shelf south of the transcontinental arch. Three episodes of epeirogenic uplift, during the Middle Ordovician, Early Silurian and Late Silurian-Middle Devonian, are recorded by stratigraphic breaks. In Pennsylvanian time, the area was epeirogenically deformed with development of the Alamo Hueco basin (Zeller, 1965) in which 610 m (2,000 ft) or more of basinal sediments were deposited. The basin was bordered on the northeast by the Florida-Moyotes-Diablo uplift. Permian Hueco Formation overlies Mississippian limestone in the Florida Mountains. Abo sediments overlie Precambrian rocks in the Pemex Moyotes test and Permian rocks were deposited on Precambrian and Paleozoic rocks on the Diablo uplift. Paleozoic strata appear to have been removed from the Burro uplift in Mesozoic time (Elston, 1958). Pennsylvanian-Permian basinal sediments are recognized in the Humble No. 1 State BA (sec. 25, T32S, R16W) and in the Pemex Villa Ahumada test. Further subsidence of the Pedregosa basin occurred during the Permian with accumulation of over 1830 m (6,000 ft) of shelf deposits along the margin of the basin.

Turner (1962) described the Deming axis (Florence-Graham-Burro-Florida-Diablo uplift of Greenwood et al., 1977) as being a positive element throughout much of Mesozoic time. Cretaceous sandstone overlies Precambrian rocks in the Burro Mountains, Fusselman Dolomite in the Victorio Mountains and in the Marshall Young Bisbee Hills test south of the Snake Hills (Fig. 1; S. Thompson, III, written commun. 1986), Mississippian rocks in the Mobil test south of El Paso and Precambrian and Paleozoic rocks on the Diablo uplift. The Late Jurassic and Early Cretaceous Chihuahua trough was present south of the Deming Axis (DeFord and Haenggi, 1970, fig. 5).

TECTONIC FRAMEWORK

The overthrust mapped by Zeller (1958) in the Sierra Rica is exposed to the southeast in Mexico (Fig. 1). The view of the southwest-dipping, dark-colored, lower Paleozoic rocks overlying the lighter Cretaceous strata is striking. Approximately eight km southeast of the Sierra Rica in the El Gato hills, Silurian Fusselman rocks appear to be thrust over Mississippian carbonates. These outcrops dip to the southwest and are 10 km west of Permo-Pennsylvanian rocks exposed in the Sierra Palomas. These rocks also dip to the southwest. It is possible that the strata exposed in the El Gato hills are thrust over the Permo-Pennsylvanian rocks exposed in the Sierra Palomas.

The Pemex Camello test, 16 km to the south of El Gato (Fig. 1), drilled in repeated Cretaceous rocks at a total depth of 6000 m (18,352 ft). At least two thrusts are reported in this test (Thompson et al., 1978). This well is located about 16 km east of the Big Hatchet Mountains where Permo-Pennsylvanian carbonates are more than 2440 m (8,000 ft) above sea level. Precambrian basement in the Camello test would appear to be at a depth of approximately 10,000 m (33,000 ft) based on the 4267 m (14,000 ft) of Paleozoic rocks drilled in the Humble No. 1 State BA test, 29 km to the west, and in the Pemex Chinos well, 32 km to the southeast (Fig. 1).

The Big Hatchet Mountains and Sierra Rica appear to be thrust over Cretaceous strata along the Sierra Rica overthrust. The Pemex Camello test is located immediately east of this thrust and drilled Cretaceous strata similar to that exposed in the Little Hatchet Mountains and the northern Sierra Rica. The Big Hatchet Mountains overlie a regional down-to-the-southwest magnetic gradient with no indication of magnetic basement involvement. Seismic data (Harvey Sales) along the border between the Big Hatchet Mountains and Pemex Camello test do not indicate any major normal faulting. Also, a thrust appears to approach the surface in the Sierra Rica on this seismic data.

Seager (1983) suggests that the Big Hatchet Mountains are a Rocky Mountain type upthrust with Laramide basins present to the north and south. Synorogenic rocks are present to the north in the Little Hatchet Mountains but not to the south. The Cockrell tests drilled west of the Big Hatchet Mountains indicate this area was more deeply eroded than the Big Hatchet Mountains before Late Tertiary Basin and Range faulting (Fig. 3; Woodward and DuChene, 1982). Seismic (Harvey Sales), magnetic and gravity data indicate that the Basin and Range normal fault on the west side of the Big Hatchet Mountains flattens with depth and that Precambrian basement may not be involved.

The leading edge of the Sierra Rica overthrust appears to lie between the Big Hatchet Mountains and the Pemex Camello well and may be exposed to the south in the Sierra Salada. A structurally complex thrust plate of Paleozoic strata dipping to the southwest overlies Lower Cretaceous rocks in the Sierra Salada.

Northwest of the Sierra Salada at least three exposures of lower Paleozoic rocks are present in the Sierra Monumento. These strata are surrounded by mid-Tertiary volcanics and are folded into northwest-trending folds characteristic of northwestern Chihuahua. Complex structural relations are also indicated in the Centuro test drilled west of Sierra Salada, which drilled 3294 m (10,800 ft) of Permian rocks (Thompson et al., 1978).

A small exposure of tightly folded Cretaceous strata is present about 24 km east of Sierra Salada near the Pemex Ascension test (Fig. 1). Very complex overturned folds and thrusts in upper Paleozoic rocks are present at the north end of the Sierra Palomas. Broad northwest-trending folds dominate the rest of the range. Complex overturned folds

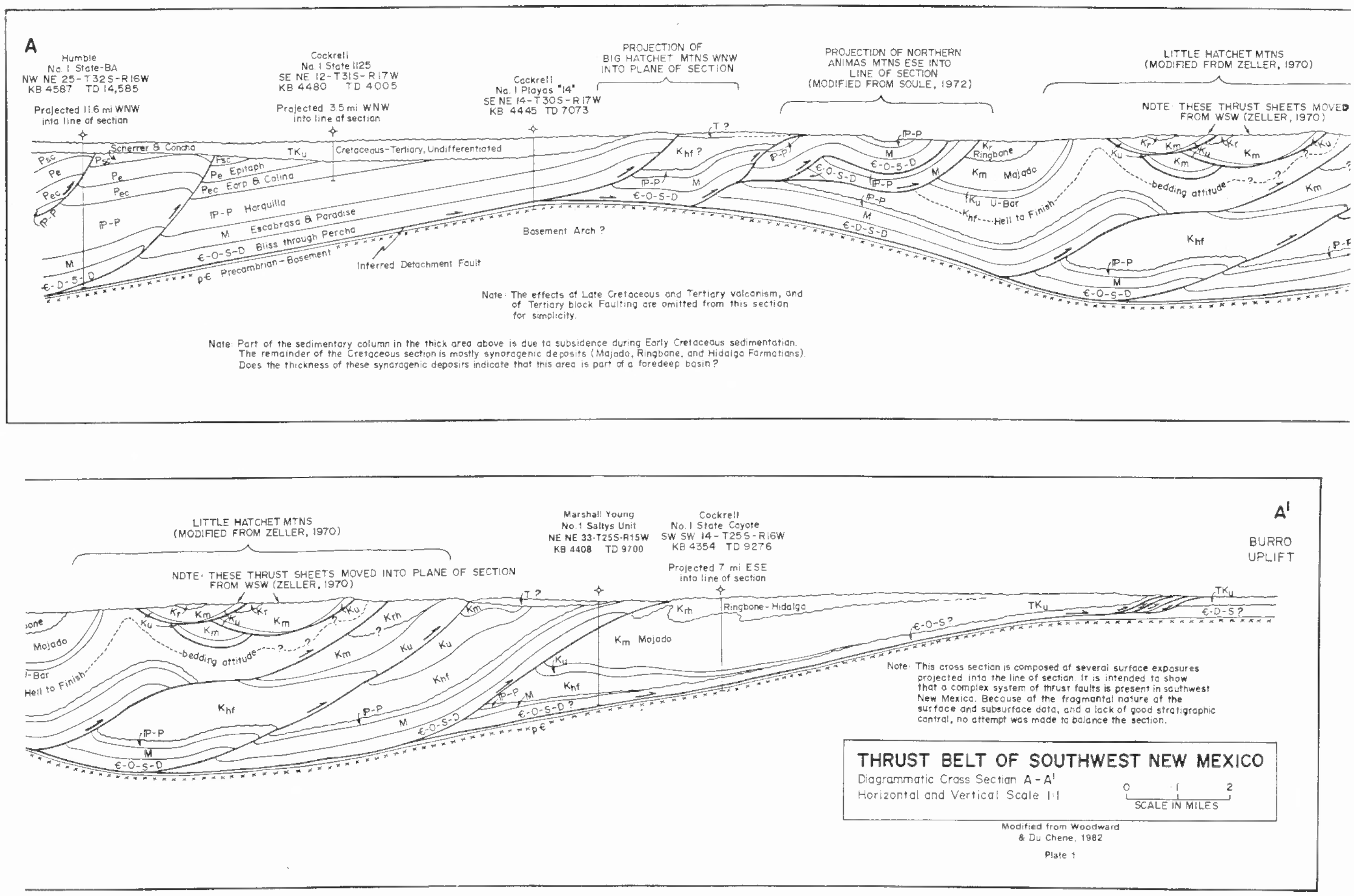

FIGURE 3. Diagrammatic cross section of the thrust belt of southwestern New Mexico. See Figure 1 for line of section.

in upper Paleozoic rocks are also present to the south in the valley between Sierra Palomas and Boca Grande, indicating yielding to the northeast. Boca Grande is a syncline similar to the smaller U-Bar syncline south of the Big Hatchet Mountains. Very tight folds dominate the Sierra Chinos (Brown and Dyer, 1986). Numerous small imbricate thrust faults and tight folds are present in the Sierra Santa Rita. This range of Permian rocks may be thrust to the northeast over Cretaceous strata. Several major folds and thrusts are exposed in Sierra Cartucho and to the southeast in the Sierras Borregos, Barrial and Nariz.

CONCLUSIONS

The evidence suggests that northwestern Chihuahua is underlain by a regional system of thrust faults and folds that have yielded toward the northeast. Total displacement on the Sierra Rica overthrust is not known but is probably several km.

The Marshall Young No. 1 Saltys Unit well (sec. 33, T23S, R15W), Grant County, New Mexico (Fig. 3) appears to verify the presence of the overthrust belt in southwestern New Mexico (Brennan, 1986). The following section was drilled in this test: surface Tertiary volcanics: 216 m (710 ft); Tertiary conglomerate: 235 m (770 ft); Epitaph Formation (Permian): 311 m (1020 ft); Colina Limestone: 356 m (1168 ft); Earp Formation: 657 m (2154 ft); Horquilla Formation (Pennsylvanian): 811 m (2660 ft); Escabrosa Formation: 1084 m (3558 ft); Percha Shale (Devonian): 1144 m (3756 ft); Montoya Formation (Ordovician): 1292 m (4238 ft); El Paso Formation: 1361 m (4466 ft); Bliss Formation (Cambrian-Ordovician): 1369 m (4494 ft); thrust fault; Mojado Formation (Lower Cretaceous): 2306 m (7564 ft); U-Bar Formation: 2348 m (7705 ft); Hell-to-Finish Formation: 2543 m (8344 ft); unconformity; Montoya Formation: 2713 m (8960 ft); El Paso Formation: 2962 m (9718 ft); Bliss Formation to T.D. (S. Thompson, III, written commun. 1986). Several kilometers of tectonic transport to the northeast is suggested.

To the southeast in the Tres Hermanas Mountains and East Potrillo Mountains Permian rocks have been thrust to the northeast over Cretaceous rocks. The following section was drilled in the Pure test (Fig. 1) east of the East Potrillo Mountains (Thompson, 1982): surface; Cretaceous: 190 m (625 ft); Permian? to Mississippian?: 1174 m (3850 ft); Percha: 1238 m (4060 ft); Fusselman: 1343 m (4405 ft); reverse fault?; Permian? to Mississippian? rocks: 1903 m (6240 ft); marble?: 2078 m (6815 ft); intrusive rocks. Several kilometers of northeast transport is indicated.

In the Juarez Mountains (Fig. 1) Lovejoy (1980) estimated a minimum northeast transport of 22 km (13.2 mi) and that the original width of Cretaceous strata had been decreased 59% by thrusting and folding.

In the Malone Mountains in Texas, Berg (1982) estimated a combined northeast tectonic transport of at least 24 km (15 mi) and that it may have been as much as 80 km (50 mi). In the Quitman Mountains and the Cieneguilla Mountains in Mexico, Reaser (1982) estimated 48 km (30 mi) of northeast tectonic transport. Similar amounts of northeast tectonic transport are probably present in northwestern Chihuahua.

The Laramide thrust and fold belt appears to have developed to the northeast of a continental-margin volcanic arc (Lipman and Sawyer, 1985). Mack (1987) indicates that a retroarc foreland basin formed in northwestern Chihuahua-southwestern New Mexico in late Albian-Cenomanian time, northeast of a complementary compressional orogenic belt. Possibly a gravitational gliding model similar to that proposed by Price and Mountjoy (1970) may have been operative with upward and outward pushing from the volcanic arc. The Laramide volcanic arc area was later covered by mid-Tertiary volcanics which make up the present-day Sierra Madre Occidental (Damon et al., 1981).

ACKNOWLEDGMENTS

I thank R. E. Clemons, L. A. Woodward and Russ Dyer for critically reviewing the manuscript.

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