Lower Wolfcampian conglomerate in the southern Caballo Mountains, Sierra County, New Mexico: stratigraphy, correlation, and implications for late Pennsylvanian-early Permian tectonics

Timothy F. Lawton, Katherine A. Giles, Greg H. Mack, David S. Singleton, and Alan D. Thompson
2002, pp. 257-265. https://doi.org/10.56577/FFC-53.257

in:

Geology of White Sands, Lueth, Virgil; Giles, Katherine A.; Lucas, Spencer G.; Kues, Barry S.; Myers, Robert G.; Ulmer-Scholle, Dana; [eds.], New Mexico Geological Society 53rd Annual Fall Field Conference Guidebook, 362 p. https://doi.org/10.56577/FFC-53

This page is intentionally left blank to maintain order of facing pages.

New Mexico Geological Society Guidebook, 53rd Field Conference, Geology of White Sands, 2002, p. 257-265.

LOWER WOLFCAMPIAN CONGLOMERATE IN THE SOUTHERN CABALLO MOUNTAINS, SIERRA COUNTY, NEW MEXICO: STRATIGRAPHY, CORRELATION, AND IMPLICATIONS FOR LATE PENNSYLVANIAN-EARLY PERMIAN TECTONICS

TIMOTHY F. LAWTON[1], KATHERINE A. GILES[1], GREG H. MACK[1], DAVID S. SINGLETON[2], AND ALAN D. THOMPSON[3]

[1]Department of Geological Sciences, New Mexico State University, Las Cruces, NM 88003; tlawton@nmsu.edu; kgiles@nmsu.edu; gmack@nmsu.edu; [2]4478 NW 63rd Drive, Coconut Creek, FL, 33073; DSingl7@aol.com; [3]1508 1/2 Custer St., Laramie, WY, 82070.

ABSTRACT.—The upper part of the Bar B Formation in the Caballo Mountains, informally termed here the upper conglomeratic member of the Bar B Formation, consists of pebble-, cobble-, and local boulder conglomerate interbedded with shale and limestone. The upper conglomeratic member thickens eastward across the southern Caballo Mountains from 7 to 107 m and unconformably overlies truncated Pennsylvanian sections at all studied localities. It is early Wolfcampian in age and equivalent to the type Bursum Formation of Socorro County. Detritus of the upper conglomeratic member was eroded from uplifted Pennsylvanian strata lying in and west of the Caballo Mountains and deposited in fan-delta, shallow-marine, and subordinate fluvial settings on the western flank of the Orogrande basin. The upper conglomeratic member is part of a record of alternating uplift and subsidence of that basin margin from the early Pennsylvanian through the Early Permian. This polycyclic subsidence history and the geometry of the Orogrande basin are consistent with basin origin by strike-slip deformation of the craton, probably in response to progressive suturing of Gondwana and Laurentia.

INTRODUCTION

Patterns and timing of uplift and subsidence are important evidence for the tectonic origins of sedimentary basins. In this paper, we describe lower Wolfcampian conglomeratic strata deposited on the western edge of the late Paleozoic Orogrande basin. Long known to have possessed an eastern flank characterized by active uplift and folding, the Orogrande basin (Fig. 1) nevertheless has long been inferred to have had a passive western margin bereft of active tectonism (Kottlowski et al., 1956; Pray, 1961). The conglomeratic strata, which crop out in the southern part of the Caballo Mountains, unconformably overlie Pennsylvanian strata and indicate that the notion of a passive western margin is incorrect. These conglomerates and local stratigraphic relations record intermittent uplift of the southern Caballo Mountains in the early Pennsylvanian and Early Permian punctuated by middle Pennsylvanian subsidence. In the context of relations elsewhere in the Orogrande basin, these patterns of deposition indicate that strike-slip faulting of the craton is a viable mechanism for Ancestral Rocky Mountain deformation in southern New Mexico.

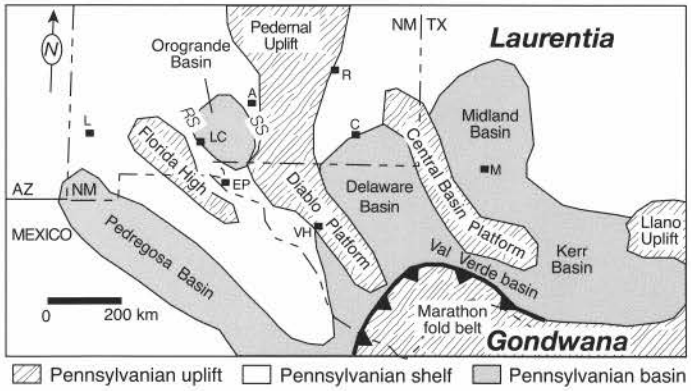

FIGURE 1. Pennsylvanian paleogeography of the Orogrande basin. Suture between Gondwana and Laurentia is indicated by barbed line in Marathon region. Modified from Kluth and Coney, (1981). Cities: A, Alamogordo; C, Carlsbad; EP, El Paso; L, Lordsburg; LC, Las Cruces; M, Midland; R, Roswell; VH, Van Horn. Paleogeographic elements of Orogrande basin (after Meyer, 1966): RS, Robledo shelf; SS, Sacramento shelf.

GEOLOGIC SETTING

The Orogrande basin contains a thick succession of Pennsylvanian and Lower Permian strata deposited in shallow-marine and deltaic settings (Kottlowski et al., 1956; Kottlowski, 1960; Meyer, 1966). The east flank of the basin, termed the Sacramento shelf (Meyer, 1966), has long been recognized as a site of active tectonism because the Pennsylvanian section there contains abundant coarse-grained epiclastic detritus (Pray, 1961; Van Wagoner, 1977; Algeo et al., 1991). In addition, strata in outcrops of the western Sacramento Mountains are deformed by pre-middle Wolfcampian folds, which are truncated by the Abo Formation (Otte, 1959; Pray, 1961). The western margin of the Orogrande basin, termed the Robledo shelf, extending northward from the vicinity of Las Cruces (Meyer, 1966), has been regarded as a passive shallow-marine paleogeographic element that lay between the basin center in the present San Andres Mountains and the Pennsylvanian Florida islands of Kottlowski (1960).

The Orogrande basin is part of a system of basins and uplifts termed the Ancestral Rocky Mountains province, a region of Pennsylvanian and Early Permian intracratonic deformation (Fig. 1; Kluth and Coney, 1981). This deformation coincided in time with progressive collision of Gondwana and Laurentia to form Pangea (Kluth and Coney, 1981; Ross, 1986). Uplift and subsidence have been attributed to either the far-field effects of the collision (Kluth and Coney, 1981) or Laramide-style flat-slab

subduction of an unnamed oceanic plate beneath southwestern Laurentia (Ye et al. 1996). In the former tectonic setting, the Orogrande basin is attributed to intracratonic transcurrent faulting; in the latter, it has been interpreted as a flexural intermontane basin adjacent to the basement-cored Pedernal uplift (Ye et al., 1996)

The study area in the southern part of the Caballo Mountains (Fig. 2) lies on the northern extension of the Robledo shelf. The fill of the Orogrande basin ranges in age from Atokan to Wolfcampian and includes the Red House, Nakaye, Bar B, and Abo formations along its western edge in the Caballo Mountains and equivalent units to the east (Fig. 3; Thompson, 1942; Kelley and Silver, 1952). The Red House Formation unconformably overlies Ordovician through Mississippian strata and is dominated by shale and limestone (Seager, 1986; Kalesky, 1988; Seager and Mack, 1991, in press). The Nakaye Formation is dominantly limestone (Kelley and Silver, 1952; Seager and Mack, in press), and the overlying Bar B Formation is primarily shale and limestone, with an upper part that consists of limestone-clast conglomerate, shale and limestone (Singleton, 1990). The Abo Formation, which overlies the Bar B Formation, consists of non-marine red beds (Sherry, 1990; Mack et al., 1995; Seager and Mack, in press). The lower part of the Bar B Formation has been interpreted as containing a relatively complete Missourian-Virgilian succession in the east-central part of the range (Soreghan, 1994), but preliminary fusulinid data from the southern part of the range indicate that unconformities may be present within the Pennsylvanian section there (Singleton, 1990; Thompson, 1991; Mack et al., 1998).

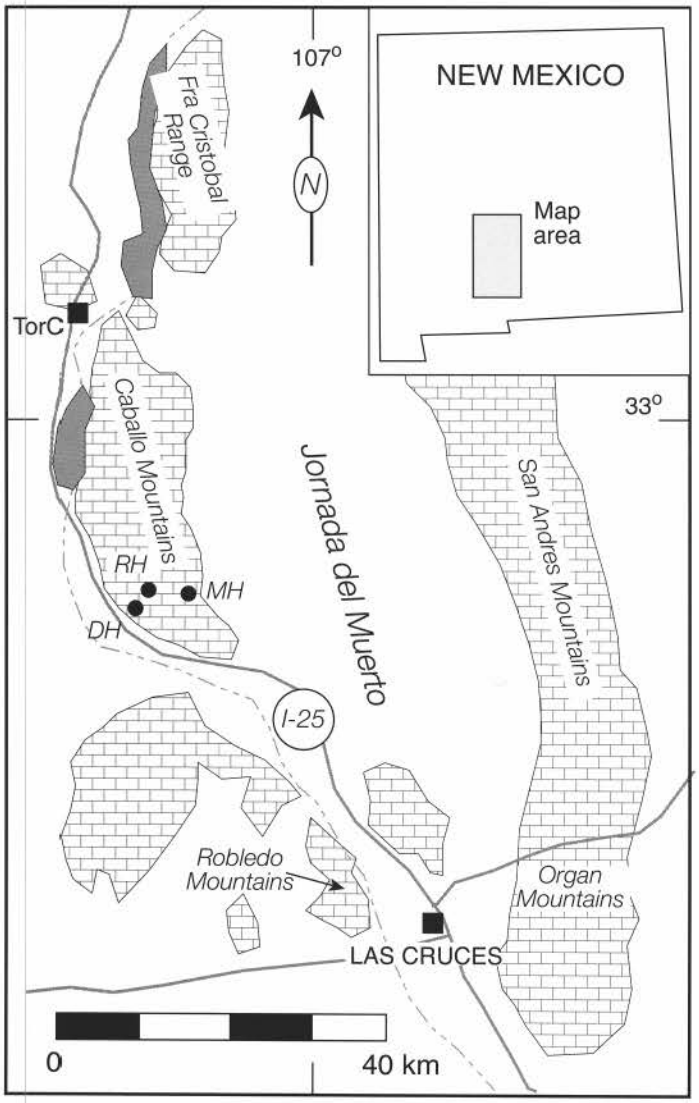

FIGURE 2. Locations of stratigraphic sections in southern part of Caballo Mountains. Sections: DH, Derry Hills; MH, McLeod Hills; RH, Red Hills Tank.

STRATIGRAPHY

In the southern part of the Caballo Mountains, the lower part of the Bar B Formation is unconformably overlain by a succession of conglomerate and limestone that thickens from west to east toward the Jornada del Muerto. Although this succession differs lithologically from the underlying limestone and shale, previous workers have included it in the Bar B Formation (Kelley and Silver, 1952; Singleton, 1990; Thompson, 1991; Seager and Mack, 1991, 1998, in press). The succession is lithologically similar to the type Bursum Formation in Socorro County (Wilpolt et al., 1946; Lucas et al., 2000); however, in this paper, we assign it to an informal upper conglomeratic member of the Bar B Formation pending formal redefinition of Bursum-equivalent strata in southern New Mexico.

Description and Thickness

Where best developed in the McLeod Hills (Fig. 2), the upper conglomeratic member of the Bar B Formation is 107 m thick (Singleton, 1990; Thompson, 1991). It consists of three distinctive lithologic intervals (Fig. 4): a lower conglomerate and siltstone, a middle limestone and shale, and an upper conglomerate and siltstone. The lower conglomerate and siltstone interval is 56 m thick and consists of conglomerate and calclithite beds 0.5-1 m thick separated by covered intervals 3-8 m thick. Calclithite is a litharenite composed predominantly of extrabasinal carbonate grains derived from uplifted carbonate source rocks (Folk, 1974; equals "carbonate extrarenite" of Zuffa, 1980). Calclithite and carbonate grainstone beds commonly have hummocky cross-stratification (Singleton, 1990). Some covered intervals are claystone, and some are pink-weathering sandstone beds, which gradationally overlie the conglomerate. Conglomerate beds in the middle part of this lower interval locally fine upward and are lenticular, with along-strike outcrop dimensions of 8-10 m. Clasts are rounded to angular limestone and angular chert, dominantly pebbles, but include platy boulders as much as 30 cm long. Many different types of limestone are present in the clast population, some of them representing facies in the underlying part of the Bar B Formation. *Triticites plummeri*, a Virgilian fusulinid, and *Triticites* cf. *T. cellomagnus*, an early Wolfcampian form (Wilde, 1990), were recovered from a carbonate grainstone bed about 3 m above the base of the conglomerate, and *Fusulina socorroensis,* a Desmoinesian form, was identified in a clast near the top of the lower interval (Thompson, 1991).

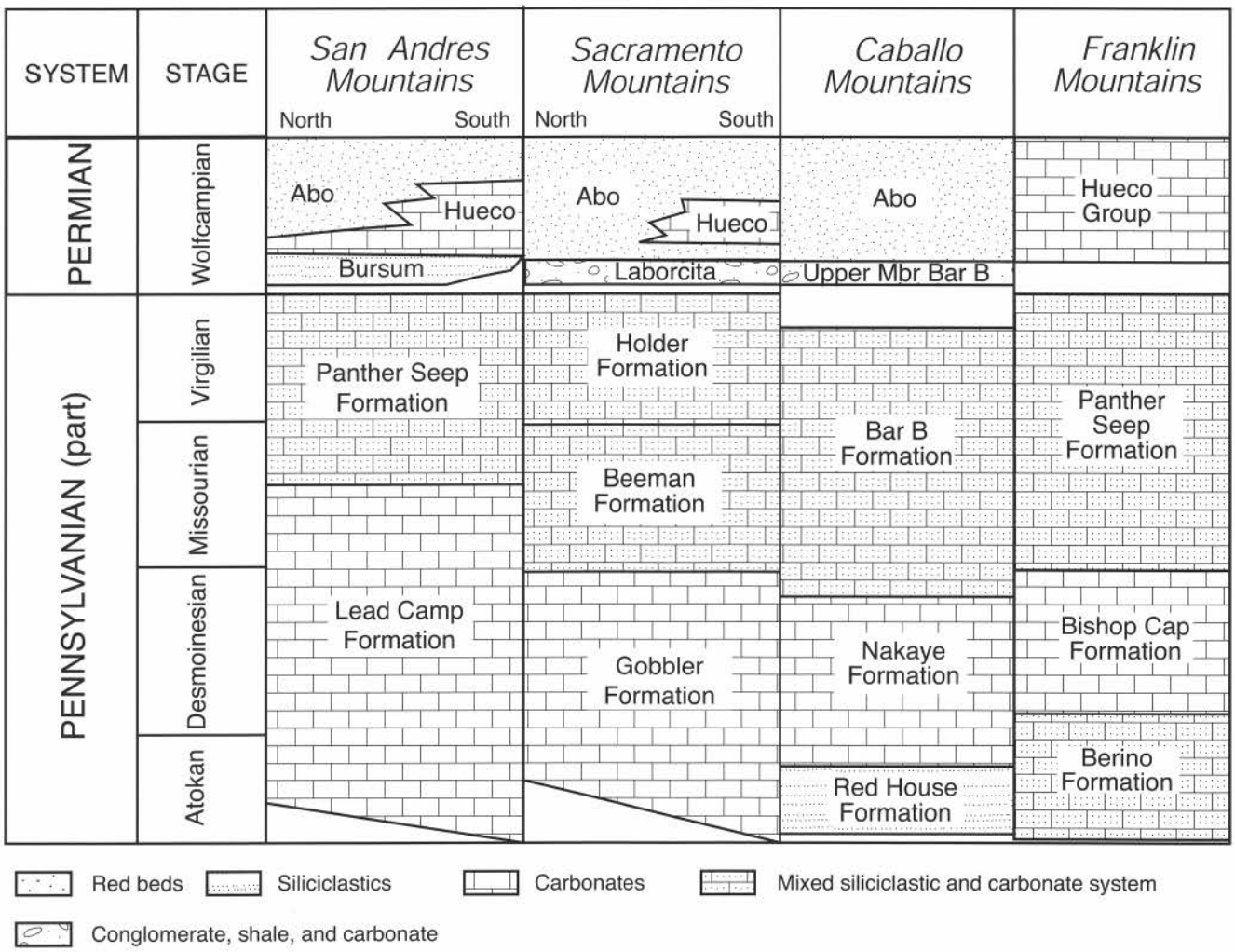

FIGURE 3. Age and correlation of Pennsylvanian and Permian strata, Orogrande basin. From Kues (2001) and sources cited in text.

The basal conglomerate overlies middle Virgilian wackestone on a sharp contact. Limestone beds 0.5-1 m thick in the lower conglomerate and siltstone interval are bioclastic wackestone and uncommon grainstone beds containing ooids, echinoderm fragments, intraclasts and bryozoans (Singleton, 1990; Thompson, 1991).

The middle limestone and shale interval is 23 m thick and consists of six prominent wackestone and grainstone beds 0.5-2 m thick with abundant brachiopods, bryozoans, ostracods, crinoid fragments, and phylloid algal debris. In the lower part, the limestone beds alternate with conglomerate beds typical of the lower interval. One bed contains a striking intraclast conglomerate. Calclithite composed of extrabasinal detritus with cross-beds is present in some limestone beds. Shale beds are grayish-green, and locally pink to red with calcic nodules (Singleton, 1990; Seager and Mack, in press). The uppermost bed of wackestone in this interval yielded a diverse assemblage of fusulinids, including *Triticites creekensis*, *T. meeki*, *Schwagerina campensis*, and *S. grandensis* (Thompson, 1991).

The upper conglomerate and siltstone interval overlies a phylloid algal wackestone on a sharp contact. The interval is 28 m thick. Conglomerate beds are 1-1.5 m thick, laterally continuous, and clast supported. Clasts are tightly packed; interbedded lenses of calclithite contain cross-beds and wave ripples. Clasts are rounded to subangular, and comprise a diverse assemblage of limestone and chert types. Inverse grading is present in some conglomerate beds. Silicified fragments of *Chaetetes*, a sclerosponge locally abundant in the Nakaye Formation, are common in the conglomerate. Interbedded claystone is silty, locally fissile and ranges from olive gray to pink (Singleton, 1990). Carbonate mudstone and wackestone beds in the upper part of the interval contain echinoderm fragments, bryozoans, ostracods, and rare gastropods. The uppermost bed of the formation, separated from underlying conglomerate by 11 m of cover, is gray- to pink-weathering carbonate mudstone with a distinctive chicken wire-like texture of gray mudstone with thin selvages of pink silty mudstone. This may represent pedogenic modification of the carbonate mudstone. This upper bed is overlain by red siltstone of the Abo Formation.

The upper conglomeratic member thins westward from the McLeod Hills. At Red Hills tank in the south-central Caballo Mountains (Fig. 2), the upper conglomeratic member overlies Virgilian strata and consists of approximately 20 m of nodular limestone, pink weathering claystone and subordinate conglom-

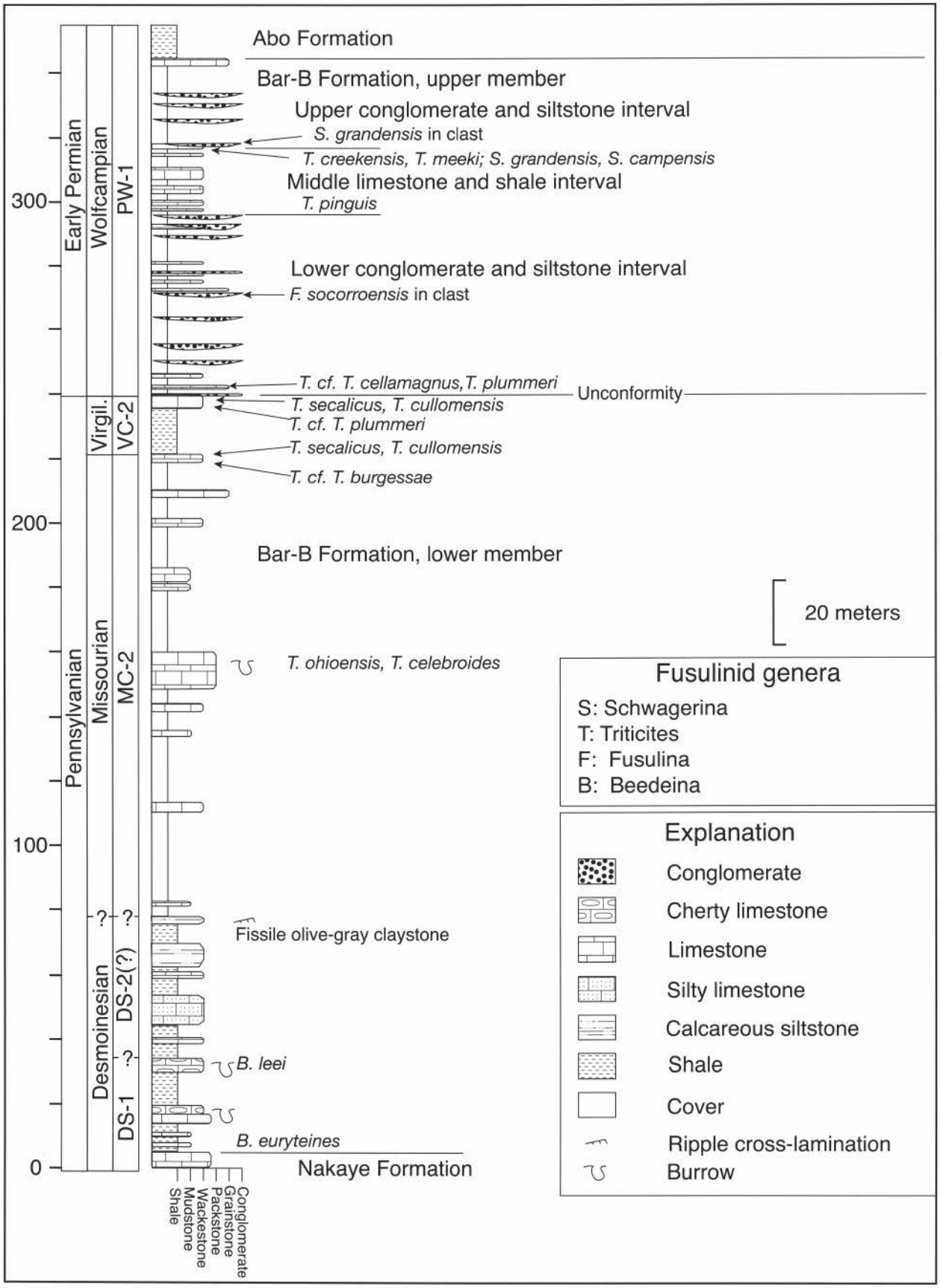

FIGURE 4. Measured section of Bar B Formation, McLeod Hills (NW 1/4 sec. 25, T17S, R2W). Upper 200 m of lithostratigraphy after Singleton (1990); fusulinid data from Thompson (1991). Fusulinid biostratigraphic zones (e.g., PW-1) adjacent to lithologic column from Wilde (1990).

erate (Singleton, 1990). In the Derry Hills, the upper conglomeratic member consists of 7 m of interbedded conglomerate and mudstone overlying Missourian strata (Fig. 5; Singleton, 1990). A clast in a conglomerate bed 3 m above the base yielded *Triticites nebraskensis*, a Missourian fusulinid (Thompson, 1991).

Depositional Environment

The upper conglomeratic member of the Bar B Formation was deposited in a complex of fluvial, shoreline, and shallow subtidal settings. We interpret tightly packed, clast-supported conglomerate and calclithite with hummocky cross-stratification as having been deposited in shallow marine bars or shoreface settings, whereas the lenticular, upward-fining conglomerate beds and interbedded red to pink sandstone and siltstone represent braided river and overbank deposits. Fossiliferous grainstone beds are shallow subtidal deposits, some representing well-winnowed shoals and bars, and fossiliferous and algal wackestone beds are assigned to generic shallow subtidal settings. These environments comprise a braid-delta system in which gravel was delivered to the shoreline by gravelly braided-river systems and reworked by waves. Subtidal settings represent the offshore and interdeltaic parts of the system.

AGE AND CORRELATION

The upper conglomeratic member of the Bar B Formation is early Wolfcampian in age based on its fusulinid fauna. Grainstone near the base of the lower conglomerate and siltstone interval contains both early Wolfcampian and late Virgilian fusulinids; we interpret the Virgilian forms as recycled from subjacent strata. Desmoinesian and Missourian fusulinids recovered from clasts in the McLeod Hills and Derry Hills sections were also recycled from nearby Pennsylvanian strata. Fusulinids from the top of the middle interval in the McLeod Hills represent the traditional lowermost fusulinid zone of the Wolfcampian (PW-1 of Wilde, 1990). Recent proposals to raise the Virgilian-Wolfcampian boundary in North America (e.g., Lucas et al., 2000; Wahlman and King, 2002) would have the effect of moving this zone into the latest Virgilian. Whether or not this stratigraphic interval should be moved to the uppermost part of the Pennsylvanian System from its traditional position at the base of the Permian System (e.g., Lucas et al., 2000) is beyond the scope of this paper.

Although subcrop relations are not firmly established in the region, the upper conglomeratic member of the Bar B Formation unconformably overlies progressively older beds westward

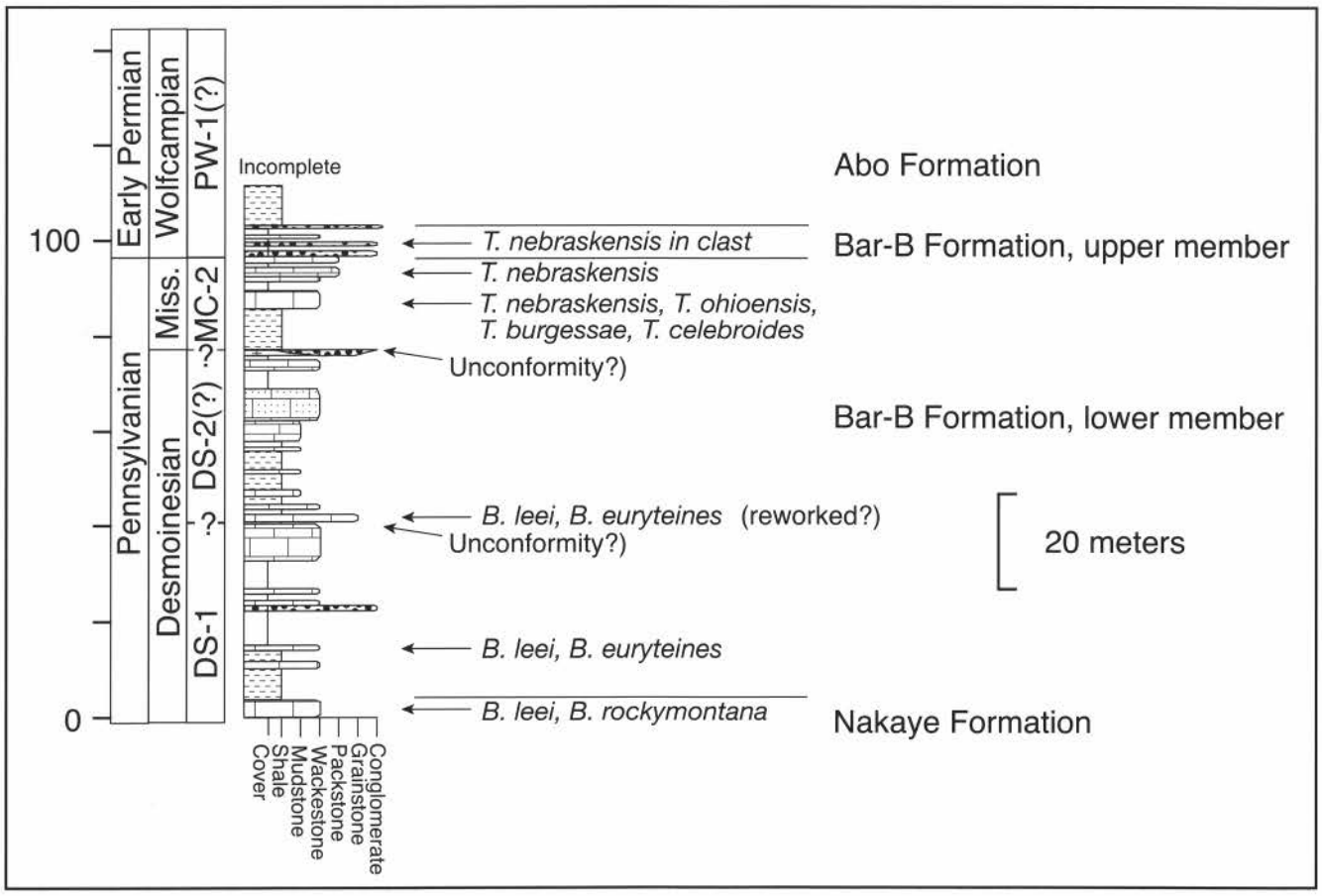

FIGURE 5. Measured section of Bar B Formation, Derry Hills (NE 1/4 sec. 33, T17S, R4W). Lithostratigraphy after Singleton (1990); fusulinid data from Thompson (1991). Fusulinid biostratigraphic zones (e.g., PW-1) adjacent to lithologic column from Wilde (1990). Symbols and explanation as in Figure 4.

through the Caballo Mountains: mid-Virgilian strata in the McLeod Hills and at Red Hills tank in the south-central Caballo Mountains and mid-Missourian strata in the Derry Hills (Fig. 6; Singleton, 1990). The subcrop relations, in combination with westward thinning of the upper conglomerate member, indicate onlap onto an uplift in the western Caballo Mountains and westward. In addition to the sub-Wolfcampian unconformity beneath the upper conglomeratic member of the Bar B Formation, preliminary fusulinid data indicate that an intra-Pennsylvanian unconformity may be present locally between Desmoinesian and Virgilian strata of the lower member of the Bar B Formation (Fig. 6; Singleton, 1990).

The upper conglomeratic member of the Bar B Formation correlates with the type Bursum Formation in Socorro County (Wilpolt et al., 1946; Lucas et al., 2000), the Bursum Formation of the San Andres Mountains (Kottlowski et al., 1956), and the Laborcita Formation of the Sacramento Mountains (Fig. 3; Otte, 1959; Pray, 1961). It differs lithologically in minor ways from the Bursum type section, which is conformable on Virgilian strata and contains only two beds of pebble conglomerate, although some shales there are also red with calcic nodules (Lucas et al., 2000). In the San Andres Mountains, the Bursum contains a basal conglomerate, limestone and pinkish and green shale, and is unconformable on Virgilian strata (Kottlowski et al., 1956). In the Sacramento

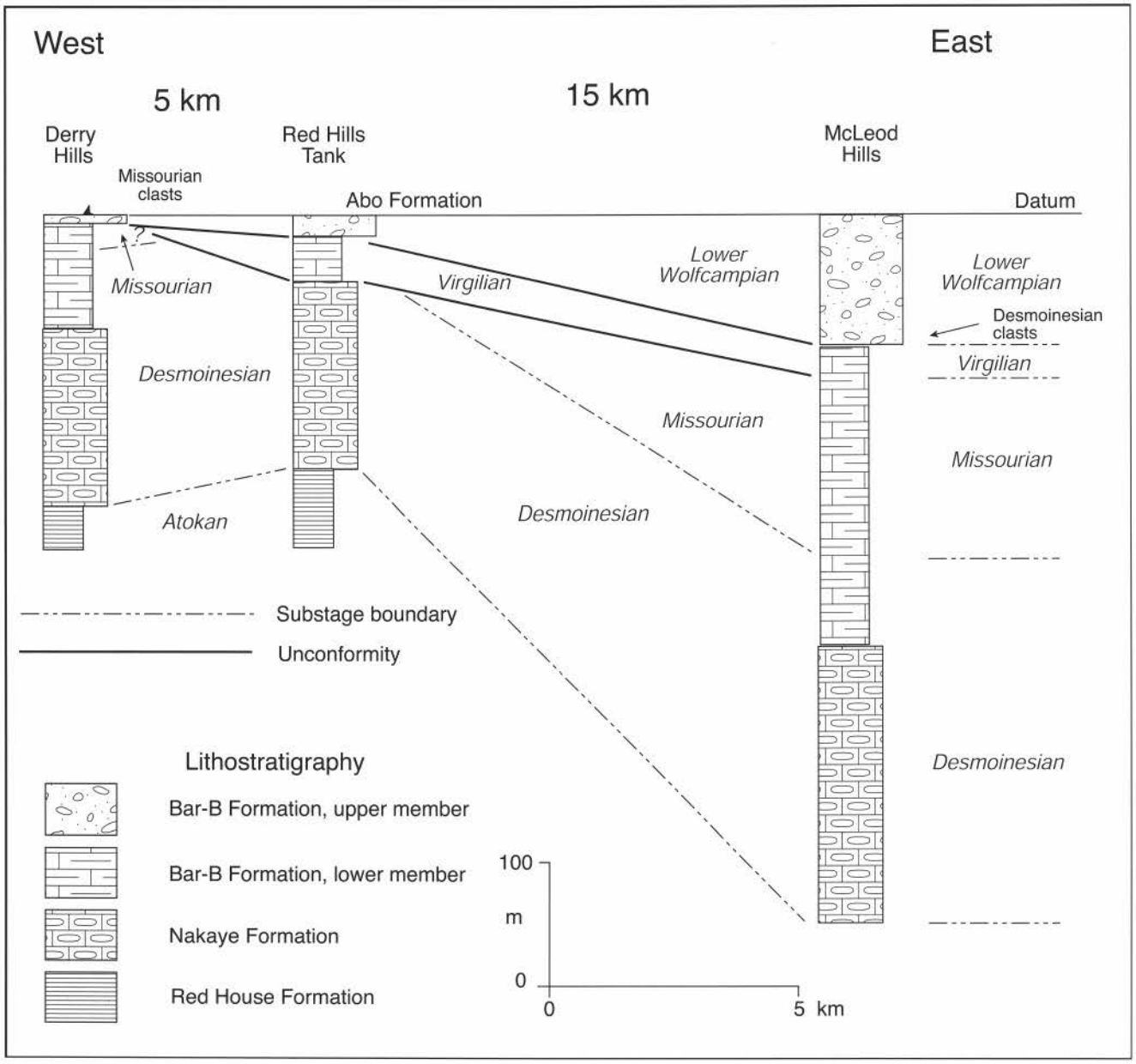

FIGURE 6. Fence diagram of Pennsylvanian and lower Wolfcampian strata across southern part of Caballo Mountains. General thinning of Pennsylvanian-Wolfcampian section takes place by onlap of Permian strata onto Pennsylvanian-Permian unconformity and may also take place by means of thinning at an unconformity beneath Virgilian strata (Singleton, 1990). Location of Red Hills Tank measured section: NW 1/4 sec. 15, T17S, R4W.

Mountains, the Laborcita Formation is conglomeratic and was folded prior to deposition of the Abo Formation (Otte, 1959; Pray, 1961). At these localities, the Bursum represents a transition to non-marine strata of the Abo Formation (Lucas et al., 2000; Kues, 2001); however, this transition is marked by unconformities and intervening conglomerate beds, making it atypical of a standard progradational shallow marine to fluvial succession.

Lower Wolfcampian conglomeratic strata are widespread in southern New Mexico and West Texas. The upper conglomeratic member of the Bar B Formation also correlates with the Wolfcampian upper part of the Horquilla Limestone in the Pedregosa basin of southwestern New Mexico and southeastern Arizona. The basal Wolfcampian of the Horquilla in the Big and Little Hatchet Mountains of southeastern New Mexico contains limestone-clast conglomerate interbedded with fusulinid-bearing limestone (Zeller, 1965; Lawton and Harrigan, 1998). The upper conglomeratic member of the Bar B Formation is probably slightly older than the conglomeratic Neal Ranch Formation near Marathon, Texas (Wahlman and King, 2002), which signals final suturing of Gondwana and Laurentia to form Pangea (Ross, 1986).

DISCUSSION

Widespread deposition of Wolfcampian conglomerate in southern New Mexico indicates that local uplifts of Early Permian age were widely distributed in the region. The time correspondence with late collision in the Marathon region of Texas suggests that these Wolfcampian strata of New Mexico likewise record the Gondwanan collision. The timing of late deformation on the east flank of the Orogrande basin is well constrained as pre-middle Wolfcampian, because folds involving Pennsylvanian strata are truncated by an unconformity beneath the Abo Formation (Otte, 1959; Pray, 1961). Synsedimentary deformation controlled both carbonate and siliciclastic depositional patterns in Virgilian and Wolfcampian strata on the west flank of the Sacramento Mountains (Otte, 1959; Wilson, 1972; Giles and Lawton, 1996). Thus, the uplift that generated the conglomerates in the upper part of the Bar B Formation was coeval with deformation on the Sacramento shelf. Repeated local uplift and subsidence are suggested by the pre-Pennsylvanian and pre-Wolfcampian unconformities in the southern Caballo Mountains, as well as the possibility of one or more intra-Pennsylvanian unconformities. Local sources for uplift are indicated by the clast types in the conglomerate, although we have not yet located a locality where Wolfcampian strata directly overlie Desmoinesian rocks that might have provided clasts to the McLeod Hills strata.

The mechanism for deformation that generated these conglomerates remains debated. Kluth and Coney (1981) advocated intracontinental wrenching during progressive collision of Laurentia and Gondwana, whereas Ye et al. (1996) favored basement-cored uplift and flexural basin formation above a flat subducted slab. Northwest-trending, en echelon folds associated with the Fresnal fault zone in the Sacramento Mountains (Otte, 1959) are consistent with dextral offset on the fault (Fig. 7). Patterns of uplift and subsidence likewise suggest strike-slip deformation: local polycyclic uplift and subsidence recorded by the strata of the southern Caballo Mountains are consistent with a strike-slip mechanism for basin formation, as are the coarse-grained fan-deltaic facies of the upper conglomeratic member (e.g., Nilsen and Sylvester, 1995). In addition, Virgilian isopachs of the Orogrande basin (Fig. 7) have an elliptical to rhomb-shaped areal pattern with a central depocenter, a geometry compatible with strike-slip origin. The basin geometry is not markedly asymmetric, as would be expected for a flexural basin formed by a flanking tectonic load (e.g., Ye et al., 1996). Thus, although the mechanism of intracratonal deformation in southern New Mexico remains unclear, a transpressive or transtensional mechanism related to progressive suturing of Laurentia and Gondwana remains attractive (Kluth and Coney, 1981; Giles and Lawton, 1996; Lawton and Giles, 2000).

ACKNOWLEDGMENTS

This paper is dedicated to the memory of John F. Kalesky (1963-1989). We thank Barry Kues and Bill Seager for reviews that improved content and clarity.

REFERENCES

Algeo, T. J., Wilson, J. L., and Lohmann, K. C., 1991, Eustatic and tectonic controls on cyclic sediment accumulation patterns in lower-middle Pennsylvanian strata of the Orogrande basin, New Mexico: New Mexico Geological Society, 42nd Field Conference, Guidebook, p. 203-212.

Folk, R. L., 1974, Petrology of sedimentary rocks: Austin, Texas, Hemphill Publishing Company, 182 p.

Giles, K. A., and Lawton, T. F., 1996, Control of Pennsylvanian facies distribution by coeval transpressional folding, Orogrande basin, New Mexico: Geological Society of America Abstracts with Programs, v. 28, no. 7, p. 445.

Kalesky, J. F., 1988, Lithofacies, stratigraphy and cyclic sedimentation in a mixed carbonate and siliciclastic system, Red House Formation (Atokan), Sierra County, New Mexico [M.S. thesis]: Las Cruces, New Mexico State University, 201 p.

Kelley, V. C., and Silver, C., 1952, Geology of the Caballo Mountains: Albuquerque, University of New Mexico, Publications in Geology 4, 286 p.

Kluth, C. F., and Coney, P. J., 1981, Plate tectonics of the Ancestral Rocky Mountains: Geology, v. 9, p. 10-15.

Kottlowski, F. E., 1960, Summary of Pennsylvanian sections in southwestern New Mexico and southeastern Arizona: New Mexico Bureau of Mines and Mineral Resources, Bulletin 66, 187 p.

Kottlowski, F. E., Flower, R. H., Thompson, M. L., and Foster, R. W., 1956, Stratigraphic studies of the San Andres Mountains, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 1, 132 p.

Kues, B. S., 2001, The Pennsylvanian System in New Mexico-overview with suggestions for revision of stratigraphic nomenclature: New Mexico Geology, v. 23, p. 103-122.

Lawton, T. F., and Giles, K. A., 2000, Southwestern Ancestral Rocky Mountains province, Arizona, New Mexico, Sonora and Chihuahua: broken foreland or continental borderland?: Geological Society of America Abstracts with Programs, v. 32, no. 7, p. 466.

Lawton, T. F., and Harrigan, P. J., 1998, Broken Jug Formation-redefinition of lower part of Bisbee Group, Little Hatchet Mountains, Hidalgo County, New Mexico: New Mexico Geology, v. 20, p. 69-77.

Lucas, S. G., Wilde, G. L., Robbins, S., and Estep, J. W., 2000, Lithostratigraphy and fusulinaceans of the type section of the Bursum Formation, Upper Carboniferous of south-central New Mexico, *in* Lucas, S. G., ed., New Mexico's fossil record 2: Albuquerque, New Mexico Museum of Natural History and Science, Bulletin 16, p. 1-13.

Mack, G. H., Lawton, T. F., and Giles, K. A., 1998, First-day road log from Las Cruces to Derry Hills and Mescal Canyon in the Caballo Mountains: New Mexico Geological Society, 49th Field Conference, Guidebook, p. 1-21.

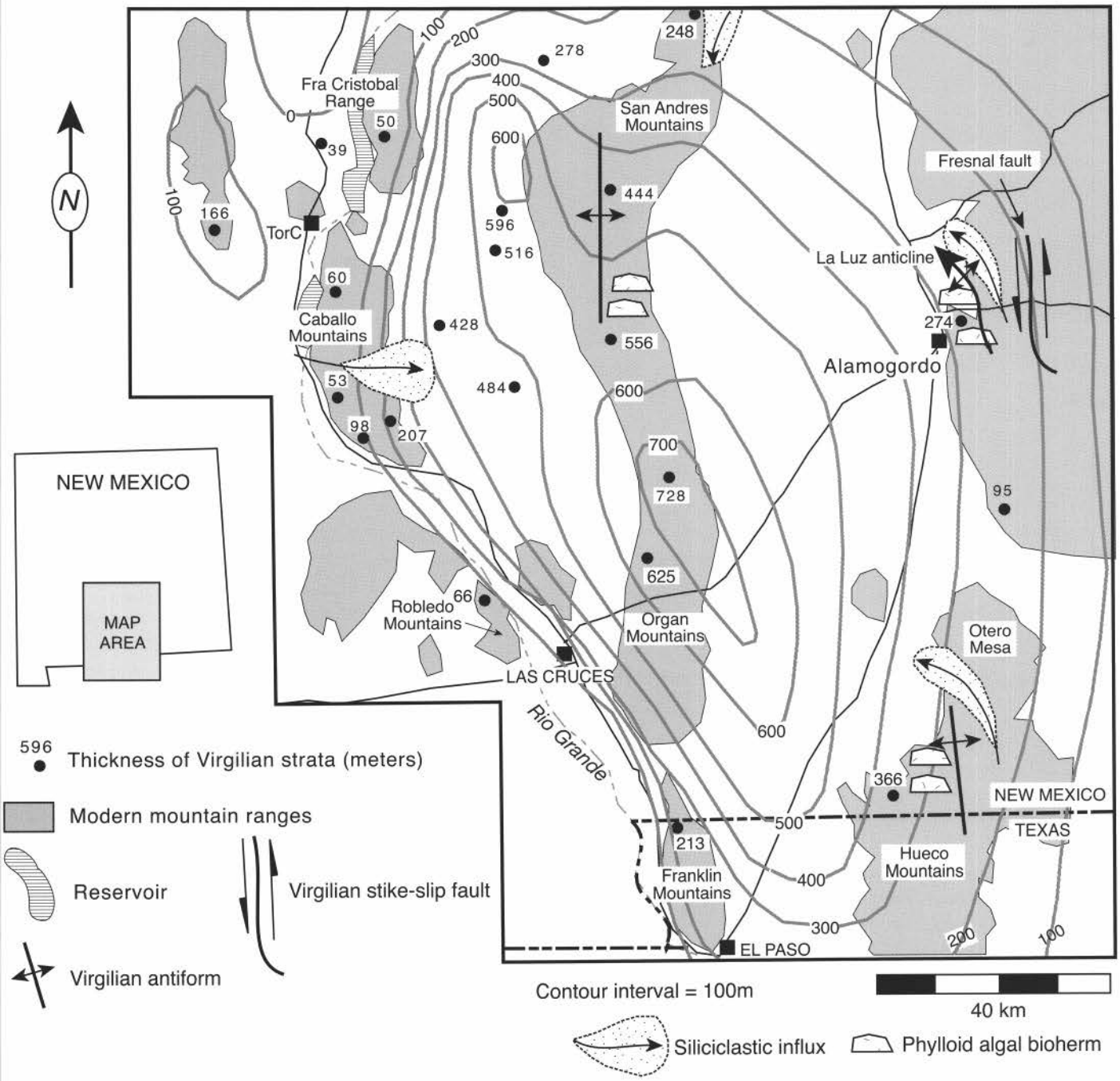

FIGURE 7. Virgilian isopach map, Orogrande basin. Major sites of extrabasinal detrital influx indicated by sediment fans. Right-lateral offset on Fresnal fault in Sacramento Mountains inferred from fold trends adjacent to fault (Otte, 1959). Rhombic basin form and central depocenter suggest basin origin by wrench faulting rather than by flexural loading by Pedernal uplift (see text). Anticline in San Andres Mountains (after Singleton, 1990) acted as nucleation site for Virgilian mounds there.

Mack, G. H., Lawton, T. F., and Sherry, C. R., 1995, Fluvial and estuarine depositional envrionments of the Abo Formation (Early Permian), Caballo Mountains, south-central New Mexico, *in* Lucas, S. G., and Heckert, A. B., eds., Early Permian footprints and facies: Albuquerque, New Mexico Museum of Natural History and Science, Bulletin 6, p. 181-187.

Meyer, R. F., 1966, Geology of Pennsylvanian and Wolfcampian rocks in southeast New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 17, 123 p.

Nilsen, T. H., and Sylvester, A. G., 1995, Strike-slip basins, *in* Busby, C. J., and Ingersoll, R. V., eds., Tectonics of sedimentary basins: Cambridge, Massachusetts, Blackwell Science, p. 425-457.

Otte, C., Jr., 1959, Late Pennsylvanian and Early Permian stratigraphy of the northern Sacramento Mountains, Otero County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 50, 108 p.

Pray, L. C., 1961, Geology of the Sacramento Mountains escarpment, Otero County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 35, 144 p.

Ross, C. A., 1986, Paleozoic evolution of southern margin of Permian basin:

Geological Society of America Bulletin, v. 97, p. 536-554.

Seager, W. R., 1986, Third-day road log, from Truth or Consequences to southeastern Caballo Mountains and San Diego Mountain via I-25 and the Jornada del Muerto: New Mexico Geological Society, 37th Field Conference, Guidebook, p. 35-52.

Seager, W. R., and Mack, G. H., 1991, Geology of Garfield quadrangle, Sierra and Doña Ana Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 128, 24 p.

Seager, W. R., and Mack, G. H., 1998, Geology of McLeod Tank quadrangle, Sierra and Doña Ana Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Geologic Map 77, scale 1:24,000.

Seager, W. R., and Mack, G. H., in press, Geology of the Caballo Mountains: New Mexico Bureau of Geology and Mineral Resources.

Sherry, C. R., 1990, Fluvial sedimentology and paleosols of the Abo Formation (Wolfcampian) in central Sierra County, New Mexico [M.S. thesis]: Las Cruces, New Mexico State University, 120 p.

Singleton, D. S., 1990, Depositional environments and tectonic significance of the Bar B Formation (Virgilian), Sierra County, New Mexico [M.S. thesis]: Las Cruces, New Mexico State University, 132 p.

Soreghan, G. S., 1994, Stratigraphic responses to geologic processes: late Pennsylvanian eustasy and tectonics in the Pedregosa and Orogrande basins: Geological Society of America Bulletin, v. 106, p. 1195-1211.

Thompson, A. D., 1991, Fusulinid biostratigraphy of the Bar B Formation (Desmoinesian-Wolfcampian), southern Caballo Mountains, New Mexico [M.S. thesis]: Las Cruces, New Mexico State University, 100 p.

Thompson, M. L., 1942, Pennsylvanian System in New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 17, 92 p.

Van Wagoner, J. C., 1977, Lower and middle Pennsylvanian rocks of the northern Sacramento Mountains; a study of contemporaneous carbonate and siliciclastic deposition in an active tectonic setting [Ph.D. dissertation]: Houston, Rice University, 204 p.

Wahlman, G. P., and King, W. E., 2002, Latest Pennsylvanian and earliest Permian fusulinid biostratigraphy, Robledo Mountains and adjacent ranges, south-central New Mexico: New Mexico Bureau of Geology and Mineral Resources, Circular 208, 26 p.

Wilde, G. L., 1990, Practical fusulinid zonation: the species concept; with Permian basin emphasis: West Texas Geological Society Bulletin, v. 29, p. 5-33.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., and Vorbe, G., 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro counties, New Mexico: U. S. Geological Survey, Oil and Gas Investigations, Preliminary Map 61, scale ~1:63,360.

Wilson, J. L., 1972, Influence of local structures on sedimentary cycles of late Pennsylvanian beds of the Sacramento Mountains, Otero County, New Mexico, *in* Elan, J. G., and Chuber, S., eds., Cyclic sedimentation in the Permian basin: Midland, Texas, West Texas Geological Society, p. 100-113.

Ye, H., Royden, L., Burchfiel, C., and Schuepbach, M., 1996, Late Paleozoic deformation of interior North America: the greater Ancestral Rocky Mountains: American Association of Petroleum Geologists Bulletin, v. 80, p. 1397-1432.

Zeller, R. A., 1965, Stratigraphy of the Big Hatchet Mountains area, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Memoir 16, 128 p.

Zuffa, G. G., 1980, Hybrid arenites: their composition and classification: Journal of Sedimentary Petrology, v. 50, p. 21-29.

Photograph of a mother oryx and her progeny, an example of some of the exotic wildlife on the White Sands Missile Range. Note the "oryx-proof" fences around the national monument on Day 2, erected to protect native ecosystems from this African intruder. Photo courtesy Robert Myers, WSMR.