

Leonardian (lower Permian) fusulinids from the Cibolo Formation, Chinati Mountains, Presidio County, Texas, USA

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ABSTRACT: Three samples from the Cibolo Formation (Leonardian, lower Permian) of the Chinati Mountains in southwestern Texas are analyzed for fusulinid biostratigraphy, and fusulinid data from previous studies in the Chinati Mountains are summarized. Sample R0900 from the allochthonous Cibolo reef block contained only *Chusenella cibolensis* and is probably early Leonardian in age. Sample 4E1 from 50–100 ft (15.24–30.48 m) above the base of the Cibolo Formation contained *Schwagerina crassitectoria*, *S. guembeli*, and *?Pseudoreichelina nevadaensis*, which are typical of early Leonardian strata in the Permian Basin region (Zone Lf1). Sample 2-40 from 420 ft (128 m) above the base of the Cibolo Formation contained *Parafusulina durhami*, *P. fountaini*, *P. guatemalensis*, and *P. bakeri*, which are late Leonardian in age (Zone Lf3). No samples containing middle Leonardian fusulinids (Zone Lf2) were found.

INTRODUCTION

The Cibolo Formation of the Chinati Mountains in southwestern Texas is significant because it is one of only a few good exposures of lower Permian strata along the southern side of the Permian Basin region (text-fig. 1). The Glass Mountains, located ~70 miles (112.6 km) to the northeast of the Chinati Mountains, contain the stratotype sections for the North American lower Permian regional chronostratigraphic stages (Wolfcampian and Leonardian). The lower Permian sections in the Glass Mountains, Guadalupe Mountains, and Sierra Diablo have been well-studied, but lower Permian strata in the Chinati Mountains and other remote outcropping sections to the northwest in the Finlay and Malone mountains have received relatively little detailed modern study (Cys 1975).

Udden (1904) and Baker (1927, 1929) first described the Pennsylvanian-Permian strata in the Chinati Mountains (text-fig. 2). Skinner (1940) outlined the fusulinid biostratigraphy of the Middle Pennsylvanian through middle Permian stratigraphic section. Additional unpublished fusulinid data, as well as biostratigraphic data from other fossil groups, were summarized by Rix (1953a). The only fusulinid previously described and illustrated from the Chinati Mountains section, however, is the early Leonardian *Chusenella ciboloensis* (Stewart 1963). During field mapping, authors Pate and Rohr made a few new fusulinid collections from the Leonardian Cibolo Formation, and fusulinids from those samples are described and illustrated herein. The documentation of the biostratigraphy of the Leonardian strata in the Chinati Mountains enables better correlations to the Glass Mountains lower Permian stratotype sections and better paleogeographic reconstructions along the southern margin of the Permian Basin region.

LEONARDIAN FUSULINID ZONES

The Leonardian Stage in the Permian Basin contains three widely recognized fusulinid zones (Ross 1960, 1962; Ross and

Ross 1987a, b, 1988, 1997, 2003, 2009; Wilde 1990; Wahlman in press). Wahlman (in press) referred to these three fusulinid zones, in ascending order, as Lf1, Lf2, and Lf3, which are equivalent to Wilde's (1990) zones PL-1, PL-2, and PL-3, respectively. The lower Leonardian Lf1 zone is characterized by *Schwagerina crassitectoria* Dunbar and Skinner 1937, *S. guembeli* Dunbar and Skinner 1937, *S. hessensis* Dunbar and Skinner 1937, *S. hawkinsi* Dunbar and Skinner 1937, *S. dugoutensis* Ross 1962, *Robustoschwagerina stanislavi* Dunbar 1953, and probably *Chusenella cibolensis* Stewart 1963. The middle Leonardian Lf2 zone is characterized by *Parafusulina leonardensis* Ross 1962, *P. spissisepta* Ross 1960, *P. brookensis* Ross 1960, *P. vidriensis* Ross 1960, *P. allisonensis* Ross 1960, and *P. deltoides* Ross 1960. Species of the fusulinid genus *Skinnerella* have been considered to range from the middle part of the Lf1 zone through at least the lower part of the Lf2 zone, but recent data suggest that species of the genus might appear in the lower part of the Lf1 zone (Coogan 1960; Skinner 1971; Wilde 1990; Wahlman, Barrick and Baumgardner 2016; Wahlman in press). The upper Leonardian Lf3 zone is characterized by *Parafusulina durhami* Thompson and Miller 1949, *P. fountaini* Dunbar and Skinner 1937, *P. bakeri* Dunbar and Skinner 1937, and *Shagonella setum* (Dunbar and Skinner 1937).

In the Leonardian stratotype of the Glass Mountains, zones Lf1 and Lf2 are recognized in the shelfal facies of the Hess Formation and the laterally equivalent slope-to-basin facies of the Skinner Ranch Formation, and zone Lf3 occurs in the overlying Cathedral Mountain Formation. The Glass Mountains Leonardian stratotype section unconformably overlies the Lenox Hills Formation (upper Wolfcampian, Lenoxian) of the Wolfcampian stage stratotype. Permian Basin Leonardian fusulinid faunas share several species described from Mexico, Central America, and northern South America (Dunbar 1939; Thompson and Miller 1944, 1949; Kling 1960; Vachard et al. 1997, 2000; Perez-Ramos and Nestell 2002; Stevens, Poole and Amaya-Martinez 2014).

CHINATI MOUNTAINS OUTCROP AREAS AND STRATIGRAPHY

The Chinati Mountains are located in Presidio County of southwestern Texas, just north of the Rio Grande River and ~70 miles (112.6 km) southwest of the Wolfcampian–Leonardian (lower Permian) stratotype sections in the Glass Mountains of Brewster County, Texas (text-fig. 1). Paleogeographically, the Pennsylvanian–Permian strata of the Chinati Mountains were deposited along the margin of the Marfa Basin (text-fig. 1). Udden (1904) published the first geological description of Upper Paleozoic strata of the Chinati Mountains. Rix (1953a) reviewed the history of geological and paleontological studies in the area. He noted that many early workers in the area made erroneous biostratigraphic age assignments to different stratigraphic units in various outcrop areas of the Chinati Mountains because of misidentifications, poor fossil preservation, and probable faunal mixing resulting from erosion and reworking in allochthonous slope-to-basin debris-flow deposits.

There are four separate areas of Upper Paleozoic exposures in the Chinati Mountains. (1) The outcrop belt north of the town of Shafter, which is where Leonardian samples studied in this paper were collected. (2) The hills west of Shafter in the southeastern Chinati Mountains, where the Guadalupian (middle Permian) Ross Mine and Mina Grande formations were described by Ross and Cartwright (1935), Ross (1943), and Rix (1953a). Skinner (1940) reported the early–middle Guadalupian (Roadian–Wordian) fusulinids *Parafusulina boesei* Dunbar and Skinner 1937 and *P. sellardsi* Dunbar and Skinner 1937 from the Ross Mines Formation, and the late Guadalupian (Capitanian) fusulinids *Polydixodina shumardi* Dunbar and Skinner 1931, *Codonofusiella paradoxica* Dunbar and Skinner 1937, and *Leela bellula* Dunbar and Skinner 1937 from the yellow dolomitic limestone of the Mina Grande Formation. (3) The Pinto Canyon section is along the northern edge of the Chinati Mountains. Those outcrops consists of ~1000 ft (304.8 m) of mostly thin-bedded limestone, chert, and dark shale deposited in deep-water slope-to-basin settings and contain common turbidite beds and large slide blocks (Baker 1927; Skinner 1940; Cress 1953; Rigby 1953; Amsbury 1957). Skinner (1940) dated fusulinids from the upper part of the section as being Wordian (early Guadalupian) in age. No fusulinids have been reported from the lower part of the section, but its lithofacies appear to be similar to Leonardian facies in the Ojo Bonito section. (4) The Ojo Bonito outcrop area is in the northwestern Chinati Mountains and was originally described by Baker (1927, 1929), who reported several typical Wordian ammonoids from the upper part of the section and brachiopods and an ammonoid of probable Leonardian age from the lower part of the section. Rix (1953a) described the Permian strata of the Ojo Bonito outcrop area, including exposures of the upper Alta Formation, which contains late Wolfcampian ammonoids, and he sampled fusulinids from limestone lenses within the Cibolo Formation that R. V. Hollingsworth (Paleontological Laboratory, Midland, Texas) identified as Leonardian *Schwagerina* and *Parafusulina*. Rix described a 412 ft (125.58 m) unfossiliferous sandstone and shale unit between the strata biostratigraphically age-dated as late Wolfcampian and Leonardian. He also described the overlying Ross Mine Formation, from which he reported the Guadalupian ammonoid *Waagenoceras*, and thin outcrops of the Mina Grande Formation at the top of the Permian section that contain the Guadalupian ammonoid *Cibolites*. No Guadalupian fusulinids have been reported from the area. The lithostratigraphy and

fusulinid biostratigraphy of the Pennsylvanian–Permian section in the Chinati Mountains are summarized in text-figure 2.

PENNSYLVANIAN–PERMIAN STRATIGRAPHY OF NORTH SHAFTER AREA

Udden (1904) first described the Pennsylvanian–Permian stratigraphy of the outcrop area north of the town of Shafter in the Chinati Mountains, work which was later modified by Rix (1953a, 1953b), Amsbury (1957), and Pate (2016). Udden (1904) named three formations, which are, in ascending order: the Cieneguita, Alta, and Cibolo. Skinner (1940) originally outlined the fusulinid biostratigraphy of those formations (text-fig. 2).

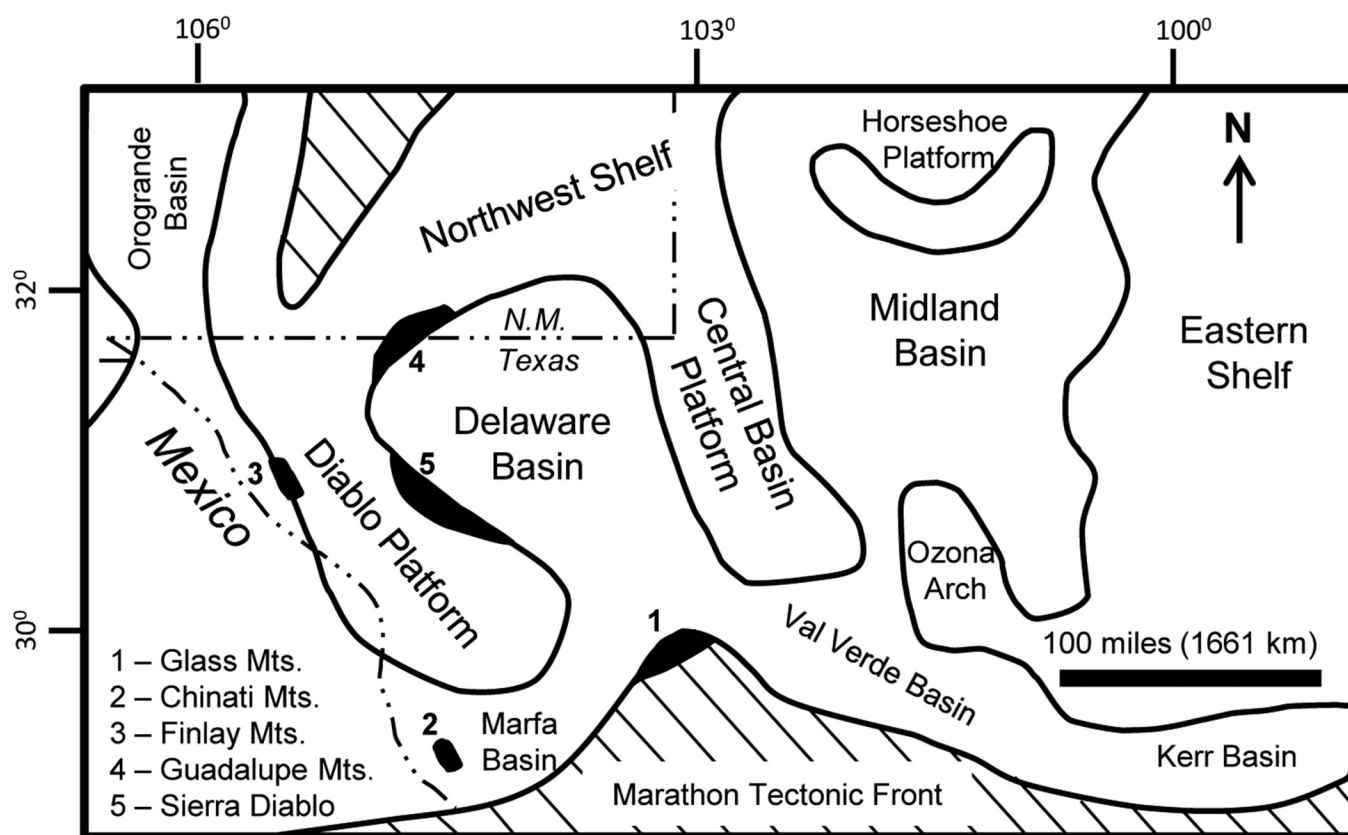
The Cieneguita Formation is composed of ~1000 ft (304.8 m) of interbedded sandstone, shale, conglomerate, and scattered limestone (text-fig. 2). About 200 ft (60.96 m) above the base, Skinner (1940) reported a limestone containing the fusulinid *Beedeina*, which indicates a Desmoinesian (Middle Pennsylvanian) age. In limestone beds of the upper half of the formation, he cited numerous *Triticites* of middle Missourian–early Virgilian age. Rix (1953a) sent fusulinid samples from the Cieneguita Formation to R.V. Hollingsworth in Midland, who dated the *Beedeina* from the lower part of the formation as correlative with those present in the upper part of the Strawn Group (late Desmoinesian) in north-central Texas. He also correlated the Virgilian-aged *Triticites* from the upper part of the formation to strata of the Cisco Group of north-central Texas and the Shawnee Group of the Midcontinent.

Skinner (1940) described the contact of the Cieneguita Formation and overlying shale-dominated Alta Formation as being gradational, with a gradual upward decrease of limestone beds. He cited the Alta shale beds as containing only very sparse brachiopod spines and crinoid ossicles, and no biostratigraphically useful fossils. Based only on the stratigraphic position, Skinner (1940) interpreted the Alta Formation as probably being Virgilian and early Wolfcampian in age.

Udden (1904) originally divided his Cibolo Formation into five informal members, which were, in descending order:

- Yellow limestone unit - 650 ft (198.12 m) of gray to yellow massive limestone
- Thin-bedded unit - 470 ft (143.26 m) of thin-bedded dark cherty limestone
- Sponge spicule unit - 85 ft (25.9 m) of siliceous limestone
- Lower brecciated unit - 133 ft (40.54 m) of massive brecciated limestone
- Transitional beds unit - 100 ft (30.48 m) of shale, sandstone and sandy limestone.

Udden's (1904) transitional beds of his lowermost Cibolo Formation are composed of mixed clastic and carbonate shelf cycles, from which Skinner (1940) reported the late Wolfcampian fusulinids *Monodixodina linearis* (Dunbar and Skinner 1937) (now assigned to *Eoparafusulina*), *Schwagerina diversiformis* Dunbar and Skinner 1937, *S. huecoensis* (Dunbar and Skinner 1931), *Pseudoschwagerina uddeni* (Beede and Kniker 1924), and *Ps. texana* Dunbar and Skinner 1937. That assemblage is typical of the Lenox Hills Formation in the Glass Mountains Wolfcampian stratotype (Ross 1959, 1963a). Skinner (1940) also reported that the Wolfcampian fusulinids *E. linearis* and *S. diversiformis* continued to within 50 ft (15.24 m) of the top of the Cibolo Formation, but all other paleontologic data summarized by Rix (1953a), as well as fusulinids described in this study, demonstrate that most of the Cibolo Formation is



TEXT-FIGURE 1

Map of structural/paleogeographic features of the Permian Basin region in west Texas and southeastern N. M. (New Mexico) and showing the location of the Chinati Mountains and other key Leonardian outcrop areas.

Leonardian in age. It is possible that field samples studied by Skinner (1940) that were thought to be from the middle and upper parts of the Cibolo Formation were mislabelled or mislocated stratigraphically, or perhaps were from allochthonous debris flow clasts containing reworked Wolfcampian fusulinids. Rix (1953a) also cited papers by King (1930) and Miller (1945) reporting occurrences of Leonardian brachiopods and ammonoids, respectively, in the Cibolo Formation.

Hollingsworth (in Rix 1953a, p. 52–53) analyzed numerous fusulinid samples from the Cibolo Formation and identified as late Wolfcampian species of *Schwagerina* and *Pseudofusulina* from Udden's transitional beds in agreement with Skinner (1940; text-fig. 2). He also identified early Leonardian *Schwagerina* and *Parafusulina* from a limestone conglomerate in the upper 35 ft (10.67 m) of Udden's lower brecciated unit. Based mainly on paleontologic evidence, Rix (1953a, p. 54) suggested that the base of the Cibolo Formation should be shifted up section to the base of that limestone conglomerate, which he correlated to the Wolfcampian-Leonardian biostratigraphic boundary. In this study, the base of the Cibolo Formation is placed at the lithostratigraphic contact at the base of the Udden's lower brecciated unit (text-figs. 2, 3).

As shown by Rix (1953a, p. 51 and pl. 5), Udden's (1904) uppermost informal member, the yellow limestone unit, is the so-called Cibolo reef block or Cibolo slide block, which is an allochthonous block that rests on the Guadalupian-age Mina

Grande Formation at the western end of the North of Shafter outcrop belt. That block was traditionally interpreted as being emplaced by thrust faulting (Rix 1953b), but Rohr, Bogle and Wilde (2002) and Bogle and Rohr (2006) reinterpreted it as a large erosional slide block that was transported downslope into the basin during Guadalupian time. The Cibolo block contains well-developed shelf-margin reef facies with calcareous sponges, *Tubiphytes*, bryozoans, brachiopods, and encrusting red algae commonly surrounded by radial calcite cementstone (pl. 2, figs. 1, 3, 5). Stewart (1963) described the new species *Chu senella cibolensis* from the Cibolo block and interpreted it as early Leonardian in age, but he did not cite any supporting biostratigraphic evidence for that age call. Based on the biostratigraphy currently available, the Cibolo reef block is considered to be early Leonardian and, therefore, a shelf-margin carbonate facies roughly age-equivalent to the lower brecciated unit, and possibly the sponge spicule unit of Udden (1904; text-fig. 2).

In agreement with Rix (1953a), in this study the upper Wolfcampian transitional unit is not included in the Cibolo Formation, and is tentatively transferred to the uppermost part of the Alta Formation. In addition, the base of the Cibolo Formation is placed at the lithostratigraphic base of Udden's (1904) lower brecciated unit (text-figs. 2, 3). Therefore, according to Pate (2016) and the current study, the Cibolo Formation is composed of Udden's (1904) lower brecciated, sponge spicule, and thin-bedded units, and the allochthonous Cibolo reef block (i.e., Udden's yellow limestone) is considered to be roughly age-

equivalent to the lower brecciated unit (text-fig. 2). Based on the biostratigraphy of the fusulinids and several other fossil groups, the Cibolo Formation, therefore, ranges in age from early–late Leonardian. This study confirms the occurrences of early Leonardian fusulinids in the upper part of the lower brecciated unit, and late Leonardian fusulinids in the middle part of the thin-bedded unit (text-fig. 2). No fusulinids were found in the upper part of the thin-bedded unit and so that interval could be late Leonardian to possibly early Guadalupian.

The Pennsylvanian–Permian depositional history of the Chinati Mountains succession is interpreted as follows. The Late Pennsylvanian (Missourian–Virgilian)–early Permian (Wolfcampian) shale and sandstone of the Alta Formation are mostly unfossiliferous, with only sparse crinoid and brachiopod debris in the north Schafter outcrop belt (Skinner, 1940), and therefore, might be largely non-marine. The overlying transitional unit of Udden (1904), which is here included in the uppermost part of the Alta Formation, is composed of marine shelf cycles with late Wolfcampian (Lenoxian) fusulinids. The deposition of those late Wolfcampian marine shelf cycles is interpreted here to represent the basinwide transgression thought to be the result of the waning of Gondwanan continental glaciation. The overlying Leonardian Cibolo Formation represents the continued sea-level rise associated with the glacial melting. Wahlman and Tasker (2013) discussed similar late Wolfcampian and Leonardian transgressions throughout the Permian Basin region. Tectonic subsidence along the active Marathon orogenic belt could have also played a role in sea-level rise in the area.

All three units of the Cibolo Formation are interpreted as slope-to-basinal depositional facies (text-fig. 3). The conglomerate beds of the lower brecciated unit represent either a lowstand clastic wedge or debris flows. Similar lower Leonardian conglomeratic units in the Decie Ranch and Sullivan Peak members of the Skinner Ranch Formation in the Glass Mountains were interpreted as lowstand clastic wedges by Ross and Ross (2003, fig. 13). The overlying sponge spicule unit is clearly a deep-water basinal facies that indicates continued sea-level rise, and the thin-bedded unit is composed of dark cherty carbonate and siltstone similar to the basinal Bone Spring Limestone facies of the Delaware Basin. The allochthonous Cibolo reef block represents an early Leonardian shelf-margin buildup facies that is thought to have been eroded and transported downslope into the basin during deposition of the upper Guadalupian Mina Grande Formation.

SAMPLE MATERIALS

Fusulinids from three new field samples from Cibolo Formation outcrops north of the town of Shafter were studied. The field samples were slabbed, selected fusulinid specimens were axially oriented by hand grinding, and the oriented specimens were thin-sectioned and analyzed under a petrographic microscope. Fusulinid thin-sections of the samples are deposited in the Non-vertebrate Paleontology Collections, Jackson School of Geosciences, University of Texas at Austin, under the numbers NPL84781–NPL84802. Note that if more than one specimen from a single thin-section (e.g., NPL84781) was figured on the plates, then the additional figured specimens were designated by the same number with a letter suffix (e.g., NPL84781b) in the plate description.

Sample 4E1 (Plate 1)

Material: Field sample collected by C. Pate from 50–100 ft (15.24–30.48 m) above base of the Cibolo Formation in the lower brecciated unit of Udden (1904). Ten oriented-fusulinid thin-sections were analyzed.

Lithology: Limestone, skeletal-peloidal-lithoclastic grainstone, poorly sorted (pl. 1, figs. 1–6). The grains are rimmed by isopachous marine cements, and then intergranular pores were filled by lime mud that appears to have filtered in after the rimming cements were precipitated. Equant calcite cement finally filled the remaining pore spaces during burial. The grains are composed of common large fusulinids (*Schwagerina*) and calcareous algae (*Pseudovermiporella* and dasycladaceans); moderately common to sparse *Tubiphytes*, small foraminifers (*Climacammina*, tubular encrusting forms, *Endothyranella*, *Monotaxinoides*, endothyrids, *Tetrataxis*), mollusc fragments (mostly gastropods), and crinoid ossicles; and rare smaller fusulinids, including *Schubertella* sp. juvenaria, and ?*Pseudoreichelina nevadaensis* Douglass and Nestell 1974. There are also sparse small lithoclasts composed of either (1) fine- to medium-grained peloidal-skeletal packstone with occasional fusulinid fragments or (2) boundstones containing encrusting foraminifers, *Tubiphytes*, and *Pseudovermiporella*.

Depositional environment: Allochthonous skeletal debris and lithoclasts considered to have originated from shelf-margin shoal and reef facies and probably redeposited as slope debris flow beds or as lowstand clastic wedges.

Fusulinid biostratigraphy: *Schwagerina crassitectoria* and *S. guembeli* (early Leonardian) are common in the sample (pl. 1, figs. 1–6). These fusulinids correlate well with the lower sequences of the Skinner Ranch Formation and Hess Limestone in the Leonardian stratotype of the Glass Mountains (see Ross and Ross, 2003). Sparse, poorly preserved specimens of smaller fusulinids are tentatively assigned to ?*Pseudoreichelina nevadaensis* (pl. 1, figs. 7, 8), a species that is also characteristic of early Leonardian strata in the Permian Basin region (Douglass and Nestell 1974). It should be noted that the sample is from an allochthonous gravity deposit, and therefore, the fusulinids could be reworked and the beds could be younger than early Leonardian.

Sample R0900 (Plate 2)

Material: Sample was collected by D. Rohr from Cibolo reef block at the west end of the north of Schafter outcrop belt. Eleven thin-sections were studied.

Lithology: Limestone, skeletal grainstone/cementstone, non-compacted, with early cementation by banded radiaxial calcite cements (pl. 2, figs. 1–6). Grain types include abundant *Tubiphytes*; common fusulinids and small calcisponges; moderately common encrusting foraminifers (*Hedraites* and *Apterinaella*?); sparse crinoid ossicles (often much coarser grained than associated bioclasts), fenestrate bryozoans, gastropods, pelecypods, biconvex brachiopods with both articulated and disarticulated valves, small foraminifers (protonodosariids and ammobaculid-types), and small lithoclasts of boundstone and peloidal packstone; and rare dasycladacean algae and ammonoids.

Depositional environment: The sample is interpreted to be from a shelf-margin reef facies, and probably represents a foreereef

Chrono-strat.		Lithostratigraphy	Lithologies	Fusulinids
Permian	Guadalupian			
	Capitan.	Mina Grande Fm. >400 ft (121.9 m)	Massive gray to yellow-brown dolomitic limestone with reef facies	<i>Polydiexodina shumardi</i> , <i>Codonofusiella paradoxa</i> , <i>Leela bellula</i> (Capitanian) (Skinner 1940; Rix 1953)
	Word.	Ross Mine Fm. 721 ft (219.8 m)	Thin-bedded shale, sandstone and fossiliferous limestone	<i>Parafusulina boesei</i> , <i>P. sellardsi</i> (Wordian) (Skinner 1940; Rix 1953)
	Leonardian	[Udden (1904) formations and members emended]		
			Thin-bedded unit 470 ft (143.2 m)	Thin-bedded dark cherty limestone similar to Bone Spring Limestone (Basinal), with two conglomeratic units probably deposited as debris flow units
		Cibolo Fm. 700 ft (213.4 m)	Sponge spicule unit 85 ft (25.9 m)	Gray, tan, and brown spiculitic limestone (Basinal)
			Lower Brecciated unit 133 ft (40.5 m)	Conglomeratic lime rudstone-framestone with reef clasts (Allochthonous Cibolo reef block probably age-equivalent to this unit)
	Wolfcampian	Alta Fm. >5000 ft (1524 m)	Transitional beds 100 ft (30.5 m)	Interbedded shale, sandstone and limestone (Marine shelf cycles)
			Upper member	Thick bedded sandstone and sandy shales, yellow to brown (Mostly nonmarine?)
			Lower member	Dark fissile shale with many thin sandstone interbeds (Mostly nonmarine?)
Pennsylvanian	Virgilian			<i>Monodiexodina linearis</i> , <i>Schwagerina diversiformis</i> , <i>S. huecoensis</i> , <i>Pseudoschwagerina uddeni</i> , <i>Ps. texana</i> (Late Wolfcampian) (Skinner 1940)
	Desm.	Cieneguilla Fm. >2000 ft (609.6 m) (Thicknesses not to scale)	Shales, sandstones, conglomerates, and scattered limestones (Interbedded marine shelf and nonmarine)	Upper Missourian to lower Virgilian types of <i>Triticites</i> in limestones of upper half of formation (Skinner 1940; Rix 1953a) Desmoinesian fusulinid <i>Beedeina</i> in limestone at 200 ft (61 m) above base (Skinner, 1940; Rix 1953a)

TEXT-FIGURE 2

Pennsylvanian-Permian stratigraphic chart for the Chinati Mountains, with chronostratigraphic units, lithostratigraphic units and their general lithologic descriptions, and fusulinids reported from those units. Data were compiled from Udden (1904), Rix (1953a), Stewart (1963), Pate (2016), and this study. Note that the relative thicknesses of the lithostratigraphic units are not to scale. Desm. = Desmoinesian.

flank bed facies deposited in a moderate-energy, upper slope setting. The pervasive cementation by calcitic radialial cementstone suggests the depositional setting was in a relatively cool-water position, and could possibly indicate upwelling, as described by Wahlman and Konovalova (2002) in the lower Permian Kozhim carbonate bank in northern Russia. Although many of the biotic constituents are reefal, no *in situ* boundstone was present in the sample. Many of the skeletal grains are fragmented, but they are not worn. As indicated by the lack of any compaction, the cementation by the radialial calcite appears to be syndepositional to early marine phreatic. Generally, there are only sparse thin microbial encrustations, sometimes on *Tubiphytes*.

Fusulinid biostratigraphy: All fusulinids in the sample studied are *Chusenella cibolensis*, which was described by Stewart (1963) from the Cibolo block and dated as early Leonardian.

Sample 2-40 (Plates 3, 4)

Material: This field sample was collected by C. Pate from a bioclastic rudstone/floatstone bed in the middle part of Udden's (1904) thin-bedded unit at 420 ft (128 m) above the base of the Cibolo Formation in the outcrops north of Shafter. Ten oriented-fusulinid thin-sections were analyzed.

Lithology: Limestone, medium-gray skeletal packstone. The sample contains common large fusulinids (*Parafusulina*) and fusulinid fragments, fenestrate bryozoan fragments, crinoid ossicles; sparse brachiopod shell fragments and spines, ostracods, and small foraminifers (*Climacammina*, *Geinetzina*, *Globivalvulina*, *Tuberitina*, *Tetrataxis*); and rare trilobite and *Tubiphytes* fragments.

Depositional environment: The biotic and lithologic composition of the samples represents normal marine, probably outer shelf facies with moderate energy. The bioclasts were transported downslope and deposited as debris flow beds in a slope setting.

Fusulinid biostratigraphy: The diverse fusulinid assemblage of *Parafusulina durhami*, *P. fountaini*, *P. bakeri*, and *P. guatemalaensis* Dunbar 1939 indicate a late Leonardian age. This fusulinid assemblage correlates well with the Cathedral Mountain Formation in the Leonardian stratotype of the Glass Mountains.

SYSTEMATIC PALEONTOLOGY

Class FORAMINIFERA d'Orbigny 1826

Order FUSULINIDA Wedekind 1937

Superfamily FUSULINACEA von Möller 1878

Family OZAWAINELLIDAE Thompson and Foster 1937

Genus *Pseudoreichelina* Leven 1970

?*Pseudoreichelina nevadaensis* Douglass and Nestell 1974
Plate 1, figures 7, 8

Pseudoreichelina nevadaensis DOUGLASS and NESTELL 1974, p. 1172, pl. 1, figs. 1–9.

Description: This species is a small fusulinid with a nautiloid-like coil, rounded inner volutions, and outer volutions that are more angular and have a distinct keel with slightly concave slopes. The shell of this species typically uncoils and becomes rectilinear in the gerontic stage of growth, and one specimen illustrated herein (pl. 1, fig. 8) appears to show initial uncoiling.

The test wall is finely granular with no distinct structure, but a possible thin tectum is visible locally.

Discussion: A few specimens of this small fusulinid occurred in a peloidal-skeletal grainstone matrix associated with dasycladacean algal fragments and micritized bioclasts and aggregate grains. The specimens resemble *Nankinella* sp., but the lack of layered structure in the wall and the apparent initial unrolling of the last volution in one specimen (pl. 1, fig. 8) suggest that they might be immature *Pseudoreichelina nevadaensis*.

Occurrence: All the ?*P. nevadaensis* specimens come from field sample 4E1. Douglass and Nestell (1974) described *Pseudoreichelina nevadaensis* from the upper part of the Pequop Formation in Nevada, and noted that Garner Wilde (personal communication 1973) had informed them that the form is also common in the latest Wolfcampian and early Leonardian strata of the Permian Basin region.

Age: Early Leonardian, as shown by being associated in the same sample with *Schwagerina crassitectoria* and *S. guembeli*.

Family SCHWAGERINIDAE Dunbar and Henbest 1930

Genus *Schwagerina* von Möller 1877

Schwagerina crassitectoria Dunbar and Skinner 1937

Plate 1, figures 1–3, 5, 6

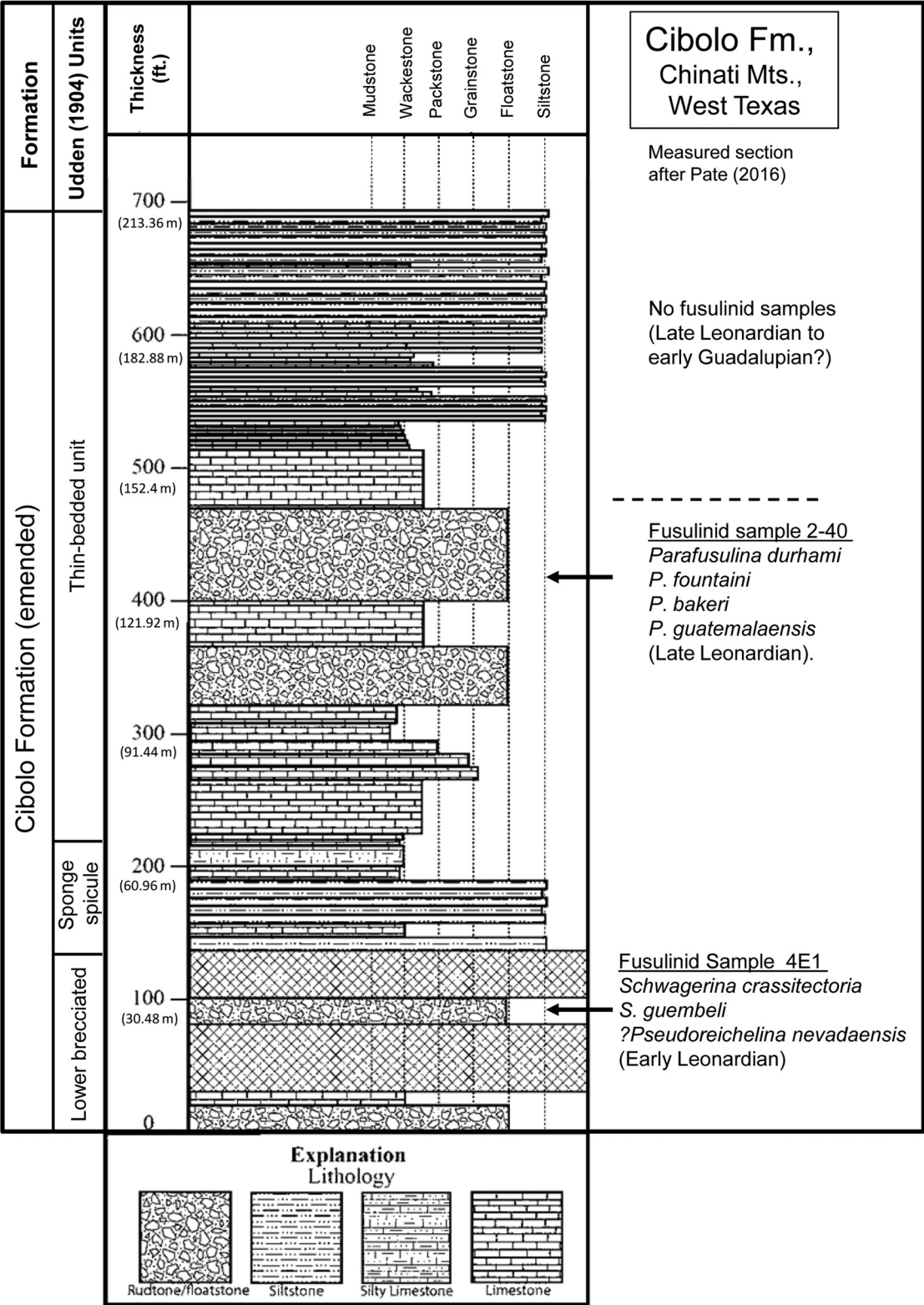
Schwagerina crassitectoria DUNBAR and SKINNER 1937, p. 641, pl. 65, figs. 1–15. – ROSS 1960, p. 123, pl. 17, figs. 1–9. – ROSS 1962, p. 9, pl. 1, figs. 15, 16.

Description: *Schwagerina crassitectoria* is a medium-sized species with a fusiform to somewhat elliptical shell shape, convex slopes, rounded poles, minor axial fillings in the early volutions, moderately intense septal fluting, and a generally well-defined tunnel. The proloculus is generally medium-sized, but one specimen illustrated here (pl. 2, fig. 6) has an unusually large proloculus. Variable-sized proloculi in this and related species are also shown by Thompson and Miller (1949), Ross (1960, 1962) and Ross and Ross (2003).

Discussion: *Schwagerina crassitectoria* is the most widely cited early Leonardian fusulinid in the Permian Basin region, and the oldest Leonardian fusulinid zone is often named after this species (Ross 1960, 1962; Wilde 1990; Wahlman in press). The species is usually associated with *Schwagerina guembeli*, as it is in this sample. It differs from *S. guembeli* species mainly by having a slightly more slender and uniformly convex shell form, but as noted by Ross (1960), gradational forms between the two species are common. It is possible that the two morphotypes actually represent phenotypic variations of a single species.

Skinner (1971) cited *S. crassitectoria* as ancestral to the late early and middle Leonardian genus *Skinnerella*. Bensch (1987) separated *S. crassitectoria*, *S. guembeli*, and *S. lineanoda* Ross 1959 into a new genus *Guembelites*, but because that name was later found to be preoccupied, Bensch (1991) renamed the genus *Praeskinnerella*. That genus name has since been used for this species group by Rauser-Chernousova et al. (1996) and some North American authors, such as Stevens, Poole and Amaya-Martinez (2014).

Occurrence: Specimens studied herein come from field sample 4E1. Dunbar and Skinner (1937), Ross (1960, 1962), and Ross and Ross (2003) have cited the species as characteristic of the



TEXT-FIGURE 3
Measured section of Cibolo Formation in the outcrop belt north of Schafer, Texas, southeastern part of the Chinati Mountains (adapted from Pate, 2016). Note that the composition of the Cibolo Formation differs somewhat from Udden's (1904) original description. The basal transitional beds are transferred from the Cibolo Formation to the upper part of the underlying Alta Formation (text-fig. 2), and the base of the Cibolo Formation is now placed at the lithostratigraphic boundary at the base of his lower brecciated unit. Udden's (1904) uppermost unit of the Cibolo Formation, the yellow limestone, is represented by the so-called Cibolo reef block or Cibolo slide block, which is exposed at the western end of the North of Schafer outcrop belt, and is not shown on this measured section. The two cross-hatched intervals in the lower brecciated unit are covered slope.

lower part of the Hess Limestone and adjacent lower Skinner Ranch Formation in the Leonardian stratotype of the Glass Mountains. Wilde (1990) cited the species as characteristic of the earliest Leonardian throughout the Permian Basin region.

Age: Early Leonardian.

Schwagerina guembeli Dunbar and Skinner 1937

Plate 1, figures 4, 5

Schwagerina guembeli DUNBAR and SKINNER 1937, p. 639, pl. 61, figs. 1–13. – ROSS 1960, p. 124, pl. 17, figs. 10–13. – ROSS 1962, p. 11, pl. 1, figs. 1–3.

Description: *Schwagerina guembeli* is a medium-sized species with a somewhat inflated fusiform shell form that is often flattened or even slightly depressed centrally in the axial view. It has secondary axial filling in the early volutions, and moderately intense and somewhat irregular septal fluting. The tunnel is variably expressed. The proloculus size varies from medium to moderately large.

Discussion: *Schwagerina guembeli* is a widely cited early Leonardian fusulinid and is usually reported in association with the similar *S. crassitectoria*. As noted above, the two morphotypes might actually represent a single species with moderate phenotypic variability.

Occurrence: The species is identified here in association with *S. crassitectoria* from field sample 4E1. Similar to *S. crassitectoria*, the species is characteristic of the lower part of the Hess Limestone and adjacent lower Skinner Ranch Formation in the Leonardian stratotype of the Glass Mountains (Dunbar and Skinner 1937; Ross 1960, 1962; Ross and Ross 2003).

Age: Early Leonardian.

Genus *Chusenella* Hsu 1942

Chusenella cibolensis Stewart 1963

Plate 2, figures 1–6

Chusenella cibolensis STEWART 1963, p. 1157, pl. 156, figs. 1–6, 13.

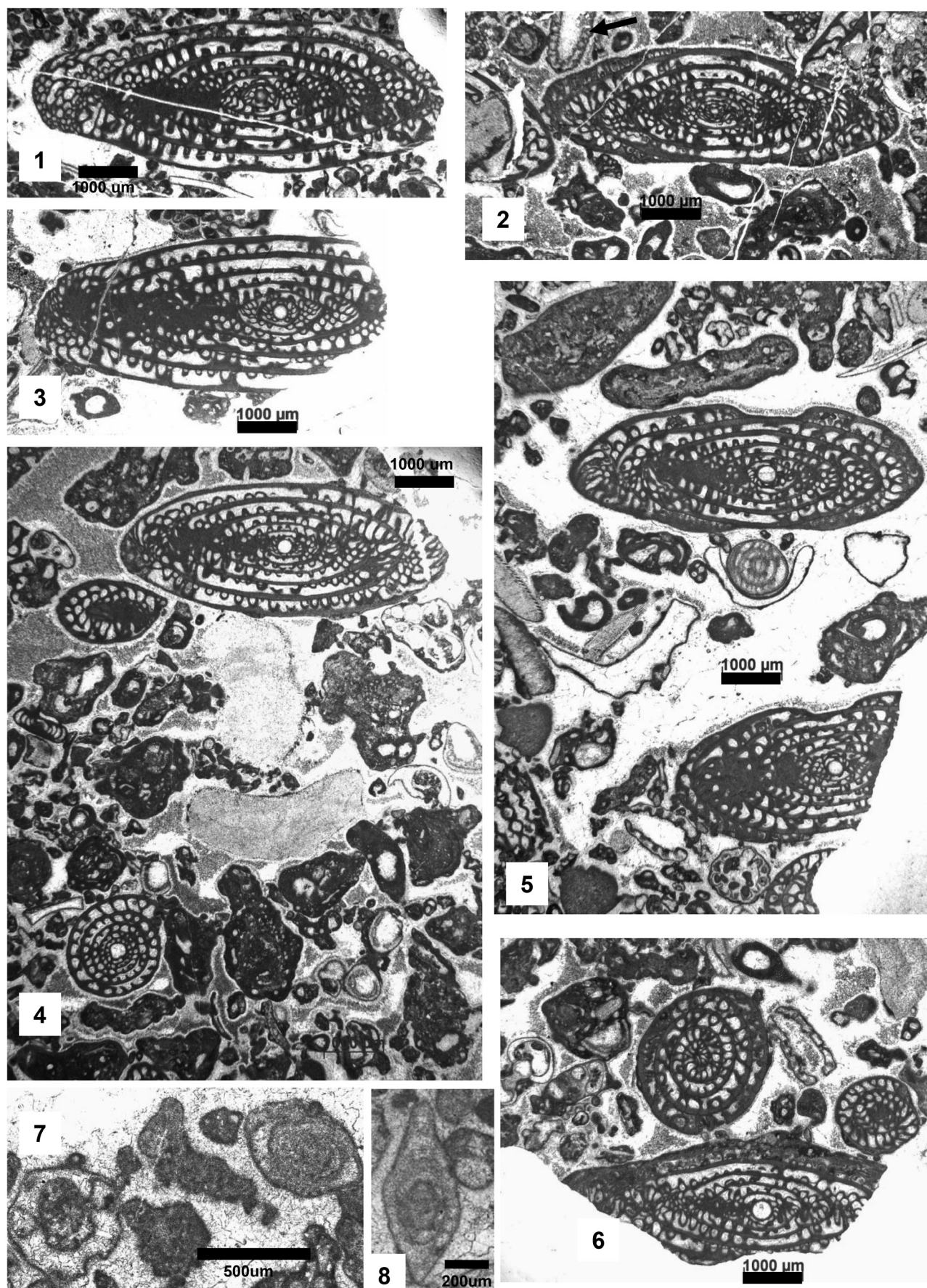
Description: *Chusenella cibolensis* has an elongate cylindrical shell shape with pointed poles. The juvenarium is tightly coiled and lacks significant septal fluting; the adult volutions expand gradually and have intense, regular, and low septal folding. The axis of coiling is often slightly curved. The proloculus is small, the tunnel is weakly developed, the wall is thin with fine keriothecal structure, and there is commonly a rather thin line of axial filling developed throughout the shell.

Discussion: Stewart (1963) described *C. cibolensis* with a few other new species of *Chusenella* from the Permian Basin region.

PLATE 1

Specimens from sample 4E1, Cibolo Formation, early Leonardian, Chinati Mountains
Figures 1–6, scale bar = 1000 microns. Figure 7, scale bar = 500 microns. Figure 8, scale bar = 200 microns.
Repository numbers in parentheses.

- 1 Axial specimen of *Schwagerina crassitectoria* Dunbar and Skinner 1937 in peloidal-skeletal grainstone. (NPL84781)
- 2 Axial specimen of *Schwagerina crassitectoria* in packstone-grainstone with *Tubiphytes* and dasycladacean algal fragments (arrow). Note that the bioclastic grains appear to have been originally deposited as a grainstone with early cements coating the bioclasts, and then carbonate mud sediments filtered into the open intergranular areas. Such a history is also evident in figures 4–6. (NPL84782)
- 3 Axial specimen of *Schwagerina crassitectoria* in packstone-grainstone. (NPL84783)
- 4 Axial (top) and sagittal (bottom left) specimens of *Schwagerina guembeli* Dunbar and Skinner 1937 in skeletal packstone-grainstone containing *Tubiphytes*, crinoid ossicles, gastropods, and a small tubular foraminifer. (NPL84784)
- 5 Slightly worn, axial specimens of *Schwagerina crassitectoria* (upper) and *Schwagerina guembeli* (lower) in skeletal grainstone with associated *Tubiphytes*, crinoid ossicles, dasycladacean algal fragments, and possible small calcisponge fragments. (NPL84785)
- 6 Partial axial specimen of *Schwagerina crassitectoria* with larger than usual large proloculus in skeletal packstone-grainstone with *Tubiphytes*, dasycladacean algal fragments, crinoid ossicles, and gastropod fragments. (NPL84786)
- 7 Oblique juvenile specimen of *?Pseudoreichelina nevadaensis* Douglass and Nestell 1974 in grainstone with small micritized bioclasts and aggregate grains, and a dasycladacean algal fragment (left). (NPL84783b)
- 8 Near axial section of an adult specimen of *?Pseudoreichelina nevadaensis* showing keeled test and apparent initial uncoiling in the upper part of the last volution. (NPL84785b)



Because there is not a significant change in juvenile-to-adult coiling rate in those Permian Basin species, they might be better placed in the genus *Pseudochusenella* Bensh 1987. Further study of this species group is needed. There are no other species of fusulinids in the Permian Basin region that closely resemble *C. cibolensis*. The species has not been illustrated from any other localities.

During the course of this study, the senior author attempted to locate the type specimens of *C. cibolensis*, but Stewart's type collections could not be found. If those collections cannot be located in the future, the topotype specimen shown here on plate 2, figure 1, could be assigned the neotype of the species.

Occurrence: The species is known only from the so-called Cibolo reef block (see previous discussion), which is located at the western end of the North of Shafter outcrop belt, about one mile from the Cibolo Ranch headquarters. The present specimens come from field sample R0900.

Age: Stewart (1963) dated *Chusenella cibolensis* as early Leonardian, but he did not cite any associated fusulinids or other biostratigraphic index fossils to corroborate his age call. We found no other fusulinids in the sample studied herein, and so cannot verify his early Leonardian age assignment. As currently known in the Permian Basin region, the genus *Chusenella* ranges from the upper part of the Wolfcampian into the lower and possibly middle parts of the Leonardian.

Genus *Parafusulina* Dunbar and Skinner 1931

Parafusulina durhami Thompson and Miller, 1949
Plate 3, figures 1, 2

Parafusulina durhami THOMPSON and MILLER 1949, p. 15, pl. 3, figs. 3–7 and pl. 5, figs. 9, 11, 12

Description: *Parafusulina durhami* is a large, elongate, subcylindrical species with a relatively thin spirotheca. The inner 5–6 volutions have a regular profile and gradual rate of growth, but outer volutions tend to become more irregular. Proloculus small to moderate in size, tunnel fairly distinct, septa highly and narrowly fluted, and axial filling rather weakly developed.

Discussion: This species is distinguished by the relatively tight coiling of its first 5–6 volutions and more expanded irregular outer volutions, thin spirotheca, small proloculus, and minor axial filling. *Parafusulina durhami* differs from the middle Leonardian species *P. leonardensis* Ross 1962 by having more closely spaced septal folds and axial secondary deposits restricted to the first 4.5 volutions. It differs from *P. guatemalensis*, which is also recognized in field sample 2-40, by having a lower form ratio, higher chambers, and secondary deposits only in the early volutions.

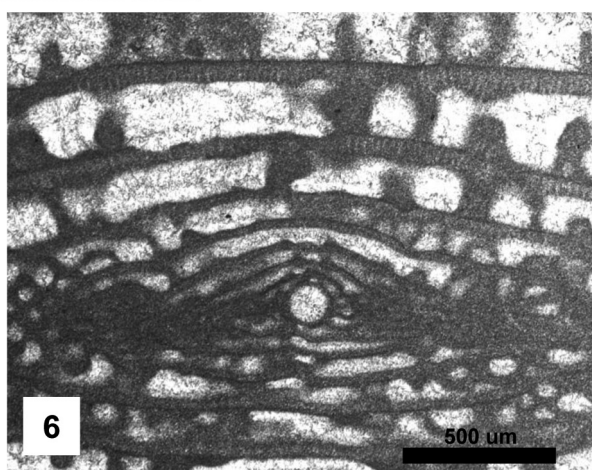
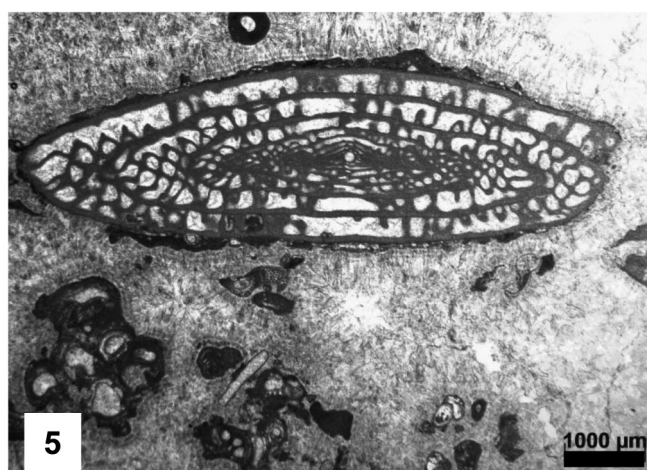
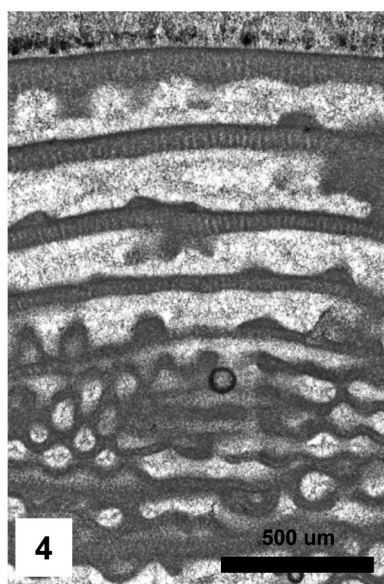
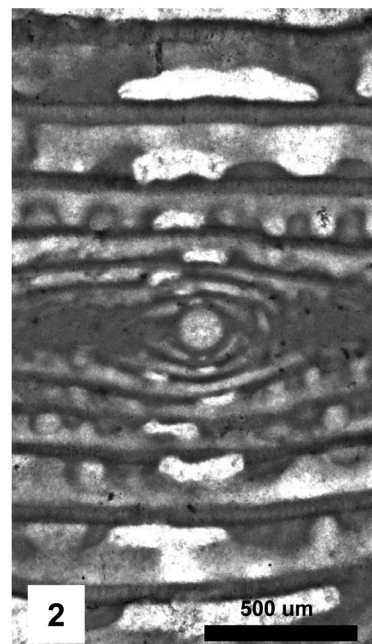
Occurrence: The present specimens come from sample 2-40, collected in the middle part of Udden's thin-bedded unit at 420 ft (128 m) above the base of the Cibolo Formation. This species was originally described by Thompson and Miller (1949) from outcrop collections made in northern South America (Colombia), but it is commonly reported in the upper part of the Leonardian section in the Permian Basin region, including the Cathedral Mountain Formation in the Glass Mountains (Ross 1962; Wilde 1990; Ross and Ross 2003, 2009). Vachard et al. (1997, 2000) and Perez-Ramos and Nestell (2002) have also reported the species from upper Leonardian strata in Mexico and Guatemala.

PLATE 2

Specimens of *Chusenella cibolensis* from sample R0900, Cibolo reef block, Cibolo Formation, early Leonardian?, Chinati Mountains
Figures 1, 3, 5, scale bar = 1000 microns; figures 2, 4, 6, scale bar = 5000 microns.

Repository numbers in parentheses.

- 1 Axial specimen of *Chusenella cibolensis* Stewart 1963 and common associated *Tubiphytes* surrounded by banded radiaxial calcite cementstone. (NPL84801)
- 2 Close-up of central axial area of same specimen of *Chusenella cibolensis* as in figure 1, showing tightly coiled juvenarium with no fluting, and intense low fluting in adult volutions.
- 3 Tangential specimen of *Chusenella cibolensis* (below) with *Tubiphytes*-encrusted calcareous sponge (above), surrounded by skeletal-peloidal packstone-grainstone and radiaxial calcite cement. (NPL84802)
- 4 Close-up of same tangential specimen of *Chusenella cibolensis*, showing weak low septal fluting and fine keriothecal wall structure.
- 5 Slightly oblique-axial section of *Chusenella cibolensis* surrounded by radiaxial calcite cementstone, with associated bryozoans and *Tubiphytes*. (NPL-84801b)
- 6 Close-up of same specimen as in figure 5, showing tightly-coiled juvenarium with no fluting followed by adult whorls with low septal fluting, and fine keriothecal wall structure.



Age: Late Leonardian.

Parafusulina fountaini Dunbar and Skinner 1937
Plate 3, figure 3

Parafusulina fountaini DUNBAR and SKINNER 1937, p. 675, pl. 70, figs. 1–10

Description: *Parafusulina fountaini* has a large, elongate fusiform shell with gently convex slopes and rounded poles; volutions increase in height toward the poles; axis of coiling is gently arched. Proloculus is medium to moderately large in size; septal fluting is high, intense, and crowded; the tunnel is generally not distinct; and axial fillings are weakly developed in the inner whorls only.

Discussion: This species is distinguished from most similar species by its large robust shell, the increase in volution height toward the poles, and intensely crowded septal fluting. *Parafusulina fountaini* differs from *P. durhami* by its more fusiform shell shape with more narrowly rounded poles, and a generally larger proloculus. In comparison to *P. guatemalaensis*, *P. fountaini* has a larger shell, lower form ratio, larger proloculus, and less axial filling.

Occurrence: *Parafusulina fountaini* was identified here from sample 2-40, where it was associated with *P. durhami* and *P. guatemalaensis*. The species was originally described by Dunbar and Skinner (1937) from the Bone Spring Limestone in the Guadalupe Mountains of west Texas. It has also been reported as characteristic of the upper part of the Leonardian throughout the Permian Basin, as well as in the Cathedral Mountain Formation in the Glass Mountains Leonardian stratotype (Wilde 1990; Ross and Ross 2003, 2009). Vachard et al. (1997, 2000) also reported the species from upper Leonardian strata in Mexico.

Age: Late Leonardian.

Parafusulina guatemalaensis Dunbar 1939
Plate 3, figures 4–6

Parafusulina guatemalaensis DUNBAR 1939, p. 347, pl. 36, figs. 1–10.
– KLING 1960, p. 649, pl. 81, figs. 1–3, 6.

Description: *Parafusulina guatemalaensis* has an elongate slender shell shape with a straight axis of coiling, gently and evenly convex slopes, and bluntly pointed poles. Proloculus is moderate sized, septal fluting is intense and high, the tunnel is weakly developed in the adult whorls, and axial filling is usually weakly developed in the inner volutions.

Discussion: The smaller shell size, more slender and evenly convex shell shape, and straight axis of coiling serve to distinguish this species from other late Leonardian species, such as *P. durhami* and *P. fountaini*. The most similar small and slender species are the early Guadalupian *P. lineata* Dunbar and Skinner 1937 and *P. ironensis* Ross 1963b, but both of those species have tighter coiling, more regular and crowded septal folding, and more advanced cuniculi development.

Occurrence: *Parafusulina guatemalaensis* was identified here from sample 2-40. It was originally described by Dunbar (1939) from Guatemala and he correlated the occurrence with the Leonardian of Texas. Kling (1960) and Vachard et al. (1997, 2000) also illustrated and discussed specimens of the species from the upper part of the Chochal Limestone in Guatemala.

Age: Late Leonardian.

Parafusulina bakeri Dunbar and Skinner 1937
Plate 4, figures 1–6

Parafusulina bakeri DUNBAR and SKINNER 1937, p. 677, pl. 71, figs. 1–10.

Description: *Parafusulina bakeri* has a stout fusiform shell shape, and relatively loose coiling. The proloculus is usually

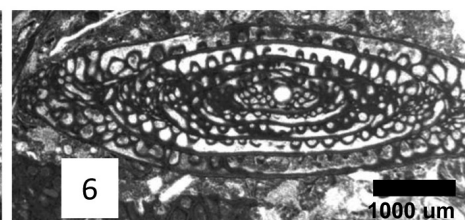
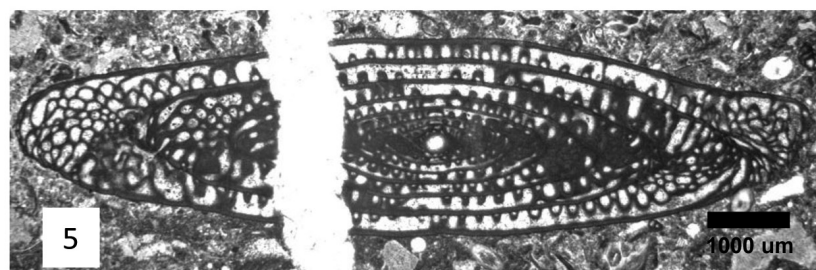
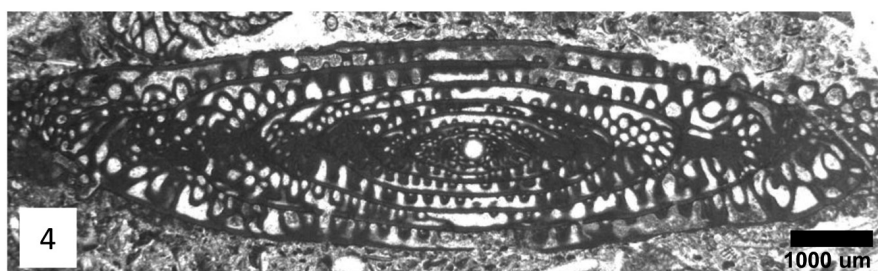
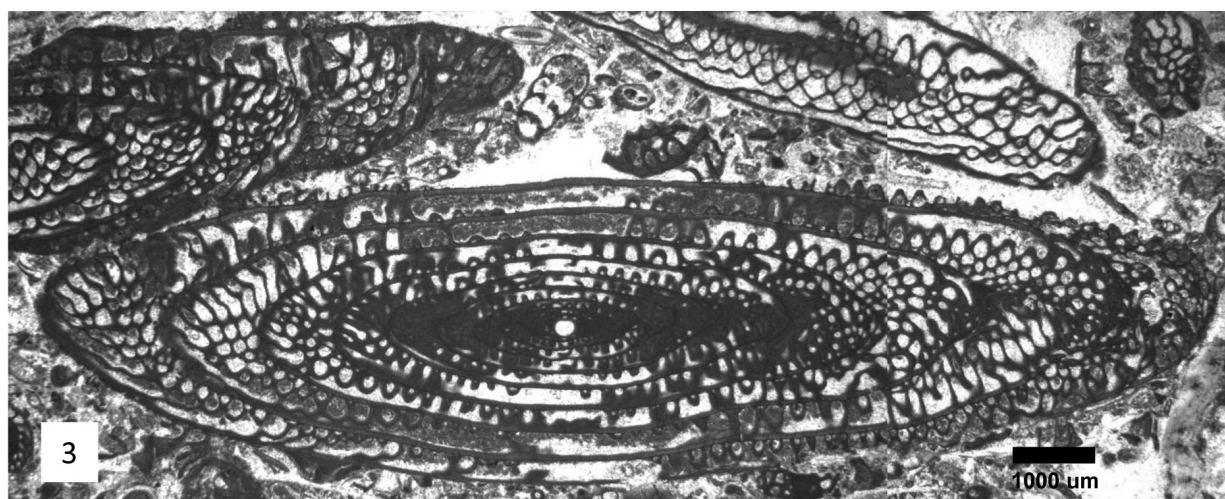
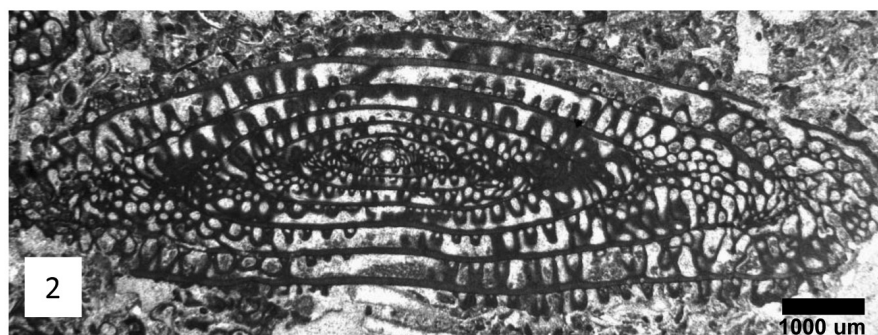
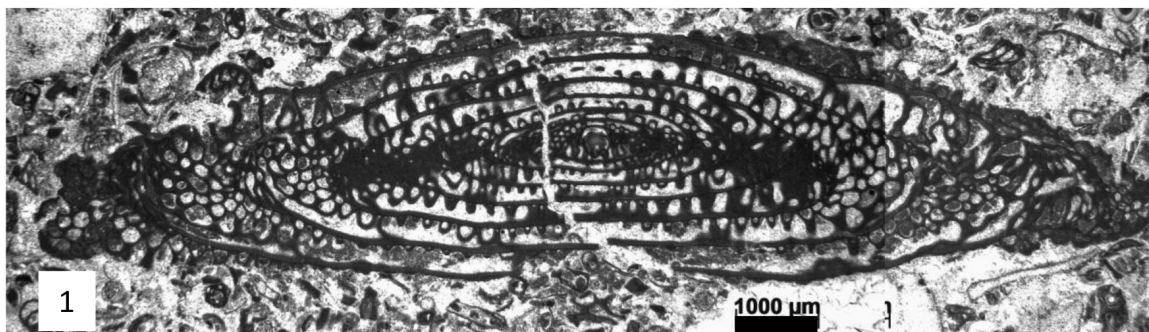
PLATE 3

Specimens from sample 2-40, Cibolo Formation, late Leonardian, Chinati Mountains
Figures 1–6, scale bar = 1000 microns.
Repository numbers in parentheses.

- 1,2 Axial specimens of *Parafusulina durhami* Thompson and Miller 1949 in matrix of fine-grained peloidal-skeletal packstone, including fenestrate bryozoan fragments and crinoid ossicles. (1 = NPL84791; 2 = NPL8492)
- 3 Axial specimen of *Parafusulina fountaini* Dunbar and Skinner 1937 in matrix of fine-grained peloidal-skeletal packstone also containing the smaller foraminifer

Climacammina, fenestrate bryozoan fragments, and brachiopod spines. (NPL84793)

- 4-6 Axial specimens of *Parafusulina guatemalaensis* Dunbar 1939 in matrix of fine-grained peloidal-skeletal packstone. (4 = NPL84794; 5 = NPL84795; 6 = NPL84796)



large, the wall is thick and has coarse keriothecal structure, the axial filling is very light to lacking, and the septa are intensely fluted across the entire profile, with no tunnel or only a poorly developed one.

Discussion: This species is distinguished from other late Leonardian species of *Parafusulina* by its stout subcylindrical shell shape with bluntly rounded poles, relative loose coiling, large and thick-walled proloculus, and relatively primitive cuniculi development. The early to middle Guadalupian *P. sellardsi* Dunbar and Skinner 1937 has a similar subcylindrical shape and mode of coiling, but is much larger in size, and has more advanced cuniculi development.

Occurrence: *Parafusulina bakeri* is the most common species in field sample 2-40. The species was first described by Dunbar and Skinner (1937) from Leonardian strata in the Glass Mountains. It is commonly cited as characteristic of the upper part of the Leonardian throughout the Permian Basin and has been reported from the Cathedral Mountain Formation of the Leonardian stratotype in the Glass Mountains (Wilde 1990; Ross and Ross 2003a, b, 2009).

Age: Late Leonardian.

SUMMARY

Three field samples from the Cibolo Formation of the Chinati Mountains were analyzed for fusulinid biostratigraphy, and fusulinid biostratigraphic data from previous studies in the area are summarized (text-fig. 2). Sample 4E1 from 50–100 ft (15.24–30.48 m) above the base of the Cibolo Formation section (text-fig. 3) contains the typical early Leonardian fusulinids *Schwagerina crassitectoria* and *S. guembeli* (pl. 1), which correlate well with the lower part of the Skinner Ranch

Formation and laterally equivalent Hess Limestone in the Glass Mountains Leonardian stratotype. That sample also contained the small fusulinid *?Pseudoreichelina nevadaensis*. Sample R0900 from the Cibolo reef block contained only *Chusenella cibolensis*, which is probably early Leonardian in age (pl. 2). Sample 2-40 from 420 ft (128 m) above the base of the Cibolo section (text-fig. 3) contained *Parafusulina durhami*, *P. fountaini*, *P. bakeri*, and *P. guatemalaensis*, which is a typical late Leonardian fusulinid assemblage and correlates well to the Cathedral Mountain Formation in the Glass Mountains Leonardian stratotype (pls. 3, 4). No samples containing middle Leonardian fusulinid have been reported from the Cibolo Formation.

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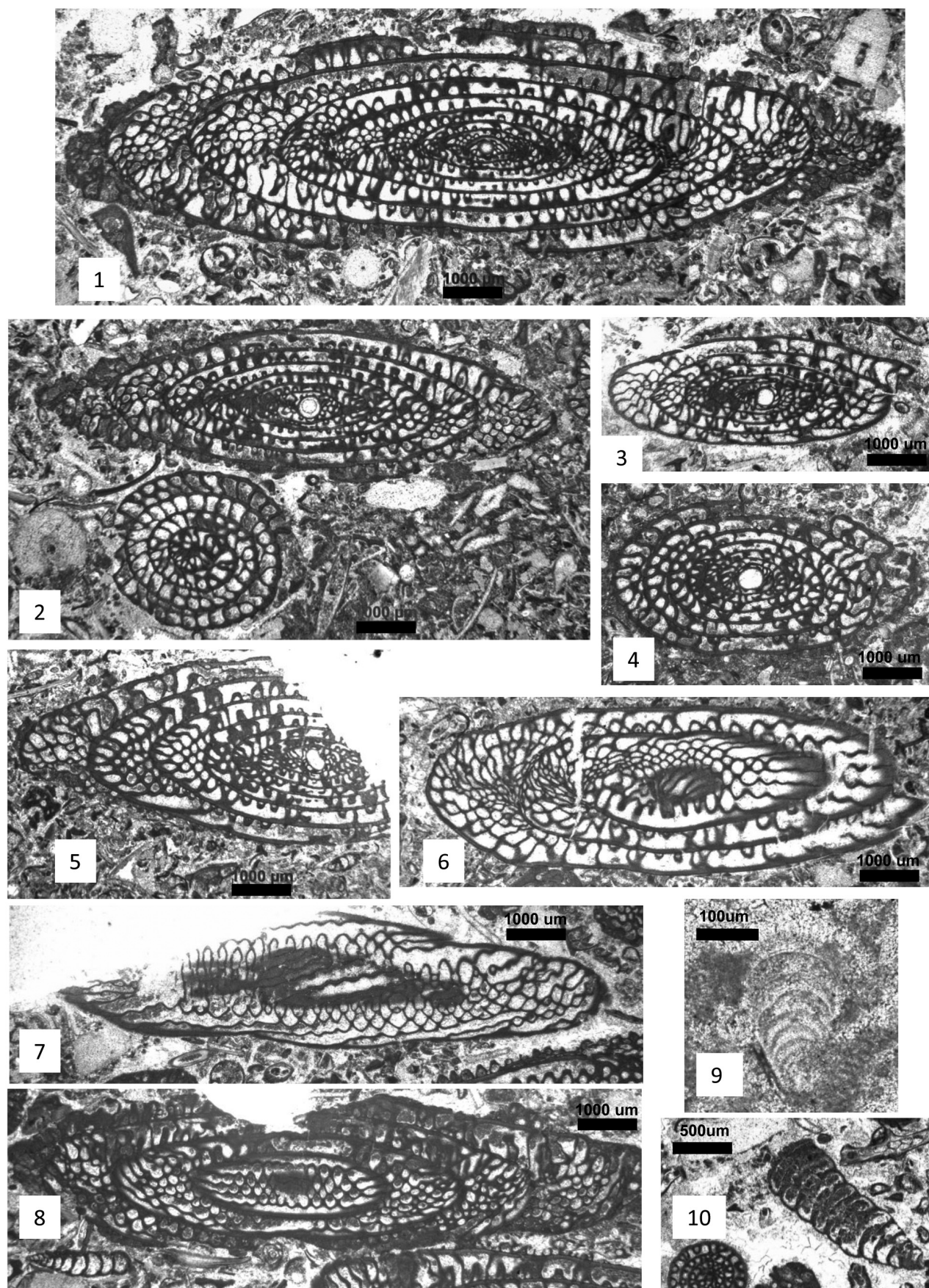
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PLATE 4

Specimens from sample 2-40, Cibolo Formation, late Leonardian, Chinati Mountains
 Figures 1–8, scale bar = 1000 microns; figure 9, scale bar = 100 microns; figure 10, scale bar = 500 microns.
 Repository numbers in parentheses.

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| <p>1–6 Axial and oblique specimens of <i>Parafusulina bakeri</i> Dunbar and Skinner 1937 in matrix composed of fine- to medium-grained peloidal-skeletal packstone with crinoid ossicles, fenestrate bryozoan fragments, brachiopod and mollusc shell fragments, and specimens of the smaller foraminifer <i>Climacammina</i>. (1 = NPL84797; 2 = NPL84798; 3 = NPL84799; 4 = NPL84795b; 5 = NPL84800; 6 = NPL84800b)</p> <p>7 Tangential section of <i>Parafusulina</i> sp. showing cuniculi. (NPL84793b)</p> | <p>8 Tangential section of <i>Parafusulina</i> sp. showing low central cuniculi. (NPL84793c)</p> <p>9 Smaller foraminifer <i>Geinetzina</i> sp., which are moderately common in the sample. (NPL84793d)</p> <p>10 Smaller foraminifer <i>Climacammina</i> sp. with fenestrate bryozoan fragments and a tangential section of a small fusulinid at the lower left. (NPL84793e)</p> |
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