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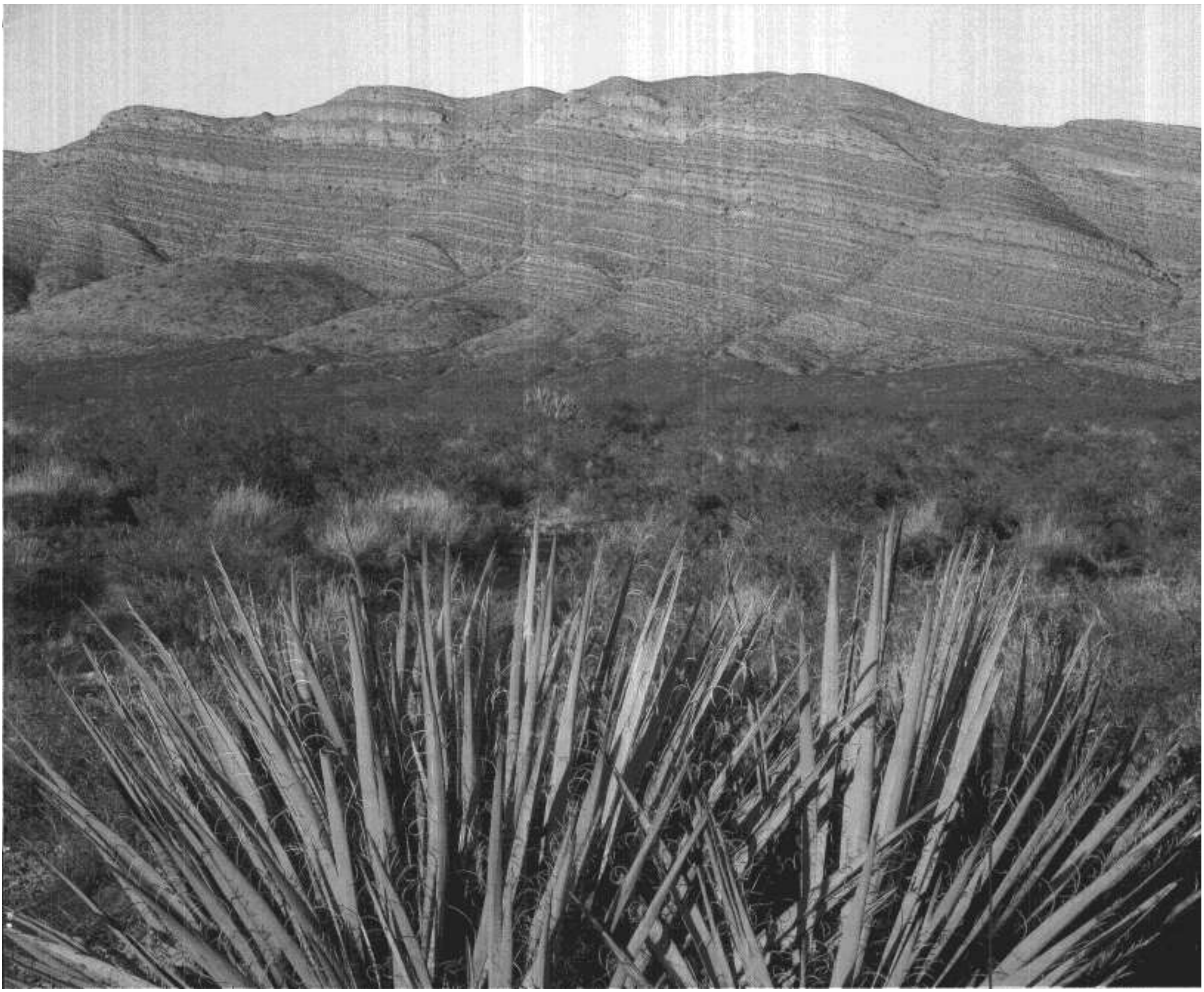

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Latest Pennsylvanian and earliest Permian fusulinid biostratigraphy, Robledo Mountains and adjacent ranges, south-central New Mexico

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Cover Photo
The Robledo Mountains from the south; photo © Tom Till

Summary

The Robledo Mountains of south-central New Mexico, and the Dona Ana and San Andres Mountains to the east, expose rocks of Late Pennsylvanian and Early Permian age (290 million years old). The Robledo Mountains contain one of the most continuous marine carbonate sections through the Pennsylvanian—Permian boundary in the southwestern United States. These strata contain the fossil remains of fusulinids, tiny single-celled animals now extinct. The abundance, diversity, and visibility in these rocks of these microfossils allow a detailed understanding of the age of these strata, and allow the authors to correlate these rocks with rocks of similar age in other parts of the United States. The authors describe this unique stratigraphic section in some detail with an emphasis on fusulinid remains, including descriptions of new species not previously reported from this area. Based on their detailed work in the field and the laboratory, the authors propose the Robledo Mountains section as a new reference for the Pennsylvanian—Permian boundary in southwestern North America.

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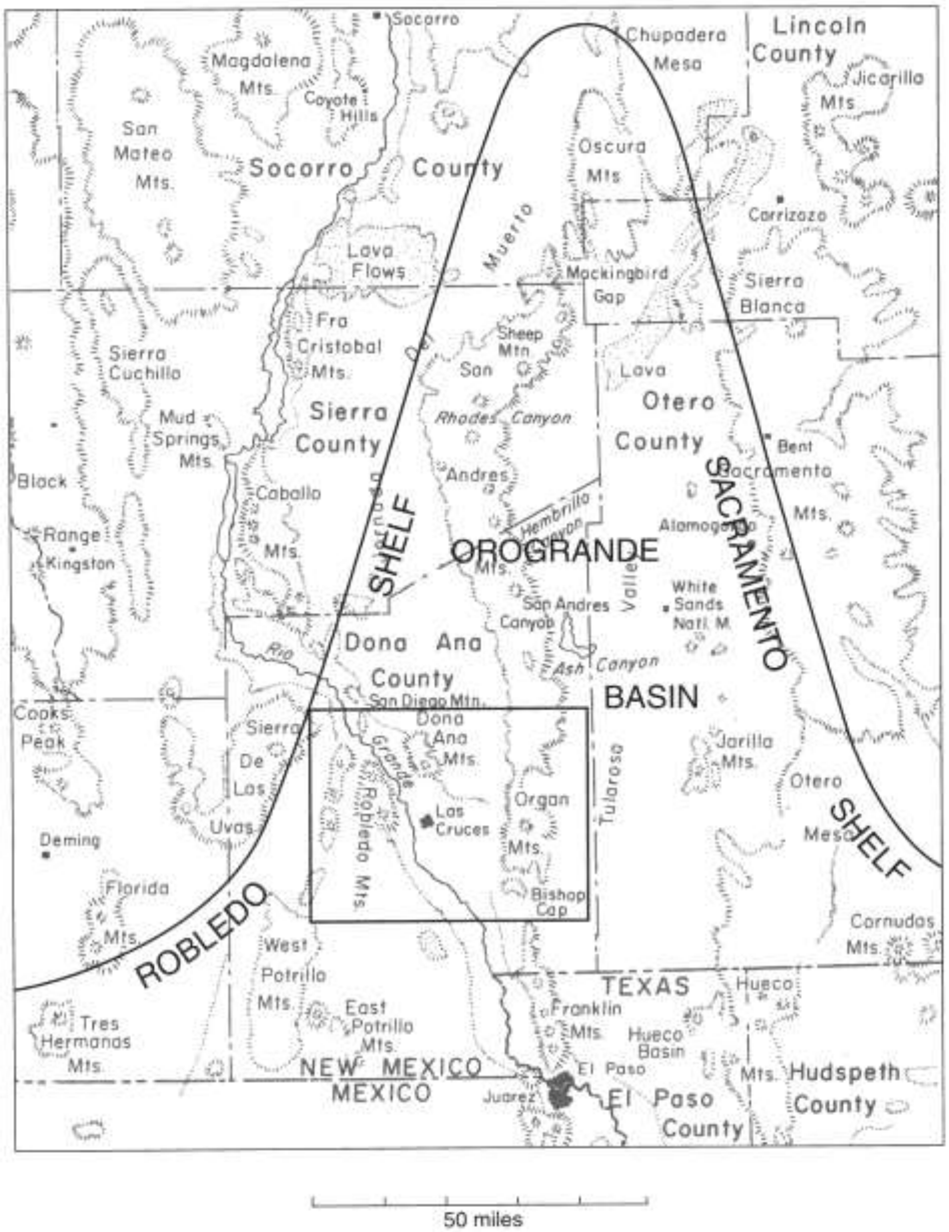

FIGURE 1—Map of south-central New Mexico showing distribution of mountain ranges, the study area (rectangle), and a general outline of the Orogrande Basin marine depositional area during latest Pennsylvanian and earliest Permian time. The western shelf area is termed the Robledo shelf, and the more narrow eastern shelf between the basin margin and the Pedernal uplift is termed the Sacramento shelf (adapted from Kottlowski, 1963, fig. 1).

Abstract

Latest Pennsylvanian and earliest Permian fusulinid foraminifera from the Robledo, Dona Ana, and southern San Andres Mountains, Doha Ana County, south-central New Mexico, are described, and their biostratigraphic significance and correlation are discussed. New collections of fusulinids from the Bursum Formation—equivalent and lower Hueco member contain a few additional species not previously reported from the area and provide better material for some other previously reported species. Descriptions of the following species from the new collections are given: *Leptotriticites* aff. *L. gracilitatus* Skinner and Wilde, L. sp. A., *Schwagerina andresensis* Thompson, S. sp. A., *Pseudofusulina robleda* Thompson, *Pseudoschwagerina morsei* Needham, *P.* cf. *P. uddeni* (Beede and Knicker), *P. texana* Dunbar and Skinner, and *P. texana ultima* Dunbar and Skinner.

The Robledo Mountains contain one of the most continuous marine carbonate sections through the Pennsylvanian—Permian boundary interval in the southwest United States of America, and therefore it has potential significance as a reference section for correlation of the new international Carboniferous—Permian boundary from Eurasia to North America. The newly proposed Pennsylvanian—Permian boundary is designated in the Robledo Peak section at the Bursum—Hueco contact, which is placed at the top of a sandy limestone interval that lies above the occurrences of *Leptotriticites hughensis, L. glenensis,* L. aff. *gracilitatus,* L. sp. A., *Pseudofusulina robleda,* and *Schwagerina grandensis,* and below the basal occurrences of *Pseudoschwagerina morsei, P. texana, P. texana* var. *ultima, P.* cf. *P. uddeni, Schwagerina andresensis,* and *Leptotriticites tumida.* The stratigraphically higher fusulinid assemblage correlates well to the faunas of the Neal Ranch Formation (Nealian) of the Wolfcampian stratotype section in the Glass Mountains of west Texas.

Introduction

The Robledo Mountains, Dona Ana Mountains, Organ Mountains, and southern San Andres Mountains are located in Doña Ana County, south-central New Mexico (Fig. 1). During Late Pennsylvanian and Early Permian time, the area now occupied by the Robledo and western Doña Ana Mountains was situated on the southwestern shelf of the Orogrande Basin, and the area now occupied by the eastern Dona Ana Mountains, southern San Andres Mountains, and Organ Mountains was situated along the basin margin.

The Robledo Mountains contain one of the most continuous Upper Pennsylvanian through Lower Permian marine carbonate stratigraphic sections in the southwestern United States. With the recent establishment of a new international Carboniferous—Permian boundary in Eurasia (Davydov et al., 1998), the conodont-based correlation of that boundary to the midcontinent United States (Ritter, 1995), and the subsequent redefinition of the Pennsylvanian—Permian boundary in North America (Baars et al., 1994; Ross and Ross, 1994; Wahlman, 1998), the Robledo Mountains section takes on new significance as a potential reference section for the North American systemic boundary.

In the Orogrande—Permian Basin region of New Mexico—west Texas, the redefinition of the Pennsylvanian—Permian boundary shifts that systemic contact upward from the base to the top of the interval represented by the Bursum Formation. As a result, the Bursum Formation is no longer included in the Lower Permian Wolfcampian Stage, but rather is now considered uppermost Pennsylvanian. However, this creates a problem of the stadial classification of the Bursum interval. Some think it unadvisable to attach the Bursum interval onto the already well-defined underlying Virgilian Stage. As a solution to this problem, Ross and Ross (1987, 1994, 1998) have suggested naming this homeless time interval between the Virgilian and Wolfcampian by the new stage name "Bursumian". They further suggested that the "Bursumian" stratigraphic section of the Robledo Mountains should be evaluated as a potential stadial stratotype. The nomenclature for the interval is still under debate, but for lack of any other currently accepted name, "Bursumian" will be used herein.

The abundance, diversity, and visibility in the field of fusulinid foraminifera makes them primary biostratigraphic tools for late Paleozoic marine strata, and they are undoubtedly the most widely used index fossils in the Orogrande—Permian Basin region. This paper discusses the fusulinid biostratigraphy of the uppermost Pennsylvanian ("Bursumian") and Lower Permian (Wolfcampian) stratigraphic sections of the Robledo Mountains, Doña Ana Mountains, Organ Mountains, and southern San Andres Mountains, and correlations are made between those mountain ranges and other key sections in the southwestern and midcontinent United States.

Materials and methods

The Robledo Mountains stratigraphic sections discussed here were measured and described by Frank Kottlowski (New Mexico Bureau of Mines and Mineral Resources) and William R. Seager (New Mexico State University). The lithostratigraphic descriptions for the Robledo Mountains given here are summaries of measured sections in Seager, Kottlowski, and Hawley (in press). Seager and W. E. King collected the fusulinid samples discussed (Figs. 2-4). The new Robledo Mountains fusulinid collections were made from the Bursum-equivalent unit and lower Hueco member in three measured sections (Figs. 2-4): section J (W1 sec. 12 T22S R1W), section K (sec. 7 T22S R1E), and section **L** (sec. 35 T21S R1W).

A few additional fusulinid collections from the adjacent Dona Ana Mountains and southern San Andres Mountains are also discussed. Seager, Kottlowski, and Hawley (1976) discussed the stratigraphy of the Doña Ana Mountains, and Seager (1981) discussed the stratigraphy of the Organ Mountains and southern San Andres Mountains, and so only the biostratigraphic aspects of those areas will be covered in this paper.

Acknowledgments

The authors wish to acknowledge the late Frank E. Kottlowski, and William R. Seager (New Mexico State University). We would like to thank and George Sanderson and George Verville (Amoco Production Company) for their advice and assistance toward the completion of this report. In particular, Drs. Kottlowski and Seager generously shared their unpublished manuscript containing Robledo Mountains measured sections and lithostratigraphic descriptions, discussed and offered advice on stratigraphic problems, and reviewed a draft of the manuscript. We would also like to thank Charles A. Ross (Western Washington University, Bellingham) and Ronald Broadhead (New Mexico Bureau of Geology and Mineral Resources) for reviewing the final manuscript and making numerous helpful suggestions. Finally, thanks to Dr. Vicki Harder, who made some of the thin sections. The New Mexico Bureau of Geology and Mineral Resources granted financial assistance for field and laboratory work, and the Department of Geological Sciences of New Mexico State University provided laboratory facilities. Thanks also to the Exploration and Production Technology Group of Amoco Corporation, and subsequently BP Amoco, Houston, Texas, for providing support to complete the study.

Pennsylvanian—Permian boundary

The Lower Permian Wolfcampian Stage in the southwestern United States has been generally divided into three parts (substages), which are characterized by the fusulinid faunas of, in ascending order, the Bursum Formation ("Bursumian") of south-central New Mexico, and the Neal Ranch (Nealian) and Lenox Hills (Lenoxian) Formations of the Glass Mountains Wolfcampian stratotype of west Texas (Ross, 1963, 1984; Ross and Ross, 1987; Wilde, 1962, 1971, 1975a, 1975b, 1984, 1990). In the Permian Basin, Ross (1963) referred to these fusulinid assemblage zones as, in ascending order, the *Triticites-Schwagerina* zone, *Pseudoschwagerina-Triticites* zone, and *Pseudoschwagerina-Monodiexodina* zone. Wilde (1990) referred to the same three zones as the *Triticites-Schwagerina* zone, the Main zone of *Pseudoschwagerina,* and the *Monodiexodina* zone, respectively. This study is concerned only with the lower two of these zones and their contact, which very nearly coincides with the new North American Pennsylvanian—Permian boundary.

The North American Pennsylvanian—Permian boundary that has been generally accepted for over 60 yrs was defined in the midcontinent region by Moore (1936, 1940), who placed the boundary at the base of the Admire Group (top of Brownsville Limestone). As justification for this boundary placement, Moore cited a widespread unconformity at that level, often marked by deep-cut sandstone channels and the basal occurrence of the fusulinacean *Schwagerina,* an Early Permian index fossil, in the lower Admire Group. That Pennsylvanian—Permian boundary placement was perpetuated by M. L. Thompson's (1954) monograph on "American Wolfcampian fusulinids" in which the "early Wolfcampian" fusulinid faunas of the midcontinent Admire—lower Council Grove Groups were correlated to faunas of the Pueblo Formation in north-central Texas and to those of the Bursum Formation of New Mexico. The distinctive fusulinid fauna characterizing that interval is transitional between Late Pennsylvanian (Virgilian) and Early Permian (Wolfcampian, Nealian) fusulinid faunas, and consists of large *Triticites* spp. (e.g., *Triticites creekensis,* T. *ventricosus, T. cellamagnus),* smaller *Leptotriticites* spp. (e.g., L. *eoextenta, L. extenta, L. americana, L. hughensis, L. glenensis),* primitive species of *Schwagerina* (e.g., *S. grandensis, S. campensis),* and primitive species of *Pseudofusulina* (e.g., *P. robleda).*

Ross (1963) described the Wolfcampian stratigraphy and fusulinid faunas of the Glass Mountains section in west Texas, which was designated as the Wolfcampian stadial stratotype by Adams et al., (1939). That stratotype section consists of two unconformity-bound formations, the Neal Ranch Formation and the overlying Lenox Hills Formation. The Neal Ranch unconformably overlies the Late Pennsylvanian Gaptank Formation. The uppermost unit of the Gaptank is known as bed 2 of the Gray Limestone, and although Bostwick (1962) and Wilde (1971) have reported what they considered to be *Triticites* and *Schwagerina* characteristic of the lower third of the Wolfcampian interval in that unit, Ross (1963, 1965, 1984) has interpreted fusulinids from that unit to be Virgilian in age. Ross (1986a) claimed that latest Virgilian and earliest Wolfcampian strata in the Glass Mountains were removed in a pre-Neal Ranch erosional event and redeposited in the adjacent foredeep. That post-Bursum/pre-Neal Ranch unconformity is widespread throughout the southwestern United States, and is thought to be related to one of the last major thrusting events in the Marathon orogenic belt (Ross, 1986b).

Ross (1963, fig. 11) suggested that the Eurasian Carboniferous—Permian boundary correlated to the base of the Neal Ranch Formation in the North American Wolfcampian stratotype, and therefore the lower third of the Wolfcampian was actually latest Carboniferous. However, although the boundary fusulinid faunas in Eurasia and North America have similarities, they are sufficiently distinct so as to prevent a definite intercontinental correlation based solely on fusulinids.

Recently, a new international stratotype for the Carboniferous—Permian boundary was designated in the southern Ural Mountains of northern Kazakhstan (Davydov et al., 1995, 1998). The new international boundary was placed at the base of the Asselian Stage and was defined by the basal occurrence of the conodont *Streptognathodus isolatus.* The basal appearance of the inflated schwagerinids of the *Sphaeroschwagerina fusuformis-S. vulgaris* zone occurs just above that conodont base. Just before the new systemic boundary designation, Baars et al., (1992, 1994) proposed to raise the North American Pennsylvanian—Permian boundary in Kansas to the Neva Limestone Member of the Grenola Limestone, because that unit contained the basal occurrences both of inflated schwagerinid fusulinaceans *(Paraschwagerina kansasensis)* and typical Permian conodont faunas (i.e., the first *Sweetognathus* and *Streptognathodus* cf. *S. longissimus* (Ritter, 1995)) in the midcontinent region. However, they noted that when final documentation of the new Pennsylvanian—Permian boundary was completed, the mid-continent boundary might be placed at a somewhat lower stratigraphic position. Then a conodont-based correlation of the new Eurasian boundary was made to the North American midcontinent in Kansas, where the basal occurrence of the *Streptognathodus isolatus* zone was found slightly lower than the Neva Limestone, at the contact between the Glenrock Limestone and Bennett Shale Members of the Red Eagle Limestone, lower Council Grove Group (Ritter, 1995; Chernykh and Ritter, 1997). Significantly, the Glenrock Limestone Member contains the uppermost "Bursumian" fusulinid fauna, consisting of *Triticites rockensis, Leptotriticites glenensis* and *Schwagerina campa* (see Thompson, 1954). The next higher fusulinid assemblage in the Kansas section is in the Neva Limestone, which contains the inflated schwagerinid *Paraschwagerina kansasensis,* as well as larger species of *Leptotriticites (L. tumida, L. obesa,* and L. *koschmanni)* and *Schwagerina longissimoidea* (Thompson, 1954).

The redefinition of the North American Pennsylvanian—Permian boundary makes it necessary to reassign the traditional lower third of the Wolfcampian. The Pennsylvanian—Permian boundary has shifted from the base of the previously recognized "early Wolfcampian" interval *(Triticites-Schwagerina* zone) to its top, and that interval is now considered to be latest Pennsylvanian (Wahlman, 1998). Ross and Ross (1987, 1994, 1998) have proposed the name "Bursumian" for the orphaned interval, based on the Bursum Formation of the Orogrande Basin area in south-central New Mexico. However, some workers believe that the Kansas or north-central Texas stratigraphic sections would make better stratotypes because they have more diverse fusulinid faunas, and better-known conodont and ammonoid faunas. Some other workers do not think that an additional stage is needed. This subject will probably be a matter of debate for some time before a resolution is reached.

The base of the Permian (Wolfcampian) in North American is now defined by the basal occurrence of the Neal Ranch Formation (Nealian) fusulinid fauna (Ross, 1963), which includes *Pseudoschwagerina uddeni, P. texana, P. beedei, Paraschwagerina gigantea,* larger *Leptotriticites* (e.g., L. *koschmanni,* L. *tumida),* and more advanced *Schwagerina* (e.g., *S. pugunculus)* in the stratotype. However, it should be noted that the Neal Ranch Formation is an unconformity-bound unit, and therefore it might not contain the earliest Wolfcampian (Nealian) fusulinid fauna. Probable earlier Nealian fusulinid faunas are represented in the midcontinent by such species as *Schwagerina jewetti* and S. *vervillei,* and in the Orogrande—Permian Basin areas by those species along with S. *andresensis, Pseudoschwagerina needhami, P. rhodesi,* and *P. morsei* (Wahlman, 1998).

Stratigraphy

During the Late Pennsylvanian and Early Permian, the Robledo Mountains area was located on the southwestern shelf of the Orogrande Basin, often called the Robledo shelf (Fig. 1). Through most of that time interval, Robledo shelf sedimentation was characterized by the cyclic deposition of normal to restricted marine carbonate strata, punctuated by periods of subaerial exposure that are commonly represented by relatively thin red bed siliciclastic units.
As the Orogrande Basin filled with sediments and Abo—Hueco depositional system prograded southward, restricted marine to transitional marine-terrestrial and non-marine paleoenvironments became generally more common upward through the Wolfcampian section. In Figure 1 here, there is drawn a very general outline of the marine depositional basin during latest Pennsylvanian and earliest Permian time. Meyer (1966, figs. 50-55), Kottlowski (1969, fig. 11), Kottlowski and Stewart (1970, fig. 13), Jordan (1971, 1975), Wilson and Jordan (1988, fig. 3), and Candelaria (1988, fig. 6) have presented various maps showing the thickness and distribution of the lithofacies in the Orogrande Basin region during this period of time. Kottlowski's (1969, fig. 11) schematic Wolfcampian paleogeologic /lithofacies map shows particularly well how the Abo red beds covered central New Mexico, prograded southward over the Bursum facies in the northern Orogrande Basin, and are transitional in the central basin with the Hueco limestones that covered the southern basin area.

Lithostratigraphic nomenclature

Traditionally, the Hueco Limestone in the Robledo Mountains has been divided into informal members, which are, in ascending order, lower Hueco member, middle Hueco member, Abo Tongue, and upper Hueco member (Kottlowski, 1960, 1963; Jordan, 1971, 1975; Seager et al., 1976; Seager, Kottlowski and Hawley, in press); Fig. 2. Because the measured stratigraphic sections and unit boundaries of Seager, Kottlowski, and Hawley (in press) were employed in this study, that lithostratigraphic nomenclature was also adopted. However, as this paper was being prepared for press, we became aware of the recent publication by Lucas et al. (1998), who proposed new formation names to replace the informal members of the Hueco Limestone used in most earlier publications (Fig. 2).

Closer comparison of the traditional informal units and the new formational units is needed, but the stratal compositions and contacts for Lucas et al.'s (1998) Community Pit, Robledo Mountain, and Apache Dam Formations appear to closely approximate the middle, Abo Tongue, and upper members of Seager, Kottlowski, and Hawley (in press) and this paper (Fig. 2). Initial evaluation indicates some disagreement between the stratal compositions and contacts in the Bursum-lower Hueco member and Shalem Colony interval that will have to be studied more closely. It should be further pointed out that Krainer, Lucas, and Kues (2000) have agreed with Seager, Kottlowski, and Hawley (in press) and this paper, by rejecting the use of the stratigraphic name Bursum Formation in the Robledo Mountains, and supporting the inclusion of those Bursum-equivalent carbonate strata in the Hueco Group. Additional field work and evaluation will be required to determine if those Bursum-equivalent strata should be included in the Shalem Colony Formation, given a new formation name, or even possibly included with underlying Virgilian strata.

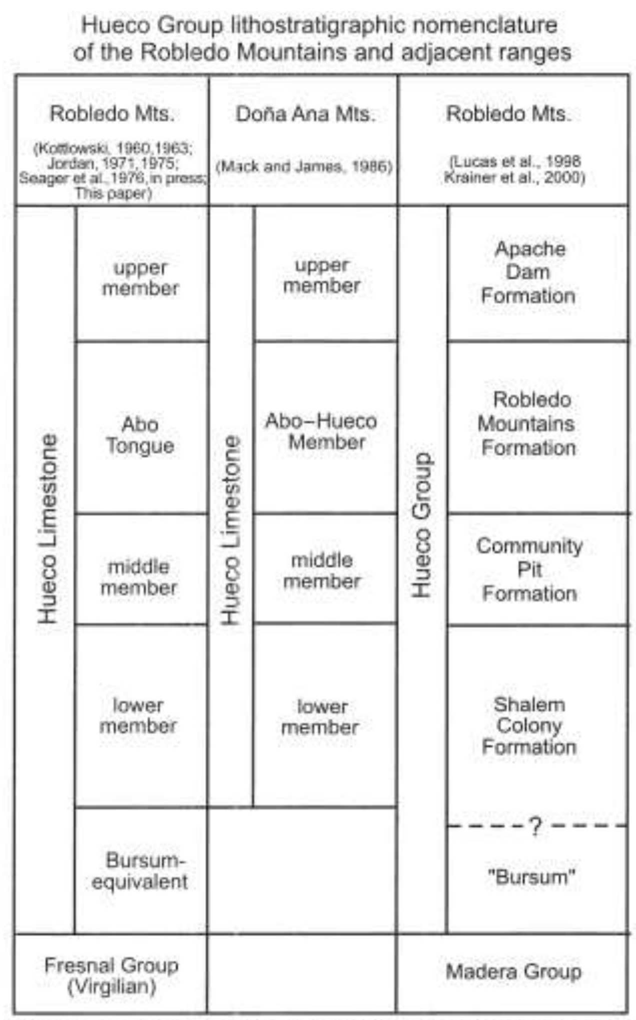

FIGURE 2—Chart showing correlation of traditional Hueco Limestone lithostratigraphic subdivisions in the Robledo Mountains, which are used in this paper, with the new formation names recently proposed by Lucas et al. (1998).

Finally, it should be noted that Thompson (1942) placed the Upper Pennsylvanian Virgilian strata of the Robledo Mountains in his Fresnal Group, and that term has been used here, but many other authors have used the term Magdalena Group for Pennsylvanian strata in the Orogrande Basin region. However, recently, Kues (2000) rejected the name Magdalena because "it has been applied in so many contradictory ways as to be meaningless", and advocated the use of the northern New Mexico term Madera Group for Pennsylvanian strata throughout most of New Mexico, including the Orogrande Basin area.

Upper Pennsylvanian

The Upper Pennsylvanian of the Robledo Mountains consists mostly of a carbonate stratigraphic section and includes Desmoinesian, Missourian, Virgilian, and "Bursumian" strata. The fusulinid faunas of Desmoinesian -Virgilian interval are planned to be the subject of a future paper, but it is instructive to begin this discussion of the lithostratigraphy of the Robledo section in the Virgilian.

Fresnal Group (Virgilian)

Thompson (1954) assigned the Virgilian strata of the Robledo Mountains to the Fresnal Group (Fig. 3). Thompson (1942) had named the Fresnal Group for most late Virgilian strata in southern New Mexico, and had designated the type section as Fresnal Canyon in the Sacramento Mountains, near La Luz, Otero County, New Mexico where the 530-ftthick section is composed of interbedded limestone, sandstone, conglomerate, and shale. Although Thompson noted marked variations in thicknesses and proportions of different sedimentary rock types within the Fresnal Group through the outcrop area, he did not name any formations.

In the Robledo Mountains, the 210-ft-thick Fresnal Limestone consists predominantly of medium- to light-gray, cliff-forming limestones with interbedded thin shales, shaly to nodular limestones and near the base and top of the unit, red to reddish-brown shales (Fig. 3). Many of the limestone units are shallowing-upward sequences. Most of the limestones are micritic, but skeletal sands are common throughout. The biota is typified by phylloid algae and fusulinids, but also commonly contains brachiopods, crinoid ossicles, and solitary horn corals. The late Virgilian fusulinid *Triticites beedei* was identified by Thompson (1954, fig. 8) near the top of the unit in the Robledo Mountains and just below the first occurrence of *Leptotriticites* (Figs. 3-4).

Virgilian strata in the Dona Ana Mountains, Organ Mountains, and southernmost San Andres Mountains are assigned to the Panther Seep Formation (Seager, Kottlowski, and Hawley, 1976). Significantly, whereas the Panther Seep is mainly Virgilian in age, the basal part is probably Missourian, and the upper few hundred feet are believed to be "Bursumian" and early Wolfcampian in age (Kottlowski et al., 1956; Seager, 1981). The Panther Seep represents cyclic basinal sedimentation within the Orogrande Basin, and it differs markedly from the correlative shelfal limestones exposed in the Robledo Mountains (Wilson, 1967; Schoderbek and Chafetz, 1988). The Panther Seep Formation consists of approximately 2,000 ft of mostly-fine to medium-grained, dark-gray to brown, siliciclastic strata with interbedded silty to sandy micrites and biomicrites. As discussed by Wilson (1967), the Panther Seep appears to represent alternating episodes of shallow restricted marine deposition and deep water basinal deposition within the Orogrande Basin. Cyclical repetitions of algal stromatolites, mud-cracked layers, ripple marks, caliche, gypsum, and gypsiferous dolomite are prevalent throughout much of the formation and indicate intertidal to supratidal depositional environments during relative sea-level lowstands (Kottlowski et al., 1956; Wilson, 1967; Seager, 1981). Intervals of dark-gray, laminated micrite, silty micrite, and porcelanite represent the intermittent deeper water basinal deposition during relative sea-level highstands. No Virgilian fusulinids have been reported from the Panther Seep in the Organ Mountains or southernmost San Andres Mountains, but farther to the north in the San Andres Mountains, Kottlowski et al., (1956) reported Virgilian-aged species of *Triticites* and *Dunbarinella* from the formation. Presumably, the intervals of shallow restricted marine Panther Seep facies within the Orogrande Basin correlate to exposure surfaces on the adjacent shelves of the basin, and correspondingly, the shelf sections must be missing significant intervals of Virgilian time. Soreghan (1994) has discussed the factors controlling Late Pennsylvanian sedimentation and cyclicity in the Virgilian of the Orogrande and Pedregosa Basins.

Bursum Formation-equivalent ("Bursumian")

The Bursum Formation was named by Wilpolt et al. (1946) for an interval of interbedded red beds and limestones that lies between Virgilian limestones and Lower Permian Abo red beds in the Oscura Mountains, in the northwestern Orogrande Basin area. Otte (1959) named the Laborcita Formation for strata of similar facies and age that are exposed in the northern Sacramento Mountains, on the eastern shelf of the basin. As discussed earlier, the distinctive Bursum fusulinid fauna has traditionally defined the earliest Wolfcampian strata in New Mexico and the adjacent Permian Basin region, but the Pennsylvanian-Permian boundary is now placed at the top of this interval, rather than at the base.

In the Robledo Mountains section, strata containing a typical Bursum fusulinid fauna differs from the Bursum strata in the type area by consisting predominantly of shelfal limestones and lacking significant interbedded red beds or conglomerates (Fig. 3). Because this Robledo Mountains limestone lithofacies is distinct from the typical Bursum lithofacies to the north, it is referred to here as the Bursum-equivalent limestone unit. Clearly, compared to the type Bursum Formation, the Robledo Mountains Bursum-equivalent limestone unit represents a relatively more distal shelf facies, or at least was deposited farther from the siliciclastic source area.

The Bursum limestones in the Robledo Mountains typically form medium- to thick-bedded cliffs and ledgy slopes and generally consist of light- to medium-gray biomicrite, oomicrite, and oosparite (Seager, Kottlowski, and Hawley, in press). In the western Robledo Mountains, the interval consists of massive cliff-forming phylloid algal biostromes, and the limestones become thinner bedded eastward. The biota is composed of abundant phylloid algae, crinoid ossicles, brachiopods, gastropods, cephalopods, and scattered echinoid spines. Fusulinids occur in three intervals (Figs. 3-4).

It is suggested here that the top of the Bursum-equivalent unit (= the Pennsylvanian-Permian boundary) in the Robledo Mountain section (section L) be placed at the top of bed L122 in the measured section of Seager, Kottlowski, and Hawley (in press), which is 358 ft above base of the Bursum (bed L91) (Fig. 4). During the measuring of the Robledo Mountains sections, Seager, Kottlowski, and Hawley suggested the top of the Bursum be placed at bed L110 in section L; however, they also pointed out that beds from L110 to L122 are more similar to the underlying Bursum than the overlying lower Hueco member. Bed L122 is a marker bed that consists of sandy limestone that weathers brown to °black, contains rounded chert pebbles, and thickens and

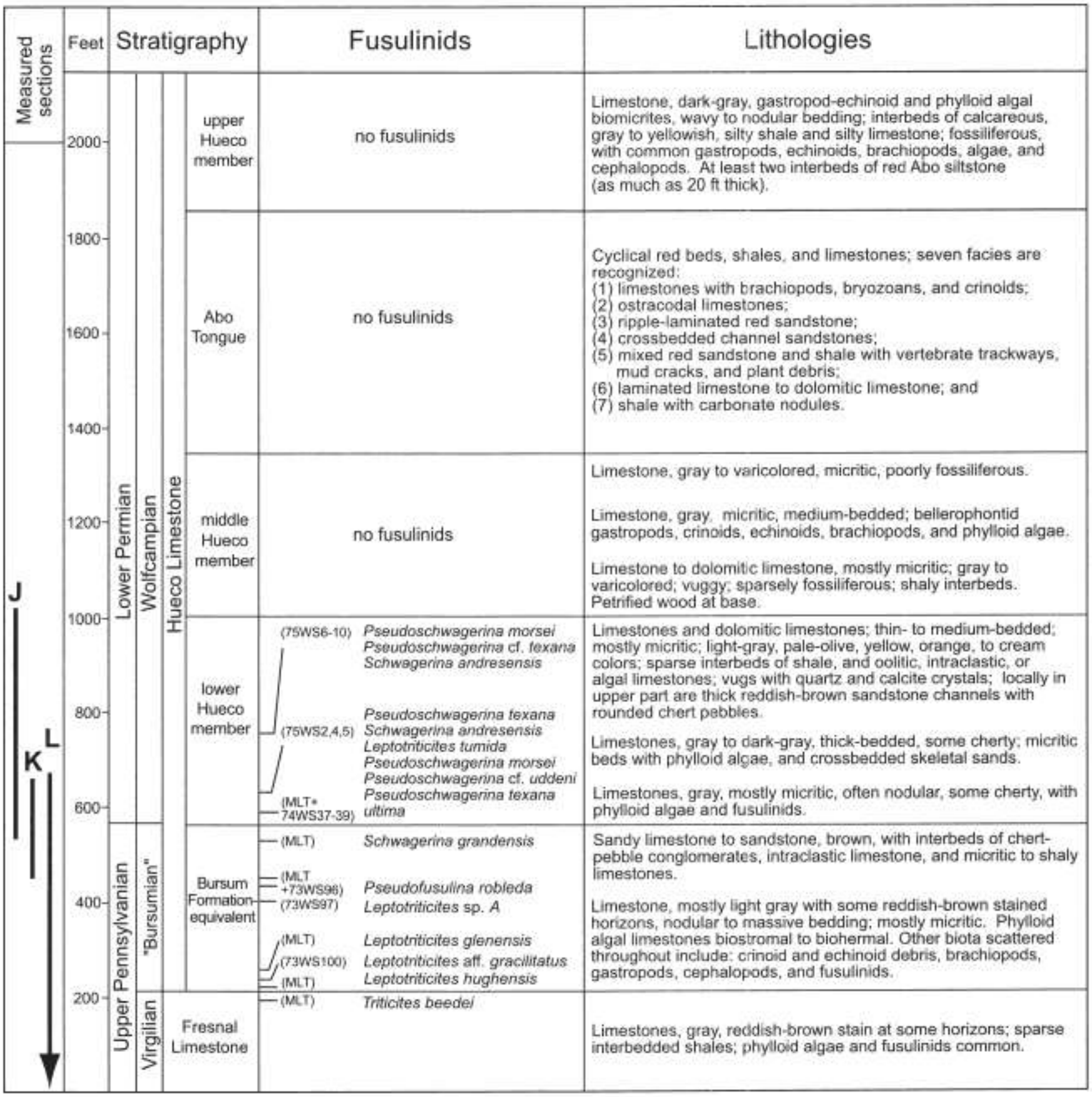

FIGURE 3—Chart showing the stratigraphy of the Upper Pennsylvanian and Lower Permian strata of the Robledo Mountains; the measured sections of Seager, Kottlowski, and Hawley (in press); the distribution of fusulinid samples in the section (MLT are Thompson, 1954, samples); the fusulinid faunas; and lithologic summaries of the stratigraphic units.

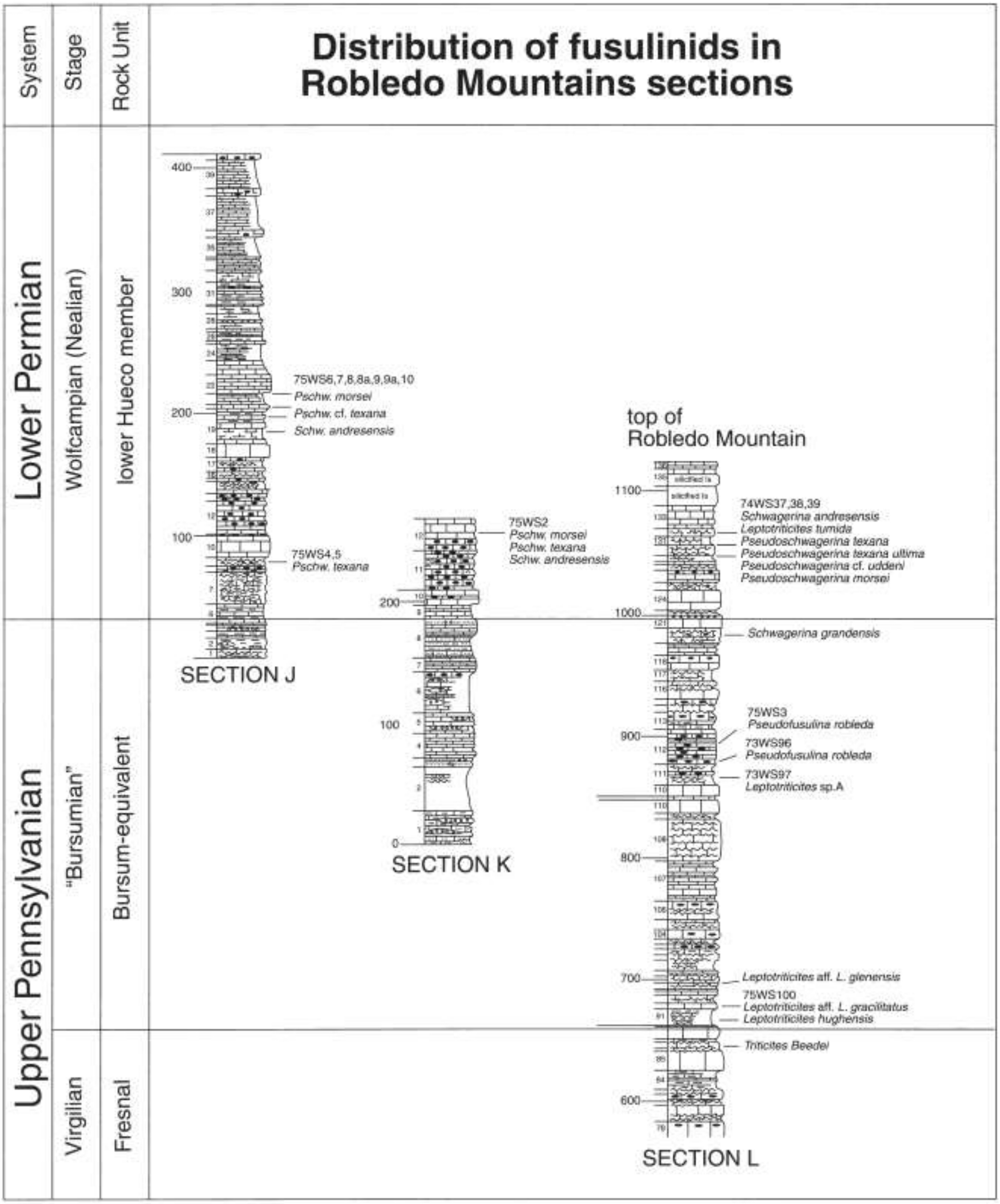

FIGURE 4—The Robledo Mountains fusulinid-bearing measured sections of Seager, Kottlowski, and Hawley (in press), their stratigraphy, their suggested correlation, and the location of fusulinid samples, sample numbers, and fusulinid faunas.

thins along strike (Fig. 4). The bed's characteristics suggest that it probably represents a sea-level lowstand and probably a period of subaerial erosion. Furthermore, the placement of the boundary at L122 is supported by the fusulinid biostratigraphy. The lower Bursum-equivalent unit is characterized by *Leptotriticites hughensis, L. glenensis,* L. aff. *gracilitatus,* and L. sp. A (beds L91-97), and the upper part of the unit is characterized by *Pseudofusulina robleda* (beds L111-112). The uppermost fusulinid sample in the Bursumequivalent unit contains *Schwagerina grandensis* (bed L120), a typical "Bursumian"-aged fusulinid that was also reported by Thompson (1954) from the Bursum stratotype. Significantly, the lowest Wolfcampian (Nealian) fusulinid assemblage occurs approximately 37 ft above bed L122, in bed L127 (Figs. 3-4).

Lower Permian (Wolfcampian)

Hueco Group

King, King, and Knight (1945) divided the Hueco Limestone in the Hueco Mountains stratotype into three informal subdivisions, termed the lower, middle, and upper divisions. That informal terminology has been applied ever since to the Hueco Limestone throughout southern New Mexico, though some publications have replaced the term "division" with the term "member" (Seager et al., 1976; Seager, 1981; Mack and James, 1986; Mack et al., 1988). In a later study on the Hueco Mountains stratotype, Williams (1963) elevated the Hueco Limestone to group status and gave the three "divisions" formation names, which are, in ascending order:

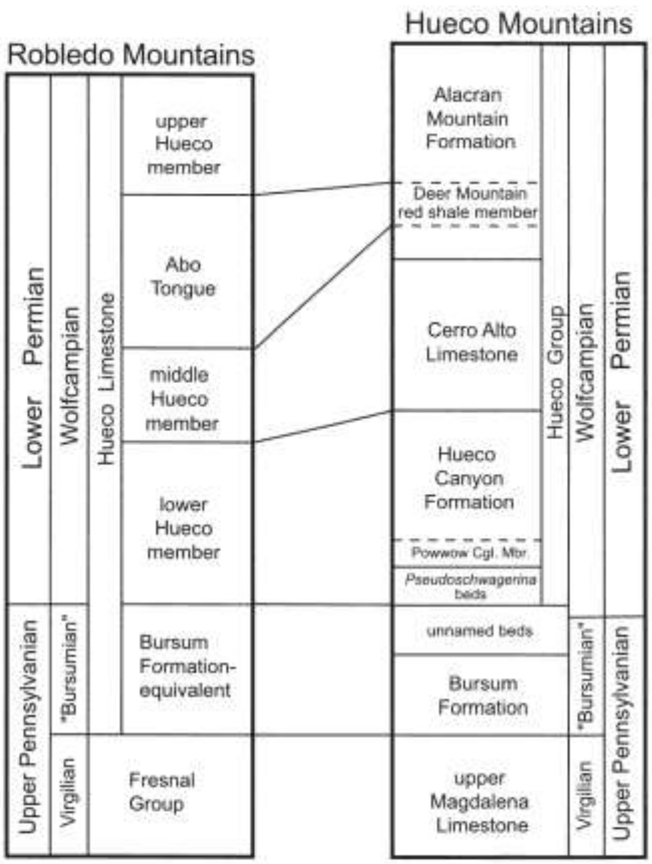

FIGURE 5—Chart showing proposed correlation of the uppermost Pennsylvanian and Lower Permian stratigraphic sections of the Robledo Mountains and Hueco Mountains.

Hueco Canyon Formation, Cerro Alto Limestone, and Alacran Mountain Formation (Fig. 5). Subsequently, Williams (1966) extended those formation names to the Hueco Group section in the Franklin Mountains, which lie directly west of the Hueco Mountains across the Orogrande Basin, and just south of the present study area (Fig. 1). The Hueco-Franklin Mountains formation names have not been applied to the more northern exposures because of marked facies changes in the Abo-Hueco transition zone. The Hueco-Franklin Mountains formation names could possibly be applied to the Robledo Mountains section (Fig. 5), but not to the Dona Ana, Organ, and southern San Andres Mountains, where the sections are more influenced by the Abo-Hueco facies transition.

As in Seager, Kottlowski, and Hawley (in press), herein the Robledo Mountains Hueco Limestone is subdivided into four informal stratigraphic units: the lower Hueco member, middle Hueco member, Abo Tongue member, and upper Hueco member (Seager et al., 1976; Seager, 1981; Mack and James, 1986; Figs. 2-5). In adjacent mountain ranges, the upper part of the section is characterized by intertongueing Abo siliciclastics and Hueco carbonate facies and is referred to as the Abo-Hueco member. In the Dona Ana Mountains, the upper Hueco member is missing, probably having been eroded away during the Laramide (Late Cretaceous -Tertiary) uplift, and the Abo-Hueco member is the uppermost unit in the section. In the southern San Andres Mountains, the Abo-Hueco member is overlain by Abo Sandstone, which becomes progressively more predominant northward. In the central Organ Mountains, the section is mostly limestone, similar to the Robledo Mountains, but northward into the southern San Andres Mountains the carbonate part of the section thins as Abo siliciclastics thicken, particularly in the upper part of the Hueco (Kottlowski et al., 1956; Bachman and Myers, 1969; Seager, 1981), reflecting the southward progradation of the Abo nonmarine red beds into the Hueco marine carbonate facies belt.

Lower member of the Hueco Limestone—With the redefinition of the top of the Bursum-equivalent limestone unit proposed herein, the lower Hueco member is now considered to be about 476 ft thick in the Robledo Mountains (Fig. 3). The lower part of the lower Hueco member consists of thick-bedded, gray limestones that form cliffs and steep slopes. Two general limestone types are present. The first is micrite to biomicrite, which is sometimes cherry and is very fossiliferous, containing brachiopods, fusulinids, gastropods, and sparse phylloid algae. The second type of limestones are fine-grained skeletal sands, some of which display large-scale crossbedding. Jordan (1975) interpreted the micrites to be mud-dominated banks and the skeletal sands to be submarine dunes.

The upper part of the lower Hueco member consists of thin- to medium-bedded, poorly fossiliferous, micritic limestones and dolomites that are light gray, pale olive, yellow, buff, orange, and cream in color and commonly have vugs filled by quartz and calcite crystals. There are poorly exposed thin interbeds of calcareous shale, oolitic limestone, intraclastic limestone, and phylloid algal limestone. In the area of Two-to-One Canyon, about 150 ft below the top of the member, there are distinctive reddish-brown chert-pebble conglomeratic sandstone channels as much as 20 ft thick. The top of the lower Hueco member is marked at the highest of three bright orange-weathering siliceous micrite beds, each being 1-3 ft thick.

The lower Hueco member represents a general shallowing-upward sequence. The lower part of the member represents mostly normal marine shelf paleoenvironments. The upper part represents mostly inner shelf, shallow water, restricted marine carbonate paleoenvironments. Seager (pers. comm. 1998) believes that the sandstone channels in the upper part of the unit might be marine in origin because they are overlain and underlain by algal limestones and are laterally discontinuous.

Under the discussion of the Bursum-equivalent unit, it was pointed out that in the Robledo Mountains measured section (section L), the first undoubtedly Wolfcampian (Nealian) fusulinid assemblages occur approximately 37 ft above sandy limestone marker bed L122, in beds L127-132, which contain *Pseudoschwagerina morsei, P. texana, P. texana* var. *ultima, P.* cf. *P. uddeni, Schwagerina andresensis,* and *Leptotriticites tumida* (Figs. 3-4). It is further suggested here that bed L122, the only sandy limestone unit in section L, might correlate to beds 1-8 of section K, which, according to Seager, Kottlowski, and Hawley (in press), are a relatively thick succession of sandstones, sandy limestones, conglomeratic limestone, and oolitic limestone. No fusulinids are known from beds K1-8, but in bed K12, *Pseudoschwagerina texana, P. morsei, and Schwagerina andresensis* occur, which is the same assemblage seen in the lower Hueco member beds L127-132 (Fig. 4). As shown in Figure 4, a tentative correlation is suggested here between the Bursum sandy units in sections K and L (K1-8 and L122), and the lower Hueco member beds containing the first occurrences of the Nealian fusulinid faunas (K12 and L127-132).

The only other fusulinid-bearing Robledo Mountains stratigraphic section, section **J,** apparently lacks any sandy limestone or sandstone beds, but beds J8-9 and J19-21 contain *Pseudoschwagerina* cf. *texana, P. morsei,* and *Schwagerina andresensis,* again the same assemblage seen in beds K12 and L127-132. Often in such shallow shelf sequences, isolated fusulinid-bearing horizons represent a minor transgressive event that brought more normal marine offshore paleoenvironments into a previously inner shelf zone, and therefore those fusulinid beds can be good time markers across a shelf area. That may be the case in sections J, K, and L, and the lower Hueco member fusulinid beds in each section might correlate to one another, representing the maximum transgression during deposition of the lower part of the lower Hueco member. In order to confirm the correlations suggested above, the stratigraphic sections should be analyzed in more detail for depositional facies and sequence stratigraphic interpretations.

Middle member of the Hueco Limestone—The middle Hueco member is about 275 ft thick in the Robledo Mountains and consists of three units (Fig. 3). The lowest unit is a 145-ft-thick micritic dolomitic limestone with interbedded shale and shaly limestone, and petrified wood is common in the basal beds. The dolomitic micrite is vuggy, slightly fossiliferous, and varies in color from light gray to light olive, yellow, orange, and cream. Chert is absent except for a marker bed 23 ft above the base. The middle unit of the member consists of 80 ft of medium- to dark-gray, medium-bedded biomicrite containing bellerophontid gastropods, echinoids, crinoids, brachiopods, and phylloid algae. The Wolfcampian gastropod *Omphalotrochus obtusispira* (Shumard) is common in this unit (Dutro and Yochelson, written comm. 1976). The upper unit of the member is 50 ft thick and consists of thin- to thick-bedded, poorly fossiliferous micrite and biomicrite, which are generally light gray, pale yellow, or cream colored.

Fossils are common only in the middle unit of the middle Hueco member, and the assemblage there indicates inner shelf lagoonal conditions. The upper and lower units represent more restricted marine paleoenvironments. No fusulinids have been found from this member. It is noteworthy that the Cerro Alto Formation, the middle formation of the Hueco Group in the Hueco and Franklin Mountains to the south, consists of similar dark, silty, mollusk-rich limestones in which fusulinids are rare to lacking.

Abo Tongue—The 435-475-ft-thick tongue of Abo red beds has a gradational contact with the underlying middle Hueco member (Fig. 3). Mack and James (1986) thoroughly studied this unit and recognized seven lithofacies: (1) bioclastic limestone with a normal marine fauna of brachiopods, bryozoans, crinoids, and echinoderms; (2) ostracodal limestone; (3) ripple-laminated red sandstones; (4) crossbedded channel sandstones as much as 20 ft thick and 300 ft wide; (5) mixed red sandstone and shale featuring ripple laminae, mud cracks, plant debris, and well-developed vertebrate trackways; (6) laminated limestone to dolomitic limestone with wavy stromatolitic laminations, calcite-filled vugs, and breccia horizons; and (7) shale with calcareous nodules that are probably pedogenic in origin. They interpreted the cyclical successions of these facies to represent the nearshore transitional zone between normal marine Hueco carbonate facies and tidal-flat, Abo, red, siliciclastic facies. LeMone et al. (1971, 1975), and the above authors, have reported a diverse fauna of gastropods and pelecypods from the marine limestones in this unit, as well as some brachiopods, crinoid ossicles, and rare nautiloids, but no fusulinids have been found. Of particular note are the famous vertebrate trackway sites in the strandline facies of this unit (Lucas and Heckert, 1995).

Upper member of the Hueco Limestone—The upper Hueco member is the youngest stratigraphic unit in the Robledo Mountains, reaching a maximum thickness of about 350 ft beneath the overlying Tertiary unconformity (Fig. 3). The unit consists of mostly wavy to nodular, 0.5-1.0-ft-thick limestone beds that are separated by thin silty shales or silty limestones. Typically, the limestones are dark-gray, gastropod-echinoid biomicrite and phylloid algal biomicrite. There are two red siltstone tongues of the Abo, each as much as 20 ft thick. The biota is fairly abundant and diverse, consisting of gastropods (including *Omphalotrochus obtusispira),* echinoids, brachiopods, phylloid algae, and cephalopods. The unit represents nearshore, shallow shelf lagoonal to strand-line depositional environments. The absence of fusulinids from this unit suggests paleoenvironmental conditions may have been characterized by variable salinities and/or silty turbid seawater.

Depositional history

The Virgilian through Wolfcampian stratigraphic section in the Robledo Mountains records the general southward progradation of the Hueco-Abo depositional system (Fig. 3), with a superimposed record of relative sea-level fluctuations that were probably related to late Paleozoic continental glaciation and/or regional tectonic movements. The Fresnal-Bursum and the lower part of the lower Hueco member indicates predominantly offshore, normal marine, shallow shelf conditions on the Robledo shelf. The overlying upper part of the lower Hueco member to the upper Hueco member represent fluctuating intervals of inner shelf, onshore, and intertidal deposition.

The predominantly limestone sections of the Virgilian, Bursum, and lower part of the lower Hueco member are characterized by phylloid algae, fusulinids, brachiopods, and crinoids, and represent shallow, predominantly normal marine, offshore conditions on the Robledo shelf. Occasional thin red-bed horizons may represent eustatic sea-level lows, or subaerial exposure at the tops of shallowing-upward cycles, or both. Significantly, fusulinids, which are an indicator of open, normal marine conditions, are not known to occur in the Robledo Mountains stratigraphic section above this interval.

The first long-term change in the Robledo shelf depositional conditions to more inner shelf restricted carbonates takes place in the upper part of the lower Hueco member, which consists of light, varicolored, sparsely fossiliferous, vuggy limestones and dolomitic limestones, with sandstone channels near the top. Petrified wood is common in the basal beds of the overlying middle Hueco member, which consists of 145 ft of similar restricted marine, vuggy, sparsely fossiliferous dolomitic limestones.

The middle unit of the middle Hueco member apparently represents a slight sea-level rise. The unit consists of dark biomicrites characterized by a biota of bellerophontid gastropods, productid brachiopods, echinoderms, and phylloid algae, representing an inner shelf lagoon with shallow, quiet, mostly normal marine waters. Clay-rich soft substrates, turbid seawater, and possibly variable salinities, probably excluded fusulinids and other open marine biota from the inner shelf environment.

A return to nearshore, restricted marine conditions is seen in the upper unit of the middle Hueco member, which consists of light, varicolored, poorly fossiliferous limestones. The overlying Abo Tongue clearly represents an extended period of cyclical normal marine, nearshore restricted marine, and intertidal (tidal flat/tidal channel) conditions. The upper Hueco member represents another long-term, but slight, marine incursion, with the deposition of inner shelf, normal to restricted marine carbonates resembling those of the middle part of the middle Hueco member, and being interrupted periodically by the incursion of red-bed deposition.

Previous Bursum—Hueco fusulinid studies from the Orogrande Basin region

Needham (1937) first described and illustrated fusulinids from the Orogrande Basin area, based on scattered samples from throughout the region. Dunbar and Skinner (1937) described several Early Permian fusulinids from the Hueco and Franklin Mountains in the southern part of the basin. However, Thompson (1954) was the first to present detailed descriptions of Bursum and Hueco fusulinid faunas from measured sections around the Orogrande Basin area, including the Robledo Mountains. In the Oscura Mountains and Los Pinos Mountains, near the northern end of the Orogrande Basin, Thompson (1954) described faunas from the Bursum Formation consisting of *Triticites creekensis, Leptotriticites eoextenta, Schwagerina grandensis,* and *S. pinosensis.* Myers (1988) described the same general assemblage from the adjacent Manzano Mountains area. The interbedded limestones and red beds of the Bursum Formation in this northern Orogrande Basin area are usually less than about 100 ft thick and are overlain by Abo nonmarine red beds. Thompson (1954) also recorded a similar "Bursumian" fusulinid fauna from Fresnal Canyon, Sacramento Mountains, on the east side of the basin. Steiner and Williams (1968) later gave a more detailed account of "Bursumian" fusulinids of the Sacramento Mountains, reporting *Triticites venticosus,* T. *creekensis, Leptotriticites americana, Schwagerina emaciata,* and *S. campensis* from the Laborcita Formation in Laborcita Canyon.

In the San Andres Mountains, Thompson (1954) described sparse Wolfcampian fusulinid occurrences in the Hueco Limestone of Rhodes and Ash Canyons. In Rhodes Canyon (northern San Andres Mountains), he found no fusulinids in limestones that he tentatively assigned to the Bursum Formation, but reported *Schwagerina andresensis* and *Pseudoschwagerina rhodesi* in the Hueco Limestone. In Ash Canyon (southern San Andres Mountains), the Bursum Formation is apparently missing, but in the Hueco Limestone he described, in ascending order of occurrence, *Schwagerina andresensis, Pseudoschwagerina needhami, Ps. morsei,* and *Ps. texana.* In the Bear Peak area at the south end of the San Andres Mountains, Bachman and Myers (1969) reported Hueco Limestone lying directly on Panther Seep Formation, with no recognizable Bursum present. Fusulinids were reported only from the basal part of the Hueco Limestone, and included *Schwagerina andresensis, Pseudoschwagerina* cf. *P. texana, P.* cf. *P. uddeni, Schwagerina* aff. *S. grandensis,* and *Triticites?* sp. indeterminant.

Farther south, in the Robledo Mountain section, Thompson (1954) described *Triticites beedei* in the uppermost Virgilian; *Leptotriticites hughensis* and L. aff. L. *glenensis* from the lower Bursum (?) Formation; *Pseudofusulina robleda* from two horizons in the upper Bursum Formation; *Schwagerina grandensis* near his Bursum—Hueco boundary; and *Schwagerina andresensis, Pseudoschwagerina uddeni?, Ps. texana?,* and *Leptotriticites aff. L. tumida* from the lower Hueco Limestone. Immediately to the northeast, in the Dona Ana Mountains, Seager, Kottlowski, and Hawley (1976) reported *Schwagerina andresensis* and *Pseudoschwagerina* sp. from the lower Hueco of the Grande dome shelf section. **And** in **the adjacent** Organ Mountains, Seager (1981) has reported *Pseudoschwagerina morsei* in the lower part of the lower Hueco member, and *Pseudoschwagerina* aff. *P. texana* in the lower part of the middle Hueco member.

In the Jarilla Mountains, due east of the Organ Mountains area and near the eastern margin of the basin, Schmidt and Craddock (1964) reported a Bursum fusulinid fauna in their unit 13, consisting of *Triticites cellamagnus, T. ventricosus sacramentoensis, T* cf. *T. gallowayi, T.* cf. *T. rhodesi, Schwagerina* aff. *S. emaciata,* and *S.* sp. indeterminant. The last three species of *Triticites* had been originally described by Needham (1937) from the upper Magdalena Limestone in the Sacramento Mountains, but in the 1930s essentially all Pennsylvanian—Permian strata below the Abo red beds were included in the Magdalena Limestone. About 800 ft higher in the Jarilla Mountains section, the same authors cited a fusulinid-bearing unit in the Hueco Limestone that contained *Pseudoschwagerina morsei, Sthwagerina emaciata,* and *S. emaciata jarillaensis.*

Dunbar and Skinner (1937) and Thompson (1954) described much more abundant and diverse fusulinid faunas from the Hueco Limestone of the Hueco Mountains, on the southeastern shelf of the Orogrande Basin, and those descriptions were greatly elaborated upon by Williams (1963). Dunbar and Skinner (1937) and Williams (1966) also described prolific Hueco fusulinid faunas from the Franklin Mountains, which are due west of the Hueco Mountains across the southern Orogrande Basin, and lie just south of the Robledo Mountains. Harbour (1972) also listed numerous fusulinids (identified by Lloyd Henbest), and other fossils, from a number of Franklin Mountains localities. Significantly, the Hueco Limestone of these more southern exposures in the Hueco Mountains and Franklin Mountains contain abundant and diverse fusulinid faunas to the top of the upper Hueco sections, indicating a generally open normal marine depositional setting in the southern Orogrande Basin to the end of Wolfcampian time.

Also noteworthy are fusulinid studies in strata correlative to the Bursum—Hueco interval in the Pedregosa Basin area in southwestern New Mexico and southeastern Arizona. From the Horquilla Limestone in the Big Hatchet Mountains of southwestern New Mexico, Skinner and Wilde (1965) described *Leptotriticites gracilitatus* n. sp., a species reported here from the "Bursumian" of the Robledo Mountain section, from the lower part of the study interval. And from the upper part of the section, in association with species of *Pseudoschwagerina* and *Paraschwagerina,* they described L. *hatchetensis,* which is very similar to L. *tumida,* a species reported here from the lower Hueco member on Robledo Mountain. Also, Sabins and Ross (1963) described the "Bursumian" and Early Wolfcampian (Nealian) fusulinid faunas of southeastern Arizona.

Fusulinid faunas and correlations of the Robledo, Dona Ana, Organ, and southern San Andres mountain ranges

Robledo Mountains

The stratigraphic distribution of fusulinids in the Bursum Formation-equivalent unit and the lower Hueco member are illustrated in Figures 3-4. Thompson (1954, fig. 8) previously described the Bursum—Hueco fusulinids in the Robledo Peak section. He recorded *Triticites beedei* from about 20 ft below the top of the Virgilian Fresnal Group. About 10 ft above the top of the Fresnal, he reported *Leptotriticites hughensis,* and at about 45 ft he reported *Leptotriticites* aff. L. *glenensis*. In the same paper, he also described the type suites for both of those species from the lower Council Grove Group (Bursum-equivalent) in the midcontinent, but for some reason he called this part of the Robledo section "Bursum (?)." At about 200 ft and 220 ft above the top of the Fresnal, Thompson described the type specimens for *Pseudofusulina robleda,* and he referred that part of the section to the Bursum Formation. At approximately 310 ft above the Fresnal, he described the type specimens of *Schwagerina grandensis*. In the same paper, he also recognized specimens with close affinity to S. *grandensis* in the Bursum of Abo Canyon (Los Pinos Mountains), Oscura Mountains, and San Andres Mountains, but he referred the Robledo type collection to the basal Hueco Limestone, probably because of the relatively pure carbonate facies in the Robledo section. At about 415 ft above the Fresnal, in the Hueco Limestone, he reported the first *Pseudoschwagerina texana* and *Ps. uddeni,* the latter being a questionable identification from a juvenile specimen. Associated with the *Pseudoschwagerina* were also the first *Schwagerina andresensis,* which occurred again at about 425 ft in association with *Leptotriticites tumida,* and then again at about 450 ft near the top of the section.

In the new Robledo Mountains collections (section L), *Leptotriticites* aff. L. *gracilitatus* was found in beds (collection 73WS100) just above Thompson's (1954) sample with L. *hughensis* and below Thompson's occurrence of L. *glenensis* (Figs. 3-4). There are then approximately 150 ft of sections with no fusulinids, after which there is an interval (beds L11-112) containing *Leptotriticites* sp. A (collection 73WS97) and abundant *Pseudofusulina robleda* (collections 75WS3 and 73WS96). After another approximately 100 ft of barren section, *Schwagerina grandensis* occurs (bed L120) near what is interpreted here to be the top of the "Bursumian" interval (bed L122). At 37 ft above bed L122, the first Wolfcampian (Nealian) fusulinids occur in bed L127 (collections 74WS37, 38 ,39), the assemblage consisting of *Pseudoschwagerina morsei, P. texana, P. texana* var. *ultima, P.* cf. *P. uddeni,* and *Schwagerina andresensis*. The highest fusulinid samples in section L occurs in bed L130 and L132, consisting of *Schwagerina andresensis* and *Leptotriticites tumida*. In section K (bed 12, collection 75WS2) and section J (beds J8-9; collections 75WS4, 5 and J19-21; collections 75WS6, 7, 8a, 9, 9a, 10), the assemblage of *Pseudoschwagerina texana, P. morsei,* and *Schwagerina andresensis* again occurred.

Dona Ana Mountains

The Dona Ana Mountains collection 73WS101 contains mostly broken, extensively recrystallized, and silicified specimens that are difficult to interpret (Pl. 3, Figs. 4-5) but are questionably referred to *Pseudoschwagerina texana*. That collection is correlated with lower Hueco member *Pseudoschwagerina morsei*—*P. texana* assemblage of the Robledo Mountains. Collection 73WS101 also includes what may be specimens of *Triticites* juvenaria, which have very large proloculi like *T. meeki* or T. *creekensis*. Also, a specimen questionably referred to *Schwagerina* was found in collection 73WS101. Previously, King (in Seager, Kottlowski, and Hawley, 1976) suggested that collection 73WS101 (= fusulinid sample on section D of sheet 3) was of probable Bursum age, but reinterpretation of poor specimens as probable *Pseudoschwagerina texana* indicates a correlation to the lower Hueco member. According to George Verville (Amoco, pers. comm. 1980), a sample from about 100 ft higher in the same section contains silicified **but** identifiable specimens of *Pseudoschwagerina texana* and *P.* aff. *P. morsei.*

Dona Ana Mountains collections 74WS2 and 74WS41 correlate with the *Schwagerina andresensis*—*Pseudoschwagerina morsei* assemblage in the lower Hueco member of the Robledo Mountains. Collections 74WS2 and 74WS41 are from the same bed and those numbers represent the fusulinids occurrences cited on section **B** of sheet 3 in Seager, Kottlowski, and Hawley (1976). The fusulinids from section B are from the shelf facies of the lower Hueco member and are much better preserved than the fusulinids from basinal facies in section D as previously discussed. *Schwagerina andresensis* and *Pseudoschwagerina morsei* are common in the collections of both the Robledo Mountains and Dona Ana Mountains, but the Robledo Mountains assemblage also has *Ps. texana* and *Ps. texana ultima,* and the Dona Ana Mountains collections also have *Schwagerina* sp. A.

Southern San Andres Mountains

Collection 75WS1 from the southern San Andres Mountains is the collection number for the citation of *Pseudoschwagerina morsei* on sheet 3 of Seager (1981), a composite columnar section of the Organ and southern San Andres Mountains. That collection correlates to the lower Hueco member samples of the Robledo Mountains that contain the same species. *Pseudoschwagerina texana* is typical of the lower Hueco member in the Robledo Mountains, but Seager (1981, sheet 3) lists *Pseudoschwagerina* aff. *texana* in the lower part of the middle Hueco member on the composite columnar section of the Organ and southern San Andres Mountains. This is not problematical because *P. texana* is known to range up into the upper Hueco Group in both the Hueco and Franklin Mountains to the south.

Regional fusulinid correlations

The fusulinid fauna of the Bursum-equivalent unit in the Robledo Mountains contains *Leptotriticites hughensis, L. glenensis,* L. aff. *gracilitatus,* L. sp. A, *Pseudofusulina robleda,* and *Schwagerina grandensis* (Figs. 3-4). This assemblage correlates well to the faunas described by Thompson (1954) from the Admire—lower Council Grove Groups in Kansas and to the Pueblo Group of north-central Texas, but the Robledo fauna is less diverse. According to Thompson

(1954), the "Bursumian" fusulinid faunas in Kansas and north-central Texas have 13 species and 17 species, respectively. The Robledo assemblage also correlates well to other "Bursumian" faunas around the Orogrande Basin, including the Oscura Mountains Bursum stratotype (Thompson, 1954), the Los Pinos (Thompson, 1954) and Manzano Mountains (Myers, 1988), and the Sacramento Mountains (Thompson, 1954; Steiner and Williams, 1968). A notable difference in the Robledo assemblage with all the above faunas is the apparent absence of typical "Bursumian" species of *Triticites,* such as T. *creekensis, T. cellamagnus,* and the *T. ventricosus* group.

"Bursumian" strata are not well understood in the southern Orogrande Basin. In the Hueco Mountains, one thin limestone unit containing "Bursumian" fusulinids is exposed at the top of the so-called Reef Hill (Toomey and Babcock, 1983; Pol, 1988) (Fig. 4), and is part of a thick, unnamed, post-Virgilian and pre-Nealian, predominantly siliciclastic sequence (Cys, 1975). In the Franklin Mountains, the Hueco Group limestones lie with apparent conformity on a poorly exposed, thick, unfossiliferous, largely siliciclastic, Panther Seep-like sequence that is thought to be Missourian, Virgilian, and "Bursumian" in age (Harbour, 1972; Jordan and Wilson, 1971). Stewart (1968) believed that the contact was unconformable but did not give any evidence for his conclusion. Jordan and Wilson (1971, p. 81) mentioned finding a possible "Bursumian" species of *Triticites* in the lower part of their measured section at Tom Mays Park, but this has not been confirmed.

The fusulinid assemblage of the lower Hueco member in the Robledo Mountains and adjacent ranges consists of *Schwagerina andresensis, Leptotriticites tumida, Pseudoschwagerina morsei, P. texana, P. texana ultima,* and *P.* cf. *P. uddeni.* The species *P. texana* and *P. uddeni* occur in the Neal Ranch Formation (Nealian) of the Glass Mountains Wolfcampian stratotype section. Both species are characteristic of the Hueco Canyon Formation (lowest division of the Hueco Group) in the Hueco Mountains and Franklin Mountains sections, first appearing in some of the lowest fusulinid beds in those sections, but then ranging upward into the lower part of the upper Hueco Group (Alacran Mountain Formation; Williams, 1963, 1966). The other three taxa in the Robledo assemblage provide somewhat tighter stratigraphic control. *Leptotriticites tumida* occurs in the lower Neal Ranch Formation in the Glass Mountains stratotype (Ross, 1963, 1997), and in the Neva Limestone (early Nealian) in Kansas (Thompson, 1954). *Pseudoschwagerina morsei* has been reported only in the Robledo Mountains and adjacent ranges and the Jarilla Mountains of the central Orogrande Basin. Likewise, *Schwagerina andresensis* has been reported only from the central Orogrande Basin area where it is also known from the lower Hueco Limestone in Rhodes and Ash Canyon sections of the San Andres Mountains. In those two sections, S. *andresensis* occurs below the lowest occurrences of *Pseudoschwagerina rhodesi* and *P. needhami,* which are two of the smallest species of that genus.

The low diversity of Hueco Limestone fusulinid faunas of the central Orogrande Basin area (San Andres Mountains, Robledo Mountains, etc.) can be partially related to their updip depositional facies position. However, the occurrences of *Leptotriticites tumida* and *Schwagerina andresensis* indicate an early Nealian age, and those faunas are probably slightly older than the lowest Hueco Canyon fusulinid faunas to the south in the Franklin Mountains, where the lowest Wolfcampian fusulinid samples consist of *Pseudoschwagerina texana* and *P. uddeni* (Williams, 1966). Possibly, the lower part of the lower Hueco member in the Robledo Mountains correlates, at least in part, with Williams' (1963) Hueco Mountains *Pseudoschwagerina* beds, which underlie the Powwow Conglomerate Member of the Hueco Canyon Formation (Fig. 5), but unfortunately the fusulinids in that unit have not yet been studied in detail. Following deposition of the lower part of the lower Hueco member fusulinid beds in the Robledo Mountains, the overlying inner shelf carbonate to terrestrial settings in that area were inhospitable to fusulinids, but open marine, fusulinid-bearing limestones continued to be deposited in the Hueco—Franklin Mountains of the southern Orogrande Basin through the end of Wolfcampian time. Currently, correlations of Wolfcampian units above the lower part of the lower Hueco member in the Robledo Mountains to stratigraphic units of the Hueco Mountains stratotype must be based on lithofacies characteristics (Fig. 5).

Summary and conclusions

1. The new designation of an international Carboniferous—Permian boundary in Eurasia, and the recent conodont-based correlation of that boundary to the midcontinent North America, necessitates the elevation of the Pennsylvanian—Permian boundary in the Orogrande and Permian Basins of west Texas—New Mexico from the base of the interval represented by the Bursum Formation to the top of that interval. Therefore, the Bursum interval is now considered to be latest Pennsylvanian in age, and it has been suggested that it should be recognized as a new stage, for which the name "Bursumian" has been proposed (Ross and Ross, 1994, 1998).

2. The Robledo Mountains has one of the most continuous marine carbonate stratigraphic sections across the new Pennsylvanian—Permian boundary in the American Southwest and could be an important regional reference section. The fusulinid faunas of the Bursum Formation-equivalent in the Robledo Mountain section consist of, in ascending order, *Leptotriticites hughensis,* L. aff. *L. gracilitatus,* L. aff. *L. glenensis,* L. sp. A, *Pseudofusulina robleda,* and *Schwagerina grandensis.*

3. The basal Permian in North America may be defined by the fusulinid fauna of the Neal Ranch Formation (Nealian) of the Wolfcampian stratotype in the Glass Mountains of west Texas. The fusulinid fauna in the lower part of the lower Hueco member in the Robledo Mountains stratigraphic section consists of *Pseudoschwagerina morsei, P. texana, P.* cf. *P. uddeni, Schwagerina andresensis,* and *Leptotriticites tumida.* This fauna is considered early Nealian in age and is probably slightly older than fusulinid faunas in the basal Hueco Group of the Hueco Mountains and Franklin Mountains of the southern Orogrande Basin.

4. Bed L122, which lies between the uppermost "Bursumian" fusulinid sample and below the lowermost Wolfcampian (Nealian) fusulinid sample in section L of Robledo Mountain, consists of a sandy limestone that weathers brown to black, contains rounded chert pebbles, and thickens and thins along strike (Seager, Kottlowski, and Hawley, in press). The top of that unit probably represents the widespread Bursum—Hueco regional unconformity, and the new Pennsylvanian—Permian boundary is tentatively placed at this level. Additional sedimentologic and stratigraphic studies of this part of the Robledo Mountain section are needed before the boundary placement can be confirmed.

Systematic descriptions

Genus *Leptotriticites* Skinner and Wilde 1965

Leptotriticites aff. L. *gracilitatus* Skinner and Wilde
P1. 1, Figs. 1-3

1965. *Triticites (Leptotriticites) gracilitatus* Skinner and Wilde, Contrib. Cushman, Found., Foram. Research, v. XVI, pt. 3, p. 99-100, pl. 14, figs. 1-5.

Description—The shells are elongate with gently rounded to pointed polar ends and a relatively straight to gently curved axis of coiling. Specimens of seven to seven and one half volutions measure from 7.95 to 8.00 mm in length and 1.90 to 2.40 mm in diameter. The form ratio varies from 3.3 to 4.2. The spirotheca is composed of a tectum and a finely alveolar thin keriotheca. In the seventh whorl the thickness of the spirotheca varies from 72 to 80 p. The septal fluting is quite prominent in the polar ends but is not well developed above the tunnel. Proloculi are spherical and small, ranging from 111 to 128 p in outside diameter. The tunnel angle varies from 27 to 37° in the sixth volution. The chomata are massive with vertical to slightly overhanging tunnel sides and steep poleward sides in many cases, particularly in the outer volutions.

In some specimens, axial fillings are fairly prominent in the inner volutions, but they are not present to any appreciable degree in outer volutions.

Discussion—Leptotriticites gracilitatus is not closely similar to any other described species. The specimens illustrated here are not as elongate as the holotype of Skinner and Wilde (1965), and their volutions expand a bit more rapidly, but they are much closer to L. *gracilitatus* than any other species.

L. aff. *gracilitatus* is longer and more slender than L. *americana* (Thompson) and less inflated than L. *hughensis* (Thompson), two species to which it bears some resemblance. As Skinner and Wilde (1965, p. 101) point out, L. *koschmanni* (Skinner) is larger and more inflated, and L. *victorioensis* (Dunbar and Skinner) is shorter at maturity and has a narrower tunnel angle.

Occurrence—Leptotriticites aff. *gracilitatus* was collected in the lower beds of the Bursum Formation-equivalent in section L on Robledo Mountain (collection 73WS100). L. aff. *gracilitatus* occurs just above a collection in which Thompson (1954) found L. *hughensis* and just below his collection bearing L. aff. *glenensis.*

Leptotriticites sp. A.
P1. 1, Figs. 4-6

Description—The shells are very small for the genus, moderately inflated with gently rounded to pointed poles. Specimens of seven to seven and one half volutions measure from 4.95 to 5.50 mm in length and 2.30 to 2.40 mm in diameter with form ratios from 2.05 to 2.4.

The spirotheca is finely alveolar and composed of a tecturn and keriotheca. Spirothecal thicknesses in the seventh whorl vary from 65 to 89 p. There is strong septal fluting in the poles, but fluting is greatly diminished to absent in the central part of the shell. Inner volutions of most specimens exhibit axial fillings.

Proloculi are spherical and quite small, ranging from 111 to 121 p in outside diameter, and the tunnel angle of the sixth volution varies from 22 to 30°. Chomata are prominent and blocky to irregular in character, often with steep tunnel and poleward sides.

Discussion—In the absence of additional better specimens, it is difficult to assign this form to a species with confidence. It most closely resembles some specimens of *Leptotriticites fivensis* (Thompson, 1954, p1. 16, figs. 8-15), but L. *fivensis* has much heavier axial filling and usually has larger and more irregular chomata. The specimens illustrated here are not considered to have enough features in common with the holotype of *Leptotriticites fivensis* to assign them to that species, or even to designate them as L. aff. *fivensis*. *Leptotriticites* sp. A also bears some resemblance to *L. americana* (Thompson), but the Robledo Mountains specimens have a smaller size and thinner walls.

Occurrence—Leptotriticites sp. A occurs in collection 73WS97 section L on Robledo Mountain, where it occurs just below the *Pseudofusulina robleda* beds.

Genus *Schwagerina* Moeller 1877

Schwagerina andresensis Thompson
Pl. 1, Figs. 7-13

1954. *Schwagerina andresensis* Thompson, Kansas Univ. Paleont. Contrib., Protozoa, art. 5, p. 60, pl. 31, figs. 1-16.

Description—The shell of *Schwagerina andresensis* is moderate to large in size with a straight axis of coiling and broadly rounded to sharply pointed polar ends. Specimens of seven volutions measure from 6.45 to 10.25 mm in length and 3.40 to 3.20 mm in diameter with form ratios varying from 1.8 to 3.2. A specimen of nine volutions measures 7.20 mm in length and 4.00 mm in diameter, with a form ratio of 1.8 (Pl. 1, Fig. 13). A similar specimen (Pl. 1, Fig. 12) has much the same characteristics, but the thin section spirals a bit. The spirotheca is moderately thick and is composed of a tectum of alveolar keriotheca. In the seventh whorl the thickness of the spirotheca varies from 66 to 91 p. Septa are narrowly and highly fluted throughout the length of the shell. Fluting extends to the tops of the septa throughout in most chambers.

Proloculi are small with the outside diameter varying from 126 to 145 p with most near the smaller figure. The proloculi are smaller than those of specimens illustrated by Thompson (1954, pl. 31). The tunnel angle varies from 28 to 38° in the sixth volution.

Chomata are high and narrow in the inner volutions and only sporadically present in outer volutions. Thin axial fillings occur in most parts of the shell.

Discussion—Throughout southern New Mexico, *S. andresensis* is characteristic of the lower part of the lower Hueco Group. As Thompson (1954, p. 60) mentioned, this species shows a fair amount of infraspecific variability, but it can be consistently recognized on the basis of characteristics like test shape, characteristics of the fluting, axial filling, and the juvenarium.

S. andresensis is a member of a group of early Nealian species (e.g., *S. vervillei* and *S. jewetti)* that are characterized by convex test shapes, axial filling, and chomata in the inner whorls. It differs from S. *bellula* Dunbar and Skinner by having a somewhat larger test size, a usually longer test shape, thinner test walls, and the presence of chomata in the inner whorls. It is clearly more primitive than *S. bellula,* which occurs in the Hueco Canyon Formation in the Hueco-Franklin Mountains area, and it is probably in the ancestral species group for that latter species. S. *andresensis* also differs from S. *aculeata* Thompson and Hazzard by having lighter axial fillings, a less inflated central region, and higher septal fluting.

Occurrence—Schwagerina *andresensis* occurs in the lower Hueco member from collection 74WS38, section L, Robledo Mountain, and from collection 75WS9a, section **J,** Robledo Mountains. In collection 75WS8 of section J, a *Schwagerina andresensis* juvenile form of five volutions was found. In the Dona Ana Mountains, *Schwagerina. andresensis* is found in collections 74WS2 and 75WS41, in the lower Hueco member of section B, the Grande dome (see Seager, Kottlowski, and Hawley, 1976, sheet 3).

Schwagerina sp. A.
Pl. 1, Figs. 14-15

Description—A mature shell of seven volutions (Pl. 1, Fig. 14) measures 5.45 mm in length and 2.58 mm in diameter with a form ratio of 2.1. The form ratio from the first to the sixth volution, respectively, is 1.4 mm, 1.5 mm, 1.6 mm, 1.7 mm, 1.6 mm, and 1.7 mm. The shell is regularly inflated with moderately large expansion in the seventh volution as shown by the radius vector measurements of 0.103 mm, 0.176 mm, 0.287 mm, 0.414 mm, 0.640 mm, 0.857 mm, and 1.24 mm from the first to the seventh volution. Poles of volutions are gently rounded.

The spirothecal thickness is 24 p, 33 p, 35 p, 66 p, 78 p, 95 p, and 124 p from the first to the seventh volution, respectively. The walls are composed of a tectum and keriotheca. The proloculus measures 122 p. The tunnel angle is narrow varying from 18° in the third volution, 22° in the fourth, and 23° in the fifth volution.

Chomata, which occur only in the first three-four volutions, are small and blocky with steep tunnel and poleward slopes. Septal fluting is irregular, moderately intense, and high through the first six volutions, becoming somewhat less intense in the seventh volution.

Discussion—Because adequate thin sections, particularly sagittal sections, are not available for study, this specimen is designated *Schwagerina* sp. A. The irregular septal fluting and possession of small chomata in the early volutions indicate it is a primitive member of the genus. It somewhat resembles some illustrated specimens of *Schwagerina grandensis* Thompson, but has a much smaller form ratio, a smaller proloculus, and thicker walls than the holotype and specimens with characteristics that are close to the holotype.

Occurrence—Schwagerina sp. A. occurs in collection 74WS2 which, is one of the collection numbers for the notation of fusulinids in the lower Hueco member of section B, the Grande dome shelf, Dona Ana Mountains (Seager and Hawley, 1976, sheet 3).

Genus *Pseudofusulina* Dunbar and Skinner, 1931
(amend. Skinner and Wilde, 1965)
Pseudofusulina robleda Thompson
Pl. 1, Figs. 16-17
Pl. 2, Figs. 1-3

1954. *Pseudofusulina robleda* Thompson, Kansas Univ. Paleont. Contrib., Protozoa, art. 5, p. 68-69, pl. 42, figs. 4-11.

Description—The shell is highly elongate with an irregular axis of coiling. It has pointed to broadly rounded polar ends and irregular lateral surfaces. Specimens of five and one half to six and one half volutions measure from 7.20 to 11.65 mm in length and 2.40 to 2.90 mm in diameter, giving form ratios of 3.0 to 4.0.

The proloculus is usually small with an outside diameter ranging from 154 to 207 p. The tunnel angle varies from 38 to 52° in the fifth volution. Chomata are prominent but narrow in inner volutions with steep tunnel and poleward slopes.

The spirotheca is moderately thin for such a large shell, varying from 103 to 109 p in the sixth volution. The shell is loosely coiled throughout, with chambers lowest above the tunnel and higher toward the polar ends.

The septa are irregularly fluted throughout the shell with the most intense fluting in the polar regions.

Discussion—The illustrated specimens (Pl. 1, Figs. 16-17; Pl. 2, Figs. 1-3) are from collection 73WS96 and have the same size range and morphological features as those illustrated by Thompson (1954). *P. robleda* somewhat resembles *Pseudofusulina laxissima* Dunbar and Skinner (1937), which has been described from the Hueco Canyon Formation in the Franklin Mountains and the Lenox Hills Formation (Lenoxian) of the Glass Mountains Wolfcampian stratotype, but *P. robleda* has a smaller test, a smaller proloculus, more loosely fluted septa, and is more tightly coiled. *P. robleda* also has general similarities to primitive species of *Schwagerina,* such as *S. longissimoidea* and *S. campensis* from the "Bursumian" strata of the midcontinent and north-central Texas (see Thompson, 1954), but *P. robleda* has more loosely fluted septa and lacks any axial secondary deposits.

Occurrence—P. *robleda* occurs in collection 73WS96 and 75WS3 in the lower Hueco member, section L, Robledo Mountain. Collection 73WS96 is from approximately the same beds from which Thompson collected *Pseudofusulina robleda* on Robledo Mountain (1954, p. 165).

Genus *Pseudoschwagerina* Dunbar and Skinner 1936
Pseudoschwagerina morsei Needham 1937
Pl. 2, Figs. 4-15

1937. *Pseudoschwagerina morsei* Needham, New Mexico State Bur. Mines Mineral Resources, Bull. 14, p. 54, 56, pl. X, figs. 5-7; p1. XI, figs. 1-4.

1954. *Pseudoschwagerina morsei* Thompson, Kansas Univ. Paleont. Contrib., Protozoa, art. 5, p. 73, pl. 48, figs. 2,8,11; pl. 49, figs. 6-9; pl. 50, figs. 3-4.

Description—Specimens of *Pseudoschwagerina morsel* of five and one half to seven volutions measure from 5.55 to 6.65 mm in length and 3.20 to 4.35 mm in diameter with form ratios of 1.5 to 1.7. The shell is medium in size and broadly fusiform. The axis is straight, and the poles are pointed to gently rounded in outer volutions.

The spirotheca is composed of a tectum and keriotheca. In the sixth whorl the thickness of the spirotheca varies from 76 to 128 p. Fluting is slight in the middle of the chambers and more intense in the poles.

Proloculi are small and vary in outside diameter from 149 to 172 p. The tunnel angle in the fourth volution varies from 45 to 63°. Chomata are weak and of highly variable shape, and may be present up to the fourth volution in some cases.

Detailed measurements of the specimen in Plate 2, Figure 5, are as follows: spirothecal thicknesses from the first to the sixth volution are 39 p, 45p, 72p, 601x, 60p, and 84p, respectively; heights of volutions from the first to the sixth volution are 0.62 mm, 0.91 mm, 0.155 mm, 0.380 mm, 0.631 mm, and 0.468 mm, respectively; form ratios from the first to the sixth volutions are 1.2, 1.6, 2.3, 2.3, 2.0, and 1.9.

Discussion—Thompson (1954) did not discuss *Pseudoschwagerina morsei* in any detail, but he illustrated numerous photographed specimens from the Jarilla Mountains and Ash Canyon in the San Andres Mountains (pls. 48-50), and one specimen from the south side of Robledo Mountain (pl. 50, Fig. 3). Also, in his figure 8, the Robledo Mountains measured section, he showed a line drawing of a small specimen labeled as *Pseudoschwagerina uddeni* that is almost certainly a mislabelled *P. morsei* (or *P. needhami),* but it is clearly not the same specimen shown in his plate 50, figure 3.

The several specimens illustrated here (Pl. 2, Figs. 4-15) are smaller than the two type specimens of *P. morsei* shown by Needham (1937), but they are otherwise similar morphologically. The present specimens are more comparable in size to some illustrated by Thompson (1954, pl. 50). Thompson (1954) said that *P. needhami* differed from *P. morsei* by having a smaller test, more nearly uniform expansion of the volutions, and larger chomata. The small test size of these specimens relative to the type suite suggests a possible relationship to *P. needhami.* It is noteworthy that Henbest (in Harbour, 1972) referred to *Pseudoschwagerina morsei* var. *needhami* in lists of fusulinids from the lower Hueco limestones of the Franklin Mountains. The more primitive species of North American *Pseudoschwagerina* (e.g., *P. rhodesi, P. need-*

hami, P. morsei, P. portalensis, and *P. beedei)* need to be restudied and more closely compared and defined.

Pseudoschwagerina morsei differs from *P. uddeni* (Beede and Knicker) in being less inflated and globose in shape, having a smaller proloculus, and more prominent chomata. All specimens of *P. morsei* studied are inflated fusiform in shape. *P. morsei* is smaller and more globose than *P. texana* Thompson; it is somewhat larger and more elongate than *P. beedei* and has a better defined juvenarium, and it is consistently larger than *P. rhodesi* Thompson.

Occurrence—In the Robledo Mountains, *Pseudoschwagerina morsei* occurs in the lower Hueco member in: collection 74WS37, section L, on Robledo Mountain (note that collections 74WS37, 74WS38, and 74WS39 are from the same bed.); collection 75WS10, at about 130 ft above the base of section J; collection 75WS8a, about 155 ft above the base of section J; and, collection 75WS2, at the same level as collection 75WS8a, but a half mile to the southeast (it was collected after tracing the bed in which 75WS8a was collected across several faults).

One of the specimens illustrated in Plate 2, Figure 14, is badly preserved and obliquely oriented, but it is probably indicative of this species in Dona Ana Mountains collection 73WS101 (see section D, Hueco Basin facies on sheet 3 of Seager, Kottlowski, and Hawley, 1976). No specimens with better preservation have been found. George Verville (Amoco Production Company, pers. comm. 1980) has sections of poorly preserved specimens tentatively identified as *P. morsei* from a collection about 100 ft above collection 73WS101 (locality is in SW 1/4 SW 1/4 sec. 9 R1E Dona Ana County). A juvenile specimen is illustrated (Pl. 2, Fig. 6) to show the presence of *P. morsei* in collections 75WS2 and 75WS41, which are the collection numbers for the notation of fusulinids in the lower Hueco member of section B, the Grande dome shelf, Dona Ana Mountains (Seager, Kottlowski, and Hawley, 1976, sheet 3).

Specimens of collection 75WS1 are from the lower Hueco member of the southern San Andres Mountains, and are noted on the composite columnar section of the Organ and southern San Andres Mountains, New Mexico (Seager, 1981, sheet 3). The geographic location is NE % NW 1/4 NE 1/4 sec. 19 T21S R3E Dona Ana County New Mexico.

Pseudoschwagerina cf. *P. uddeni* (Beede and Knicker)
Pl. 3, Fig. 1

1924.Schwagerina uddeni Beede and Knicker, Species of the genus Schwagerina and their stratigraphic significance, p. 27, pl. 1, fig. 1, pl. 4, fig. 1, pl. 6, figs. 1, 2, 4.

1937. *Pseudoschwagerina uddeni* Beede and Knicker, Needham, New Mexico State Bur. Mines and Mineral Resources, Bull. 14, p. 53, pl. 8, figs. 1-4.

1937. *Pseudoschwagerina uddeni* Dunbar and Skinner, Texas Univ. Bull. 3701, p. 658, pl. 50, figs. 1-10.

1954. *Pseudoschwagerina uddeni* Thompson, Kansas Univ. Paleont. Contrib., Protozoa, art. 5, pl. 50, fig. 6.

1963. *Pseudoschwagerina uddeni* Williams, Peabody Mus. Nat. Hist., Bull. 18, p. 45-46, pl. 8, figs. 1-3.

1963. *Pseudoschwagerina uddeni* Ross, Geol. Soc. Amer. Mem. 88, p. 153-154, pl. 23, figs. 1-4; pl. 24, fig. 4.

Description—A globose shell of six volutions measuring 6.95 mm in length and 4.85 mm in width for a form ratio of 1.4. The shell is broadly rounded at the polar ends.

The proloculus measures 227 p in outside diameter, and the first three volutions form a tightly coiled juvenarium. Rapid expansion of chamber height occurs in the fourth and fifth volutions, and the sixth volution is reduced in height. Radius vectors measure 0.211 mm, 0.354 mm, 0.648 mm, 1.53 mm, 2.20 mm, and 2.57 mm from the first through the sixth volutions, respectively. Form ratios for the first through the fifth volutions are 1.3, 1.4, 1.6, 1.5, and 1.3, respectively.

The wall is composed of a tectum and thin keriotheca. Spirothecal thicknesses of the first through the sixth volution are 31p , 41 p, 53 p, 60 p, 79 p, and 97 p, respectively.
Septal fluting is confined almost entirely to the poles in the outer volutions.

Discussion—Typical *Pseudoschwagerina uddeni* have a distinctive highly inflated globose test, often with protuberant knobs at the poles of the adult whorls. Its globose form easily distinguishes it from more elongate species such as *P. texana* Dunbar and Skinner, *P. needhami* Thompson, *P. convexa* Thompson, and *P. beedei* Dunbar and Skinner.

In the fauna under study here, *P. morsei* is the most similar species, but the single specimen distinguished here as *P.* cf. *P. uddeni* has a somewhat more inflated test, its rate of whorl expansion is much greater, and it shows traces of incipient polar knobs in the adult shell. However, it should be noted that the single specimen of *P.* cf. *P. uddeni* occurred in the same collection (74WS37) with *P. morsei,* and therefore it could be a variant of that species.

Occurrence—Pseudoschwagerina cf. *P. uddeni* was found in the lower Hueco member, in collection 74WS37, section L, on Robledo Mountain.

Pseudoschwagerina texana Dunbar and Skinner
Pl. 3, Figs. 4-12

1924. *Schwagerina fusulinoides* Beede and Knicker (part), Tex. Univ. Bull. 2433, p. 19-23, pl. 1, fig. 4; pl. 7, figs. 1-3, (not pl. 3, figs. 1-4, 8)

1927 [1928]. *Schwagerina fusulinoides* Dunbar and Condra (part), Nebr. Geol. Survey Bull. 2, 2nd ser., p. 121-123, pl. 14, figs. 2-5 Q ? (not pl. 14, fig. 1)

1932. *Schwagerina fusulinoides* White, (part), Tex. Univ. Bull. 3211, p. 81-82, pl. 8, figs. 1-12.

1937. *Pseudoschwagerina fusulinoides,* Needham (part), New Mexico State Bur. Mines Mineral Resources, Bull. 14, p. 51-43, pl. 8, fig. 11; pl. 9, figs. 1-4.

1937. *Pseudoschwagerina texana* Dunbar and Skinner, Tex. Univ. Bull. 3701, p. 662-665, pl. 52, figs. 1-8; pl. 53, fig. 9.

1954. *Pseudoschwagerina texana* Thompson, Kansas Univ. Paleont. Contrib., Protozoa, art. 5, p. 74-75, pl. 47, figs. 1-6, 9-10; pl. 48, figs. 1,3-7,9,10; pl. 49, figs. 1-5; pl. 50, figs. 8-9.

1963. *Pseudoschwagerina texana* Williams, Peabody Mus. Nat. Hist., Bull. 18, p. 43-44, pl. 7, figs. 1-4.

1963. *Pseudoschwagerina texana* Ross, Geol. Soc. Amer. Mem. 88, p. 150-152, pl. 25, figs. 1-2; p1.28, fig. 1.

Description—The shell is quite large, highly elongate and fusiform with narrowly rounded to broadly rounded polar ends at maturity. Inner volutions have pointed to narrowly rounded polar ends. Specimens of seven to eight volutions vary from 8.05 to 10.70 mm in length and 3.55 to 4.45 mm in diameter, giving form ratios from 2.3 to 2.4.

The spirotheca is composed of a tectum and a thick keriotheca. In the seventh volution, the thickness of the wall varies from 72 to 118 p. The septa are closely spaced throughout the shell and are much more intensely fluted in inner volutions. In outer volutions there is a marked decrease in fluting in the central part of the shell.

Proloculi are spherical, and outside diameters range from 151 to 186 p. The tunnel path is relatively straight and gives measurements of 36 to 52° in the sixth volution. Chomata deposits are quite massive in inner volutions but are sparsely distributed and irregular in outer volutions.

Discussion—The specimens of *P. texana* illustrated in Plate 3, Figures 6-12, are comparable to some of those illustrated by Thompson (1954) from his study of the fusulinids of Texas, Kansas, and New Mexico, but they have greater similarity to the *Pseudoschwagerina texana* illustrated by Dunbar and Skinner (1937, pl. 52). The poorly preserved specimens illustrated in Plate 3, Figures 4-5, co–occur in the same sample as the specimen of *P.*

morsei in Plate 2, Figure 14, but they were tentatively identified as *P. texana* because of their more narrowly fusiform test shape and more pointed poles. In the southwestern United States faunas, *P. texana* is more elongate than *P. uddeni,* and adults are significantly larger than *P. beedei, P. morsei, P. needhami,* and *P. rhodesi.* Also *P. texana* is not easily confused with *P. robusta* (Meek), *P. arta* Thompson and Hazzard, or *P. roeseleri* Thompson and Hazzard, because its septa are more highly and narrowly fluted, its spirotheca is thicker, and it expands more uniformly and gradually.

Occurrence-Pseudoschwagerina texana is found in Wolfcampian rocks in several localities in southern New Mexico. In the Robledo Mountains, *P. texana* occurs in the lower part of the lower Hueco member. A juvenile specimen was found in collection 74WS39, section L, Robledo Mountain. Specimens were also found in collections 75WS4 and 75WS5, section J. And what appears to be another juvenile of *P. texana* was found in collection 75WS9, 135 ft above the base of section J.

P. texana was also found in collection 76WS38, in the lowermost middle Hueco member of the southern San Andres Mountains, as noted on the composite columnar section of the Organ and southern San Andres Mountains, New Mexico (Seager, 1981, sheet 3) at the 5,510 ft level. The geographic location is SE 1/4 SE 1/4 SW 1/4 sec. 13 T21S R3E, Dona Ana County, New Mexico.

Poorly preserved specimens referred with question to *P. texana* were found in collection 73WS101 (Pl. 3, Figs. 4-5) of the Dona Ana Mountains. Collection 73WS101 is the collection number for the notation of fusulinids found on section D of the Hueco Basin facies, on sheet 3 of Seager, Kottlowski, and Hawley (1976). George Verville (Amoco Production Company, pers. comm. 1980) has found additional poorly preserved, silicified specimens tentatively identified as *P. texana* at approximately 100 ft above collection 73WS101. The collection locality is in SW 1/4 SW 1/4 sec. 9 T21S R1E.

Pseudoschwagerina texana ultima Dunbar and Skinner
Pl. 3, Figs. 2-3

1937. *Pseudoschwagerina texana* var. *ultima* Dunbar and Skinner, Texas Univ. Bull. 3701, p. 665-666, pl. 53, figs. 6-7, 10.

1954. *Pseudoschwagerina texana* var. *ultima* Thompson, Kansas Univ. Paleont. Contrib., Protozoa, art. 5, p. 74, pl. 50, figs. 8-9.

Description-Specimens of seven to eight volutions measure from 11.95 to 11.60 mm in length and 4.65 to 4.15 mm in diameter for form ratios from 2.6 to 2.8. The shell is very large for the number of volutions and expands more slowly than some specimens of *P. texana.*

The spirotheca is composed of a tectum and coarsely alveolar keriotheca. In the seventh volution the wall thickness varies from 89 to 114 p. Septal fluting is high and prominent in the polar ends, becoming low and irregular in the central part of the shell in outer volutions.

The proloculus of one specimen is 184 p. The tunnel angle of the fifth volution ranges from 24 to 39°. Chomata are present only in inner volutions.

Discussion-Dunbar and Skinner (1937) distinguished *Pseudoschwagerina texana* var. *ultima* from the typical *P. texana* by its somewhat larger size, more slender test proportions, less elevated whorls, and more strongly fluted septa. Williams (1963) named *P. geiseri* for a very similar large elongate form in the Hueco Mountains.

The specimens referred here to *P. texana ultima* (Pl. 3, Figs. 2-3) are somewhat larger than other more typical specimens in our collections (Pl. 3, Figs. 6-12), but they are also somewhat more inflated than the type specimens of *P. texana ultima.* Charles A. Ross (written comm. 1999) has suggested to us that alternatively these specimens might be assignable to *Stewartina,* a genus erected by Wilde (1971) for species morphologically intermediate between typical *Schwagerina* and *Pseudoschwagerina,* and characterized by relatively minor inflation of the adult whorls (as compared to *Pseudoschwagerina texana),* low rounded septal folds, and chomata in the first two-three volutions. Wilde (1971) chose *Pseudofusulina? moranensis* Thompson (1954) as the genotype of *Stewartina,* and also included the genus *Pseudofusulina robleda* Thompson (1954) and *Schwagerina laxissima* Dunbar and Skinner, 1937. Although the present specimens resemble S. *moranensis* is test shape, they have somewhat more tightly coiled inner volutions, more loosely coiled adult volutions, and less well-developed juvenile chomata. As pointed out by Wilde (1971), there are strong morphological similarities between his *Stewartina* and the *Pseudoschwagerina texana* group, but the present specimens seem to fall more within the morphological boundaries of the latter.

Occurrence-Two specimens of *P. texana ultima* were found in the lower Hueco member, collection 74WS38, section L, on Robledo Mountain.

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Plates 1-3

PLATE 1

(All figures x 10)

1-3 *Leptotriticites aff. L. gracilitatus* Skinner and Wilde Axial sections from collection 73WS100, Robledo Mountain.

4-6 *Leptotriticites* sp. A.
Axial sections from collection 73WS97, Robledo Mountain.

7-13 *Schwagerina andresensis* Thompson
Axial sections; 7, 8, 9, from collection 74WS38, Robledo Mountain; 10, 12, from collections 74WS2 and 74WS41, Dona Ana Mountains (12, a poor spiral section, is figured because it is a representative specimen from the Dona Ana Mountains); 11, juvenile specimen from collection 75WS8, section J, Robledo Mountains; 13, from collection 75WS9a, section J, Robledo Mountains.

14-15 *Schwagerina* sp. A.
Axial sections from collections 74WS2 and 41, Dona Ana Mountains.

16-17 *Pseudofusulina robleda* Thompson
Axial sections from collection 73WS96, Robledo Mountain.

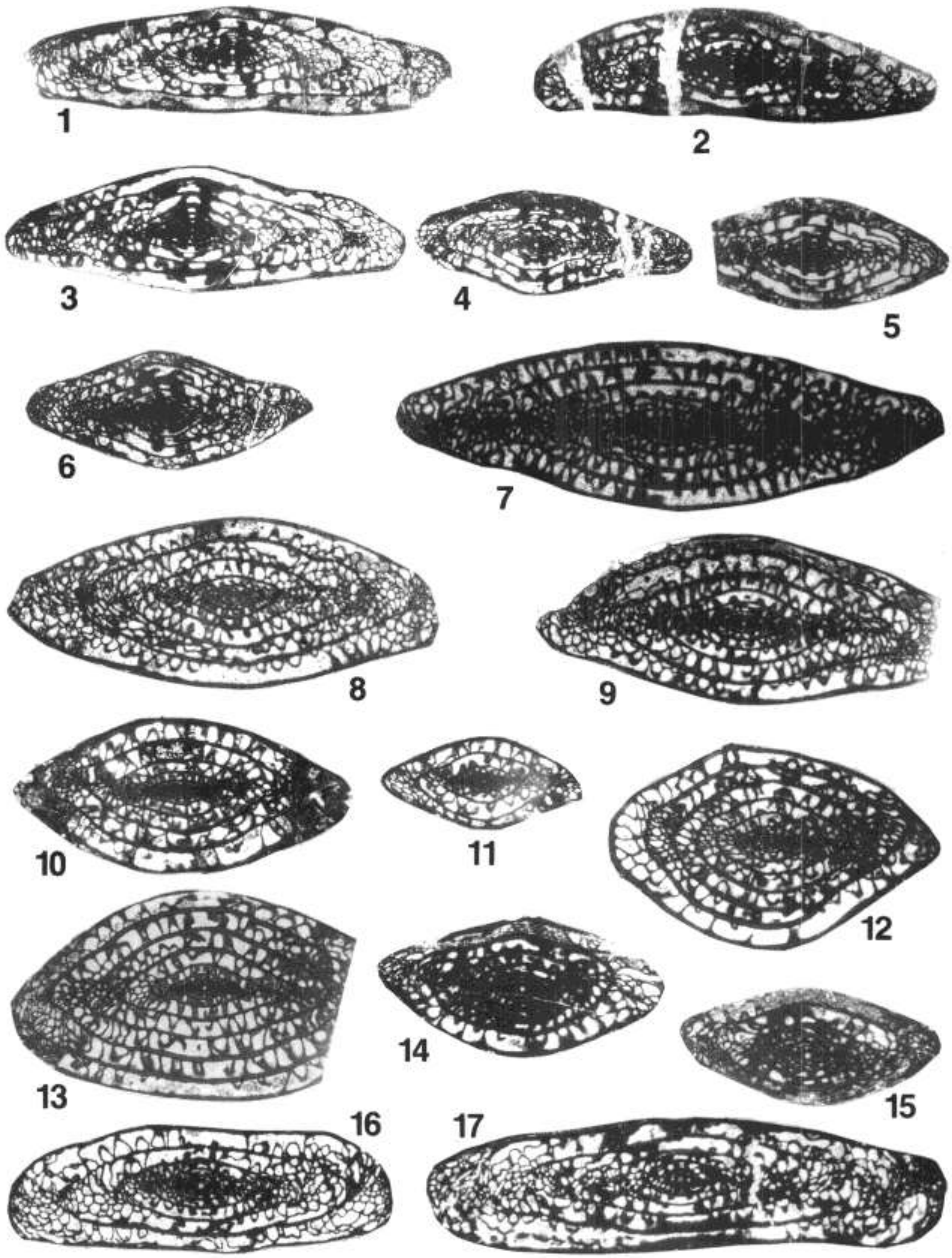
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PLATE 2

(All figures x 10)

1-3 *Pseudofusulina robleda* Thompson
Axial sections from collection 73WS96, Robledo Mountain.

4-15 *Pseudoschwagerina morsei* Needham
Axial sections; 4, from collection 75WS8a, section J, Robledo Mountains; 5, 13, 15, from collection 74WS37, Robledo Mountains; 6, juvenile specimen from collections 74WS2 and 75WS41, Dona Ana Mountains; *7,* 9, from collection 75WS2, Robledo Mountains; 8, from collection 75WS10, section J, Robledo Mountains; 10, 11, 12, from collection 75WS1, southern San Andres Mountains; 14, from collection 75WS101, poorly preserved specimen, Dona Ana Mountains.

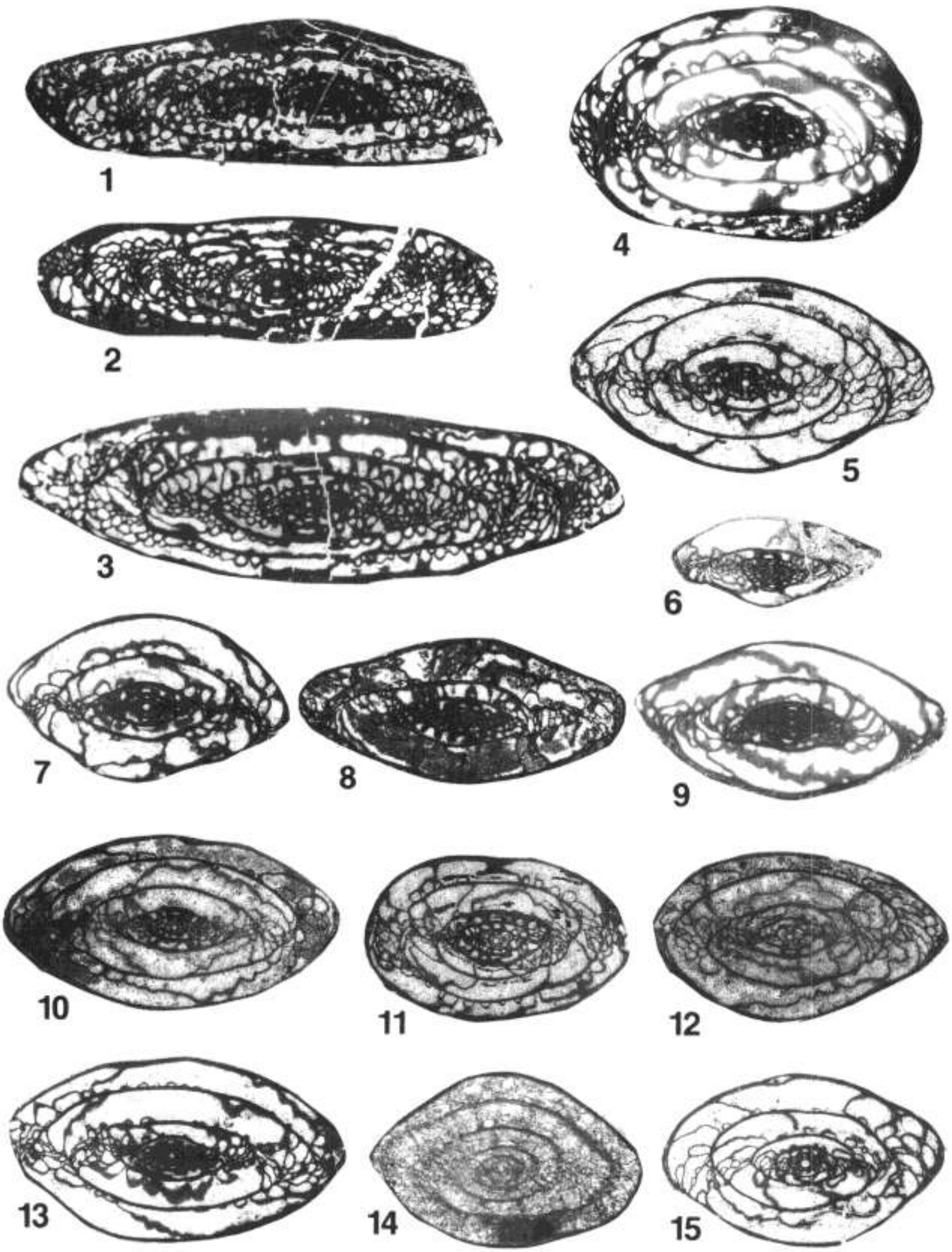
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PLATE 3

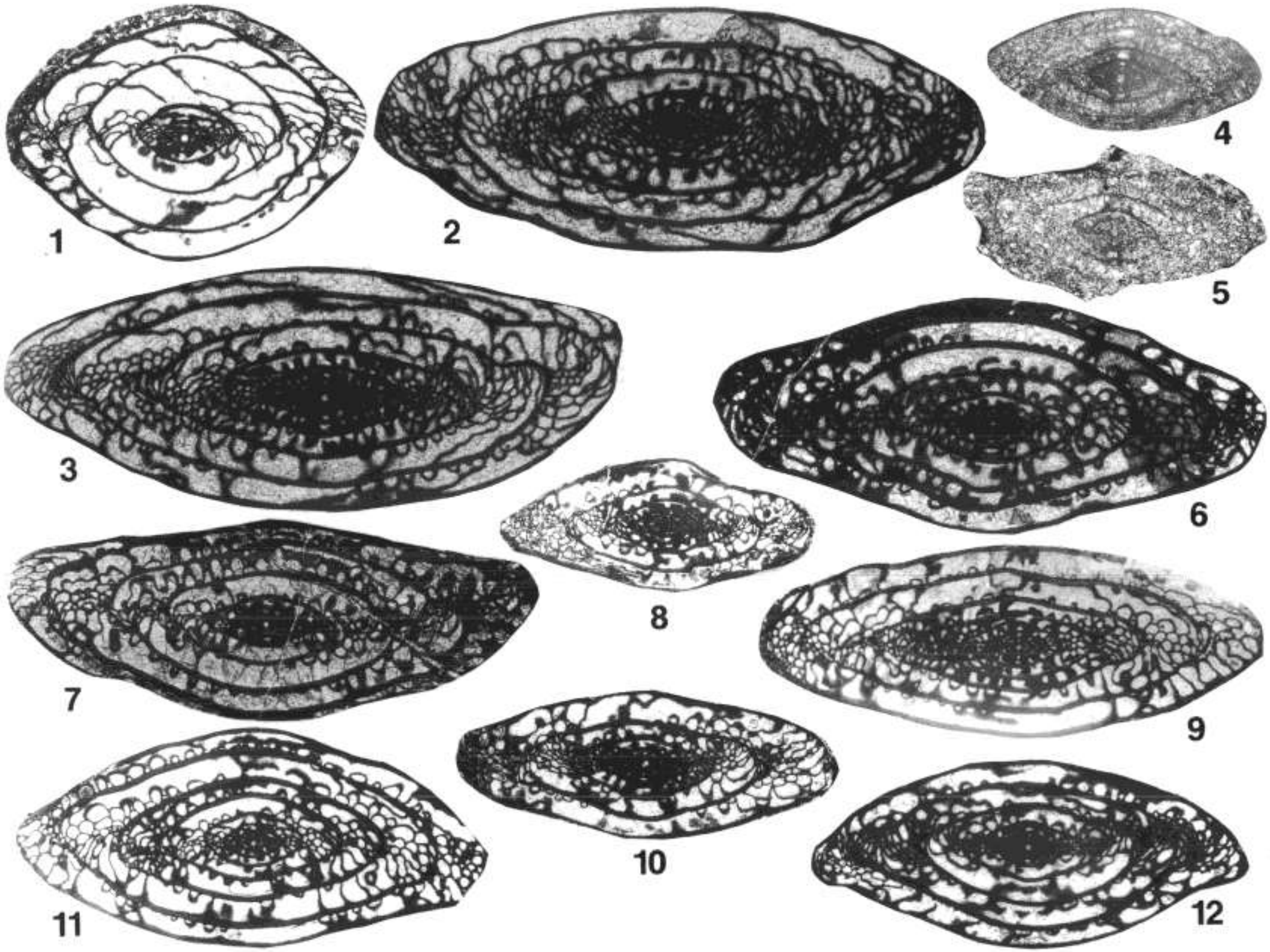
(All figures x 10)

1 *Pseudoschwagerina* cf. *P. uddeni* **(Beede and Knicker)** Axial section from collection 74WS37, Robledo Mountain.

2-3 *Pseudoschwagerina texana ultima* **Dunbar and Skinner**
Axial sections from collection 74WS38, Robledo Mountain.

4-5 *Pseudoschwagerina texana?* **Dunbar and Skinner**
Poorly preserved specimens questionably referred to *P. texana* from collection 73WS101, Doña Ana Mountains.

6-12 *Pseudoschwagerina texana* **Dunbar and Skinner**
Axial sections; 6, 12, from collection 75WS5 from section J, Robledo Mountains; 7, from collection 76WS38, southern San Andres Mountains; 8, juvenile specimen from collection 75WS9, section J, Robledo Mountains; **9, 11,** from collection 75WS4 of section J, Robledo Mountains; **10,** juvenile specimen from collection 74WS39, Robledo Mountain.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Selected conversion factors*

TO CONVERT	MULTIPLY BY	TO OBTAIN
Length		
inches, in	2.540	centimeters, cm
feet, ft	3.048×10^{-1}	meters, m
yards, yds	9.144×10^{-1}	m
statute miles, mi	1.609	kilometers, km
fathoms	1.829	m
angstroms, Å	1.0×10^{-8}	cm
Å	1.0×10^{-4}	micrometers, µm
Area		
in^2	6.452	cm^2
ft^2	9.29×10^{-2}	m^2
yds^2	8.361×10^{-1}	m^2
mi^2	2.590	km^2
acres	4.047×10^{3}	m^2
acres	4.047×10^{-1}	hectares, ha
Volume (wet and dry)		
in^3	1.639×10^{1}	cm^3
ft^3	2.832×10^{-2}	m^3
yds^3	7.646×10^{-1}	m^3
fluid ounces	2.957×10^{-2}	liters, l *or* L
quarts	9.463×10^{-1}	l
U.S. gallons, gal	3.785	l
U.S. gal	3.785×10^{-3}	m^3
acre-ft	1.234×10^{3}	m^3
barrels (oil), bbl	1.589×10^{-1}	m^3
Weight, mass		
ounces avoirdupois, avdp	2.8349×10^{1}	grams, gr
troy ounces, oz	3.1103×10^{1}	gr
pounds, lb	4.536×10^{-1}	kilograms, kg
long tons	1.016	metric tons, mt
short tons	9.078×10^{-1}	mt
oz mt^{-1}	3.43×10^{1}	parts per million, ppm
Velocity		
ft sec^{-1} (= ft/sec)	3.048×10^{-1}	m sec^{-1} (= m/sec)
mi hr^{-1}	1.6093	km hr^{-1}
mi hr^{-1}	4.470×10^{-1}	m sec^{-1}

TO CONVERT	MULTIPLY BY	TO OBTAIN
Pressure, stress		
lb in^{-2} (=lb/in^2), psi	7.03×10^{-2}	kg cm^{-2} (kg/cm^2)
lb in^{-2}	6.804×10^{-2}	atmospheres, atm
lb in^{-2}	6.895×10^{3}	newtons (N)/m^2, N m^{-2}
atm	1.0333	kg cm^{-2}
atm	7.6×10^{2}	mm of Hg (at 0°C)
inches of Hg (at 0°C)	3.453×10^{-2}	kg cm^{-2}
bars, b	1.020	kg cm^{-2}
b	1.0×10^{6}	dynes cm^{-2}
b	9.869×10^{-1}	atm
b	1.0×10^{-1}	megapascals, MPa
Density		
lb in^{-3} (= lb/in^3)	2.768×10^{1}	gr cm^{-3} (= gr/cm^3)
Viscosity		
poises	1.0	gr cm^{-1} sec^{-1} *or* dynes cm^{-2}
Discharge		
U.S. gal min^{-1}, gpm	6.308×10^{-2}	l sec^{-1}
gpm	6.308×10^{-5}	m^3 sec^{-1}
ft^3 sec^{-1}	2.832×10^{-2}	m^3 sec^{-1}
Hydraulic conductivity		
U.S. gal day^{-1} ft^{-2}	4.720×10^{-7}	m sec^{-1}
Permeability		
darcies	9.870×10^{-13}	m^2
Transmissivity		
U.S. gal day^{-1} ft^{-1}	1.438×10^{-7}	$m^2 sec^{-1}$
U.S. gal min^{-1} ft^{-1}	2.072×10^{-1}	l sec^{-1} m^{-1}
Magnetic field intensity		
gausses	1.0×10^{5}	gammas
Energy, heat		
British thermal units BTU	2.52×10^{2}	calories, cal
BTU	1.0758×10^{2}	kilogram-meters, kgm
BTU lb^{-1}	5.56×10^{-1}	cal kg^{-1}
Temperature		
°C + 273	1.0	°K (Kelvin)
°C + 17.78	1.8	°F (Fahrenheit)
°F - 32	5/9	°C (Celsius)

**Divide by* the factor number to reverse conversions.
Exponents: for example 4.047×10^{3} (see acres) = 4,047; 9.29×10^{-2} (see ft^2) = 0.0929

Colophon

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