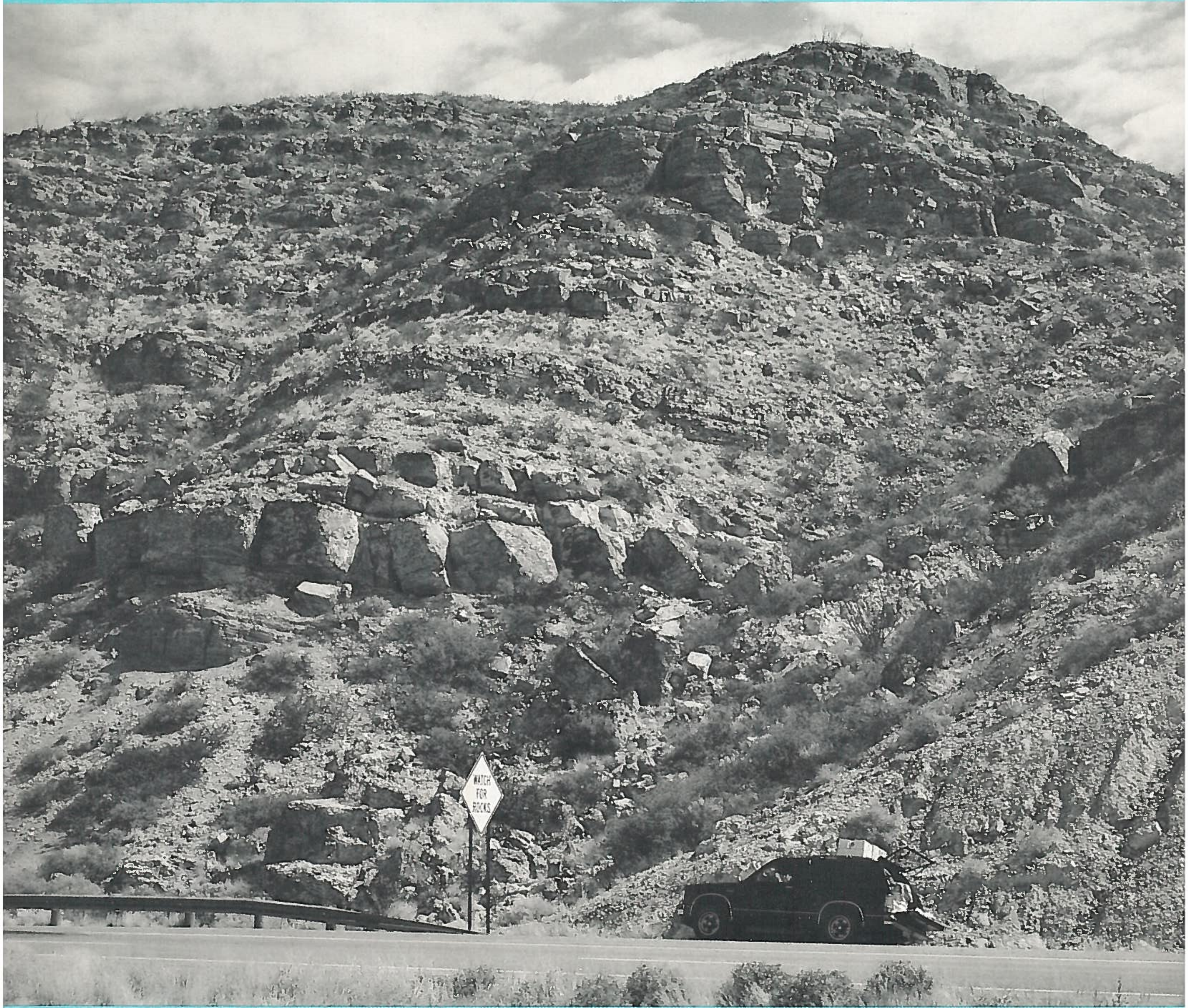
Lower and Middle Pennsylvanian fusulinid biostratigraphy of southern New Mexico and westernmost Texas

William W. Clopine



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Abstract—This paper summarizes biostratigraphic and lithostratigraphic analyses of Lower and Middle Pennsylvanian strata in southern New Mexico and westernmost Texas. Fusulinid foraminifera offer the best means of subdivision and biostratigraphic correlation within this interval. Nineteen species in seven genera are documented. One new species, *Profusulinella thompsoni,* is described. Eight biozones are correlated across the study area: the Zone of *Millerella,* the Zone of *Eoschubertella,* the *Profusulinella copiosa* Range Zone, the *Profusulinella munda* Range Zone, the *Fusulinella acuminata* Lineage Zone, the *Profusulinella thompsoni* Range Zone, the *Fusulinella devexa* Interval Zone, and the Zone of *Beedeina* (partial). The first occurrence of *Wedekindellina* is also an important biostratigraphic horizon.

Morrowan, Atokan, and early Desmoinesian sediments in the study area represent carbonate-shelf deposits. Shallow subtidal facies are dominant, but limited intertidal and supratidal deposits also occur. Fusulinid foraminifera occur in most carbonate lithologies, but are most abundant and best preserved in shallow subtidal biomicrite–wackestone, the dominant carbonate lithology encountered.

Morrowan strata in the study area do not extend northward beyond the center of the Robledo Shelf. Earliest Morrowan deposits are restricted to the center of the Orogrande Basin. Morrowan strata thin rapidly to the northwest due to basal onlap above the pre-Pennsylvanian unconformity. Atokan and early Desmoinesian sediments (upper range of study) extend across the Robledo Shelf. The significant thickness variations in these strata across the study area reflect the lower subsidence rate of the Robledo Shelf relative to the Orogrande and San Mateo Basins during Atokan and early Desmoinesian time.

Regional correlations indicate that the lower 0.95 m of the "Derryan Series" type section overlaps the Morrowan Series. However, fusulinid faunas from the remainder of the Derryan type section correlate closely with Atokan faunas from the midcontinent. The upper boundary of the Derryan type section falls just below the first occurrence of *Beedeina* and corresponds with most authors' concept of the Atokan/Desmoinesian Series boundary.

Introduction

The Atokan Series (lower Middle Pennsylvanian System), as used in the midcontinent, and the Derryan Series, as defined in south-central New Mexico, include approximately the same stratigraphic interval. Recent workers (e.g. Webster & Langenheim, 1984), however, have abandoned the term Derryan in favor of Atokan. The Atokan Series remains a controversial chronostratigraphic subdivision due in part to its lack of an adequate type section (Sutherland & Manger, 1984a; Myers, 1988). This paper provides biostratigraphic and lithostratigraphic analyses of Lower and Middle Pennsylvanian strata in southern New Mexico and westernmost Texas, which form a highly fossiliferous sequence of dominantly carbonate rocks. This sequence represents essentially continuous Morro-wan through Desmoinesian deposition. These analyses were undertaken in order to better establish the relationships between Pennsylvanian chronostratigraphic units that are in current use but are not adequately defined.

Acknowledgments

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Location of study area

The study area is located in south-central New Mexico and westernmost Texas (Fig. 1). Four sections have been measured within the study area along a roughly linear northwest—southeast trend stretching approximately 160 km (100 mi). Pennsylvanian strata crop out along this trend in a series of discontinuous fault-block mountains.

Measured section (MS) 1 is located in the northern Franklin Mountains, El Paso County, Texas. MS 2 is located on the northwest slope of Pyramid Peak at Bishop Cap in Doña Ana County, New Mexico. MS's 3 and 4 are located in Sierra County, New Mexico.

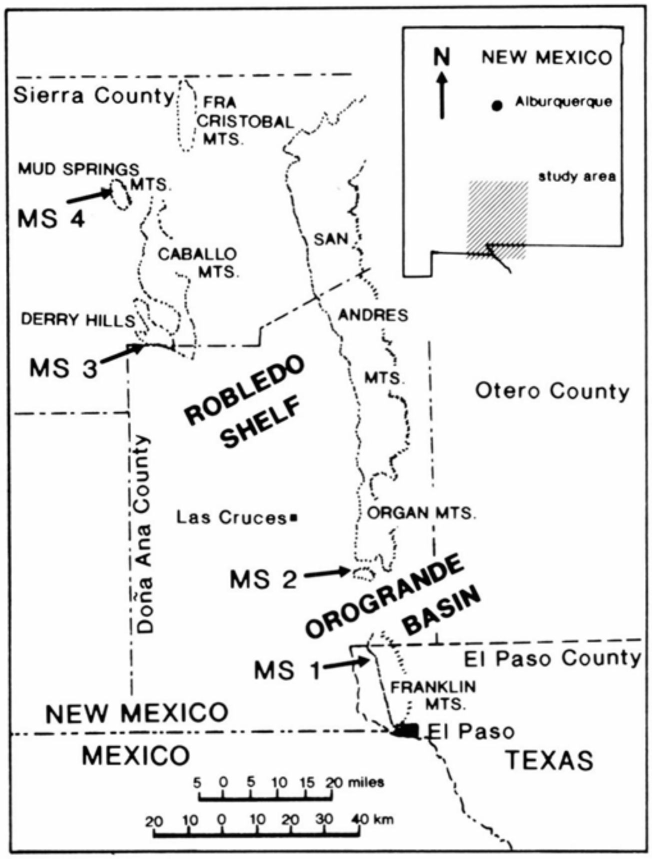

FIGURE 1—Index map of measured sections. MS 1: Vinton Canyon, northern Franklin Mountains. MS 2: Bishop Cap, southern Organ Mountains. MS 3: type Derryan, Derry Hills, southern Caballo Mountains. MS 4: Whiskey Canyon, northern Mud Springs Mountains. Modified from Kottlowski (1960).

MS 3 is on the southwest slope of the Derry Hills at the southwest end of the Caballo Mountains, and MS 4 is at Whiskey Canyon in the northern Mud Springs Mountains. See Clopine (1990, 1991) for specific locality information and detailed descriptions of the measured sections.

Previous investigations

Many previous authors have contributed to the nomenclature and understanding of Pennsylvanian lithostratigraphy and biostratigraphy in southern New Mexico and westernmost Texas. Gordon (1907) proposed the term Magdalena Group for Pennsylvanian exposures in the Magdalena mining district of **Socorro** County, New Mexico. The Magdalena Group includes all sedimentary rocks in central New Mexico above the Mississippian System and below the base of the Permian System. Gordon (1907) divided the Magdalena Group into a lower clastic unit, the Sandia Formation, and an upper carbonate unit, the Madera Limestone (Fig. 2). Later workers commonly divided the Madera Limestone into a lower carbonate member and an upper, more arenaceous carbonate member. This general pattern of a three-fold lithologic division remains even today the basis for much of New Mexico's Pennsylvanian lithostratigraphic nomenclature. Most workers, however, have used stratigraphic names of local significance, as regional lithologic correlations are generally difficult due to abrupt facies changes over short distances.

Needham (1937) included the entire Pennsylvanian System in the Magdalena Formation. He (1937: 14) recognized that near the Rio Grande in central New Mexico the Magdalena had been divided into the Sandia Formation below and the Madera Formation above, but he rejected this division as inconsistent and unrecognizable in many parts of the state. Needham (1937) also provided the first account of fusulinids in New Mexico. He described and illustrated specimens from 26 localities across the state, three of which (nos. 16, 17, and 18) fall within the current study area but cannot be precisely located.

In southern New Mexico and westernmost Texas the clastic lithology described farther north is replaced with a carbonate-dominated sequence. Nelson (1940: 166-167) subdivided the lower portion of the Magdalena Formation in the northern Franklin Mountains into three members. The 110 m (361 ft) thick basal Pennsylvanian unit termed the La Tuna Member is overlain by the 169 m (555 ft) thick Berino Member, which in turn is overlain by the 189 m (619 ft) thick Bishop Cap Member. Although Nelson stated that these members were employed for convenience only and offered no criteria for differentiating these units, several later workers have used Nelson's informal units as members or formations (Seager, 1973; Lane, 1974; Lane et al., 1972; Harbour, 1958; Thompson, 1948).

Thompson (1942a) rejected all previous classifications of Pennsylvanian strata in central and southern New Mexico due to the lack of adequately described boundaries between most lithologic units. He proposed an entirely new system for lithostratigraphic classification based on measured sections mainly in the Mud Springs Mountains and the Derry Hills of Sierra County, New Mexico. One new series (the "Derryan Series"), eight groups, fifteen formations, and one new member were proposed.

Unfortunately, the type sections for many of Thompson's units were not well defined. Upper and lower boundaries were not well described, and many of the units are difficult or impossible to map. Kelley & Silver (1952) argued that Thompson's "groups" and "formations" are based on field and laboratory examination of fusulinids and thus are faunal zones, not lithostratigraphic units. Kottlowski (1960: 21) disagreed with Kelley & Silver (1952), stating that Thompson's (1942a) proposed formations are recognizable on lithology alone in areas near their type localities. Kottlowski (1960) further stated that some of Thompson's formations retain their distinctive lithologic character for long distances, and he claimed some success in mapping these units. However, Kottlowski (1960: 21) recognized that many of Thompson's formations change markedly in lithology away from the type localities and can be traced only with the help of detailed fusulinid studies.

Gehrig (1958: 6) also disagreed with Kelley & Silver's (1952) criticisms, arguing that Thompson's formations within the Derryan (Atokan) and Desmoinesian

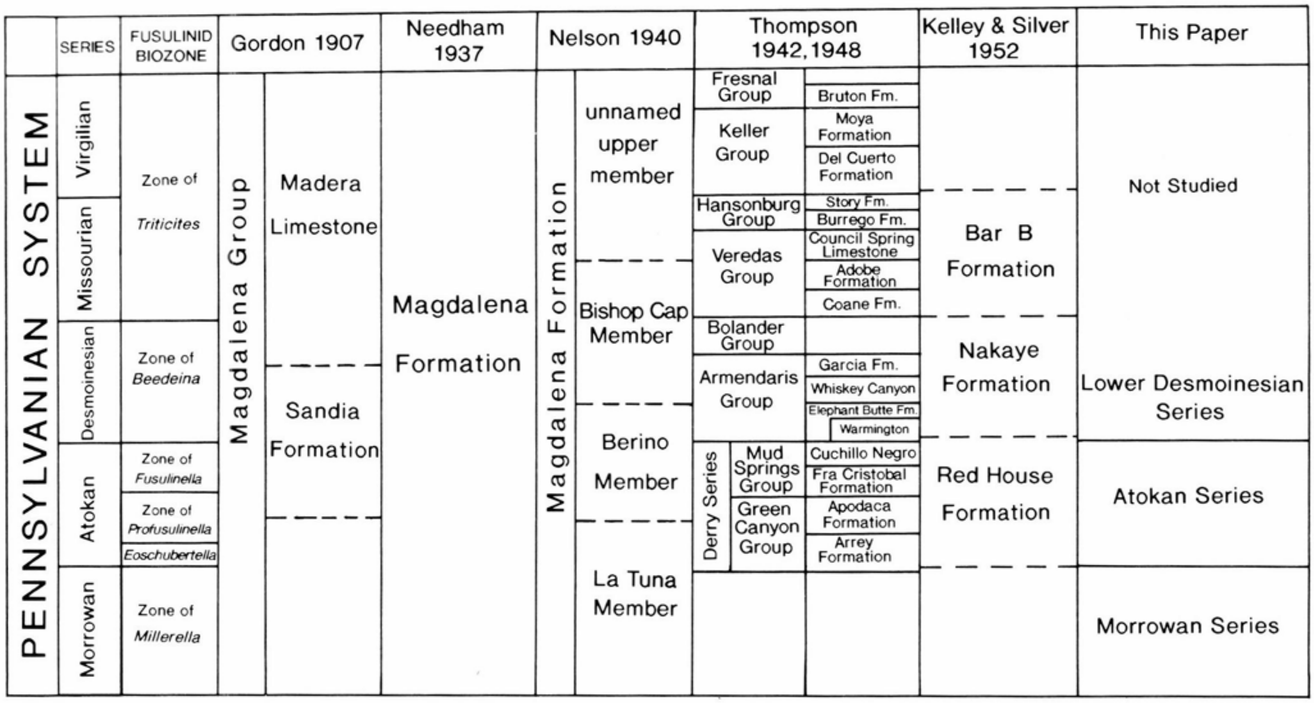

FIGURE 2—Lithostratigraphic subdivisions used by several authors in central and south-central New Mexico and westernmost Texas, with approximate chronostratigraphic and biostratigraphic correlations.

Series could be recognized as lithic units and that they had priority throughout the area. Gehrig (1958) described brachiopod assemblages, which together with the distinctive fusulinid assemblages determined by Thompson (1948) provide biostratigraphic information and increase the usefulness of the lithic unit.

Thompson's (1942a) "groups" and "formations" gained some limited acceptance (King, 1973; Gehrig, 1958), but they have been rejected not only by Kelley & Silver (1952) but also by most other subsequent workers. None of the subdivisions proposed by Thompson (1942a) are currently utilized by the New Mexico Bureau of Mines & Mineral Resources (Sutherland & Manger, 1984a).

Kelly & Silver (1952) proposed three new formation names for Pennsylvanian rocks in the Caballo Mountains to replace the subdivisions proposed by Thompson (1942a). These are (ascending) the Red House, the Nakaye, and the Bar B. No faunal evidence was used for Kelley & Silver's formations, so unlike Thompson's "formations" they are true lithostratigraphic units. However, the contacts between these formations are poorly defined, and they too may be unmappable.

Revision of the lithostratigraphic nomenclature in southern New Mexico is beyond the scope of this study. Rather than proposing new lithostratigraphic names or attempting to use poorly defined or inappropriate subdivisions of previous authors, I have used fusulinid foraminifera as a basis for subdividing the strata in the area into Morrowan, Atokan, and lower Desmoinesian Series. The boundaries between these chronostratigraphic subdivisions are also somewhat controversial, but they are better defined than the lithostratigraphic subdivisions in the study area. A summary correlation of stratigraphic nomenclature for southern New Mexico, showing approximate chronostratigraphic equivalents, is provided in Fig. 2.

The "Derryan" Series was Thompson's (1942a) only subdivision to gain some regional acceptance. As originally defined (Thompson, 1942a: 26-27), the Derryan Series included all Pennsylvanian strata in south-central New Mexico below the base of the Desmoinesian Series. The Derryan was named for the village of Derry in Sierra County. The type locality is on the steep west slope of the Derry Hills (MS 3 of this study). Thompson (1942a) stated that the Derryan Series type section included species of *Millerella*, *Eoschubertella*, *Profusulinella*, and *Fusulinella.* No mention of the relationship of the basal Derryan to the Morrowan Series was made, but, as originally defined, the Derryan Series significantly overlaps Morrowan strata in southern New Mexico.

Thompson (1948) redefined the Derryan Series to include all rocks of post-Morrowan and pre-Desmoinesian age in south-central New Mexico. This correlation excluded the Morrowan "La Tuna Limestone" of Nelson (1940) from the Derryan, although the Derryan type section remained unchanged. Thompson (1948: 68) further stated that the Derryan may be almost the exact equivalent of the Atokan Series as proposed by Spivey & Roberts (1946).

Sutherland & Manger (1984b) and Sutherland (1991), on close examination of a new roadcut exposure immediately adjacent to the original type section, identified a well preserved late Morrowan brachiopod fauna from basal Derryan beds, indicating overlap of type Derryan strata with the Morrowan Series.

Spivey & Roberts (1946) proposed the name Atokan to denote a post-Morrowan and pre-Desmoinesian interval in southeastern Oklahoma, represented by *post-Millerella* and *pre-Fusulina—Wedekindellina* fusulinids. They rejected the term Derryan because at its type locality it "is only about 130 feet thick, whereas the Atoka beds reach 7,000 feet in thickness" (Spivey & Roberts, 1946: 186). The Atokan Series has gained widespread acceptance in the literature despite the fact that no type section was proposed, its base is unconformable in the type area, and later workers (Douglass & Nestell, 1984) identified *Beedeina* within "Atokan" strata. Sutherland & Manger (1984a) proposed that the first appearance of the conodont *Diplognathodus* and the foraminifer *Eoschubertella* be taken to mark the base of the Atokan Series, and noted that the appearance of *Fusulina* had been taken to mark the base of the Desmoinesian Series. This working definition of the Atokan Series coincides with that used by most authors, and it is followed in this study.

Only a few fusulinid studies have been done in New Mexico since Thompson (1948). Van Sant (1954) studied fusulinids from Whiskey Canyon (MS 4), but Atokan faunas were not discussed in detail. Kottlowski & Stewart (1970) and Stewart (1970) provide biostratigraphic and taxonomic data on fusulinids from the Joyita Hills in Socorro County, New Mexico. Lane et al. (1972) provided limited fusulinid and conodont data from the Derryan type section. King (1973) discussed Morrowan and Atokan strata in his study of *Millerella* and *Eostaffela* from southern New Mexico and the Marble Falls section in Burnet County, Texas. Verville et al. (1986) studied Pennsylvanian fusulinids from the Fra Cristobal Range, Sierra County, New Mexico, where the Atokan Series is restricted to 10 m of upper Atokan strata. Myers (1988) described the stratigraphic distribution of fusulinid foraminifera in the Manzano Mountains of central New Mexico.

A number of authors (e.g. Verville & Sanderson, 1988; Douglass & Nestell, 1984; Ross & Sabins, 1965) referred to the New Mexico faunas in their studies of fusulinids from the midcontinent and the western United States. Many of these studies are discussed later in this report.

Biostratigraphic analysis

Zone of *Millerella*

The Zone of *Millerella* was designated by Thompson (1945: 40) as the lowermost Pennsylvanian fusulinid zone. Thompson (1945: 40) pointed out that species of *Millerella* (now *Millerella* and *Eostaffella)* predominate "in rocks of Morrowan age almost to the exclusion of other fusulinids." Thompson (1945, 1948) distinguished the Zone of *Millerella* by the occurrence of *Millerella* (and *Eostaffella)* below the first occurrence of commonly associated more advanced forms such as *Profusulinella*.

Thompson (1948: 22) noted the occurrence of *Eoschubertella* and *Pseudostaffella* below the first occurrence of *Profusulinella*, but he did not give this zonal significance. These forms were included within the upper portion of the Zone of *Millerella* (presumably *Eoschubertella* and *Pseudostaffella* are the "other" fusulinids which Thompson, 1945: 40, recognized within the Zone of *Millerella).* Mamet & Skipp (1970: 338) defined the interval that includes *Millerella* in association with *Eoschubertella* and *Pseudostaffella* as Faunal Zone 21, which they regarded as Atokan in age. Thompson (cited by Lane et al., 1972: 533) considered faunas containing *Eoschubertella* and *Pseudostaffella* below the first *Profusulinella* to be Atokan (Derryan) in age, but he continued to assign this interval to the Zone of *Millerella.* Groves (1986, 1991) followed this usage, assigning Mamet & Skipp's (1970) Zone 21 to the lower Atokan but including this interval in the upper portion of the Zone of *Millerella.*

For the purpose of this paper, the Zone of *Millerella* is modified from Thompson (1945, 1948) to range from the first occurrence of *Millerella* and/or *Eostaffella* (base of the Pennsylvanian System in the study area) to the first occurrence of *Eoschubertella* and/or *Pseudostaffella* (i.e. the widely accepted Morrowan Series boundary markers). The occurrence of *Eoschubertella* and/or *Pseudostaffella* below the first occurrence of *Profusulinella* (Mamet & Skipp, 1970, Faunal Zone 21) is informally termed the Zone of *Eoschubertella.* The reader is referred to the following section for a discussion of the Zone of *Eoschubertella.*

Groves (1986) indicated that at present there is no reliable foraminiferal basis for subdivision of the Morrowan. Groves (1983, 1984a, 1984b) suggested that, with further investigation, the appearances of *Hemigordius harltoni* Cushman & Waters, *Eostaffella?* sp. A, and *Millerella extensa* Marshal may prove diagnostic of the upper Morrowan. *Hemigordium harltoni* has not been identified within the study interval. Species-level identification and stratigraphic evaluation of *Millerella* and *Eostaffella* are beyond the scope of this paper. King (1973), however, reported *Millerella extensa* (as *M. extensus)* from several units at the type Derryan section.

The zone of *Millerella* occurs in three of the four studied measured sections (Fig. 3). It reaches maximum thickness at Vinton Canyon where it includes 75 m (246 ft) of Morrowan strata. *Millerella* and *Eostaffella* are abundant in many horizons of this interval. The base of the zone falls at the contact between Morrowan strata and the Mississippian Helms Formation. Conodont evidence (Lane, 1974) suggests that this contact is conformable or nearly conformable.

The upper datum of the Zone of *Millerella* at Vinton Canyon falls within a carbonate sequence with no apparent lithologic breaks. Northward, at Bishop Cap, the Zone of *Millerella* is reduced to 44 m (143 ft). This is a thickness loss of more than 40% over 25 km (15.5 mi). The base of the Zone of *Millerella* at Bishop Cap also falls at the contact between Morrowan strata and the Mississippian Helms Formation. In addition, as at Vinton Canyon, at Bishop Cap the upper datum of the Zone of *Millerella* falls within a carbonate sequence with no apparent lithologic breaks.

Conodont information is not currently available for the Bishop Cap sequence, but most, if not all, of the thickness reduction of Morrowan strata from Vinton Canyon to Bishop Cap is due to loss of lower Morrowan strata at the basal Pennsylvanian unconformity. The occurrence of the colonial rugose coral *Petalaxis 7* m (23 ft) below the upper datum of the Zone of *Millerella* at Bishop Cap supports this interpretation. *Petalaxis is* a consistent upper Morrowan

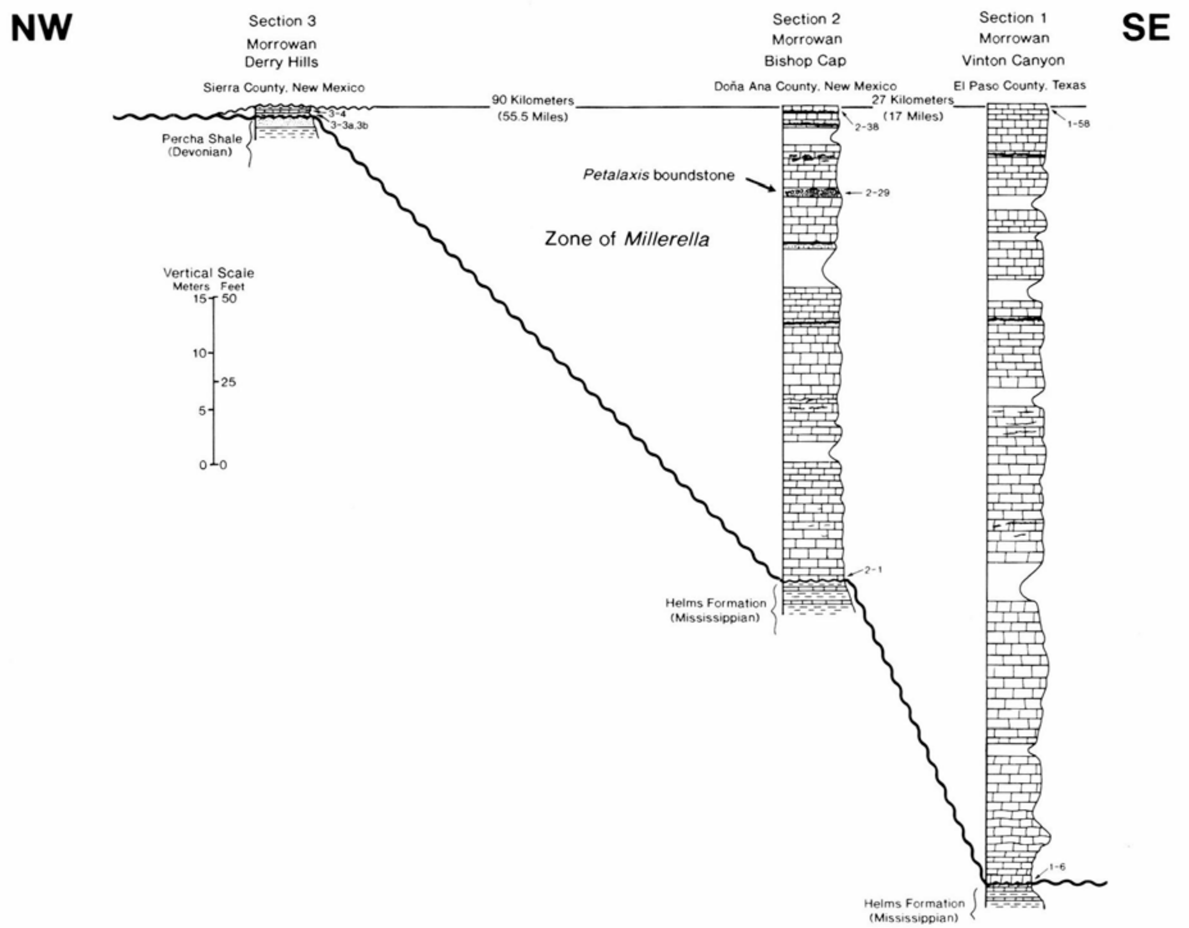

FIGURE 3—Zone of *Millerella* correlations across the study area. Datum is the lowest documented occurrence of *Eoschubertella*.

marker at all known occurrences in the southern midcontinent (Sutherland, 1985). If the dramatic change in thickness of Morrowan strata from Vinton Canyon to Bishop Cap was due to truncation at an unconformity at the Morrowan/Atokan boundary, the observed *Petalaxis* occurrence might not have been preserved. Northwest of Bishop Cap the Zone of *Millerella* is greatly reduced or absent. At the type Derryan section the Zone of *Millerella* is reduced to less than 1 m (3.2 ft). Here the Morrowan strata rest on the Devonian Percha Shale. *Millerella* and *Eostaffella* occur in carbonate wackestone in the absence of more advanced forms 0.5 m (1.6 ft) above the base of the Pennsylvanian System. The upper limit of the Zone of *Millerella* is interpreted to fall at an unconformity marking the Morrowan/Atokan boundary. This unconformity, while significant, is much less pronounced than the basal Pennsylvanian unconformity.

Lithologic evidence for the Morrowan/Atokan boundary unconformity can be observed in a fresh outcrop at the type Derryan section (Manger et al., 1987), but loss of section and/or truncation at this unconformity is minor. Morrowan strata at this locality contain an upper Morrowan brachiopod fauna (Sutherland, 1991) as well as *Millerella extensa* (suggested as an upper Morrowan indicator by Groves, 1986). Thus, as at Bishop Cap, at the type Derryan section most or all of the reduction in thickness of the Zone of *Millerella* is due to loss of lower Morrowan strata at the basal Pennsylvanian regional unconformity. The magnitude of this unconformity increases northward and, as a result, the Zone of *Millerella* does not occur in the Mud Springs Mountains at the northern margin of the study area.

Zone of ***Eoschubertella***

The Zone of *Eoschubertella* is proposed here as an equivalent to Mamet & Skipp's (1970: 338) Faunal Zone 21 as used in the midcontinent and western United States. Zone 21 is defined (Mamet & Skipp, 1970: 338; Mamet & Armstrong, 1972: 135; Mamet, 1975: 6) by the "outburst" of *Eoschubertella* and *Pseudostaffella,* as well as by an increased abundance of diaphanotheca-bearing *Globivalvulina.* It ranges upward to the first occurrence of *Profusulinella.* Globivalvulinids have not been considered in this study; consequently, the Zone of *Eoschubertella* is recognized in practice by the occurrence of *Eoschubertella* and/or *Pseudostaffella* below appearance of *Profusulinella.*

Mamet & Skipp (1970), Mamet (1975), Sutherland & Manger (1983), Groves (1986), and others have included this zone in the lower Atokan Series. Groves (1986: 347) pointed out that this usage results in a widely practicable threefold fusulinacean subdivision of the Atokan. Application of the Zone of *Eoschubertella,* however, can be problematical.

Groves (1986: 348) noted that (1) the origins of *Eoschubertella* and *Pseudostaffella* are poorly understood, and (2) there is evidence suggesting that the level of appearance of *Pseudostaffella* may be younger in the midcontinent and western North America than in portions of the Arctic and Eurasia. While these problems are important on a global scale, they do not appear significant for intrabasinal or regional correlations across the midcontinent and western North America.

The most significant problem encountered in recognition and use of the Zone of *Eoschubertella* in this area is the rarity of both *Eoschubertella* and *Pseudostaffella.* In many cases the first occurrence (base of the zone) is recognized by the identification of only one or two specimens. For this reason, the oldest identified occurrences of *Eoschubertella* and/or *Pseudostaffella* may not represent the true first occurrences. This is especially true at Bishop Cap where the thickness of this zone is reduced to less than 1 m.

The Zone of *Eoschubertella* is recognized at each of the four sections included in this study (Fig. 4). *Eoschubertella* sp. first occurs 75 m (246 ft) above the base of the Pennsylvanian System at Vinton Canyon (unit 1-58). Rare *Eoschubertella* sp. occurs throughout the zone, which is 3.75 m (12 ft) thick at this section. *Eoschubertella(?)* first occurs 44 m (143 ft) above the base of the Pennsylvanian at Bishop Cap (unit 2-38). *Profusulinella copiosa* occurs only 0.75 m (2.5 ft) above this level.

The base of the Atokan Series at the type Derryan section falls at a minor unconformity within a poorly fossiliferous shale interval (between units 3A and 3B). *Eoschubertella(?)* first occurs 0.25 m (0.8 ft) above this unconformity and 1.2 m (3.9 ft) above the base of the Pennsylvanian (unit 3-5). Rare unequivocal *Eoschubertella* first occurs 1.2 m (3.9 ft) higher in the section (unit 3-7). *Eoschubertella mexicana* becomes somewhat more abundant and occurs with *Pseudoendothyra* sp. slightly higher in the type Derryan section (unit 3-8).

The thickness of the Zone of *Eoschubertella* at the type Derryan section has been a matter of some disagreement. Thompson (1942a: 33) reported *Profusulinella* in the "Arrey Formation" at the type Derryan section 5 m (16.5 ft) above the base of the Pennsylvanian System (unit 3 of Thompson, 1942a; unit 3-10 of this study). Thompson (1948: 82) altered his earlier interpretation, stating that further study seemed to indicate that specimens from his unit 3, formerly referred to as *Profusulinella*, may be a primitive form of *Eoschubertella.* Thompson's latter view, fully supported by data from my research, has apparently not been noted by other workers. Lane et al. (1972: 553) reported *Profusulinella* 4.5 m (15 ft) above the base of the type Derryan section (same as Thompson's, 1942a, lowest *"Profusulinella"* horizon). These specimens have been re-examined by George Verville (pers. comm. 1989), who concluded that they should be assigned to *Eoschubertella.* King (1973: 2) reported *Profusulinella* in bed 2 of Thompson (1942a; unit 3-7 of this study). In addition, King (1973: 2) suggested from "unidentifiable fragments" that the lower *Profusulinella* occurrence may be in Thompson's bed 1. King's material is no longer available for study, but he now believes that those specimens were probably *Eoschubertella* (William King, pers. comm. 1989).

The lowest documented occurrence of *Profusulinella*

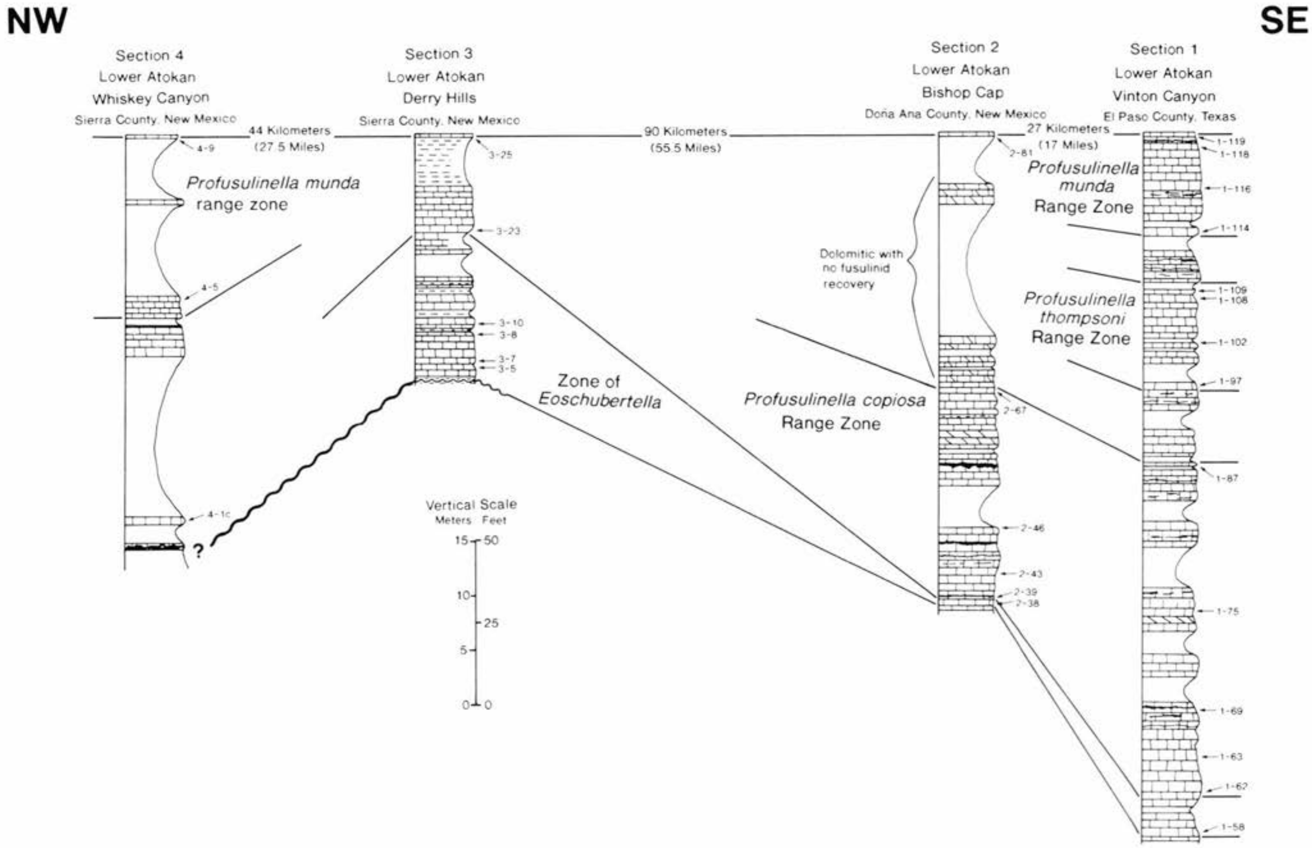

FIGURE 4—Zone of *Eoschubertella* and Zone of *Profusulinella* correlations across the study area. Datum is the lowest documented occurrence of *Fusulinella.*

at the type Derryan section is in a previously unreported horizon (base of unit 3-23; unit 10 of Thompson, 1942a) 13.4 m (44 ft) above the base of *Eoschubertella(?)* and 13.65 m (44.8 ft) above the lowest Atokan strata. This interval includes all of the "Arrey Formation" and the lower 2.7 m (9 ft) of the "Apodaca Formation" of Thompson (1942a).

Pseudostaffella occurs with *Eoschubertella* 2.25 m (7.4 ft) above the lowest exposed Pennsylvanian strata at Whiskey Canyon (unit 4-1c). Strata below this occurrence are poorly exposed, cherry, and sparsely fossiliferous. They have been assigned to the Atokan Series based on regional stratigraphic relationships, but this has not been confirmed biostratigraphically.

Profusulinella munda occurs 18.1 m (59.4 ft) above the lowest *Eoschubertella* and *Pseudostaffella* and 20.4 m (66.8 ft) above the lowest presumed Atokan strata at Whiskey Canyon. *Profusulinella munda* is more advanced than species commonly found at the base of the Zone of *Profusulinella.* The apparent marked increase in the thickness of the Zone of *Eoschubertella* northward may only reflect poor recovery or environmental controls on fusulinid occurrence. Thompson (1942a, 1948) did not include strata from the Zone of *Eoschubertella* in his discussion of the Whiskey Canyon section.

Zone of *Profusulinella*

The Zone of *Profusulinella* was designated by Thompson (1945: 40-41) as the lower and middle "Derryan" (Atokan) fusulinid zone. It is bounded below and above by the first occurrences of *Profusulinella* and *Fusulinella,* respectively, and falls between the Zones of *Eoschubertella* and *Fusulinella.* The Zone of *Profusulinella* has gained widespread acceptance as the middle Atokan fusulinid biozone.

Three subzones have been recognized within the Zone of *Profusulinella* in the study area (Fig. 4). These are (ascending) the *Profusulinella copiosa* Range Zone, the *Profusulinella thompsoni* Range Zone, and the *Profusulinella munda* Range Zone. Each of these subzones occurs at Vinton Canyon, but *Profusulinella* occurrences are more limited northward.

The Zone of *Profusulinella* is 61.5 m (202 ft) thick at Vinton Canyon. *Profusulinella copiosa* first occurs in unit 1-62 and ranges through unit 1-87. This subzone is 31.2 m (102.4 ft) thick. Rare *Profusulinella* cf. *fittsi* occurs with *P. copiosa* at the base of the zone. *Profusulinella thompsoni* n. sp. first occurs in unit 1-97, 6.8 m (22.3 ft) above the highest *P. copiosa,* and ranges through unit 1-109. The *P. thompsoni* Range Zone is 9.3 m (30.5 ft) thick at this section. *Profusulinella munda* first occurs in unit 1-114, 5.05 m (16.5 ft) above the highest *P. thompsoni,* and ranges through unit 1-118. The *P. munda* Range Zone is 9.1 m (29.9 ft) thick and includes occurrences of *Profusulinella decora* at Vinton Canyon.

The Zone of *Profusulinella* is 41.6 m (136.5 ft) thick at Bishop Cap. Here *P. copiosa* first occurs in unit 239 where it is associated with *P.* cf. *fittsi.* The upper limit of the *P. copiosa* Range Zone, and the remaining *Profusulinella* subzones, cannot be recognized at this section due to unfavorable lithologies that are barren of fusulinids.

The Zone of *Profusulinella* is approximately 8.5 m (27.9 ft) thick at the type Derryan section. *P. copiosa* has not been recovered here or at the Whiskey Canyon section. However, a single horizon yielding rare *P.* cf. *fittsi* (base of unit 3-23) occurs at the type Derryan section. This horizon is tentatively correlated with the lower portion of the *Profusulinella copiosa* Range Zone based on *P. fittsi* occurrences at MS 3 and MS 4. No other *Profusulinella* has been recovered from the type Derryan section.

The Zone of *Profusulinella* is recognized at Whiskey Canyon, but its lower boundary is not well defined. Here the *Profusulinella munda* Range Zone (partial) is the only *Profusulinella* subzone identified. Unfavorable environments apparently precluded *Profusulinella* occurrences lower in the section. Thompson (1948: 73) correlated this horizon (Thompson's unit 11-5; unit 4-5 of this study) with the upper "Apodaca Formation" at the type Derryan section based on the occurrence of *Profusulinella apodacensis.* This species is associated with the *Profusulinella munda* Range Zone at Whiskey Canyon. However, all fusulinids recovered in this study from the upper "Apodaca Formation" at the type Derryan section have proven to be *Fusulinella,* and Thompson's correlation does not appear justified.

Zone of *Fusulinella*

The Zone of *Fusulinella* was designated by Thompson (1945: 41) to include upper Derryan (Atokan) and lowermost Desmoinesian strata. Thompson (1945: 41) included lowermost Desmoinesian strata within this zone because "many of the lowermost Desmoinesian fusulinids are so nearly intermediate in development that they are arbitrarily assigned to *Fusulina* or to *Fusulinella"* but "most of them seem more closely related to the genotype of *Fusulinella."* Thompson (1948: 23) modified his earlier definition of the Zone of *Fusulinella,* lowering its upper datum to "just below the lowest occurrence of *Fusulina."* The base of the zone remained unchanged at the first occurrence of *Fusulinella.* The Zone of *Fusulinella* has gained widespread acceptance as the upper Atokan fusulinid biozone.

Two subzones have been recognized within the Zone of *Fusulinella* in the study area (Fig. 5). These are (ascending) the *Fusulinella acuminata* Lineage Zone and the *Fusulinella devexa* Interval Zone. The *Fusulinella acuminata* Lineage Zone ranges from the first occurrence of this species (first occurrence of the genus in the study area) to the first occurrence of its apparent direct descendant, *Fusulinella devexa.* The *Fusulinella devexa* Interval Zone ranges from the first occurrence of this species to the first occurrence of *Beedeina.* Both species range into strata above their respective upper zonal boundaries. Several other species of *Fusulinella,* with lesser apparent biostratigraphic utility, also occur in the study area. Both *Fusulinella* subzones occur at the Vinton Canyon, type Derryan, and Whiskey Canyon sections. The *Fusulinella acuminata* subzone cannot be recognized at the Bishop Cap section.

The Zone of *Fusulinella* reaches its maximum thickness within the study area at Vinton Canyon, where it is 42.18 m (138.4 ft) thick. The *Fusulinella acuminata* Lineage Zone (thickness 16.0 m, 52.5 ft) ranges from

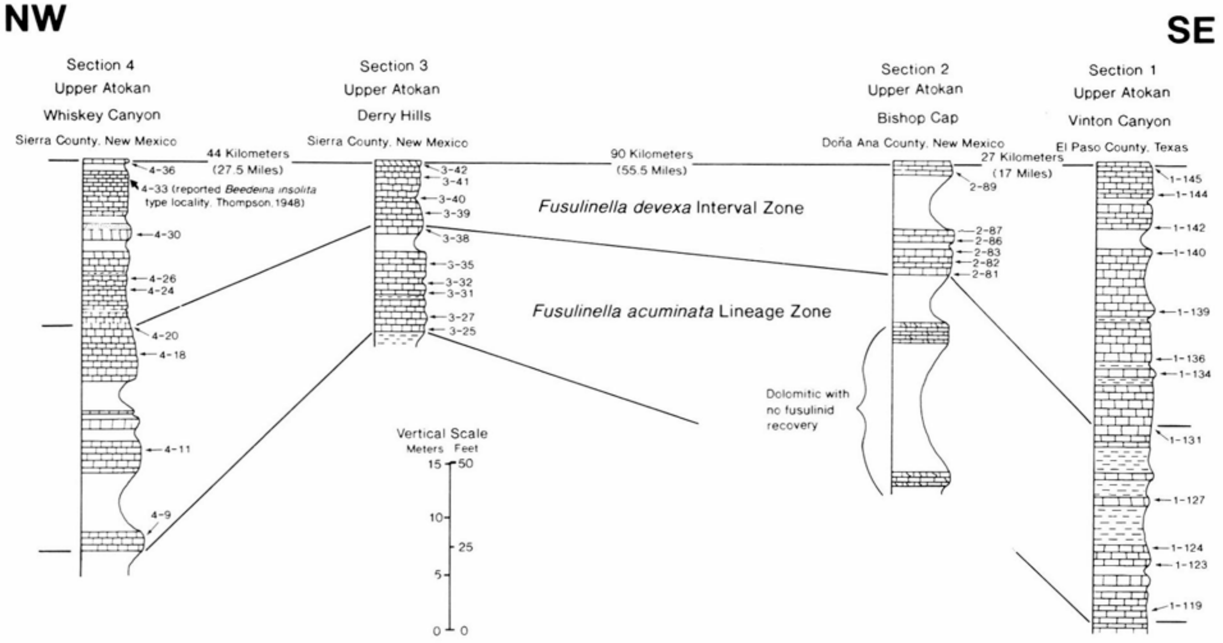

FIGURE 5—Zone of *Fusulinella* correlations across the study area. Datum is the lowest documented occurrence of *Beedeina*.

unit 1-119 through unit 1-130. The *Fusulinella devexa* Interval Zone (thickness 26.18 m, 85.9 ft) ranges from unit 1-131 through unit 1-144.

The Zone of *Fusulinella* is reduced to 9.25 m (30.4 ft) in thickness at the Bishop Cap section locality, where only the *Fusulinella devexa* Interval Zone is recognized. At the southwest end of Bishop Cap, where *F. acuminata* does occur, the Zone of *Fusulinella* is approximately 30.5 m (100 ft) thick (George Verville, pers. comm. 1990). The *Fusulinella acuminata* Lineage Zone is not recognized in MS 2 due to the lack of fusulinids in the dolomitic lithologies below the *F. devexa* Interval Zone. Here *F. devexa* (with associated *F. acuminata)* first occurs in unit 2-81. The *F. devexa* Interval Zone ranges through unit 2-89.

The Zone of *Fusulinella* is 15.05 m (49.4 ft) thick at the type Derryan section. Here *Fusulinella acuminata* first occurs in the upper portion of the "Apodaca Formation" (Thompson, 1942a). Thompson (1948) indicated the occurrence of *Profusulinella apodacensis* at this horizon. However, only members of the genus *Fusulinella* were recovered from the upper "Apodaca Formation" in this study.

The *Fusulinella acuminata* Lineage Zone (thickness 9.45 m, 31.0 ft) ranges from unit 3-25 through unit 3-38 at the type Derryan section. In addition to the upper portion of the "Apodaca Formation," this interval includes most of the "Fra Cristobal Formation" (Thompson, 1948; "Hot Springs Formation" of Thompson, 1942a). The *Fusulinella devexa* Interval Zone (thickness 5.6 m, 18.4 ft) ranges from unit 3-39 through unit 3-41. This interval includes the upper portion of the "Fra Cristobal Formation" and the "Cuchillo Negro Formation" (Thompson, 1942a). The upper boundary of the *Fusulinella devexa* Interval Zone corresponds with the top of the type Derryan Series, which occurs at the base of a 0.5 m (1.6 ft) thick dolomite immediately below the first occurrence of *Beedeina insolita.*

The Zone of *Fusulinella* is 34.95 m (114.7 ft) thick at Whiskey Canyon. Here the *Fusulinella acuminata* Lineage Zone (thickness 20.5 m, 67.3 ft) ranges from unit 4-9 through unit 4-19. This interval includes most of the "Fra Cristobal Formation." The *Fusulinella devexa* Interval Zone (thickness 14.45 m, 47.4 ft) ranges from unit 4-20 through unit 4-35. Thompson (1948), however, reported "rare" *Beedeina insolita* (the type locality, Thompson 1942a, 1948, his unit 11-24; unit 4-33 of this study) approximately 2 m (6.5 ft) lower than found in this study. This occurrence could not be confirmed but, if correct, the thickness of the *Fusulinella devexa* Interval Zone would be reduced to approximately 12.45 m (40.9 ft) and the thickness of the entire Zone of *Fusulinella* to approximately 32.7 m (107.3 ft) at Whiskey Canyon.

The *Fusulinella devexa* Interval Zone includes the upper portion of the "Fra Cristobal Formation," the "Cuchillo Negro Formation," and the lower "Elephant Butte Formation" (Thompson 1942a) at Whiskey Canyon. It is interesting to note that there is no apparent lithologic basis for the subdivision of these "formations." In addition, they include fusulinid faunas of somewhat different age than those found in the same "formations" at the type Derryan section. As a result, these subdivisions are found to be of no lithostratigraphic or biostratigraphic significance.

Zone of *Beedeina (partial)*

The Zone of *Beedeina (Fusulina)* was designated by Thompson (1945: 41-42). Ishii (1958) argued that *"Fusulina"* of North America should be included in the genus *Beedeina.* Most later authors followed this usage and, subsequently, the Zone of *Fusulina* became known as the Zone of *Beedeina* (see remarks under *Beedeina insolita* for a discussion of the *Fusulina/Beedeina* problem).

The Zone of *Beedeina* originally included Pennsylvanian strata from "shortly above the base of the Desmoinesian" to "near the top of the Desmoinesian" (Thompson, 1945). This interval includes the range of the genus as known at that time. *Beedeina* is now known to range into Missourian strata (Thompson et al., 1956) and the upper limit of the zone is marked by the first occurrence of the genus *Triticites* (Douglass, 1977). Modern usage has equated the Zone of *Beedeina* with the Desmoinesian Series at its upper and lower boundaries (Douglass, 1977).

Thompson (1945) noted the presence of *Wedekindellina* in Desmoinesian strata above the base of the Zone of *Beedeina.* Other authors have equated the first occurrence of *Wedekindellina* with the base of the Desmoinesian Series (Douglass, 1977). The Atokan/Desmoinesian boundary has remained controversial due to the lack of adequate type sections and, in part, due to the transitional nature of fusulinid species within the boundary interval.

In this paper, the first occurrence of *Beedeina,* regardless of its primitive evolutionary development, is taken to indicate basal Desmoinesian strata. The first occurrence of *Wedekindellina* is somewhat higher at all sections studied. Strata above the first occurrence of *Wedekindellina* have not been considered in this study.

In the study area, several species of *Beedeina* occur within the interval between the base of the Zone of *Beedeina* and the first occurrence of *Wedekindellina* (Fig. 6). This subzone is informally referred to as the *Beedeina* Interval Zone. Its lower portion is characterized by *B. insolita,* a very primitive member of the genus. The middle and upper portions of the *Beedeina* Interval Zone are characterized by somewhat more advanced species including *Beedeina hayensis, Beedeina* aff. *joyitaensis, Beedeina* aff. *curta,* and *Beedeina?* aff. *rockymontana.* Each of these species is relatively primitive compared to *Beedeina* species found above the first occurrence of *Wedekindellina.*

The *Beedeina* Interval Zone reaches its maximum thickness at Vinton Canyon (51.6 m, 169.3 ft) where it ranges from unit 1-145 through unit 1-174. The *Beedeina* Interval Zone is somewhat reduced in thickness at the Bishop Cap section and MS 3 in Derry Hills. The *Beedeina* Interval Zone ranges from unit 2-90 through unit 2-116 (thickness 27.3 m, 89.6 ft) at Bishop Cap, and from unit 3-43 through unit 3-59 (thickness 16.9 m, 55.5 ft) in Derry Hills.

The base of the *Beedeina* Interval Zone at Whiskey Canyon, as identified in this study, occurs at the base of unit 4-36. Thompson (1948), however, reported the type locality of *Beedeina (Fusulina) insolita* 2 m (6.5 ft) from lower in the section, at unit 4-33 of this study (Thompson, 1942a, 1948, measured section 11, bed 24, specimens reported to be "rare"). If the reported *B. insolita* type locality is correct, the *Beedeina* Interval Zone ranges from unit 4-33 through unit 4-61 (thickness approximately 44.9 m, 147.3 ft). The *Beedeina* Interval Zone ranges 42.9 m (104.8 ft) above the lowest confirmed occurrence of the genus at Whiskey Canyon.

Lithostratigraphic analysis

Paleogeography

Early and Middle Pennsylvanian sediments in the study area were deposited in a broad carbonate-shelf setting bounded by the Pedernal Uplift to the east and northeast, the Florida Axis to the southwest, and the Zuni—Defiance Arch to a somewhat more distant northwest (Fig. 7). This area includes portions of the Orogrande Basin and the Robledo Shelf, and approaches the southern limit of the San Mateo Basin.

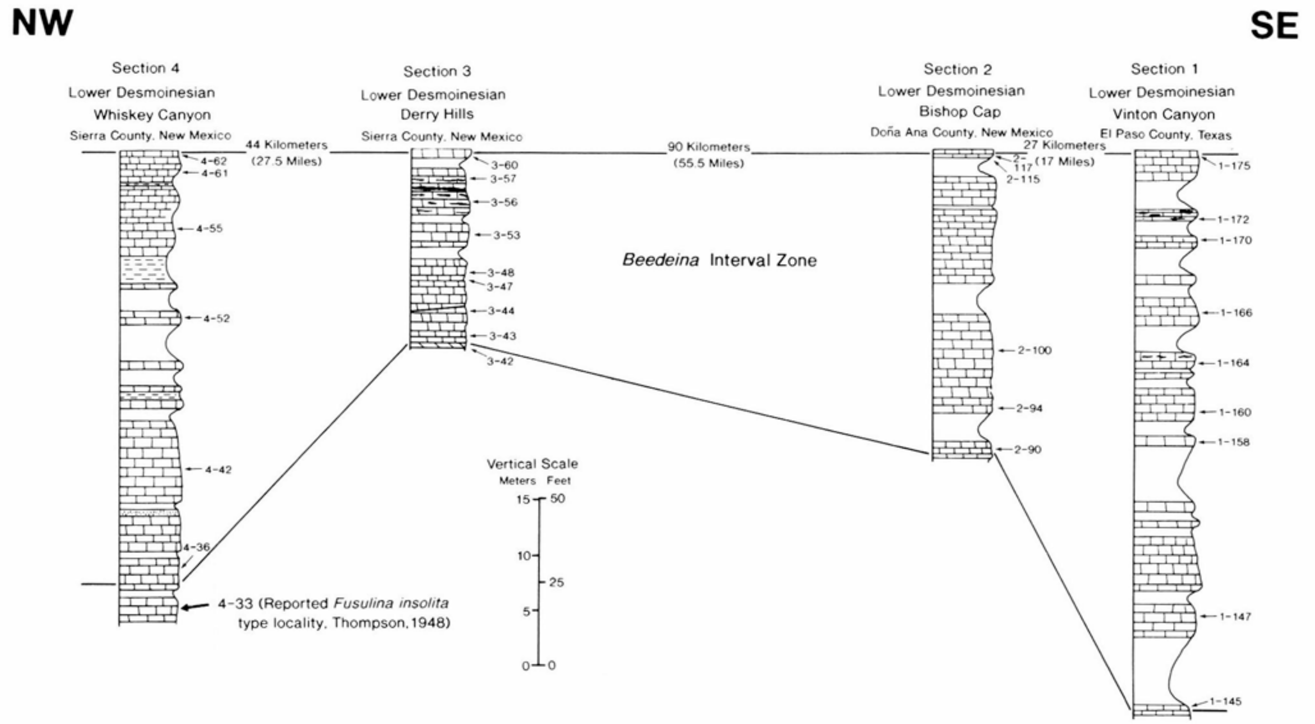

FIGURE 6—Zone of *Beedeina* (partial) correlations across the study area. Datum is the lowest documented occurrence of *Wedekindellina.*

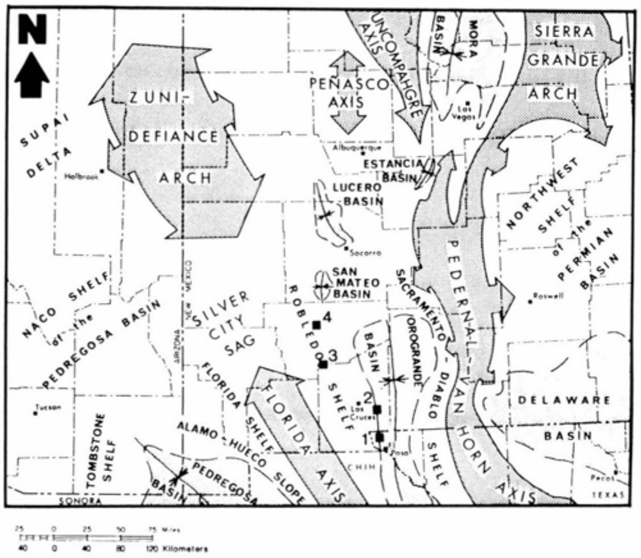

FIGURE 7—Pennsylvanian paleotectonic and paleogeographic map of the region showing the position of measured sections included in this study. The north–south orientation of the Orogrande Basin axis reflects a strong Late Pennsylvanian bias. The northeast–southwest orientation of the basin's axis in Early Pennsylvanian time is shown in Fig. 8. Modified from LeMone et al. (1974).

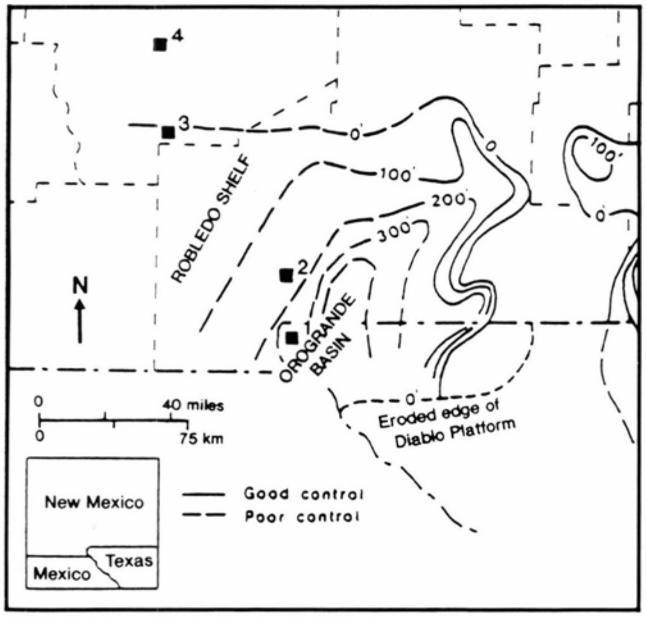

FIGURE 8–Morrowan isopach map of the study area showing regional Morrowan thickness trends and the northeast–southwest orientation of the Orogrande Basin in early Pennsylvanian. Modified from Connolly & Stanton (1986).

The interpretations of Pennsylvanian tectonic evolution and paleogeography of this area have been somewhat controversial. Meyer (1966) concluded that the Pedernal Uplift reached "maximal relief" in Morrowan time and was subsequently eroded as the Pennsylvanian Period progressed. Crosby & Mapel (1975) concluded that little is known of Early Pennsylvanian tectonic elements in west Texas (and presumably New Mexico) and that the Pedernal Uplift may have extended from New Mexico into west Texas as a "low" high at this time. Kottlowski (1960, 1969) argued that the "Florida Islands" and/or a Pennsylvanian high near the modem Joyita Hills may have been a significant clastic source.

Bachman (1975) concluded that no major orogenic uplifts occurred in New Mexico in Early Pennsylvanian time. He argued that some regional warping allowed seas to invade local shallow basins (like the Orogrande) during Morrowan time. He further argued that there is no evidence of major orogenic activity in the region until late in the Pennsylvanian. Connolly & Stanton (1986) concurred with the latter interpretation, describing the Morrowan Orogrande Basin as a "broad shelf lagoon."

Lithofacies analyses of Lower and Middle Pennsylvanian strata in the Orogrande Basin support the broad, shallow shelf interpretation of Bachman (1975) and Connolly & Stanton (1986). Osleger's (1981) and Mims' (1971) studies in the Franklin Mountains and Connolly & Stanton's (1983) study in the Hueco Mountains found shallow-water carbonate facies in Morrowan and Atokan strata to the exclusion of basinal facies. These observations have been corroborated by the present study (see the section on depositional environments for further discussion).

The axis of the Orogrande Basin had a northeast—southwest orientation in Morrowan time (Fig. 8). The Vinton Canyon section (MS 1) is located near this axis. The Bishop Cap section (MS 2) is located northwest of the Orogrande Basin proper, near the margin of the Robledo Shelf (Meyer, 1966; equivalent to the Potrillo Shelf of Wengerd, 1969). Both sections include relatively thick (75 m and 44 m, respectively) Morrowan deposits of shallow-marine carbonates. The decrease in thickness from MS 1 to MS 2 reflects the northward transgression of the Morrowan sea onto the margin of the Robledo Shelf. Regional topography appears to have been quite low and very limited clastic input is discernible in this sequence.

The type Derryan section (MS 3) is located northwest of the Orogrande Basin, on the central Robledo Shelf. This area received at least limited latest Morrowan carbonate deposits. The Robledo Shelf continued to have little topographic relief relative to the Orogrande Basin in Atokan and early Desmoinesian time.

The Whiskey Canyon section (MS 4) is also located on the Robledo Shelf, but is adjacent to the southern margin of the San Mateo Basin. This small depositional center on the northeast margin of the Robledo Shelf began to receive sediment in early Atokan time. Increased accumulation and/or subsidence rates at this locality relative to the more stable central Robledo Shelf are indicated by the increase in thickness of Atokan and early Desmoinesian strata from MS 3 to MS 4.

Limited Morrowan clastics at MS 1 and MS 2 suggest that the Pedernal Uplift was a minor topographic high at this time. Clastic input (dominantly shales) increased slightly in Atokan and early Desmoinesian time, although carbonate lithologies remain dominant. The "Florida Islands" of Kottlowski (1960, 1969) do not appear to have contributed a significant volume of sediment to the study area. Sands and shales become somewhat more common in Atokan and lower Desmoinesian strata at MS 3, and are much more common at MS 4. This may indicate clastic input from the postulated Pennsylvanian Joyita Hills high of Wilpolt et al. (1946). However, the larger Zuni—Defiance Arch is a more probable source area.

Depositional environments

Morrowan, Atokan, and early Desmoinesian sediments were deposited on a broad, shallow carbonate shelf in the Orogrande Basin and Robledo Shelf area of south-central New Mexico and westernmost Texas. Subtidal deposits are dominant, but interbedded intertidal and supratidal facies also occur. The variable petrographic characteristics reflect a range of specific depositional environments within this regional setting. Minor changes in subsidence and/or sedimentation rates, depositional energy, bioclast production, and clastic source areas resulted in a complex, vertically and laterally variable "facies mosaic" (Laporte, 1967). Eight carbonate and three clastic microfacies are recognized for descriptive convenience. However, there is a continuous gradation between these subdivisions.

Microfacies 1. Mixed skeletal biomicrite—wackestone: Most carbonate units are assigned to this microfacies. Skeletal grains approach 50% of the rock volume but remain mud-supported. They include crinoid columnals, brachiopods, bryozoan fragments, fusulinids, pellets, spicules, algal debris, and a variety of less significant bioclasts. The carbonate-mud matrix is generally organic-rich and may be partially neomorphosed to microspar.

Microfacies 2. Crinoidal biosparite—packstone grainstone: This microfacies is very similar to microfacies 1, but occurs in a slightly higher energy setting. The skeletal grains are concentrated as the carbonate-mud component is removed. Crinoid columnals are the most resistant skeletal grain and are thus preferentially preserved.

Microfacies 3. Fossiliferous micrite—mudstone: This microfacies is much less abundant than microfacies 1 and 2. Algal laminations occur at the type Derryan section (unit 3-3a), but they have not been noted at other localities. Rare spicules, pellets, and millerellid foraminifera are the only larger skeletal grains included in this microfacies.

Microfacies 4. Phylloid-algal biomicrite—wackestone: This microfacies forms thick (up to 5.2 m, 17 ft), wavy-bedded units with spar-replaced phylloidalgal grains as the dominant bioclasts. Crinoid columnals, fusulinids, other foraminifera, brachiopods, and ostracodes are also common in this microfacies.

Microfacies 5. *Coral—Chaetetes* boundstone: This microfacies is distinctive, but forms only a limited portion of the section. **The** most prominent boundstone occurs at Bishop Cap (unit 2-29) where a 0.75 m (2.5 ft) thick *Petalaxis—Chaetetes* boundstone layer can be traced laterally over 2.8 km (1.75 mi). Thinner, less laterally traceable *Aulopora(?)* and/or *Chaetetes* boundstone beds occur in several horizons at all the measured sections studied.

Microfacies 6. Intraclastic biosparite—packstone: This microfacies includes a wide range of skeletal-debris and intraclast lithologies. Dolomitic and mudstone intraclasts probably represent storm deposits derived from intertidal and near-shore supratidal environments. The associated skeletal fragments represent the subtidal component of this facies.

Microfacies 7. Oolitic biosparite—grainstone: This microfacies is highly restricted, occurring at a single horizon at Vinton Canyon (unit 1-36). Few true ooids are present, although most skeletal grains are coated.

Microfacies 8. Fossiliferous dolomite: This microfacies occurs at each section but is best developed at Bishop Cap (MS 2). The dolomite is finely crystalline and includes rare but well preserved skeletal grains. In addition, evaporite molds occur in discontinuous lenticular bands within some dolomite units (unit 269).

The clastic microfacies include (1) calcareous shale, (2) silty shale, and (3) quartzarenite/quartz-pebble conglomerate. Most shale horizons are not well exposed within the study area. Where exposed, they tend to be light gray (calcareous-shale microfacies) or dark gray to black, silty, and fissile (silty-shale microfacies). The quartzarenite/quartz-pebble-conglomerate microfacies is very poorly sorted. Grains are more than 95% quartz but also include rare mica flakes. Apparent wood clasts are included at Bishop Cap (unit 2-21). Quartzarenites occur above scoured surfaces at Whiskey Canyon (units 4-31 and 4-40).

These microfacies are typical of a shallow carbonate-shelf setting. Subtidal phylloid-algal blades act as baffles, trapping fine carbonate mud to form the phylloid algae biomicrite—wackestone microfacies. The lateral extent and lack of mounded geometries suggest that this microfacies formed in broad bank deposits. Other skeletal grains are relatively less abundant within the phylloid-algal deposits due to their high mud content.

Crinoids, brachiopods, fusulinids, and other organisms were more abundant on the margins of the phylloid-algal banks, where mixed skeletal biomicrite—wackestone was deposited. These units are generally highly burrowed, eliminating most internal bedding. *Coral—Chaetetes* boundstones formed locally in this shallow open-marine setting in areas where carbonate-mud production was relatively low.

When the mixed skeletal biomicrite—wackestone facies reached wave base, carbonate mud was removed and the grains became more concentrated. Continued wave action produced the crinoidal biosparite—packstone/grainstone microfacies. During storm deposition, intraclasts were incorporated into the crinoidal-packstone and mixed skeletal-wackestone microfacies to form the intraclastic-biosparite-packstone microfacies.

Fossiliferous mudstones were deposited in very low-energy, restricted environments. Faint algal laminations in fossiliferous mudstones at the type Derryan section (unit 3-3a) suggest intertidal deposition.

The fossiliferous-dolomite microfacies represents supratidal deposits. Evidence of evaporites in these dolomites may suggest deposition in a sabkha setting.

Silty shales and quartzarenites periodically prograded over these deposits. Calcareous shales formed at the distal margin of the clastic deposits.

Fusulinids occur in all the carbonate microfacies, but are too rare for detailed study in the fossiliferous-dolomite, oolitic-grainstone, coral-Chaetetes-boundstone, phylloid-algae-wackestone, and fossiliferous-mudstone microfacies. Fusulinids are generally very poorly preserved in the intraclastic-packstone and crinoidal-packstone/grainstone microfacies. Most fusulinids studied were recovered from the mixed skeletal biomicrite—wackestone microfacies, which includes the most abundant and well preserved faunas.

Depositional history

Pennsylvanian deposition in the study area followed a period of regional regression and erosion. The magnitude of the hiatus at the pre-Pennsylvanian unconformity increases northward from westernmost Texas to central New Mexico. The Helms Formation (Upper Mississippian) is the youngest pre-Pennsylvanian unit in the study area. It represents the more clastic regressive phase of middle and late Chesterian deposition (Lane, 1974). Post-Helms Formation carbonate deposition began with renewed transgression in early Morrowan time.

Lane (1974) found earliest Morrowan conodonts *(Rhachistognathus primus* Zone) in basal Pennsylvanian deposits at Vinton Canyon (MS 1 of this study). Only the most basinward portion of the study area received sediment at this time. Regional topography was low and clastic input limited. Phylloid-algal bank deposits and associated mixed-skeletal-wackestone buildups kept pace with the slowly subsiding Orogrande Basin.

North- and westward transgression continued through the Morrowan, resulting in the onlap of shallow-subtidal carbonate-shelf deposits onto progressively older strata. By early middle Morrowan time these deposits spread onto the margins of the Robledo Shelf. Phylloid-algal banks and mixed-skeletal-wackestone buildups stretched across the Orogrande Basin. By late Morrowan time, associated intertidal facies were deposited on the central Robledo Shelf over the Percha Shale (Devonian). These facies are preserved as thin algal mudstones, marlstones, and shales at the type Derryan section (MS 3). Coral and/or *Chaetetes* boundstones intermittently developed in the shallow-subtidal and open-marine environments more basinward at Bishop Cap and Vinton Canyon (MS 2 and MS1). Clastic input remained low, with only thin quartz sands and silty shales derived from the Pedernal Uplift interrupting carbonate deposition.

There is no apparent depositional break at the Morrowan/Atokan boundary in the Orogrande Basin. A minor unconformity is recognized at this boundary on the Robledo Shelf. This unconformity falls within a thin (less than 0.6 m; 2 ft) shale interval at the type Derryan section (Manger et al, 1987; Clopine et al., 1991). It may extend to the southeast, occurring within a covered interval. However, the low relief of this unconformity where it is exposed and the upper Morrowan *Petalaxis* boundstones at Bishop Cap suggest that this was not a major regressive event within the study area.

Renewed transgression in early Atokan covered the Robledo Shelf. Relative subsidence rates remained higher in the Orogrande Basin, but carbonate deposition kept up with subsidence. This produced a blanket-like sequence of shallow-subtidal, intertidal, and supratidal carbonate-dominated deposits across the entire area. By early middle Atokan, these carbonate-shelf facies reached the northwestern margin of the Robledo Shelf. Somewhat thicker shales and thin sandstones derived from the Zuni—Defiance Arch prograded over carbonate deposits in this area (Whiskey Canyon section, MS 4). The Pedernal Uplift also became a somewhat more significant clastic source by early middle Atokan time, resulting in thicker and more abundant shale intervals in the Orogrande Basin and across the central Robledo Shelf.

Shallow-shelf carbonates, with minor influxes of sand and mud, continued to be deposited in the Orogrande Basin and across the Robledo Shelf through the early Desmoinesian time (upper limit of this study) and later. The results of the variable subsidence rates across the study area in Atokan and early Desmoinesian time are evident (Figs. 4-6). The thickest sequences are in the Orogrande Basin and on the margins of the Robledo Shelf, where subsidence was the greatest. A thinner sequence is preserved on the more slowly subsiding shelf. This is in sharp contrast to the Morrowan thickness variation (Fig. 8), which is due to progressive loss of early Morrowan strata as the onlapping sequence transgressed onto the Robledo Shelf.

Conclusions

1. Fusulinid foraminifera offer one of the best means for subdivision and biostratigraphic correlation of the Morrowan, Atokan, and lower Desmoinesian Series in south-central New Mexico and westernmost Texas.

2. Lower and Middle Pennsylvanian fusulinid biozones recognized in the study area are: the Zone of *Millerella;* the Zone of *Eoschubertella;* the *Profusulinella copiosa* Range Zone; the *Profusulinella thompsoni* Range Zone; the *Profusulinella munda* Range Zone; the *Fusulinella acuminata* Lineage Zone; the *Fusulinella devexa* Interval Zone; and the Zone of *Beedeina* (partial). The first occurrence of *Wedekindellina* is also an important biostratigraphic marker.

3. Thompson's (1948) species and correlations were found valid with two notable exceptions: (1) occurrence of *Profusulinella* at the type Derryan section could not be confirmed; and (2) *Beedeina insolita* was not found at its reported type locality.

4. Thompson's (1942a) "groups" and "formations" do not follow accepted guidelines for lithostratigraphic or biostratigraphic subdivisions and are not recognizable away from their type sections.

5. The lower 0.95 m of the "Derryan Series" type section overlaps the Morrowan Series. However, fusulinid faunas from the remainder of the Derryan type section correlate closely with Atokan fusulinid faunas

from the midcontinent. In addition, the upper boundary of the Derryan type section falls just below the first occurrence of *Fusulina* and corresponds to most authors' concept of the Atokan/Desmoinesian Series boundary.

6. Morrowan, Atokan, and lower Desmoinesian sediments in the study area represent carbonate-shelf deposits. Shallow-subtidal facies dominate, but limited intertidal and supratidal deposits also occur. Deep-water facies do not occur in the study interval.

7. Fusulinid foraminifera occur in most carbonate lithologies, but are most abundant and best preserved in shallow-subtidal wackestones, the dominant carbonate lithology in the study interval.

8. Morrowan strata in the study area do not extend north of the central Robledo Shelf. Earliest Morrowan deposits in the study area are restricted to the center of the Orogrande Basin. Morrowan strata thin rapidly to the northwest due to basal onlap of progressively younger sediments above the pre-Pennsylvanian unconformity. This basal onlap documents the Morro-wan transgression onto the Robledo Shelf.

9. Atokan and lower Desmoinesian sediments (upper range of this study) extend across the Robledo Shelf. The significant variations in thickness of these strata across the study area reflect the lower subsidence rate of the Robledo Shelf relative to the Orogrande and San Mateo Basins. Shallow-carbonate-shelf deposits are present throughout the study interval, documenting that carbonate production and deposition kept pace with subsidence.

Systematic paleontology

Introduction

Species identification and description of fusulinid foraminifers require measurements and analyses of morphologic characters in oriented thin sections; two orientations are required (Moore, 1964; Waddell, 1964). More quantitative and qualitative characters can be measured and studied in axial section (cut through the initial chamber parallel to axis of coiling). Septal count, the only character which cannot be studied in this orientation, must be made in sagittal section (cut through initial chamber perpendicular to axis of coiling). Quantitative data on the following morphologic characters are included in the Appendix.

Proloculus diameter—Diameter (normally maximum) of the initial chamber measured from top to top of tectum across the center of the chamber.

Half-length—Specimen length from the center of the proloculus to the outermost polar extremity of each volution.

Radius vector—Specimen height from the center of the proloculus to the top of the tectum of each volution measured as close to the center of the tunnel as possible.

Wall thickness—Thickness of the primary wall (protheca) at each volution measured as close to the center of the tunnel as possible.

Tunnel width—Linear distance between bisected near tunnel slopes of adjacent chomata.

Septal count—Number of septa per volution, counted following Dunbar & Henbest (1942: 63).

Mean values for the preceding quantitative measurements are included in the systematic descriptions. The mean form ratio (half-length/radius vector) of mature specimens is presented for most species. Additional not readily quantifiable characters are also included. These are wall structure, shape of mature test, shape of lateral slopes, shape of polar extremities, chomata development, and degree of septal fluting.

Where possible, systematic descriptions are grouped using the suprageneric classification scheme of the Treatise of Invertebrate Paleontology (Thompson *in* Loeblich & Tappan, 1964). Verville & Sanderson (1988) have been followed where family affiliation is not specified by the Treatise. Synonymies are limited to the original description of the species and selected reports of regional significance. The recommendations of Bengtson (1988) have been followed in all use of open nomenclature. Some figured specimens are not included in the systematic descriptions. Very rare occurrence, poor preservation, or limited biostratigraphic usefulness of these forms make detailed description difficult or unnecessary.

Each systematic description is followed by a listing of recorded occurrences and relative abundances at each of the measured sections studied (R = rare, U = uncommon, C = common, A = abundant).

All specimens are in the Oklahoma Museum of Natural History Invertebrate Paleontology collection, at the University of Oklahoma (OU).

Superfamily FUSULINACEA Miller 1878
Family OZAWAINELLIDAE Thompson & Foster 1937
Genus *MILLERELLA* Thompson 1942(b)
MILLERELLA spp.

Pl. 1, figs. 1-13

Description—Small, discoidal test of four to seven volutions with a short axis of coiling and narrowly rounded to subangular periphery. Axial length of most specimens is 0.05 to 0.1 mm. Equatorial width of most specimens is 0.3 to 0.6 mm. Test is planispiral throughout growth. Later volutions may be offset slightly from early coiling plane. Earliest volutions may be involute, but later volutions are evolute to strongly evolute. Coiling expands relatively smoothly except the final volution, which may be disproportionately highly inflated. Proloculus is small and spherical. Most prolocular outer diameters are 0.02 to 0.04 mm. Chomata are poorly developed or absent. Wall is very thin, composed of a tectum with inner and outer tectoria, but individual layers can rarely be differentiated. Septa are straight to gently curved. Septal count approximately 8, 13, 15, 16, and 20 in first through fifth volutions.

Remarks—Millerella has not been subdivided into species in this study. Groves (1986) pointed out the limited utility of this genus for detailed biostratigraphic correlation. Significant problems associated with discrimination of species within this genus are similar to those of *Eostaffela* (see Stewart, 1970: 36).

King (1973), however, compared species of *Millerella* from the type Derryan section (MS 3 of this study) to faunas from the Marble Falls Formation in Burnet County, Texas. Groves (1986: 350) identified *Millerella extensa* from the lowest Pennsylvanian beds at the type Derryan section (Unit 3-3 of this study).

Occurrence—Millerella occurs in most carbonate units within the study interval and is very abundant in many horizons.

Genus *EOSTAFFELLA* Rauzer-Chernousova 1948 *EOSTAFFELLA* spp. Pl. 1, figs. 14-18

Description—Small, discoidal test of four to six volutions with a short axis of coiling and narrowly rounded to subangular periphery. Axial length of most specimens is 0.1 to 0.25 mm. Equatorial width of most specimens is 0.3 to 0.6 mm. Test is planispiral, with a completely involute growth habit. Coiling expands in a relatively smooth progression. Proloculus is small and spherical. Most prolocular outer diameters are 0.01 to 0.04 mm. Chomata are poorly developed or absent. Wall is very thin, composed of a tectum with inner and outer tectoria, but individual layers can rarely be differentiated. Septa are straight to very gently curved. Septal count approximately 7, 11, 15, and 18 in first through fourth volutions.

Remarks—Eostaffella has not been subdivided into species in this study. Stewart (1970: 36) outlined problems associated with differentiation of species in this genus and Groves (1986) pointed out its limited utility for detailed biostratigraphic correlation. King (1973) compared several species of *Eostaffella* from the type Derryan section (MS 3 of this study) to forms from the Marble Falls Formation in Burnet County, Texas.

Occurrence—Eostaffella occurs in many carbonate units within the study interval and is very abundant in many horizons.

Family **FUSULINIDAE** Moller 1878
Genus *PSEUDOSTAFFELLA* Thompson 1942(b)
PSEUDOSTAFFELLA sp.
Pl. 1, figs. 24-26

Description—Small, spherical to subspherical test of four or five volutions with straight or slightly depressed polar regions and convex to straight equatorial periphery. Maximum axial length of eight specimens is 0.5 mm, with a maximum equatorial width of 0.6 mm. Axis of coiling in initial chambers is commonly at high angle to coiling axis in later volutions. Proloculus is small, spherical, with outer diameter up to 0.04 mm. Chomata are high and broad. Wall consists of a tectum with inner and outer tectoria. Individual wall layers can be differentiated in most specimens. Septa are straight to very gently curved.

Remarks—Thompson (1942b) described *Pseudostaffella needhami* (type species) from specimens collected at Whiskey Canyon (MS 4 of this study), but the genus is generally rare within the study interval, and sufficient well-oriented specimens were not available for detailed comparison or species identification.

Occurrence—Rare *Pseudostaffella* occurs in units 3-10 and 4-1c.

Genus *EOSCHUBERTELLA* Thompson 1937
EOSCHUBERTELLA MEXICANA Thompson 1948 Pl. 2, figs. 1-7

1948. *Eoschubertella mexicana* Thompson, p. 79, pl. 28, figs. 1-8. 1948. *Eoschubertella?* sp., Thompson, pl. 28, figs. 9-13. 1948. *Millerella?* sp., Thompson, pl. 23, figs. 13(?), 14.

Description—Small, globular to inflated fusiform test with up to four loosely coiled volutions, convex periphery, and broadly rounded to truncate polar extremities. Axis of coiling is somewhat erratic, with early volutions commonly at high angle to later ones. Axial length of mature specimens is 0.4 to 0.6 mm. Equatorial width at fourth volution is up to 0.45 mm. Form ratio of mature specimens is approximately 1.3. Proloculus is spherical to semispherical and relatively large for test size. Proloculus diameter ranges from 0.05 to 0.1 mm, with a mean of 0.8 mm for six specimens. Chomata are variable, ranging from absent or low, narrow, and indistinct to high and broad. Wall is thin, with indistinct tectum and upper and lower tectoria.

Remarks—The prolocular diameters noted in this study are generally larger than those in the type specimens. The poor orientation of many of Thompson's (1948) specimens suggests that the originally reported values are somewhat low. *E. mexicana* is a primitive form easily confused with juvenile stages of more advanced species. It is differentiated on the basis of its relatively large proloculus, loose coiling, and erratically coiled early volutions. Thompson (1948: 159) separated *Eoschubertella?* sp. from *E. mexicana,* but no reasons were given and the separation does not appear justified. Thompson (1948: pl. 23, figs. 13(?), 14) figured juvenile forms of *E. mexicana* as *Millerella?* sp. *E. mexicana* is similar in growth form, but is nearly twice the size of *E. bluensis* Ross & Sabins from the Horquilla Limestone in southeast Arizona. It is similar in size to the more advanced *E. gallowayi* (Skinner) from Oklahoma, but has significantly less developed septa. *E. mexicana* is very similar to *E. texana* Thompson 1947, but is slightly smaller, somewhat more fusiform, and has a smaller proloculus.

Occurrence—E. *mexicana* occurs in units 1-97 (C), 1-102 (U), 2-83 (C), 3-8 (R), and 4-33 (C).

Genus *PROFUSULINELLA* Rauzer-Chernousova & Belyaev 1936
(in Rauzer-Chernousova et al., 1936)
PROFUSULINELLA COPIOSA Thompson 1948
Pl. 2, figs. 12-29

1948. *Profusulinella copiosa* Thompson, **pp.** 80-82, pl. 27, figs. 1-3, pl. 28, figs. 14-32.

1990. *Profusulinella copiosa* Thompson: Groves & Sanderson, pl. 5, figs. 36-48.

Description—Small, globular to elliptical test of four to five volutions with highly convex lateral slopes and broadly rounded to truncate poles. Loosely coiled, with asymmetrical coiling in the early volutions of many specimens. Mature specimens with five volutions range from 1.0 to 1.66 mm in length and 0.93 to 1.22 mm in width. Mean length is 1.36 mm and mean width 1.02 mm, with the form ratio approximately 1.33. Proloculus is spherical to subcylindrical or ovate, and is large for the genus. Proloculus diameter ranges from 0.072 to 0.186 mm, with a mean of 0.13 mm. Half-lengths of first through fourth volutions average 0.130 mm, 0.238 mm, 0.397 mm, and 0.581 mm. Radius vectors of first through fourth volutions average 0.118 mm, 0.199 mm, 0.310 mm, and 0.481 mm. Chomata are poorly developed, low, and narrow. Tunnel may be erratic due to asymmetric coiling in early volutions. Tunnel widths of first through fourth volutions average 0.057 mm, 0.093 mm, 0.166 mm, and 0.259 mm. Wall is composed of a tectum with relatively thick upper and lower tectoria. Septa are unfluted. Septal count averages 8, 14, 18, and 19 in first through fourth volutions.

Remarks—Specimens are similar to types in all respects, differing only in a slightly higher septal count, slightly lower proloculus mean diameter, and wider range in proloculus diameters. *P. copiosa* is a primitive species of the genus. Thompson (1948: 80-81) noted that its shape, small size, and unfluted septa suggest a close relation to the genus *Eoschubertella.* Its stratigraphic appearance as the lowest *Profusulinella* in this and other studies (e.g. Thompson, 1948; Coogan, 1964; Verville & Sanderson, 1988) supports this hypothesis.

The large proloculus of this species is perhaps its most interesting characteristic. Groves & Sanderson (1990) suggested that the types, which came from a fusulinacean packstone, may be megalospheric variants and that their interpreted primitive morphology may be the result of reproductive dimorphism. However, over 50 specimens studied by myself show a steady progression in prolocular diameter (see above). The mean value is similar to the types, but the range of the prolocular diameter is significantly greater. This suggests that the morphology of *P. copiosa* is not a consequence of reproductive dimorphism.

P. copiosa has smaller, narrower chomata, a lower form ratio, and a larger proloculus than *P. fittsi* (Thompson 1935) from the Atoka Formation of Oklahoma. *P. copiosa* is similar in size and shape to *Profusulinella thompsoni* n. sp., but has a larger, less spherical proloculus, less advanced septa, a smaller form ratio, and asymmetrically coiled early volutions.

Thompson (1942a) suggested the occurrence of *P. copiosa* in the "Arrey Formation" at the type Derryan section, but later (Thompson, 1948: 82) reidentified those specimens as primitive forms of *Eoschubertella.*

Occurrence—P. *copiosa* has been recovered from units 1-62 (A), 1-63 (C), 1-69 (A), 1-75 (R), 1-87 (C), 2-39 (A), 2-43 (R), 2-46 (A), and 2-67 (R). It is the lowest occurring member of the genus at the Vinton Canyon and Bishop Cap sections. *P. copiosa* has not been found at the type Derryan or Whiskey Canyon sections.

PROFUSULINELLA cf. *FITTSI* (Thompson 1935)
Pl. 2, figs. 8-11

1935. *Fusulinella fittsi* Thompson, pp. 300-301, pl. 26, figs. 1-6. 1948. *Profusulinella fittsi* (Thompson): Thompson, pl. 26, fig. 11. 1953. *Profusulinella fittsi* (Thompson): Thompson, pl. 41, figs. 13-20.

Description—Small, fusiform to thickly fusiform test of four to five volutions with convex lateral slopes and broadly rounded polar extremities. Coiling is relatively tight around a straight axis. Specimens of five volutions range from 1.26 to 1.54 mm in length and 0.91 to 1.0 mm in width. Mean length is 1.41 mm and mean width 0.95 mm, with the form ratio approximately 1.48. Proloculus is spherical. Proloculus diameter ranges from 0.047 to 0.089 mm, with a mean of 0.067 mm. Half-lengths of first through fourth volutions average 0.080 mm, 0.176 mm, 0.349 mm, and 0.545 mm. Radius vectors of first through fourth volutions average 0.077 mm, 0.130 mm, 0.203 mm, and 0.310 mm. Chomata are well developed, high, and very broad, often extending well onto the lateral slopes. Tunnel is distinct but erratic. Tunnel widths of first through third volutions average 0.036 mm, 0.066 mm, and 0.138 mm. Wall is composed of a tectum with upper and lower tectoria. Septa are weakly fluted in polar areas. Specimens were not recovered in numbers sufficient for an accurate septal count.

Remarks—P. *fittsi* was the first species of the genus described from North America. The type specimens are generally poorly preserved, and most are missing the outermost volutions. These specimens were originally placed under *Fusulinella* and Thompson (1935: 300-301) discussed the wall structure, which included an apparent diaphanotheca. Thompson (1948: 81) correctly reassigned this species to *Profusulinella* when its characteristic three-layered wall structure became apparent. The reported occurrence of P. *fittsi* in the lower Atoka Formation was important to the original faunal characterization of the Atokan Series (Spivey & Roberts, 1946). However, the locality information given by Thompson (1935) for the type specimens is incorrect, and all subsequent attempts to collect *P. fittsi* from the lower Atoka Formation have failed (Douglass & Nestell, 1984). The reader is referred to Douglass & Nestell (1984), Groves (1986), and Groves & Sanderson (1990) for further evaluation of the type specimens and their reported locality.

Occurrences of *P.* cf. *fittsi* in the study area are rare, and the specimens are not sufficient for positive identification. However, chomata development, proloculus diameter, and half-lengths are nearly identical to the types. The specimens are slightly less tightly coiled and elongate than the types, but these differences are minimal. The occurrence of rare *P.* cf. *fittsi* in association with *P. copiosa* (Vinton Canyon and Bishop Cap) tends to confirm Thompson's assignment of this species to middle lower Atokan strata.

Occurrence—P. cf. *fittsi* has been recovered from units 1-62 and 2-39, where rare specimens are found in association with abundant *P. copiosa.* Rare *P.* cf. *fittsi* also occurs at the base of unit 3-23. In each case,P. *cf. fittsi* occurs at the lowest horizon containing members of the genus.

PROFUSULINELLA THOMPSONI n. sp.
Pl. 3, figs. 1-15

Diagnosis—Small, inflated to obese test of four to five volutions with gently convex to straight lateral slopes and broadly rounded polar extremities. Loosely coiled around a straight axis. Mature specimens with five volutions range from 1.19 to 1.55 mm in length and 0.85 to 1.14 mm in width. Mean length 1.40 mm and mean width 0.96 mm, with form ratio approximately 1.46. Proloculus spherical to subspherical.

Proloculus diameter ranges from 0.062 to 0.118 mm, with a mean of 0.083 mm. Half-lengths of first through fourth volutions average 0.084 mm, 0.077 mm, 0.321 mm, and 0.479 mm. Radius vectors of first through fourth volutions average 0.081 mm, 0.141 mm, 0.228 mm, and 0.354 mm. Chomata high, narrow to broad, commonly overhanging. Tunnel narrow, slightly erratic. Tunnel widths of first through fourth volutions average 0.037 mm, 0.060 mm, 0.101 mm, and 0.164 mm. Wall composed of a tectum with upper and lower tectoria. Septa weakly to moderately fluted in polar regions. Septal count averages 8, 13, 17, and 20 on first through fourth volutions.

Remarks-P. *thompsoni* is similar to *P. copiosa* but has more advanced septal development, somewhat greater chomata development, a smaller, more spherical proloculus, narrower tunnel, slightly higher form ratio, and more symmetrically coiled early volutions. *P. thompsoni* is similar to *P. ohioensis* Douglas, but is slightly larger and more inflated. *P. thompsoni* is also similar to *P.* aff. *psi,* but has a more advanced septal development, narrower and/or overhanging chomata, and narrower tunnel.

P. thompsoni occurs stratigraphically higher and is more advanced than *P. copiosa.* However, intermediate forms can be found in populations of both species, and mean character states show gradual change.

Occurrence-P. *thompsoni* has been recovered from units 1-97 (U), 1-108 (C), and 1-109 (A, type locality).

PROFUSULINELLA MUNDA Thompson 1948

P1. 3, figs. 16-27

1948. *Profusulinella munda* Thompson, pp. 82-83, pl. 27, fig. 4, p1. 30, figs. 1-7.

Description-Small, fusiform to thickly fusiform test of five, six, or rarely seven volutions with convex lateral slopes, broadly rounded polar extremities, and straight axis of coiling. Mature specimens of six volutions range from 1.62 to 2.62 mm in length and 0.98 to 1.34 mm in width. Mean length is 2.27 mm and mean width 1.17 mm, with the form ratio approximately 1.94. Proloculus is spherical. Its diameter ranges from 0.050 to 0.096 mm, with a mean of 0.074 mm. Half-lengths of first through fifth volutions average 0.082 mm, 0.192 mm, 0.356 mm, 0.612 mm, and 0.937 mm. Radius vectors of first through fifth volutions average 0.080 mm, 0.135 mm, 0.211 mm, 0.317 mm, and 0. 460 mm. Chomata are asymmetrical, high and broad, to high, broad, and overhanging. Tunnel is well defined, relatively narrow. Tunnel widths on first through fifth volutions average 0.034 mm, 0.071 mm, 0.119 mm, 0.224 mm, and 0.371 mm. Wall is composed of a tectum with upper and lower tectoria. Septa are unfluted to weakly fluted in polar areas. Septal count averages 6, 12, 13, 15, and 17 in first through fifth volutions.

Remarks-Specimens are similar to the types but differ in possessing a slightly wider range of length and width, slightly higher mean form ratio, and slightly smaller range of prolocular diameters. *P. munda* is very similar to *P. decora,* but is differentiated by its narrower width, higher form ratio, narrower tunnel in outer volutions, larger proloculus, and planispirally coiled juvenarium. *P. munda* is also very similar to *P. regia.* Thompson (1948: 82) differentiated *P. munda* from *P. regia* on the basis of a smaller proloculus, more tightly coiled test, and narrower tunnel of the former. Thompson (1948: 82) argued that *P. munda* was ancestral to *P. regia* based on stratigraphic appearance and morphologic similarity, but suggested that alternatively these forms could be conspecific.

P. munda is one of the stratigraphically highest members of the genus. Its morphologic similarity and overlap of stratigraphic range with *P. regia* suggest that these forms are environmental variants of the same species.

Occurrence-P. *munda* has been recovered from units 1-114 (A), 1-118 (A), and 4-5 (U). This includes the highest occurrence of the genus at Vinton and Whiskey canyons.

PROFUSULINELLA DECORA Thompson 1948

Pl. 4, figs. 1-8

1948. *Profusulinella decora* Thompson, p. 83, pl. 27, figs. 5, 6, 12, pl. 29, figs. 5-30.

Description-Small, thickly fusiform test of five or six volutions with convex lateral slopes and broadly rounded polar extremities. juvenarium is coiled at high angle to later volutions. Coiling axis is straight in outer volutions. Mature specimens with six volutions range from 2.07 to 2.71 mm in length and 1.22 to 1.38 mm in width. Mean length is 2.25 mm and mean width 1.32 mm, with the form ratio approximately 1.7. Proloculus is small and spherical. Its diameter ranges from 0.038 to 0.075 mm, with a mean of 0.059 mm. Half-lengths of first through fifth volutions average 0.083 mm, 0.179 mm, 0.376 mm, 0.619 mm, and 0.868 mm. Radius vectors of first through fifth volutions average 0.078 mm, 0.128 mm, 0.212 mm, 0.331 mm, and 0.496 mm. Chomata development is irregular, ranging from absent to high and broad. Tunnel is narrow and straight in early volutions and wide and irregular in outer volutions. Tunnel widths on first through fifth volutions average 0.037 mm, 0.081 mm, 0.148 mm, 0.307 mm, and 0.502 mm. Wall is composed of a tectum with upper and lower tectoria. Septa are unfluted to weakly fluted in polar regions. Septal count averages 7, 11, 14, 16, and 18 in first through fifth volutions.

Remarks-Specimens are similar to the types in all respects except a slightly smaller prolocular diameter. *P. decora* is similar to *P. munda* and *P. regia,* from which it differs primarily by its asymmetrically coiled juvenarium. Thompson (1948: 83) suggested that the juvenarium and the overall smaller size of *P. decora* indicate that it is ancestral to *P. regia.* However, *P. regia* has not been identified in this study (see remarks under *P. munda* for further discussion). *P. decora* is associated with *P. munda* in all of its occurrences, and its morphology may be the result of reproductive dimorphism within this species.

Occurrence-P. *decora* has been recovered from units 1-116 (C) and 4-5 (U). This includes the highest occurrence of the genus at the Whiskey Canyon section.

PROFUSULINELLA APODACENSIS Thompson 1948

Pl. 4, figs. 9-12

1948. *Profusulinella apodacensis* Thompson, pp. 85-86, pl. 27, figs. 9, 10, pl. 31, figs. 10-17.

1956. *Profusulinella spicata* Thompson: Thompson & Zeller, text-fig. 1.

Description-Fusiform test of five to six volutions with convex to gently convex lateral slopes, bluntly pointed polar extremities, and straight axis of coiling. Specimens with five volutions range from 1.906 to 2.504 mm in length and 0.994 to 1.340 mm in width. Mean length is 2.22 mm and mean width 1.13 mm. Mean form ratio at fifth volution is 1.96, but the form ratio is as high as 2.63 in the single specimen with six volutions. Proloculus is spherical. Proloculus diameter ranges from 0.061 to 0.079 mm, with a mean of 0.070 mm. Half-lengths of first through fourth volutions average 0.114 mm, 0.263 mm, 0.445 mm, and 0.739 mm. Radius vectors-of first through fourth volutions average 0.084 mm, 0.145 mm, 0.235 mm, and 0.376 mm. Chomata are high, broad, and overhanging. Tunnel is relatively straight and narrow in early volutions. Tunnel widths on first through fourth volutions average 0.046 mm, 0.081 mm, 0.130 mm, and 0.319 mm. Wall is composed of tectum with thick upper and lower tectoria. Septa are weakly fluted in polar regions. Sagittally oriented specimens were not recovered.

Remarks-The three specimens recovered in this study came from the same horizon as Thompson's type specimens and thus are topotypes. They are similar to the original types in all respects except a slightly lower mean axial length. *P. apodacensis* is a very advanced member of the genus. It is similar to *P. munda* but has a larger test at maturity and a higher form ratio at each volution. *P. apodacensis* is similar to *P. spicata* but has smaller, less consistently developed chomata. However, *P. spicata* has not been encountered in this study, and these forms may be environmental variants of the same species. *P. apodacensis* is closely similar to the more advanced *Fusulinella primaeva* (Skinner), but does not show diaphanotheca development in any volution.

Thompson (1948: 86) noted the occurrence of *P. apodacensis* at Whiskey Canyon in "Bed 5, section 11" (Bed 5, MS 4 of this study) and near the top of the type section of the "Apodaca Formation" at the type Derryan section (MS 3 of this study). The former occurrence has been confirmed. However, after extensive sampling, the later horizon has been found to have common *Fusulinella* but no occurrences of *Profusulinella.* The lack of *P. apodacensis* in the "Apodaca Formation" at the type Derryan section leaves the type locality as the only documented occurrence of this species in New Mexico. At this horizon, *P. apodacensis* is associated with specimens of *P. munda* and *P. decors.* Groves (1991) identified *P. apodacensis* in the Marble Falls Limestone in central Texas.

Occurrence-P. *apodacensis* has been recovered from unit 4-5 (C). This horizon represents the highest occurrence of the genus at the Whiskey Canyon section.

Genus *FUSULINELLA* Miller 1877

FUSULINELLA FUGAX Thompson 1948 Pl. 4, figs. 13-18

1948. *Fusulinella fugax* Thompson, pp. 88-89, pl. 32, fig. 2, pl. 33, figs. 1-8.

Description-Small, fusiform test of five to six volutions with convex lateral slopes, broadly rounded polar extremities, and straight axis of coiling. Mature specimens of six volutions range from 1.93 to 3.0 mm in length and 1.13 to 1.24 mm in width. Mean length is 2.46 mm and mean width 1.14 mm, with the form ratio approximately 2.2. Proloculus is small and spherical. Proloculus- diameter ranges from 0.048 to 0.084 mm, with a mean of 0.065 mm. Half-lengths of first through fifth volutions average 0.098 mm, 0.194 mm, 0.376 mm, 0.605 mm,and 0.907 mm. Radius vectors on first through fourth volutions average 0.127 mm, 0.121 mm, 0.185 mm, 0.273 mm, and 0.403 mm. Chomata are well developed, high, and very broad. Tunnel is well developed, narrow. Tunnel widths on first through fourth volutions average 0.045 mm, 0.044 mm, 0.064 mm, 0.088 mm, and 0.131 mm. Wall is composed of tectum with relatively thick upper and lower tectoria in inner volutions; outer three to four volutions include a thin diaphanotheca. Septa are weakly fluted in polar regions. Specimens were not recovered in numbers sufficient for an accurate septal count.

Remarks-Specimens are closely similar to the types. They include a single topotype from Whiskey Canyon and several specimens from the type Derryan section. They differ from the types in smaller prolocular diameters, slightly smaller overall size, and maximum of six volutions. *F. fugax* is a primitive form of the genus, transitional betwen *Profusulinella* and *Fusulinella.* This species is one of the stratigraphically lowest members of the genus to occur in the study area. Thompson (1948: 89) noted its similarity to *Profusulinella apodacensis* and *Fusulinella primaeva. F. fugax* is differentiated from *P. apodacensis* on the basis of its more advanced wall structure. *F. fugax* has much broader and more massive chomata than *F. primaeva.*

F. fugax is similar to *F. acuminata,* but has broader chomata, lower form ratio, smaller overall size, and more primitive diaphanotheca development. However, these forms occur together throughout the range of *F. fugax* and somewhat intermediate forms do occur.

Occurrence-F. *fugax* has been recovered from units 4-9 (U) (Thompson, 1948, type specimens collected from this horizon), 3-25 (C), and 3-27 (C). This includes the lowest occurrence of the genus at Whiskey Canyon and the type Derryan section.

FUSULINELLA ACUMINATA Thompson 1936
Pl. 5, figs. 1-11

1936. *Fusulinella acuminate* Thompson, p. 101, pl. 13, figs. 5-7.
1948. *Fusulinella acuminate:* Thompson, pp. 89-90, pl. 32, fig. 3, pl. 34, figs. 1-19.
1970. *Fusulinella* cf. *F. acuminate:* Stewart, p. 42, pl. 17, fig. 20.

Description-Small, fusiform test of five, six, or rarely seven volutions with gently convex to slightly concave lateral slopes, bluntly pointed polar extremities, and a straight axis of coiling. Mature specimens of six volutions range from 2.5 to 3.75 mm in length and 1.0 to 1.2 mm in width. Mean length is 3.09 mm and mean width 1.10 mm, with the form ratio approximately 2.8. Proloculus is small, spherical in most specimens but irregular in some. Its diameter ranges from 0.062 to 0.116 mm, with a mean of 0.085 mm. Half-lengths of first through fifth volutions average 0.109 mm, 0.248 mm, 0.478 mm, 0.793 mm, and 1.170 mm. Radius vectors of first through fourth volutions average 0.075 mm, 0.130 mm, 0.207 mm, 0.302 mm, and 0.439 mm. Chomata development is irregular and asymmetrical. Chomata are typically low and narrow or high, narrow, and overhanging, but may be broader in some specimens. Tunnel is well developed, slightly irregular. Tunnel widths of first through fifth volutions average 0.036 mm, 0.057 mm, 0.093 mm, 0.168 mm, and 0.253 mm. Wall includes diaphanotheca in all but innermost one or two volutions. Septa are weakly to moderately fluted in polar regions. Septal count averages 9, 14, 17, 19, and 21 in first through fifth volutions.

Remarks-The type specimens of *F. acuminata* are from the Minnelusa Formation of South Dakota (Thompson, 1936). Thompson (1948) clarified his concept of the species with the description of additional specimens from the "Fra Cristobal Formation" in the Mud Springs Mountains of New Mexico. The latter specimens were similar to the types in all respects except a somewhat smaller range of prolocular diameters.

Specimens recovered in this study are similar to the types and nearly identical to Thompson's (1948) New Mexico specimens. They are slightly more fusiform and have a smaller proloculus than the types. Mean proloculus diameter is also slightly smaller than Thompson's New Mexico specimens, but the range is similar.

Thompson (1948) noted the low, narrow, and asymmetrical chomata characteristic of the species. Specimens recovered in this study have a wider range of chomata development, including typical forms as well as high overhanging and, in some cases, broad chomata. This development shows a continuum within acceptable limits of intraspecific variability. The most massive chomata are similar to those of *F. fugax,* but that species is somewhat smaller, more inflated, and has a more primitive diaphanotheca development and a smaller proloculus than *F. acuminata.*

F. acuminata is closely similar to *F. protensa* (Thompson, 1936) from the Atokan Hartville Formation of Wyoming and the Horquilla Limestone of southeast Arizona (Ross & Sabins, 1965). Differences between these nominal species are unclear. *F. acuminata* is also closely similar to *F. prolifica* (Thompson, 1935) from the Atoka Formation of south-central Oklahoma. *F. acuminata* can be differentiated from *F. prolifica* on the basis of its overall larger size, but use of size as the sole character for taxonomic separation is difficult to justify. *F. acuminata* is similar to *F. devexa* but is smaller and has a less continuous diaphanotheca and a more consistent shape. The reader is referred to remarks under *Fusulinella devexa* for further discussion of its relation to *F. acuminata.*

F. acuminata is found at the lowest stratigraphic occurrence of the genus at all measured sections. Stewart (1970) also found *F. acuminata* at the lowest occurrence of the genus north of the study area in the Joyita Hills, Socorro County, New Mexico.

Occurrence—F. *acuminata* has been recovered from units 1-119 (A), 1-123 (A), 1-127 (C), 1-131 (C), 2-81 (C), 2-82 (C), 2-86 (U), 3-25 (U), 3-27 (C), 3-31 (C), 3-32 (C), 3-35 (C), 3-38 (C), 3-39 (C), 4-9 (C), 4-11 (A), 4-18 (U), 4-24 (U), and 4-30 (C). This includes a zone below the first occurrence of *Fusulinella devexa* at the Vinton Canyon, type Derryan, and Whiskey Canyon sections. *F. acuminata* first occurs in association with *F. devexa* at the Bishop Cap section.

FUSULINELLA PROXIMA Thompson 1948

Pl. 5, figs. 12-15

1948. *Fusulinella proxima* Thompson, pp. 90-91, pl. 33, figs. 9-20.

Description—Relatively large, inflated fusiform test of seven to eight volutions with gently convex to gently concave lateral slopes, broadly rounded to truncate polar extremities, and a straight axis of coiling. Mature specimens of eight volutions range from 2.28 to 3.93 mm in length and from 1.43 to 2.02 mm in width. Mean length is 3.21 mm and mean width 1.78 mm, with the form ratio approximately 1.8. Proloculus is spherical to cylindrical. Its diameter ranges from 0.054 to 0.103 mm, with a mean of 0.081 mm. Half-lengths of first through seventh volutions average 0.070 mm, 0.153 mm, 0.294 mm, 0.469 mm, 0.667 mm, 0.955 mm, and 1.235 mm. Radius vectors of first through seventh volutions average 0.077 mm, 0.125 mm, 0.183 mm, 0.288 mm, 0.375 mm, 0.506 mm, and 0.676 mm. Chomata are high, broad, and overhanging. Tunnel is highly erratic, narrow in early volutions and rapidly widening in outer volutions. Tunnel widths of first through seventh volutions average 0.028 mm, 0.041 mm, 0.084 mm, 0.10 mm, 0.167 mm, 0.282 mm, and 0.598 mm. Wall includes distinct diaphanotheca in outer volutions. Septa are weakly fluted in polar regions. Specimens were not recovered in numbers sufficient for a septal count.

Remarks—Specimens are similar to the types but are more inflated and somewhat less elongate. However, their high number of volutions, large overall size, chomata development, septal fluting, and wall structure are characteristic of the species.

F. proxima has more volutions than other co-occurring members of the genus. It is more inflated and has larger chomata and a straighter axis of coiling than *F. devexa. F. proxima* is larger and more inflated than *F. fugax* or *F. acuminata.* The chomata are broader than in *F. acuminata,* and high and overhanging unlike in *F. fugax.*

Occurrence—F. *proxima* has been recovered from units 1-127 (R), 3-27 (R), and 3-31 (R). Specimens have not been recovered from the type locality at Whiskey Canyon (Thompson, 1942a: 37, unit 11-17; unit 4-26 of this study). This horizon is within the *Fusulinella devexa* Lineage Zone. *F. proxima* occurs with *F. acuminata* at the type Derryan and Vinton Canyon sections.

FUSULINELLA DEVEXA Thompson 1948

Pl. 6, figs. 1-12

1948. *Fusulinella devexa* Thompson, pp. 94-95, pl. 32, figs. 6, 10, pl. 35, figs. 1-15, pl. 36, figs. 7-10, 12-17.

1948. *Fusulinella* sp. A: Thompson, p. 96, pl. 36, figs. 1-6, 11.

1961. *Fusulinella devexa* Thompson: Rich, pl. 143, figs. 6-9.

1965. *Fusulinella devexa* Thompson: Ross & Sabins, p. 186, pl. 24, figs. 13-18, ?19-22.

Description—Relatively large test of six or seven volutions with gently convex to concave lateral slopes and bluntly pointed polar extremities. Axis of coiling is straight to broadly curved. Mature specimens of seven volutions range from 3.69 to 5.42 mm in length and 1.34 to 2.0 mm in width. Mean length is 4.51 mm and mean width 1.58 mm, with the form ratio approximately 2.8. Proloculus is spherical. Its diameter ranges from 0.073 to 0.126 mm, with a mean of 0.091 mm. Half-lengths of first through sixth volutions average 0.120 mm, 0.205 mm, 0.459 mm, 0.748 mm, 1.215 mm, and 1.758 mm. Radius vectors of first through sixth volutions average 0.087 mm, 0.132 mm, 0.215 mm, 0.314 mm, 0.456 mm, and 0.642 mm. Chomata are well developed, asymmetrical, high, narrow, and overhanging to high and broad. Tunnel is well developed and relatively straight. Tunnel widths of first through sixth volutions average 0.033 mm, 0.058 mm, 0.107 mm, 0.185 mm, 0.346 mm, and 0.445 mm. Wall includes a well developed, relatively thick diaphanotheca in all but the innermost volutions. Septa are fluted in polar regions. Weakly fluted septa extend out of polar regions in some specimens, especially on lateral slopes of specimens near upper range of occurrence. Septal count averages 10, 14, 17, 18, 22, and 25 in first through sixth volutions.

Remarks-Specimens show a range of variability very similar to the types. However, the mean length and form ratios are somewhat higher. Ross & Sabins (1965: 186) noted that specimens in southeast Arizona from the upper part of the range of this species tend to be more elongate. New Mexico specimens also increase in length and overall size at higher strati-graphic horizons. The most elongate forms of *F. devexa* are similar to *F. juncea* but have a more irregular axis of coiling, a smaller form ratio, slightly smaller chomata, and less intensely folded septa in the polar areas.

F. devexa is larger, but otherwise is morphologically very similar to *F. acuminata*. The division between these two species is somewhat arbitrary, as they appear to form a continuous evolutionary sequence. Typical *F. devexa* tends to be larger, has more advanced septa, more advanced diaphanotheca development, larger chomata, and a more variable axis of coiling. However, the stratigraphic ranges of these species overlap significantly and a continuum of intermediate forms occurs.

Rich (1961) identified *F. devexa* from upper Atokan strata in the Bird Springs Formation of Nevada. Ross & Sabins (1965) identified *F. devexa* from the Horquilla Limestone of southeastern Arizona. Stewart (1970) described large and somewhat inflated *F. devexa* from near the upper range of the species in the Joyita Hills of central New Mexico. Myers (1988) figured *F. devexa* from the Sandia Formation in the Manzano Mountains, New Mexico. Douglass & Nestell (1984) described *F.* aff. *devexa* from the Atoka Formation in south-central Oklahoma. *F. barnettensis* Douglass & Neste11 1984, from the upper Atoka Formation, is very similar to *F. devexa* in the upper part of its New Mexico range. Differences between these nominal species are unclear. *F. devexa* is similar to *F. vacua* Waddell 1966 from the Ardmore Basin, Oklahoma, but has a shorter axis of coiling, slightly lower septal count, narrower tunnel, and a smaller proloculus.

Occurrence-F. *devexa* has been recovered from units 1-131 (U), 1-136 (C), 1-139 (A), 1-140 (C), 1-142 (A), 2-81 (R), 2-86 (A), 2-87 (A), 2-89 **(R),** 3-39 (U), 3-40 (C), 3-41 (C), 4-20 (U), 4-30 (U), 4-33 (C), and 4-42 (R).

FUSULINELLA cf. *JUNCEA* Thompson 1948
Pl. 5, figs. 16-18

1948. *Fusulinella juncea* Thompson, pp. 93-94, pl. 32, fig. 1, pl. 37, figs. 1-18.

1970. *Fusulinella juncea* Thompson: Stewart, p. 42, pl. 3, figs. 18, 19, 21-25.

Description-Highly elongate fusiform test of six to seven volutions with straight to gently convex lateral slopes and bluntly to sharply pointed polar extremities. Specimens are tightly coiled around a relatively straight axis. Form ratios range from 3.1 to 3.66, with a mean of 3.4. Other characteristics are closely similar to *F. devexa.*

Remarks-Thompson (1948) described this distinctly elongate fusiform species from Whiskey Canyon in the Mud Springs Mountains. Stewart (1970) assigned specimens with a slightly lower form ratio (3.3 as opposed to 3.7 in the types) from the Joyita Hills to this species. The most elongate members of the genus recovered in this study are similar to Ste-wart's (1970) specimens, but do not match the types. Thompson (1948: 94) noted the similarity of *F. devexa* to *F. juncea* and differentiated the two in part on the basis of the larger form ratio of the latter. Several specimens with form ratios higher than that of typical *F. devexa* but lower than most types of *F. juncea* are tentatively assigned to the latter species. These intermediate forms, and the fact that in the study area the range of *F. juncea* is completely within the range of *F. devexa,* suggest that these nominal species could be ecological variants rather than separate species.

Occurrence-F. cf. *juncea* has been recovered from units 1-140 (U), 2-86 (U), and 3-41 (U). It was not recovered from the type section of *F. juncea* at Whiskey Canyon (Thompson, 1942a, unit 11-20; unit 4-30 of this study).

FUSULINELLA FAMULA Thompson 1948
Pl. 7, figs. 1-8

1948. *Fusulinella famula* Thompson, pp. 91-93, pl. 32, figs. 4, 5, pl. 38, figs. 1-8.

Description-Small to medium size, inflated or obese test of seven to eight volutions with straight to concave lateral slopes and broadly rounded polar extremities. Relatively tightly coiled around a straight axis. Mature specimens with seven volutions range from 2.27 to 3.99 mm in length and 1.19 to 2.01 mm in width. Mean length is 2.87 mm and mean width 1.55 mm, with the form ratio approximately 1.8. Proloculus is small and spherical. Its diameter ranges from 0.063 to 0.107 mm, with a mean of 0.079 mm. Half-lengths of first through seventh volutions average 0.121 mm, 0.230 mm, 0.376 mm, 0.542 mm, 0.784 mm, 1.071 mm, and 1.434 mm. Radius vectors of first through seventh volutions average 0.085 mm, 0.142 mm, 0.241 mm, 0.311 mm, 0.433 mm, 0.589 mm, and 0.774 mm. Chomata are well developed, very broad, high or high and overhanging. Tunnel is narrow but well developed. Tunnel path is only slightly irregular. Tunnel widths of first through seventh volutions average 0.029 mm, 0.041 mm, 0.062 mm, 0.096 mm, 0.154 mm, 0.244 mm, and 0.366 mm. Wall includes a well developed diaphanotheca in all but innermost volutions. Septa are fluted in polar regions, with some weak septal fluting extending onto lateral slopes. Septal count on rare saggital specimens averages 9, 16, 19, 22, 26, 28, and 29 in first through seventh volutions.

Remarks—Specimens show a range of variation similar to the types. *F. famula* is a highly advanced member of the genus similar to *Beedeina insolita,* but *F. famula* has more massive, broader chomata, a more regular tunnel path, and less septal fluting. However, these species occur together and some specimens have somewhat intermediate morphologies. The reader is referred to remarks under *B. insolita* for further discussion of its relation to *F. famula.*

F. famula is closely similar to *F. iowensis* Thompson 1934 from the Desmoinesian of Iowa and *F. leyi* Thompson 1945 (as *F. iowensis* var. *leyi)* from northwest Colorado, and these forms appear closely related. *F. famula* is larger and has more massive chomata than *F. iowensis* or *F. leyi,* and is more elongate than *F. iowensis.* Each of these forms occurs in lower Desmoinesian strata.

Ross & Sabins (1965) found *F. famula* in lower Desmoinesian strata of the Horquilla Limestone of southeast Arizona. Stewart (1970) described *F.* cf. *famula* from the Joyita Hills in central New Mexico. Myers (1988) described *F. famula* and *F.* cf. *famula* from the Los Moyos Limestone in the Manzano Mountains of central New Mexico, but his specimens are unconvincing.

Occurrence—F. *famula* has been recovered from units 1-145 (U), 1-147 (U), 3-43 (U), 3-44 (U), 3-48 (U), and 4-42 (U).

Genus *BEEDEINA* Galloway 1933

BEEDEINA INSOLITA (Thompson 1948) Pl. 7, figs. 9-16

1948. *Fusulina? insolita* Thompson, pp. 96-97, pl. 32, fig. 7, pl. 38, figs. 9-13.
1965. *?Fusulinella famula:* Ross & Sabins, pl. 25, fig. 27.
1970. *Beedeina insolita:* Stewart, pp. 44-45, pl. 4, figs. 11-19.

Description—Small to medium size, inflated or rhomboidal test of six to eight volutions with straight to slightly concave lateral slopes, bluntly pointed polar extremities, and straight axis of coiling. Mature specimens of seven volutions range from 2.08 to 4.14 mm in length and 1.50 to 1.86 mm in width. Mean length is 3.19 mm and mean width 1.66 mm, with the form ratio approximately 1.9. Proloculus is spherical. Its diameter ranges from 0.060 to 0.127 mm, with a mean of 0.082 mm. Half-lengths of first through sixth volutions average 0.114 mm, 0.242 mm, 0.393 mm, 0.622 mm, 0.922 mm, and 1.305 mm. Radius vectors of first through sixth volutions average 0.081 mm, 0.142 mm, 0.226 mm, 0.347 mm, 0.506 mm, and 0.689 mm. Chomata are well developed, high, narrow, and overhanging. Tunnel path is erratic to strongly erratic. Tunnel widths of first through sixth volutions average 0.031 mm, 0.051 mm, 0.086 mm, 0.128 mm, 0.218 mm, and 0.335 mm. The wall includes a well developed diaphanotheca and relatively thick inner and outer tectoria. Septa are strongly fluted in polar regions and weakly to moderately fluted across rest of shell. Septal count in a single sagittal section identified 4, 14, 18, 23, 30, 32, 36, and 40 septa in first through eighth volutions.

Remarks—Ishii (1958) argued that most species previously referred to as *Fusulina* (including *Beedeina insolita)* in North America are more closely related, and should be assigned, to *Beedeina.* Most recent workers accepted Ishii's arguments and followed his usage (e.g. Ross, 1969; Stewart, 1970; Douglass, 1977; Douglass & Nestell, 1984). Groves (1991), however, argued against this reassignment and rejected it on several grounds. An analysis of the *Beedeina/Fusulina* problem is beyond the scope of this paper. Following the more widely accepted nomenclature, *Beedeina* has been chosen over *Fusulina* in this paper.

B. insolita is a very primitive member of the genus. The figured type specimens show a wide range of variation, but, for the most part, they are poorly oriented. No sagittal sections are included in the types, possibly due to the difficulties in preparing specimens with erratic tunnel paths in this orientation. Specimens recovered in this study have a wider range of length and width values than the types, but their form ratios are similar at all stages of growth. Prolocular diameters are somewhat smaller than in the types.

B. insolita is similar to *Fusulinella famula.* Both species are somewhat intermediate between typical *Fusulinella* and *Beedeina. B. insolita* is differentiated from *F. famula* on the basis of its wider tunnel, more erratic tunnel path, narrower chomata, and more advanced septal fluting. However, *F. famula* occurs in the lower part of the *B. insolita* range, and the two are clearly closely related.

B. insolita is similar to *B. lewisi* Douglass & Nestell 1984, but is larger and has straighter lateral slopes and a more irregular tunnel path. *B. insolita* is smaller, slightly more inflated, and has more massive chomata and a much more irregular tunnel path than *B. hayensis* (Ross & Sabins 1965). It is more primitive and stratigraphically lower than *B. pristina* (Thompson 1945). *B. insolita* has been identified in many studies of lowest Desmoinesian fusulinids in the central and southwestern United States, including Waddell (1966), Stewart (1970), Verville et al. (1986), and Myers (1988).

Occurrence—B. *insolita* has been recovered from units 1-145 (U), 1-147 (U), 1-160 (R), 2-9((R), 2-100 (R), 343 (U), 3-44 (U), 3-47 (R), 3-48 (U , 4-33? (reported type locality, see Thompson, 1948, section 11, bed 24, "specimens rare"), 4-36 (specimens very rare), and 442(C).

BEEDEINA aff. *HAYENSIS* (Ross & Sabins 1965) Pl. 8, figs. 1-12

1948. *?Fusulina* n. sp.: Thompson, pl. 32, fig. 8.
1965. *Beedeina hayensis* Ross & Sabins, pp. 192-193, pl. 27, figs. 9-16.

Description—Relatively small, rhomboidal to inflated fusiform test of seven or eight volutions with straight to concave lateral slopes, bluntly pointed polar extremities, and a straight to gently curved axis of coiling. Mature specimens with eight volutions range from 3.86 to 4.49 mm in length and 1.57 to 2.04 mm in width. Mean length is 4.10 mm and mean width is 1.87 mm, with the form ratio approximately 2.0. Proloculus is small and spherical. Its diameter ranges from 0.043 to 0.095 mm, with a mean of 0.064 mm. Half-lengths of first through seventh volutions average 0.085 mm, 0.207 mm, 0.366 mm, 0.607 mm, 0.900 mm, 1.320 mm, and 1.648 mm. Radius vectors of first through seventh volutions average 0.071 mm, 0.124 mm, 0.192 mm, 0.317 mm, 0.468 mm, 0.657 mm, and 0.798 mm. Chomata are well developed, high, narrow, and overhanging. Tunnel is relatively narrow and regular. Tunnel widths of first through seventh volutions average 0.032 mm, 0.059 mm, 0.091 mm, 0.145 mm, 0.232 mm, 0.302 mm, and 0.368 mm. Septal fluting is somewhat erratic but moderate to strong across entire shell. Septal count averages 8, 13, 14, 18, 23, and 27 in first through sixth volutions.

Remarks-B. *hayensis* from the Horquilla Limestone of southeastern Arizona is a primitive species of the genus, only slightly more advanced than *B. insolita. B. hayensis* is slightly smaller and somewhat less inflated than *B. arizonensis* (Ross & Sabins 1965). These forms show a minimal range of variation with no obvious morphologic breaks, however, and their separation may not be justifiable.

Specimens collected in this study are similar to the types but differ in their slightly smaller proloculus and somewhat more advanced septal fluting. *B. aff. hayensis* has more advanced septal fluting, a wider, more regular tunnel, narrower chomata, and a slightly more fusiform test than *B. insolita.* It is more inflated than *B. cedarensis* (Ross & Sabins) and has less septal fluting than *B. taosensis* (Needham).

B. aff. hayensis is abundant in a zone ranging from near the base of the Desmoinesian Series through the first occurrence of *Wedekindellina* in the study area and in southeastern Arizona (Ross & Sabins, 1965).

Occurrence-B. aff. *hayensis* has been recovered from units 1-164 (U), 1-170 (C), 2-100 (R), 2-115 (A), 2-117 (U), 3-44 (R), 3-56 (U), 3-57 (C), 3-60 (U), 4-52 (C), 455 (C), and 4-61 (C).

BEEDEINA aff. *CURTA* (Thompson 1945)
P1. 9, figs. 1-8

1945. *Fusulina curta* Thompson, pp. 63-64, pl. 6, figs. 10-16.

Description-Relatively large, inflated to obese test of eight to ten volutions with concave to gently convex lateral slopes and broadly polar extremities. Somewhat loosely coiled, with asymmetrical early volutions. Mature specimens of eight volutions range from 2.97 to 5.15 mm in length and 2.07 to 2.77 mm in width. Mean length is 3.93 mm and mean width 2.37 mm. Shape of test shows little change during growth. Form ratios of second through ninth volutions average 1.3, 1.3, 1.5, 1.6, 1.5, 1.5, 1.6, and 1.6. Proloculus is spherical to ovoid. Its diameter ranges from 0.105 to 0.135 mm, with a mean of 0.111 mm. Half-lengths of first through seventh volutions average 0.126 mm, 0.243 mm, 0.384 mm, 0.572 mm, 0.889 mm, 1.059 mm, and 1.44 mm. Radius vectors of first through seventh volutions average 0.115 mm, 0.187 mm, 0.296 mm, 0.379 mm, 0.540 mm, 0.732 mm, and 0.732 mm. Chomata are high, narrow, and overhanging. Tunnel is narrow and somewhat erratic. Tunnel widths of first through seventh volutions average 0.032 mm, 0.051 mm, 0.072 mm, 0.107 mm, 0.166 mm, 0.245 mm, and 0.346 mm. Wall is composed of tectum with well developed diaphanotheca and upper and lower tectoria. Protheca thicknesses of first through eighth volutions average 0.012 mm, 0.014 mm, 0.015 mm, 0.017 mm, 0.019 mm, 0.020 mm, 0.022 mm, and 0.021 mm. Septa are moderately to strongly fluted throughout test. Septal count on two specimens averages approximately 9, 15, 17, 24, 28, 29, and 32 on first through seventh volutions.

Remarks-Specimens are larger, slightly more fusiform, and have a more variable coiling axis, more erratic tunnel path, and a lower septal count than the types of *B. curta* from the Youghall Formation of northwestern Colorado.

The axis of coiling in *B.* aff. *curta* is more variable than in other members of the genus. *B. aff. curta* has more advanced septal fluting and a larger, more inflated test than *B. insolita.* It is larger, but has less advanced septal fluting and a more erratic tunnel path than *B. girtyi* (Dunbar & Condra). *B. aff. curta* is similar in size to *B. novamexicana* (Needham) but has less regular septal fluting and a more inflated shape. The morphology and stratigraphic position of *B. aff. curta* indicate that it is an evolutionary intermediate between the very primitive *B. insolita* and more advanced members of the genus such as *B. novamexicana.*

Occurrence-B. *aff. curta* has been recovered from unit 1-166 (C).

BEEDEINA? aff. *ROCKYMONTANA*
(Roth & Skinner 1930) Pl. 11, figs. 1-6

1930. *Fusulina rockymontana* Roth & Skinner, **pp.** 344-345, **pl.** 31, figs. 4-6.

1936. *Fusulina rockymontana:* Thompson, p. 109, pl. 16, figs. 1, 10, 11.

1945. *Fusulina rockymontana:* Thompson, pp. 62-63, pl. 5, figs. 19-25.

Description-Fusiform to elongately fusiform test of seven or rarely eight volutions with concave to straight lateral slopes, bluntly pointed polar extremities, and a straight axis of coiling. Mature specimens with seven volutions range from 3.47 to 4.78 mm in length and 1.45 to 1.78 mm in width. Mean length is 4.18 mm and mean width 1.64 mm, with the form ratio approximately 2.5. Proloculus is small and spherical. Its diameter ranges from 0.078 to 0.117 mm, with a mean of 0.093 mm. Half-lengths of first through sixth volutions average 0.130 mm, 0.257 mm, 0.464 mm, 0.775 mm, 1.186 mm, and 2.088 mm. Radius vectors of first through sixth volutions average 0.091 mm, 0.144 mm, 0.220 mm, 0.337 mm, 0.481 mm, and 0.646 mm. Chomata are high and narrow, commonly overhanging in outer volutions. Tunnel is relatively narrow and slightly irregular. Tunnel widths of first through fourth volutions average 0.034 mm, 0.058 mm, 0.109 mm, 0.177 mm, 0.262 mm, and 0.499 mm. Wall is composed of a tectum and diaphanotheca with relatively thin but consistent upper and lower tectoria. Septa are strongly fluted in polar areas and moderately to weakly fluted over the rest of test. Septal count for a single specimen is 9, 14, 18, 22, and 24 in first through fifth volutions.

Remarks-These specimens are similar to *B. rockymontana* (Roth & Skinner 1930) from the McCoy Formation of Colorado, but they are smaller, more fusiform, and have less advanced septal fluting on the lateral slopes. They are similar in size and shape to *Fusulinella devexa,* but have slightly more developed septal fluting. They have less septal fluting than *B. rockymontana* (Thompson 1936) from the Hartville Formation of Wyoming, but appear closely similar to *B. rockymontana* from the Youghall Formation in northeastern Utah (Thompson, 1945). *B.? aff. rockymontana* is smaller and has less septal fluting, a straighter axis of coiling, and a more regular shape than *B. portalensis* (Ross & Sabins 1965) from the Horquilla Limestone in southeastern Arizona. However, all these forms are more similar than different, are found in nearly equivalent stratigraphic horizons, and appear to be closely related.

B.? aff. rockymontana has very primitive septal fluting for the genus. It is associated with *B. aff. hayensis* in each of its occurrences at the Bishop Cap and type Derryan sections. It appears closely related to, and is almost certainly the direct evolutionary descendant of, *Fusulinella devexa.*

Occurrence-B.? aff. *rockymontana* has been recovered from units 2-100 (R), 2-115 (R), 3-56 (C), and 360(U).

BEEDEINA aff. *JOYITAENSIS* Stewart 1970
Pl. 10, figs. 1-9

1970. *Beedeina joyitaensis* Stewart, p. 48, pl. 6, figs. 1-8.

Description-Relatively large, inflated fusiform test of seven to eight volutions with straight lateral slopes, broadly rounded to bluntly pointed polar extremities, and a straight axis of coiling. Mature specimens of seven volutions range from 2.90 to 4.92 mm in length and 1.61 to 2.59 mm in width. Mean length is 3.93 mm and mean width 2.02 mm, with the form ratio approximately 1.9. Proloculus is spherical and relatively large. Its diameter ranges from 0.084 to 0.119 mm, with a mean of 0.101 mm. Half-lengths of first through sixth volutions average 0.111 mm, 0.242 mm, 0.446 mm, 0.713 mm, 1.052 mm, and 1.477 mm. Radius vectors of first through sixth volutions average 0.099, 0.167 mm, 0.261 mm, 0.387 mm, 0.563 mm, and 0.789 mm. Chomata are high, narrow, and overhanging. Tunnel path is somewhat erratic. Tunnel widths of first through sixth volutions average 0.039 mm, 0.064 mm, 0.097 mm, 0.163 mm, 0.227 mm, and 0.373 mm. Wall is relatively thin. Diaphanotheca is absent in inner volutions but well developed in outer volutions. Septal fluting is irregular but moderate to strong across the entire test. Septal count for a single specimen is 10, 17, 16, 20, 27, and 25 in first through sixth volutions.

Remarks-Specimens are somewhat intermediate between *B. joyitaensis* Stewart from the Joyita Hills in central New Mexico and *B. hayensis* (Ross & Sabins) from the Horquilla Limestone of southeast Arizona. *B. aff. joyitaensis* is slightly larger than *B. hayensis,* but not as large or as fusiform as the types of *B. joyitaensis.* The proloculus is significantly larger than in *B. hayensis* but smaller than in *B. joyitaensis.* Septal fluting and chomata development of *B. aff. joyitaensis* are also intermediate between *B. hayensis* and *B. joyitaensis,* though they more closely resemble the latter species.

B. aff. joyitaensis is more inflated than *B. rockymontana* (Roth & Skinner). It is larger and has more complex septal fluting than *B. pristina (*Thompson 1945). *B. aff. joyitaensis* is similar to *B. boviensis* (Ross & Sabins) but is smaller, less fusiform, and has a smaller proloculus and more erratic septal fluting.

Occurrence-B. aff. *joyitaensis* is .ssociated with *B. hayensis, B. aff. rockymontana,* and *Wedekindellina excentrica* at the Vinton Canyon and ype Derryan sections. *B. aff. joyitaensis* has been recovered from units 1-164 (C), 1-172 (C), 1-175 (R), 3-57 U), and 3-60 (U).

Genus *WEDEKINDELLINA* Dunbar Sr Henbest 1933
WEDEKINDELLINA EXCENTRICA (Roth & Skinner 1930) Pl. 11, figs. 7-16

1930. *Wedekindella excentrica* Roth & Skinne pp. 340-341, pl. 30, figs. 1-3.

1936. *Wedekindellina excentrica* (Roth and Skinner): Thompson, pp. 105-106, pl. 15, figs. 6, 9-11, pl. 6, fig. 12.

Description-Relatively small, elongately fusiform

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test of eight, nine, or rarely ten vol ions with straight to concave lateral slopes, bluntly pointed polar extremities, and a straight to gently curved axis of coiling. Mature specimens with nine v utions range from 2.47 to 4.16 mm in length and 0. 37 to 1.63 mm in width. Mean length is 3.55 mm anc mean width 1.16 mm, with the form ratio approxin ately 3.1. Proloculus is small and spherical. Its diameter ranges from 0.041 to 0.076 mm, with a mean o 0.057 mm. Half-lengths of first through eighth volut ons average 0.066 mm., 0.135 mm, 0.277 mm, 0.442 mm, 0.663 mm, 0.915 mm, 1.203 mm, and 1.497 in] n. Radius vectors of first through eighth volutions a' Average 0.053 mm, 0.082 mm, 0.117 mm, 0.166 nun, 0.221 mm, 0.294 mm, 0.392 mm, and 0.468 mm. Chomata are high and narrow. Tunnel is narrow and slightly to strongly irregular. Wall is relatively thin and includes diaphanotheca in equatorial regions. Individual wall layers are obscured by strong axial filling in poll r areas. Septa are straight to weakly fluted in polar regions, but are completely obscured by axial filling g in some specimens. Septal count for a single sp ecimen is 10, 14, 18, 20, 24, 27, and 40 in first throe: gh seventh volutions.

Remarks-Specimens are closely simlar to the types, but are slightly smaller. Some specimens have a more regular tunnel path, and rare individluals have a more irregular axis of coiling.

W. excentrica is closely similar to W . *alveolata* Stewart 1970. These species were differentiated on the basis of the higher form ratio in the sixth and seventh volutions, and the lack of axial filling in the later volutions of W. *alveolata.* However, Stewart (1970) found *W. alveolata* always associated with *N. excentrica,* and these forms may not be truly distinct.

W. excentrica has a lower form rati) than W. *elongata* Stewart. It is similar to W. *euthysepte* (Henbest) but is somewhat smaller and has more volul ions and a slightly lower form ratio. W. *cabezasensis* Ros 3 & Sabins is similar in size but has lighter axial filling than W. *excentrica.*

W. excentrica is the stratigraphicall y lowest member of the genus in the study area. Its first occurrence is a biostratigraphically significant horizon. Since no form immediately ancestral to the germ: is found in the western United States, this may be a migratory first occurrence.

Occurrence—W. *excentrica* has been recovered from units 1-175 (R), 2-117 (U), 3-60 (C), and 4-62 (U).

References

Bachman, G. 0., 1975, New Mexico; *in* McKee, E. D. & Crosby, E. J. (coordinators), Paleotectonic investigations of the Pennsylvanian System, part I: Introduction and regional analyses of the Pennsylvanian System: U.S. Geological Survey, Professional Paper 853-L: 233-243.

Bengtson, P., 1988, Open nomenclature: Palaeontology, 31 P(1): 223-227.

Clopine, W. W., 1990, Middle Pennsylvanian fusulinid biostratigraphy of the type Derryan area in southern New Mexico and westernmost Texas: Unpublished PhD Dissertation, University of Oklahoma, Norman, 271 pp.

Clopine, W. W., 1991, Lower and Middle Pennsylvanian measured sections, type Derry region, southern New Mexico and westernmost Texas: New Mexico Bureau of Mines & Mineral Resources, Open-File Report 373: 122 pp.

Clopine, W. W., Manger, W. L., Sutherland, P. K. & Kaiser, D. A., 1991, Lower and Middle Pennsylvanian stratigraphic relations, type Derryan region, southern New Mexico and westernmost Texas; *in* Julian, B. & Zidek, J. (eds.), Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines & Mineral Resources, Bulletin 137: 173-181.

Connolly, W. M. & Stanton, R. J., Jr., 1983, Sedimentation and paleoenvironment of Morrowan strata in the Hueco Mountains, West Texas; *in* Guidebook to the Geology of the Sierra Diablo and Southern Hueco Mountains: Permian Basin Section, Society of Economic Paleontologists and Mineralogists, pp. 36-64.

Connolly, W. M. & Stanton, R. J., Jr., 1986, Lower Pennsylvanian (Morrowan) sedimentation in the Orogrande Basin; *in* Southwest Section of A.A.P.G., Transactions and guidebook of 1986 Convention, Ruidoso, New Mexico: New Mexico Bureau of Mines & Mineral Resources, pp. 129-142.

Coogan, A. H., 1964, Early Pennsylvanian history of Ely Basin, Nevada: American Association of Petroleum Geologists, Bulletin, 48: 487-495.

Crosby, E. J. & Mapel, W. J., 1975, Central and West Texas; *in* McKee, E. D. & Crosby, E. J. (coordinators), Paleotectonic investigations of the Pennsylvanian System, part I: Introduction and regional analyses of the Pennsylvanian System: U.S. Geological Survey, Professional Paper 853-L: 196-232.

Cushman, J. A. & Waters, J. A., 1928, Some foraminifera from the Pennsylvanian and Permian of Texas: Contributions from the Cushman Laboratory for Foraminiferal Research, 4 (2): 31-55.

Douglass, R. C., 1977, The development of fusulinid biostratigraphy; *in* Kauffman, E. G. & Hazel, J. E. (eds.), Concepts and Methods of Biostratigraphy: Dowden, Hutchinson, and Ross, Stroudsburg, Pennsylvania, pp. 463-481.

Douglass, R. C., 1987, Fusulinid biostratigraphy and correlations between the Appalachian and eastern interior basins: U.S. Geological Survey, Professional Paper 1451: 95 pp.

Douglass, R. C. & Nestell, M. K., 1984, Fusulinids of the Atoka Formation, Lower–Middle Pennsylvanian, south-central Oklahoma; *in* Sutherland, P. K. & Manger, W. L. (eds.), The Atokan Series (Pennsylvanian) and its boundaries—A symposium: Oklahoma Geological Survey, Bulletin 136: 19-39.

Dunbar, C. O. & Condra, G. E., 1927, The Fusulinidae of the Pennsylvanian System in Nebraska: Nebraska Geological Survey Bulletin, 2nd ser., 2: 135 pp.

Dunbar, C. O. & Henbest, L. G., 1933, *Wedekindellina; in* Cushman, J. A., Foraminifera, their classification and economic use: Harvard University Press, Cambridge, Massachusetts, p. 134, key pl. 10, figs. 13-15.

Dunbar, C. O. & Henbest, L. G., 1942, Pennsylvanian Fusulinidae of Illinois: Illinois State Geological Survey, Bulletin 67: 218 pp.

Galloway, J. J., 1933, A Manual of Foraminifera: Principia Press, Bloomington, Indiana, 483 pp.

Gehrig, J. L., 1958, Middle Pennsylvanian brachiopods from the Mud Springs Mountains and Deny Hills, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Memoir 3: 24 pp.

Gordon, C. H., 1907, Mississippian (Lower Carboniferous) formations in the Rio Grande Valley: American Journal of Science (4), 24 (174): 58-64.

Groves, J. R., 1983, Calcareous foraminifers and algae from the type Morrowan (Lower Pennsylvanian) region of northeastern Oklahoma and northwestern Arkansas: Oklahoma Geological Survey, Bulletin 133: 65 pp.

Groves, J. R., 1984a, Stratigraphic significance of *Hemigordius harl-toni* Cushman and Waters, 1928 (Foraminiferida): Journal of Paleontology, 58 (1): 78-81.

Groves, J. R., 1984b, Foraminifers and biostratigraphy of the Arco Hills, Bluebird Mountain, and lower Snaky Canyon Formations (mid-Carboniferous) of east-central Idaho: Journal of Foraminiferal Research, 14: 282-302.

Groves, J. R., 1986, Foraminiferal characterization of the Morrowan–Atokan (lower Middle Pennsylvanian) boundary: Geological Society of America, Bulletin, 97: 346-353.

Groves, J. R., 1988, Calcareous foraminifers from the Bashkirian stratotype (Middle Carboniferous, south Urals) and their significance for intercontinental correlations and the evolution of the Fusulinidea: Journal of Paleontology, 62: 368-399.

Groves, J. R., 1991, Fusulinacean biostratigraphy of the Marble Falls Limestone (Pennsylvanian), western Llano region, central Texas: Journal of Foraminiferal Research, 21 (1): 67-95.

Groves, J. R. & Sanderson, G. A., 1990, Systematics of the North American species of *Profusulinella* (Middle Pennsylvanian), Fusulinidae: Micropaleontology, 36 (2): 105-140.

Harbour, R. L., 1958, Pennsylvanian and Permian rocks in the northern Franklin Mountains, Texas (abstract): Geological Society of America, Bulletin, 69 (12), pt. 2: 1727-1728.

Henbest, L. G., 1928, *Fusulinellas* from the Stonefort Limestone Member of the Tradewater Formation: Journal of Paleontology, 2: 70-85.

Ishii, K., 1958, On the phylogeny, morphology and distribution of *Fusulina, Beedeina,* and allied fusulinid genera: Journal of the Institute of Polytechnics, Osaka City University, Series G, 4: 29-70.

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

King, W. E., 1973, Fusulinids *Millerella* and *Eostaffella* from the Pennsylvanian of New Mexico and Texas: New Mexico Bureau of Mines & Mineral Resources, Memoir 26: 34 pp.

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

Kottlowski, F. E., 1969, Summary of late Paleozoic in El Paso border region; *in* Kottlowski, F. E. & LeMone, D. V. (eds.), Border stratigraphy symposium: New Mexico Bureau of Mines & Mineral Resources, Circular 104: 38-51.

Kottlowski, F. E. & Stewart, W. J., 1970, The Wolfcampian Joyita Uplift in central New Mexico: New Mexico Bureau of Mines & Mineral Resources, Memoir 23 (1): 1-31.

Lane, H. R., 1974, Mississippian of southeastern New Mexico and West Texas: A wedge-on-wedge relation: American Association of Petroleum Geologists, Bulletin, 58 (2): 269-282.

Lane, H. R., Sanderson, G. A. & Verville, G. J., 1972, Uppermost Mississippian–basal Middle Pennsylvanian conodonts and fusulinids from several exposures in the south-central and southwestern United States: Twenty-fourth International Geological Congress, Montreal, Section 7: 549-555.

Laporte, L. F., 1967, Carbonate deposition near mean sea level and resultant facies mosaic: Manlius Formation (Lower Devonian) of New York State: American Association of Petroleum Geologists, Bulletin, 51 (1): 73-101.

LeMone, D. V., King, W. E. & Cunningham, J. E., 1974, Pennsylvanian System of Chloride Flat, Grant County, New Mexico: New Mexico Bureau of Mines & Mineral Resources, Circular 131: 18 PP•

Loeblich, A. R. & Tappan, H., 1964, Sarcodina, chiefly "The Thecamoebians" and Foraminiferida; *in* Moore, R. C. (ed.), Treatise on Invertebrate Paleontology, Part C, Protista 2: Geological Society of America and University of Kansas Press, 510 pp.

Mamet, B. L., 1975, Carboniferous foraminifera and algae of the Amsden Formation (Mississippian and Pennsylvanian) of Wyoming: U.S. Geological Survey, Professional Paper 848-B: 18 pp.

Mamet, B. L. & Armstrong, A. K., 1972, Lisburne Group, Franklin and Romanzof Mountains, northeastern Alaska: U.S. Geological Survey, Professional Paper 800-C: 127-144.

Mamet, B. L. & Skipp, B., 1970, Preliminary foraminiferal correlations of Early Carboniferous strata in the North American Cordillera: Congres et Colloques, Colloque sur la Stratigraphie du Carbonifère, Université de Liege, 55: 325-348.

Manger, W. L., Sutherland, P. K. & Clopine, W. W., 1987, Morrowan-Atokan boundary relations, type "Derryan" section, New Mexico (abstract): Geological Society of America, South-Central Section Abstracts with Programs, 19 (3): 173.

Marshall, F. C., 1969, Lower and Middle Pennsylvanian fusulinids from the Bird Spring Formation near Mountain Spring Pass, Clark County, Nevada: Brigham Young University Geology Studies, 16 (1): 97-154.

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

Mikhailov, A. V., 1939, K kharakteristike rodov nizhnekamennougolnykh foraminifer territorii SSSR: Sbornik Leningradskogo Geologicheskogo Upravlenia, Glavnoe Geologicheskoe Upravlenie, 3: 47-62 (not seen).

Mims, R. L., 1971, Microfacies analysis of the La Tuna Formation (Morrowan), Vinton Canyon, El Paso County, Texas; *in* Guidebook to Robledo and Franklin Mountains: Permian Basin Section, Society of Economic Paleontologists and Mineralogists, pp. 87106.

Moller, V., von, 1878, Die spiral-gewunden Foraminiferen des russischen Kohlenkalks: Académie Impériale des Sciences de St.-Pétersbourg, Mémoires (7), 25: 147 pp.

Moore, R. C., Lalicker, C. G. & Fischer, A. G., 1952, Invertebrate Fossils: McGraw-Hill, New York, 766 pp.

Myers, D. A., 1988, Stratigraphic distribution of some Pennsylvanian fusulinids from the Sandia Formation and the Los Moyos Limestone, Manzano Mountains, New Mexico: U.S. Geological Survey, Professional Paper 1446-A: 21 pp.

Needham, C. E., 1937, Some New Mexico Fusulinidae: New Mexico Bureau of Mines & Mineral Resources, Bulletin 14: 59 pp.

Nelson, L. A., 1940, Paleozoic stratigraphy of Franklin Mountains, West Texas: American Association of Petroleum Geologists, Bulletin, 24 (1): 157-172.

Osleger, D. A., 1981, Stratigraphy and microfacies analysis of the La Tuna Formation (Morrowan-Atokan), Franklin Mountains, Texas and New Mexico, and Bishop Cap Hills, New Mexico: Unpublished MS thesis, University of Texas (El Paso), 138 pp.

Rauzer-Chernousova, D. M., 1948, Some new species of Foraminifera from the Lower Carboniferous sediments of the Moscow Basin [in Russian]: Akademia Nauk SSSR, Trudy Geologicheskogo Instituta, 62 (19): 227-238.

Rich, M., 1961, Stratigraphic section and fusulinids of the Bird Spring Formation near Lee Canyon, Clark County, Nevada: Journal of Paleontology, 35: 1159-1180.

Ross, C. A., 1969, Middle and Upper Pennsylvanian fusulinaceans, Gila Mountains, Arizona: Journal of Paleontology, 43: 1405-1422.

Ross, C. A. & Sabins, F. F., 1965, Early and Middle Pennsylvanian fusulinids from southeast Arizona: Journal of Paleontology, 39: 173-209.

Roth, R. & Skinner, J., 1930, The fauna of the McCoy Formation, Pennsylvanian of Colorado: Journal of Paleontology, 4: 332-352.

Seager, W. R., 1973, Geologic map and sections of Bishop Cap-Organ Mountains area: New Mexico Bureau of Mines & Mineral Resources, Geologic Map 29, scale 1:24,000.

Skinner, J. W., 1931, Primitive fusulinids of the mid-continent region: Journal of Paleontology, 5: 253-259.

Spivey, R. C. & Roberts, T. G., 1946, Lower Pennsylvanian terminology in central Texas: American Association of Petroleum Geologists, Bulletin, 30: 181-186.

Stewart, W. J., 1970, Fusulinids of the Joyita Hills, Socorro County, central New Mexico: New Mexico Bureau of Mines & Mineral Resources, Memoir 23 (2): 32-82.

Sutherland, P. K., 1985, The colonial rugose coral *Petalaxis* in the Middle Carboniferous of North America and its stratigraphic significance (abstract): Geological Society of America, Abstracts with Programs, 17 (7): 730.

Sutherland, P. K., 1991, Morrowan brachiopods from the type Derryan Series (Pennsylvanian), southern New Mexico; *in* Julian, B. & Zidek, J. (eds.), Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado: New Mexico Bureau of Mines & Mineral Resources, Bulletin 137: 186-188.

Sutherland, P. K. & Manger, W. L., 1983, The Morrowan-Atokan (Pennsylvanian) boundary problem: Geological Society of America, Bulletin, 94: 543-548.

Sutherland, P. K. & Manger, W. L., 1984a, The Atokan Series: An interval in search of a name; *in* Sutherland, P. K. & Manger, W. L. (eds.), The Atokan Series (Pennsylv nian) and its boundaries—A symposium: Oklahoma Geologic it Survey, Bulletin 136: 1-8.

Sutherland, P. K. & Manger, W. L., 1984b, Morrowan brachiopods in the type "Derryan" Series (Pennsylva ian), New Mexico (abstract): Geological Society of America, Al stracts with Programs, 16 (2): 115.

Thompson, M. L., 1934, The fusulinids of the Des Moines Series of Iowa: University of Iowa Studies, Stu lies in Natural History (n.s. no. 284), 16: 277-332.

Thompson, M. L., 1935, Fusulinids from th Lower Pennsylvanian Atoka and Boggy Formations of Oklahoma: Journal of Paleontology, 9: 291-306.

Thompson, M. L., 1936, Fusulinids from the Black Hills and adjacent areas in Wyoming: Journal of Pal: mtology, 10: 95-113.

Thompson, M. L., 1937, Fusulinids of the subfamily Schubertellinae: Journal of Paleontology, 11: 118-12^5

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

Thompson, M. L., 1942b, New genera of Pe Penn-sylvanian fusulinids: American Journal of Science, 240: 403-4 3.

Thompson, M. L., 1945, Pennsylvanian rock s and fusulinids of east Utah and northwest Colorado correlates with Kansas section: State Geological Survey of Kansas, Bullet in 60 (2): 19-84.

Thompson, M. L., 1947, Stratigraphy and fusulinids of pre-Desmoinesian Pennsylvanian rocks, Llano t plift, Texas: Journal of Paleontology, 21: 147-164.

Thompson, M. L., 1948, Studies of American fusulinids: University of Kansas Paleontological Contributions, Protozoa, Article 1: 1-184.

Thompson, M. L., 1953, Primitive *Fusuline la* from southern Missouri: Journal of Paleontology, 27: 321-327.

Thompson, M. L. & Foster, C. L., 1937, Mid Ile Permian fusulinids from Szechuan, China: Journal of Paleontology, 11: 126-144.

Thompson, M. L. & Riggs, E. A., 1959, Pritive fusulinids in the southern part of the Illinois Basin; *in* Thompson, M. L., Shaver, R. H. & Riggs, E. A., Early Pennsylvanian fusulinids and ostracods of the Illinois Basin: Journal of Paleontology, 33 (5) 770-792.

Thompson, M. L. & Zeller, D. N., 1956, *Profusulinella* in western Utah: Journal of Paleontology, 30: 333-337.

Thompson, M. L., Verville, G. J. & Lokke, D. H., 1956, Fusulinids of the Desmoinesian-Missourian contact: Journal of Paleontology, 30: 793-810.

Van Sant, J. F., 1954, Pennsylvanian fusulinids from Whiskey Canyon, New Mexico: Unpublished MS thesis, University of Kansas, Lawrence, 152 pp.

Verville, G. J. & Sanderson, G. A., 1988, Early Atokan fusulinids from the lower Antler overlap sequence, Lander and Humboldt Counties, Nevada: Journal of Paleontology, 62: 520-529.

Verville, G. J., Sanderson, G. A. & Madsen, M. E., 1986, Pennsylvanian fusulinids from the Fra Cristobal Range, Sierra County, New Mexico: New Mexico Geological Society, Guidebook 37: 215-223.

Waddell, D. E., 1966, Ardmore Basin fusulinids: Oklahoma Geological Survey, Bulletin 113: 128 pp.

Webster, G. D. & Langenheim, R. L., Jr., 1984, Atokan stratigraphy of the southern cordilleran miogeosyncline and adjacent shelf platform, southeastern California to northwestern Arizona; *in* Sutherland, P. K. & Manger, W. L. (eds.), The Atokan Series (Pennsylvanian) and its boundaries—A symposium: Oklahoma Geological Survey, Bulletin 136: 123-132

Wengerd, S. A., 1969, Geologic history and the exploration for oil in the border region; *in* Còrdoba, D. A., Wengerd, S. A. & Shomaker, J. (eds.), Guidebook of the border region: Chihuahua and the United States: New Mexico Geological Society, Guidebook 20: 197-204.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L. & Vorbe, G., 1946, Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance and Socorro Counties, New Mexico: U.S. Geological Survey, Oil and Gas Investigations Map OM61, scale 1:63,360.

Plates 1-11

PLATE 1

(Figures ×100 except as noted)

1–13, *Millerella* spp.
1, OU 10866, axial section, unit 3-3; **2,** OU 10867, axial section, unit 3-3; **3,** OU 10868, axial section, unit 3-3; **4,** OU 10869, axial section, unit 3-3; **5,** OU 10870, axial section, unit 3-3; **6,** OU 10871, sagittal section, top of unit 4-1c; **7,** OU 10872, axial section, top of unit 4-1c; **8,** OU 10873, axial section, top of unit 4-1c; **9,** OU 10874, axial section, top of unit 4-1c; **10,** OU 10875, axial section, base of unit 3-7; **11,** OU 10876, axial section, top of unit 4-1c; **12,** OU 10877, axial section, top of unit, 4-1c; **13,** OU 10878, sagittal section, unit 3-3.

14–18, *Eostaffella* spp.
14, OU 10879, axial section, unit 3-3; **15,** OU 10880, axial section, top of unit 3-8; **16,** OU 10881, axial section, top of unit 4-1c; **17,** OU 10882, axial section, top of unit 4-1c; **18,** OU 10883, sagittal section, unit 3-3.

19–23, *Pseudoendothyra* sp.
19, OU 10884, axial section ×40, base of unit 1-102; **20,** OU 10885, axial section ×40, base of unit 1-102; **21,** OU 10886, axial section ×40, top of unit 3-8; **22,** OU 10887, sagittal section ×40, top of unit 3-8; **23,** OU 10888, sagittal section ×40, base of unit 1-102.

24–26, *Pseudostaffella* sp.
24, OU 10889, axial section, top of unit 4-1c; **25,** OU 10890, axial section, top of unit 4-1c; **26,** OU 10891, tangential section, top of unit 4-1c.


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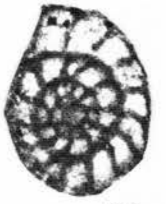
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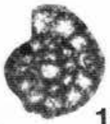
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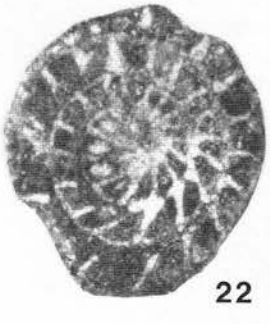
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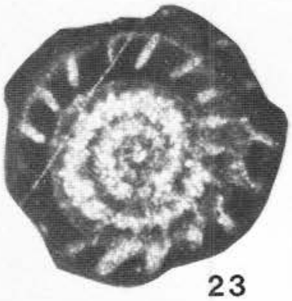
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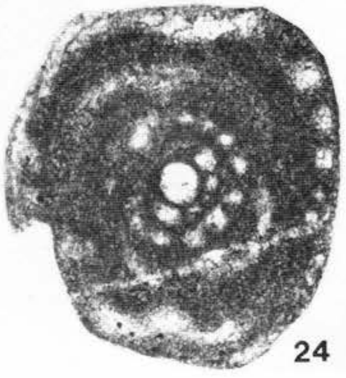
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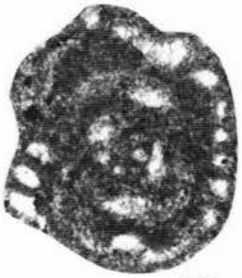
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PLATE 2

(Figures 1–7 × 100, figures 8–29 ×20)

1–7, *Eoschubertella mexicana* Thompson 1948
1, OU 10892, axial section of juvenile, base of unit 3-7; **2,** OU 10893, tangential section of juvenile, base of unit 3-7; **3,** OU 10894, axial section, top of unit 3-8; **4,** OU 10895, sagittal section, top of unit 3-8; **5,** OU 10896, axial section of juvenile, top of unit 3-8; **6,** OU 10897, axial section, top of unit 3-8; **7,** OU 10898, axial section, top of unit 3-8.

8–11, *Profusulinella* cf. *fittsi* Thompson 1935
8, OU 10899, axial section, unit 2-39, center #1; **9,** OU 10900, axial section, unit 1-62, 0.15 m above base #2; **10,** OU 11057, axial section, unit 3-23, 0.15 m above base #1; **11,** OU 11058, axial section, unit 3-23, 0.15 m above base #2.

12–29, *Profusulinella copiosa* Thompson 1948
12, OU 10903, axial section, unit 1-69, 2 m above base #1; **13,** OU 10904, axial section, unit 1-69, 2 m above base #2; **14,** OU 10905, axial section, unit 1-69, 2 m above base #3; **15,** OU 10906, axial section, unit 1-69, 2 m above base #4; **16,** OU 10907; axial section, unit 1-69, 2 m above base #5; **17,** OU 10908, axial section, unit 1-69, 2 m above base #6; **18,** OU 10909, axial section, unit 1-69, 2 m above base #7; **19,** OU 10910, axial section, unit 1-69, 2 m above base #8; **20,** OU 10911, axial section, unit 1-69, 2 m above base #9; **21,** OU 10912, axial section, unit 1-69, 2 m above base #10; **22,** OU 10918, axial section, unit 2-46, top #8; **23,** OU 10915, sagittal section, unit 1-69, 2 m above base #13; **24,** OU 10919, sagittal section, unit 2-46, top #9; **25,** OU 10916, axial section, unit 2-46, top #1; **26,** OU 10917, axial section, unit 2-46, top #3; **27,** OU 10914, sagittal section, unit 1-69, 2 m above base #12; **28,** OU 10913, sagittal section, unit 1-69, 2 m above base #11; **29,** OU 10920, sagittal section unit 2-46, top #10.


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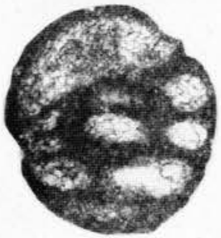
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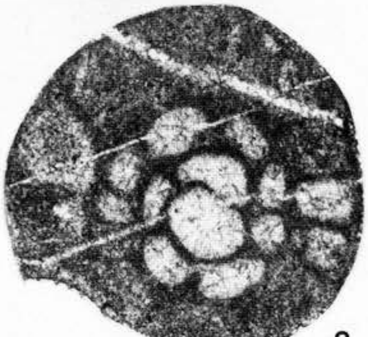
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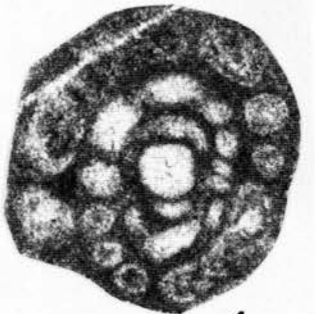
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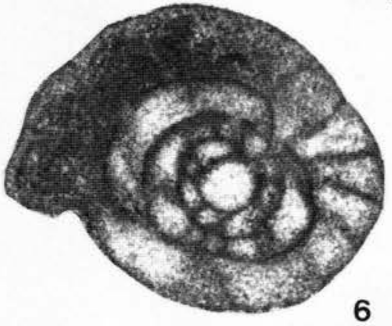
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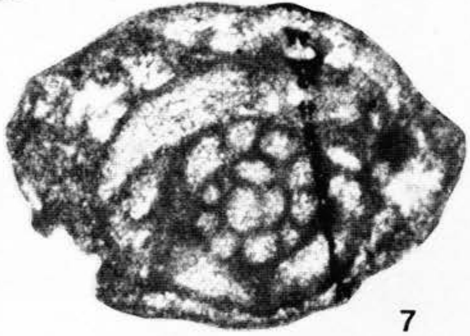
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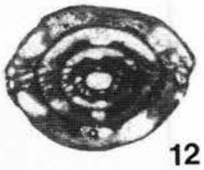
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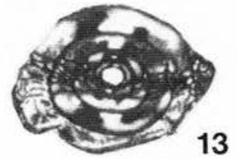
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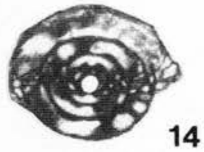
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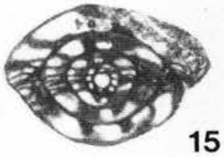
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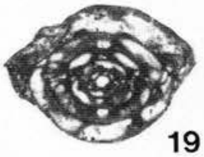
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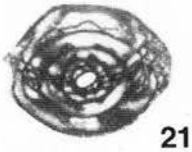
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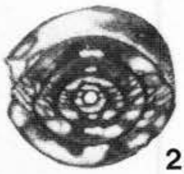
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PLATE 3

(All figures ×20)

1–15, *Profusulinella thompsoni* n. sp.
1, paratype OU 10921, axial section, unit 1-109, center #1; **2,** paratype OU 10922, axial section, unit 1-109, center #2; **3,** paratype OU 10923, axial section, unit 1-109, center #3; **4,** paratype OU 10924, axial section, unit 1-109, center #4; **5,** paratype OU 10925, axial section, unit 1-109, center #7; **6,** paratype OU 10926, axial section, unit 1-109, center #5; **7,** holotype OU 10927, axial section, unit 1-109, center #6; **8,** paratype OU 10928, axial section, unit 1-109, center #8; **9,** OU 10931, axial section, unit 1-108, top #3; **10,** OU 10932, axial section, unit 1-108, top #1; **11,** paratype OU 10929, axial section, unit 1-109, center #9; **12,** OU 10934, axial section, unit 1-108, top #2; **13,** OU 10935, axial section, unit 1-108, top #4; **14,** paratype OU 10930, sagittal section, unit 1-109, center #11; **15,** paratype OU 10936, sagittal section, unit 1-108, top #9.

16–27, *Profusulinella munda* Thompson 1948
16, OU 10937, axial section, unit 1-114, 0.3 m below top #1; **17,** OU 10938, axial section, unit 1-114, 0.3 m below top #2; **18,** OU 10939, sagittal section, unit 1-114, 0.3 m below top #9; **19,** OU 10940, axial section, unit 1-114, 0.3 m below top #3; **20,** OU 10941, axial section, unit 1-114, 0.3 m below top #4; **21,** OU 10942, sagittal section, unit 1-114, 0.3 m below top #8; **22,** OU 10948, axial section, unit 4-5, top #9; **23,** OU 10943, axial section, unit 1-114, 0.3 m below top #5; **24,** OU 10944, axial section, unit 1-114, 0.3 m below top #6; **25,** OU 10945, axial section, unit 1-114, 0.3 m below top #7; **26,** OU 10946, axial section, unit 1-118, 0.6 m above base #1; **27,** OU 10947, axial section, unit 1-118, 0.6 m above base #3.


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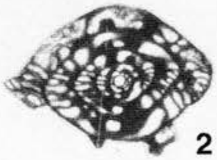
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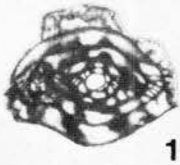
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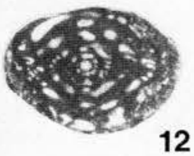
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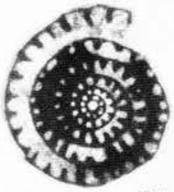
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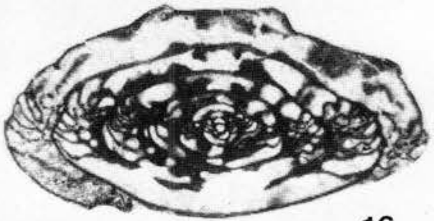
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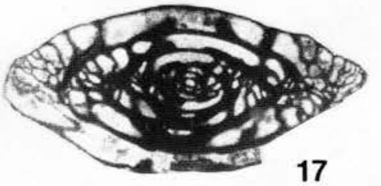
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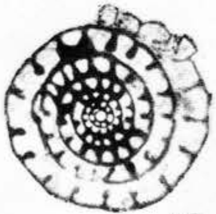
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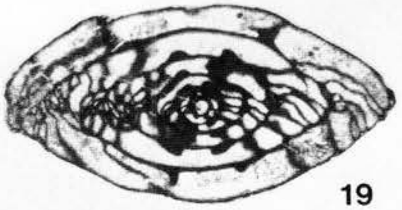
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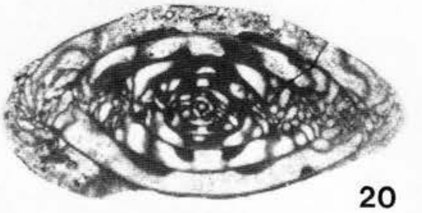
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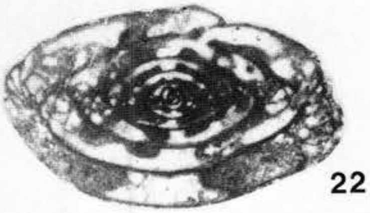
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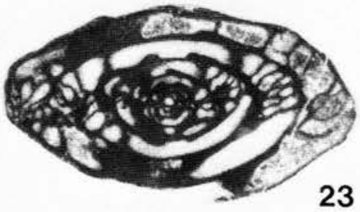
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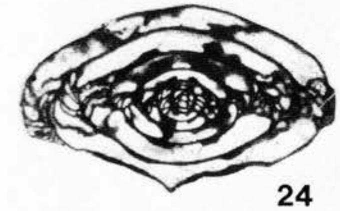
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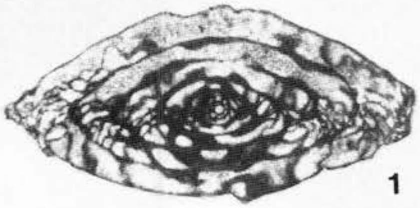
PLATE 4

(Figures ×20 except as noted)

1–8, *Profusulinella decora* Thompson 1948
1, OU 10949, axial section, unit 1-116, top #1; **2,** OU 10950, axial section, unit 1-116, top #2; **3,** OU 10951, axial section, unit 1-116, top #3; **4,** OU 10957, axial section, unit 4-5, top #7; **5,** OU 10958, axial section, unit 4-5, top #3; **6,** OU 10954, sagittal section, unit 1-116, top #7; **7,** OU 10956, sagittal section, unit 1-116, top #8; **8,** OU 10949, axial section ×40 showing juvenarium coiled at a high angle to later volutions.

9–12, *Profusulinella apodacensis* Thompson 1948
9, OU 10962, axial section, unit 4-5, top #2; **10,** OU 10962, axial section ×100 showing typical profusulinelid three-layered wall structutre; **11,** OU 10963, axial section, unit 4-5, top #5; **12,** OU 10959, axial section, unit 4-5, top #1.

13-18, *Fusulinella fugax* Thompson 1948
13, OU 10960, axial section ×100 showing thin but consistent diaphanotheca development in fourth, fifth, and sixth volutions; **14,** OU 10960, axial section, unit 3-25, base #1; **15,** OU 10968, sagittal section, unit 3-25, top #9; **16,** OU 10961, axial section, unit 3-25, base #2; **17,** OU 10967, axial section, unit 3-25, top #8; **18,** OU 10970, axial section, top of unit 3-25.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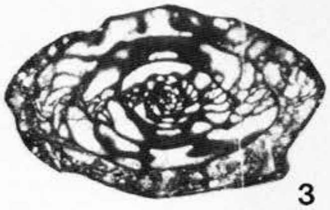
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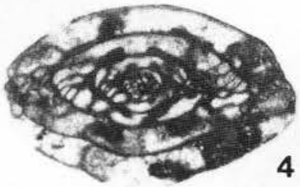
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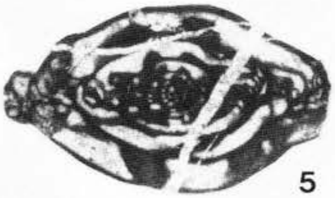
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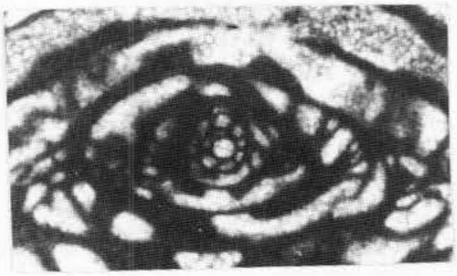
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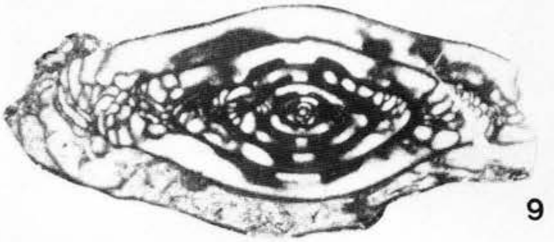
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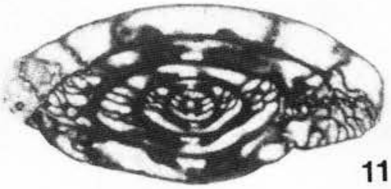
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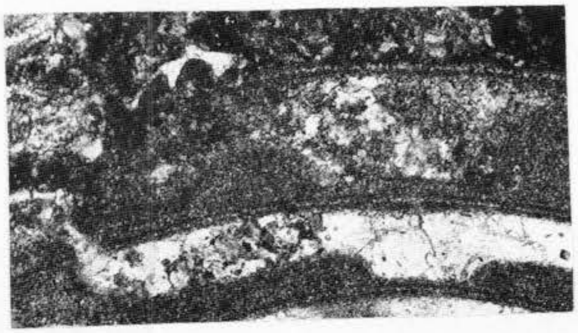
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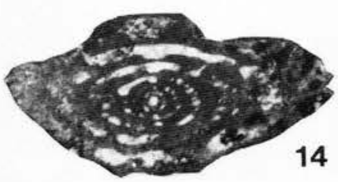
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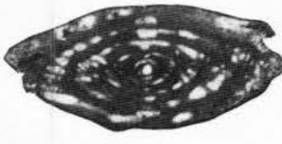
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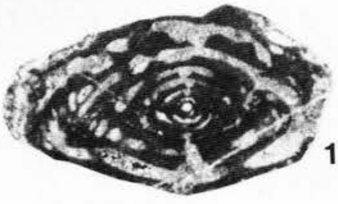
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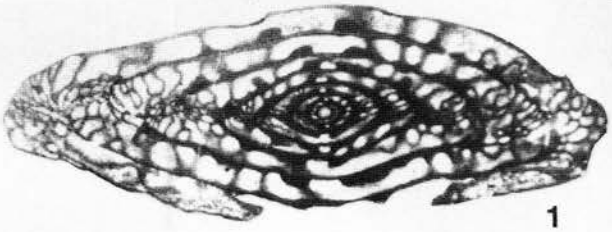
PLATE 5

(All figures ×20)

1–11, *Fusulinella acuminata* Thompson 1936
1, OU 10971, axial section, unit 3-32, 0.15 m below top #1; **2,** OU 10981, axial section, unit 1-119, 1.8 m above base #10; **3,** OU 10978, axial section, unit 3-32, 0.15 m below top #8; **4,** OU 10975, axial section, unit 3-32, 0.15 m below top #5; **5,** OU 10982, sagittal section, unit 1-119, 1.8 m above base #11; **6,** OU 10983, axial section, unit 1-119, 1.8 m above base #6; **7,** OU 10988, axial section, unit 1-131, 0.45 m below top #2; **8,** OU 10986, axial section, unit 1-123, 0.45 m below top #1; **9,** OU 10984, axial section, unit 1-119, 1.8 m above base #7; **10,** OU 10985, axial section, unit 1-119, 1.8 m above base #4; **11,** OU 10987, sagittal section, unit 1-123, 0.45 m below top #8.

12–15, *Fusulinella proxima* Thompson 1948
12, OU 10989, axial section, unit 3-31, top #4; **13,** OU 10991, axial section, unit 3-27, base #4; **14,** OU 10992, sagittal section, unit 3-27, base #8; **15,** OU 10990, axial section, unit 3-31, top #2.

16–18, *Fusulinella* cf. *juncea* Thompson 1948
16, OU 10995, axial section, unit 4-30, 0.3 m below top #8; **17,** OU 10996, axial section, unit 3-41, 1.2 m above base #8; **18,** OU 10997, axial section, unit 1-140, 0.6 m below top #2.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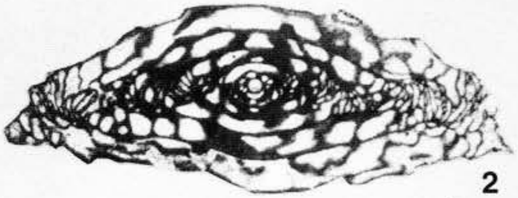
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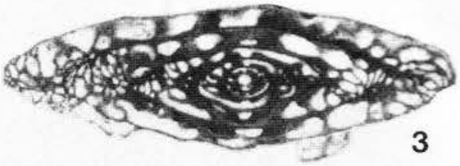
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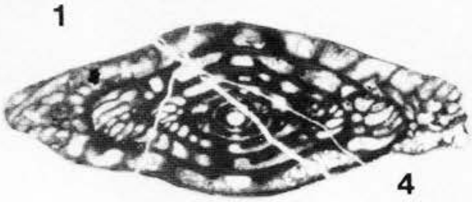
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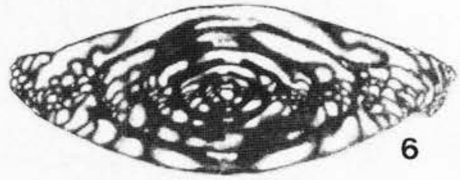
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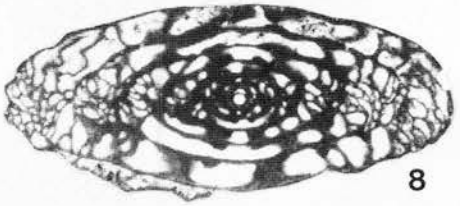
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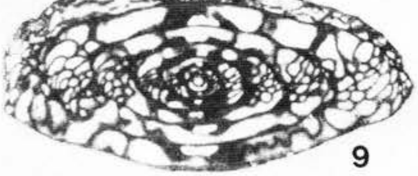
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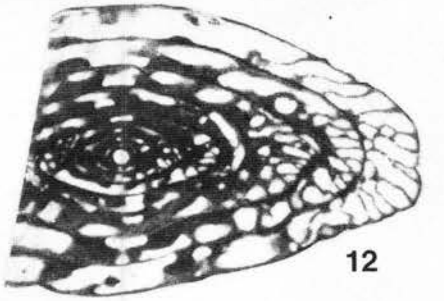
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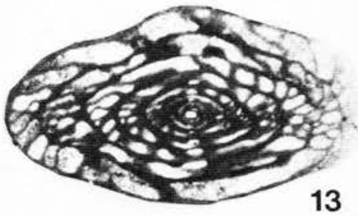
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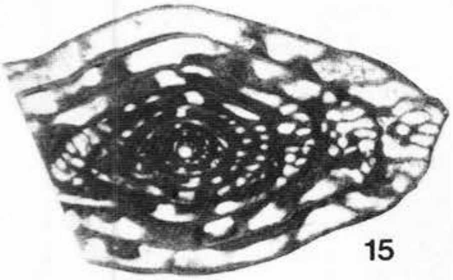
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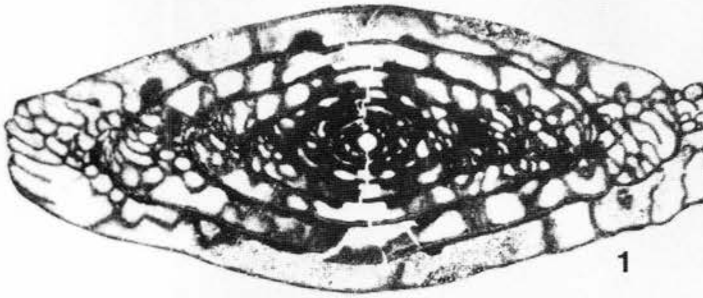
PLATE 6

(All figures ×20)

1–12, *Fusulinella devexa* Thompson 1948
1, OU 10998, axial section, unit 1-139, 0.3 m above base #1; **2,** OU 10999, sagittal section, unit 1-142, base #12; **3,** OU 11000, axial section, unit 1-139, 0.3 m above base #2; **4,** OU 11001, sagittal section, unit 1-142, base #10; **5,** OU 11002, sagittal section, unit 1-136, 0.15 m below top #4; **6,** OU 11003, axial section, unit 1-139, 0.3 m above base #4; **7,** OU 11009, axial section, unit 3-39, base #4; **8,** OU 11004, axial section, unit 1-139, 0.3 m above base #5; **9,** OU 11007, axial section, unit 3-39, base #1; **10,** OU 11005, axial section, unit 1-142, base #1; **11,** OU 11008, axial section, unit 3-39, base #2; **12,** OU 11006, axial section, unit 1-142, base #2.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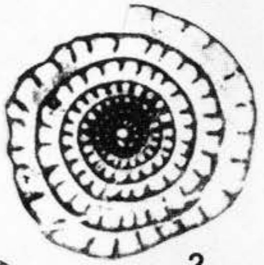
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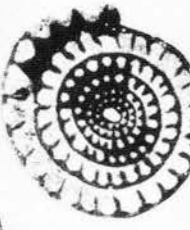
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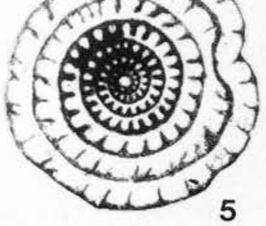
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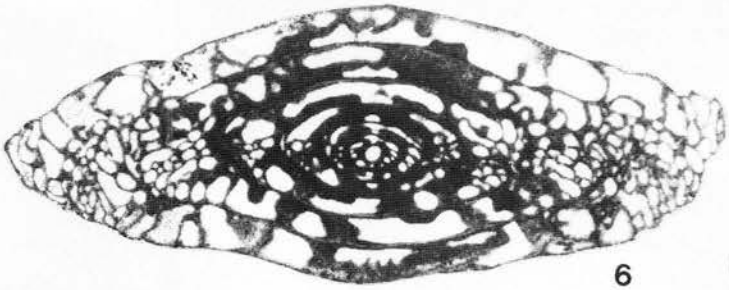
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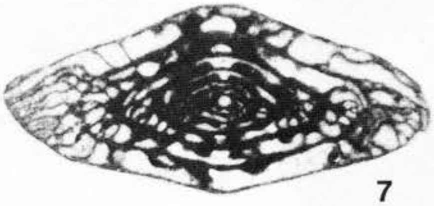
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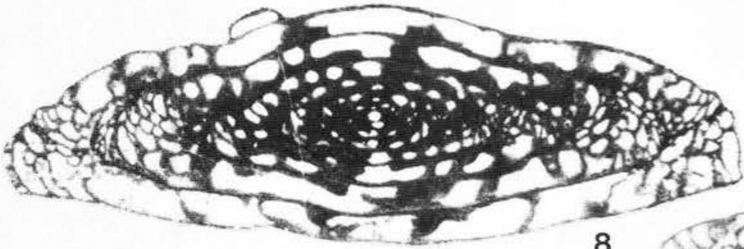
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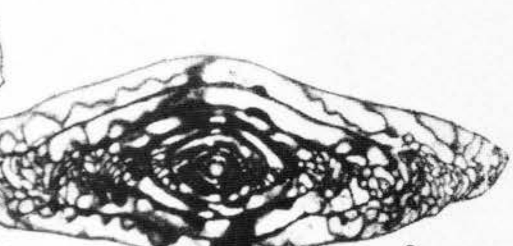
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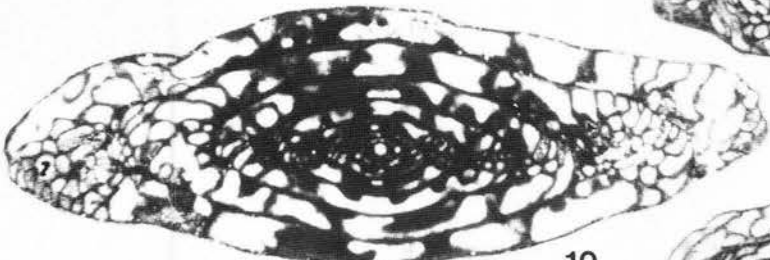
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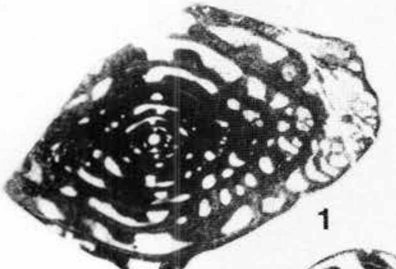
PLATE 7

(All figures ×20)

1–8, *Fusulinella famula* Thompson 1948
1, OU 11011, axial section, unit 1-145, top #5; **2,** OU 11012, axial section, unit 1-145, top #1; **3,** OU 11013, axial section, unit 1-145, top #4; **4,** OU 11014, axial section, unit 1-147, top #1; **5,** OU 11015, axial section, unit 3-44, 0.9 m above base #2; **6,** OU 11016, axial section, unit 1-147, base #5; **7,** OU 11017, sagittal section, unit 3-43, 0.8 m above base #7; **8,** OU 11018, axial section, unit 3-43, 0.8 m above base #4.

9–16, *Beedeina insolita* (Thompson 1948)
9, OU 11021, axial section, unit 3-47, base #5; **10,** OU 11023, axial section, unit 4-42, top #3; **11,** OU 11022, axial section, unit 3-47, base #2; **12,** OU 11024, axial section, unit 3-44, 0.9 m above base #5; **13,** OU 11025, sagittal section; unit 4-42, top #6; **14,** OU 11026, axial section, unit 1-145, top #2; **15,** OU 11027, axial section, unit 3-44, 0.9 m above base #3; **16,** OU 11028, axial section, unit 3-47, base #1.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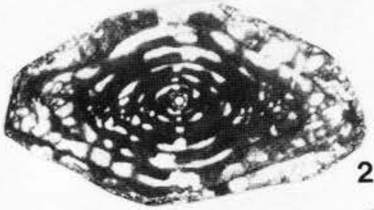
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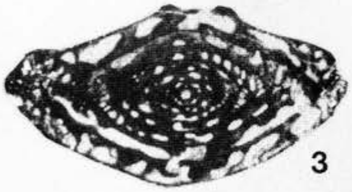
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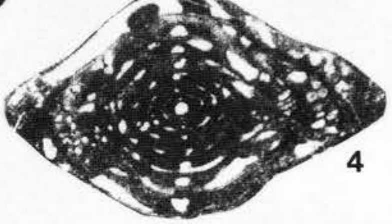
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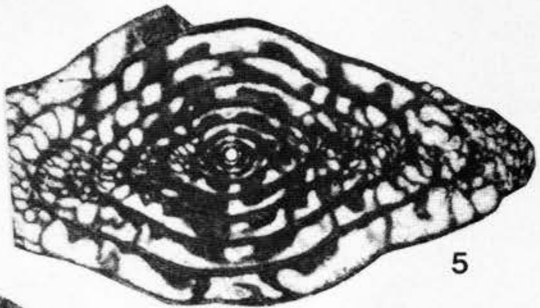
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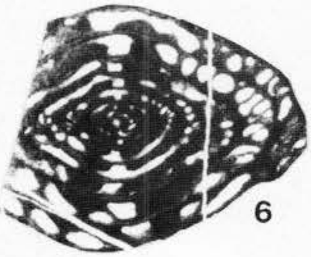
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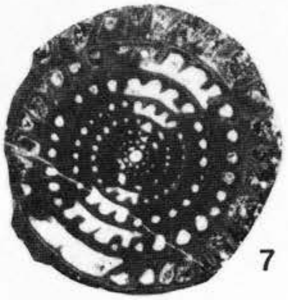
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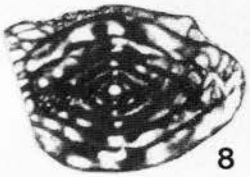
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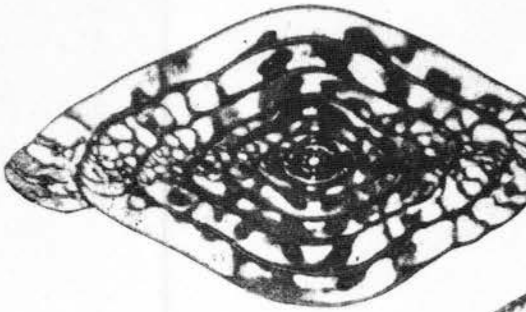
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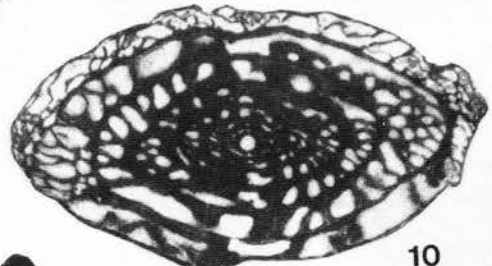
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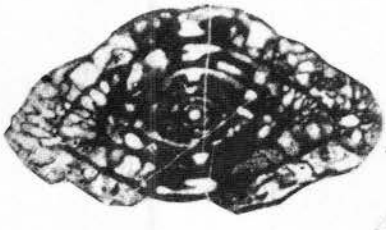
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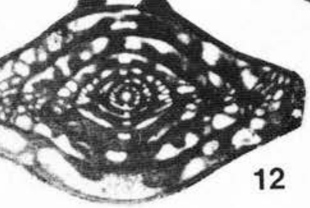
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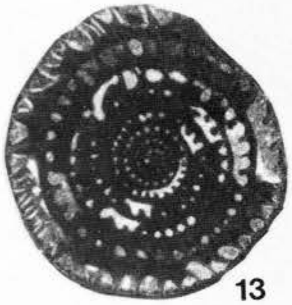
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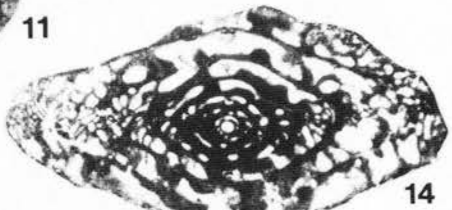
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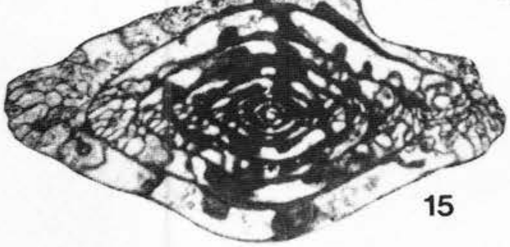
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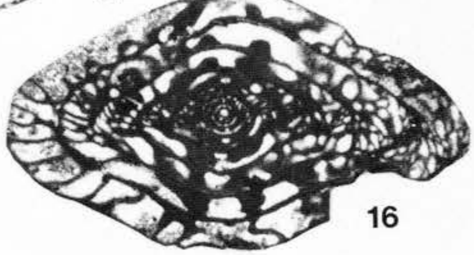
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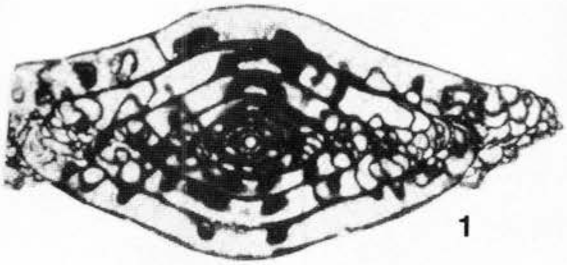
PLATE 8

(All figures ×20)

1–12, *Beedeina* aff. *hayensis* (Ross & Sabins 1965)
1, OU 11034, axial section, unit 3-57, top #1; **2,** OU 11035, axial section, unit 3-57, 1.5 m above base #3; **3,** OU 11038, axial section, unit 3-44, 0.9 m above base #1; **4,** OU 11039, axial section, unit 4-55b, 0.3 m below top #1; **5,** OU 11040, axial section, unit 4-61, 0.45 m above base #4; **6,** OU 11041, axial section, unit 4-52, 0.15 m below top #1; **7,** OU 11044, axial section, unit 4-61, 0.45 m above base #2; **8,** OU 11043, axial section, unit 4-61, 0.45 m above base #3; **9,** OU 11042, axial section, unit 4-55b, 0.3 m below top #2; **10,** OU 11045, axial section, unit 4-61, 0.45 m above base #1; **11,** OU 11046, sagittal section, unit 4-61, 0.45 m above base #9; **12,** OU 11047, sagittal section, unit 4-55b, 0.3 m below top #5.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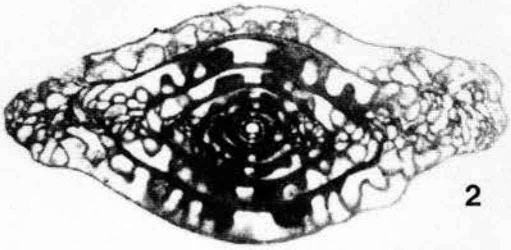
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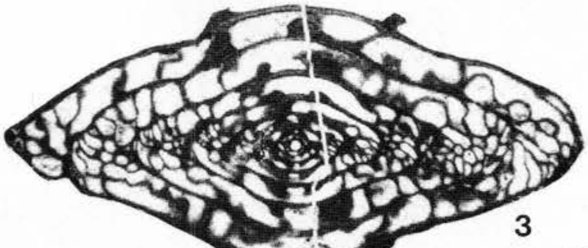
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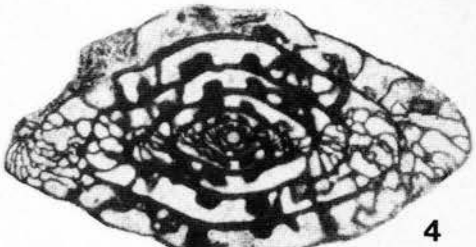
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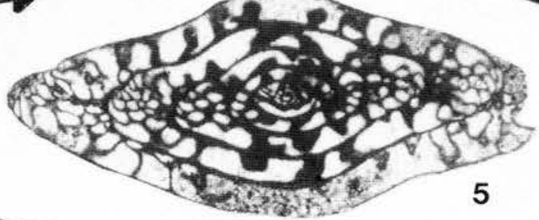
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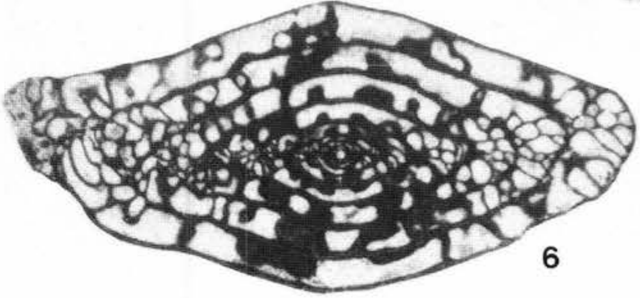
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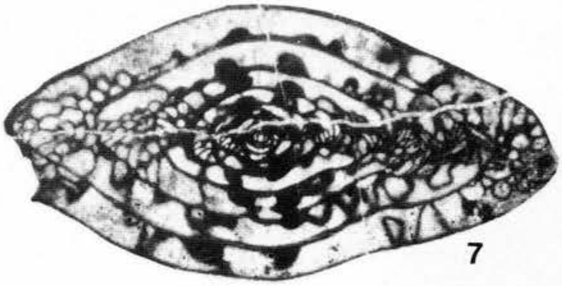
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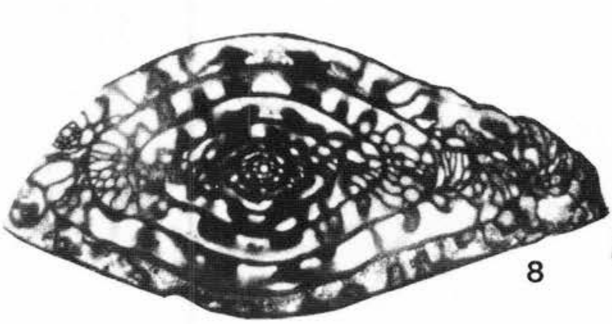
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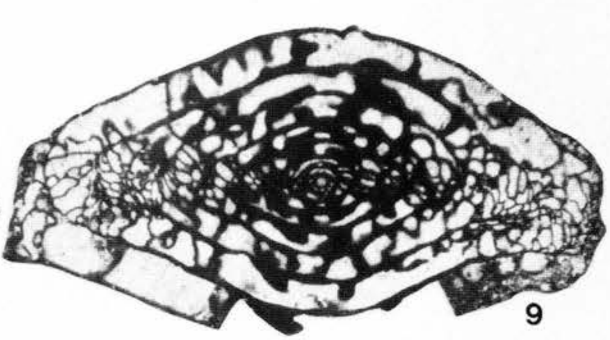
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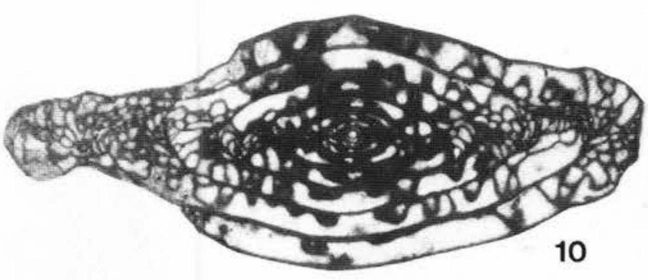
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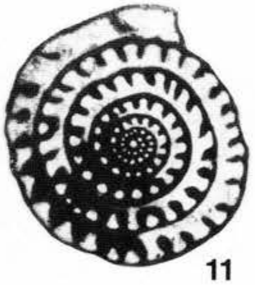
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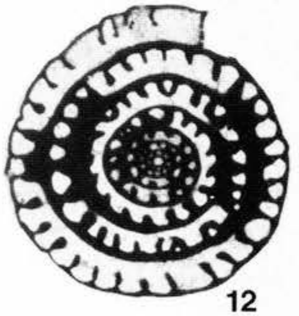
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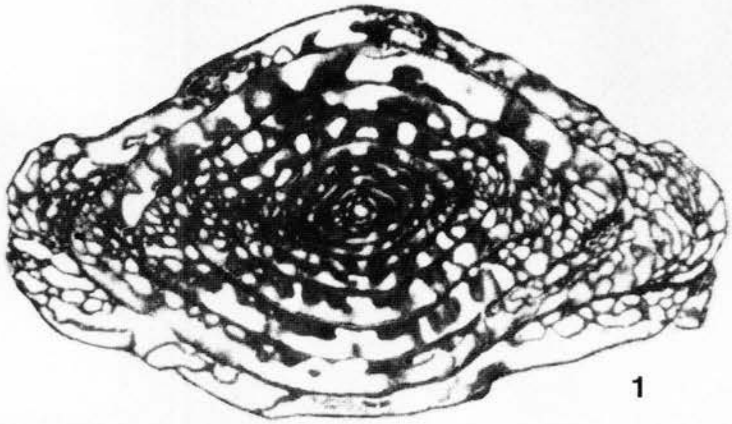
PLATE 9

(All figures ×20)

1–8, *Beedeina* aff. *curta* (Thompson 1945)
All specimens are from unit 1-166, 0.45 m above base.
1, OU 11048, axial section, #1; **2,** OU 11056 sagittal section #9; **3,** OU 11049, axial section #2; **4,** OU 11055, sagittal section #8; **5,** OU 11052, axial section #5; **6,** OU 11051, axial section #4; **7,** OU 11054, axial section #7; **8,** OU 11050, axial section #3.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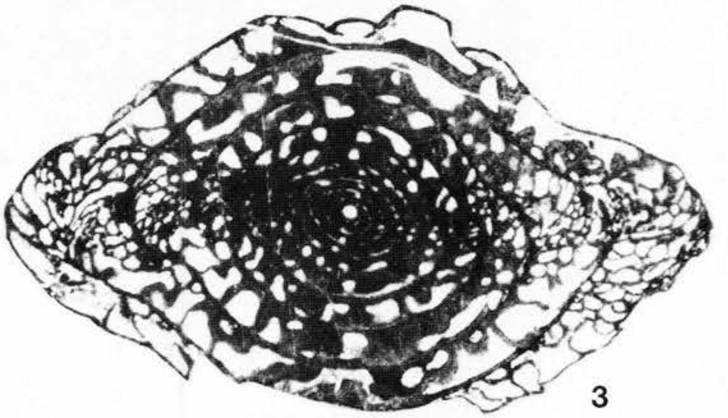
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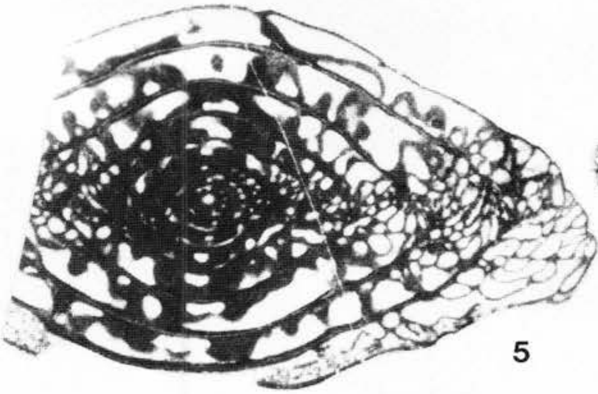
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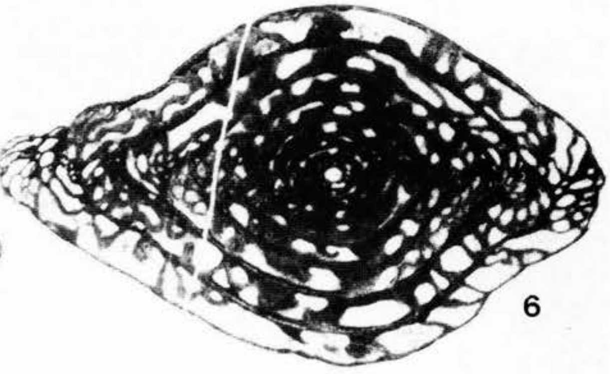
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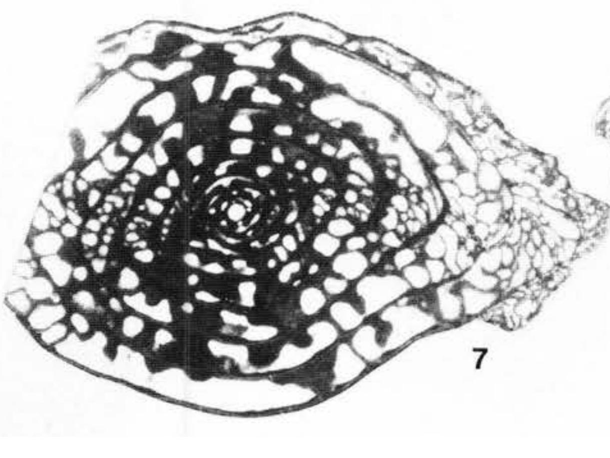
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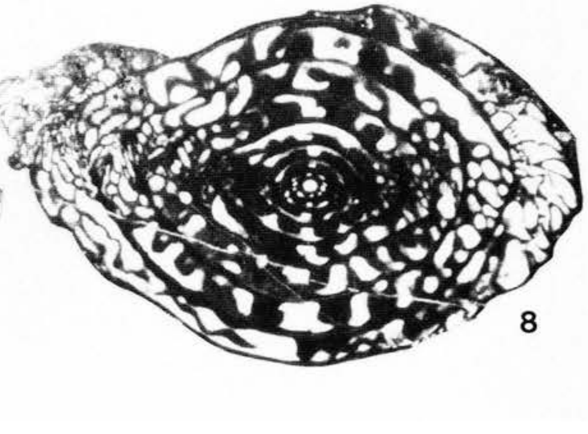
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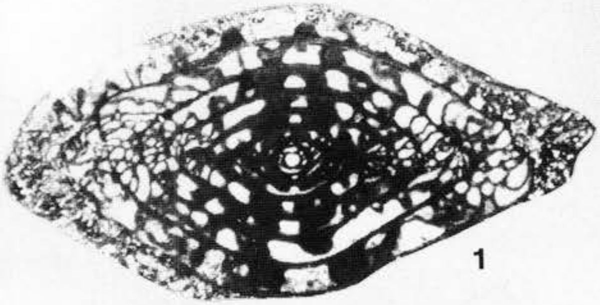
PLATE 10

(All figures ×20)

1–9, *Beedeina* aff. *joyitaensis* Stewart 1970
1, OU 11078, axial section, unit 1-172, base #2, **2** OU 11079, axial section, unit 1-172, base #3; **3,** OU 11080, axial section, unit 1-172, base #4; **4,** OU 11081, axial section, unit 1-172, base #5; **5,** OU 11075, axial section, unit 1-164, 0.3 m above base #1; **6,** OU 11084, sagittal section, unit 1-172, base #9; **7,** OU 11076, axial section, unit 1-164, 0.3 m above base #2; **8,** OU 11083, axial section, unit 1-172, base #7; **9,** OU 11077, axial section, unit 1-172, base #1.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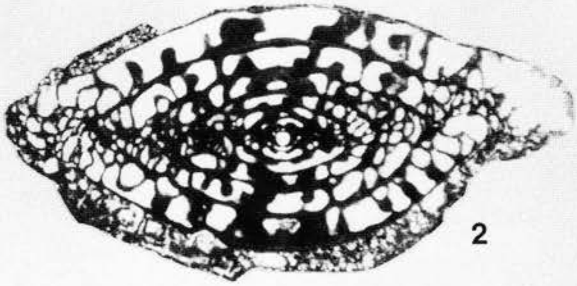
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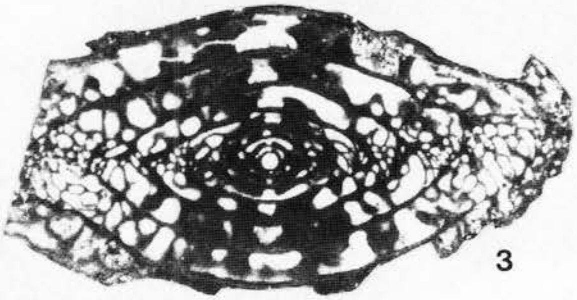
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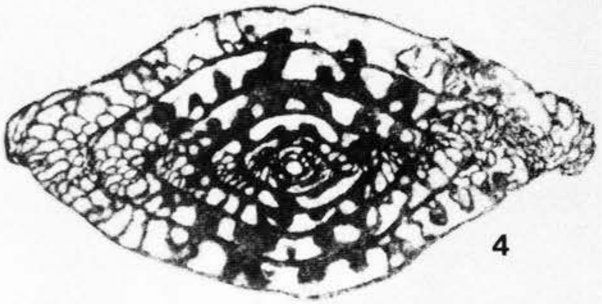
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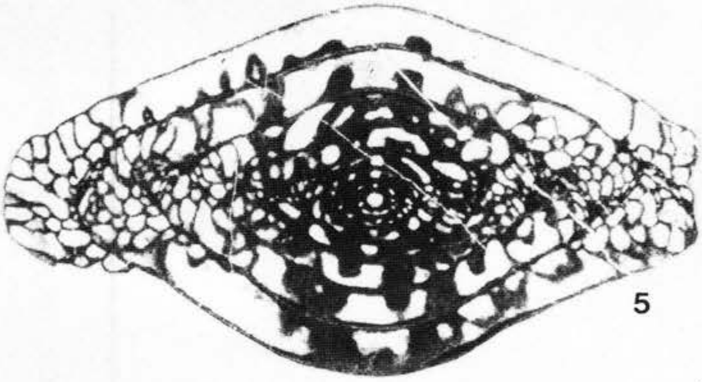
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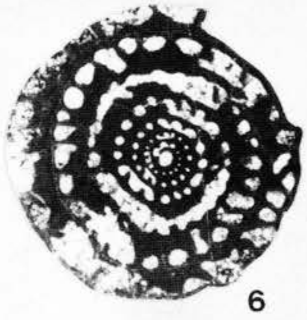
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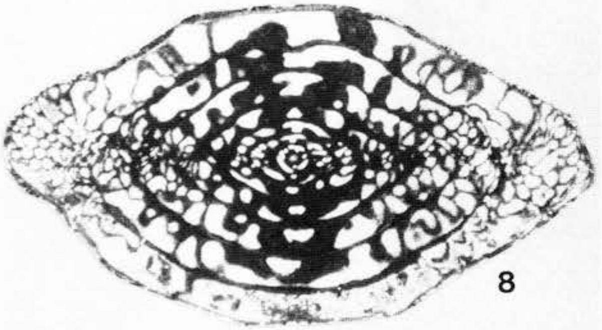
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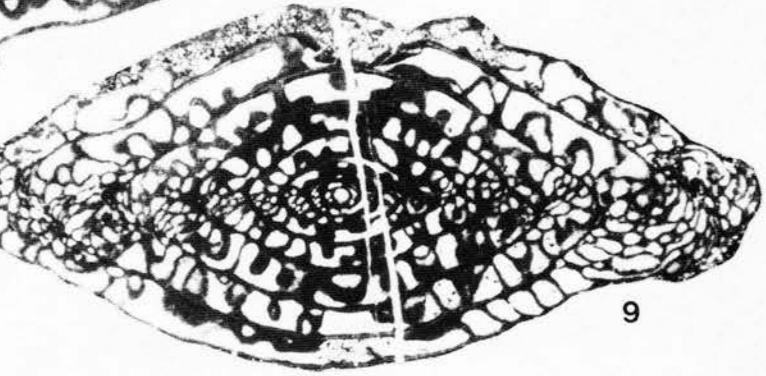
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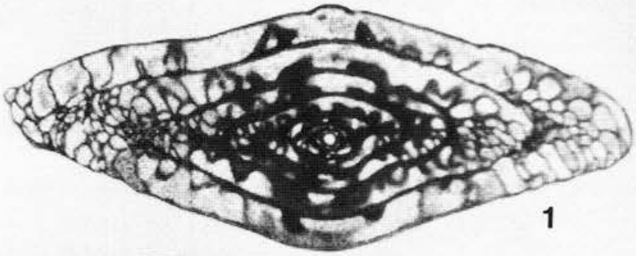
PLATE 11

(All figures ×20)

1–6, *Beedeina*? aff. *rockymontana* (Roth & Skinner 1930)
All specimens are axial sections from top of unit 3-56. **1,** OU 11086, top #2; **2,** OU 11088, top #4; **3,** OU 11087, top #3; **4,** OU 11085, top #1; **5,** OU 11091, top #9; **6,** OU 11090, top #8.

7–16, *Wedekindellina excentrica* (Roth & Skinner 1930)
7, OU 11073, axial section, unit 4-62, 0.45 m below top; **8,** OU 11071, axial section, unit 1-175, 0.45 m below top; **9,** OU 11074, axial section, unit 4-62, 0.45 m below top #1; **10,** OU 11067, axial section, unit 2-117, base #1; **11,** OU 11072, axial section, unit 1-175, 0.45 m below top; **12,** OU 11062, axial section, unit 3-60, base #2; **13,** OU 11061, axial section, unit 3-60, base #1; **14,** OU 11063, axial section, unit 3-60, base #3; **15,** OU 11069, axial section, unit 1-175, 0.45 m below top #1; **16,** OU 11070, sagittal section, unit 1-175, 0.45 m below top #3.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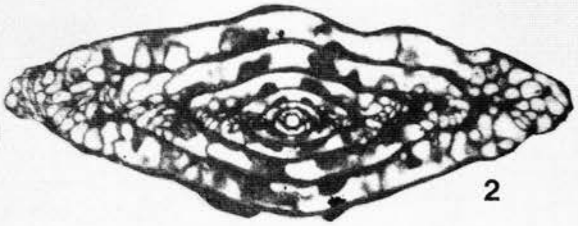
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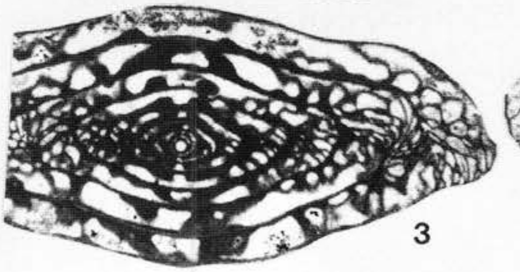
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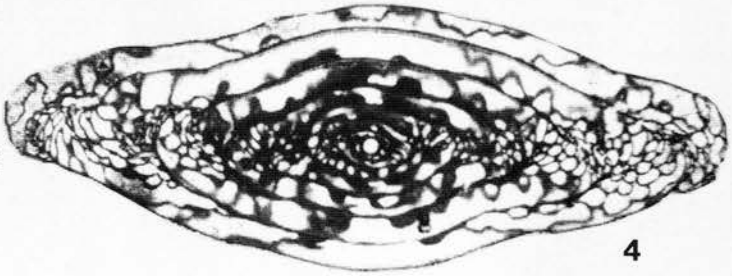
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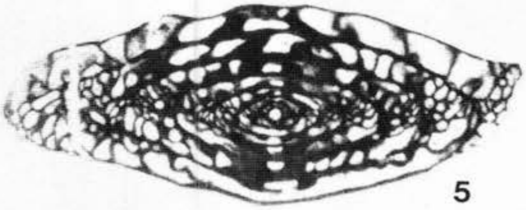
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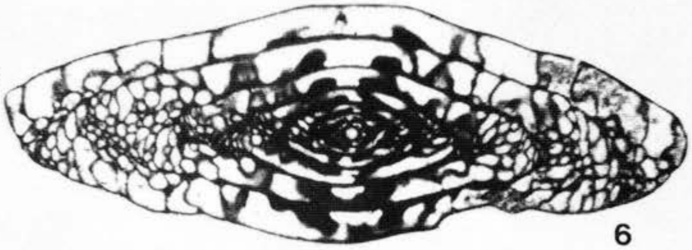
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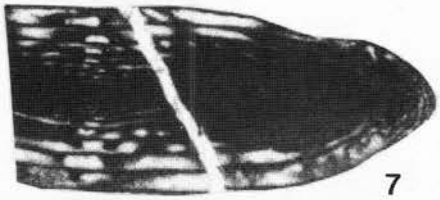
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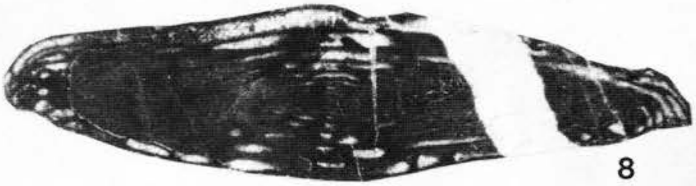
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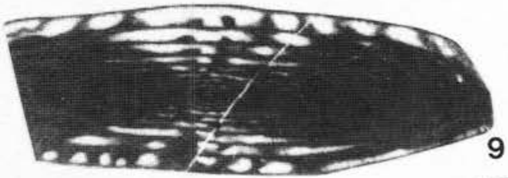
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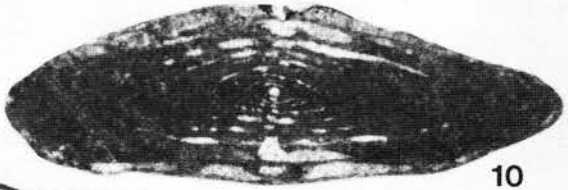
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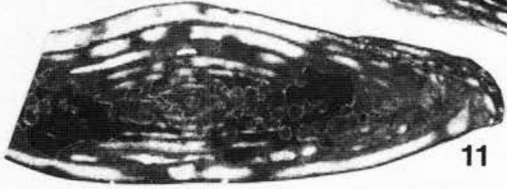
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Appendix—Quantitative morphologic data

TABLE 1—Representative quantitative morphologic data for *Profusulinella copiosa* Thompson. Values in millimeters where applicable.

	Specimen number and horizon of occurrence									
Character	OU10903	OU10904	OU10905	OU10906	OU10907	OU10908	OU10909	OU10910	OU10913	OU10914
(by volution)	1-69-1	1-69-2	1-69-3	1-69-4	1-69-5	1-69-6	1-69-7	1-69-8	1-69-11	1-69-12
Proloculus diameter	.186	.146	.114	.109	.089	.125	.160	.098	.124	.101
Radius vector										
1	.134	.155	.120	.118	.096	.095	.112	.083	.106	.113
2	.234	.248	.207	.205	.180	.158	.196	.151	.184	.197
3	.366	.394	.314	.329	.286	.244	.324	.222	.311	.321
4	.486	.525	.507	.510	.494	.358	.501	.324	.413	.482
5						.521		.505		
6										
7										
Half-length										
1	.173	.172	.109	.117	.099	.119	.190	.080		
2	.262	.264	.203	.248	.222	.226	.348	.160		
3	.424	.415	.342	.413	.494	.390	.517	.250		
4	.638	.651	.520	.644	.706	.560	.665	.395		
5						.721		.574		
6										
7										
Volution height										
1	.041	.082	.063	.063	.051	.032	.032	.034	.044	.062
2	.100	.093	.087	.087	.084	.063	.084	.068	.078	.084
3	.132	.146	.107	.124	.106	.086	.128	.071	.127	.124
4	.120	.131	.193	.181	.208	.114	.177	.102	.102	.161
5						.163		.181		
6										
7										
Wall thickness										
1	.004	.005	.006	.006	.005	.005	.006	.004	.005	.005
2	.007	.005	.006	.004	.005	.006	.007	.004	.005	.006
3	.006	.006	.006	.004	.007	.006	.004	.007	.008	.006
4	.008	.006	.006	.006	.007	.004	.006	.007	.003	.007
5						.007		.007		
6										
7										
Tunnel width (axials) or septal count (sagittals)										
1	.066	.085	.045	.054	.049	.059	.059	.055	11	9
2	.130	.145	.083	.101	.105	.078	.082	.052	15	16
3	.231			.118	.213	.154	.238	.090	17	20
4						.327		.207		22
5										
6										
7										

TABLE 2—Representative quantitative morphologic data for *Profusulinella* cf. *fittsi* (Thompson). Values in millimeters where applicable.

	Specimen number and horizon of occurrence					
Character (by volution)	OU10900 1-62-2	OU10899 2-39-1	OU11057 3-23-1	OU11058 3-23-2	OU11059 3-23-3	OU11060 3-23-4
Proloculus diameter	.088	.089	.063	.049	.055	.047
Radius vector						
1	.070	.077	.092	.072	.064	.065
2	.125	.126	.148	.119	.108	.105
3	.208	.206	.207	.190	.185	.150
4	.320	.322	.302	.297	.298	.217
5	.463	.503	.456			
6						
7						
Half-length						
1	.065	.076	.081	.099	.061	
2	.118	.175	.176	.235	.128	
3	.288	.347	.275	.485	.396	
4	.474	.525	.419	.763	.659	
5	.710	.770	.632			
6						
7						
Volution height						
1	.026	.032	.060	.047	.036	.041
2	.055	.049	.056	.047	.044	.040
3	.083	.080	.059	.071	.077	.045
4	.112	.116	.095	.107	.113	.067
5	.143	.181	.154			
6						
7						
Wall thickness						
1	.007	.006	.005	.008	.003	.004
2	.008	.006	.007	.007	.004	.006
3	.008	.005	.007	.006	.006	.004
4	.010	.007	.004		.004	.005
5	.006	.004	.008			
6						
7						
Tunnel width (axials) or septal count (sagittals)						
1		.024	.024	.040	.021	6
2	.062	.044	.074	.073	.060	12
3	.071	.069	.107	.140	.112	14
4	.234	.152			.317	17
5						
6						
7						

TABLE 3—Representative quantitative morphologic data for *Profusulinella thompsoni* n. sp. Values in millimeters where applicable.

Character (by volution)	Specimen number and horizon of occurrence									
	OU10921 1-109-1 (Paratype)	OU10922 1-109-2 (Paratype)	OU10923 1-109-3 (Paratype)	OU10924 1-109-4 (Paratype)	OU10927 1-109-6 (Holotype)	OU10929 1-109-9 (Paratype)	OU10932 1-108-1	OU10934 1-108-2	OU10930 1-109-11 (Paratype)	OU10936 1-108-9
Proloculus diameter	.105	.074	.077	.080	.080	.118	.094	.084	.082	.072
Radius vector										
1	.084	.059	.142	.124	.087	.101	.092	.074	.081	.085
2	.154	.123	.243	.206	.191	.164	.147	.141	.144	.151
3	.262	.206	.376	.311	.298	.239	.223	.226	.201	.266
4	.404	.335	.564	.428	.445	.357	.357	.322	.323	.379
5	.570	.492				.491		.437	.477	.512
6										
7										
Half-length										
1	.101	.065	.132	.127	.120	.095	.083	.079		
2	.215	.162	.290	.237	.229	.188	.164	.187		
3	.383	.303	.479	.343	.397	.324	.297	.341		
4	.589	.474	.859	.544	.616	.447	.474	.468		
5	.777	.748				.594		.608		
6										
7										
Volution height										
1	.031	.022	.103	.084	.047	.042	.045	.032	.040	.049
2	.070	.064	.101	.082	.104	.063	.055	.067	.063	.066
3	.108	.083	.133	.105	.107	.075	.076	.085	.057	.115
4	.142	.129	.188	.117	.147	.118	.134	.096	.122	.113
5	.166	.157				.134		.115	.154	.133
6										
7										
Wall thickness										
1	.004	.003	.006	.006	.005	.005	.004	.003	.005	.005
2	.006	.006	.005	.007	.005	.006	.004	.003	.005	.005
3	.006	.005	.008	.006	.006	.007	.004	.005	.007	.008
4	.007	.006	.005	.007	.006	.008	.006	.005	.007	.006
5	.007	.005				.006		.006	.007	.006
6										
7										
Tunnel width (axials) or septal count (sagittals)										
1	.057	.040	.058	.032	.073	.052	.041	.047	7	8
2	.063	.056	.117	.103	.087	.068	.065	.043	11	13
3	.109	.074	.229	.159	.206	.118	.124	.049	17	17
4	.161	.179				.159		.101	18	22
5									20	28
6										
7										

TABLE 4—Representative quantitative morphologic data for *Profusulinella munda* Thompson. Values in millimeters where applicable.

	Specimen number and horizon of occurrence									
Character (by volution)	OU10937 1-114-1	OU10938 1-114-2	OU10940 1-114-3	OU10941 1-114-4	OU10943 1-114-5	OU10944 1-114-6	OU10945 1-114-7	OU10946 1-118-1	OU10942 1-114-8	OU10939 1-114-9
Proloculus diameter	.076	.069	.091	.057	.078	.068	.070	.072	.050	.072
Radius vector										
1	.073	.108	.108	.073	.068	.062	.065	.107	.075	.078
2	.119	.186	.173	.129	.107	.103	.114	.196	.119	.129
3	.167	.296	.261	.191	.178	.157	.183	.311	.193	.215
4	.243	.450	.399	.280	.276	.234	.283	.441	.301	.330
5	.370	.582	.621	.426	.418	.345	.432	.609	.474	.463
6	.541			.586	.604	.489	.611		.665	.645
7	.784					.649				
Half-length										
1	.050	.102	.159	.080	.053	.053	.047	.132		
2	.119	.304	.332	.179	.128	.106	.106	.326		
3	.273	.515	.643	.351	.285	.167	.250	.546		
4	.504	.861	.961	.767	.558	.313	.455	.943		
5	.774	1.215	1.302	1.014	.856	.489	.876	1.380		
6	1.096			1.313	1.185	.807	1.212			
7	1.396					1.099				
Volution height										
1	.035	.073	.062	.044	.029	.028	.030	.071	.050	.042
2	.046	.078	.065	.056	.039	.041	.049	.089	.044	.051
3	.048	.110	.088	.062	.071	.054	.069	.115	.074	.086
4	.076	.154	.138	.089	.098	.077	.100	.130	.108	.115
5	.127	.132	.222	.146	.142	.111	.149	.168	.173	.133
6	.171			.160	.186	.144	.179		.191	.182
7	.243					.160				
Wall thickness										
1	.005	.005	.007	.005	.004	.005	.007	.003	.004	.005
2	.007	.007	.006	.005	.006	.006	.005	.003	.006	.007
3	.004	.004	.006	.005	.005	.004	.007	.005	.006	.009
4	.007	.007	.007	.007	.005	.006	.008	.005	.007	.006
5	.006	.006	.007	.004	.005	.006	.007	.004	.008	.010
6	.007			.004	.006	.007	.009		.005	.006
7	.007					.007				
Tunnel width (axials) or septal count (sagittals)										
1	.022	.073	.047	.035	.025	.015	.022	.051	6	6
2	.064	.101	.099	.055	.065	.044	.055	.092	11	12
3	.111	.155	.195	.089	.102	.074	.112	.175	12	13
4	.157	.396	.399	.179	.187	.124	.211	.290	14	15
5	.327			.457	.372	.285	.680		16	17
6	.435				.599	.471				18
7										

TABLE 5—Representative quantitative morphologic data for *Profusulinella decora* Thompson. Values in millimeters where applicable.

	Specimen number and horizon of occurrence						
Character	OU10949	OU10950	OU10951	OU10952	OU10953	OU10954	OU10956
(by volution)	1-116-1	1-116-2	1-116-3	1-116-4	1-116-6	1-116-7	1-116-8
Proloculus diameter	.068	.069	.038	.066	.040	.058	.075
Radius vector							
1	.092	.088	.072	.065	.094	.056	.079
2	.138	.153	.096	.115	.145	.105	.146
3	.215	.249	.189	.183	.231	.177	.240
4	.336	.418	.307	.290	.328	.269	.367
5	.480	.623	.461	.443	.480	.412	.573
6	.692		.648		.688	.610	
7							
Half-length							
1	.064	.083	.066	.077	.123		
2	.162	.199	.117	.182	.236		
3	.434	.451	.220	.337	.436		
4	.653	.735	.439	.579	.689		
5	.924	.900	.724	.858	.932		
6	1.283		1.037		1.353		
7							
Volution height							
1	.058	.053	.053	.032	.074	.027	.041
2	.046	.065	.024	.050	.051	.049	.067
3	.077	.096	.093	.068	.086	.072	.094
4	.121	.169	.118	.107	.097	.092	.127
5	.144	.205	.154	.153	.152	.143	.206
6	.212		.187		.208	.198	
7							
Wall thickness							
1	.004	.004	.005	.005	.005	.004	.006
2	.004	.006	.005	.006	.005	.005	.005
3	.005	.004	.007	.006	.005	.008	.007
4	.004	.006	.006	.006	.005	.005	.005
5	.007	.006	.007	.006	.005	.004	.006
6	.005		.006		.003	.008	
7							
Tunnel width (axials) or septal count (sagittals)							
1	.037	.032	.035	.028	.053	8	6
2	.082	.093	.077	.061	.091	10	12
3	.163	.149	.162	.118	.150	13	14
4	.431	.346	.294	.239	.224	16	16
5	.814		.323		.376	19	16
6			.644				
7							

TABLE 6—Representative quantitative morphologic data for *Fusulinella fugax* Thompson. Values in millimeters where applicable.

	Specimen number and horizon of occurrence						
Character (by volution)	OU10960 3-25b-1	OU10961 3-25b-2	OU10964 3-25t-1	OU10965 3-25t-2	OU10966 3-25t-7	OU10967 3-25t-8	OU10968 3-25t-9
Proloculus diameter	.068	.058	.080	.065	.060	.068	.051
Radius vector							
1	.087	.072	.065	.061	.063	.070	.057
2	.118	.116	.117	.105	.104	.129	.098
3	.184	.172	.191	.148	.158	.199	.163
4	.276	.263	.294	.224	.249	.288	.268
5	.393	.389	.404	.335	.377	.413	.370
6	.567			.471		.599	.540
7							
Half-length							
1	.083	.092	.089	.054	.087	.109	
2	.145	.195	.207	.128	.169	.240	
3	.261	.421	.408	.244	.305	.417	
4	.456	.605	.649	.423	.520	.544	
5	.718	.914	.794	.725	.878	.808	
6	.966			.962		1.091	
7							
Volution height							
1	.053	.043	.025	.028	.033	.036	.031
2	.031	.044	.052	.044	.041	.059	.041
3	.066	.056	.074	.043	.054	.070	.065
4	.092	.091	.103	.076	.091	.089	.105
5	.117	.126	.110	.111	.128	.125	.202
6	.174			.136		.186	.170
7							
Wall thickness							
1	.003	.005	.005	.008	.008	.010	.012
2	.005	.004	.009	.014	.009	.011	.008
3	.005	.008	.009	.010	.013	.008	.012
4	.009	.010	.012	.013	.014	.010	.012
5	.009	.015	.008	.013	.014	.015	.015
6	.010			.012		.021	.005
7							
Tunnel width (axials) or septal count (sagittals)							
1	.019	.021	.032	.025	.030	.035	7
2	.041	.031	.048	.028	.043	.045	12
3	.079	.071	.103	.087	.070	.071	15
4	.136	.150	.120	.194	.110	.180	18
5	.236	.290		.180		.242	21
6						.400	
7							

TABLE 7—Representative quantitative morphologic data for *Fusulinella acuminata* Thompson. Values in millimeters where applicable.

	Specimen number and horizon of occurrence									
Character (by volution)	OU10971 3-32-1	OU10972 3-32-2	OU10973 3-32-3	OU10974 3-32-4	OU10975 3-32-5	OU10976 3-32-6	OU10977 3-32-7	OU10979 3-32-10	OU10980 3-32-11	OU10982 1-119-11
Proloculus diameter	.081	.073	.071	.111	.088	.073	.097	.100	.079	.085
Radius vector										
1	.056	.073	.074	.101	.063	.069	.087	.080	.073	.075
2	.117	.133	.137	.159	.103	.108	.153	.133	.123	.141
3	.189	.196	.201	.241	.171	.178	.241	.205	.179	.229
4	.276	.283	.301	.366	.269	.255	.362	.307	.261	.359
5	.380	.424	.448	.525	.384	.401	.520	.441	.372	.530
6	.531	.569	.589		.539	.540		.600	.513	.725
7	.710									
Half-length										
1	.108	.106	.092	.161	.086	.085	.165	.091		
2	.233	.249	.251	.305	.177	.143	.372	.218		
3	.468	.490	.407	.595	.339	.276	.646	.435		
4	.690	.865	.894	.934	.596	.558	.947	.694		
5	1.198	1.409	1.284	1.506	.851	.906	1.179	1.120		
6	1.694	1.789	1.673		1.370	1.250		1.703		
7	2.129									
Volution height										
1	.015	.036	.038	.045	.019	.032	.038	.030	.033	.032
2	.061	.060	.063	.058	.040	.039	.066	.053	.050	.066
3	.072	.063	.064	.082	.068	.070	.088	.072	.056	.088
4	.087	.087	.100	.125	.098	.077	.121	.102	.082	.130
5	.104	.141	.147	.159	.115	.146	.158	.134	.111	.171
6	.151	.145	.141		.155	.139		.159	.141	.195
7	.179									
Wall thickness										
1	.008	.009	.008	.011	.007	.007	.009	.007	.008	.007
2	.010	.010	.012	.011	.008	.008	.014	.012	.009	.008
3	.012	.012	.014	.019	.012	.012	.014	.018	.013	.010
4	.019	.013	.014	.016	.019	.014	.019	.018	.014	.017
5	.019	.018	.020	.017	.019	.013	.021	.019	.016	.014
6	.018	.017	.017		.018	.014		.018	.015	.009
7	.019									
Tunnel width (axials) or septal count (sagittals)										
1	.027	.024	.032	.050	.023	.028	.052	.041	10	11
2	.045	.036	.059	.067	.037	.042	.105	.067	15	14
3	.076	.076	.097	.104	.082	.065	.153	.098	18	15
4	.097	.138	.174	.215	.110	.116	.294	.159	18	18
5	.215	.244	.315	.364	.197	.214		.263	18	22
6	.342									
7										

TABLE 8—Representative quantitative morphologic data for *Fusulinella proxima* Thompson. Values in millimeters where applicable.

	Specimen number and horizon of occurrence					
Character (by volution)	OU10993 3-27-3	OU10991 3-27-4	OU10990 3-31-2	OU10989 3-31-4	OU10992 3-27-8	OU10994 3-27-9
Proloculus diameter	.054	.071	.097	.103		.082
Radius vector						
1	.071	.045	.083	.108	.070	.064
2	.112	.085	.146	.155	.110	.116
3	.162	.133	.210	.236	.167	.185
4	.238	.193	.306	.334	.238	.261
5	.342	.288	.408	.460	.331	.372
6	.459	.389	.568	.607	.464	.526
7	.608	.540	.767	.790	.618	.702
		.716	.951	1.010		
Half-length						
1	.047	.064	.058	.111		
2	.119	.123	.168	.201		
3	.216	.268	.266	.416		
4	.381	.415	.423	.656		
5	.663	.610	.573	.823		
6	.834	.798	.870	1.317		
7	1.098	.985	1.262	1.594		
		1.142	1.701	1.965		
Volution height						
1	.044	.009	.034	.056	.046	.023
2	.041	.040	.063	.047	.040	.052
3	.050	.048	.064	.081	.057	.069
4	.076	.060	.096	.098	.071	.076
5	.104	.095	.102	.126	.093	.111
6	.117	.101	.160	.147	.133	.154
7	.149	.151	.199	.183	.154	.176
		.176	.184	.220		
Wall thickness						
1	.004	.009	.008	.006	.004	.005
2	.012	.007	.009	.007	.006	.009
3	.011	.010	.015	.015	.014	.006
4	.011	.010	.022	.011	.013	.009
5	.016	.012	.026	.016	.014	.011
6	.015	.011	.026	.020	.013	.012
7	.014	.015	.033	.015	.014	.014
		.016	.032	.022		
Tunnel width (axials) or septal count (sagittals)						
1	.016	.027	.029	.039	8	11
2	.035	.041	.032	.057	16	14
3	.051	.076	.057	.153	18	17
4	.086	.062	.113	.140	22	26
5	.139	.147	.169	.211	28	29
6	.259	.144	.350	.374	29	32
7		.311	.881	.603	30	

TABLE 9—Representative quantitative morphologic data for *Fusulinella devexa* Thompson. Values in millimeters where applicable.

	Specimen number and horizon of occurrence									
Character	OU11007	OU11008	OU11009	OU11010	OU10998	OU11000	OU11003	OU11004	OU11001	OU10999
(by volution)	3-39-1	3-39-2	3-39-4	3-39-5	1-139-1	1-139-2	1-139-4	1-139-5	1-142-10	1-142-12
Proloculus diameter	.109	.081	.088	.092	.126	.092	.101	.083	.117	.089
Radius vector										
1	.094	.066	.086	.087	.119	.110	.127	.197	.113	.122
2	.149	.121	.123	.153	.180	.179	.205	.159	.172	.194
3	.232	.196	.200	.215	.266	.269	.326	.247	.259	.292
4	.307	.309	.291	.321	.398	.381	.488	.333	.382	.410
5	.415	.446	.453	.435	.547	.530	.732	.462	.559	.574
6	.565	.642	.619	.616	.800	.737	.982	.657	.796	.767
7	.739	.853			1.001	.909		.840		
Half-length										
1	.100	.055	.186	.146	.175	.136	.179	.161		
2	.175	.142	.340	.275	.371	.268	.336	.316		
3	.303	.279	.569	.463	.682	.459	.598	.553		
4	.468	.492	.717	.749	1.067	.748	1.039	.919		
5	.868	.940	.965	1.070	1.507	1.319	1.792	1.583		
6	1.419	1.513	1.454	1.516	2.086	2.100	2.352	1.941		
7	1.932	1.843			2.771	2.522		2.436		
Volution height										
1	.039	.025	.042	.041	.056	.064	.076	.055	.054	.077
2	.055	.055	.037	.066	.061	.069	.078	.062	.059	.072
3	.083	.075	.077	.062	.086	.090	.121	.088	.087	.098
4	.075	.113	.091	.106	.132	.112	.162	.086	.123	.118
5	.108	.137	.162	.114	.149	.149	.244	.129	.177	.164
6	.150	.196	.166	.181	.253	.207	.250	.195	.237	.193
7	.174	.211			.201	.172		.183		
Wall thickness										
1	.007	.011	.013	.014	.009	.009	.012	.012	.008	.009
2	.009	.015	.012	.013	.012	.016	.008	.015	.012	.006
3	.011	.014	.011	.017	.014	.014	.013	.016	.011	.009
4	.010	.014	.021	.016	.013	.011	.014	.014	.018	.011
5	.015	.011	.014	.018	.018	.014	.019	.011	.017	.015
6	.016	.016	.018	.012	.021	.020	.014	.019	.020	.015
7	.016	.016			.015	.014		.012		
Tunnel width (axials) or septal count (sagittals)										
1	.019	.033	.032	.030	.038	.036	.055	.033	10	10
2	.050	.049	.040	.058	.067	.080	.101	.057	17	20
3	.066	.081	.121	.104	.129	.105	.204	.110	18	21
4	.102	.140	.130	.192	.277	.231	.365	.173	21	23
5	.268	.266	.232	.248	.466	.420	.789	.331	24	26
6	.332	.349			.788			.576	26	28
7										

TABLE 10—Representative quantitative morphologic data for *Fusulinella famula* Thompson. Values in millimeters where applicable.

	Specimen number and horizon of occurrence								
Character	OU11012	OU11013	OU11011	OU11014	OU11019	OU11016	OU11020	OU11018	OU11017
(by volution)	1-145-1	1-145-4	1-145-5	1-147-1	1-147-2	1-147-5	3-43-1	3-43-4	3-43-7
Proloculus diameter	.063	.077	.066	.089	.075	.075	.079	.082	.087
Radius vector									
1	.059	.079	.092	.095	.095	.088	.063	.066	.089
2	.103	.132	.148	.174	.137	.149	.113	.118	.149
3	.161	.192	.223	.253	.213	.233	.173	.187	.237
4	.237	.257	.327	.353	.315	.328	.264	.298	.343
5	.341	.345	.453	.463	.451	.432	.395	.408	.492
6	.470	.461	.609	.629	.619	.607	.550	.541	.685
7	.611	.453	.787	.799	.816	.759	.782		.902
Half-length									
1	.066	.095	.124	.156	.111	.135	.081	.083	
2	.162	.246	.241	.267	.195	.268	.144	.155	
3	.281	.367	.376	.428	.374	.406	.280	.312	
4	.437	.524	.534	.596	.484	.558	.467	.500	
5	.663	.700	.763	.771	.684	.766	.749	.675	
6	.930	.927	1.087	1.054	1.035	1.037	1.134	.874	
7	1.134	1.226	1.516	1.379	1.383	1.390	1.317		
Volution height									
1	.027	.040	.059	.050	.057	.050	.023	.025	.045
2	.044	.053	.056	.079	.042	.061	.050	.052	.060
3	.058	.060	.075	.079	.076	.084	.060	.069	.088
4	.076	.065	.104	.100	.102	.095	.091	.111	.106
5	.104	.088	.126	.110	.136	.104	.131	.110	.149
6	.129	.116	.156	.166	.168	.175	.155	.133	.193
7	.141	.132	.178	.170	.197	.152	.232		.217
Wall thickness									
1	.006	.013	.015	.007	.010	.011	.010	.010	.006
2	.006	.012	.013	.010	.013	.011	.008	.013	.010
3	.009	.011	.016	.012	.010	.012	.012	.016	.007
4	.012	.012	.014	.017	.011	.020	.012	.016	.014
5	.017	.016	.014	.020	.019	.017	.014	.017	.012
6	.019	.012	.017	.015	.020	.019	.014	.021	.020
7	.013	.012	.022	.016	.019	.018	.019		.018
Tunnel width (axials) or septal count (sagittals)									
1	.025	.030	.026	.025	.029	.028	.024	.030	8
2	.028	.047	.045	.049	.033	.052	.034	.035	15
3	.049	.056	.065	.060	.032	.083	.058	.051	18
4	.081	.066	.080	.091	.106	.098	.093	.104	23
5	.117	.131	.146	.112	.118	.138	.183	.189	25
6	.174	.155	.225	.154	.208	.138	.219	.359	28
7	.297		.286			.252	.444		29

TABLE 11—Representative quantitative morphologic data for *Beedeina insolita* (Thompson). Values in millimeters where applicable.

	Specimen number and horizon of occurrence									
Character (by volution)	OU11028 3-47-1	OU11022 3-47-2	OU11029 3-47-3	OU11030 3-47-4	OU11021 3-47-5	OU11031 3-47-6	OU11032 4-42-1	OU11033 4-42-2	OU11023 4-42-3	OU11025 4-42-6
Proloculus diameter	.070	.076	.067	.070	.074	.060	.086	.127	.116	.074
Radius vector										
1	.062	.084	.093	.057	.071	.070	.060	.116	.111	.103
2	.111	.131	.168	.097	.119	.113	.144	.205	.186	.135
3	.183	.204	.269	.156	.196	.164	.228	.319	.303	.230
4	.296	.328	.413	.249	.302	.262	.353	.487	.468	.319
5	.444	.490	.585	.394	.439	.398	.521	.685	.682	.468
6	.644		.781	.609	.619	.593	.726	.846	.791	.635
7	.806				.841					.815
8					1.054					1.018
Half-length										
1	.100	.097	.096	.054	.088	.084	.074	.144	.213	
2	.205	.173	.233	.096	.207	.187	.176	.301	.497	
3	.318	.283	.405	.216	.387	.329	.311	.489	.637	
4	.575	.441	.632	.504	.576	.532	.586	.688	.912	
5	.860	.900	.899	.738	.845	.819	.910	1.055	1.361	
6	1.326	1.272	1.199	1.053	1.196	1.167	1.560	1.642	1.572	
7	1.668				1.596					
8					2.072					
Volution height										
1	.027	.046	.059	.022	.034	.040	.017	.052	.053	.066
2	.049	.047	.075	.040	.048	.043	.084	.089	.075	.032
3	.072	.073	.101	.059	.077	.051	.084	.114	.117	.095
4	.113	.124	.144	.093	.106	.098	.125	.168	.165	.089
5	.148	.162	.172	.145	.137	.136	.168	.198	.214	.149
6	.200	.343	.196	.215	.180	.195	.205	.161	.109	.167
7	.162				.222					.180
8					.213					.203
Wall thickness										
1	.008	.012	.013	.010	.014	.005	.009	.008	.010	.016
2	.009	.010	.010	.011	.010	.009	.007	.013	.012	.007
3	.013	.011	.012	.013	.012	.006	.010	.024	.011	.010
4	.017	.015	.018	.016	.012	.009	.015	.022	.015	.013
5	.016	.017	.019	.013	.016	.012	.022	.025	.013	.020
6	.021	.016	.021	.017	.015	.014	.021	.025	.010	.017
7	.018				.022					.019
8					.016					.015
Tunnel width (axials) or septal count (sagittals)										
1	.016	.024	.047	.021	.036	.018		.043	.042	4
2	.021	.060	.069	.027	.047	.027	.050	.060	.089	14
3	.061	.076	.096	.064	.058	.065	.068	.114	.136	18
4	.108	.139	.132	.090	.102	.118	.105	.183	.207	23
5	.229	.178	.311	.173	.139	.178	.172	.182	.417	30
6	.233		.527		.270		.276	.230		32
7					.455					36
										40

TABLE 12—Representative quantitative morphologic data for *Beedeina* aff. *hayensis* (Ross & Sabins). Values in millimeters where applicable.

	Specimen number and horizon of occurrence									
Character (by volution)	OU11034 3-57t-1	OU11035 3-57-3	OU11036 3-57-4	OU11037 3-57-5	OU11045 4-61-1	OU11044 4-61-2	OU11043 4-61-3	OU11040 4-61-4	OU11046 4-61-9	OU11047 4-55-5
Proloculus diameter	.076	.082	.083	.061	.060	.047	.072	.055	.070	.62
Radius vector										
1	.082	.070	.064	.057	.057	.067	.074	.071	.106	.073
2	.130	.125	.113	.014	.097	.104	.120	.122	.189	.130
3	.203	.191	.187	.178	.170	.153	.191	.210	.317	.218
4	.312	.291	.302	.287	.285	.252	.294	.332	.500	.337
5	.471	.428	.437	.435	.429	.372	.442	.497	.694	.523
6	.678	.620	.613	.648	.598	.560	.644	.718	.925	.753
7	.906	.816	.217	.903	.772	.748	.837			.974
8						.950	.985			
Half-length										
1	.087	.073	.066	.056	.095	.080	.068	.088		
2	.182	.114	.143	.168	.203	.301	.147	.236		
3	.368	.251	.277	.340	.360	.529	.306	.378		
4	.511	.388	.477	.592	.530	.912	.494	.732		
5	.786	.716	.705	.896	.818	1.157	.814	1.194		
6	1.504	1.210	1.074	1.239	1.242	1.357	1.385	1.882		
7	2.056	1.658	1.533	1.538	1.883	1.599	1.721			
8						1.961	2.247			
Volution height										
1	.044	.029	.022	.026	.027	.043	.038	.043	.071	.042
2	.048	.055	.049	.047	.040	.037	.046	.051	.083	.057
3	.073	.066	.074	.074	.073	.049	.071	.088	.128	.088
4	.109	.100	.115	.109	.115	.099	.103	.122	.183	.119
5	.159	.137	.135	.148	.144	.120	.148	.165	.194	.186
6	.207	.192	.176	.213	.169	.188	.202	.221	.231	.230
7	.228	.196	.396	.255	.174	.188	.193			.221
8						.202	.148			
Wall thickness										
1	.006	.008	.006	.006	.007	.007	.009	.007	.010	.006
2	.010	.011	.009	.012	.009	.005	.010	.012	.013	.006
3	.011	.011	.009	.012	.009	.011	.010	.010	.011	.013
4	.013	.010	.009	.012	.011	.017	.014	.014	.011	.012
5	.022	.009	.012	.011	.015	.011	.016	.017	.013	.012
6	.016	.016	.011	.015	.019	.016	.017	.009	.010	.016
7	.017	.014	.014	.013	.015	.016	.018			.017
8						.015	.020			
Tunnel width (axials) or septal count (sagittals)										
1	.031	.040	.034	.028	.024	.019	.022	.031	10	7
2	.037	.044	.034	.033	.044	.043	.040	.070	14	11
3	.078	.067	.073	.070	.084	.057	.081	.144	15	12
4	.147	.115	.086	.113	.124	.171	.114	.188	19	16
5	.291	.211	.181	.129	.250	.142	.226	.335	26	21
6	.372	.366	.209	.238	.291	.307	.275		26	29
7						.342				

TABLE 13—Representative quantitative morphologic data for *Beedeina* aff. *curta* (Thompson). Values in millimeters where applicable.

	Specimen number and horizon of occurrence								
Character (by volution)	OU11048 1-166-1	OU11049 1-166-2	OU11050 1-166-3	OU11051 1-166-4	OU11052 1-166-5	OU11053 1-166-6	OU11054 1-166-7	OU11055 1-166-8	OU11056 1-166-9
Proloculus diameter	.108	.106	.105	.135	.112	.084	.111	.105	.107
Radius vector									
1	.101	.109	.111	.109	.101	.144	.147	.096	.120
2	.154	.164	.179	.179	.186	.226	.227	.161	.204
3	.239	.243	.279	.231	.280	.310	.322	.216	.304
4	.318	.337	.400	.307	.407	.436	.452	.347	.409
5	.436	.442	.553	.453	.575	.604	.707	.506	.580
6	.564	.599	.801	.610	.801	.805	.908	.725	.779
7	.792	.797	1.020	.823	1.056	1.053	1.140	.946	.974
8	1.016	1.036	1.216	1.067	1.287	1.256	1.385	1.234	
9	1.242	1.278		1.280					
Half-length									
1	.104	.092	.132	.122	.125	.117	.188		
2	.217	.194	.256	.210	.258	.236	.329		
3	.356	.306	.395	.299	.420	.363	.548		
4	.498	.478	.660	.420	.625	.596	.727		
5	.668	.587	.975	.619	.932	.864	.990		
6	.853	.781	1.191	.757	1.445	1.096	1.353		
7	1.127	1.032	1.587	1.090	1.938	1.521	1.794		
8	1.518	1.487	2.141	1.501	2.575	2.208	2.310		
9	1.942	2.240		1.803					
Volution height									
1	.047	.056	.058	.041	.045	.102	.091	.043	.066
2	.053	.055	.068	.070	.085	.082	.080	.065	.084
3	.085	.079	.100	.052	.094	.084	.095	.055	.100
4	.079	.094	.121	.076	.127	.126	.130	.131	.105
5	.118	.105	.153	.146	.168	.168	.255	.159	.171
6	.128	.157	.248	.157	.226	.201	.201	.219	.199
7	.228	.198	.219	.213	.255	.248	.232	.221	.195
8	.224	.239	.196	.244	.231	.203	.245	.288	
9	.226	.242		.213					
Wall thickness									
1	.011	.009	.014	.013	.012	.012	.010	.011	.012
2	.010	.009	.014	.011	.019	.017	.018	.014	.016
3	.013	.014	.019	.010	.016	.016	.016	.011	.019
4	.015	.016	.014	.013	.017	.017	.015	.022	.021
5	.019	.013	.022	.020	.014	.017	.019	.017	.030
6	.017	.017	.023	.020	.018	.020	.020	.024	.022
7	.022	.017	.018	.026	.020	.018	.021	.032	.020
8	.016	.020	.019	.029	.015	.021	.024	.024	
9	.015	.012		.025					
Tunnel width (axials) or septal count (sagittals)									
1	.028	.031	.034	.032	.038	.025	.033	8	9
2	.048	.038	.065	.040	.057	.047	.059	15	15
3	.064	.045	.083	.058	.074	.097	.082	12	21
4	.064	.073	.127	.094	.144	.147	.101	23	24
5	.128	.080	.178	.158	.244	.221	.155	31	24
6	.158	.146	.266	.172	.393	.259	.249	34	24
7	.252	.170	.362	.233	.608	.378	.416	32	31
8	.212	.318		.337					
9	.430								

TABLE 14—Representative quantitative morphologic data for *Beedeina* aff. *rockymontana* (Roth & Skinner). Values in millimeters where applicable.

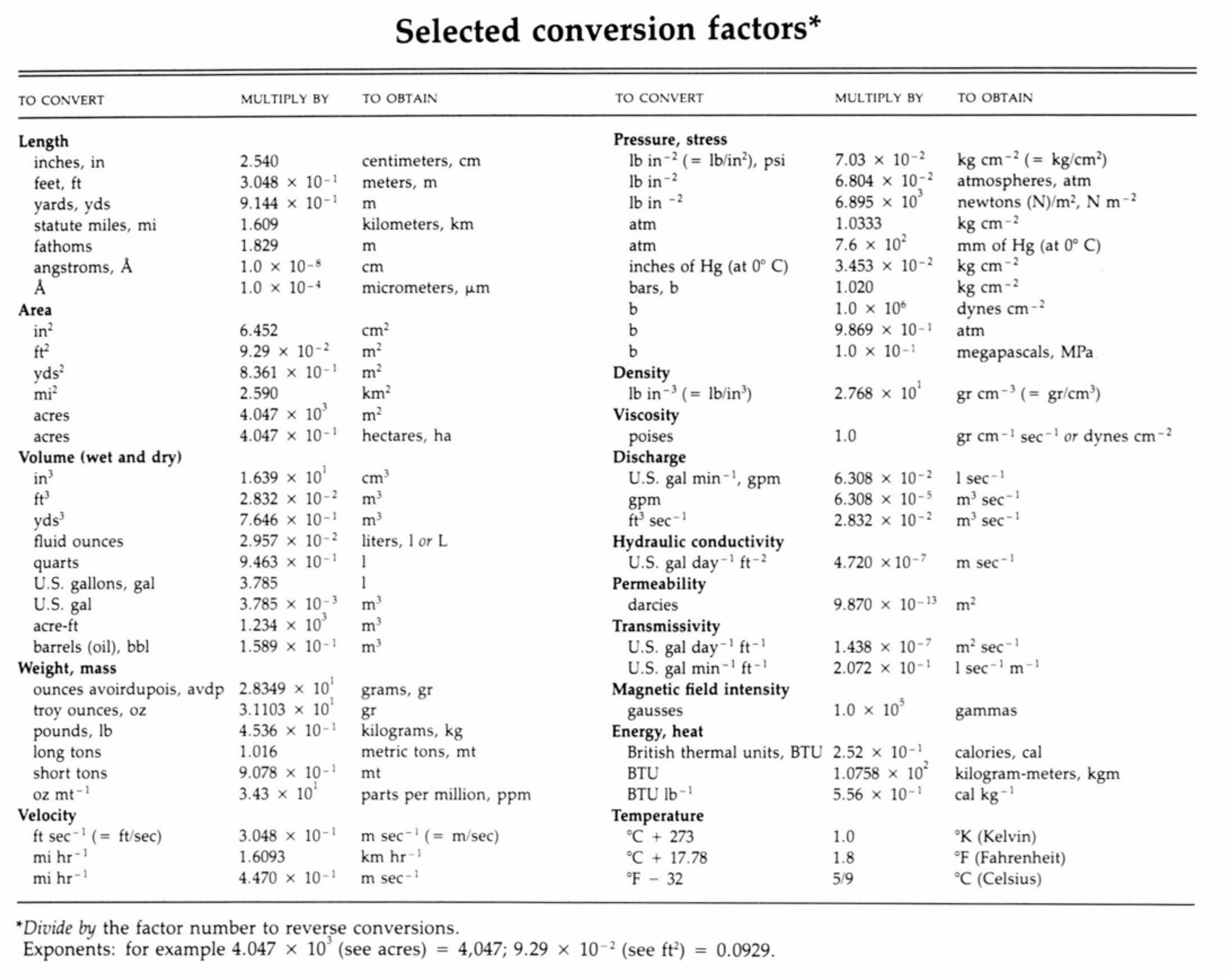
	Specimen number and horizon of occurrence							
Character (by volution)	OU11085 3-56-1	OU11086 3-56-2	OU11087 3-56-3	OU11088 3-56-4	OU11089 3-56-6	OU11090 3-56-8	OU11091 3-56-9	OU11092 3-56-10
Proloculus diameter	.117	.083	.079	.083	.078	.087	.107	.109
Radius vector								
1	.103	.063	.077	.089	.131	.083	.096	.113
2	.155	.105	.113	.138	.215	.139	.154	.186
3	.238	.171	.181	.218	.319	.206	.237	.277
4	.348	.292	.273	.357	.469	.308	.346	.386
5	.469	.451	.387	.543	.642	.448	.493	.538
6	.661	.654	.536	.766		.647	.688	.706
7	.839	.888	.721			.858	.892	
8			.917					
Half-length								
1	.114	.097	.078	.103	.216	.146	.146	
2	.226	.226	.196	.194	.397	.274	.281	
3	.429	.435	.312	.387	.645	.457	.531	
4	.717	.662	.502	.746	1.146	.819	.929	
5	.966	1.229	.728	1.216	1.707	1.169	1.339	
6	1.440	1.816	1.286	1.860		1.728	1.814	
7	2.389	2.139	1.802			2.282	2.150	
8			2.325					
Volution height								
1	.044	.021	.037	.047	.092	.039	.042	.058
2	.052	.042	.036	.049	.084	.056	.058	.073
3	.083	.066	.068	.080	.104	.067	.083	.091
4	.110	.121	.092	.139	.150	.102	.109	.109
5	.121	.159	.114	.186	.173	.140	.147	.152
6	.192	.203	.149	.223		.199	.195	.168
7	.178	.234	.185			.211	.204	
8			.196					
Wall thickness								
1	.010	.011	.004	.010	.013	.007	.011	.007
2	.009	.011	.008	.014	.009	.013	.014	.015
3	.015	.015	.009	.012	.016	.011	.017	.014
4	.015	.013	.012	.014	.019	.013	.015	.014
5	.014	.014	.016	.015	.023	.015	.020	.013
6	.014	.019	.016	.017		.018	.018	.020
7	.014	.018	.017			.015		
8			.014					
Tunnel width (axials) or septal count (sagittals)								
1	.044	.028	.017	.034	.038	.038	.031	9
2	.053	.041	.041	.076	.072	.061	.069	14
3	.102	.078	.065	.155	.189	.084	.110	18
4	.155	.161	.102	.270	.285	.156	.151	22
5	.258	.213	.189	.398		.323	.274	24
6	.651	.421	.253	.767		.623	.475	
7			.505					

TABLE 15—Representative quantitative morphologic data for *Beedeina* aff. *joyitaensis* Stewart. Values in millimeters where applicable.

	Specimen number and horizon of occurrence								
Character (by volution)	OU11075 1-164-1	OU11076 1-164-2	OU11077 1-172-1	OU11078 1-172-2	OU11079 1-172-3	OU11080 1-172-4	OU11081 1-172-5	OU11082 1-172-6	OU11084 1-172-9
Proloculus diameter	.111	.094	.103	.094	.085	.109	.107	.119	.107
Radius vector									
1	.109	.100	.091	.094	.096	.104	.097	.107	.119
2	.216	.166	.149	.151	.143	.164	.148	.182	.207
3	.342	.256	.232	.230	.226	.251	.239	.296	.323
4	.517	.382	.339	.339	.324	.355	.369	.433	.542
5	.741	.565	.523	.461	.471	.503	.573	.610	.764
6	1.028	.830	.780	.635	.655	.729	.823	.818	.939
7	1.297	1.066	.972	.804	.875	1.037	1.057	1.039	
8		1.276	1.167	1.040					
Half-length									
1	.120	.121	.117	.098	.071	.098	.134	.116	
2	.263	.262	.213	.215	.147	.217	.260	.303	
3	.518	.504	.391	.348	.331	.378	.466	.569	
4	.891	.776	.639	.643	.520	.573	.737	.848	
5	1.477	1.169	.946	.849	.820	.859	1.079	1.177	
6	1.986	1.759	1.471	1.173	1.234	1.352	1.428	1.538	
7	2.459	2.278	2.039	1.594	1.779	1.865	1.948	2.243	
8			2.501	2.097					
Volution height									
1	.053	.053	.039	.047	.053	.049	.043	.047	.065
2	.107	.066	.058	.057	.047	.060	.051	.075	.088
3	.126	.090	.083	.079	.083	.087	.091	.114	.116
4	.175	.126	.107	.109	.098	.104	.130	.137	.219
5	.224	.183	.184	.122	.147	.148	.204	.177	.222
6	.287	.265	.257	.174	.184	.226	.250	.208	.175
7	.269	.236	.192	.169	.220	.308	.234	.221	
8		.210	.195	.236					
Wall thickness									
1	.006	.006	.007	.014	.008		.009	.011	.012
2	.010	.007	.011	.011	.010	.009	.010	.011	.016
3	.012	.009	.014	.018	.011	.014	.014	.016	.020
4	.016	.014	.013	.015	.012	.010	.013	.016	.019
5	.016	.012	.015	.019	.011	.015	.019	.015	.018
6	.016	.024	.011	.018	.014	.020	.021	.023	.018
7	.015	.018	.026	.015	.018	.015	.022	.022	
8		.009	.020	.014					
Tunnel width (axials) or septal count (sagittals)									
1	.053	.051	.038	.014	.032	.039	.047	.042	10
2	.086	.066	.051	.038	.056	.060	.055	.077	17
3	.115	.100	.087	.076	.095	.102	.093	.104	16
4	.188	.219	.142	.115	.125	.168	.146	.154	20
5	.306	.297	.195	.151	.234	.208	.238	.182	27
6	.413	.430	.326	.261	.396	.410	.382	.320	25
7			.503	.339					

TABLE 16—Representative quantitative morphologic data for *Wedekindellina excentrica* (Roth & Skinner). Values in millimeters where applicable.

	Specimen number and horizon of occurrence									
Character (by volution)	OU11061 3-60-1	OU11062 3-60-2	OU11063 3-60-3	OU11064 3-60-4	OU11065 3-60-5	OU11066 3-60-6	OU11067 2-117-1	OU11068 2-117-2	OU11069 1-175-1	OU11070 1-175-3
Proloculus diameter	.048	.057	.064	.063	.044	.065	.070	.044	.041	.076
Radius vector										
1	.055	.055	.054	.052	.041	.052	.057	.061	.055	.057
2	.087	.084	.076	.082	.067	.076	.091	.074	.087	.104
3	.119	.119	.111	.116	.098	.104	.120	.108	.115	.180
4	.161	.161	.155	.167	.138	.145	.178	.157	.183	.270
5	.221	.210	.210	.236	.190	.193	.230	.203	.249	.376
6	.282	.277	.286	.302	.264	.262	.292	.261	.328	.512
7	.390	.363	.389	.402	.351	.356	.372	.332	.461	.762
8	.476	.439	.497		.469	.440	.500	.423	.605	
9								.545	.817	
Half-length										
1	.062	.054	.052	.060	.046	.049	.145	.071	.085	
2	.115	.107	.071	.157	.087	.098	.220	.116	.191	
3	.263	.241	.175	.318	.194	.226	.354	.235	.456	
4	.508	.379	.389	.553	.397	.414	.515	.344	.640	
5	.693	.612	.659	.830	.584	.672	.769	.706	.845	
6	.964	.908	1.057	1.048	.723	.899	.950	.913	1.159	
7	1.334	1.128	1.372	1.224	1.058	1.192	1.361	1.165	1.602	
8	1.555	1.271	1.747		1.476	1.586	1.693	1.597	2.085	
9							1.925	2.078	2.315	
Volution height										
1	.031	.026	.022	.020	.019	.019	.022	.039	.034	.019
2	.032	.029	.022	.030	.026	.024	.034	.013	.032	.047
3	.032	.035	.035	.034	.031	.028	.029	.034	.028	.076
4	.042	.042	.044	.051	.040	.041	.058	.049	.068	.090
5	.060	.049	.055	.069	.052	.048	.052	.046	.066	.106
6	.061	.067	.076	.066	.074	.069	.062	.058	.079	.136
7	.108	.086	.103	.100	.087	.094	.080	.071	.133	.250
8	.086	.076	.108		.118	.084	.128	.091	.144	
9								.122	.212	
Wall thickness										
1	.005	.005	.007	.006	.006	.005	.007	.006	.007	.007
2	.003	.005	.008	.005	.007	.005	.005	.006	.009	.008
3	.005	.007	.008	.006	.007	.008	.010	.006	.010	.009
4	.009	.008	.007	.008	.008	.007	.012	.007	.008	.010
5	.008	.009	.006	.013	.009	.007	.011	.009	.009	.012
6	.005	.010	.008	.007	.009	.012	.013	.011	.014	.013
7	.010	.011	.011	.006	.012	.012	.008	.012	.006	.014
8	.007		.013		.012	.011	.013	.012	.014	
9							.009	.013	.007	
Tunnel width (axials) or septal count (sagittals)										
1	.013	.020	.011	.015	.015	.017	.026	.024	.029	10
2	.017	.033	.018	.026	.028	.020	.039	.039	.058	14
3	.041	.049	.042	.048	.045	.038	.047	.024	.053	18
4	.055	.067	.078	.077	.059	.078	.065	.062	.105	20
5	.087	.093	.110	.134	.087	.086	.081	.049	.135	24
6	.126	.119	.122	.135	.126	.139	.134	.072	.145	27
7	.170	.200	.168		.210	.198	.142	.115	.229	40
8			.293				.399	.103	.277	
9									.462	



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}
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^{-1}	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.

Editor: Jiri Zidek

Typeface: Palatino

Presswork: Miehle Single Color Offset
Harris Single Color Offset

Binding: Smyth sewn with softbound cover

Paper: Cover on 12-pt Kivar
Text on 70-lb white matte

Ink: Cover—Black and PMS 320
Text—Black

Quantity: 1000