# THE MICROFOSSIL ASSOCIATION OF THE UPPER PART OF THE SALESVILLE FORMATION (LOWER MISSOURIAN, PENNSYLVANIAN) NEAR MINERAL WELLS, NORTH-CENTRAL TEXAS

by

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# ABSTRACT

## THE MICROFOSSIL ASSOCIATION OF THE UPPER PART OF THE SALESVILLE FORMATION (LOWER MISSOURIAN, PENNSYLVANIAN) NEAR MINERAL WELLS, NORTH-CENTRAL TEXAS

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The microfossil association of the Salesville Formation (Strawn Group, Missourian, Pennsylvanian) of small foraminifers, fusulinids, conodonts, ostracodes, holothurian sclerites, and rare radiolarians, has received very little study. The upper part of the Salesville Formation, as exposed at two sections near Mineral Wells, North-Central Texas, represents deposits of the upper Salesville major cycle and is the stratigraphic interval of interest in this study whose primary objective is to evaluate the biostratigraphic significance of the microfossil association found at the two exposures of this cycle. The distribution of the early Missourian microfaunas is used to interpret the depositional environments of the major cycle and its context within the upper part of the Strawn Group (lower part of the Missourian Stage, Pennsylvanian).

Twelve new species of small foraminifers are described along with several updated descriptions of previously described species of small foraminifers and fusulinids. Other microfossils are discussed and illustrated, but not formally described. The upper part of the Salesville Formation is assigned herein to the biostratigraphic zones: fusulinid (Eowaeringella Zone), conodont (Idiognathodus cancellosus Zone), and ostracode (Kegelites dattonensis Zone). A correlation of two Salesville Formation sections is made along with suggested correlations of this interval to similar aged strata at other localities in North America using the microfossil association. The Salesville Formation contains a diverse microfossil association that allows excellent biostratigraphic correlation of its strata to other areas where similar aged Pennsylvanian strata are present. The geochemistry of abundant phosphate nodules present in the lower part of one of the sections is noted. The relative sea level change through the upper part of the Salesville major cycle at both studied localities is suggested in addition to an interpretation of the depositional environment.

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# CHAPTER 1: INTRODUCTION TO THE SALESVILLE FORMATION

Exposures of Middle and Upper Pennsylvanian strata found in much of the Brazos River Valley in North-Central Texas provide an opportunity for micropaleontologists to study the marine microfauna associated with the southern part of the Midcontinent Sea that covered large areas of the middle part of North America during the Pennsylvanian. Over the past several decades, some formations of the Strawn Group have not been studied, and the Salesville Formation (Missourian) is one such formation that contains a microfauna with outdated taxonomy. The upper part of the Salesville Formation that lies above the Devil's Hollow Sandstone is the principal stratigraphic interval of interest in the current study and represents the deposits of the third Missourian marine eustatic event in North-Central Texas, referred to as the upper Salesville major cycle (Boardman and Heckel 1989). Previous biostratigraphic studies of the region have correlated the upper Salesville major cycle with the Swope Cyclothem of the Midcontinent, but recent micropaleontological work concerning Missourian faunas in the Midcontinent region, New Mexico, and Nevada has brought attention to the outdated work of North-Central Texas (see Barrick et al. 2013; Wahlman 2013; Allen and Lucas 2018; Read and Nestell 2019).

The only microfossils studied directly from the upper part of the Salesville Formation in the past half-century were the fusulinids by Nestell (1989) and the conodonts by Barrick and Boardman (1989), and Rosscoe and Bader (2010). Furthermore, it has been over forty years since most of the work on any of the microfossil assemblages of the Strawn Group was completed. The last study of the foraminifers from the Strawn Group was by Plummer (1945), and the last study of the ostracodes was by Melnyk and Maddocks (1988). Missourian age radiolarians in North-Central Texas have only been reported as a single specimen by Boardman et al. (1995) and in an abstract by Nestell and Blome (1996). Holothurian sclerites from the Strawn Group have never been published.

The need for a comprehensive reevaluation of the microfossil assemblages of the upper part of the Salesville Formation has become apparent from the lack of recent work and is the basis for the current study. Two localities were chosen for investigation in Palo Pinto County, North-Central Texas, where the upper part of the Salesville Formation is exposed. A detailed study of the stratigraphy in conjunction with recording the distribution of the microfossils aids in creating an accurate correlation between the two localities, and their biostratigraphic significance within the North American Missourian Stage. Interpretations of the depositional environments are suggested by using evidence from the reevaluation of the microfossil assemblages and study of the stratigraphy.

## 1.1 Upper Pennsylvanian Geology of North-Central Texas

During the Missourian, the area of North-Central Texas was located on the southern part of the Midcontinent Sea, positioned within approximately 5° of the paleoequator, implying a regional tropical climate (Figure 1) (Schutter and Heckel 1985; Heckel 1991; Blakey 2003). The Middle to Late Pennsylvanian paleogeographic setting of North-Central Texas has been regarded as both the Eastern Shelf (Wermund and Jenkins 1969) and the North Texas Shelf (Heckel 1991), the latter of which is used herein. The North Texas Shelf was a relatively tectonically stable platform compared to the physiographic and geologic features that bounded it (Erxleben 1975). The North Texas Shelf was bounded to the northeast by the granite knobs of the Red

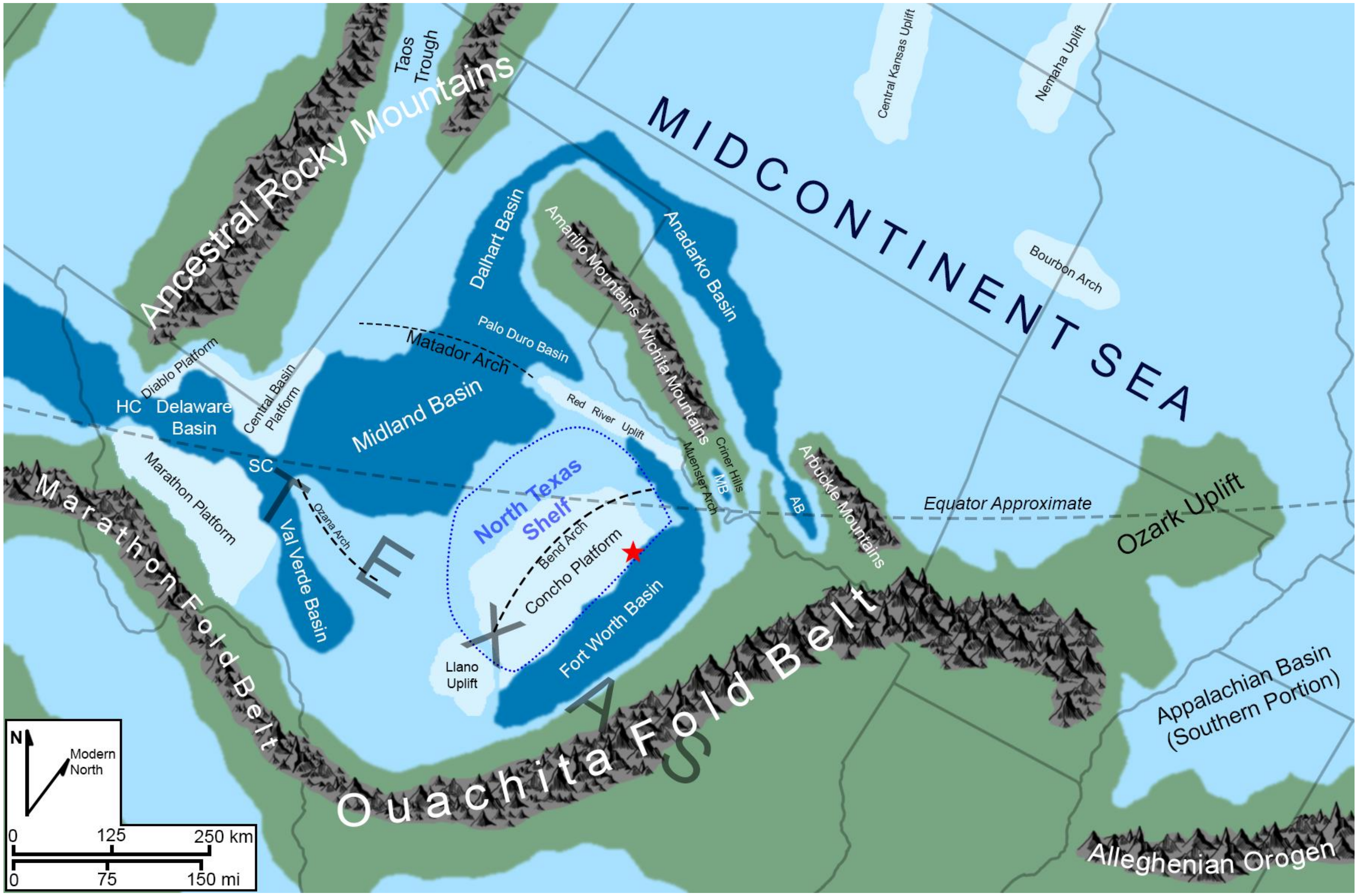


**Fig. 1.** A paleogeographic map of North-Central Texas and surrounding areas showing the geologic setting during Late Pennsylvanian time. The location of the current study is shown by the red star. The approximate area of the North Texas Shelf is outlined by the blue dotted line. AB = Ardmore Basin. HC = Hovey Channel. SC = Sheffield Channel. MB = Marietta Basin (modified from Blakey 2003; Algeo and Heckel 2008; Hogancamp et al. 2015).

River Uplift and the Muenster Arch. This northeast to southwest trending series of parallel, faulted, anticlinal folds represents a higher topography than found on the North Texas Shelf that supported large carbonate systems around islands (Erxleben 1973; Cleaves 1975). Immediately northeast of the Red River Uplift-Muenster Arch complex are the NNW-SSE trending Amarillo, Wichita, and Arbuckle Mountain Range groups. These mountain ranges form a thin strip of highlands that nearly segregates the Texas basins from the rest of the Midcontinent Sea with only relatively narrow channels located at the north and south ends of the groups (Heckel 1991; Blakey 2003).

The collision of Laurentia and Gondwana during the formation of Pangea in the later part of the Pennsylvanian led to extensive uplifting of the Ouachita Fold Belt that bounded the North Texas Shelf to the south (Walper 1982; Blakey 2003). The Ouachita Fold Belt was part of the larger Marathon-Ouachita Orogenic Belt consisting of orogenically deformed rocks that spanned approximately 2,100 km in length (Cleaves 1975). Most of the clastic terrigenous sediments transported to the North Texas Shelf during the Missourian originated from the Ouachita Fold Belt, and lesser quantities were sourced from the Amarillo, Wichita, and Arbuckle Mountain ranges and the Red River Uplift-Muenster Arch (Cleaves 1975). The southwestern boundary of the North Texas Shelf was formed by the Llano Uplift in Central Texas (Cleaves 1975). The Llano Uplift is a dome composed of Mesoproterozoic age igneous and metamorphic rocks that were uplifted and tectonically modified multiple times throughout its geologic history (Flawn 1961; Ewing 2005).

The Fort Worth Basin is an accompanying foreland basin to the Ouachita Fold Belt that formed by subsidence immediately north of the fold belt in the early part of the Pennsylvanian (Cleaves 1975; Walper 1982). The Fort Worth Basin was the closest active depocenter to the

North Texas Shelf, and thick Strawn deposits began to fill the basin during the Desmoinesian. By the Missourian, most of the Fort Worth Basin had been filled-in with only the northeasternmost portion of the basin having any remaining accommodation space (Cleaves 1975; Greimel and Cleaves 1979). Additionally, the Ouachita Fold Belt and the southeastern margin of the Fort Worth Basin began to experience post-orogenic uplift, further limiting the accommodation space in the basin (Bradshaw 1996). The loss of accommodation space in the Fort Worth Basin roughly coincided with the subsidence of the Permian Basin, which was located to the west and northwest of the North Texas Shelf during the Middle and Late Pennsylvanian (Yang and Dorobek 1995). The Permian Basin is a foreland basin of the Marathon-Ouachita Orogenic Belt and is made up of several sub-basins. One of these sub-basins, the Midland Basin, bounds the North Texas Shelf to the northwest (Yang and Dorobek 1995).

The Concho Platform was a broad carbonate shelf located centrally on the greater North Texas Shelf that formed during the Morrowan and Atokan (Brown 1973; Bradshaw 1996). The location of the Concho Platform between the Fort Worth and Midland basins led to the platform being altered by the formation of both basins over time. The formation and initial subsidence of the Fort Worth Basin defined the eastern margin of the Concho Platform and caused the margin to have an eastward dip (Cheney 1929). As the Fort Worth Basin filled during the Desmoinesian, the Concho Platform started to gradually subside, allowing deltaic systems to begin to propagate out over the filled basin and onto the Concho Platform (Greimel and Cleaves 1979). Later, during the Missourian, the subsidence of the Permian Basin and the uplift of the Fort Worth Basin caused the once stable Concho Platform between them to begin sloping northwestward (Cleaves and Erxleben 1985). The sloping of the platform caused the North Texas Shelf to develop a gradual slope to the northwest and formed a northeast to southwest hinge line (flexure) known as the Bend Arch (Cheney 1929; Cleaves 1975). The combination of the subsidence of the Permian Basin, the filling and uplift of the Fort Worth Basin, and the sloping of the Concho Platform allowed deltaic systems from the east and southeast to propagate great distances westward in the direction of the Midland Basin over the North Texas Shelf during the Missourian (Cleaves 1982).

### 1.1.1 Palo Pinto County

During the Missourian, the area around present-day Mineral Wells was situated on the North Texas Shelf near the area where the Concho Platform and the mostly filled Fort Worth Basin meet (Figure 1). This area, which had a maximum transgressive water depth of ~100-250 m, was particularly susceptible to glacioeustatic fluctuations resulting in the depositional pattern associated with cyclothems (Heckel 1989; Herrmann et al. 2015; Ortiz 2018). During times of regression, the area of present day northern and central Palo Pinto County was dominated by the Perrin delta system that propagated from the southeast to the northwest up to 160 km onto the Concho Platform (Cleaves 1975). The Perrin delta system consisted of a complex network of thin lobes composed of sediments primarily derived from the Ouachita Fold Belt and were deposited mostly along the southeastern margin of the Concho Platform (Cleaves 1975). The Devil’s Hollow Sandstone Member of the Salesville Formation is representative of one of the sandy, shallow marine lobes of the Perrin delta system. During times of transgression, the Perrin delta system was pushed back closer to the Ouachita Fold Belt and the paleoenvironment of present-day Palo Pinto County transitioned to an open shelf environment. The increased sea level resulted in the encroachment of the oxygen-minimum zone from the Midland Basin onto the North Texas Shelf and resulted in the deposition of black shale units such as the Salesville Shale

(Boardman and Malinky 1985; Brown 1989; Teo 1991). The Salesville Shale represents the deposits of the third Missourian marine eustatic event in North-Central Texas referred to as the upper Salesville major cycle (Figure 2) (Boardman and Heckel 1989).

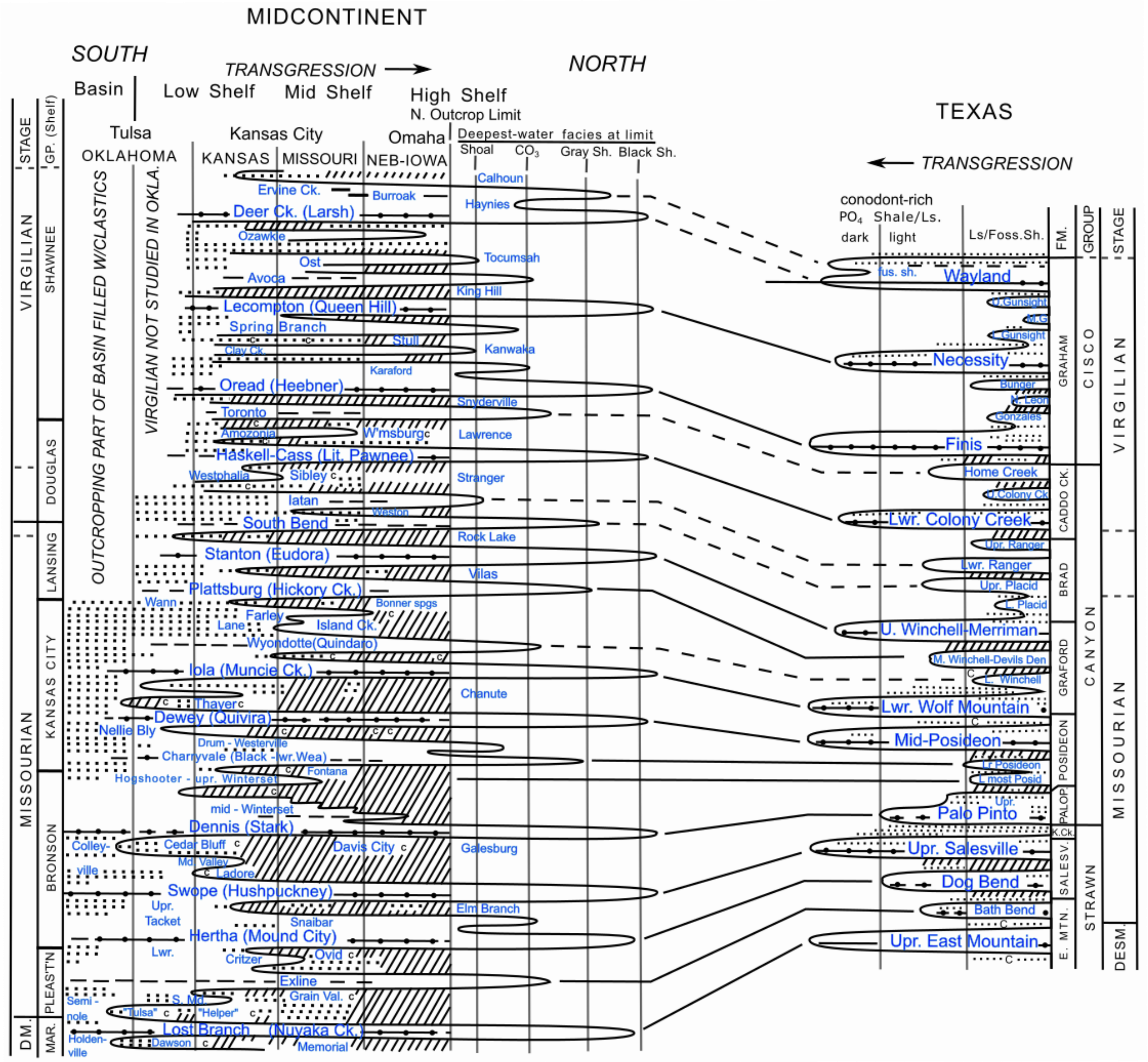


**Fig. 2.** Midcontinent and North-Central Texas sea level curves showing the correlation of cycles in Texas to cyclothems in the Midcontinent. The upper Salesville major cycle (Upr. Salesville) is included on the lower right side (redrawn from Boardman and Heckel 1989).

## 1.2 Review of Stratigraphic Nomenclature

The Pennsylvanian stratigraphic nomenclature used in North-Central Texas has undergone numerous revisions since the late 1800's. Many of these revisions were made in hopes of creating a standard lithostratigraphic scheme that can be easily correlated across Texas and with other areas outside of the state. The lithostratigraphic schemes used today only vaguely resemble the schemes created nearly a century ago; however, after so many revisions and decades of confusion, geologists in Texas are no closer to agreeing on a single lithostratigraphic scheme. To understand why the problem persists to this day, a comprehensive review of the history of the Strawn Group and the Salesville Formation was undertaken. In this work, unit levels, such as group or formation, follow the capitalization method of the original publication being discussed.

### 1.2.1 History of the Strawn Group

The first introduction of the name "Strawn" in conjunction with lithostratigraphy in North-Central Texas was by Dumble (1890) when he used the term to describe a series of beds containing coal seams near the town of Strawn, Texas (Figure 3). The Strawn division was formally defined by Cummins (1891) when he assigned it to contain all rock units between the top of coal seam No. 1 (Thurber Coal) and the base of the Canyon limestone units. Drake (1893) discarded the Millsap division that was stratigraphically below the Strawn and reassigned its strata to the Strawn division. The reassignment made the top of the Bend division (Smithwick Shale) as the new lower boundary of the Strawn division. The Strawn division was briefly assigned to formation status by Udden et al. (1919), but this change was never widely accepted, and Plummer (1919) reversed it.

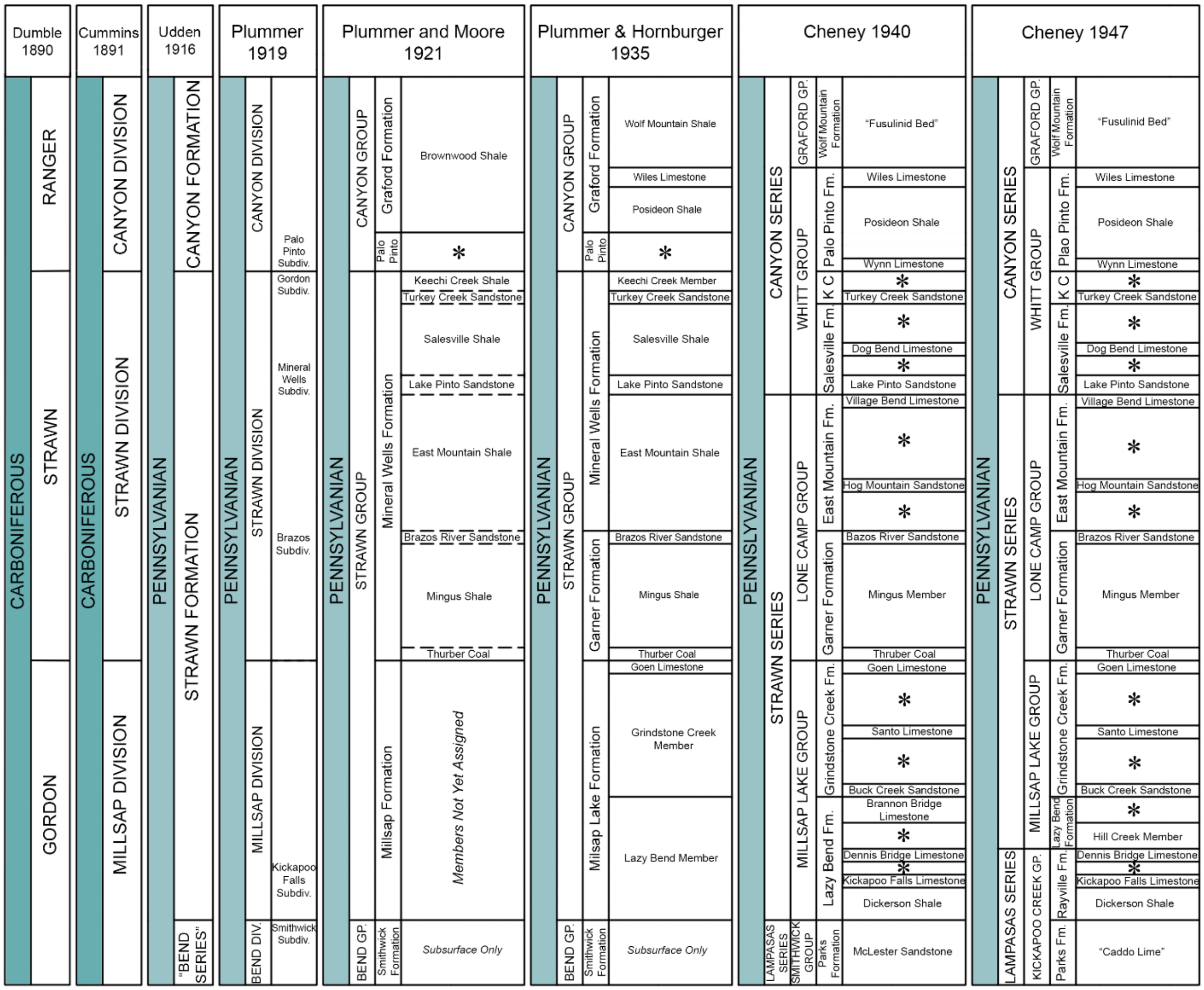


**Fig. 3.** A composite history of different lithostratigraphic schemes used in North-Central Texas from 1890 to 1947. Member names in quotations indicates a member name that the author considered to be informal. Dashed lines indicate an uncertain or unknown boundary. * = Interval where no member is defined; K C = Keechi Creek Formation; GP. = Group; Fm. = Formation.

Plummer and Moore (1921) formally introduced the Strawn group when they redefined all of the informal divisions of Cummins (1891) and were the first to subdivide the Strawn into formations. The work of Sellards (1933) continued to refine formations and members of the

Strawn group and he introduced the first published type sections for the formations. After Plummer and Hornburger (1935) published their work on the geology of Palo Pinto County using Sellards' (1933) scheme, the majority of lithostratigraphic work on the Strawn group appeared to have been completed.

The lithostratigraphic scheme of North-Central Texas was drastically changed when Cheney (1940) introduced his classification scheme that reassigned the previously established Pennsylvanian lithostratigraphic groups of North-Central Texas to chronostratigraphic series. This reassignment included changing the Strawn group to the Strawn series. These changes were made to facilitate better correlation between North-Central Texas and the series defined in the northern Midcontinent, and the boundaries of the new series were largely based on unconformities and faunal changes (Cheney 1940). The Strawn series had become nearly the provincial equivalent to the Desmoinesian series, and the now defunct Strawn group was replaced by the Millsap Lake group, the Lone Camp group, and the Whitt group (Cheney 1940).

The Strawn series was further refined with the creation of the Lampasas series, which included the lower part of the Strawn series (Cheney et al. 1945; Cheney 1947). The prevalence of provincial series in use in the late 1940's led Moore and Thompson (1949) to argue that these series created more confusion when attempting interregional correlations instead of less as their intended purpose. As a result, they demoted the Strawn series (along with many other provincial series) to the Strawn stage, and a new set of series was created for use across all of North America (Figure 4) (Moore and Thompson 1949). In Texas, these changes were largely ignored. Instead, Cheney and Goss (1952) reiterated their opinion that the Strawn should be regarded as a series.

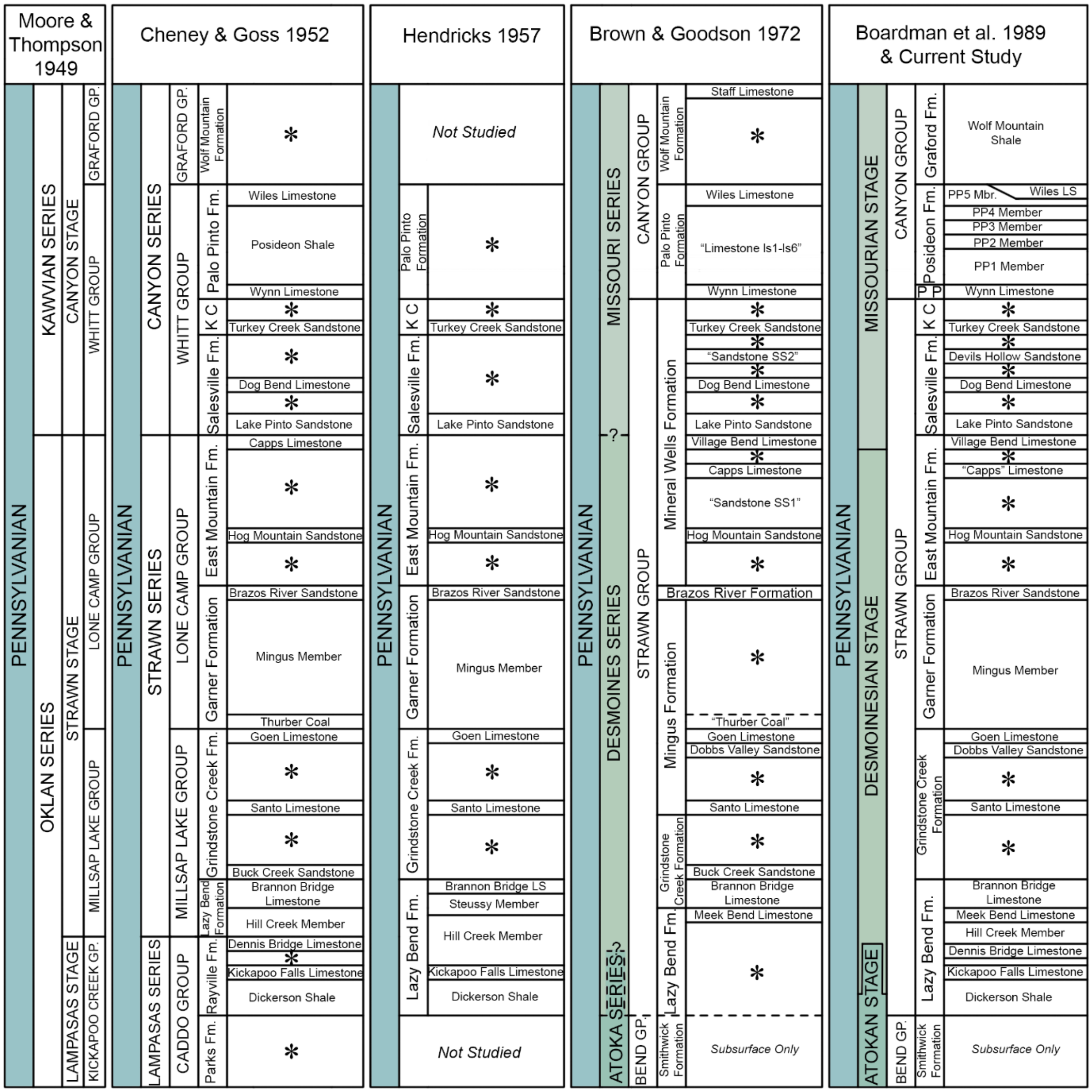


**Fig. 4.** A composite history of different lithostratigraphic schemes used in North-Central Texas from 1949 to 1989. Member names in quotations indicates a member name that the author considered to be informal. Dashed lines indicate an uncertain or unknown boundary. * = Interval where no member is defined; K C = Keechi Creek Formation; P P = Palo Pinto Formation; GP. = Group, Fm. = Formation.

Beginning in the late 1950's, the drastic changes made by Cheney (1940) came under question. Hendricks (1957) summarized the problems associated with changing the Strawn from a group to a series, and although he found solving the issue to be beyond the scope of his work, he opened discussion for possibly changing the North-Central Texas lithostratigraphic classification scheme once again. Shelton (1958) dismissed Cheney’s (1940) use of unconformities as series boundaries in favor of using biostratigraphy and attempted to use fusulinids to find and correlate Cheney’s Strawn-Canyon series boundary between sections in the Colorado River Valley and the Brazos River Valley.

A clear shift away from the use of the Strawn as a series occurred when Brown (1959) claimed that many of the changes in the North-Central Texas lithostratigraphic classification scheme made by Cheney (1940) did not improve mapping accuracy and he disregarded the differentiating characteristics of groups and series. Instead, Brown called for a reemphasis of lithostratigraphy and the use of field information over revising units to simply agree with changing chronostratigraphic concepts. Brown’s school of thought prevailed when Laury (1962) openly rejected Cheney’s (1940) North-Central Texas classification scheme in favor of a scheme similar to that of Plummer and Hornburger (1935), and he formally changed the Strawn back to a Group. Laury’s work centered on the Canyon Group, but he also studied the uppermost limestone units of the Strawn Group for the purpose of establishing the Strawn-Canyon boundary. The publishing of the Bureau of Economic Geology’s Abilene Sheet encouraged the use of a scheme similar to Plummer and Hornburger (1935) and reestablished the Strawn Group as a formal unit (Brown and Goodson 1972). Brown and Goodson made several changes on the formation and member level, but the Strawn Group was restored to its rank prior to Cheney’s alterations.

In the time since the 1972 Abilene Sheet was published, the status of the Strawn Group has not been questioned, and there have been very few changes to the Strawn Group. The most recent work is that of Nestell and Kimball (2007), who sought to refine the Strawn-Canyon boundary in Wise County, Texas, where the boundary was not well understood or exposed. In their follow-up work, Kimball and Nestell (2007) were able to find and establish the Strawn-Canyon boundary in Wise County, answering one of the last remaining questions regarding the Strawn Group. The use and definition of the Strawn Group is now widely accepted among stratigraphers in Texas. However, geologists working in the petroleum industry still tend to use a scheme influenced by Cheney (1940) in which they illustrate the Strawn Group to be equivalent to the Desmoinesian, and some workers choose to refer to the Strawn as a series or a formation ignoring formal stratigraphic nomenclature (Ball and Perry 1996; Newell et al. 2003; McDonnell et al. 2007; Pollastro et al. 2007).

### 1.2.2 History of the Salesville Formation

The Salesville shale was first described by Plummer and Moore (1921) as a 150 feet (45 m) thick shale member of the Mineral Wells formation that contained lentils of sandstone and they named it after the small town of Salesville located in the northeast corner of Palo Pinto County, Texas (Figure 3). The Mineral Wells formation was also formalized by Moore and Plummer (1921) after being first introduced as the Mineral Wells subdivision within the Strawn Group by Plummer (1919). The Mineral Wells formation was divided into eight members (ascending order): Thurber Coal, Mingus, Brazos River, Lake Pinto, Salesville, Turkey Creek, and Keechi Creek. The Dog Bend bed, a limestone bed found within the Salesville shale, was named by Scott and Armstrong (1932), who at the same time also proposed the creation of the Garner formation from the lower part of the Mineral Wells formation that included the Thurber Coal, Mingus, and Brazos River members. These changes were accepted in subsequent works by Sellards (1933) and Plummer and Hornburger (1935).

The Salesville shale was elevated to a formation and expanded vertically downward to include the Lake Pinto member by Cheney (1940) when he revised much of the North-Central Texas Pennsylvanian lithostratigraphic classification scheme. As a result of the many changes that Cheney made, the Salesville formation was no longer considered to be part of the Strawn group which he had changed to become the Strawn series. Instead, the Salesville formation was placed in the newly created Whitt group that correlated with the lowest part of the Canyon series after the Strawn-Canyon boundary was moved to the disconformity at the base of the Lake Pinto sandstone (Cheney 1940). The Salesville formation was not altered in any of Cheney's later work that focused primarily on refining the boundaries of the North-Central Texas series (Cheney et al. 1945; Cheney 1947; Cheney and Goss 1952).

Hendricks (1957) was the first to comment specifically on the elevation of the Salesville shale to a formation. Hendricks argued that it was confusing to elevate the Salesville shale member to a formation and then extend it vertically downward to include the Lake Pinto sandstone member (Figure 4). Hendricks then suggests that Cheney should have considered the name "Salesville" already occupied by the shale member and therefore should have chosen a different name for the new formation. Hendricks did not question the validity of the Salesville formation but found it outside the scope of his current work to rename it. Cheney's (1940) classification scheme was largely dismissed by the work of Brown (1959) and Laury (1962) in favor of reverting to a scheme similar to Plummer and Hornburger's (1935). The formal status of the Salesville unit remained uncertain after the work of Brown (1959) and Laury (1962). The publishing of Brown and Goodson's 1972 Abilene Sheet brought further refinement to the formations and members of the Strawn Group. Brown and Goodson (1972) elevated the Mingus and Brazos River Members to formations and discarded the Salesville Shale as a formal unit altogether by reassigning its units to the Dog Bend and Lake Pinto Members. An important sandstone unit located in the upper part of the informal (at that time) Salesville Shale unit was first identified and informally named SS2 by Brown and Goodson (1972) in the 1972 Abilene Sheet. Later, the same sandstone unit was mentioned as "unnamed sandstone" by Brown (1973). The sandstone unit was then informally named as the Devil's Hollow Sandstone by Cleaves (1975) after an ephemeral creek in northeast Palo Pinto County, Texas.

A significant change to the North-Central Texas lithostratigraphic classification scheme was made by Boardman et al. (1989) when they introduced a hybridized scheme by combining the lithostratigraphic groups of Plummer and Hornburger (1935) with many of the formations and members introduced by Cheney (1940). The new scheme was created to better represent cycles in North-Central Texas and to aid Boardman and Heckel (1989) in correlating these cycles to the Midcontinent (M. K. Nestell, personal communication, 2020). The Salesville unit was once again raised back to the rank of formation and the Devil's Hollow Sandstone was finally introduced as a formal member of the Salesville Formation. Within the Salesville Formation Boardman and Heckel (1989) identified two major cycles: the Dog Bend major cycle (also referred to as the lower Salesville major cycle) that correlates with the Hertha major cycle of the Midcontinent, and the upper Salesville major cycle that correlates with the Swope major cycle of the Midcontinent. However, the scheme created by Boardman et al. (1989) has not been adopted outright with some geologists working in Texas preferring use of the 1989 scheme (see Teo 1991; Leyva 2010), whereas other geologists (see Bradshaw 1996; Alsalem et al. 2017) continued to use Brown and Goodson's (1972) scheme.

### 1.2.3 A Case for the Boardman et al. (1989) Scheme

M. G. Cheney received much criticism for the drastic changes he made to the stratigraphic nomenclature in North-Central Texas in the 1940’s and 1950’s, but his reasoning for doing so was not entirely unjustified. Altering a lithostratigraphic scheme to facilitate better correlations to other areas could be a great benefit if done correctly. Many of the changes on the group and series levels made by Cheney (1940; 1947) were erroneous and arbitrary, but at the same time many of the changes on the formation and member level had the potential to increase the accuracy of correlations if they were properly defined by lithologic features. Overly large formations were split into smaller, manageable formations, such as the Mineral Wells Formation being split into the East Mountain, Salesville, and Keechi Creek Formations, and the Millsap Lake Formation being split into the Lazy Bend and Grindstone Creek Formations. Important units, such as the Brannon Bridge Limestone, the Village Bend Limestone, and the Dog Bend Limestone were hidden under excessively large and imprecise members created by Plummer and Hornburger (1935) but were made into prominent members under Cheney’s scheme.

The increased precision from the changes on the formation and member level is why the Boardman et al. (1989) scheme was created, to combine the best aspects of Plummer and Hornburger (1935), and Cheney (1940) (Figure 5). Brown and Goodson’s (1972) scheme is also a significant improvement over the Plummer and Hornburger (1935) and Cheney and Goss (1952) schemes, but the inclusion of the Mineral Wells formation is especially problematic. The Mineral Wells Formation, as used today, spans the upper third of the Desmoinesian and much of the lower part of the Missourian, whereas the modern East Mountain and Salesville Formations take advantage of a natural stratigraphic division point at the base of the Lake Pinto Sandstone. The East Mountain Formation spans the Desmoinesian-Missourian boundary, and the Salesville

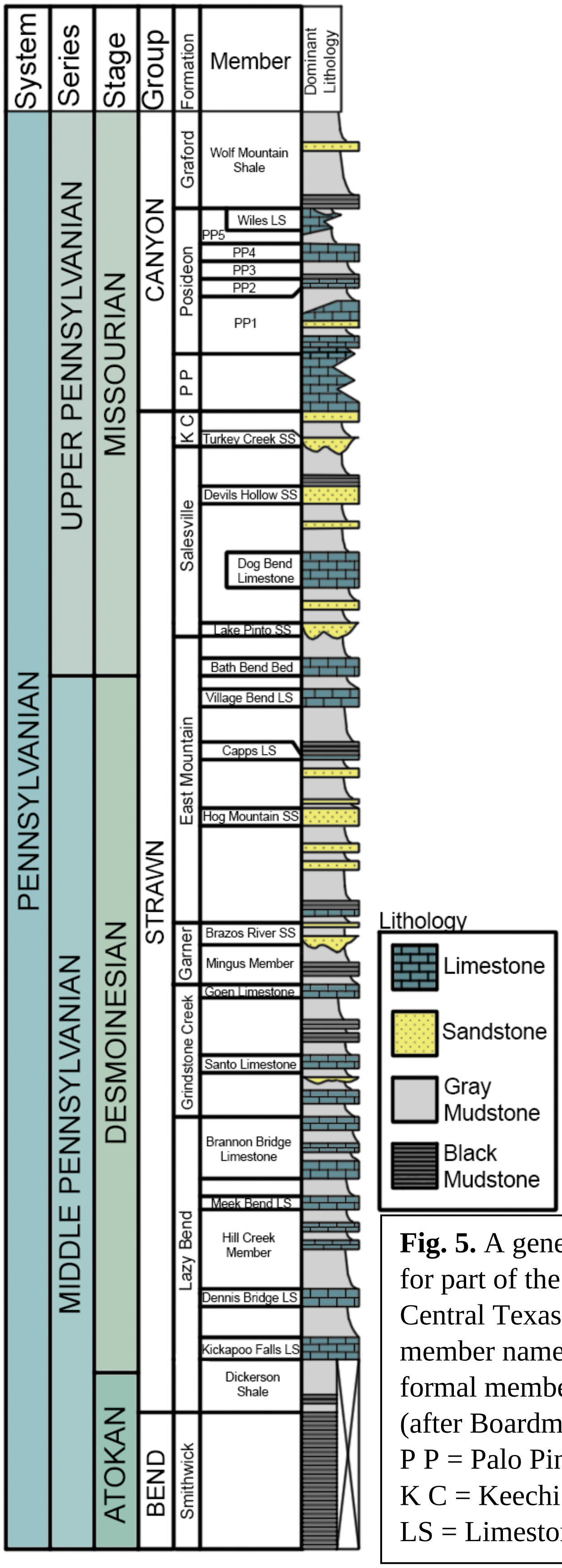


**Fig. 5.** A generalized stratigraphic column for part of the Pennsylvanian of the North-Central Texas region. Intervals where no member name is listed implies there is no formal member defined for that interval (after Boardman et al. 1989).
P P = Palo Pinto
K C = Keechi Creek
LS = Limestone

Formation represents strata from the lower part of the Missourian, giving both formations lithostratigraphic and chronostratigraphic importance. Additionally, both formations contain different faunas further supporting their utility. The East Mountain Formation contains fusulinids of the genus *Beedeina* and conodonts such as *ldiognathodus delicatus* Gunnell 1931 (Nestell 1989; Barrick and Boardman 1989). The Salesville Formation contains fusulinids of the genus *Eowaeringella*, and conodonts such as *ldiognathodus cancellosus* (Ellison 1941) and *ldiognathodus eccentricus* (Ellison 1941) (Nestell 1989; Barrick and Boardman 1989), giving the East Mountain Formation a distinctly Desmoinesian fauna and the Salesville Formation a distinctly Missourian fauna.

For the reasons stated above, the current study will use the scheme of Boardman et al. (1989) (Figure 5). The biostratigraphic results discussed later in this paper further supports the Salesville Formation as a distinct and important formation containing a fauna that is easily correlatable not only within Texas but also across North America, and a stratigraphic succession in the upper part of the formation that represents an important North Texas major cycle.

## 1.3 Previous Studies of Pennsylvanian Microfossils

### 1.3.1 Small Foraminifers of Texas and Oklahoma

The first study of Late Pennsylvanian foraminifers in Texas and Oklahoma was conducted by Harlton (1927a) when he described foraminifers found in drill cuttings from the Glenn Formation (Desmoinesian) of southern Oklahoma. From those cuttings Harlton identified 17 genera and 31 species, including 12 new taxa: *Ammobaculites powersi* (now *Endothyranella powersi*), *Archaelagena adaensis*, *A. kansasensis*, *A. plummerae* (all species of the genus

*Archaelagena* in recent taxonomy probably belong to the order Tuberitinida), *Bradyina holdenvillensis*, *Cribrostomum jeffersonensis*, *C. lucilleae*, *Endothyra ameradaensis*, *E. elegans*, *Nodosinella ardmorensis*, *N. glennensis* (species of the genus *Nodosinella* in recent taxonomy have been assigned to the genus *Reophax*), and *Nummulostegina ardmorensis* (now *Ozawainella ardmorensis* after Dunbar and Henbest 1942). Cushman and Waters (1927) described 15 new Pennsylvanian and Permian species of 11 genera of small foraminifers from Texas. The new species *Glomospira duplex*, *Hyperammina glabra*, *Nodosinella arenata* (now *Reophax arenatus*), and *Turritellella grandis* (now *Trepeilopsis grandis*) were described from the Mineral Wells Formation presently considered to be within the Palo Pinto and Garner Formations, marking the first study of foraminifers from these formations. Several other species were described by Cushman and Waters (1927) from different formations of the Strawn and Cisco Groups in North-Central Texas: *Ammobaculites spirans*, *Ammochilostoma* (?) *triloculina*, *Glomospira umbilicata*, *Nodosinella glabra* (now *Hyperamminoides glabra* after Cushman and Waters 1928c), *Psammophis inclusus* (now *Ammovertella inclusa* after Ireland 1956), *Spiroplectammina clavata*, *Tetrataxis multiloculata*, *Textularia exrayensis* (Paleozoic species of the genus *Textularia* are now considered to be *Palustrella* according to the current author), *T. grahamensis* (now *Palustrella*), *T. puscalignensis* (now *Palustrella*), and *Trochammina arenosa*.

Waters (1927) sampled multiple “rather pure” shale units in the Ardmore Basin from the Dornick Hills Formation (now known as the Dornick Hills Group) of the Missourian in Oklahoma. He described eight new species of six genera: *Ammobaculites minuta*, *Ammodiscus semiconstrictus*, *Ammolagena contorta*, *Hyperammina gracilis*, *Nodosinella brevis* (should be *Reophax brevis* according to the current author but that name is preoccupied by *R. brevis* of Parr 1950), *N. crassa* (now *Reophax crassa*), *N. laheeii* (now *Reophax laheeii*), and *Stacheia* *subglobosa* as well as two new varieties: *Ammodiscus semiconstrictus* var. *regularis*, and *Hyperammina gracilis* var. *rugosa*. Waters (1927) also compared chemical compositions of the cement found in foraminiferal walls from the Lower Pennsylvanian with foraminifers from the Upper Pennsylvanian. According to him, Late Pennsylvanian foraminifers have cement with less iron and more calcite than Early Pennsylvanian foraminifers.

Harlton (1928a) described 15 more new species of Middle and Late Pennsylvanian foraminifers from various road cuts and exposures in North-Central Texas, West Texas, and Oklahoma. One of the new species, *Cribrostomum cushmani*, was described from the Kickapoo Falls Limestone in the lower part of the Strawn Group. Cushman and Waters (1928a) described assemblages of small foraminifers from Cisco and Strawn units in the Brazos River Valley as well as in the Colorado River Valley along with several Permian foraminifers from North-Central Texas. In total, they described 30 species of 22 genera, including 26 new species and nine new genera: *Calcitornella*, *Calcivertella*, *Glyphostomella, Hyperamminella* (now *Hyperamminoides* after Cushman and Waters 1928c), *Mooreinella, Orthovertella, Plummerinella, Polytaxis,* and *Trepeilopsis*. In another paper, Cushman and Waters (1928b) described one new genus and eight new species from Cisco Group units near Graham, Texas. The new genus described was *Apterrinella*, and the eight new species were: *Bigenerina ciscoensis* (now *Aaptotoichus ciscoensis*), *Geinitzina ciscoensis, Globivalvulina biserialis, G. ovata, Tetrataxis corona, T. scutella*, *Tolypammina delicatula*, and *Spiroplectammina castensis*.

Galloway and Harlton (1928) studied foraminifers from the Glenn Formation (Desmoinesian) and Lower Pennsylvanian localities in Oklahoma. They identified 18 species of nine genera. These authors paid particular attention to the previously discarded genus *Orobias* Eichwald 1859, which they restored to usage in place of *Nummulostegina* Schubert 1907, *Palaeonummulites* Schubert 1908, and *Ozawaina* Lee 1927, and listed 19 species of these genera to be reassigned to *Orobias*. Presently, the genus *Orobias* is not considered valid (Dunbar and Henbest 1942). Galloway and Harlton (1928) also described one new genus, *Tuberitina*, and several new species: *Ammovertella confusa*, *Bullopora wapanuckaensis*, *B. redoakensis*, *Tuberitina bulbacea*, *Orobias biumbonata*, *O. oklahomaensis*, and *O. bassleri*.

Cushman and Waters (1930) analyzed foraminifers found in 16 samples from Cisco Group rocks in the Brazos River Valley. From these samples they identified 50 species belonging to 32 genera, and of those species, four were new: *Endothyra pauciloculata*, *Glomospira diversa* (now *Hemigordiellina diversa* after Deleau and Marie 1961), *Glomospira reversa*, and *Placopsilina ciscoensis* (possibly belongs to the genus *Bullopora*).

Plummer (1930) studied foraminifers from a 7.5 m thick section of the Brownwood Shale (Missourian) exposed in the Bridgeport Brick Company's quarry near Bridgeport, Texas. Nine species of seven genera were described, including one new genus, *Earlandia*. She also described five new species: *Earlandia perparva*, *Nodosinella perelegans* (now *Earlandinita perelegans* after Cummings 1955), *Endothyra watersi*, *Hemigordius regularis*, and *Orthovertella sellardsi*.

Warthin (1930) studied the foraminifers along with other fossils from the Wetumka, Wewoka and Holdenville Formations (all Desmoinesian) of central Oklahoma. He identified 29 species belonging to 20 genera and described one new genus, *Rectocornuspira*, and six new species: *Endothyra rotaliformis*, *Nodosinella fittsi* (now *Reophax fittsi* after Plummer 1945), *N. delicatula*, *Monogenerina grandis*, *Rectocornuspira holdenvillana*, and *R. lituiformis*.

Harlton (1933) studied foraminifers from the Johns Valley Shale (Morrowan) in eastern Oklahoma and identified 12 species belonging to nine genera. Three new species were described, *Hippocrepina bendensis*, *Hyperammina johnsvalleyensis*, and *Spirillina bendensis*. The identification of *S. bendensis* is problematic because, according to Loeblich and Tappan (1987), the genus *Spirillina* ranges from the Triassic to the Holocene.

Plummer (1945) published a comprehensive study of foraminifers from the upper part of the Bend Group and the lower part of the Strawn Group. Samples were taken from Pennsylvanian exposures near the Llano Uplift in the Colorado River Valley. In total, Plummer (1945) described 41 species of 22 genera. Two new genera, *Glomospirella* and *Thuramminodes*, and 14 new species were described: *Bigenerina perexigua* (now *Aaptotoichus perexigus*), *Cribrostomum marblense*, *Endothyra distensa*, *Glomospira articulosa*, *Haplophragmoides confragosus*, *Hyperammina clavacoidea*, *H. elegantissima* (now *Sansabaina elegantissima* after Loeblich and Tappan 1984b), *Hyperamminoides expansus* (now *Kechenotiske expansa* after Loeblich and Tappan 1984b), *Reophax bendensis*, *R. emaciatus*, *R. expatiatus*, *R. minutissimus* (now *Scherochorella minutissima* after Loeblich and Tappan 1984b), *R. tumidulus,* and *Thuramminodes sphaeroidalis*. One new subspecies was also described by Plummer (1945), *Endothyranella armstrongi* subsp. *sobrina*. Plummer's work represents the last major foraminiferal study from the Strawn Group.

Cooper (1947) referenced Plummer (1945) in his discussion of Pennsylvanian interregional correlations using various microfossils and concluded that foraminifers (excluding fusulinids) were not good index fossils for the Pennsylvanian due to the long range of known genera and species, and the lack of extensive works (Cooper 1947).

Boardman et al. (1995) illustrated 16 species of 11 genera of foraminifers but did not provide their descriptions. Three of the specimens illustrated were collected from the Strawn Group, *Ammobaculities stenomecus*, *Ammodiscus* cf. *A. semiconstrictus*, and *Reophax* cf. *R. fittsi*.

### 1.3.2 Other Small Foraminiferal Studies in the United States

Roth and Skinner (1930) described foraminifers as well as many other different groups of fossils from the McCoy Formation (now the Minturn Formation, Desmoinesian) in Colorado. They described four new species belonging to four genera: *Bradyina magna*, *Climacammina magna*, *Deckerella goessi*, and *Tetrataxis vaccula*. They concluded that the McCoy Formation correlated well with the lower part of the Strawn and Bend groups of North-Central Texas.

Ireland (1956) undertook a considerable study of the Pennsylvanian foraminifers from the Shawnee and Wabaunsee groups and spanning 14 formations in eastern Kansas. In his work, 50 species of 15 genera were described with 26 of the species being new. Two new genera were also described: *Saccamminoides* (now *Saccamminis* after Ireland 1960) and *Ammodiscella*. Ireland (1956) found that the Kansas foraminiferal fauna correlates well with the Central Texas fauna described by Plummer (1930; 1945), but, according to Ireland, the Kansas forms were consistently much smaller than the Texas forms. Ireland also suggested a relationship of the quantity and variety of foraminifers to phases of Midcontinent cyclothems and discovered that the foraminifers were most abundant in the algal limestone units associated with regressions. He hypothesized the abundance of foraminifers in the regressive limestone unit was due to the increased amount of silt that became available at shallower depths as sea level dropped.

St. Jean (1957) studied foraminifers from the Staunton Formation (upper part of the Atokan to the lower part of the Desmoinesian) in southern Indiana and was able to identify 19 species of 11 genera. Six of the species described were new: *Endothyra kennethi*, *E. teres*, *E. tortillis*, *Endothyranella pugnoidea*, *Tetrataxis biconvexa*, and *T. labiata*. He found that the fauna correlates very well with the foraminifers of the lower part of the Desmoinesian in Texas (Strawn Group) and Oklahoma.

### 1.3.3 Ostracodes

Several early studies on Pennsylvanian ostracodes conducted in Kansas by Ulrich and Bassler (1906), in Oklahoma by Coryell (1928), Harlton (1929), Warthin (1930), and Coryell and Osorio (1932), and in Illinois by Cooper (1946) are notable for biostraigrphic purposes and for the original descriptions of several species identified herein: *Amphissites centronotus* (Ulrich and Bassler 1906), *Bairdia beedei* Ulrich and Bassler 1906, *Hollinella warthini* Cooper 1946, *Schleesha pinguis* (Ulrich and Bassler 1906), and *Seminolites truncatus* Coryell 1928.

The first study of Pennsylvanian ostracodes in Texas was conducted by Harlton (1927b) who studied ostracodes from North-Central Texas and southern Oklahoma. Harlton described 24 species (13 new) ostracodes from the Cisco Formation (now the Cisco Group, Virgilian) of North-Central Texas, the Glenn Formation (Desmoinesian) and the Hoxbar Formation (now Hoxbar Group, Missourian) from Oklahoma. The newly described species included *Bairdia oklahomaensis* (now *Orthobairdia oklahomaensis* after Sohn 1960).

Coryell and Billings (1932) studied the ostracodes of the Wayland Shale (Cisco Group, Virgilian) in North-Central Texas. They described 17 new species and two new genera: *Waylandella* and *Moorites* (the genus *Moorites* was recently revised by Hoare 1998).

Coryell and Sample (1932) studied ostracodes from the “Mineral Wells shale pit” that they believed to be in the East Mountain Shale (now the East Mountain Formation) of the Mineral Wells Formation 3 miles west of Mineral Wells, Texas. The “Mineral Wells shale pit” likely refers to what is now commonly called the Mineral Wells fossil pit (32°49’34.2”N 98°11’28.7”W) and is thought to be in the lower part of the Salesville Formation. Coryell and Sample described 21 new species and one new genus: *Hollites*. The newly described species included *Bythocypris palopintoensis* (now *Pseudobythocypris palopintoensis* after Shaver 1958).

Coryell and Booth (1933) also studied the ostracodes of the Wayland shale (Cisco Group, Virgilian) in North-Central Texas. They described 16 new species and five new genera: *Artifactella*, *Burlella*, *Girtyites*, *Kirkbyella*, and *Silenites*.

Bradfield (1935) completed a study of the ostracodes from the Ardmore Basin in southern Oklahoma looking at several sections from the Springer Formation (now Springer Group) to the Hoxbar Formation (now Hoxbar Group) that encompass nearly the entire Pennsylvanian. He described 10 new genera and 89 new species among them: *Bairdiacypris deloi*, *Bythocypris pediformis, B. subpedifromis* (both *B. pediformis* and *B. subpedifromis* are now assigned to the genus *Pseudobythocypris* after Shaver 1958), and *Mammoides mammillata*.

Kellett (1936) reviewed and synthesized several previously completed works on Mississippian and Pennsylvanian ostracodes. She placed 32 species of ostracodes in synonymy with previously described species as well as three genera based on her opinion that many of the species were young or sexual variants of previously described species. Kellett placed three species, *Seminolites elongatus* Coryell 1928, *S. extensus* Coryell 1928, and *S. compressus* Coryell 1928, in synonymy with *S. truncatus*. She also placed *Bythocypris* (*Pseudobythocypris*) *subpediformis* in synonymy with *B.* (*Pseudobythocypris*) *pediformis*, but this change was later rejected by Shaver (1958) who listed them as two separate species. Kellett synonymized the genus *Mammoides* with the genus *Aechminella*.

Sohn (1960) revised the taxonomy of Paleozoic species of the genus *Bairdia* and other genera. Some of the species noted by Sohn include: *Bairdia beedei*, *Bairdiacypris deloi*, and *Orthobairdia oklahomaensis*. Sohn (1961) completed a similar study that revised some taxonomy and provided updated descriptions of the genera *Aechminella*, *Amphissites, Kirkbyella* and 15 other genera. Some of the species noted by Sohn include: *Amphissites centronotus,* *Mammoides mammillata*, and *Shleesha pinguis*. He also rejected Kellett's synonymy of the genus *Mammoides* with the genus *Aechminella*. Sohn (1960; 1961) also illustrated ostracodes from several Strawn, Canyon, and Cisco Group units in Central and North-Central Texas.

Later, Sohn (1982) published a literature review and summary for all Carboniferous and Permian ostracode studies completed in Texas. He also noted the paleogeography of Texas during those times and evaluated the biostratigraphic utility of Carboniferous and Permian ostracodes. Sohn stated that most Pennsylvanian ostracodes described from Texas are found in shallow marine bay-fill and nearshore deposits. He reported that the species *Orthobairdia oklahomaensis* was particularly important because of its wide distribution during the Pennsylvanian. That species is found in Oklahoma, Texas, Illinois, Indiana, Ohio, Kentucky, and West Virginia from the Atokan to the Missourian (Sohn 1982).

Melnyk and Moddocks (1988) attempted to assign and describe ostracode zones to the Pennsylvanian and Permian strata of North-Central Texas by working extensively with ostracode distributions and statistically quantifying their findings. Their zones ranged from the uppermost Atokan of the Pennsylvanian to the Leonardian of the Lower Permian and covered deltaic and marginal marine to offshore environments. Melnyk and Moddocks (1988) tested their proposed ostracode zones by comparing the distribution of species found in Texas with the ostracode assemblages described by Brondos and Kaesler (1976) from the Beil Limestone (Lecompton Formation, Virgilian) of Kansas and by Burke (1985) from the Skelley Member (Conemaugh Group, Virgilian) of Ohio. They were able to confidently assign these units to the Waylandella spinosa Zone and conclude that their zones may have biostratigraphic utility outside of Texas.

Boardman et al. (1995) illustrated 15 species of 12 genera of ostracodes including *Amphissites girtyi, A. centronotus, Aurikirkbya knighti, Cavellina pulchella, Healdia oblongata,* *Hollinella ulrichi*, *Kegelites* aff. *K*. sp B (in the sense of Sohn 1961), *Orthobairdia oklahomaensis*, and *Shlessha pinguis* recovered from the Dog Bend Limestone in the lower part of the Salesville Formation. The specimen they called *Mammoides* cf. *M. mammillata* from the East Mountain Formation is incorrectly identified and is actually *Mammoides dorsospinosa* Sohn 1961 (Boardman et al. 1995, p. 104, pl. 3 fig. 17).

Hoare and Merrill (2004) published the most recent relevant Pennsylvanian ostracode study in which they described ostracodes from a Barnett Shale (Morrowan, Lower Pennsylvanian) exposure in Central Texas. Hoare and Merrill described 31 species of ostracodes that show connections to both Mississippian forms and Middle Pennsylvanian forms.

### 1.3.4 Fusulinids

Thompson et al. (1956) completed one of the first relevant fusulinid studies concerning the Desmoinesian-Missourian boundary. They studied fusulinids from across much of the Midcontinent region as well as Oklahoma and New Mexico and found that the species *Wedekindellina ultimata* (now *Eowaeringella ultimata* after Stewart 1968) consistently appeared near the base of the Missourian. Thompson et al. (1956) compared the fusulinids from their study to the fusulinids from the "lower Canyon" (lower part of the Canyon Group) of Texas and concluded that the Kansas City group of the Midcontient is a similar age to the "lower Canyon". Studies conducted by Shelton (1958) and Stewart (1958) were the first to describe fusulinids from the Strawn Group in North-Central Texas. Waddell (1966) completed a study of Pennsylvanian fusulinids in the Ardmore Basin, Oklahoma and described the fusulinid species *Wedekindellina*? *ardmorensis* (now *Eowaeringella ardmorensis* after Stewart 1968) from the

Confederate Limestone in the Hoxbar Group that permitted the assignment of that unit to the Eowaeringella Zone by Wahlman (2013).

Stewart (1968) described the stratigraphic significance of the genus *Eowaeringella* and its usefulness as an index fossil for the early part of the Missourian. Stewart also provided a list of localities where specimens of *Eowaeringella* had been found in North America. One of the species described was *Eowaringella zimmermani* from a locality in a section that he considered to be the Turkey Creek (?) Sandstone Member of the Keechi Creek Formation at a locality in Eastland County east of Ranger, Texas and over 40 miles southwest of the Salesville localities. Its stratigraphic assignment is questionable.

Nestell (1989) was first to complete a comprehensive study on the fusulinids in the Brazos River Valley of North-Central Texas and described the fusulinid succession from the Desmoinesian to the early part of the Missourian. As part of this study, Nestell found the fusulinid species *Eowaeringella* cf. *E. joyitaensis* in the siltstone unit immediately below the Devil’s Hollow Sandstone in the Salesville Formation at locality 1013. This discovery of *Eowaeringella* was very important with respect to correlation as it allowed for confident assignment of the Salesville Formation to the lower part of the Missourian. The Salesville species measurements agree very closely with those given for *E. joyitaensis* and thus the “cf.” is not necessary. Also, the Salesville specimens are clearly much larger than the *E. zimmermani* described by Stewart (1968).

Wahlman (2013) completed an extensive study on the fusulinid biostratigraphy of the Midcontinent from the Morrowan to the Wolfcampian. He defined the Eowaeringella Zone as ranging from the Galesburg Shale to the top of the Dennis Limestone (Dennis Cyclothem) in the Kansas City Group. Wahlman (2013) also correlated and applied zones to Pennsylvanian strata in southern Oklahoma, North-Central Texas, Illinois, and Missouri. Wahlman (2019) continued this work by reviewing and updating the fusulinid biostratigraphy of the Permian Basin, Texas. In this work, Wahlman also provided updates to some correlations made in the 2013 study.

The recent studies of Allen and Lucas (2018) and Read and Nestell (2019) reported finding specimens of *Eowaeringella* in New Mexico and Nevada respectively, opening the possibility for correlation of the upper part of the Salesville Formation with other areas in the United States.

### 1.3.5 Conodonts

Several important early studies of Pennsylvanian conodonts by Stauffer and Plummer (1932), Gunnell (1933), and Bitter (1972) laid the groundwork for work of Barrick and Boardman (1989) who studied the stratigraphic distribution of the conodont genera *Idiognathodus* and *Streptognathodus* in North-Central Texas from the upper part of the Desmoinesian to the Virgilian. Barrick and Boardman were able to recognize three successive faunas based on varying morphotypes, the first of which begins in the Salesville Formation. They describe an *Idiognathodus* morphotype from the Salesville Formation as having a row of central nodes that sometimes are expanded into transverse ridges and noted that the latest Desmoinesian *Idiognathodus* specimens from the East Mountain Formation lack this feature. Based on this study, Barrick and Boardman (1989) suggested that conodont zones could be assigned in North-Central Texas to facilitate correlation with the Midcontinent.

Rosscoe and Bader (2010) compared the conodont faunas of the upper part of the Salesville Formation in North-Central Texas and the Hushpuckney Shale of Oklahoma, Kansas and Nebraska. They identified the species *Idiognathodus cancellosus* (Gunnell 1933), *I. sulciferus* Gunnell 1933, and *I. swadei* Rosscoe and Barrick 2009 in the upper part of the Salesville Formation and noted that *I. biliratus* was not present in the Salesville Formation. Rosscoe and Bader found the Midcontinent units contained a higher diversity of conodonts than in the upper part of the Salesville Formation but were able to confirm the correlation to the Hushpuckney Shale based on the presence of *I. cancellosus* and *I. swadei* in both units.

All other relevant conodont studies completed after Barrick and Boardman (1989) were conducted in the Midcontinent region beginning with Ritter (1995), who presented a conodont zonation of the Midcontinent from the uppermost Missourian, Pennsylvanian to the lower Wolfcampian, Lower Permian. Boardman et al. (1995) described three primary biofacies (and several subfacies) that related certain conodont assemblages to water depth. The primary biofacies are the nearshore *Adetognathus* biofacies, the non-depth restricted *Idiognathodus-Streptognathodus* biofacies, and the open shelf *Idioprioniodus-Gondolella* biofacies.

The Midcontinent conodont zones were reevaluated and improved by Barrick et al. (2013) who defined conodont zones ranging for the entire Pennsylvanian. Two conodont studies in Midcontinent strata near the Desmoinesian-Missourian boundary focusing on specimens of *Idiognathodus* and *Streptognathodus* were conducted by Rosscoe (2008) and Rosscoe and Barrick (2013). Hogancamp et al. (2017) conducted a morphometric analysis of the platform elements of the Late Pennsylvanian conodont *Idiognathodus magnificus* Stauffer and Plummer 1932.

Nestell et al. (2015) discovered well presurved conodont elements in carbonate nodules from the Excello Shale Member of the Mouse Creek Formation (Desmoinesian) of South-Central Iowa. They described the new species *Idiognathodus tuberis* and *G. wardlawi*, and they were able to reconstruct multielement apparatuses of four conodont species: *Gondolella wardlawi*, *Idiognathodus acutus* Ellison 1941, *Idioprioniodus conjunctus* Gunnell 1931, and *Neognathodus roundyi* Gunnell 1931.

Roy (2017) also studied the conodonts in the Excello Shale Member in Kansas, Missouri, and Iowa, and found an assemblage that closely resembled that of Nestell et al. (2015). Roy had hoped to find a succession of conodont faunal changes that followed the shallowing-upwards sequence of his sections. However, he concluded that the core shale units of the Midcontinent are too condensed to show the more subtle changes in conodont distribution.

### 1.3.6 Radiolarians

Boardman et al. (1995) illustrated a single specimen of the genus *Albaillella* from the Wolf Mountain Shale Member of the Graford Formation (Missourian) in North-Central Texas. This specimen was not described or used in their depth-related biofacies model.

Nestell and Blome (1996) also reported Missourian radiolarians in North-Central Texas. The pyritized radiolarians were found in gray to black shale units from two localities in the Lake Bridgeport Shale and near Bridgeport, Texas, and in lithofacies similar to the gray to black core shale of the upper Salesville major cycle.

## **1.4 Other Previous Studies of the Salesville Formation**

### 1.4.1 Palynology

Gupta (1970) studied the palynology of the Salesville Formation to determine whether the Salesville Formation is Desmoinesian or Missourian in age, which at the time of the study was not well understood. Gupta attempted to use miospores for biostratigraphic correlation of the Salesville Formation with similar age strata at localities in the Saar Basin in Germany, in England and Wales, and in eastern Canada. In his study, Gupta presented a figure showing the Upper Pennsylvanian stratigraphic units in North-Central Texas where he shows that the Lake Pinto Sandstone Member stratigraphically is above both the Salesville Shale Member and the Dog Bend Limestone Member (Gupta 1970, fig. 1). This stratigraphic level is incorrect because the Lake Pinto Sandstone lies below the Salesville Shale (lower cycle). Gupta's study concluded that the miospore assemblage of the Salesville Formation correlated well with "Late Desmoinesian (Late Westphalian D) miospore associations" (Gupta 1970, p. 77). This result is inconsistent with nearly every study of the Salesville Formation conducted afterwards, and it is now known with certainty that the Salesville Formation is lower Missourian and that the Desmoinesian-Missourian boundary is within the Bath Bend Bed Member of the East Mountain Formation, and stratigraphically below the Salesville Formation (Boardman and Heckel 1989; Nestell 1989).

Peppers (1989) studied the palynology of the Desmoinesian-Missourian boundary in the East Mountain Formation. He noted problems with the work of Gupta (1970) dating the Salesville Formation as Desmoinesian. Peppers attempted to gather more conclusive palynological data, but his results were inconclusive, and suggested more sampling was needed to determine if palynology can be used to confidently place the Desmoinesian-Missourian boundary.

### 1.4.2 Geochemistry

Teo (1991) studied the chemical composition of shale units at several localities in North-Central Texas (including the Salesville Formation) and claimed that the wide range of depositional environments allowed the study of depositional controls on the distribution of certain elements. Teo used the same two road cuts as the current study (1013 and 1117 sections) and provided a lithofacies description for each one. The Devil’s Hollow Sandstone was described as a calcareous sandstone, but this description is not accurate because no unit of the Devil’s Hollow Sandstone was found to be calcareous in the current study. In his conclusions, Teo noted several elemental spikes in calcium, magnesium, copper, and cobalt in various samples from both localities, but these peaks were isolated and there was not enough evidence to draw inferences as to why. The only chemical difference between the two Salesville road cuts was their display of strikingly different patterns of sodium content, but the reason for the contrasting distributions of sodium was not clear (Teo 1991).

## 1.5 Geologic Setting

The upper part of the Salesville Formation including the upper Salesville major cycle is well exposed in two road cuts (1013 and 1117 sections) near Mineral Wells, North-Central Texas (Figure 6).

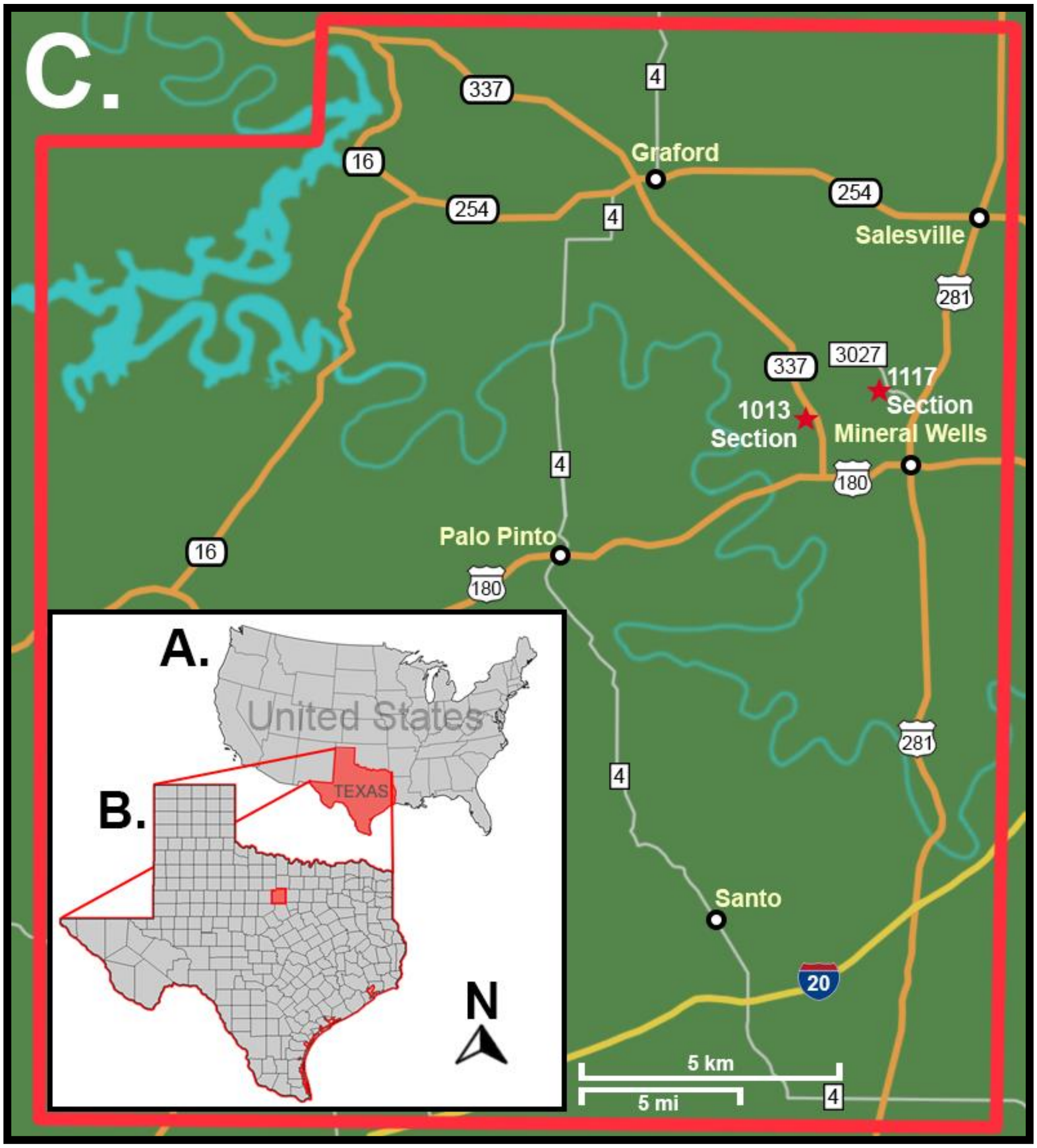


**Fig. 6. A.** The location of Texas within the United States. **B.** The location of Palo Pinto County within Texas. **C.** A map of Palo Pinto County with the boundaries of the county outlined in red. The red stars show the sampling localities of the current study.

### 1.5.1 1013 Section

The first road cut is referred to herein as the 1013 section and is located on the west side of Texas State Highway 337 approximately 1.5 km north of the intersection with U.S. Highway 180 west of Mineral Wells (32°49’12.8”N 98°09’33.8”W). The total thickness of the 1013 section is 3.65 m at the present time, but a lower portion of this road cut was once exposed

(Figures 7A, 8). In the 1990's, the Texas Department of Transportation covered up large parts of the section including all of the exposure below the Devil's Hollow Sandstone. The road cut is widely covered in talus and vegetation, and digging is required to access fresh material.

The now inaccessible stratum at the base of the section is a fusulinid-bearing crinoidal siltstone that is at least 30 cm thick (Nestell 1989; M. K. Nestell, personal communication, 2020). Overlying the siltstone unit is the 0.65 m thick Devil's Hollow Sandstone. The Devil's Hollow Sandstone at this locality is an orange, loosely consolidated sandstone that is non-fossiliferous. Above the Devil's Hollow Sandstone is a 0.5 m thick black to dark gray unit, which is shaly, transgressive mudstone containing phosphate nodules. The next 2.5 m of the section is a dark gray mudstone that transitions into a regressive variegated mudstone with upward decreasing fissility. The Salesville Shale higher than 3.65 m above the base of the section is inaccessible due to its location on fenced private property. The Turkey Creek Sandstone that overlies the Salesville Formation is present at this locality but is not easily visible from the highway.

### 1.5.2 1117 Section

The second exposure is located on both the east and west sides of Farm to Market Road 3027 approximately two kilometers northwest of the intersection with U. S. Highway 28 (Figure 6). The more complete 4.7 m thick section on the west side of the road cut was chosen for sampling and is referred to as the 1117 section in the current study (32°50'40.8"N 98°07'28.4"W) (Figures 7B, 8). Above the sandstone, this road cut is also widely covered in talus and vegetation, and digging is required to access fresh material.

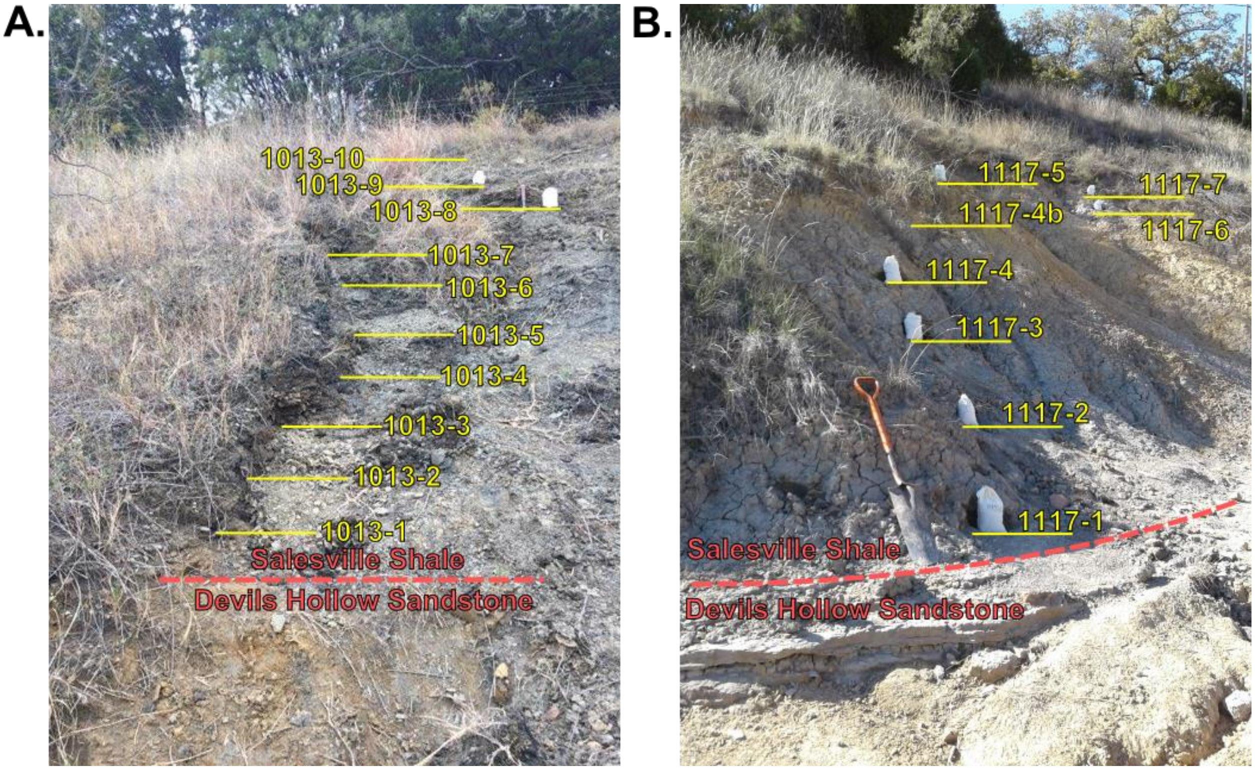


**Fig. 7. A.** Photograph of the 1013 section with sampling locations and the Devil's Hollow Sandstone-Salesville Shale contact shown; **B.** Photograph of the 1117 section with sampling locations and the Devil's Hollow Sandstone-Salesville Shale contact shown. In both figures the yellow lines indicate the level where the sample was taken, and the dashed red line shows the contact of the Devil's Hollow Sandstone with the Salesville Shale.

No strata below the Devil's Hollow Sandstone Member are exposed at this section. The lowest lithologic unit is a 0.75 m thick poorly exposed and loosely consolidated sandstone that transitions to a thinly bedded sandstone. Above that is a two meter thick non-calcareous mature sandstone unit that is well consolidated in contrast to the strata below. Abundant worm borrows are present in the sandstone approximately one meter above the thinly bedded unit. Directly overlying the Devil's Hollow Sandstone is a 0.25 m thick gray non-fissile sandy mudstone with abundant quartz grains. The next 1.45 m of the section is a transgressive black to dark gray shaly mudstone that makes up the core shale of the upper part of the Salesville Formation. Above that, two meters of brown non-fissile regressive mudstone is present. At six meters above the base of

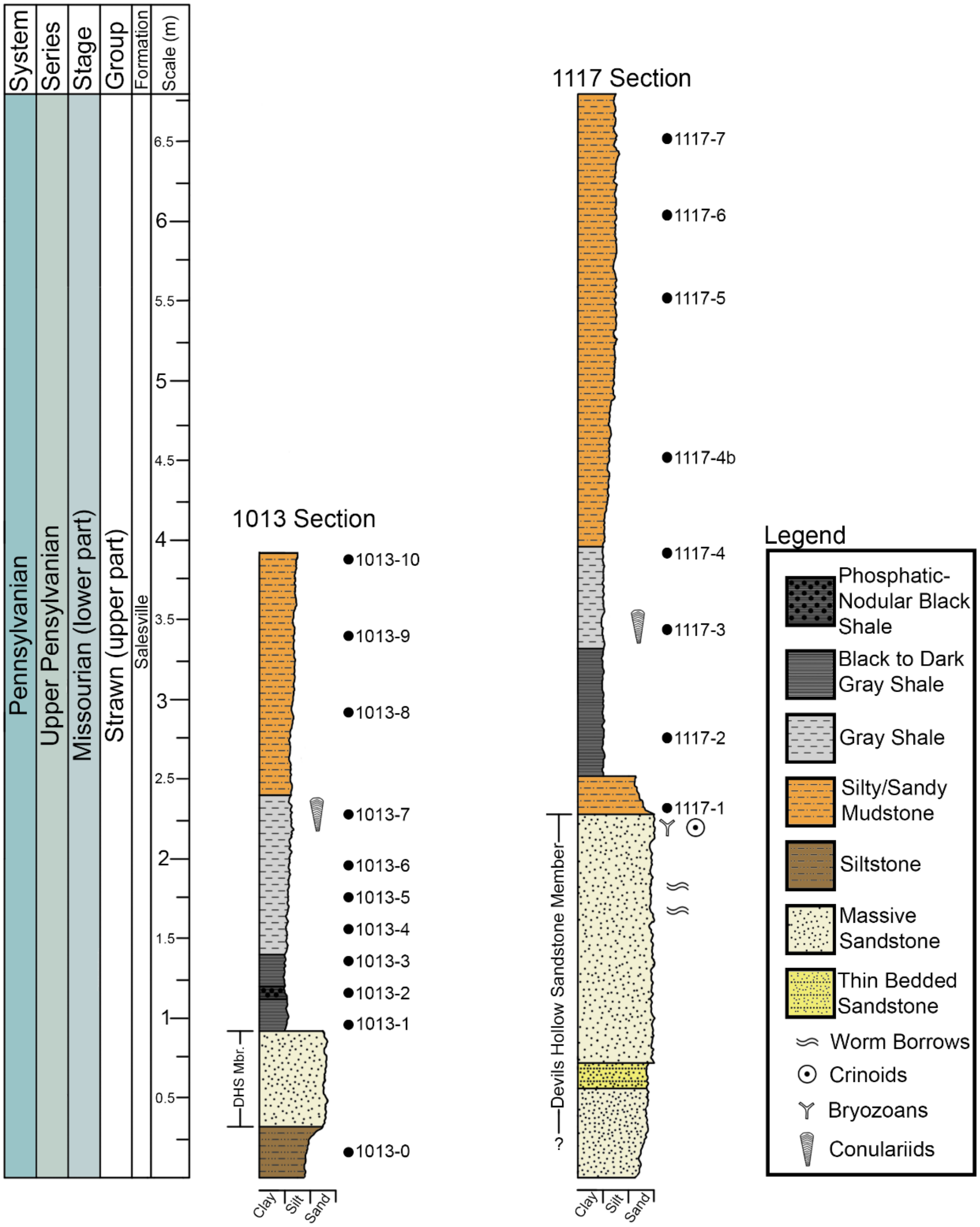


**Fig. 8.** Stratigraphic columns for the 1013 and 1117 sections. Black dots show sampling levels. DHS Mbr. = Devil's Hollow Sandstone Member.

the section, the brown mudstone briefly transitions to a mottled brown and gray mudstone with increased fissility for half a meter before transitioning back to the brown mudstone. The brown mudstone continues for several centimeters before becoming heavily covered in vegetation. The overlying Turkey Creek Sandstone visibly outcrops several meters above the top of the measured section but is inaccessible due to being on private property.

## 1.6 Materials and Methods

### 1.6.1 Measuring and Sampling

Measuring and sampling of the two sections took place on five separate trips to the area between October 2017 and July 2019. One sample from the lower part of the 1013 section collected by Merlynd Nestell (University of Texas at Arlington) in the 1980's and used by Nestell (1989) is also used in this study. In both sections, the thicknesses were measured using a 1.5 m Jacob's Staff in conjunction with a combination sight and level. The 1013 section was sampled at 0.2 m intervals in the black mudstone and at intervals between 0.3 m and 0.5 m in the grey mudstone, and 11 samples were collected. The 1117 section was sampled at intervals between 0.5 m and 0.9 m where less covered surfaces were available, and eight samples were collected. At both localities, samples were taken after digging back 0.3 m to ensure access to fresh material.

### 1.6.2 Sample Processing

In order to non-destructively extract the microfossils from the mudstone, a process of soaking, washing, and sieving of samples was used. All samples were thoroughly dried before the process either by natural evaporation or by resting on a hot plate to accelerate the drying process. After becoming sufficiently dry, samples were immersed in a beaker of mineral spirits for one to two days. At the end of the mineral spirit immersion, the saturated samples were transferred to pans of water. Over the course of a few days to a week, the water replaces the mineral spirits in the sample and in the process breaks down the mudstone into unconsolidated sediment. The sediment is then wet sieved through a 1.8 mm (No. 16) mesh sieve to separate out the course material, and then run through a 75 µm (No. 200) mesh sieve to separate out the fine silt- and clay-sized material. The sieved sediment is allowed to dry for several days. Once dry, the sediments are run through a series of sieves to fractionate the material to make it easier to pick the microfauna. Material from each sample is then handpicked for microfossils under a reflected light microscope. After the microfossils from each sample were picked and sorted, the most well-preserved specimens were photographed or subjected to further preparation before being photographed when necessary.

### 1.6.3 Conodont Separation

Washed and sieved samples that were determined to contain a high concentration of conodont elements were chosen to undergo heavy liquid separation though preferential floatation. This method separates the heavier conodont bearing material from the lighter, non-conodont bearing material to aid in picking. The chosen sediments were immersed in a tetrabromoethane (TBE) and acetone solution within a separation funnel. The ratio of the components was adjusted until the measured specific gravity of the solution was approximately 2.82. After several days of occasional stirring, the heavy fraction was collected and placed in a fume hood for drying. Once the residue had dried sufficiently to the point that TBE fumes could no longer be detected, the residue was safely picked through.

### 1.6.4 Foraminiferal Thin Section Preparation

All foraminifers were found as free specimens, so a method for making thin sections from each individual has been chosen for proper identification of species. Free specimens of fusulinids were placed into shallow cups containing a small amount of two-part transparent epoxy. Once cured, the epoxy “puck” was thinned down to until the proloculus of the fusulinid was visible under a reflected light microscope. The epoxy billet containing the fusulinid was placed on a glass slide, thinned, and a cover slip applied for photomicrography and preservation.

For small foraminifers, glass laboratory slides were thoroughly cleaned with alcohol and allowed to dry before a small amount of liquid Canada balsam was placed on it. The slide was then placed on a hot plate set to 65°C (150°F) to allow the Canada balsam to melt. The slide was then allowed to cool sufficiently to the point at which Canada balsam could no longer be deformed by moderate pressure applied with a finger. Then, a foraminifer was placed on top of the now solidified Canada balsam. The slide was then transferred back to the hot plate set at the same temperature to allow the foraminifer to settle into the Canada balsam so that it rested just below the surface of the Canada balsam. Once the foraminifer was checked to make sure it had settled in an acceptable orientation, the slide was allowed to cool and cure overnight before being thinned down.

### 1.6.5 Small Foraminiferal Translucent Preparation

Several well-preserved small foraminiferal tests with calcareous or thin agglutinate walls were chosen to make them translucent. This method was used by G. P. Nestell for radiolarians.

# CHAPTER 2: STUDY OF THE SALESVILLE FORMATION

## 2.1 Small Foraminifers

The Pennsylvanian small foraminifers of North-Central Texas were studied by Cushman and Waters (1927; 1930), Harlton (1928a), and Plummer (1930; 1945), but no one has studied the small foraminifers of the Salesville Formation. These authors illustrated many described species with drawings and rarely provided illustrations of species' internal structure. The lack of these details has led to common misidentifications and highlights the need for the revisions included in the current study.

### 2.1.1 Distribution of Small Foraminifers in the Studied Sections

Small foraminifers were found in every sample collected in the current study from the 1013 and 1117 sections, but they varied greatly in their distributions and concentrations (Table 1, Figures 9, 10).

The lowest sample in the 1013 section, 1013-0, contains calcareous species: *Apterrinella grahamensis* (Harlton 1928a), *Brunsia* sp. A, and *Brunsiella* sp. A, in addition to the more common agglutinated species *Ammodiscus* sp. A, and rare *Thuramminoides* sp. A (Table 1, Figure 9). Sample 1013-0 is the only sample in the study from the unit below the Devil's Hollow Sandstone Member and contains a foraminiferal assemblage with an abundance of calcareous tests not seen in any of the other samples.

The next three samples, above the Devil's Hollow Sandstone, 1013-1, 1013-2, and 1013-3, from the 1013 section are characterized by an abundance of the species *Thuramminioides* sp.

| Sample Numer:<br>Species Name: | Small foraminiferal distribution from the upper part of the Salesville Formation | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1013-0 | 1013-1 | 1013-2 | 1013-3 | 1013-4 | 1013-5 | 1013-6 | 1013-7 | 1013-8 | 1013-9 | 1013-10 | 1117-1 | 1117-2 | 1117-3 | 1117-4 | 1117-4b | 1117-5 | 1117-6 | 1117-7 |
| *Thuramminoides* sp. A | R | A | A | A | R | | A | | | A | | | | R | R | | R | | |
| *Lagenammina cervicifera* | | | R | R | R | | | R | | | | | R | R | | | | | |
| *Lagenammina* sp. A | | | | R | R | U | U | | | U | | | U | | R | R | | | |
| *Hyperammina bulbosa* | | | U | | R | C | U | R | R | R | R | | | R | U | | | | |
| *Hyperammina clavacoidea* | | | U | R | | C | R | | | R | | | | | | | | | |
| *Hyperammina* sp. | | | | | | | | | | R | | | | | | | | | |
| *Ammodiscus* sp. A | C | A | A | A | A | A | A | A | A | A | A | C | A | A | A | A | A | A | A |
| *Tolypammina* sp. | | U | U | R | U | A | U | R | C | C | R | R | | U | U | | U | R | C |
| *Reophax emaciatus* | | A | R | C | | U | R | | R | | | | R | R | | C | U | U | U |
| *Reophax fittsi* | | A | C | A | A | C | U | C | C | U | U | | C | U | U | | U | C | U |
| *Reophax* sp. A | | | | | | | | | | | | | R | | | | | | |
| *Reophax* sp. B | | | | | | | | | | | | C | | | | | | | |
| *Reophax* sp. C | | A | R | C | R | A | U | U | C | U | R | | C | U | U | | U | U | U |
| *Scherochorella kunklerensis* | | R | | C | U | U | U | | U | R | R | | C | R | R | | | U | U |
| *Ammobaculites gutschicki* | | | | | U | U | C | A | A | C | | R | R | | U | R | | | U |
| *Ammobaculites inconspicuus* | | | | | U | U | R | | | | | R | U | R | U | | | R | R |
| *Ammobaculites minutus* | | | | | R | R | C | A | C | U | | | C | U | A | U | R | U | U |
| *Ammobaculites parallelus* | | | | R | U | | R | | | | | | | R | R | R | | U | R |
| *Ammobaculites* sp. A | | A | R | U | C | | | R | | | | R | | C | C | R | R | C | A |
| *Ammobaculites* sp. B | | | | | R | U | U | C | R | U | | R | U | U | U | R | R | U | C |
| *Ammobaculites* sp. C | | R | | | U | U | R | U | U | | | R | R | | R | R | | | R |
| *Ammobaculites* sp. D | | U | | R | R | R | | R | | | | | R | | C | | | R | U |
| *Ammobaculites* sp. | | | | | | | R | | | | | R | R | | R | | | | |
| *Palustrella bucheri* | | | | | | | R | | | | | | | | | | | | |
| *Palustrella eximia* | | | | | U | R | C | R | C | U | | | R | U | R | | | | R |
| *Spiroplectammina* sp. A | | | | | R | U | R | U | U | R | | R | R | R | | R | | | U |
| *Aaptotoichus ciscoensis* | | | | C | C | C | U | U | C | R | | | U | | | | | | |
| *Aaptotoichus virgilensis* | | | | U | U | U | R | U | C | U | | R | U | R | | | | R | R |
| *Aaptotoichus* sp. A | | | | R | U | R | | | | | | | R | R | U | | | | R |
| *Apterrinella grahamensis* | A | | | | | | | | | | | | | | | | | | |
| *Brunsia* sp. A | C | | | | | | | | | | | | | | | | | | |
| *Brunsiella* sp. A | A | | | | | | | | | | | | | | | | | | |
| *Endothyra media* | | | | | | | | | | R | | | | | | | | | |
| *Endothyra pauciloculata* | | | | | | | | | | R | | | | | | | | | |
| *Endothyra watersi* | | | | | | | | | | C | R | | | | | | | | |
| *Endothyranella* sp. | | | | | | | | | | R | | | | | | | | | |
| *Tuberitina bulbacea* | | | | | | | R | | | | | | | | | | | | |

**Table 1.** A table showing the small foraminiferal distribution and abundance in the 1013 and 1117 sections. Abundance is based on number of specimens found in an average of 10 grams of material. A = abundant, 20+ specimens; C = common, 19-10 specimens; U = uncommon, 9-3 specimens; R = rare, 1 or 2 specimens.

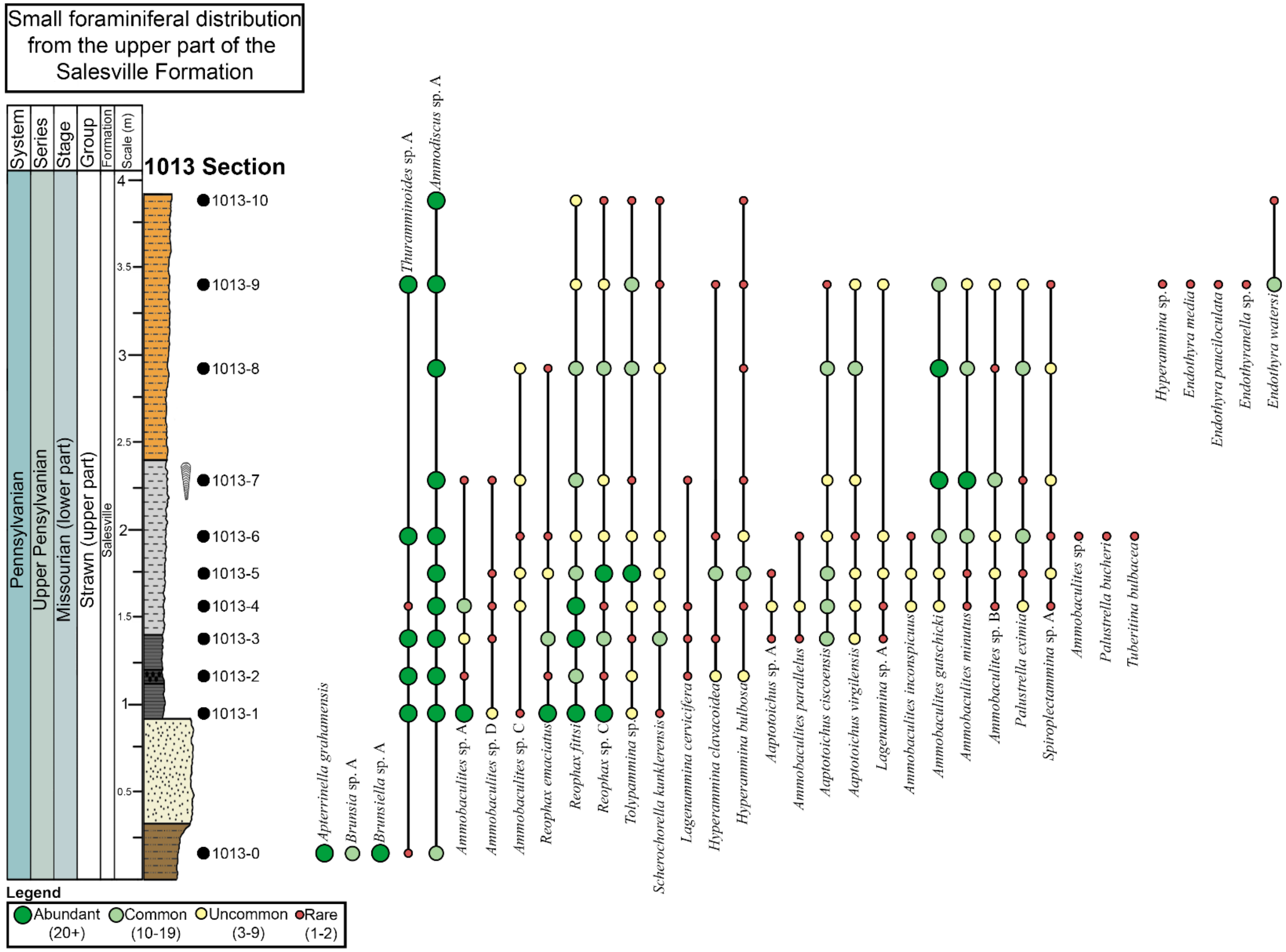


**Fig. 9.** A figure showing the small foraminiferal distribution and abundance in the 1013 section. Black dots indicate sampling level. Colored dots show where a species was recovered, and the color of the dot corresponds to the number of specimens found as defined in the legend. For lithologic and faunal symbols see Fig. 8.

A, *Ammodiscus* sp. A, *Reophax emaciatus*, *R. fittsi* (Warthin 1930), *R*. sp. C, and *Ammobaculites* sp. A. In sample 1013-2, the species *Hyperammina bulbosa*, and *H. clavacoidea* first appear, and in sample 1013-3, *Aaptotoichus ciscoensis* (Cushman and Waters 1928b), *A. virgilensis*, and *Aaptotoichus* sp. A also make their first appearance. Samples 1013-4, 1013-5 and 1013-6 contain abundant *Ammodiscus* sp. A, *Tolypammina* sp., and *Reophax fittsi* along with common numbers of the species *Palustrella eximia*, and *Aaptotoichus ciscoensis*. The species *Ammobaculites gutschicki*, *A. inconspicuous, A. minutus*, *Palustrella eximia*, and *Spiroplectammina* sp. A first appear in sample 1013-4 and are present in rare to common numbers in samples 1013-5 and 1013-6. The species *Hyperammina bulbosa* and *H. clavacoidea* are found in their highest abundance in sample 1013-5, and the species *Tuberitina bulbacea*, and *Palustrella bucheri* are found only in sample 1013-6. The next two higher samples, 1013-7 and 1013-8, are characterized by an abundance of *Ammodiscus* sp. A, *Ammobaculites gutschicki*, and *A. minutus* along with common numbers of *Reophax fittsi*. Also, *Palustrella eximia*, *Spiroplectammina* sp. A, *Aaptotoichus ciscoensis*, and *A. virgilensis* are found in mostly uncommon to common numbers in these two samples. The species *Hyperammina bulbosa* and *Reophax emaciatus*, are very rare in samples 1013-7 and 1013-8 as compared to samples1013-5 and 1013-6. In the uppermost two samples, 1013-9 and 1013-10, one can see a rapid decrease in diversity by the end of the section. One notable exception is the appearance of endothyriids (*Endothyra media*, *E. pauciloculata*, and *E. watersi*) in sample 1013-9 and a single specimen of *E. watersi* found in sample 1013-10. They are only calcareous small foraminifers recovered above the Devil's Hollow Sandstone Member. In sample 1013-10 only *Ammodiscus* sp. A is found in abundant numbers, and the only other agglutinated foraminifers present are rare to uncommon:

*Hyperammina bulbosa*, *Tolypammina* sp., *Reophax fittsi*, *R*. sp. C, and *Scherochorella kunklerensis*.

The lowest sample from the 1117 section, 1117-1, taken from just above the Devil's Hollow Sandstone Member contained common *Ammodiscus* sp. A along with the only occurrence of *Reophax* sp. B (Table 1, Figure 10). Sample 1117-1 also contained rare *Aaptotoichus virgilensis*, *Ammobaculites gutschicki*, *A. inconspicuous*, *A*. sp. A, *A*. sp. B, *A*. sp. C, *Spiroplectammina* sp. A, and *Tolypammina* sp. Next three samples, 1117-2, 1117-3, and 1117-4, are characterized by a relative increase in the diversity and abundance of small foraminifers with abundant *Ammodiscus* sp. A and *Ammobaculites minutus*. Twelve species first appear in sample 1117-2 including *Ammobaculites minutus*, *Reophax fittsi*, *R*. sp. C, and *Scherochorella kunklerensis* that are found in common numbers. The species *Hyperammina bulbosa* and *Ammobaculites parallelus* first appear in sample 1117-3. Beginning from sample 1117-4b, the number of small foraminifers sharply decreases with only the species *Ammodiscus* sp. A and *Reophax emaciatus* still present in common numbers. The decline in the number of small foraminifers continues in sample 1117-5 where only the species *Ammodiscus* sp. A, *Ammobaculites minutus*, *A*. sp. A, *A*. sp. B, *Reophax emaciatus*, *R. fittsi*, *R*. sp. C, *Thuramminoides* sp. A, and *Tolypammina* sp. are present. In the highest two samples, 1117-6 and 1117-7, the diversity and abundance of small foraminifers rapidly increases to numbers similar to sample 1117-4 with abundant *Ammodiscus* sp. A, and common numbers of *Ammobaculites* sp. A, *A*. sp. B, *Reophax fittsi*, and *Tolypammina* sp.

Based on the distribution of species, one can see that the several species of small foraminifers are environmental indicators. The calcareous species are particularly useful because they are only found in a very limited number of samples suggesting they are stenobiontic

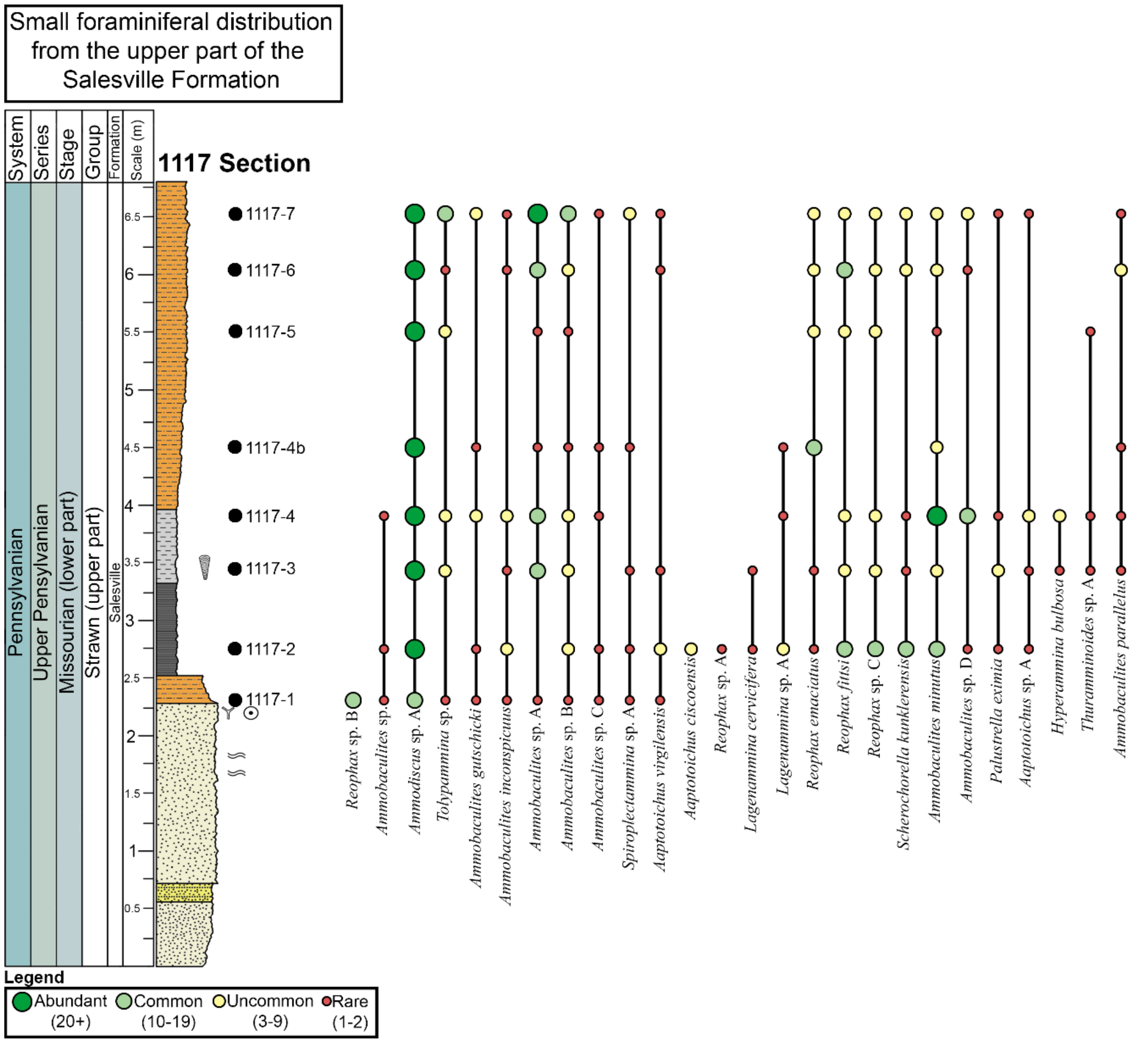


**Fig. 10.** A figure showing the small foraminiferal distribution and abundance in the 1117 section. Red dots indicate sampling level. Black dots indicate sampling level. Colored dots show where a species was recovered, and the color of the dot corresponds to the number of specimens found as defined in the legend. For lithologic and faunal symbols see Fig. 8.

*Apterrinella grahamensis*, *Brunsia* sp. A, and *Brunsiella* sp. A are only found in sample 1013-0 below the Devil's Hollow Sandstone, contrasting with the other calcareous species *Endothyra media*, *E. pauciloculata*, and *E. watersi* that appear only in samples 1013-9 and 1013-10. The species *Apterrinella grahamensis*, *Brunsia* sp. A, and *Brunsiella* sp. A found in the crinoidal siltstone are good indicators for carbonate rich, shallow marine environment. The presence of *Endothyra media*, *E. pauciloculata*, and *E. watersi* in the variegated mudstone that represents a relatively less carbonate-rich, shallow marine environment suggests that those species might have been subjected to environmental stressors related to the receding sea level.

*Reophax* sp. B appears only in the sandy mudstone, sample 1117-1, where it is found in common numbers and is notable because it has relatively large (161-217 μm) and angular grains in its test wall (Pl. 2, figs. 10-11). Medium sized sand grains are also far more abundant in the matrix of sample 1117-1, as compared to the other samples of the current study. These grains are less likely to have been transported into the area in a deeper marine environment. The presence of *Reophax* sp. B only in the sandy mudstone (1117-1) is in contrast to *Reophax emaciatus*, *R. fittsi*, and *R*. sp. C that are found in the highest abundance in samples from the black shale units (1013-1, 1013-2, 1013-3, 1117-2) in the deeper parts of the cycle. Unfortunately, no complete tests of this species were found, so a formal description of this species could not be completed.

### 2.1.2 Small Foraminiferal Assemblage Comparisons

Late Pennsylvanian small foraminiferal studies in North America outside of North-Central Texas that are extensive enough to facilitate correlation are nearly non-existent. Plummer's (1945) study of the small foraminifers from the Colorado River Valley, Texas shows an assemblage with many similarities and differences to the assemblage found in the current study of the upper part of the Salesville Formation. Plummer sampled the Marble Falls and Smithwick Formations of the Bend Group and Strawn Group units (Atokan to Desmoinesian). It seems that Plummer did not find any Missourian species of foraminifers in her studied units. However, some of the foraminiferal tests of the genera *Thuramminioides, Ammodiscus*, *Ammobaculites*, and *Reophax* described by Plummer are similar in the appearance to the tests from the upper part of the Salesville Formation. The species *Ammobaculites minutus*, *Hyperammina bulbosa* Cushman and Waters 1927, *H. clavacoidea* Plummer 1945, *Lagenammina cervicifera* (Cushman and Waters 1928a), *R. emaciatus*, *R. fittsi*, and *R.* sp. C, which was incorrectly identified as *R. glennensis* (Harlton 1927a) by Plummer, were found in both Plummer's assemblage and the assemblage in the upper part of the Salesville Formation, but these species account for a small percentage of the 37 species identified in the current study. Many of Plummer's illustrated specimens are notably larger than comparable specimens found in the upper part of the Salesville Formation, likely due to environmental constraints during the deposition of the Salesville Formation.

Ireland (1956) studied Virgilian small foraminifers from Kansas in the Midcontinent region and compared many of his species with those described by Plummer (1945). The Kereford Member of the Oread Formation of Kansas contained the highest number of species of small foraminifers that were also identified in North-Central Texas. Ireland illustrated and described tests assigned to the genera *Ammodiscus* and *Tolypammina* that closely resemble those found in the current study. *Aaptotoichus ciscoensis* (Cushman and Waters 1928b), *A. virgilensis* (Ireland 1956), *Ammobaculites parallelus* Ireland 1956, *A. inconspicuus* (Cushman and Waters 1928a), *A.* sp. B (identified incorrectly as *A. nitidus* by Ireland), *A.* sp. C (identified incorrectly as *A. spirans* by Ireland), *Apterrinella grahamensis*, *Hyperammina bulbosa*, *H. clavacoidea*, *Palustrella eximia* (Eichwald 1859), and *Scherochorella kunklerensis* (identified incorrectly as *Nodosinella perelegans* by Ireland), all species identified in both the Kansas and the current studies. Ireland found a much higher proportion of attached forms which are almost absent in the upper part of the Salesville Formation except *Tolypammina* sp. and *Apterinella grahamensis*. No specimens of the genus *Reophax* were recovered in the Kansas study which contrasts with the presence of abundant *R. emaciatus*, *R. fittsi*, and *R.* sp. C in the Pummer's and current studies.

Based on the number of the same species, the small foraminiferal assemblage of the upper part of the Salesville Formation most closely resembles the assemblage identified by Ireland (1956) from the Virgilian of Kansas, rather than by Plummer (1945) from the Desmoinesian of Central Texas. This comparison suggests that the species identified both in Kansas and in the current study have long biostratigraphic ranges. It is also not known to what extent that glacioeustatic fluctuations influenced the deposits that Plummer studied because she did not include any detailed notes on the stratigraphy of her sections. However, it is known that the upper part of the Salesville Formation and the formations that Ireland studied were both influenced by glacioeustatic fluctuations, although changing sea levels may explain why the assemblage identified by Ireland has more in common with the assemblage in the upper part of the Salesville Formation.

### 2.1.3 Descriptions of Agglutinated Foraminifers

The classification for higher taxa (phylum and class levels) of foraminifers of Adl et al. (2005; 2019) is used herein. The classification of the agglutinated foraminifers of Kaminiski

(2014) is used on the order, suborder, family, and subfamily levels. The method of the description of chamber shape, transverse section shape, aperture shape, and shape of the apertural end of the last chamber follows Gerke (1967). Definitions of test size used in the descriptions of current study is presented in Table 2. Schemes for measurements and the chamber counting order used on different morphotypes of small foraminifers are shown in Figure 11.

| **Definition of sizes used in descriptions** | |
|---|---|
| Test Length or Test Diameter | |
| Extremely Large | 1500 µm – 2000 µm |
| Very Large | 1000 µm – 1499 µm |
| Large | 600 µm – 999 µm |
| Small | 300 µm – 599 µm |
| Very Small | <300 µm |

**Table 2.** A table showing the ranges that define test length or test diameter descriptors used in the current study for descriptions of small foraminifers.

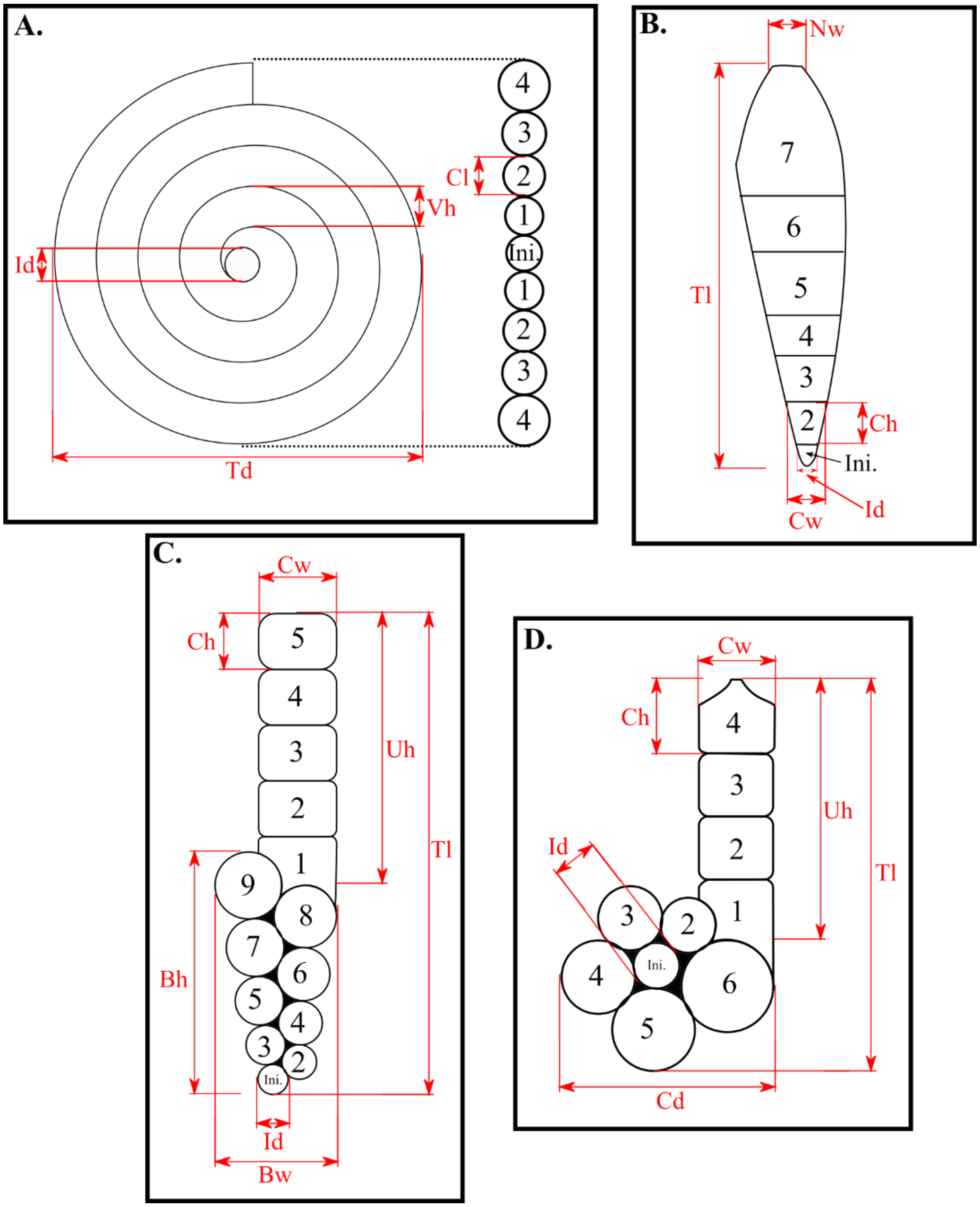


**Fig. 11.** Figures showing the measurement schemes used for the descriptions of small foraminifers in the current study. **A.** Scheme for planispiral and coiled forms like *Ammodiscus*. **B.** Scheme for uniserial forms like *Reophax*. **C.** Scheme for biserial to uniserial forms like *Aaptotoichus*. Purely biserial forms like *Palustrella* use this method without the uniserial part. **D.** Scheme for coiled to uniserial forms like *Ammobaculites*. Abbreviations for all figures: numbers = chamber counting order, Bh = biserial part height, Bw = biserial part width, Cd = coiled part diameter, Ch = chamber height, Cl = chamber lumen, Cw = chamber width, Id = proloculus diameter, Ini. = proloculus, Nw = neck width, Td = test diameter, Tl = (total) test length, Uh = uniserial part width, Vh = volution height.

Phylum FORAMINIFERA Orbigny 1826

Class MONOTHALAMEA Pawlowski et al. 2013

Order ASTRORHIZIDA Lankester 1885

Suborder SACCAMMININA Lankester 1885

Subfamily STEGNAMMININAE Moreman 1930

### Genus ***Thuramminoides*** Plummer 1945; emend. Conkin 1961

*Type species: Thuramminoides sphaeroidalis* Plummer 1945.

*Diagnosis* (after Loeblich and Tappan 1987): Test free, subglobular to discoidal with broadly rounded periphery; wall agglutinated of fine quartz grains, both inner and outer wall surfaces smoothly finished; no distinct aperture.

*Remarks*: The original description of the genus *Thuramminoides* by Plummer (1945) indicated that, internally, the genus had a labyrinthic structure, but she provided poor evidence for the existence of such a structure. She illustrated one example of a spherical object with a perforate structure on her pl. 15, fig. 9 that was proclaimed to have been found separately from the test and was assigned to the species *Thuramminoides sphaeroidalis*. With this one object being the only evidence for such a structure, it is exceedingly unlikely that the highly perforate, spherical object is in any way related to *Thuramminoides*.

The emendation of the genus by Conkin (1961) dismissed the labyrinthic internal structure as being a diagnostic feature of the genus. Conkin (1961) also discussed the presence of “centripetal tubes” that extend outwards from the interior boundary of the test and sporadically connect to the exterior of the test forming pores. Neither Loeblich and Tappan (1987) nor the current study considers the labyrinthic internal structure or the centripetal tubes to be diagnostic features of the genus.

### ***Thuramminoides*** sp. A

Plate 1, figures 1-3; Plate 5, figures 1-2; Plate 7 figure 1; Plate 9, figure 5

*Thurammina sphaeroidalis* – BOARDMAN et al. 1995, pl. 4, fig. 1.

*Description*: Test free, very small to small, unilocular, discoidal, compressed. Interior of test is hollow and lacks any structures (Pl. 9, fig. 5). Aperture(s) not present, and no pores or tubes in the sense of Conkin (1961) were observed in the test wall. Test wall is agglutinated, smooth on the internal and external sides, of color ranges from light to dark tan, composed of probably quartz grains and other grains of unknown composition.

*Measurements* ($\mu m$): Diameter of test 161-532.

*Material*: Common, 18 specimens were photographed, two specimens were studied in SEM, and two specimens were studied in transmitted light.

*Discussion*: Based on the shape of the test, described species is similar to some illustrated species of *Thuramminoides sphaeroidalis* by Plummer (1945, p. 266, pl. 15, figs. 4, 6) from the Pennsylvanian Strawn Group, but differs from it by the size of the test. The new species is significantly smaller than *T. sphaeroidalis* Plummer which has a maximum observed test diameter of 1600 μm and an average diameter of 700 μm. Plummer (1945) illustrated several different tests assigned to *T. sphaeroidalis*, one of which (pl. 15, fig. 8) is now considered to be *Thuramminoides plummerae* by Kaminski and Perdana (2017).

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-0, 1013-1, 1013-2, 1013-3, 1013-4, 1013-6, 1013-9, and 1117 section, samples: 1117-3, 1117-4, 1117-5, North-Central Texas, USA (this study); Upper Pennsylvanian, Virgilian, Graham Formation, North-Central Texas, USA (Boardman et al. 1995).

### Family SACCAMMINIDAE Brady 1884

### Subfamily SACCAMMININAE Brady 1884

### Genus ***Lagenammina*** Rhumbler 1911

*Type species: Lagenammina laguncula* Rhumbler 1911

*Diagnosis* (after Loeblich and Tappan 1987): Test flask-shaped, with elongate neck; wall with proteinaceous organic layer densely covered by agglutinate material; aperture terminal, produced on an elongate neck.

### ***Lagenammina*** sp. A

Plate 1, figures 5-8

*Description*: Test free, from very small to small, unilocular, compressed, discoidal in axial view with short (58 μm-109 μm) and relatively wide (46 μm-74 μm) neck. Some tests are asymmetrical in shape (Pl. 1, figs. 5, 7). The aperture located at the end of the neck is slit-shaped because of the compression. Wall of the test is agglutinated, with relatively coarse grains, composed of probably quartz grains and other grains of unknown composition. Color of the test is white to tan to dark red.

*Measurements (μm)*: Test length including neck 231-322, width 231-271.

*Material*: Uncommon, eight specimens were photographed.

*Discussion*: Based on a unilocular test with a protruding neck, this species is similar to *Lagenammina cervicifera* (Cushman and Waters 1928a, p. 34, pl. 4, fig. 11) but differs from it by smaller grains of the test wall and a smaller test size. In the current study, *L. cervicifera* has a total test length including the neck from 324 μm to 738 μm.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-3, 1013-4, 1013-5, 1013-6, 1013-9, and 1117 section, samples: 1117-2, 1117-4, 1117-4b, North-Central Texas, USA.

### Class TUBOTHALAMEA Pawlowski et al. 2013

### Order AMMODISCIDA Mikhalevich 1980

### Suborder AMMODISCINA Mikhalevich 1980

### Family AMMODISCIDAE Reuss 1862

### Subfamily AMMODISCINAE Reuss 1862

### Genus ***Ammodiscus*** Reuss 1862 [= *Arammodiscum* Rhumbler 1913; = *Grybowskiella* Myatlyuk 1970]; emend. Loeblich and Tappan 1954; emend. Gerke 1960; emend. Loeblich and Tappan 1961

*Type species: Orbis infimus* Bornemann 1874 (not *Orbis infimus* Strickland 1846).

*Diagnosis* (after Loeblich and Tappan 1987): Globular proloculus followed by a planispirally enrolled, undivided, tubular second chamber, tightly appressed against the preceding whorl that serves as a floor for the chamber, surface with occasional transverse growth constrictions but no internal subdivisions; wall agglutinated; aperture an arch at the open end of the tubular chamber.

### ***Ammodiscus*** sp. A

Plate 1, figures 16-18; Plate 5, figures 6-8; Plate 7, figures 3-4; Plate 9, figures 6-7

*Description*: Test free, small to large, evolute, bichambered, psedotubular, planispirally coiled. Number of volutions is 4-7. Proloculus small, spherical to subspherical, with diameter of 28 to 46 μm. First four volutions increase gradually in height. The height of the first four volutions ranges from 12 to 37 μm. The following volutions increase relatively rapidly in height. The height of the fifth to seventh volutions ranges from 43 to 93 μm. The chamber lumen measured in thin section is: in first volution 24 μm, second 27 μm, third 33 μm, fourth 33 μm, fifth 48 μm, and sixth 60 μm (Pl. 9, fig. 7). Aperture is rounded in shape, open end of pseudotube. Wall is agglutinated, with varying grain size from relatively fine (Pl. 1, fig. 18) to coarse (Pl. 1, fig. 17), composed of probably quartz grains and other grains of unknown composition. Color of the test is highly variable, and may be white, tan, orange, brown, black, or dark red.

*Measurements (μm)*: Diameter of test 230-747.

*Material*: Abundant, 57 specimens were photographed, three specimens were studied in SEM, and eight specimens were studied in transmitted light.

*Discussion*: Based on a bichambered, planispiral test this species is similar to *Ammodiscus semiconstrictus* Waters (1927, p. 132, pl. 22, fig. 1), and *Ammodiscus annularis* (Brady 1876) in the sense of Ireland (1956, p. 848, pl. 4, figs. 4-6). From *A. semiconstrictus*, the described species differs by the absence of the “constrictions” seen on the last two outer volutions and much smaller test diameter (*A. semiconstrictus* has a diameter of 1000 μm). Compared to the specimens of *A. annularis* illustrated by Ireland (1956, pl. 4, figs. 4-6), *Ammodiscus* sp. A differs by significantly larger test (*A. annularis* has a diameter of 150 to 200 μm).

Waters (1927) described a subspecies *A. semiconstrictus* var. *regularis* that differs from the typical form of *A. semiconstrictus* by a lack of “constrictions” of the outer volutions. However, the most diagnostic feature of *A. semiconstrictus* is the presence of such “constrictions”, and because the description of *A. semiconstrictus* var. *regularis* contradicts the description of *A. semiconstrictus*, it is not considered a valid variety by the present study. *A. semiconstrictus* var. *regularis* is very similar to *Ammodiscus* sp. A based on the test shape, but its test diameter is slightly larger than the largest specimens of *A.* sp. A. However, at the present the author cannot synonymize *A. semiconstrictus* var. *regularis* with the new species until the specimens of the species in the collection of Waters can be studied.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-0, 1013-1, 1013-2, 1013-3, 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, 1013-10, and 1117 section, samples: 1117-1, 1117-2, 1117-3, 1117-4, 1117-4b, 1117-5, 1117-6, 1117-7, North-Central Texas, USA.

### Class GLOBOTHALAMEA Pawlowski et al. 2013

### Order LITUOLIDA Lankester 1885

### Suborder HORMOSININA Mikhalevich 1980

## Family REOPHACIDAE Cushman 1927

### Genus ***Reophax*** Montfort 1808 [= *Reophagus* Agassiz 1884; = *Proteonina* Williamson 1858; = *Lituolina* Göes 1881; = *Arproteonum* Rhumbler 1913; = *Arreophaxum* Rhumbler 1913]; emend. Brönnimann and Whittaker 1980

*Type species: Reophax scorpiurus* Montfort 1808; neotype was designated by Brönnimann and Whittaker 1980.

*Diagnosis* (after Loeblich and Tappan 1987): Test free, elongate, with few rounded to pryriform chambers in slightly irregular or arcuate series, each succeeding chamber attached near the base of the apertural neck of the preceeding chamber; wall thin, of a single layer of agglunated grains of quartz, mica, sponge spicules, or foraminieral tests held in a minimum of organic cement but without a true organic inner layer; aperture terminal, rounded, produced on a slight neck.

*Remarks*: The author follows the synonymy of the genus proposed by Loeblich and Tappan (1987). Several species originally assigned to the genus *Nodosinella* by Halton (1927), Cushman and Waters (1927), and Warthin (1930) were considered to be *Reophax* by Plummer (1945), which the current study agrees with.

### ***Reophax emaciatus*** Plummer 1945

Plate 2, figures 4-6; Plate 5, figure 9

*Reophax emaciatus* – PLUMMER 1945, p. 227, pl. 17, figs. 18-22.

*Description*: Test free, large to extremely large, uniserial, slightly compressed, straight, strongly elongate, ovate in transverse section. Number of chambers is 5-6. Proloculus is rounded and large with a diameter 141- 204 μm, and sometimes it is broken off in some specimens. The following chambers are subrectangular in shape. The second and third chambers rapidly expand in width (164-346 μm) and height (111-192 μm). In the fourth and fifth chambers, the width (321-424 μm) and height (176-260 μm) increase more gradually. The last or sixth chamber, when present, is disproportionally large compared to the previous chambers, with a width from 357 to 506 μm and a height from 408 to 624 μm. Sutures are not well defined and are difficult to see even in well-preserved specimens. The aperture is large and ovate due to compression and located on a short and wide (117-212 μm) neck. Wall is coarsely agglutinated, rough, composed of probably quartz grains and other grains of unknown composition. Color of the test is black to tan, with more poorly preserved specimens appearing orange in color.

*Measurements (μm)*: Test length 856-1656, width 316-553.

*Material*: Common, 19 specimens were photographed, and one specimen was studied in SEM.

*Discussion*: The specimens of *Reophax emaciatus* collected in the current study match the original description of Plummer (1945) very well, and the test shape and size are nearly identical. The only notable difference between the specimens from the upper part of the Salesville Formation and those described by Plummer is the color of the test. Plummer notes that her specimens use clear quartz grains and clear silica cement that make the tests of *R. emaciatus* semi-transparent; whereas the specimens found in the Salesville Formation are all opaque.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-1, 1013-2, 1013-3, 1013-5, 1013-6, 1013-8 and 1117 section, samples: 1117-2, 1117-3, 1117-4b, 1117-5, 1117-6, 1117-7, North-Central Texas, USA (this study); Middle Pennsylvanian, Desmoinesian, Strawn Group, Central Texas, USA (Plummer 1945).

### ***Reophax fittsi*** (Warthin 1930)

Plate 2, figures 7-8; Plate 6, figures 1-2

*Nodosinella*? *fittsi* n. sp. – WARTHIN 1930, p. 27, pl. 2, fig. 7.

*Reophax fittsi* (Warthin) – PLUMMER 1945, p. 228, pl. 17, figs. 10-17; POPE et al. 2011, pl. 1, fig. 10; NESTELL et al. 2012, p. 228, pl. 1, figs. 11-20.

*Reophax* cf. *R. fittsi* – BOARDMAN et al. 1995, pl. 4, figs. 12, 19, 23.

*Description*: Test free, large to extremely large, uniserial, compressed, straight, lanceolate, ribbon-shaped in transverse section. Number of chambers is 4-6. Proloculus is rounded and large with a diameter 75-144 μm. The following chambers are subrectangular in shape. The second to fourth chambers increase relatively rapidly in width (75-235 μm), but only gradually increase in height (55-104 μm). The last chamber is disproportionally large compared to the previous chambers with a width from 267 to 332 μm and a height from 306 to 373 μm. Sutures are poorly defined to moderately well-defined. The aperture is large, rounded, located on a long (130-159 μm) and wide (103-219 μm) neck. Wall is coarsely agglutinated, rough, composed of probably quartz grains and other grains of unknown composition. Color of the test is black to tan, with more poorly preserved specimens appearing orange in color.

*Measurements (μm)*: Test length 622-1516, width 258-614.

*Material*: Abundant, 33 specimens were photographed, and two specimens were studied in SEM.

*Discussion*: Based on test shape, the specimens of *Reophax fittsi* collected in the current study match the original description of the species described by Warthin (1930) very well. The only notable difference is that Warthin listed a maximum test length of his Central Oklahoma specimens as 900 μm, which is somewhat smaller than some of the Salesville Formation specimens of *R. fittsi*. The specimens of *R. fittsi* from South-Central Iowa described and illustrated by Nestell et al. (2012) have a test wall of much finer grains and longer (900-2600 μm) and wider (300-900 μm) than *R. fittsi* from the upper part of the Salesville Formation.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-1, 1013-2, 1013-3, 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, 1013-10, and 1117 section, samples: 1117-2, 1117-3, 1117-4, 1117-5, 1117-6, 1117-7, North-Central Texas, USA (this study); Upper Pennsylvanian, Desmoinesian, Wewoka Formation, Oklahoma, USA (Warthin 1930); Middle Pennsylvanian, Atokan, Smithwick Formation, and Desmoinesian, Strawn Group, Central Texas, USA (Plummer 1945); Upper Pennsylvanian, Desmoinesian, Mouse Creek Formation, Excello Shale, Booneville section and Medora sections, South-Central Iowa, USA (Pope et. al. 2011; Nestell et al. 2012); Upper Pennsylvanian, Desmoinesian, East Mountain Formation; Missourian, Graford Formation, Wolf Mountain Shale; and Virgilian, Graham Formation, Finis Shale, North-Central Texas, USA (Boardman et al. 1995).

### ***Reophax*** sp. C

Plate 2, figures 12-18; Plate 6, figures 3-4

*Reophax glennensis* – PLUMMER 1945, p. 229, pl. 17, fig. 24.

*Description*: Test free, large to extremely large, uniserial, straight, lanceolate, rounded in transverse section. Number of chambers is 5-7. Proloculus is large, rounded,  with a diameter 38-96 μm. The following chambers are rectangular in shape and increase gradually in width and height. The second, third, and fourth chambers range in width from 51 to 246 μm and in height from 38 to 156 μm. The fifth and sixth chambers range in width from 127 to 378 μm and in height from 106 to 319 μm. The last chamber is disproportionally large compared to the previous chambers and can range in width from 221 to 412 μm and in height from 314 to 534 μm. Sutures are well-defined. The aperture is large, rounded, located on a long (70-149 μm) and wide (76-284 μm) neck. Wall is coarsely agglutinated, composed of probably quartz grains and other grains of unknown composition. Color of the test is black to brown.

*Measurements (μm)*: Test length 814-2026, width 251-584.

*Material*: Abundant, 30 specimens were photographed, and two specimens were studied in SEM.

*Discussion*: Based on a large to extremely large test, *Reophax* sp. C is similar to *Reophax fittsi* (Warthin 1930, p. 85, pl. 2, fig. 7) and *Reophax emaciatus* Plummer (1945, p. 271, pl. 17, fig. 18) From *R. fittsi*, the described species differs by narrower chambers, a smoother test surface, and more well-defined sutures. From *R. emaciatus*, the described species differs by chambers gradually increasing in width and height. The chambers of *R. emaciatus* increase relatively rapidly in height and width in the first 2-3 chambers and more slowly thereafter.

Plummer (1945) illustrated a specimen under the name *Reophax glennensis* (Harlton 1927a) that closely resembles *Reophax* sp. C found in the Salesville Formation. However, after investigation of the holotype of the species, it is clear that the Plummer's specimen belongs to a different species, not *R. glennensis* described by Harlton, because the holotype of *R. glennensis* has much finer grains of the test wall, inflated cask-shaped chambers, and a much shorter last chamber that lacks a neck. Therefore, Plummer's specimen of *R. glennensis* is synonymized with the described species. Plummer reported one notable difference in her description of *R.*

*glennensis* that the species sometimes used conodonts, holothurian sclerites, and other smaller foraminiferal tests as constituents of its tests, but none of these cases were illustrated by Plummer and such species probably represent different species.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-1, 1013-2, 1013-3, 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, 1013-10, and 1117 section, samples: 1117-2, 1117-3, 1117-4, 1117-5, 1117-6, 1117-7, North-Central Texas, USA (this study); Middle Pennsylvanian, Atokan, Smithwick Formation, Central Texas, USA (Plummer 1945).

### Suborder LITUOLINA Lankester 1885

### Family LITUOLIDAE Blainville 1827

### Subfamily AMMOMARGINULINAE Podobina 1978

### Genus ***Ammobaculites*** Cushman 1910

*Type species: Spirolina agglutinans* Orbigny 1846.

*Diagnosis* (after Loblich and Tappan 1987): Test free, elongate, early portion close coiled, later uncoiling and rectilinear, rounded in section; wall coarsely agglutinated, interior simple; aperture terminal, rounded.

### ***Ammobaculites gutschicki*** Conkin 1961

Plate 3, figures 4-6; Plate 7, figures 8-9

*Ammobaculites gutschicki* – CONKIN 1961, p. 334, p1. 7, figs. 11-12, pl. 11, fig. 15.

*Description*: Test free, straight, compressed, with two stages of growth. Initial part is small, planispirally coiled, projected to one side relative to the uniserial part, consisting of two volutions with 9-12 chambers in it. Sutures of the outer volutions are distinct, and straight. Proloculus is small to large, spherical, with a diameter 16-27 µm. Terminal part is uniserial, straight, lens-shaped in transverse section. The uniserial part consists of 2- 4 chambers. Chambers in the uniserial part are inflated, rounded (Pl. 7, fig. 9) to helmet-shaped (Pl. 7, fig. 8) with straight to slightly arcuate septa. The chambers of the uniserial part increase slightly in size from the first chamber (height 67-94 µm, width 65-121 µm) to the last chamber (height 85-116 µm, width 87-136 µm). The apertural end of the last chamber is blunt-angular. Sutures in the uniserial part are strongly defined. Aperture is very small and slit-shaped, but is almost impossible to see (Pl. 3, fig. 4c). Wall of the test is agglutinated, smooth, composed of probably quartz grains and other grains of unknown composition. Color of the test is white to brown to black.

*Measurements (µm)*: Total test length 278-430, diameter of coiled part 121-238, length of uniserial part 158-375, width 87-136.

*Material*: Common, 16 specimens were photographed, and two specimens were studied in transmitted light.

*Discussion*: The specimens of *Ammobaculites gutschicki* collected in the current study match the original description of the species by Conkin (1961, p. 321, pl. 23, fig. 11) very well in test shape, and size of the coiled portion. The only notable difference is that the uniserial part of the holotype is slightly longer (420 µm) than any of the specimens collected from the Salesville Formation.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, and 1117 section, samples: 1117-1, 1117-2, 1117-4, 1117-4b, 1117-7, North-Central Texas, USA (this study); Early Mississippian, Osagean, New Providence Formation, Kentucky and southern Indiana; Brodhead Formation, Kentucky; Cuyahoga Formation, Ohio, USA (Conkin 1961).

### ***Ammobaculites minutus*** (Waters 1927)

Plate 3, figure 9; Plate 8, figures 1-3

*Ammobaculites minuta* – WATERS 1927, p. 133, pl. 22, fig. 3.

*Ammobaculites minutus* – PLUMMER 1945, p. 236, pl. 15, figs. 15-16.

*Description*: Test free, straight, slightly compressed, with two stages of growth. Initial part is small, planispirally coiled, projected to one side relative to the uniserial part, consisting of two volutions with 9-11 chambers in it. Sutures of the coiled part are well-defined. Septa of the coiled part are straight and relatively thick (12 to 28 µm) (Pl. 8, fig. 1). Proloculus is small to large, spherical, with a diameter 15-27 µm. Terminal part is uniserial, straight, subcircular in transverse section. The number of chambers is 3-4. Chambers are inflated, rounded (Pl. 8, fig. 1), with thin arcuate septa. Chambers in this part increase slightly in width (83-138 µm) and in height (79-104 µm). The apertural end of the last chamber of the uniserial part is either truncate (Pl. 3, fig. 9) or blunt-angular (Pl. 8, figs. 2-3). Sutures in the uniserial part are well-defined.

Aperture is small and rounded with a diameter 15-27 μm. Wall of the test is agglutinated, smooth, composed of probably quartz grains and other grains of unknown composition. Color of the test is white to brown.

*Measurements (μm)*: Total test length 376-509, diameter of coiled part 142-207, length of uniserial part 222-335, width 83-138.

*Material*: Common, 15 specimens were photographed, and three specimens were studied in transmitted light.

*Discussion*: The specimens of *Ammobaculites minutus* collected in the current study match the original description of the species described by Waters (1927, p. 133, pl. 22, fig. 3) very well in test shape and size.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, and 1117 section, samples: 1117-2, 1117-3, 1117-4, 1117-4b, 1117-5, 1117-6, 1117-7, North-Central Texas, USA (this study); Upper Pennsylvanian, Missourian, Dornick Hills Group, southern Oklahoma, USA (Waters 1927); Middle Pennsylvanian, Atokan, Smithwick Formation; Desmoinesian, lower part of the Strawn Group, Central Texas, USA (Plummer 1945).

### ***Ammobaculites*** sp. A

Plate 3, figures 12-13; Plate 8, figure 4

*Description*: Test free, straight or curved, compressed, with two stages of growth. Initial part is very small, planispirally coiled, projected to one side relative to the uniserial part, consisting of one volution with 7 chambers in it. Sutures of the coiled part are completely indistinct exteriorly and chamber divisions were only visible when test was studied in transmitted light (Pl. 8, fig. 4). Proloculus is small, spherical, with a diameter of 13 μm. Terminal part is uniserial, straight (Pl. 3, fig. 12) or sometimes strongly curved (Pl. 3, fig. 13), ovate in transverse section. The uniserial part consists of 4-7 chambers. Chambers in this part are rounded to oval with thin arcuate septa (Pl. 8, fig. 4b), increasing gradually in size. The height of the first chamber is 52-63 μm, width 57-79 μm, and the height of the last chamber 119-130 μm, and width 96-139 μm. The last chamber of the uniserial part usually has an external build-up of grains near the apertural area in a flaring manner. Sutures in this part are faintly distinct to moderately distinct. Aperture is not distinguishable due to compression. Wall of the test is agglutinated, thick and very coarse, making the surface rough, composed of probably quartz grains and other grains of unknown composition. Color of the test is white to tan to brown.

*Measurements (μm):* Total test length 376-536, diameter of coiled part 53-89, length of uniserial part 307-504, width 96-139.

*Material*: Uncommon, seven specimens were photographed, and one specimen was studied in transmitted light.

*Discussion*: Based on a curved uniserial part, this species is similar to *Ammobaculites spirans* Cushman and Waters (1927, p. 149, pl. 26, fig. 10), and *Ammobaculites* sp. C. From *A. spirans*, described species differs significantly in size (the length of the holotype of *A. spirans* is 700 μm), and the uniserial part of *A. spirans* is twisted. From *A.* sp. C, the described species differs by curved uniserial part in only a one direction, whereas *A.* sp. C has a uniserial part that is wavy.

The uniserial part of described *Ammobaculites* sp. A tests can be confused with *Aaptotoichus* sp. A based on similar test size. The initial parts of these two genera can be distinguished only in thin sections or viewing specimens in the transmitted light.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-1, 1013-2, 1013-3, 1013-4, 1013-7, and 1117 section, samples: 1117-1, 1117-3, 1117-4, 1117-4b, 1117-5, 1117-6, 1117-7, North-Central Texas, USA.

### ***Ammobaculites*** sp. B

Plate 3, figures 14-15

*Ammobaculites nitidus* – IRELAND 1956, p. 858, pl. 6, figs. 18-20.

*Description*: Test free, straight, compressed, with two stages of growth. Initial part is small, planispirally coiled, projected symmetrically relative to the uniserial part, consists of one volution with 5-7 chambers in it. Sutures of the coiled part are well-defined. Proloculus is large, spherical, with a diameter 31-35 μm. Terminal part is uniserial, straight, elongate oval in transverse section. The uniserial part consists of 3-4 rectangular to cask-shaped chambers. The chambers maintain a similar size from the first chamber (height 56-85 μm, width 78-115 μm) to the last chamber (height 96-102 μm, width 79-131 μm). The apertural end of the last chamber of the uniserial part is helmet-shaped. Sutures in this part are well-defined. Aperture is not distinguishable due to compression. Wall of the test is agglutinated, fine-grained, composed of probably quartz grains and other grains of unknown composition. Color of the test is white to tan to brown.

*Measurements (µm)*: Total test length 230-489, diameter of coiled part 124-201, length of uniserial part 144-331, width 79-131.

*Material*: Common, 18 specimens were photographed.

*Discussion*: Based on a coiled part that projected symmetrically relative to the uniserial part, this species is similar to *Ammobaculites nitidus* (Waters 1928, p. 274, pl. 42, fig. 15) but differs by smaller size of the test. The holotype of *A. nitidus* has a total test length of 1000 µm. The specimens identified as *A. nitidus* by Ireland (1956, p. 856, pl. 6, fig. 18-20) are similar to the test size of *A*. sp. B found in the Salesville Formation and are herein considered to be the same species.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, and 1117 section, samples: 1117-1, 1117-3, 1117-4, 1117-4b, 1117-5, 1117-6, 1117-7, North-Central Texas, USA (this study); Upper Pennsylvanian, Virgilian, Oread, Lecompton, and Deer Creek Formations, Kansas, USA (Ireland 1956).

### ***Ammobaculites*** sp. C

Plate 3, figures 16-17; Plate 8, figure 5

*Ammobaculites spirans* – IRELAND 1956, p. 858, pl. 6, figs. 28-29.

*Description*: Test free, curved, slightly compressed, with two stages of growth. Initial part is small, planispirally coiled, projected to one side relative to the uniserial part, consisting of one volution with 6-7 chambers in it. Sutures of the coiled part are poorly defined. Proloculus is large, spherical, with a diameter 31 μm. Terminal part is uniserial, curved in multiple directions in developed specimens (Pl. 3, fig. 17), and ovate in transverse section. The uniserial part consists of 4-7 cask-shaped chambers. The first chamber of the uniserial part is notably less wide than the last chamber of the coiled part so that the test narrows between coiled and the beginning of the uniserial part (Pl. 3, figs. 16-17). The chambers of the uniserial part gradually increase in size from the first chamber (height 48-57 μm, width 69-108 μm) to the last chamber (height 96-133 μm, width 81-141 μm). The apertural end of the last chamber of the uniserial part is blunt-angular to helmet-shaped. Sutures in this part are well-defined, and septa are relatively very thick (Pl. 8, fig. 5). Aperture is not distinguishable due to compression. Wall of the test is agglutinated, somewhat coarse, composed of probably quartz grains and other grains of unknown composition. Color of the test is brown to dark red.

*Measurements (μm)*: Total test length 316-607, diameter of coiled part 109-167, length of uniserial part 213-509, width 81-141.

*Material*: Uncommon, seven specimens were photographed, and one specimen was studied in transmitted light.

*Discussion*: Based on a curved uniserial part, *Ammobaculites* sp. C is similar to *Ammobaculites spirans* Cushman and Waters (1927, p. 149, pl. 25, fig. 10) and *Ammobaculites* sp. A. From *A. spirans*, described species differs by smaller size of the test (in the type specimen of *A. spirans* the length is 700 μm) and not twisted uniserial part. From *A.* sp. A, the described species differs by a wavy uncoiled part and coarser grains of the wall.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-1, 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, and 1117 section, samples:

1117-1, 1117-2, 1117-4, 1117-4b, 1117-7, North-Central Texas, USA (this sudy); Upper Pennsylvanian, Virgilian, Oread Formation, Kansas, USA (Ireland 1956).

### ***Ammobaculites*** sp. D

Plate 3, figures 18-19; Plate 8, figure 6-7

*Ammobaculites gracilis* – IRELAND 1956, p. 855, pl. 6, figs. 13-16.

*Description*: Test free, straight or insignificantly curved, compressed, with two stages of growth. Initial part is small, planispirally coiled, projected to one side relative to the uniserial part, consisting of two volutions with total 9 chambers. Sutures of the outer volutions are distinct. Proloculus is large, spherical, with a diameter 20-26 μm. Terminal part is uniserial, sometimes insignificantly curved (Pl. 3, fig. 18), and ovate in transverse section. The uniserial part consists of 4-5 subrectangular to oval chambers. Chambers rapidly increase in size from the second chamber (height 58-68 μm, width 107-116 μm) to the fourth chamber (height 80-121 μm, width 138-158 μm). The last chamber is disproportionally larger than preceding chambers with a width 157-174 μm and a height 141-143 μm. Sutures in this part are moderately distinct. Aperture is slit-shaped due to compression. Wall of the test is agglutinated, very coarse, making the surface rough, composed of probably quartz grains and other grains of unknown composition. Color of the test is tan to dark red.

*Measurements (μm)*: Total test length 316-607, diameter of coiled part 109-167, length of uniserial part 213-509, width 157-174.

*Material*: Uncommon, five specimens were photographed, and two specimens were studied in transmitted light.

*Discussion*: Based on the size of the test and a straight uniserial part, *Ammobaculites* sp. D is similar to *Ammobaculites minutus* (Waters 1927, p. 274, pl. 42, fig. 4) but differs from it by rapidly increasing in size chambers of the uniserial part and coarser grains of the test wall giving an impression of a rougher surface.

Ireland (1956, p. 856, pl. 6, figs. 13-16) described and illustrated several specimens under the name *Ammobaculites gracilis* Waters 1928, but the specimens illustrated exhibit gradual increasing width and height of chambers in the uniserial part, a feature not included in Waters' type description of the species. Ireland also noted in his description that the length of the species he recovered was 320 μm or about a third of the length of the holotype of *A. gracilis* (the length is 900 μm). The present author can conclude that Ireland's specimens are probably not *A. gracilis* of Waters (1928) but are similar to the specimens of *A*. sp. D recovered from the Salesville Formation.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-1, 1013-2, 1013-3, 1013-4, 1013-7, and 1117 section, samples: 1117-1, 1117-2, 1117-4, 1117-6, 1117-7, North-Central Texas, USA (this study); Upper Pennsylvanian, Virgilian, Oread and Lecompton Formations, Kansas, USA (Ireland 1956).

## Suborder SPIROPLECTAMMININA Mikhalevich 1992

### Family SPIROPLECTAMMINIDAE Cushman 1927

### Subfamily SPIROPLECTAMMININAE Cushman 1927

### Genus ***Palustrella*** Brönnimann, Whittaker and Zaninetti 1992

*Type species: Textularia palustris* Warren 1957.

*Diagnosis* (after Brönnimann et al. 1992): Test free, biserial throughout, in macrospheric individual first planispiral, then biserial in microspheric individual. Aperture an interiomarginal elongate arch-like opening in the equatorial position. Wall thin, agglutinated, of *Trochamminina* Parker and Jones 1859, type.

*Remarks*: According to Loeblich and Tappan (1987), the genus *Textularia* occurs only in the Cenozoic, so Paleozoic agglutinated, biserial forms originally assigned to the genus *Textularia* are reassigned to *Palustrella* in the current study following Haig and McCartain (2010) who assigned some Mesozoic (Triassic) agglutinated, biserial species to *Palustrella.*

Brönnimann et al. (1992) described the microspheric form of *Palustrella* as having a planispiral initial part, but that feature not illustrated along with the diagnosis of the genus nor was it noted in the description of the type species, *Textularia palustris* (Warren 1957). No specimens of *Palustrella* with a planispiral initial part were observed in the current study, and it is uncertain whether it is a valid diagnostic feature of the genus.

### ***Palustrella eximia*** (Eichwald 1859) sensu Ireland 1956

Plate 4, figure 2; Plate 8, figure 8

*Textularia eximia* – EICHWALD 1859, p. 355, pl. 22, fig. 19; – BRADY 1876, p. 132, pl. 10, figs. 27-29; – IRELAND 1956, p. 859, pl. 7, figs. 6-9.

*Description*: Test free, small, biserial, tapered in the initial end, rounded in transverse section. Number of chambers is 5-7 in each row. Proloculus is rounded with a diameter 23 μm. The following chambers are rounded in shape and increase relatively rapidly in size. Sutures are fairly defined and form a zigzag pattern that goes up the middle of the test in the axial view (Pl. 4, fig. 2). Septa are arcuate and relatively think in later chambers (Pl. 8, fig. 8). The crescent shaped aperture is located interiomarginally on the last chamber. Wall is finely agglutinated, smooth, composed of probably quartz grains Color of the test is white.

*Measurements (μm)*: Total test length 274-378, width 117-192.

*Material*: Uncommon, five specimens were photographed, and two specimens were studied in transmitted light.

*Discussion*: The original description of this species by Eichwald (1859, pl. 22, fig. 19) is insufficient as it provided no measurements and a poorly drawn illustration of the type specimen. Therefore, it is hard to accurately compare the similar specimens found in the Salesville Formation to the type specimen. The description of the species given by Ireland (1956) is more complete and the specimens from the Salesville Formation match Ireland's description very well based on test shape and size.

The specimens identified as *Textularia eximia* by Cushman and Waters (1930, p. 53, pl. 4, figs. 9-11) differ from the description given by Ireland (1956) by the last chamber being located centrally in the axial view rather than to one side. Therefore, the specimens of *Textularia eximia* of Cushman and Waters should be considered a different species and are not synonymized herein.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, and 1117 section, samples: 1117-2, 1117-3, 1117-4, 1117-7, North-Central Texas, USA (this study); Carboniferous, Russia (Eichwald 1859); Carboniferous, England and Scotland, United Kingdom (Brady 1876); Upper Pennsylvanian, Virgilian, Lecompton, Deer Creek, Topeka and Howard Formations, Kansas, USA (Ireland 1956).

## Genus ***Spiroplectammina*** Cushman 1927

*Type species*: *Textularia agglutinans* var. *biformis* Parker and Jones 1865.

*Diagnosis* (after Loeblich and Tappan 1987): Test free, elongate, narrow ovoid in section, margins broadly rounded, large early planispiral coil of few chambers, the coil commonly of greater breadth than the first few pairs of biserial chambers; wall agglutinated, solid and non-canaliculate; aperture a low arch at the inner margin of the final chamber.

*Remarks*: Loeblich and Tappan (1987) stated that the initial coiled part of this genus is “large”. The current study disagrees with Loeblich and Tappan’s use of “large” in that situation as it is a vague description, and species with a small coiled initial part along with all the other diagnostic features should be considered as a part of the genus.

### ***Spiroplectammina*** sp. A

Plate 4, figures 3-5; Plate 8, figure 9

*Description*: Test free, small, rounded in the initial part, rounded in transverse section, with two stages of growth. Initial part small, planispiral, consisting of a single volution with 4-5 chambers in it. Sutures of the coiled part are sometimes distinct (Pl. 4, fig. 5) and sometimes hard to see (Pl. 4, figs. 3-4). Proloculus is rounded and small with a diameter 17 μm. Terminal part is biserial, consisting of 7 chambers in each row. The chambers of the biserial part are rounded in shape and increase relatively rapidly in size in the first 3 chambers and then more gradually thereafter. Sutures are well-defined and form a zigzag pattern that goes up the middle of the test in the axial view (Pl. 4, fig. 5). The crescent shaped aperture is located interiomarginally on the last chamber. Wall is finely agglutinated, smooth, composed of probably quartz grains. Color of the test is white to light tan.

*Measurements (μm)*: Total test length 308-443, width 108-153.

*Material*: Common, 13 specimens were photographed, and one specimen was studied in transmitted light.

*Discussion*: The described species differs from *Spiroplectammina castensis* Cushman and Waters (1928b, p. 62, pl. 8, fig. 4) and *Spiroplectammina clavata* Cushman and Waters (1927, p. 150, pl. 26, fig. 11), the only two other species of *Spiroplectammina* reported from North-Central Texas. From *S. castensis*, the described species differs by having a smaller test length and finer grains in the test wall. From *S. clavata*, the described species differs by fewer chambers in the initial coiled part and a smaller test length. The holotypes of both *S. castensis* and *S. clavata* have a length of 750 *μm*.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, and 1117 section, samples: 1117-1, 1117-2, 1117-3, 1117-4b, 1117-7, North-Central Texas, USA.

### Family TEXTULARIOSPIDAE Loeblich and Tappan 1982

### Genus ***Aaptotoichus*** Loeblich and Tappan 1982

*Type species: Bigenerina clavellata* Loeblich and Tappan 1946.

*Diagnosis* (after Loeblich and Tappan 1987): Short biserial stage followed by a longer uniserial portion of broad low chambers; wall of fine siliceous agglutinated particles held in organic material, solid, non-canaliculate, insoluble in HCl; aperture terminal, small and rounded.

*Remarks*: Loeblich and Tappan (1987) stated that the genus *Bigenerina* only occurs in the Cenozoic, so Paleozoic agglutinated, biserial to uniserial forms originally assigned to the genus *Bigenerina* are reassigned to *Aaptotoichus* in the current study following Haig and McCartain (2010) who assigned some similar Mesozoic (Triassic) species to *Aaptotoichus.*

### ***Aaptotoichus ciscoensis*** (Cushman and Waters 1928b)

Plate 4, figures 6-8; Plate 9, figure 1

*Bigenerina ciscoensis* – CUSHMAN and WATERS 1928b, p. 63, pl. 8, fig. 5; – IRELAND 1956, p. 862, pl. 7, figs. 24-28.

*Description*: Test free, straight (Pl. 4, fig. 7) or slightly curved (Pl. 4, figs. 6, 8), compressed, with two stages of growth. Initial part is small, biserial, consisting of 4-5 chambers in each row. Chambers in this part increase in size relatively rapidly. Sutures of the biserial part are indistinct (Pl. 4, fig. 6) to well-defined (Pl. 4, fig. 7). Proloculus is spherical, with a diameter 27 μm. Terminal part is uniserial, straight, elongate oval in transverse section. The uniserial part consists of 3 to 5 rectangular-shaped chambers. The chambers increase very slightly in size from the first chamber (height 40-53 μm, width 83-93 μm) to the last chamber (height 69-80 μm, width 86-107 μm). The apertural end of the last chamber is truncate (Pl. 9, fig. 1) to blunt-angular (Pl. 4, fig. 7) in shape. Sutures in the uniserial part are indistinct (Pl. 4, fig. 6) to well-defined (Pl. 4, fig. 7). Aperture is slit-shaped due to compression. Wall of the test is agglutinated consisting of fine grains, smooth, composed of probably quartz grains and other grains of unknown composition. Color of the test is white to brown.

*Measurements (μm)*: Total test length 324-474, biserial part length 132-168, width 84-114, uniserial part length 169-311, width 86-107.

*Material*: Uncommon, nine specimens were photographed, and one specimen was studied in transmitted light.

*Discussion*: The specimens of *Aaptotoichus ciscoensis* collected in the current study match the original description of the species by Cushman and Waters (1928b, p. 66, pl. 8, fig. 5) very well in test shape and size. The only notable difference between Cushman and Waters' and the Salesville specimens is in Cushman and Waters' specimens the wall consists of coarser grains.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-3, 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, and 1117 section, sample: 1117-2, North-Central Texas, USA (this study); Upper Pennsylvanian, Virgilian, Graham Formation, North-Central Texas, USA (Cushman and Waters 1928b); Upper Pennsylvanian, Virgilian, Oread, Topeka, Howard, Wakarusa, and Reading Formations, Kansas, USA (Ireland 1956).

### ***Aaptotoichus virgilensis*** (Ireland 1956)

Plate 4, figure 9; Plate 9, figures 2-3

*Bigenerina virgilensis* – IRELAND 1956, p. 863, pl. 7, figs. 18-19.

*Description*: Test free, straight, with two stages of growth. Initial part is small, thin, biserial, consisting of 4-5 chambers in each row. Chambers in this part increase in size gradually. Sutures of the biserial part are faintly distinct. Proloculus is spherical, with a diameter 20-21 μm. Terminal part is uniserial, straight, ovate in transverse section, consists of 4-6 rectangular-shaped chambers. The chambers increase very slowly in size from the first chamber (height 54-65 μm, width 90 μm) to the last chamber (height 82-89 μm, width 91-106 μm). The aperural end of the last chamber is truncate in shape. Sutures in the uniserial part are moderately well-defined. Aperture is very small and rounded. Wall of the test is agglutinated consisting of moderately coarse grains, composed of probably quartz grains and other grains of unknown composition. Color of the test is white to tan to brown.

*Measurements (μm)*: Total test length 272-535, biserial part length 129-269, width 77-128, uniserial part length 170-369, width 91-106.

*Material*: Uncommon, seven specimens were photographed, and two specimens were studied in transmitted light.

*Discussion*: The specimens of *Aaptotoichus virgilensis* collected in the current study match the original description of the species by Ireland (1956) very well in test shape and size.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-3, 1013-4, 1013-5, 1013-6, 1013-7, 1013-8, 1013-9, and 1117 section, samples: 1117-1, 1117-2, 1117-3, 1117-6, 1117-7, North-Central Texas, USA (this study); Upper Pennsylvanian, Virgilian, Oread Formation, Kansas, USA (Ireland 1956).

### ***Aaptotoichus*** sp. A

Plate 4, figures 10-11; Plate 9, figure 4

*Description*: Test free, straight (Pl. 4, fig. 10) or slightly curved (Pl. 4, fig. 11), compressed, with two stages of growth. Initial part is very small, wide, biserial, consisting of 3-4 chambers in each row. Sutures of the biserial part are completely indistinct and chambers are only visible when test is viewed in transmitted light (Pl. 9, fig. 4). Proloculus is spherical, with a diameter 21 µm. Terminal part is uniserial, elongate oval in transverse section. The uniserial part consists of 3-6 rounded chambers. The chambers increase very slowly in size from the first chamber (height 48-56 µm, width 96-114 µm) to the last chamber (height 84-85 µm, width 101-126 µm). The apertural end of the last chamber is rounded (Pl. 4, fig. 10) to blunt-angular (Pl. 4, fig. 11) in shape. Sutures in the uniserial part are faintly distinct. Aperture is slit-shaped due to compression. Wall of the test is agglutinated consisting of relatively coarse grains, composed of probably quartz grains and other grains of unknown composition. Color of the test is tan to brown.

*Measurements (µm)*: Total test length 312-546, biserial part length 87-128, width 87-121, uniserial part length 223-388, width 101-126.

*Material*: Uncommon, 10 specimens were photographed, and one specimen was studied in transmitted light.

*Discussion*: Based on test size, this species is similar to *Aaptotoichus ciscoensis* (Cushman and Waters 1928b, p. 63, pl. 8, fig. 5) and *Aaptotoichus virgilensis* (Ireland 1956, p. 863, pl. 7, fig. 18-19), but differs from both in the length of the test and definition of the sutures in the biserial part of the test. *Aaptotoichus ciscoensis* and *A. virgilensis* have biserial parts that account for about one third to one half of the total test length, whereas *A*. sp. A has a biserial part that accounts for only one fifth to one third of the total test length. Also, the sutures in the biserial part of *A*. sp. A are significantly less defined than in *A. ciscoensis* and *A. virgilensis*.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, samples: 1013-3, 1013-4, 1013-5, and 1117 section, samples: 1117-2, 1117-3, 1117-4, 1117-7, North-Central Texas, USA.

## Plate 1

Agglutinated foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 μm.

Fig. 1-3. *Thuramminoides* sp. A., axial views, 1013 section, 1, 2 – sample 1013-0; 3 – sample 1013-2.

Fig. 4. *Lagenammina cervicifera* (Cushman and Waters 1928), axial view, 1013 section, sample 1013-3.

Fig. 5-8. *Lagenammina* sp. A. 5, 7, 8a – axial views, 8b – axial view of the opposite side of fig. 8a, 8c – apertural view. 5 – 1013 section, sample 1013-6; 6, 7, 8 – 1117 section, sample 1117-2.

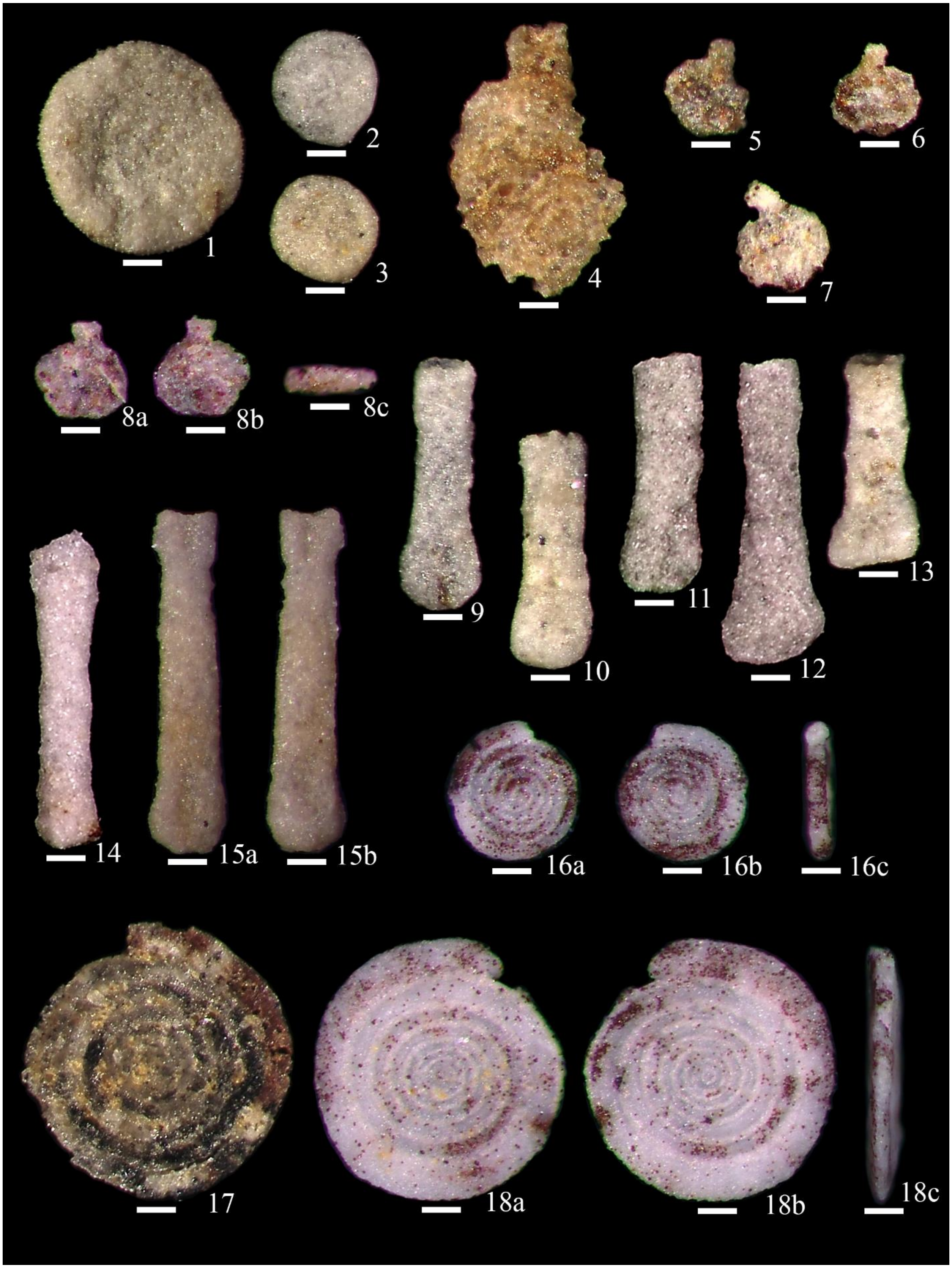
Fig. 9-11. *Hyperammina bulbosa* Cushman and Waters 1927, axial views, 1013 section,9, 11 – sample 1013-5, 10 – sample 1013-2.

Fig. 12-13. *Hyperammina clavacoidea* Plummer 1945, axial views, 1013 section, 12 – sample 1013-5, 13 – sample 1013-2.

Fig. 14-15. *Hyperammina* sp. 14, 15a – axial views, 15b – axial view of the opposite side of fig. 15a; 1013 section, sample 1013-9.

Fig. 16-18. *Ammodiscus* sp. A. 16a, 17, 18a – transverse views, 16b, 18b – transverse views of the opposite side of fig. 16a and 18a, 16c, 18c – axial views. 16, 18 – 1117 section, sample 1117-2, 17 – 1013 section, sample 1013-1.

## PLATE 1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# Plate 2

Agglutinated foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 μm, except: figs. 4-6, 10-11 = 200 μm, figs. 7-8, 14-18 = 150 μm.

Fig. 1-3. *Tolypammina* sp., fragments of specimens, 1013 section, 1, 2 – sample 1013-9; 3 – sample 1013-3.

Fig. 4-6. *Reophax emaciatus* Plummer 1945, axial views, 1013 section, sample 1013-1.

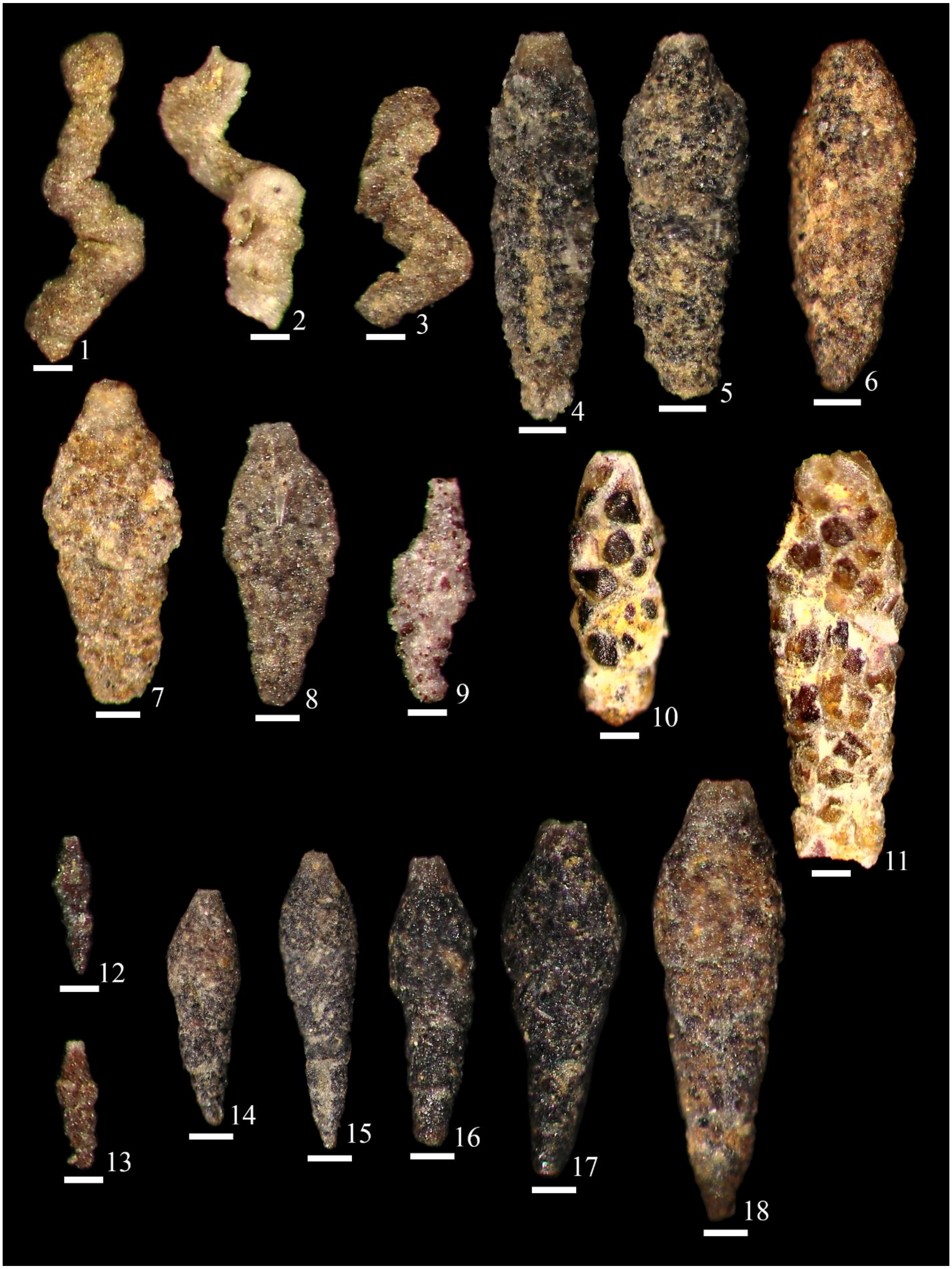
Fig. 7-8. *Reophax fittsi* (Warthin 1930), axial views, 1013 section, 7 – sample 1013-1, 8 – sample 1013-7.

Fig. 9. *Reophax* sp. A, axial views, 1117 section, sample 1117-2.

Fig. 10-11. *Reophax* sp. B, axial views, 1117 section, sample 1117-1.

Fig. 12-18. *Reophax* sp. C, axial views, 1013 section. 12, 13 – juvenile forms. 12, 15-18 – sample 1013-5; 13 – sample 1013-9; 14 – sample 1013-2.

# PLATE 2



# Plate 3

Agglutinated foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 µm, except: figs. 1-3 = 50 µm.

Fig. 1-3. *Scherochorella kunklerensis* (Conkin 1961), axial views, 1013 section, 1 – sample 1013-5; 2 – sample 1013-7; 3 – sample 1013-2.

Fig. 4-6. *Ammobaculities gutschicki* Conkin 1961. 4a, 5, 6 – axial views; 4b – axial view of opposite side of fig. 4a; 4c – apertural view. 1013 section, sample 1013-7.

Fig. 7-8. *Ammobaculites inconspicuus* (Cushman and Waters 1928). 7, 8a – axial views; 8b – axial view of opposite side of fig. 8a. 7 – 1013 section, sample 1013-5; 8 – 1117 section, sample 1117-4.

Fig. 9. *Ammobaculites minutus* (Waters 1927), a – axial view; b – axial view of opposite side of fig. a; c – apertural view; d – axial view submersed in water; 1013 section, sample 1013-7.

Fig. 10-11. *Ammobaculites parallelus* Ireland 1956, axial views. 10 – 1013 section, sample 1013-4; 11 – 1117 section, sample 1117-6.

Fig. 12-13. *Ammobaculites* sp. A, axial views, 1013 section, 12 – sample 1013-7; 13 – sample 1013-1.

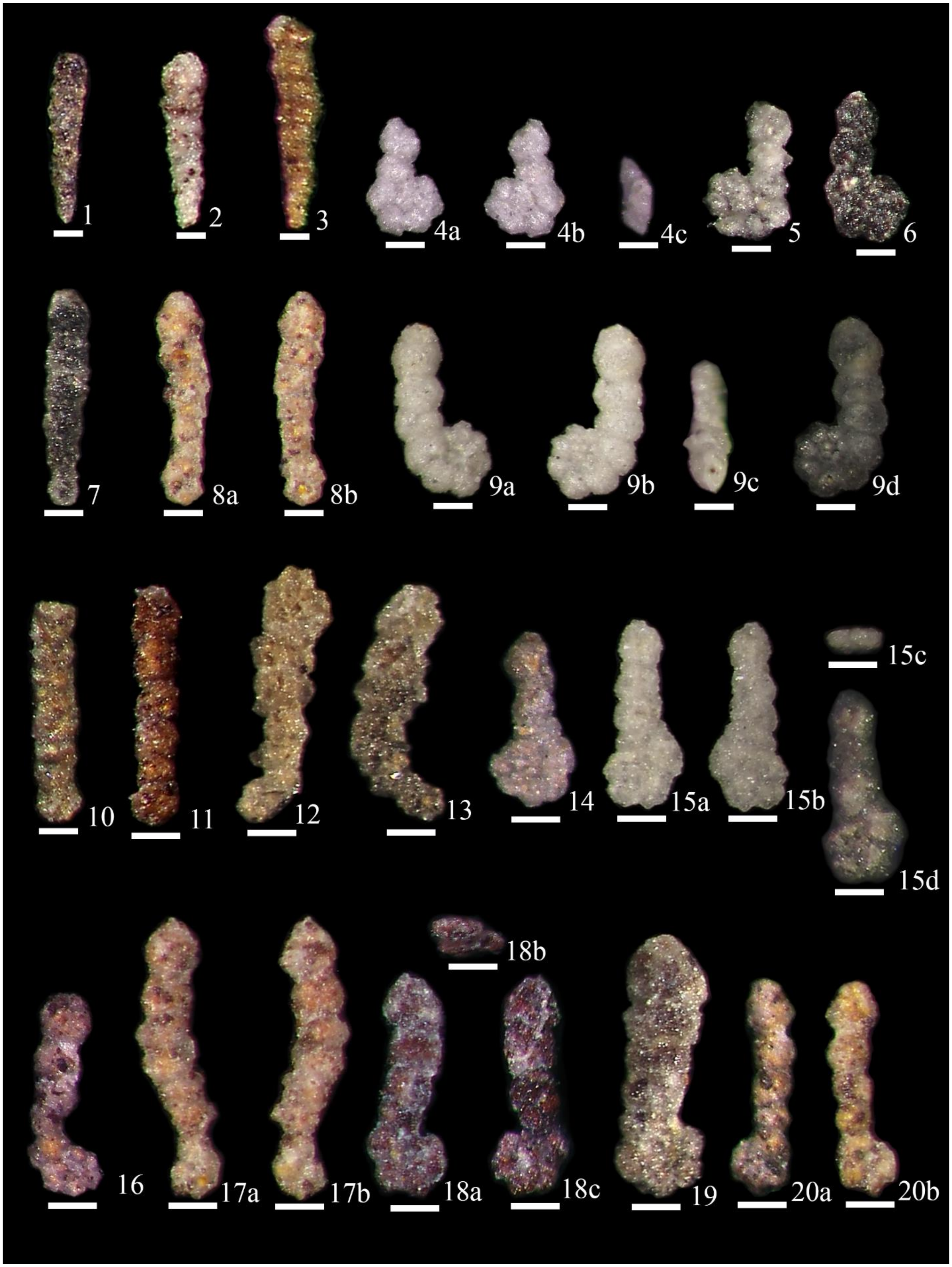
Fig. 14-15 *Ammobaculites* sp. B. 14, 15a – axial views; 15b – axial view opposite side of fig. 15a; 15c – apertural view; 15d – axial view submersed in water. 1013 section, 14 – sample 1013-6; 15 – sample 1013-7.

Fig. 16-17. *Ammobaculites* sp. C. 16, 17a – axial views; 17b – axial view of opposite side of fig. 17a. 1117 section, sample 1117-4.

Fig. 18-19. *Ammobaculites* sp. D. 18a, 19 – axial views; 18b – apertural view; 18c – axial view of opposite side of fig. 18a. 18 – 1117 section, sample 1117-2; 19 – 1013 section, sample 1013-7.

Fig. 20. *Ammobaculites* sp. a – axial view; b – axial view of opposite side of fig. a; 1117 section, sample 1117-4.

# PLATE 3



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# Plate 4

Agglutinated foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 μm.

Fig. 1. *Palustrella bucheri* (Ireland 1956), axial view, 1117 section, sample 1117-6.

Fig. 2. *Palustrella eximia* (Eichwald 1859), a – axial view; b – axial view of opposite side of fig. a; 1013 section, sample 1013-8.

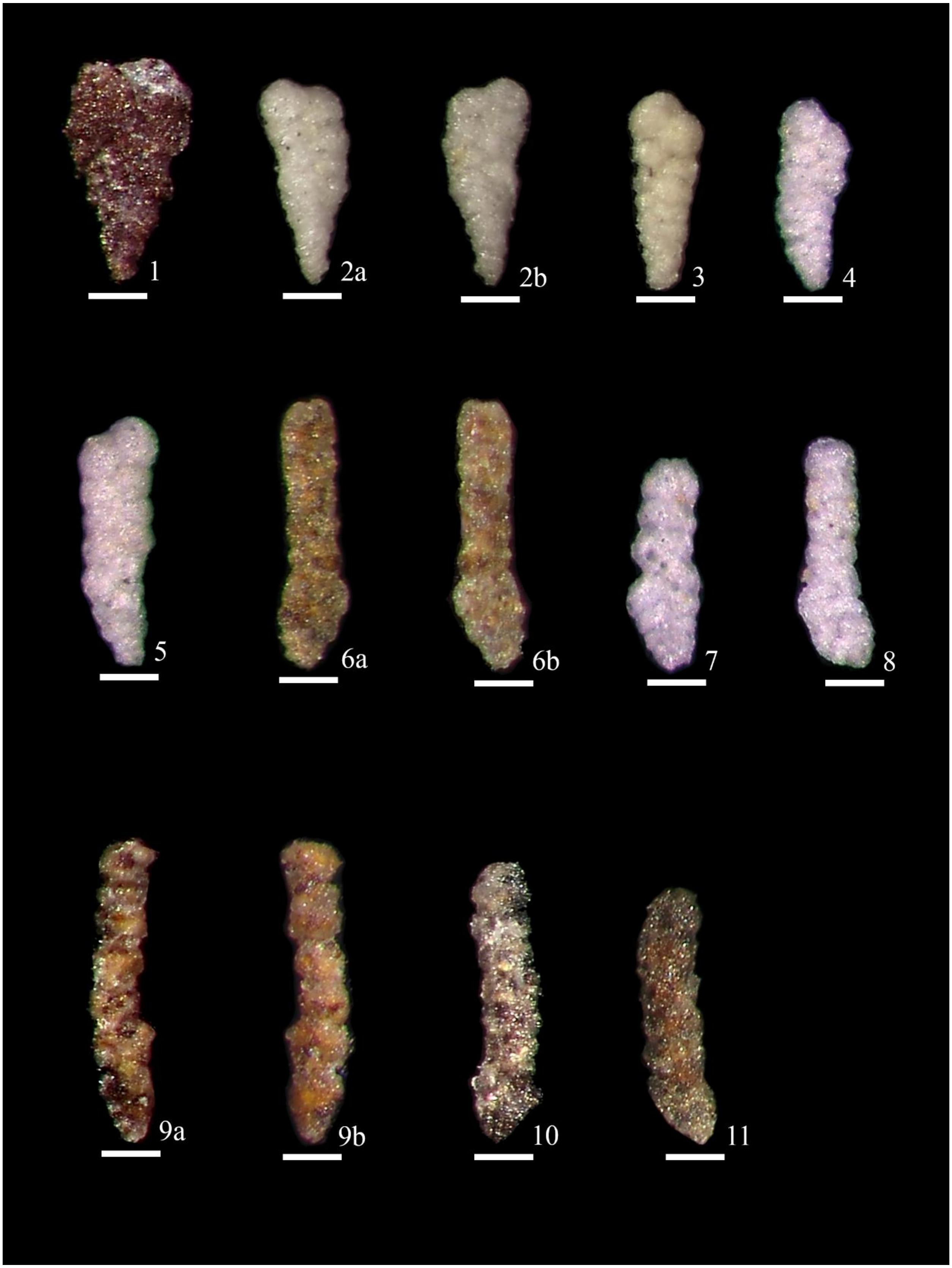
Fig. 3-5. *Sprioplectammina* sp. A, axial views, 1013 section, 3, 4 – sample 1013-6; 5 – sample 1013-7.

Fig. 6-8. *Aaptotoichus ciscoensis* (Cushman and Waters 1928). 6a, 7, 8 – axial views; 6b – axial view of opposite side of fig. 6a. 1013 section, 6 – sample 1013-6; 7 – sample 1013-7; 8 – sample 1013-8.

Fig. 9. *Aaptotoichus virgilensis* (Ireland 1956), a – axial view, b – axial view of opposite side of fig.9a; 1117 section, sample 1117-6.

Fig. 10-11. *Aaptotoichus* sp. A, axial views, 1013 section, sample 1013-4.

# PLATE 4



## Plate 5

Agglutinated foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 µm, except: figs. 3a, 5, 7 = 150 µm; figs. 3b, 6b, 9b = 50 µm; figs. 4, 6a = 200 µm; fig. 9a = 250 µm.

Fig. 1-2. *Thuramminoides* sp. A, axial views, 1013 section, sample 1013-1.

Fig. 3. *Lagenammina cervicifera* (Cushman and Waters 1928), a – axial view; b – enlarged view of the wall structure; 1013 section, sample 1013-2.

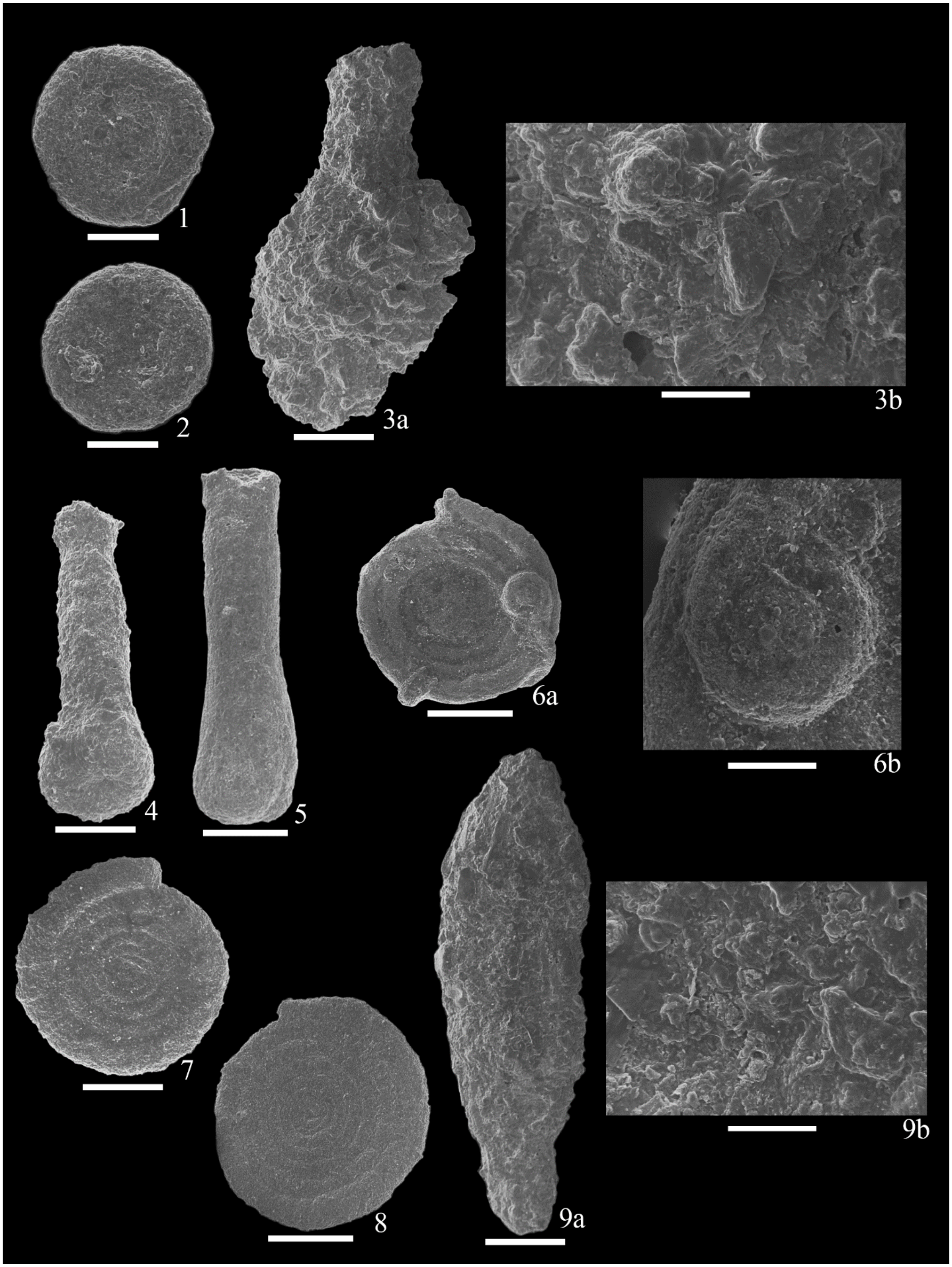
Fig. 4. *Hyperammina bulbosa* Cushman and Waters 1927, axial view, 1013 section, sample 1013-5.

Fig. 5. *Hyperammina clavacoidea* Plummer 1945, axial view, 1013 section, sample 1013-5.

Fig. 6-8. *Ammodiscus* sp. A. 6a – transverse view with an attached specimen of *Apterrinella grahamensis* (Harlton 1928); 6b – an enlarged view of the initial part of the attached *A. grahamensis*; 7, 8 – transverse views. 1013 section, 6 – sample 1013-0; 7 – sample 1013-3; 8– sample 1013-4.

Fig. 9. *Reophax emaciatus* Plummer 1945, a – axial view, b - enlarged view of the wall structure; 1013 section, sample 1013-1.

# PLATE 5



# Plate 6

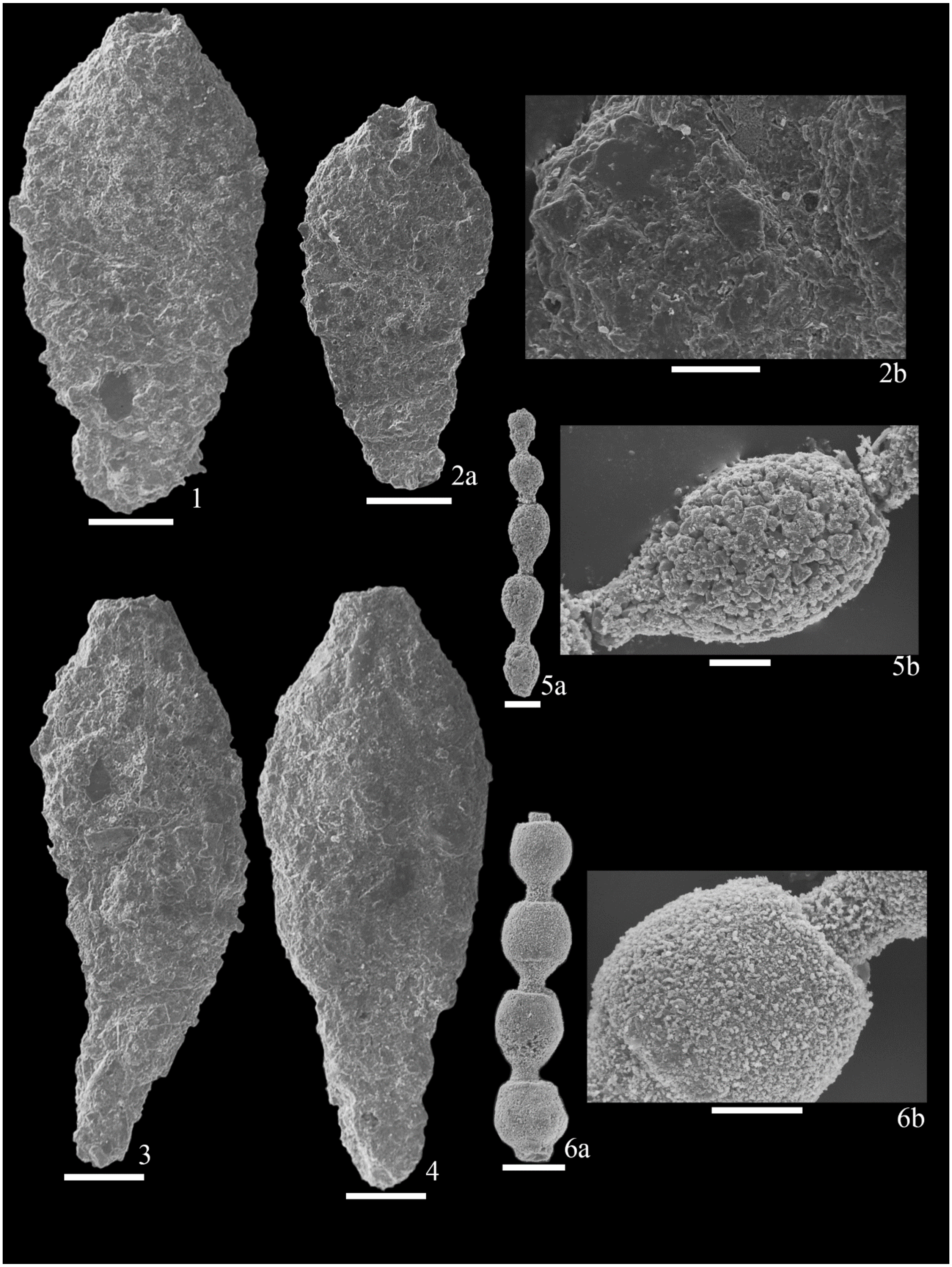
Agglutinated foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 200 µm, except: figs. 2b, 5a, and 6a = 50 µm; figs. 3-4 = 150 µm; figs. 5b and 6b = 20 µm.

Fig. 1-2. *Reophax fittsi* (Warthin 1930). 1, 2a – axial views; 2b – enlarged view of the wall structure. 1013 section, sample 1013-1.

Fig. 3-4. *Reophax* sp. C, axial views, 1013 section, 3 – sample 1013-1; 4 – sample 1013-3.

Fig. 5-6. Incertae Sedis. 5a, 6a – axial views, 5b, 6b – enlarged view of the wall structure. 1013 section, sample 1013-5.

## PLATE 6



## Plate 7

Agglutinated foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 µm, except: figs. 5-7 = 50 µm.

Fig. 1. *Thuramminoides* sp. A, axial view, a – test in transmitted light; b – view under crossed nicols; 1013 section, sample 1013-1.

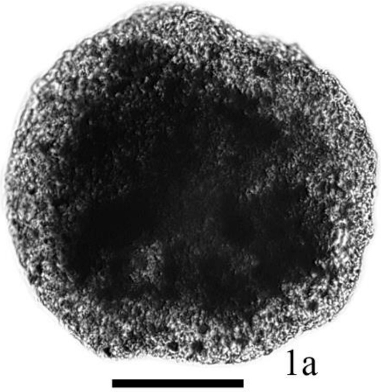
Fig. 2. *Hyperammina bulbosa* Cushman and Waters 1927, axial view, a – test in transmitted light, b – view under crossed nicols; 1013 section, sample 1013-6.

Fig. 3-4. *Ammodiscus* sp. A, transverse views, 1013 section, sample 1013-6.

Fig. 5-7. *Scherochorella kunklerensis* (Conkin 1961), axial views, 1013 section, sample 1013-6.

Fig. 8-9. *Ammobaculities gutschicki* Conkin 1961, axial views. 8a, 9a – tests in transmitted light; 8b, 9b – view under crossed nicols; 1013 section, sample 1013-7.

# PLATE 7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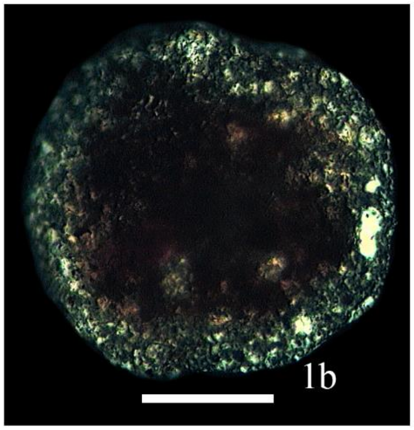
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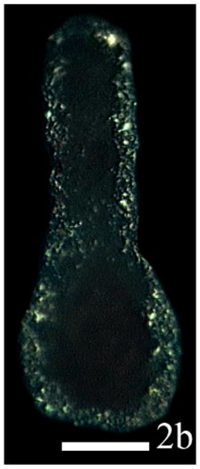
2a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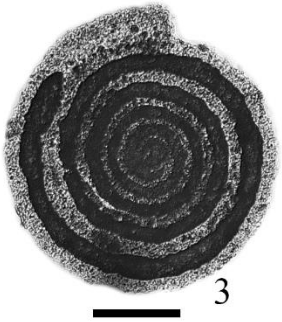
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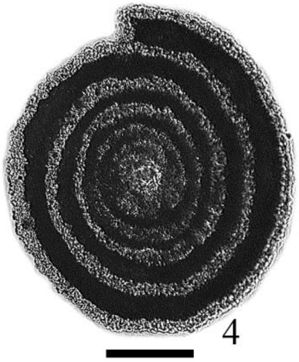
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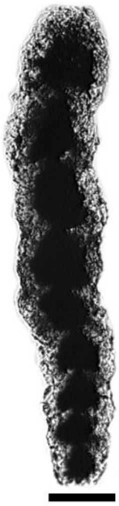
5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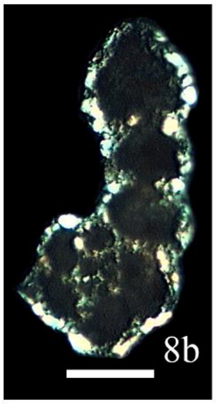
7


8a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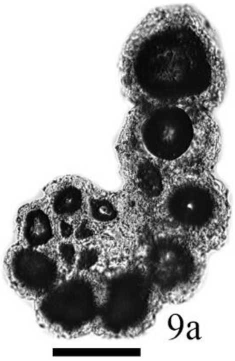
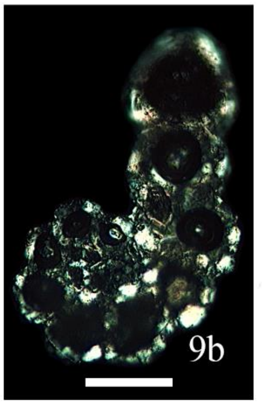

9a


9b

# Plate 8

Agglutinated foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 μm.

Fig. 1-3. *Ammobaculites minutus* (Waters 1927), axial views. 1, 2a, 3 – tests in transmitted light; 2b – view under crossed nicols; 1013 section, sample 1013-7.

Fig. 4. *Ammobaculites* sp. A, axial view, a – test in transmitted light; b – view under crossed nicols; 1013 section, sample 1013-1.

Fig. 5. *Ammobaculites* sp. C, axial view, a – test in transmitted light; b – view under crossed nicols; 1013 section, sample 1013-6.

Fig. 6-7. *Ammobaculites* sp. D, axial views. 6a, 7 – tests in transmitted light; 6b – view under crossed nicols; 1013 section, sample 1013-7.

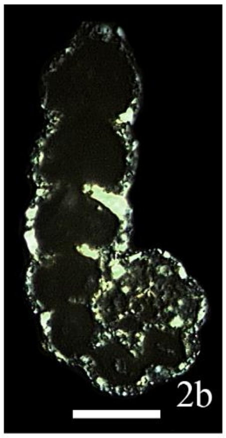
Fig. 8. *Palustrella eximia* (Eichwald 1859), axial view, 1013 section, sample 1013-9.

Fig. 9. *Spiroplectammina* sp. A, axial views, a – test in transmitted light; b – view under crossed nicols; 1013 section, sample 1013-9.

# PLATE 8

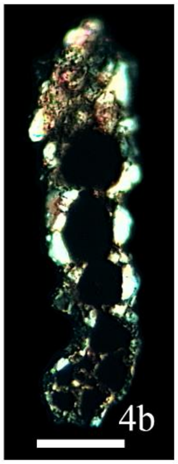

1


2a

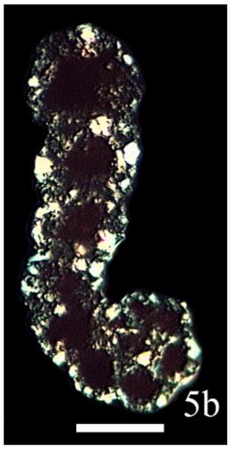

2b


3

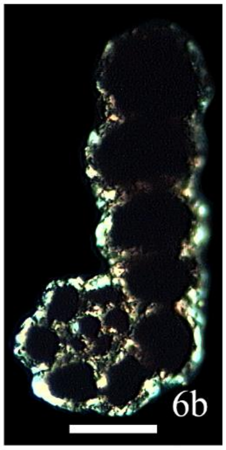

4a


4b


5a


5b


6a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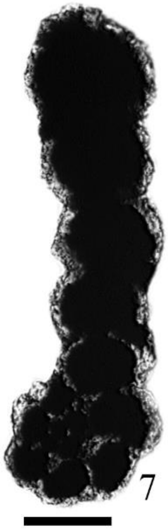
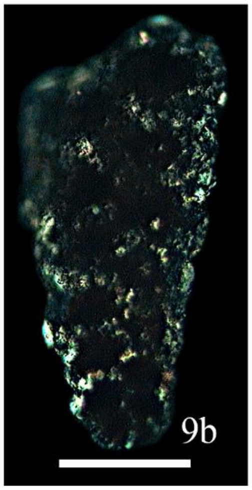

7


8


9a


9b

## Plate 9

Agglutinated foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 μm.

Fig. 1. *Aaptotoichus ciscoensis* (Cushman and Waters 1928), axial view, a – test in transmitted light, b – view under crossed nicols; 1013 section, sample 1013-7.

Fig. 2-3. *Aaptotoichus virgilensis* (Ireland 1956), axial views. 2a, 3a – tests in transmitted light; 2b, 3b – view under crossed nicols; 1013 section, sample 1013-7.

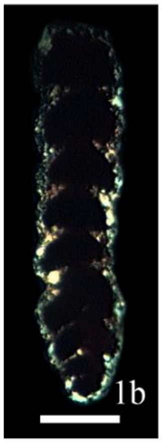
Fig. 4. *Aaptotoichus* sp. A, axial view, a – test in transmitted light; b – view under crossed nicols; 1013 section, sample 1013-4.

Fig. 5. *Thuramminoides* sp. A, axial view, a – test in transmitted light; b – test in plain light; 1013 section, sample 1013-1.

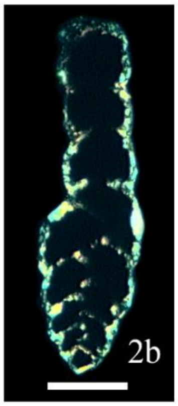
Fig. 6-7. *Ammodiscus* sp. A, axial views. 6a, 7a – thin sectioned test in transmitted light; 6b, 7b – in plain light; 1117 section, sample 1117-2.

# PLATE 9

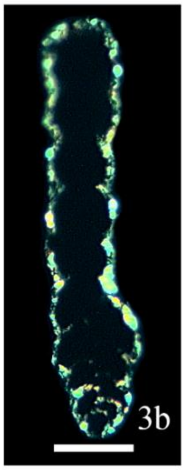

1a


1b

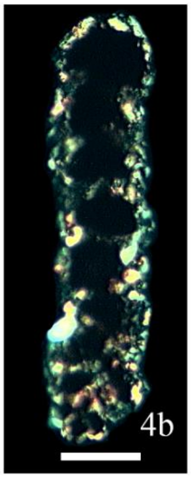

2a

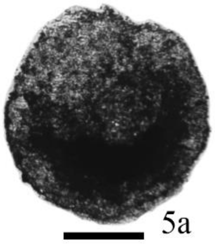

2b


3a


3b


4a


4b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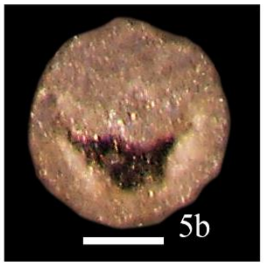

5b


6a


6b


7a


7b

### 2.1.4 Descriptions of Calcareous Foraminifers

For the description of the calcareous foraminifers, the author uses classification of Mikhalevich (2013) on the class and subclass levels. The classification scheme for hemigordiopsids proposed by Pronina (1994) is used on the order, suborder and family levels.

Class MILIOLATA Saidova 1981

Subclass MILIOLANA Saidova 1981

Order HEMIGORDIOPSIDA Mikhalevich 1987

Suborder PSEUDOAMMODISCINA Pronina 1990

Family PSEUDOAMMODISCIDAE Conil and Lys in Conil and Pirlet 1970

Genus ***Brunsia*** Mikhailov 1935

*Type species: Spirillina irregularis* von Möller 1879.

*Diagnosis* (after Loeblich and Tappan 1987): Test with proloculus followed by streptospirally early coil and later planispirally enrolled tubular chamber; wall calcareous; finely granular; aperture at the open end of the tubular chamber.

*Remarks*: See Loeblich and Tappan (1987) for remarks regarding the problems with the type species of *Brunsia*.

***Brunsia*** sp. A

Plate 10, figures 4-5; Plate 11, figure 1

*Description*: Test free, very small to small, discoidal, bichambered, with pseudotubular second chamber. The first 3 volutions are streptospirally coiled, following volutions are planispirally coiled. Number of volutions is 4-6. Proloculus is large, subspherical, with a diameter 43-54 μm. First 4 to 5 volutions increase gradually in height. The final volution increases in height relatively rapidly (30-83 μm). The aperture is rounded formed by the open end of the pseudotubular second chamber. Wall is calcareous, microgranular and thin. Color of test is typically white but can be mottled tan to brown.

*Measurements (μm)*: Test diameter 209-502.

*Material*: Uncommon, eight specimens were photographed, and two specimens were studied in transmitted light.

*Discussion*: Based on streptospirally coiled early part and test diameter, the described species is similar to *Brunsia pulchra* Mikhailov (1939, p. 64, pl. 1) However, the holotype of *B. pulchra* has 7 streptospirally coiled volutions, whereas *B.* sp. A has only 3 streptospirally coiled volutions.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, sample 1013-0, North-Central Texas, USA.

### Genus ***Brunsiella*** Reitlinger 1950

*Type species: Glomospira ammodiscoidea* Rauser-Chernousova 1938.

*Diagnosis* (after Loeblich and Tappan 1987): Test with globular proloculus followed by undivided enrolled tubular second chamber, a few early whorls streptospirally coiled, later one planispiral and evolute; wall calcareous, thick, microgranular and homogenous; aperture formed by the open end of the tube.

### ***Brunsiella*** sp. A

Plate 10, figures 6-8; Plate 11, figures 2-4

*Description*: Test free, very small to small, discoilal, bichambered, with pseudotubular second chamber, first 1 to 2 volutions are insignificantly displaced (almost planispiral) relative to axis of coiling, following volutions planispirally coiled. Number of volutions is 4-6. First 4 volutions increase gradually in height, the final 1 to 2 volutions increase relatively rapidly in height (20-76 μm). Proloculus is small to large, spherical, with a diameter 19-48 μm. The proloculus in megalospheric form rises above the plain of coiling due to its size, whereas in microspheric form the proloculus does not rise above the plane of coiling. The aperture is rounded and formed by the open end of the pseudotubular second chamber. Wall is calcareous, microgranular and smooth. Color of test is typically white to tan.

*Measurements (μm)*: Test diameter 165-460.

*Material*: Uncommon, seven specimens were photographed, and two specimens were studied in transmitted light.

*Discussion*: Based on the type of coiling of the test, the described species is similar to *Brunsiella densa* Reitlinger (1950, p. 18, pl. 2, fig. 1), but differs from it by the nearly planispiral coiling of the first 2 volutions versus the larger degree of displacement of the first 2 volutions in *B. densa*.

Also, the tests of the species *Brunsiella* sp. A. are larger than most specimens of *Brunsiella densa* (test diameter is 200-280 μm).

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, sample 1013-0, North-Central Texas, USA.

## Plate 10

Calcareous small foraminifers and radiolarians from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 µm, except: figs. 15-17 = 150 µm.

Fig. 1-3. *Apterrinella grahamensis* (Harlton 1928), attached forms on a shell fragments, 1013 section, sample 1013-0.

Fig. 4-5. *Brunsia* sp. A. 4a, 5 – transverse views; 4b – transverse view of opposite side of fig. 4a; 1013 section, sample 1013-0.

Fig. 6-8. *Brunsiella* sp. A. 6, 7, 8a – transverse views; 8b – transverse view of opposite side of fig. 8a; 8c – longitudinal view. 1013 section, sample 1013-0.

Fig. 9. *Endothyra media* Waters 1928, a – transverse view, b – transverse view of opposite side of fig. a, c – longitudinal view; 1013 section, sample 1013-9.

Fig. 10. *Endothyra pauciloculata* Cushman and Waters 1930, a – transverse view, b – transverse view of opposite side of fig. a, c – longitudinal view; 1013 section, sample 1013-9.

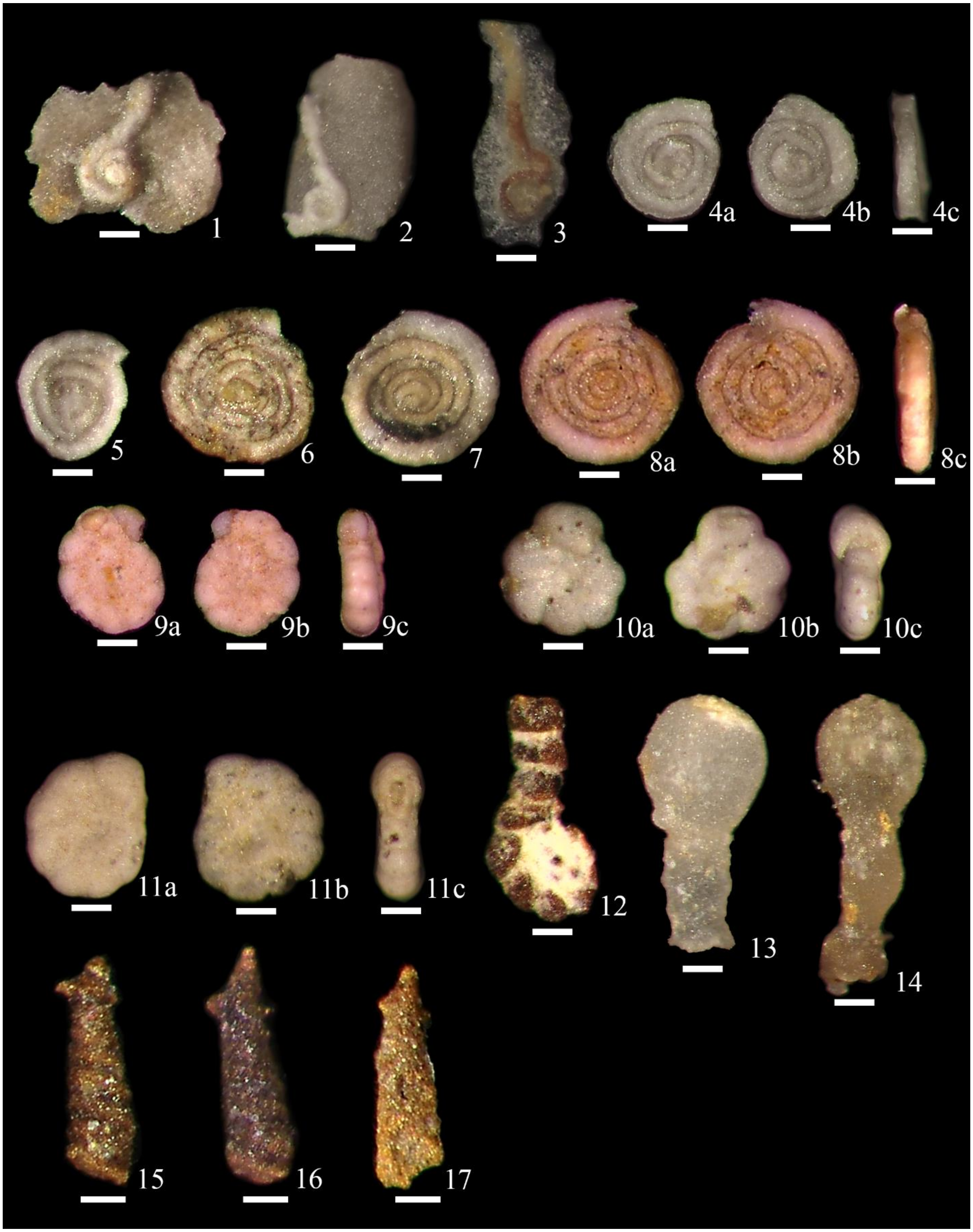
Fig. 11. *Endothyra watersi* Plummer 1930, a – transverse view, b – transverse view of opposite side of fig. a, c – longitudinal view; 1013 section, sample 1013-9.

Fig. 12. *Endothyranella* sp., axial view, 1013 section, sample 1013-9.

Fig. 13-14. *Tuberitina bulbacea* Galloway and Harlton 1928, axial views, 1013 section, sample 1013-6.

Fig. 15-17. *Pseudoalbaillella annulata* Ishiga 1984. 15, 16 – 1013 section, sample 1013-8; 17 – 1117 section, sample 1117-1.

## PLATE 10


1
2
3
4a
4b
4c
5
6
7
8a
8b
8c
9a
9b
9c
10a
10b
10c
11a
11b
11c
12
13
14
15
16
17

# Plate 11

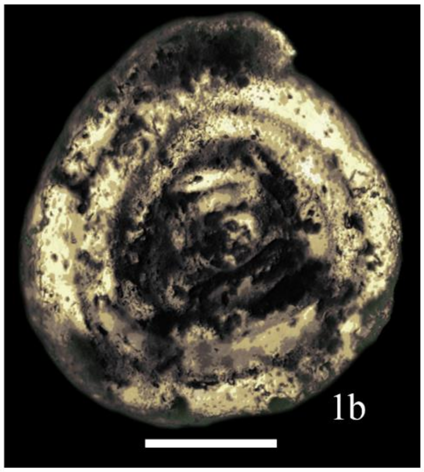
Calcareous small foraminifers from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian. Scale bar = 100 μm.

Fig. 1. *Brunsia* sp. A, transverse view, a – test in transmitted light, b – view in crossed nicols; 1013 section, sample 1013-0.

Fig. 2-4. *Brunsiella* sp. A, transverse views. 2, 3a, 4a – tests in transmitted light, 3b, 4b –view in crossed nicols; 1013 section, sample 1013-0.

# PLATE 11


1a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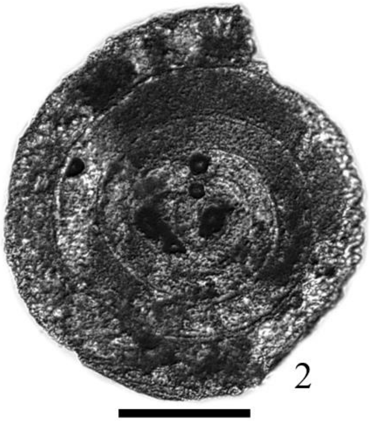
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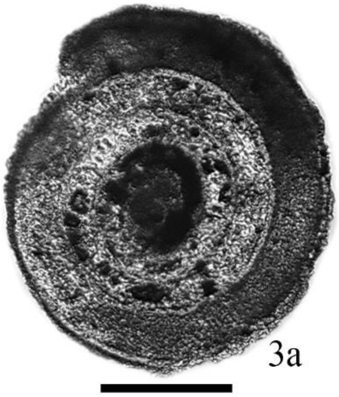
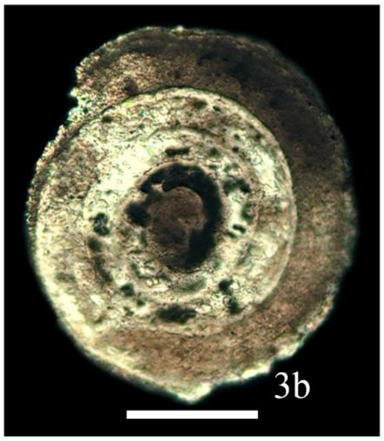

3a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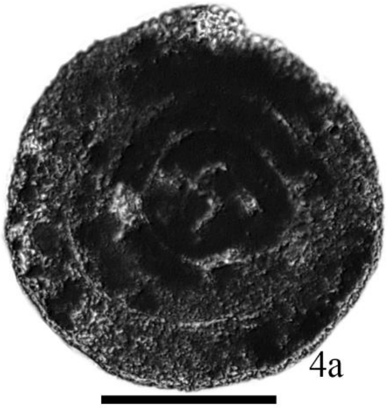

4a


4b

## 2-2: Fusulinids

To date, the work on Brazos River Valley fusulinids by Nestell (1989) is the most important publication with regards to dating the Salesville Formation. Nestell noted the presence of rare specimens of the fusulinid *Eowaeringella* cf. *E. joyitaensis* in calcareous siltstone immediately under the Devil’s Hollow Sandstone, which places the upper part of the Salesville Formation confidently in the early Missourian. However, Nestell only illustrated two specimens from a single locality, the same locality as the 1013 section of the present study. The fusulinids recovered in this study from the upper part of the Salesville Formation not only help support the findings of Nestell (1989), but also play a significant role in confidently correlating the two localities of the Salesville Formation.

### 2.2.1 Fusulinid Distribution in the Studied Sections

A total of nine fusulinid specimens of two genera were found at the two localities of this study (Figure 12). Four specimens of *Eowaeringella joyitaensis* Stewart 1968 were recovered from a crinoidal siltstone (sample 1013-0 of the 1013 section), located below the Devil's Hollow Sandstone Member. This sample came from the same Salesville Formation level used by Nestell (1989). Additionally, four specimens of *Fusiella texana* Stewart 1958 were found in the same sample. Specimens of *F. texana* from the Salesville Formation were also illustrated by Stewart (1958), but his specimens were recovered from the Dog Bend Limestone Member in the lower part of the Salesville Formation. The fusulinids found in the 1013 section are filled with a significant amount of an iron-rich mineral that is possibly limonite. Three specimens of *E. joyitaensis* were also recovered from the quartz rich sandy mudstone in the 1117 section (sample

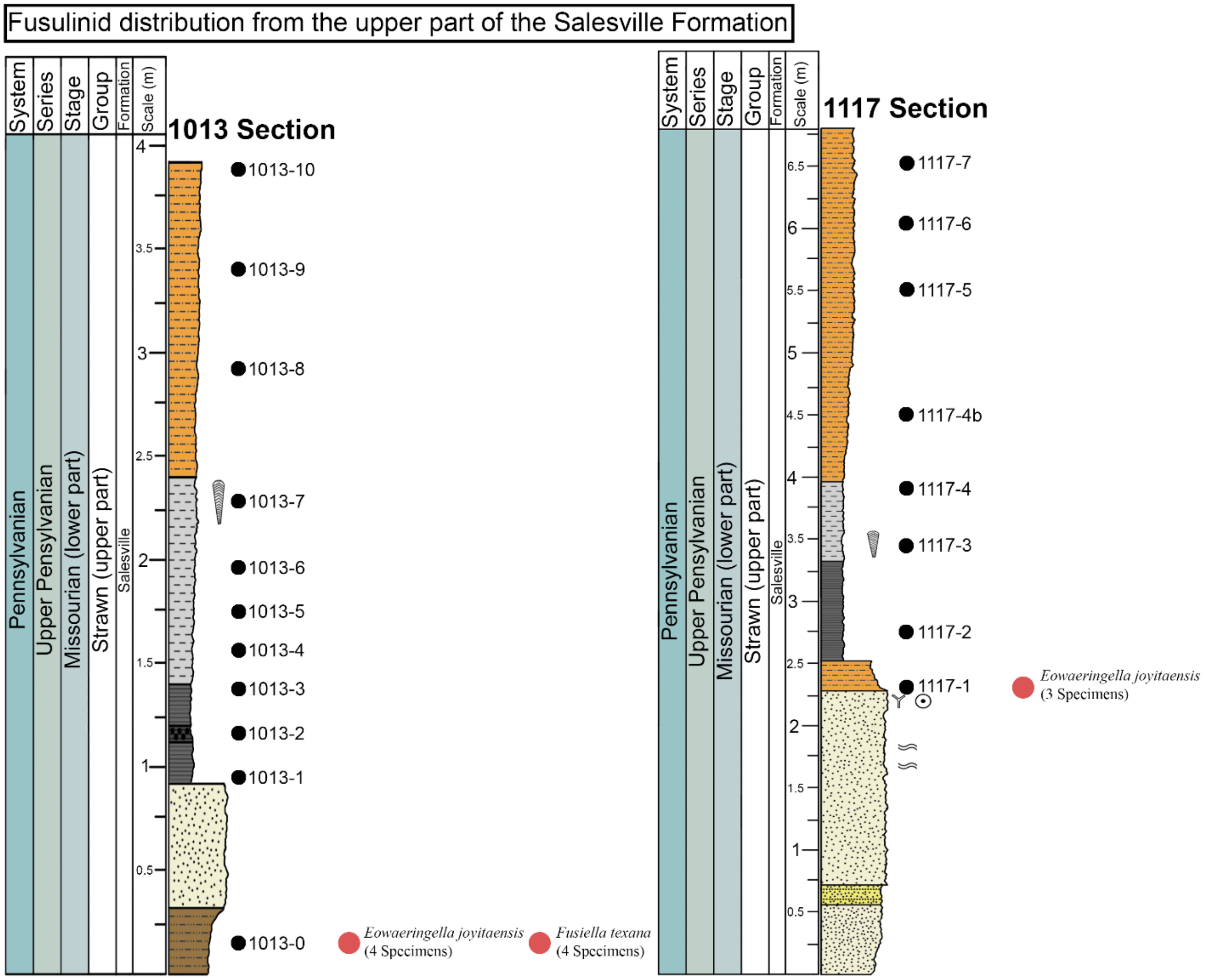


**Fig. 12.** A distribution of fusulinids from the upper part of the Salesville Formation from the 1013 and 1117 sections. Red dots indicate sampling level. Black dots indicate sampling level. Red dots indicate the level at which a fusulinid species was recovered. For lithologic and faunal symbols see Fig. 8.

1117-1), a locality from which fusulinids had not previously been reported. Fusulinids found in the 1117 section are recrystallized and their interior structure is not well preserved. The fusulinids in both localities are recovered from units that represent the deposits of shallow marine environments, supporting the convention that fusulinids are good indicators for the upper part of a transgressive system tract (Boardman et al. 1995).

### 2.2.2 Fusulinid Biostratigraphy

The fusulinid biostratigraphic zonation used herein is based on the work of Wahlman (2013). The base of the Eowaeringella Zone is defined as the first occurrence of the genus *Eowaeringella* and extends upwards until the first occurrence of the genus *Triticites* where it is followed by a series of more specific zones based on species of *Triticites* (Wahlman 2013). Below the Eowaeringella Zone is a series of zones in the Desmoinesian based on species of the Desmoinesian genus *Beedeina* (Wahlman 2013). The presence of the species *Eowaeringella joyitaensis*, as found in both localities of this study, allows for confident dating and correlation of the studied sections to other areas, because the genus *Eowaeringella* has a short biostratigraphic range restricted to the lower part of the Missourian in the Midcontinent and in North-Central Texas (Stewart 1968; Nestell 1989; Wahlman 2013). The Eowaeringella Zone does not extend down to the Desmoinesian-Missourian boundary in most locations because of a widespread fusulinid hiatus in the uppermost Desmoinesian and lowermost Missourian units across much of the Midcontinent (Wahlman 2019). In North-Central Texas, this fusulinid hiatus is represented by a lack of fusulinids between the Village Bend Limestone and the Dog Bend Limestone (Nestell 1989). The hiatus is also responsible for the Desmoinesian-Missourian boundary being defined by the first appearance of the conodont *Idiognathodus eccentricus* rather than a fusulinid (Barrick et al. 2013).

*Eowaeringella* typically does not occur with other major index genera, but there are a few known cases where this is not true. Stewart (1968) noted that *Eowaeringella* in New Mexico has been found to co-occur with the latest Desmoinesian species of *Beedeina*. Also, Wahlman (2013) noted that the upper range of *Eowaeringella* slightly overlaps the overlying zone of *Triticites* in the southern Midcontinent and in West Texas. Read and Nestell (2019) also reported a similar

*Eowaeringella* and *Triticites* co-occurring in Northeast Nevada. None of those cases apply to the upper part of the Salesville Formation in North-Central Texas because the highest reported occurrence of *Beedeina* in North-Central Texas is in the Capps Limestone of the East Mountain Formation, and the first reported occurrence of *Triticites* in North-Central Texas is in the Palo Pinto Formation (Nestell 1989). The fusulinid biostratigraphic evidence found herein agrees with Nestell (1989) in that the upper part of the Salesville Formation is lower Missourian, and that the Eowaeringella Zone can be assigned to the studied units.

### 2.2.3 Fusulinid Assemblage Correlation

Stewart (1968) included the Salesville Formation in a correlation based on *Eowaeringella* that spans 17 localities from Nevada, Wyoming, New Mexico, Texas, Oklahoma, Kansas, Iowa, and Mexico. Stewart's correlation utilized some outdated stratigraphy but remains an important correlation for the distribution of *Eowaeringella* in North America.

As a result of the extensive synthesis and re-interpretation of Pennsylvanian fusulinid studies by Wahlman (2013; 2019), correlation of the upper part of the Salesville with many other areas not difficult. Correlation of the Salesville Formation to the Midcontinent based on North-Central Texas cycles and Midcontinent cyclothems by Boardman and Heckel (1989) provides a frame of reference when correlating to the Midcontinent. In that study, Boardman and Heckel found that the upper part of the Salesville major cycle correlates with the Swope Limestone (Formation) in the Midcontinent, and that the core shale of the Salesville Shale correlates with the Hushpuckney Shale Member of the Swope Limestone. The Eowaeringella Zone in the Midcontinent (Kansas and adjacent areas), as presented by Wahlman (2013), ranges from the base of the Bethany Falls Limestone Member, where the first appearance of *Eowaeringella ultimata* is reported, to the Dennis Limestone-Cherryvale Shale contact. This zone explicitly excludes the Hushpuckney Shale Member, and because the specimens of *Eowaeringella* were found below the core shale of the Salesville Shale, there is a small but noticeable discrepancy. If the Midcontinent Eowaeringella Zone is taken at face-value then the upper part of the Salesville Formation would seem to correlate better with the Dennis cyclothem rather than the Swope Cyclothem. The discrepancy between the cycle correlation and the fusulinid correlation could be rectified in several ways, but it is proposed that *Eowaeringella* first occurs in North-Central Texas at a slightly earlier time than in the Midcontinent and that the correlation of the core shale of the Salesville Shale to the Hushpuckney Shale Member should be maintained as accurate.

Correlation to the Ardmore Basin, southern Oklahoma, is challenging due to the current state of the lithostratigraphic scheme used therein. Wahlman (2013) was able to apply a new fusulinid zonation scheme to the Ardmore Basin units using work of Waddell (1966). Specimens originally described by Waddel as *Wedekindellina? ardmorensis* are now considered to be *Eowaeringella ardmorensis*, and the presence of this species in the Confederate Limestone Member is what Wahlman (2013) used to define the Eowaeringella Zone in the Ardmore Basin. The Confederate Member is the lowest member of the Hoxbar Group and its base is considered to be the Desmoinesian-Missourian boundary in the Ardmore Basin. The next limestone member above the Confederate Member is the Crinerville Member with a shale unit in between (Waddell 1966). Wahlman (2013) assigned the first *Triticites* based zone to the Crinerville Member because it contains *T. tomlinsoni*. The Salesville Formation does not extend down to the Desmoinesian-Missourian boundary like the Confederate Member and does not contain the first occurrence of *Triticites* like the Crinerville Member, so the Salesville Formation correlates best with the shale unit between the Confederate and Crinerville Members. More precise work needs to be completed in the Ardmore Basin for a more accurate correlation.

Allen and Lucas (2018) recovered specimens of *Eowaeringella huecoensis* from the Tinajas Member of the Atrasado Formation (Desmoinesian to Wolfcampian) in the Manzanita Mountains of central New Mexico. The Tinajas Member overlies the Amado Member that contains the Desmoinesian-Missourian boundary. The specimens of *E. huecoensis* were found near the base of the Tinajas Member, whereas specimens of *Triticites* were found higher in the member. The Salesville Formation appears to correlate well with the lower part of the Tinajas Member between the base of the unit and the first occurence of *Triticites*.

The monograph concerning the fusulinds in the Big Hatchet Mountains, New Mexico by Wilde (2006) outlined fusulinid zones for the Horquilla Formation. Specimens belonging to seven species of *Eowaeringella* were recovered from the middle part of the Horquilla Formation and are one of the primary markers for the lower to middle Missourian zone MC-1, 2. *Eowaeringella* is also present in zone MC-3, 4, but that zone is considered to be middle to late Missourian. Specimens of *Triticites* and *Tumulotriticites* were also recovered from units assigned to zone MC-1, 2 with no interval illustrated where *Eowaeringella* exists before the appearance of *Triticites*, and thus breaking the trend whereby the first appearance of *Triticites* occurs well after the first appearance *Eowaeringella*. The upper part of the Salesville Formation would correlate best with the lower part of the zone MC-1, 2, but the existence of *Triticites* so low in the Horquilla Formation in the relative to the first occurrence *Eowaeringella* causes accuracy of this correlation to be questionable.

Read and Nestell (2019) recovered specimens of *Eowaeringella* from the upper part of the Ely Limestone (Desmoinesian to Missourian) and from the lower informal member of the

Riepe Spring Limestone (Missourian to Wolfcampian) in northeastern Nevada. The Desmoinesian-Missourian contact could not be confidently identified, but the presence of *Eowaeringella nevadaensis* in the upper part of the Ely Limestone gives an upper limit for the Desmoinesian-Missourian boundary. The species *Eowaeringella riepensis* was also recovered from the lower informal member of the Riepe Spring Limestone above the first occurrence of *Triticites* indicating that *E. riepensis* probably occurs near the end of the *Eowaeringella* range. Given the position of early *Triticites* in the Riepe Spring Limestone, the upper part of the Salesville Formation probably correlates best with the strata near the Ely Limestone-Riepe Spring Limestone contact.

### 2.2.4 Correlation of the Studied Sections

The assignment of the strata of the 1013 section to the Salesville Formation is well established due to the previous studies of Nestell (1989) and Barrick and Boardman (1989). However, the assertion that the strata of the 1117 section of the current study is part of the Salesville Formation has had very little published evidence prior to the present investigation. The finding of *Eowaeringella joyitaensis* in both of the sections is very important because the genus *Eowaeringella* is confined to the lower Missourian with short taxon ranges of the various species and is clear evidence that the 1013 and 1117 sections are of equivalent age. Similar conodont assemblages found in both sections, as discussed later, further provide evidence of an equivalent age.

### 2.2.5 Descriptions of Fusulinids

Descriptions of fusulinids are organized according to the classification of Rauser-Chernousova et al. (1996).

Superorder FUSULINOIDA Fursenko 1958; emend. Rauser-Chernousova et al. 1996

Order FUSULINIDA Fursenko 1958

Family FUSULINELLIDAE Staff and Wedekind 1910

Genus ***Eowaeringella*** Skinner and Wilde 1967

*Type species: Wedekindellina ultimata* Newell and Keroher 1937.

*Diagnosis* (after Read and Nestell 2019): Elongate fusiform test of small to moderate size with a small, spherical proloculus. Inflation of the equatorial region is typically minimal. Innermost volutions often difficult to observe due to small size and presence of secondary deposits. Chomata well-developed and moderately large, tapering poleward in many species. Chomata may be reduced or lacking in the outermost volutions. Septa nearly plane in the inner volutions and moderately to intensely fluted near the poles. Thin, three-layered spirotheca composed of tectum, diaphanotheca, and lower tectorium.

***Eowaeringella joyitaensis*** Stewart 1968

Plate 12, figures 1-3

*Eowaeringella joyitaensis* – STEWART 1968, pl. 5, figs. 9-12.

*Eowaeringella* cf. *E. joyitaensis* – NESTELL 1989, pl. 3, figs. 4-5.

*Description*: A species of *Eowaeringella* with a small, elongate-fusiform test with a length of 3.07 mm, and a diameter of 0.88 mm. The mature measured specimen has six volutions, and a form ratio of 3.49. Heights of the first though sixth volutions are 0.033, 0.037, 0.062, 0.081, 0.094, and 0.101 mm. The axis of coiling is straight, and the lateral slopes are usually concave, but sometimes closer to straight. The proloculus is small, spherical, with a diameter of 0.070 mm.

The thin, tripartite spirothecia is composed of tectum, diaphanotheca, and lower tectorium. Wall thickness for the proloculus though the sixth volution average 0.014, 0.020, 0.034, 0.025, 0.021, and 0.026 mm. The septa are weakly folded. The chomata are large, steep to overhanging, and commonly exceed three-quarters the height of the volution. The tunnel is narrow and highly irregular in its path with a tunnel angle that ranges from 17° to 24°.

*Material*: Rare, seven free specimens and one axial specimen studied in thin section.

*Remarks*: The specimen of *E. joyitaensis* from the upper part of the Salesville Formation is widely filled and somewhat replaced with an iron rich mineral, possibly limonite and obscuring some of the details of the internal structure. Despite the less than ideal preservation, accurate measurements could still be taken, and are all well within the ranges provided in the type description by Stewart (1968).

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, sample 1013-0, and 1117 section, sample 1117-1, North-Central Texas, USA (this study); Upper Pennsylvanian, Missourian, Madera Formation, Central New Mexico, USA (Stewart 1968).

### Order SCHUBERTELLIDA Skinner 1931

### Family SCHUBERTELLIDAE Skinner 1931

### Genus ***Fusiella*** Lee and Chen in Lee et al. 1930

*Type species: Fusiella typica* Lee and Chen 1930.

*Diagnosis* (after Loeblich and Tappan 1987): Test very small, elongate, early whorls discoidal and endothyroid, later with 90° change in axis of coiling and test fusiform, wall thin, of tectum, diaphanotheca, and thin outer tectorium, axial fillings prominent.

### ***Fusiella texana*** Stewart 1958

Plate 12, figures 4-6

*Fusiella texana* – STEWART 1958, pl. 137, figs. 13-14

*Description*: A species of *Fusiella* with a very small, fusiform to rhomboidal test. First two volutions form an ovate juvenarium with tight, endothyroid coiling. Later volutions have a coiling axis that is rotated 90° with respect to the initial coiling axis. The test ranges in length from 0.827 to 0.589 mm, averaging 0.708 mm. Test diameters range from 0.333 to 0.220 mm, averaging 0.277 mm. Mature specimens have at least four volutions. Form ratios range from 2.67 to 2.48. Axis of coiling is straight, and the lateral slopes are highly variable ranging from concave to convex. The proloculus is very small and spherical, with an outside diameter ranging from 0.053 to 0.045 mm. Heights of the first though fifth volutions average 0.049, 0.023, 0.023, 0.029, 0.031, and 0.036 mm.

The thin, tripartite spirothecia is composed of tectum, diaphanotheca, and lower tectorium. Wall thickness for the proloculus through the fifth volution average 0.009, 0.012, 0.012, 0.011, and 0.012 mm. The septa are linear to weakly folded, especially near the poles, but are greatly obscured by axial filling. The weakly developed chomata are board and low. The tunnel is narrow and straight with an angle that ranges from 14° to 18°.

*Material*: Rare, two free specimens and two axial specimens studied in thin sections.

*Remarks*: The specimens of *F. texana* recovered from the upper part of the Salesville Formation strongly resemble the holotype of the species described by Stewart (1958, p. 1071, pl. 137, figs. 14-15) and match well in measurements with the only notable difference being that of the tunnel angle. The tunnel angle of the holotype of *F. texana* is far wider than the tunnel angle of the specimens from the current study. The tunnel angle of the holotype may appear wider than it actually is due to the slightly oblique angle at which it was thin sectioned, and might account for some of the difference.

*Occurrence*: Upper Pennsylvanian, Missourian, upper part of the Salesville Formation, 1013 section, sample 1013-0, North-Central Texas, USA (this study); Upper Pennsylvanian, Missourian, lower part of the Salesville Formation, North-Central Texas, USA (Stewart 1968).

## Plate 12

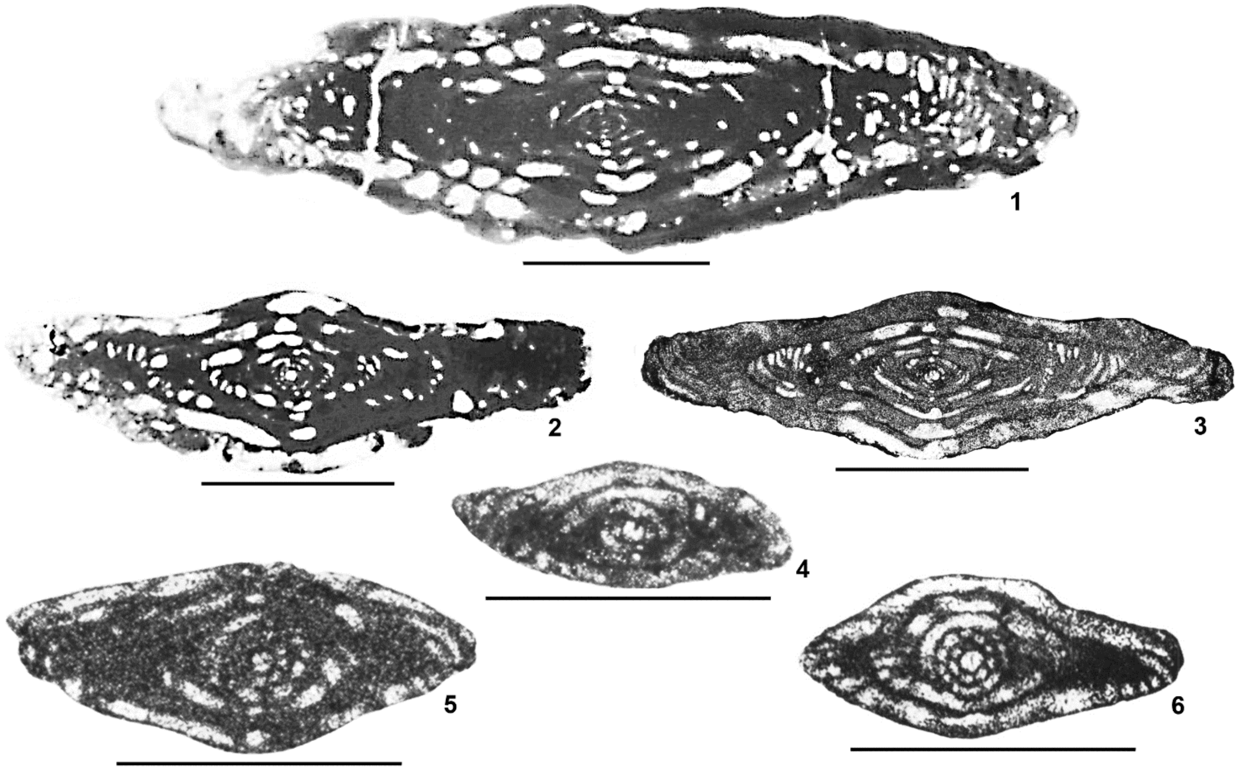
Fusulinids from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian.

Scale bar = 1 mm, except: figs. 4-6 = 500 μm.

Fig. 1-3. *Eowaeringella joyitaensis* Stewart 1968, axial sections. 1, 2 – TXPP4-1-1 (from Nestell 1989, pl. 3, figs. 3 and 4); 3 – 1013 section, sample 1013-0.

Fig. 4-6. *Fusiella texana* Stewart 1958, axial sections. 1, 2 – 1013 section, sample 1013-0; 3 – T-S-908 (from Stewart 1958, pl. 137, fig. 14).

## PLATE 12



## 2.3 Radiolaria

Missourian age radiolarians in North-Central Texas, in the Bridgeport area have been reported by Nestell and Blome (1996) in an abstract, where they mentioned the presence of *Albaillella* aff. *furcata* Won group, *Pseudoalbaillella annulata* Ishiga, *P*. cf. *chilensis* Ling and Forsythe, and very rare representatives of latentifistullids. Boardman et al. (1995) illustrated a single specimen of *Albaillella* sp. that should be assigned to the genus *Pseudoalbaillella* based on its morphology. Surprisingly, abundant radiolarians have been discovered in the upper part of the Salesville Formation in the current study.

### 2.3.1 Radiolarian Distribution in the Studied Sections

The radiolarian assemblage of the upper part of the Salesville Formation consists of only a single species, *Pseudoalbaillella annulata* Ishiga in Ishiga et al. 1984 (Pl. 10, figs. 15-17), that is present in both localities in six out of the 18 samples studied (Figure 13). All specimens of *P. annulata* are poorly preserved and are exclusively replaced with an unknown substance of orange to brown and sometimes black color. In the 1013 section no specimens of *P. annulata* were recovered in the lowest seven samples from 1013-0 to 1013-6. The first radiolarians appeared in sample 1013-7 but are rather uncommon. In sample 1013-8, among all microfossils, the species *P. annulata* is the most abundant. The species is absent in sample 1013-9 but reappeared abundantly again in sample 1013-10.

In the 1117 section, the species *P. annulata* is absent in the two lowest samples, 1117-1 and 1117-2 but in samples 1117-3 and 1117-4 rare specimens of the species are present. *Pseudoalbaillella annulata* is absent again in sample 1013-4b but reappeared abundantly in sample 1117-5. In this sample, as in sample 1013-8 of the other locality, *P. annulata* is the most abundant among the microfossil association. *P. annulata* is also absent in sample 1117-6, but is common in the highest sample, 1117-7.

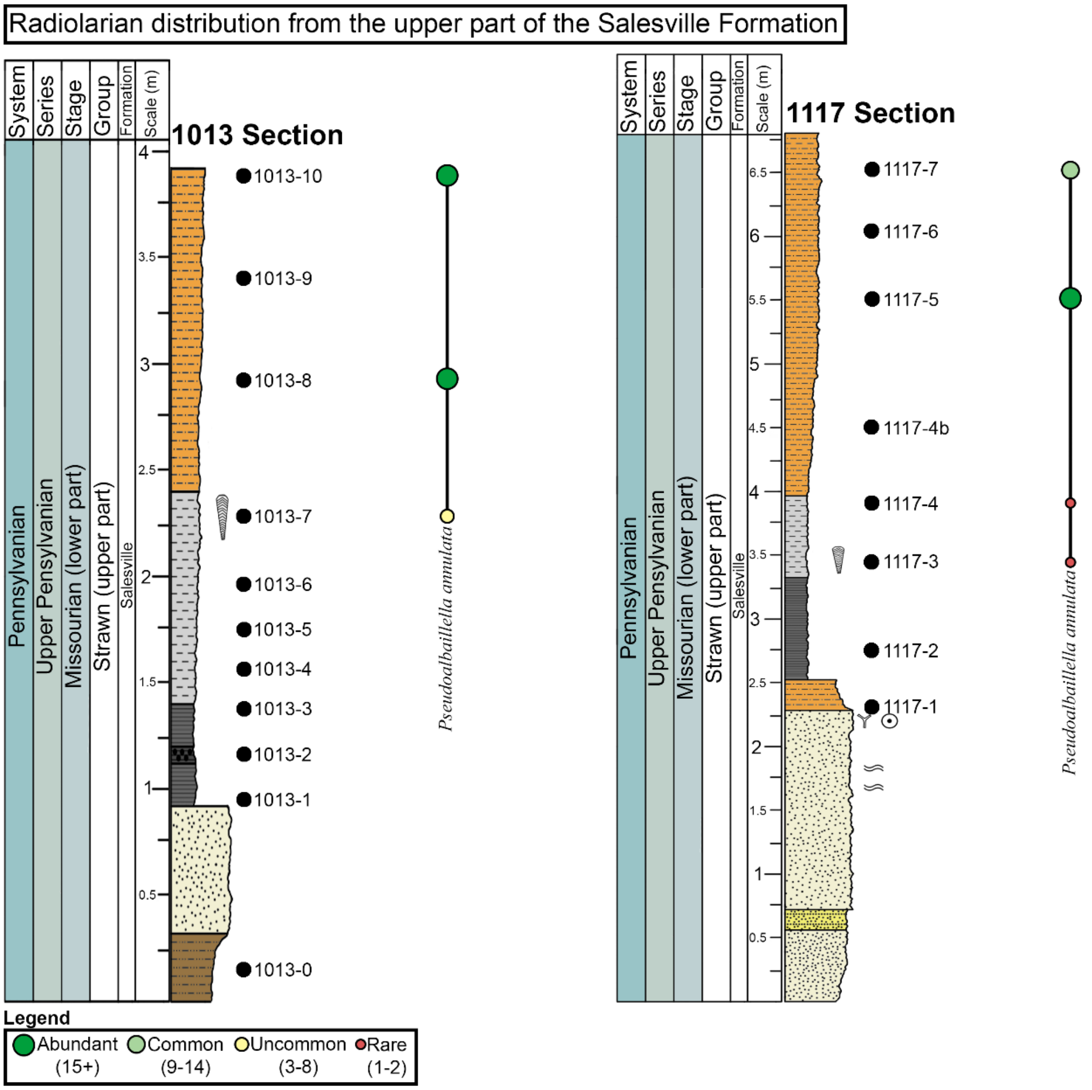


**Fig. 13.** A figure showing the distribution and abundance of the radiolarian species *P. annulata* Ishiga in Ishiga et al. (1984) in the 1013 and 1117 sections. Black dots indicate sampling level. Colored dots show where a species was recovered, and the color of the dot corresponds to the number of specimens found as defined in the legend. For lithologic and faunal symbols see Fig. 8.

Of all the microfossils observed in this study, radiolarians are the most erratic in their distribution, appearing in great numbers in one sample and absent in the following sample. The occurrence of poorly preserved *P. annulata* in the upper part of the Salesville Formation in the shallower parts of the cycle cannot be easily explained. It appears that no radiolarians are present in the deeper water black shale units at both localities.

### 2.3.2 Radiolarian Biostratigraphy

The species *Pseudoalbaillella annulata* has been found in several regions such as Japan, Chile, and in the Midcontinent of North America with a global biostratigraphic range of the Atokan to the Wolfcampian (Ishiga et al. 1984; Ling and Forthsythe 1987; Pope et al. 2011; Nestell et al. 2012). However, *P. annulata* has only been reported in North America from the Excello Shale Member of the Mouse Creek Formation (middle to upper Desmoinesian) in south-central Iowa (Pope et al. 2011; Nestell et al. 2012). Nestell et al. (2012) proposed the *Pseudoalbaillella desmoinesiensis-P. annulata* radiolarian assemblage zone that ranged from the middle to the upper Desmoinesian. The presence of *P. annulata* in the upper part of the Salesville Formation suggests that the range of the *Pseudoalbaillella desmoinesiensis-P. annulata* radiolarian assemblage zone should be extended to the lower Missourian.

## **2.4 Ostracodes**

Since the conclusion of Melnyk and Maddocks' North-Central Texas ostracode zonation study in 1988, there have been very few studies on Pennsylvanian ostracodes despite the potential biostratigraphic utility presented in their study. The ostracode assemblage of the upper part of the Salesville Formation is found to be far more diverse than initially anticipated. The diversity of ostracodes provided a surprising amount of utility with respect to relative dating and depositional environment interpretation.

### 2.4.1 Ostracode Distribution in Studied Sections

A total of 19 species of ostracodes of 15 genera are recovered from the two localities of the current study (Pl. 13-16), and 15 out the 18 samples taken contained ostracodes, but their diversity and concentration varied greatly from sample to sample (Table 3). The lowest sample, sample 1013-0, from the 1013 section exhibited greatest amount diversity and concentration with 16 species recovered (Figure 14). The most abundant species of sample 1013-0 is *Amphissites centronotus* (Ulrich and Bassler 1906) with all other species being rare to uncommon. Samples 1013-1, 1013-2, and 1013-4 contained no ostracodes. Only one poorly preserved specimen of *Pseudobythocypris* cf. *P. palopintoensis* (Coryell and Sample 1932) is present in sample 1013-3. These samples lacking ostracodes coincide with the black shale and lowermost grey shale intervals in the 1013 section. A resurgence of ostracodes is in sample 1013-5. Specimens of *P.* cf. *P. palopintoensis* were abundant in this sample with rare specimens of *Mammoides* cf. *M. mammilata* Bradfield 1935 and *Pseudobythocypris* cf. *P. subpedifromis* (Bradfield 1935) also present. The ostracodes become scarce once again in sample 1013-6, but in samples 1013-7 and 1013-8 ostracodes increase in abundance again with many *Pseudobythocypris* specimens along with less common specimens of *Bairdia beedei* Ulrich and Bassler 1906, and *M.* cf. *M. mammilata*. Sample 1013-9 is unique due to a sudden abundance of *Seminolites truncatus* Coryell 1928 along with rare *Moorites knighti* (Wilson 1933) and *M. percultus* Hoare 1998.

| Species Name: \ Sample Numer: | Ostracode distribution from the upper part of the Salesville Formation | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1013-0 | 1013-1 | 1013-2 | 1013-3 | 1013-4 | 1013-5 | 1013-6 | 1013-7 | 1013-8 | 1013-9 | 1013-10 | 1117-1 | 1117-2 | 1117-3 | 1117-4 | 1117-4b | 1117-5 | 1117-6 | 1117-7 |
| *Hollinella warthini* | R | | | | | | | | | | R | | | U | R | R | R | | R |
| *Mammoides* cf *M. mammillata* | | | | | | R | | R | | | | R | | | | | | | |
| *Healdia simplex* | U | | | | | | | | | | | | | | | | | | |
| *Seminolites truncatus* | | | | | | | | | | A | R | | | | | R | R | R | |
| *Pseudobythocypris* cf *P. palopintoensis* | U | | | R | | A | R | C | A | C | U | R | U | A | U | C | A | U | U |
| *Pseudobythocypris* cf *P. pediformis* | R | | | | | R | | R | R | R | U | U | | R | R | U | C | R | R |
| *Pseudobythocypris subpedifromis* | R | | | | | | | R | | R | R | | R | R | | | U | | |
| *Bairdia sp.* | R | | | | | | | | | | | | | | | | | | |
| *Bairdia beedei* | U | | | | | | | | R | | | | | | R | | R | | |
| *Bairdiacypris deloi* | U | | | | | | | | | | | | | | | | | | |
| *Orthobairdia oklahomaensis* | R | | | | | | | | | | | R | | | | | | | |
| *Paraparchites wapanuckaensis* | R | | | | | | | | | | | | | | | | | | |
| *Cavellina sp.* | R | | | | | | | | | | | | | | | | | | |
| *Cytherella sp.* | | | | | | | | | | | R | | | | | | | | |
| *Amphissites centronotus* | A | | | | | | | | | | | R | | | | | | | |
| *Kegelites cooperi* | R | | | | | | | | | | | | | | | | | | |
| *Schleesha pinguis* | R | | | | | | | | | | | | | | | | | | |
| *Moorites knighti* | U | | | | | | | | | R | | | | | | R | | | |
| *Moorites percultus* | U | | | | | | | | | U | | | | | R | | | | |

**Table 3.** A table showing the ostracode distribution and abundance in the 1013 and 1117 sections. Abundance is based on number of specimens found in an average of 10 grams of material. A = abundant, 15+ specimens; C = common, 14-9 specimens; U = uncommon, 8-3 specimens; R = rare, 1 or 2 specimens.

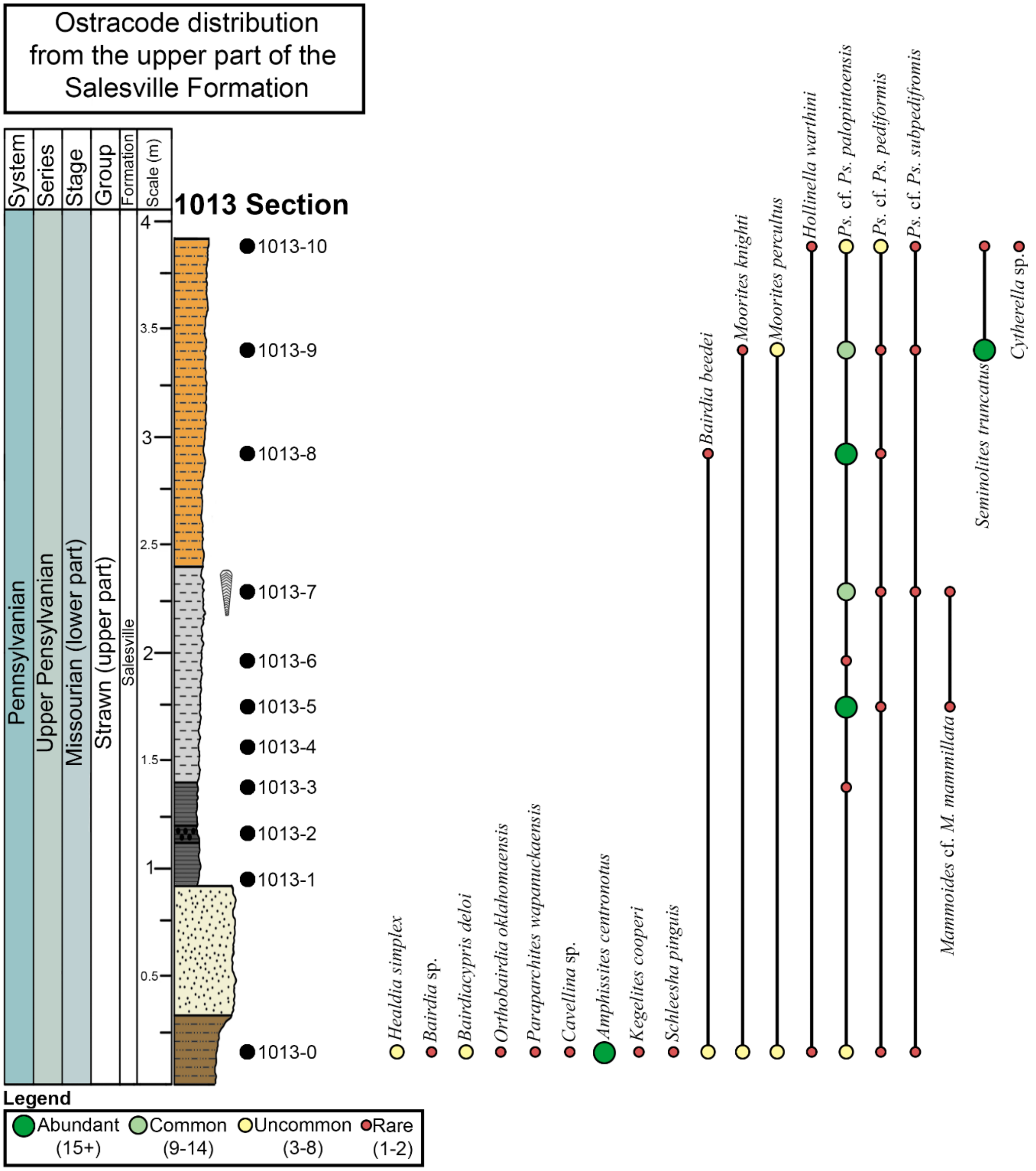


**Fig. 14.** A figure showing the ostracode distribution and abundance in the 1013 section. Black dots indicate sampling level. Colored dots show where a species was recovered, and the color of the dot corresponds to the number of specimens found as defined in the legend. For lithologic and faunal symbols see Fig. 8.

The highest sample at the 1013 section, sample 1013-10, exhibits moderate diversity, but specimens are mostly rare.

The 1117 section contains a lower diversity ostracode fauna, but the species that are present were more consistent (Figure 15). The lowest sample from the 1117 section, sample 1117-1, contains six species of ostracodes, including *M.* cf. *M. mammilata,* but most of the species were rare. The following sample, 1117-2, is in stark contrast because it contains only uncommon specimens of *P.* cf. *P. palopintoensis* and rare specimens of *P. pediformis* marking the lowest diversity sample in the 1117 section. Samples 1117-3 to 1117-5 contain roughly the same ostracode species consisting of abundant specimens of *P.* cf. *P. palopintoensis* and less common *B. beedei*, *Hollinella warthini* Cooper 1946, *P.* cf. *P. subpedifromis,* and *P. pediformis*. Sample 1117-4 contains a decreased amount of ostracodes compared to samples 1117-3 and 1117-5. The highest two samples in the section, 1117-6 and 1117-7, contains far fewer ostracodes than the preceding four samples and is much less diverse, containing only four species: *Hollinella warthini*, *Seminolites truncatus*, *Pseudobythocypris* cf *P. palopintoensis,* and *P.* cf *P. pediformis*.

The abundance and diversity of ostracodes in the upper part of the Salesville Formation closely follows the lithology in both sections. Samples taken from units that represent the deposits of shallow marine environments such as 1013-0 and 1013-10 contain the highest diversity of ostracodes. Samples taken from black to dark grey shale units, samples 1013-1 to 1013-4 and 1117-2, are almost devoid of ostracodes. The samples taken in the gray shale, 1013-5, 1013-6, 1013-7, 1117-3, and variegated mudstone, 1013-8, 1117-4, 1117-4b, 1117-5, units contains a low diversity, but a high abundance of just a few species, especially of the genus

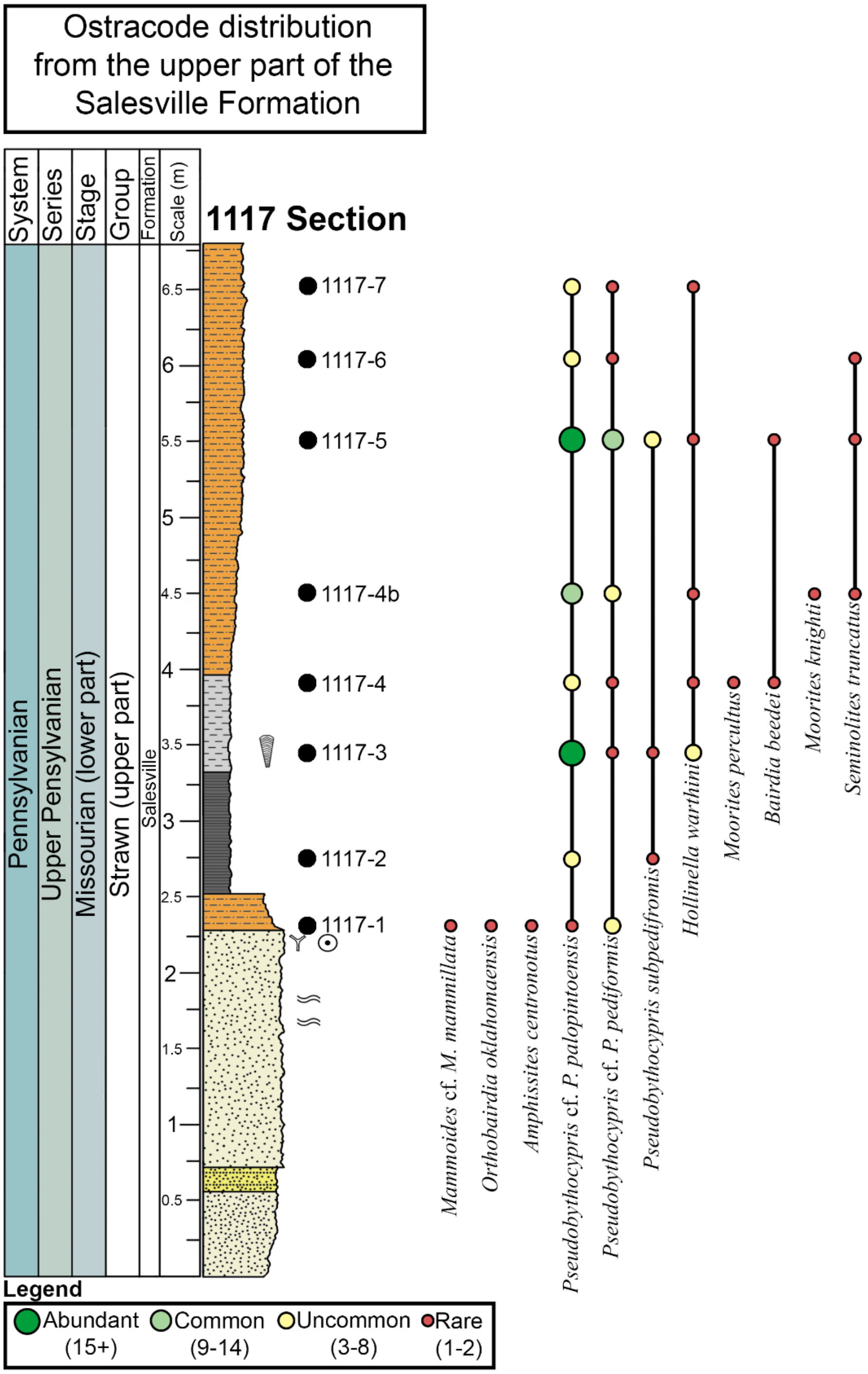


**Fig. 15.** A figure showing the ostracode distribution and abundance in the 1117 section. Black dots indicate sampling level. Colored dots show where a species was recovered, and the color of the dot corresponds to the number of specimens found as defined in the legend. For lithologic and faunal symbols see Fig. 8.

*Pseudobythocypris*. The evidence presented herein suggests that ostracodes can be useful for determining depositional environments.

### 2.4.2 Ostracode Biostratigraphy

Pennsylvanian ostracode zonation in North-Central Texas is based on the scheme presented in Melnyk and Maddocks (1988). These authors assigned five zones to the Pennsylvanian strata of North-Central Texas with names based on the index species for each zone.

The lowest zone described by Melnyk and Maddocks (1988) is the Bairdia whitesidei Zone, and its lower boundary is defined by the first appearance of the ostracode species *Bairdia whitesidei* Bradfield 1935. According to these authors, it ranges from the base of the Dickerson Formation (now the Dickerson Shale Member of the Lazy Bend Formation) to the middle part of the Mineral Wells Formation (now the East Mountain and Salesville Formations). The second ostracode zone is the Kegelites dattonensis Zone, and its lower boundary is defined by the first appearance of the ostracode species *Kegelites dattonensis* (Harlton 1927b). The Kegelites dattonensis Zone ranges from the middle part of the Mineral Wells Formation to the lower part of the Wolf Mountain Formation (now the Wolf Mountain Shale Member of the Graford Formation). The Bairdia whitesidei Zone- Kegelites dattonensis Zone boundary given as the “middle part of the Mineral Wells Formation” is imprecise and it is presently unclear whether this boundary is in the East Mountain or Salesville Formations (Melnyk and Maddocks 1988, p. 25). The third Pennsylvanian ostracode zone is the Bairdiacypris acetalata Zone, and its lower boundary is defined by the first appearance of the ostracode species *Bairdiacypris acetalata*

(Coryell and Billings 1932). The Bairdiacypris acetalata Zone ranges from the lower part of the Wolf Mountain Formation to the middle part of the Colony Creek Formation (now the Colony Creek Shale Member of the Caddo Creek Formation). The fourth and fifth ostracode zones described by Melnyk and Maddocks are the Waylandella spinosa Zone (Pennsylvanian) and the Cryptobairdia forakerensis Zone, the lower part of which is Pennsylvanian and rest of it belongs to the Lower Permian. These zones are beyond the scope of this study.

Several of the ostracode species recovered in the studied sections provide usefulness in the biostratigraphic aspect of the study (Figures 14, 15, 16). The most interesting is the discovery of the species *Mammoides mammilata* (herein identified as *Mammoides* cf. *M. mammilata* due to poor preservation) in the upper part of the Salesville Formation. This taxon had been described by Melnyk and Maddocks as “a good marker for the base of it [the Bairdiacypris acetalata Interval-Zone]” and was seemingly only found in the Wolf Mountain Shale with a very short range (Melnyk and Maddocks 1988, p. 28). *M. mammilata* was originally described from Oklahoma in the Crinerville Limestone Member of the Hoxbar Formation (now Hoxbar Group), which is middle-upper Missourian (Bradfield 1935). However, the Salesville Formation lies well below the Wolf Mountain Shale of Texas that approximately correlates to the middle part of the Hoxbar Group, leading to the conclusion that *M. mammilata* has a longer range than previously known. Despite this, *M. mammilata* seems to be a good indicator for the Missourian. The discovery of the species *Seminolites truncatus* and *Pseudobythocypris subpedifromis* in the upper part Salesville Formation mark their lowest recorded occurrence in North-Central Texas, though they have been described from the upper part of the Desmoinesian in Oklahoma (Coryell 1928; Bradfield 1935). Other notable species found in the upper part of the Salesville Formation are *Healdia simplex* Roundy 1926 and *Bairdia beedei* that first occurrence is possibly near the East

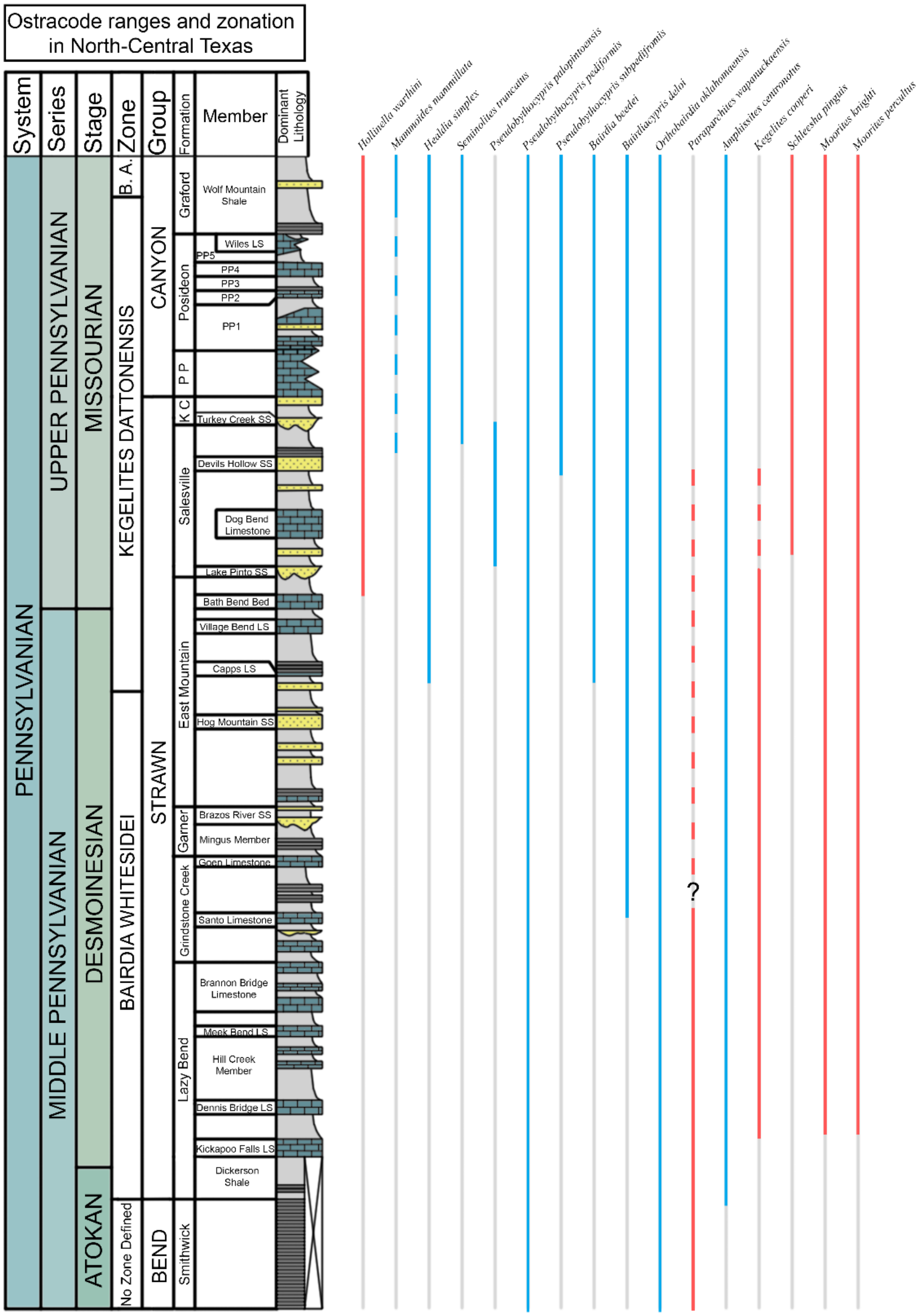


**Fig. 16.** A figure showing Desmoinesian-lower Missourian zonation and biostratigraphic ranges for ostracodes in North-Central Texas (after Melnyk and Maddocks 1988). The solid blue lines represent ranges known in North-Central Texas. The solid red lines represent ranges defined outside of North-Central Texas. Dashed lines, both red and blue, represent proposed extensions to the known ranges by the presence of the corresponding species in the Salesville Formation.

Mountain Formation-Salesville Formation boundary based on the ranges given by Melnyk and Maddocks (1988). The species *Pseudobythocypris palopintoensis* is one of the only ostracode species described directly from the Salesville Formation with the type locality given at the Mineral Wells shale pit (now commonly known as the Mineral Wells Fossil Pit), which is thought to belong to the lower part of the Salesville Formation (Coryell and Sample 1932). Previously, *P. palopintoensis* was present only in the lower part of the Salesville Formation and now is found in the upper part of the Salesville Formation of this study. It seems that this species may have a very limited range and primarily occurs in the Salesville Formation.

Several species that have only been described outside of North-Central Texas were recovered from the upper part of the Salesville Formation and have been useful biostratigraphcally as well (Figure 16). The species *Hollinella warthini* has been described from the uppermost part of the Desmoinesian in Oklahoma (Warthin 1930) and Illinois (Cooper 1946) as well as throughout the Missourian in the Appalachian Basin (Christopher et al. 1990). The species *Shleesha pinguis* was originally described by Ulrich and Bassler (1906) from the lower Permian Cottonwood Limestone in Kansas, but, according to Echols and Creath (1959) and Christopher et al. (1990), its range extends down to the lower part of the Missourian and is found in the upper part of the Salesville Formation. The species *Paraparchites wapanuckaensis* was originally described by Harlton (1928b) from the Wapanucka Limestone (now the Wapanucka Formation) of Oklahoma, and its age is late Morrowan. Cooper (1946) reported this species from Desmoinesian units of Illinois. The presence of *P. wapanuckaensis* in the upper part of the Salesville Formation suggests this species has a relatively long range from the Morrowan to the Missourian.

The presence of the species *Moorites knighti* and *M. percultus* is interesting because Hoare (1998) restudied the genus *Moorites* and its species *M. minutus*, and he proposed to separate this species into several species including *M. knighti* and *M. percultus*. The long biostratigraphic range of *M. minutus s. l.* has been changed and now *M. minutus s. s.* now ranges from the upper Atokan to the middle Desmoinesian. According to Hoare (1998), the range of both species *M. knighti* and *M. percultus* is from the lower Desmoinesian to the lower Virgilian.

The other species identified in the upper part of the Salesville Formation such as *Pseudobythocypris pediformis*, *Bairdiacypris deloi* Bradfield 1935*,* *Orthobairdia oklahomaensis* (Harlton 1927b), and *Amphissites centronotus* have much longer ranges and are characteristic of Desmoinesian-Missourian age faunas (Melnyk and Maddocks 1988).

No species-indexes of the ostracode zones of Melnyk and Maddocks (1988) are found in the upper part of the Salesville Formation. However, there are several species (*Bairdia beedei*, *Healdia simplex*, and *Pseudobythocypris subpedifromis*), mentioned by Melnyk and Maddocks (1988), that occur for the first time in the Kegelites dattonensis Zone. Based on the presence of these species, the upper part of the Salesville Formation is assigned to this zone.

According to Melnyk and Maddocks (1988), the first appearance of the species *Mammoides mammilata* is near the base of the Bairdiacypris acetalata Zone in the middle Missourian. However, the discovery of this species in the upper part of the Salesville Formation of the lower Missourian suggests its first appearance is earlier in the middle part of the Kegelites dattonensis Zone in the early Missourian. It is also proposed that the species *Pseudobythocypris palopintoensis* is another species that is useful for marking the middle part of the Kegelites dattonensis Zone in North-Central Texas.

### 2.4.3 Ostracode Assemblage Correlation

The correlation of the ostracode fauna from the upper part of the Salesville Formation appears to be best correlated with a recent study of Missourian ostracodes in the Appalachian Basin (Christopher et al. 1990). These authors reported several species from the Brush Creek Limestone, the lowermost unit of the Conemaugh Group (Missourian to Virgilian) that are also found in the upper part of the Salesville Formation: *Hollinella warthini*, *Amphissites centronotus*, and *Shleesha pinguis*. The species *Kegelites cooperi* is also reported from the Appalachian Basin, but its biostratigraphic range terminates at the Desmoinesian-Missourian boundary just prior the Brush Creek Limestone. Christopher et al. (1990) assigned the Kegelites dattonensis Zone to the Missourian and Virgilian units of the Conemaugh Group, which is also assigned to the upper part of the Salesville Formation. Later Hoare (1998), a co-author of the 1990 study, published another paper on the Pennsylvanian ostracodes from the Appalachian Basin, focusing on the genus *Moorities*. Hoare reported *Moorites knighti* and *M. percultus* (both species found in the upper part of the Salesville Formation) in the Brush Creek Limestone, but assigned in his paper to a part of the Glenshaw Formation (within the Conemaugh Group). Based on the ostracode assemblages, it is proposed herein that the upper part of the Salesville Formation correlates well with the Brush Creek Limestone of the Glenshaw Formation of the Appalachian Basin.

## Plate 13

Ostracodes from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian.
Scale bar = 200 μm, except: figs. 2 – 11b, 13 = 125 μm; 12, 14a – 14c = 300 μm

Fig. 1. *Hollinella warthini* Cooper 1946, right valve, 1013 section, sample 1013-0.

Fig. 2-3. *Mammoides* cf *M. mammillata* Bradfield 1935, 2 – right valve oblique view to show the topology of the carapace, 3 – left valve; 1013 section, sample 1013-5.

Fig. 4-6. *Seminolites truncatus* Coryell 1928. 4, 5a – left valve; 5b, 6 – right valve; 5c – dorsal view; 1013 section, sample 1013-9.

Fig. 7-8. *Pseudobythocypris* cf *P. palopintoensis* (Coryell and Sample 1932). 7 – left valve; 8 – right valve; 1013 section, sample 1013-5.

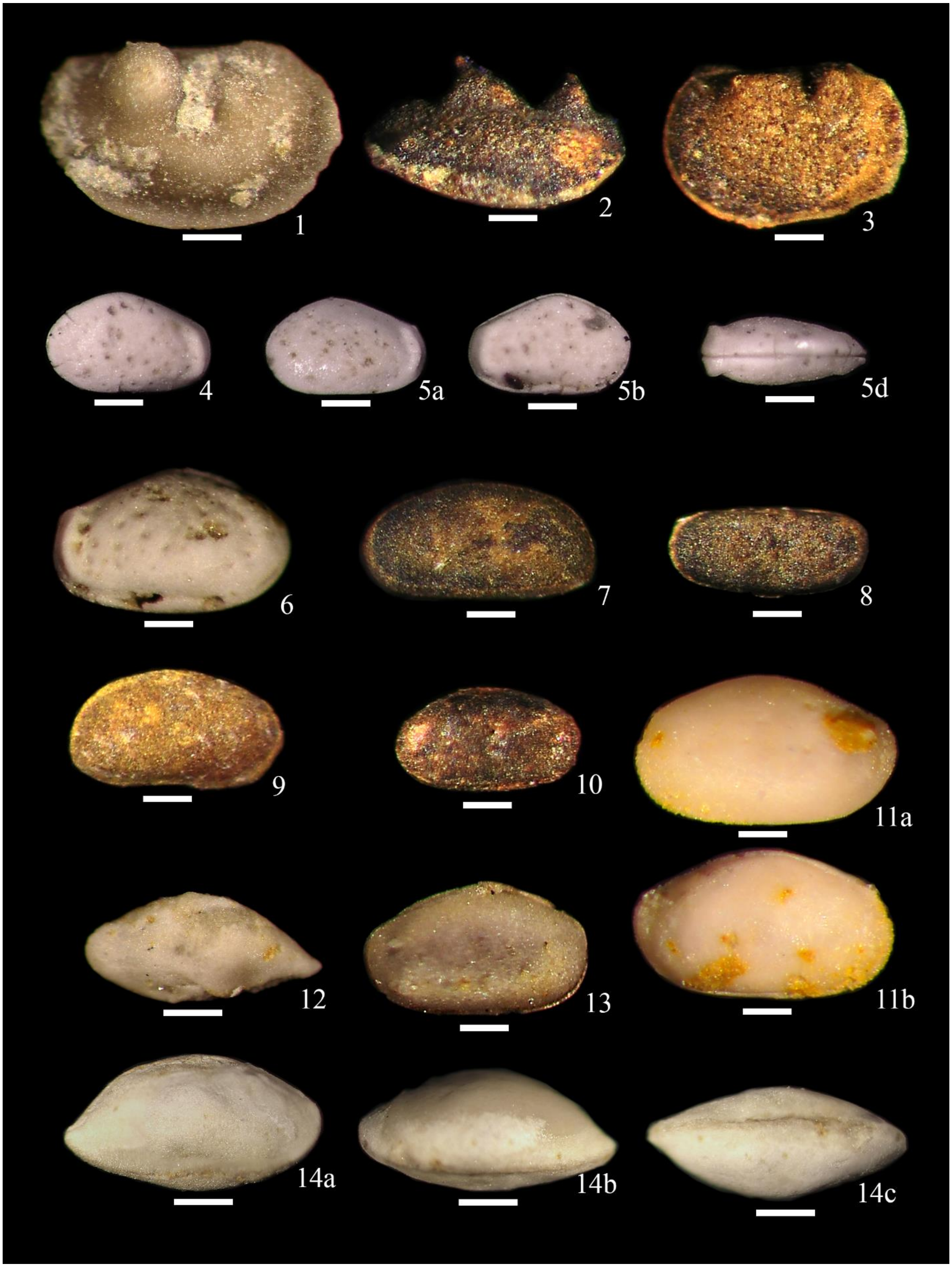
Fig. 9-10. *Pseudobythocypris* cf *P. pediformis* (Bradfield 1935). 9 - right valve; 10 – left valve; 1013 section, sample 1013-7.

Fig. 11, 13. *Pseudobythocypris subpedifromis* (Bradfield 1935). 11a – left valve; 11b, 13 – right valve. 1013 section, 11 – sample 1013-10, 13 – sample 1013-9.

Fig. 12. *Bairdia* sp., left valve, 1013 section, sample 1013-0.

Fig. 14. *Bairdia beedei* Ulrich and Bassler 1906, a – right valve, b – oblique view of the left valve, c – dorsal view; 1013 section, sample 1013-0.

## PLATE 13



# Plate 14

Ostracodes from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian.
Scale bar = 125 µm, except: fig. 2 = 300 µm; figs. 3-5 = 200 µm; fig. 9 = 100 µm.

Fig. 1. *Bairdiacypris deloi* Bradfield 1935, left valve, 1013 section, sample 1013-0.

Fig. 2. *Orthobairdia oklahomaensis* (Harlton 1927), right valve, 1013 section, sample 1013-0.

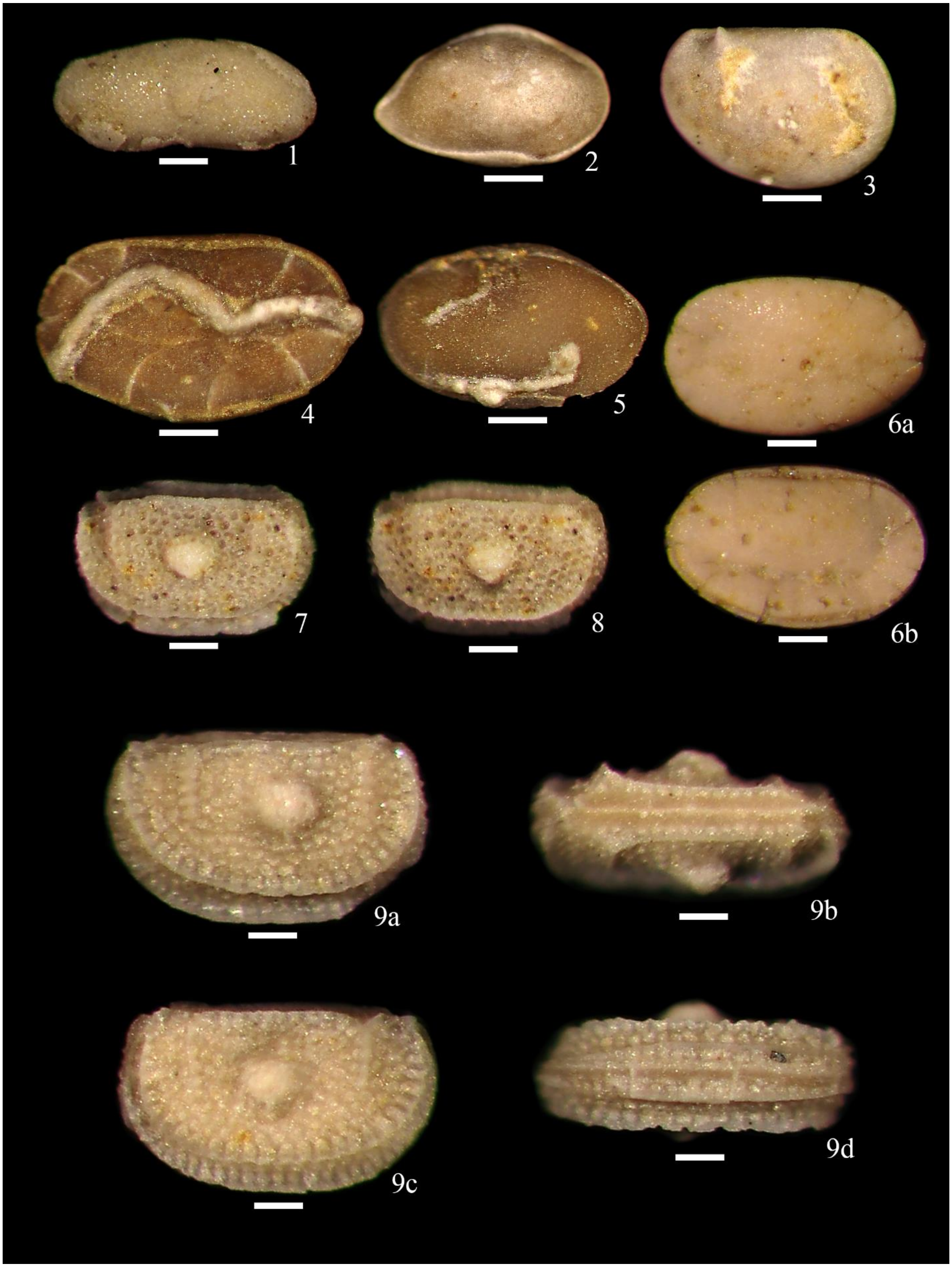
Fig. 3. *Paraparchites wapanuckaensis* Harlton 1928, right valve, 1013 section, sample 1013-0.

Fig. 4-5. *Cavellina* sp. 4 – left valve with an attached foraminifer, 5 – right valve at a slightly oblique angle with an attached foraminifer; 1013 section, sample 1013-0.

Fig. 6. *Cytherella* sp., a – right valve, b – left valve; 1013 section, sample 1013-10.

Fig. 7-9. *Amphissites centronotus* (Ulrich and Bassler 1906). 7, 9c – right valves, 8, 9a – left valves, 9b – dorsal view, 9d – ventral view; 1013 section, sample 1013-0.

# PLATE 14



# Plate 15

Ostracodes from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian.
Scale bar = 125 μm.

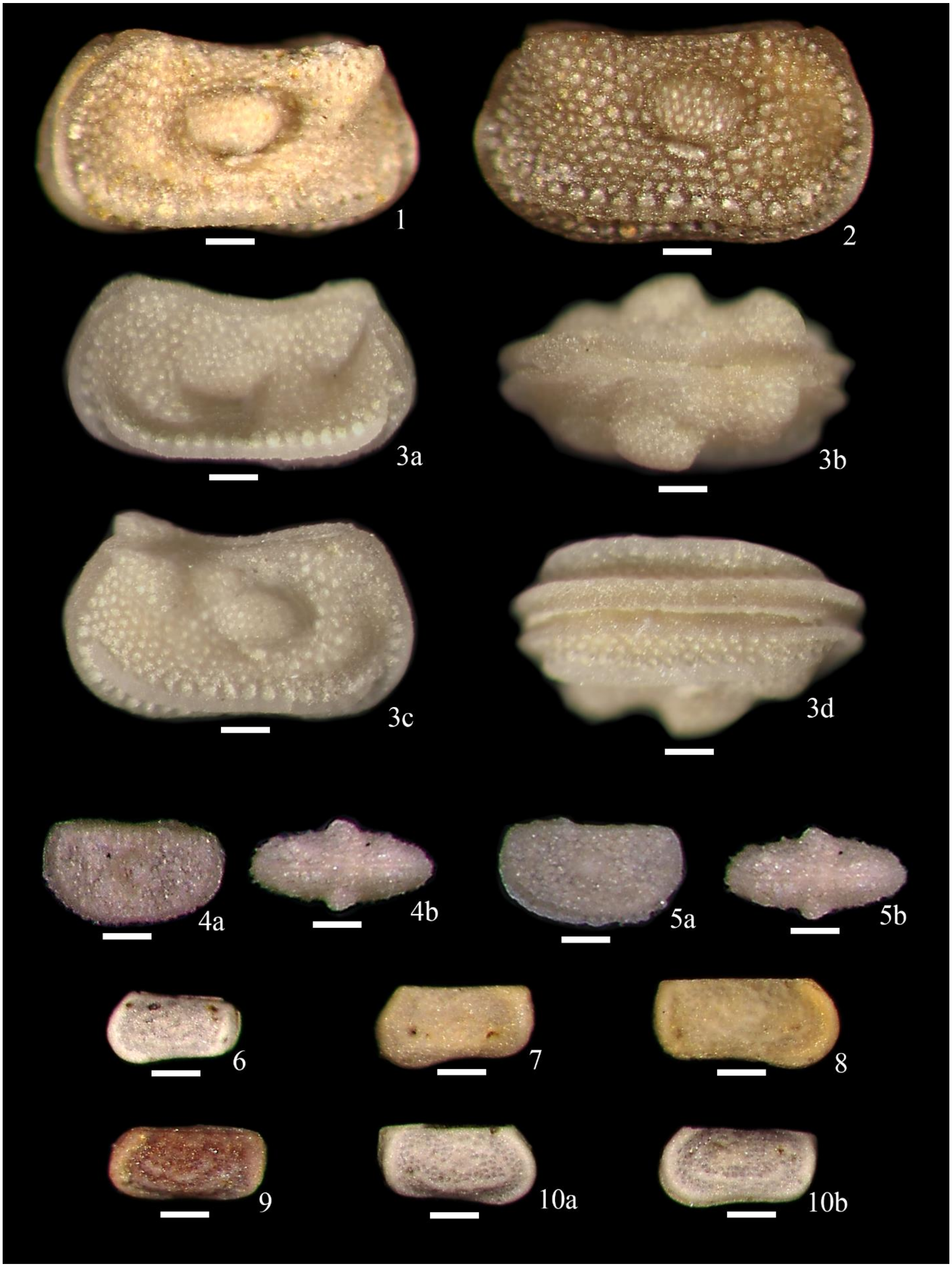
Fig. 1-3. *Kegelites cooperi* Christopher et al. 1990. 1, 3c – left valves, 2, 3a – right valves, 3b – dorsal view, 3d – ventral view; 1013 section, sample 1013-0.

Fig. 4-5. *Schleesha pinguis* (Ulrich and Bassler 1906). 4a – left valve, 4b, 5b – ventral views, 5a – right valve; 1013 section, sample 1013-0.

Fig. 6-8. *Moorites knighti* (Wilson 1933). 6, 7 – left valves, 8 – right valve; 1013 section, sample 1013-9.

Fig. 9-10. *Moorites percultus* Hoare 1998. 9, 10b – left valves, 9a – right valve; 1013 section, 9 – sample 1013-0, 10 – sample 1013-9.

PLATE 15



# Plate 16

Ostracodes from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian.
Scale bar = 100 µm, except: fig. 5b = 75 µm.

Fig. 1. *Mammoides* cf *M. mammillata* Bradfield 1935, right valve, 1013 section, sample 1013-5.

Fig. 2. *Healdia simplex* Roundy 1926, right valve, 1013 section, sample 1013-0.

Fig. 3. *Bairdia beedei* Ulrich and Bassler 1906, right valve, 1013 section, sample 1013-0.

Fig. 4. *Bairdiacypris deloi* Bradfield 1935, right valve, 1013 section, sample 1013-0.

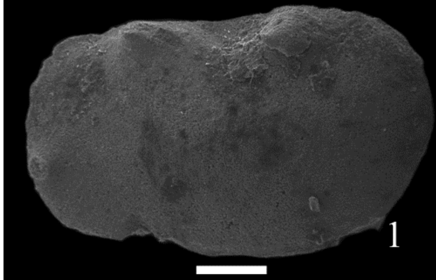
Fig. 5-7. *Amphissites centronotus* (Ulrich and Bassler 1906). 5a – right valve, 5b – enlarged view of the surface of the carapace, 6 – ventral view, 7 – dorsal view. 1013 section, sample 1013-0.

Fig. 8. *Kegelites cooperi* Christopher, Hoare and Sturgeon 1990, left valve, 1013 section, sample 1013-0.

Fig. 9. *Schleesha pinguis* (Ulrich and Bassler 1906), left valve, 1013 section, sample 1013-0.

Fig. 10. *Moorites percultus* Hoare 1998, left valve, 1013 section, sample 1013-0.

# PLATE 16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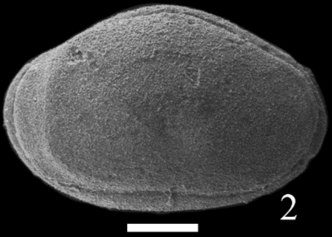
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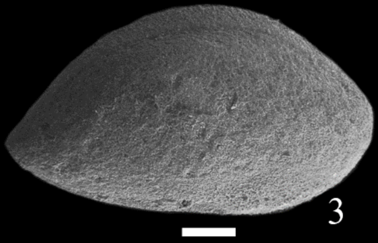
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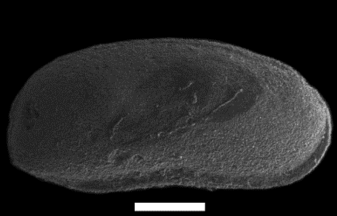
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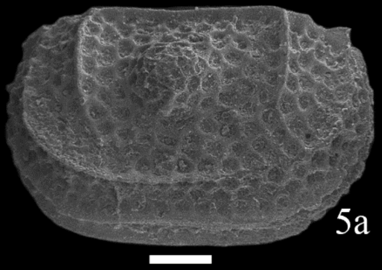
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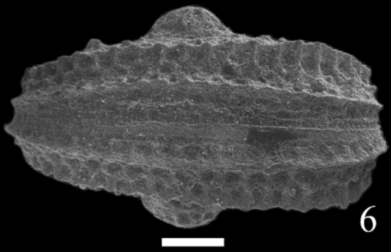
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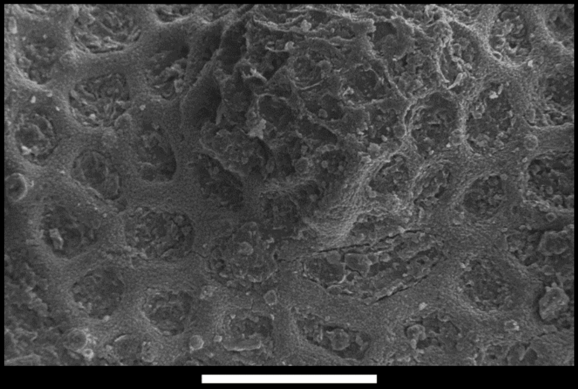
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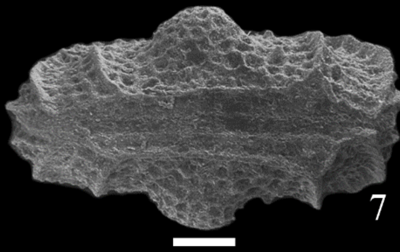
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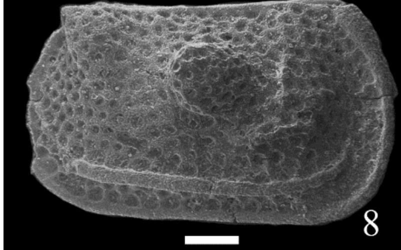
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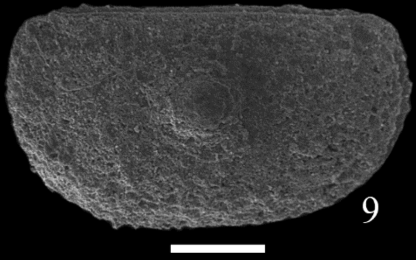
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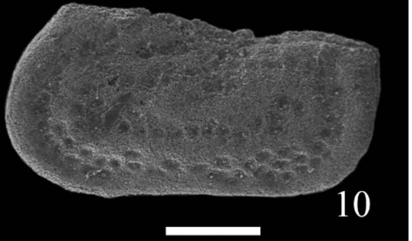
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## 2.5 Conodonts

The conodont fauna of the upper part of the Salesville Formation was most recently studied by Rosscoe and Bader (2010) who reported three species of conodonts (*Idiognathodus cancellosus, I. sulciferus,* and *I. swadei*) in the upper part of the Salesville Formation and confirmed the correlation of the Hushpuckney Shale (Swope Cyclothem) to the upper part of the Salesville Formation (upper Salesville major cycle) as proposed by Boardman and Heckel (1989). The conodont assemblage idenifed herein is found to be far more diverse than previously reported and provides a great deal of biostratrigraphic utility. Rosscoe (2008) and Rosscoe and Barrick (2013) have provided recent detailed descriptions for most of the conodont species identified in the current study.

### 2.5.1 Conodont Distribution in the Studied Sections

A total of 14 species of conodonts of two genera are recovered from the two localities of the current study (Pl. 17-18), and 14 out the 18 samples taken contain conodont elements. The conodont elements are approximately a 2 on the conodont alteration index of Epstein et al. (1977) and vary in preservation with the majority of specimens possessing broken blades (Table 4). The lowest sample taken at the 1013 section, sample 1013-0, contains no conodonts (Figure 17). Above the Devil's Hollow Sandstone in sample 1013-1, six species of *Idiognathodus* are found: *Idiognathodus biliratus* (Gunnell 1933), *I. cancellosus* Ellison 1941, *I. heckeli* Rosscoe and Barrick 2013, *I. eccentricus* (Gunnell 1933), *I. gemmiformis* Gunnell 1933, and *I. turbatus* Rosscoe and Barrick 2009. In sample 1013-2, the relative abundance of conodonts increases with *I. cancellosus* and *I. eccentricus* being present in more common numbers. All species present in

| Sample Numer: / Species Name: | Conodont distribution from the upper part of the Salesville Formation | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1013-0 | 1013-1 | 1013-2 | 1013-3 | 1013-4 | 1013-5 | 1013-6 | 1013-7 | 1013-8 | 1013-9 | 1013-10 | 1117-1 | 1117-2 | 1117-3 | 1117-4 | 1117-4b | 1117-5 | 1117-6 | 1117-7 |
| *Gondolella bella* | | | | | | | U | | | U | | U | U | | | | | | |
| *Gondolella* sp. 2 | | | | | | | R | | | | | | | R | | | | | |
| *Idiognathodus swadei* | | | | | | R | | | | | | | | | | | | | |
| *Idiognathodus sulciferus* | | | R | | U | U | R | | | | | U | R | | | | | | R |
| *Idiognathodus turbatus* | | R | R | R | R | R | | | | | | R | | | | | | | |
| *Idiognathodus eccentricus* | | U | C | U | **A** | U | U | | | R | | **A** | U | U | R | | | R | R |
| *Idiognathodus cancellosus* | | R | C | U | U | R | | | | | R | U | | U | R | | | U | |
| *Idiognathodus* aff. *cancellosus* | | | | | | R | | | | | | R | | | | | | | |
| *Idiognathodus biliratus* | | R | R | R | U | U | R | | | | | U | | R | | | | R | |
| *Idiognathodus pseudocarinatus* | | | R | | U | | | | | | | | | | | | | | |
| *Idiognathodus gemmiformis* | | U | U | R | R | R | | | | | | C | U | | | | | | |
| *Idiognathodus heckeli* | | R | U | R | U | R | | | | | | U | R | | | | | | |
| *Idiognathodus* cf. *I. neverovensis* | | | R | | | | | | | | | R | | | | | | | |
| *Idiognathodus* cf. *I. corrugatus* | | | R | R | U | U | R | | | | | R | | R | | | | R | |

**Table 4.** A table showing the conodont distribution and abundance in the 1013 and 1117 sections. Abundance is based on number of specimens found in an average of 10 grams of material. A = abundant, 15+ specimens; C = common, 14-9 specimens; U = uncommon, 8-3 specimens; R = rare, 1 or 2 specimens.

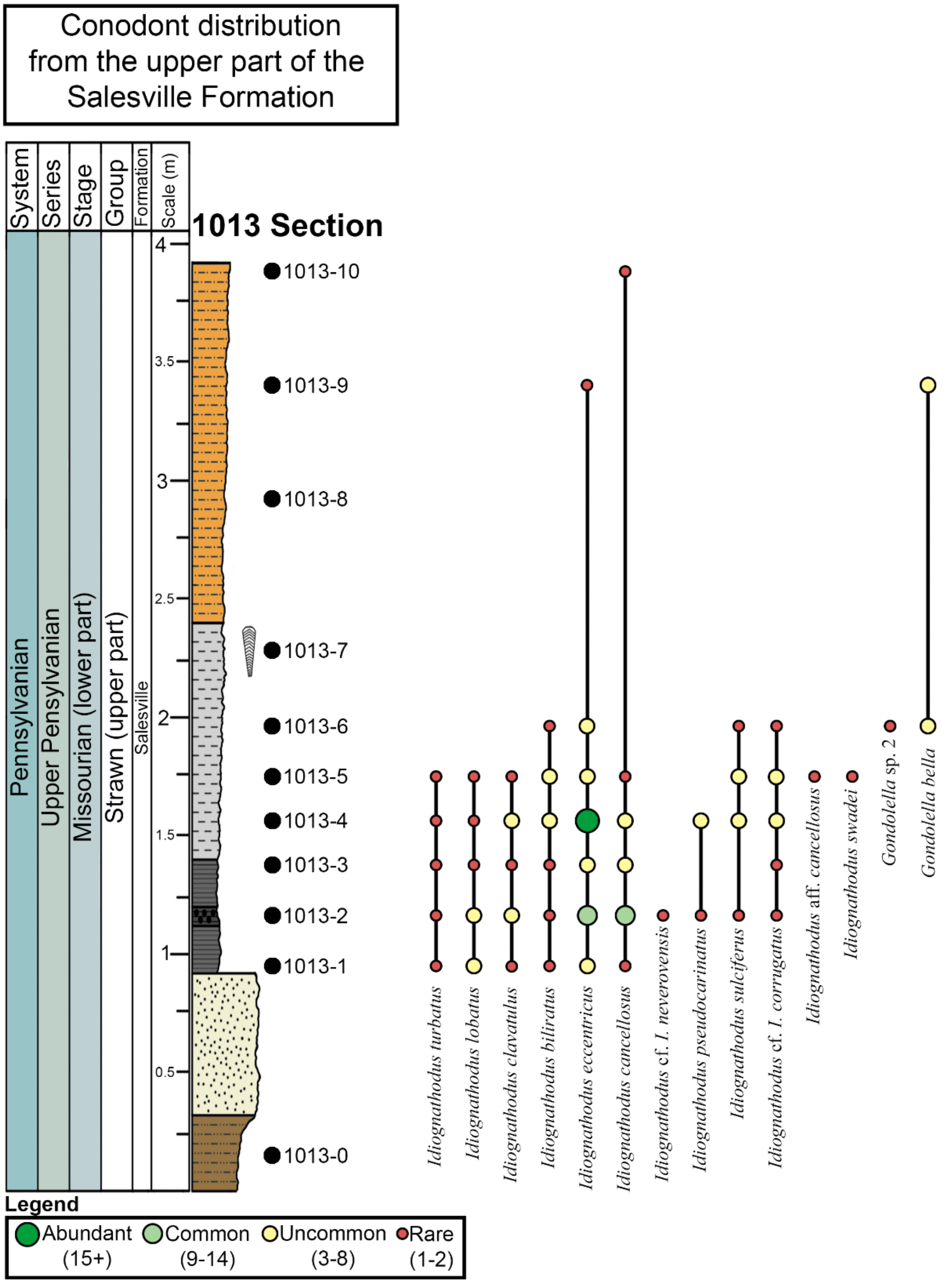


**Fig. 17.** A figure showing the conodont distribution and abundance in the 1013 section. Black dots indicate sampling level. Colored dots show where a species was recovered, and the color of the dot corresponds to the number of specimens found as defined in the legend. For lithologic and faunal symbols see Fig. 8.

sample 1013-1 are also recovered in sample 1013-2 along with *I.* cf. *I. neverovensis* (Goreva and Alekseev 2006) and *I. sulciferus* Gunnell 1933. The diversity and abundance of conodonts decrease in sample 1013-3. Sample 1013-4 contains the highest diversity and abundance of conodonts in the section with abundant numbers of *I. eccentricus*. Conodont abundance steadily declines over the next two samples, 1013-5 and 1013-6. A notable exception is the brief first appearance of the genus *Gondolella*, with the species *G. bella* Stauffer and Plummer 1932 and *G.* sp. 2 present in sample 1013-6. The uppermost four samples, 1013-7, 1013-8, 1013-9, 1013-10, in the section contain just a few specimens or were devoid of conodont elements entirely.

The lowest sample in the 1117 section, sample 1117-1, contains abundant conodont elements and was the most diverse sample in this study with 11 species present (Figure 18). In 1117-1 there are abundant *I. eccentricus* and common numbers of *I. gemmiformis* with lesser numbers of the other species that included *G. bella*. The abundance and diversity of conodonts sharply declines over the next three samples from 1117-2 to 1117-4, before becoming completely absent in samples 1117-4b and 1117-5. Five species of conodonts, *Idiognathodus sulciferus, I. eccentricus, I. cancellosus, I. biliratus,* and *I.* sp., reappear in rare to uncommon numbers in the two uppermost samples, 1117-6 and 1117-7.

Conodont elements of the genus *Idiognathodus* recovered from the upper part of the Salesville Formation are confined almost entirely to the black to gray shale units in both localities and would seem to be good indicators for open shelf environments. Conodont elements are also found in limited but not insignificant numbers higher than the black and gray shale units in the 1117 section in samples 1117-6 and 1117-7. *Gondolella* is a genus that is generally considered to be a deeper-water genus as compared to *Idiognathodus,* but specimens of *Gondolella* from the current study are found primarily in the variegated and non-fissile mudstone

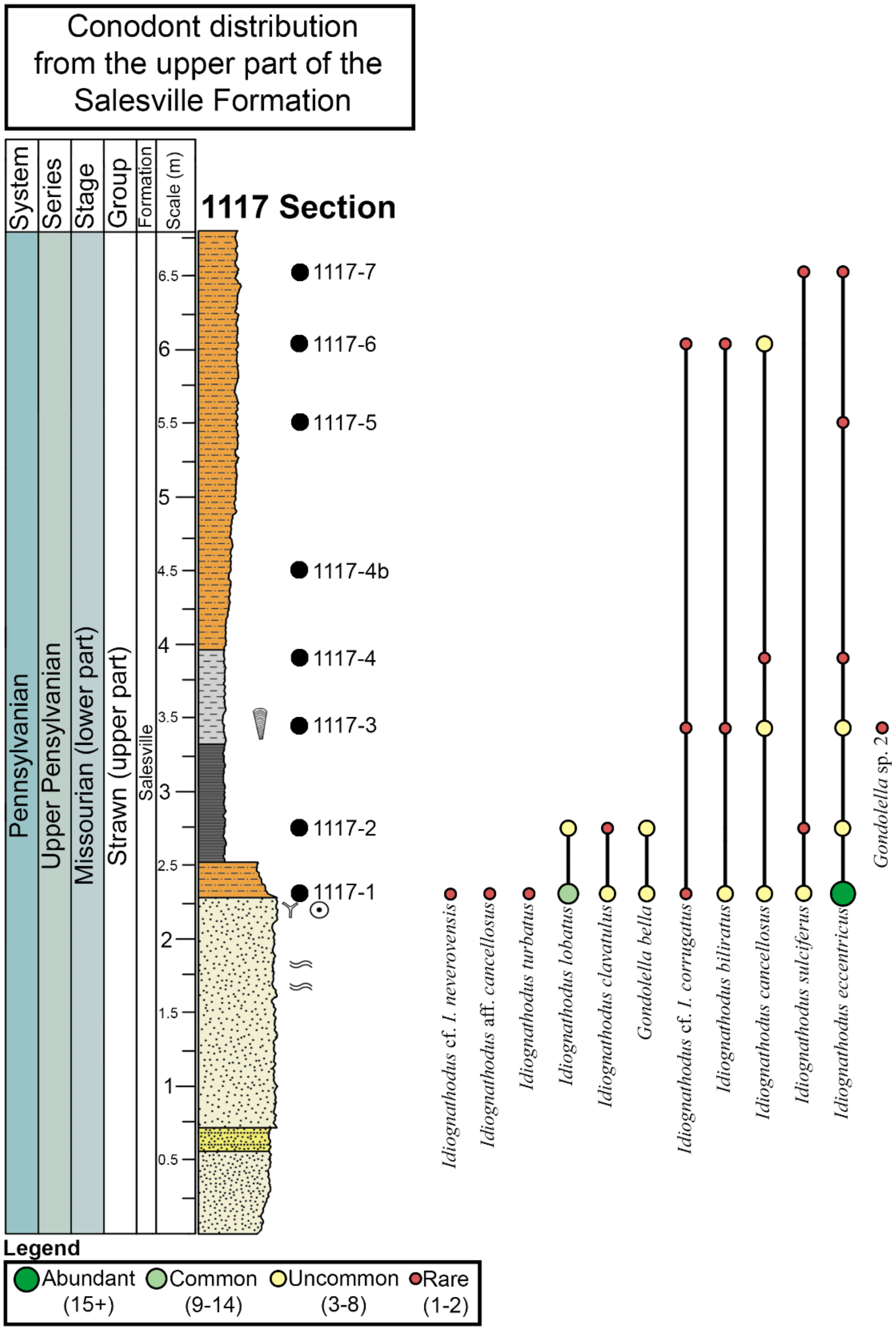


**Fig. 18.** A figure showing the conodont distribution and abundance in the 1117 section. Black dots indicate sampling level. Colored dots show where a species was recovered, and the color of the dot corresponds to the number of specimens found as defined in the legend. For lithologic and faunal symbols see Fig. 8.

units (samples 1013-6, 1013-6, 1117-1) and were not present in most of the black shale units (Boardman et al. 1996). However, specimens were found in small numbers across only five samples, which is not a large enough sample size to justify their use as a depositional environment indicator in this case.

### 2.5.2 Conodont Biostratigraphy

The conodont biostratigraphic zonation used herein is based on the zonation of Pennsylvanian Midcontinent conodonts of Barrick et al. (2013). In that study, Barrick et al. already assigned the upper part of the Salesville Formation to the Idiognathodus cancellosus Zone based on the previous conodont work of Barrick and Boardman (1989). The current study attempts to recreate that assignment while integrating new data.

Using the cyclothem to North-Texas cycle correlation by Boardman and Heckel (1989), it was determined that the upper part of the Salesville Formation was correlated with Swope Cyclothem in the Midcontinent and, according to Barrick et al. (2013), the Swope Cyclothem was assigned to the Idiognathodus cancellosus Zone. Using that logic, the Idiognathodus cancellosus Zone is the most likely candidate for correlation with the upper part of the Salesville Formation. The base of the Idiognathodus cancellosus Zone is defined by the first appearance of the species *Idiognathodus cancellosus* and extends upwards until the first appearance of *Idiognathodus confragus* (Barrick et al. 2013). Barrick and Boardman (1989) illustrated that the first appearance of *I. cancellosus* (then known as *Streptognathodus cancellosus*) is in the Dog Bend Limestone Member in the lower part of the Salesville Formation. The biostratigraphic zone above the Idiognathodus cancellosus Zone is the Idiognathodus confragus Zone marked by the first appearance of the species *I. confragus*; which is not found in the current study and the first occurrence of the species in Barrick and Boardman (1989) was in the Palo Pinto Formation. Barrick et al. (2013) also illustrated the ranges of many other Midcontinent conodont species and showed that the species *I. sulciferus*, *I. eccentricus*, and *I. turbatus* Rosscoe and Barrick 2009 are present in the Idiognathodus cancellosus Zone, all of which are recovered from both localities in the current study.

Hogancamp and Barrick (2018) presented an expanded figure of Midcontinent conodont ranges that included many more species. The species *I. corrugatus* Gunnell 1933 and *I. biliratus* were both included in the Idiognathodus cancellosus Zone by Hogancamp and Barrick and are found in the current study. Three other species recovered from the upper part of the Salesville Formation, *I. neverovensis* (Goreva and Alekseev 2006) (herein identified as *Idiognathodus* cf. *I. neverovensis* due to poor preservation), *I. heckeli*, and *I. pseudocarinatus* are all reported from the Hushpuckney Shale Member in the Midcontinent, part of the Swope Cyclothem and the Idiognathodus cancellosus Zone, by Rosscoe and Barrick (2013).

Both species of *Gondolella* recovered in the current study are only previously known from Desmoinesian units. *G. bella* was previously only known from the East Mountain Formation, just below the Salesville Formation, and *G.* sp. 2 (in the sense of Roy 2017) was previously only known from the Excello Shale Member of the Mouse Creek Formation. Due to their presence in the upper part of the Salesville Formation it is proposed that the range of both species should be extended upwards to the lower part of the Missourian.

The conodont assemblage recovered from the upper part of the Salesville Formation in the current study supports the assignment of this interval to the Idiognathodus cancellosus Zone of Barrick et al. (2013).

### 2.5.3 Conodont Assemblage Correlation

Heckel et al. (2011) identified conodont biostratigraphic zones in the lower part of the Conemaugh Group (Missourian to Virgilian) units in the northern Appalachian Basin. They assigned the Brush Creek Limestone Member of Glenshaw Formation to the Idiognathodus cancellosus Zone based to the presence of *Idiognathodus cancellosus*. Later, Rosscoe and Barrick (2013) reported *I. cancellosus, I. biliratus, I. eccentricus, I. neverovensis*, and *I. pseudocarinatus* from both the Hushpuckney Shale of the Midcontinent Swope Cyclothem and the (lower) Brush Creek Limestone in the Appalachian Basin. All the previously mentioned species are present in the upper part of the Salesville Formation. The presence of the *I.* cf. *I. neverovensis* in the upper part of the Salesville Formation is of particular interest because it is thought to be an immigrant from the Moscow Basin where it was originally described, and allows for correlation to the Upper Neverovo major cycle in the middle part of the Neverovo Formation in the Moscow Basin (Goreva and Alekseev 2006; Heckel et al. 2007; Rosscoe and Barrick 2013). North American forms such as *I.* cf. *I. cancellosus*, and *I. turbatus* have also been identified in the Neverovo Formation (Goreva and Alekseev 2010; Rosscoe and Barrick 2013). Both Heckel et al. (2011) and Rosscoe and Barrick (2013) correlated the Swope Cyclothem and the (lower) Brush Creek Limestone to the Macoupin Cyclothem in the Illinois Basin using conodont and cyclothem data. Based on conodont correlation data from these studies, the upper part of the Salesville Formation correlates well with the Hushpuckeny Shale in the Midcontinent, the Macoupin Cyclothem in the Illinois Basin, the middle part of the Neverovo Formation in the Moscow Basin, and the Brush Creek Limestone in the Appalachian Basin.

Lucas et al. (2021) analyzed conodonts as part of a comprehensive study of the Sacramento Mountains in South-Central New Mexico. They recovered *Idiognathodus* *cancellosus* and *I. turbatus* from the uppermost part of the Gobbler Formation and from the Space History Member in the upper part of the Gray Mesa Formation along with a few other morphologically similar species. Based on the conodont assemblage, Lucas et al. assigned the aforementioned units to the Idiognathodus cancellosus Zone and correlated them with the Hushpuckeny Shale in the Midcontinent which in turn also correlates the two units to the upper part of the Salesville Formation.

## Plate 17

Conodonts from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian.

Scale bar = 100 µm.

Fig. 1. *Gondolella bella* Stauffer and Plummer 1932, P element, 1117 section, sample 1117-1.

Fig. 2. *Gondolella* sp. 2 (in the sense of Roy 2017), P element, 1117 section, sample 1117-1.

Fig. 3. *Idiognathodus swadei* Rosscoe and Barrick 2009, P element, 1013 section, sample 1013-5.

Fig. 4-6. *Idiognathodus sulciferus* Gunnell 1933, P elements, 1013 section. 4 – sample 1013-4; 5-6 – sample 1013-5.

Fig. 7. *Idiognathodus turbatus* Rosscoe and Barrick 2009, P element, 1013 section, sample 1013-1.

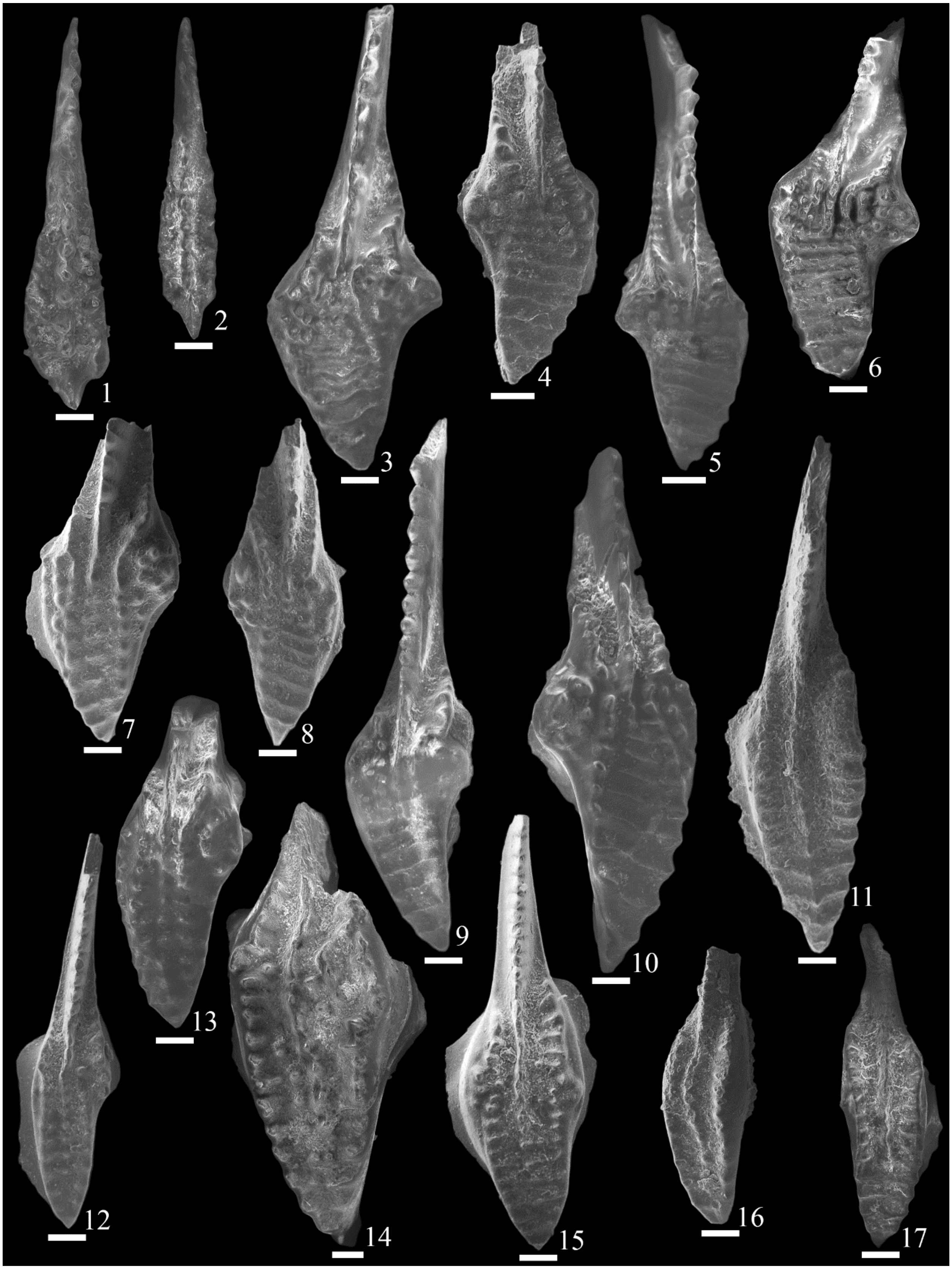
Fig. 8-10. *Idiognathodus eccentricus* Ellison 1941, P elements, 1013 section, 8 – sample 1013-1, 9 – sample 1013-5, 10 – sample 1013-4.

Fig. 11-14. *Idiognathodus cancellosus* (Gunnell 1933), P elements. 11-13 – 1013 section, 11 – sample 1013-2; 12 – sample 1013-3; 13 – sample 1013-4; 14 – 1117 section, sample 1117-1.

Fig. 15. *Idiognathodus* aff. *cancellosus* (in the sense of Rosscoe 2008), P element, 1013 section, sample 1013-4.

Fig. 16-17. *Idiognathodus biliratus* (Gunnell 1933), P elements. 16 – 1013 section, sample 1013-3; 17 – 1117 section, sample 1013-6.

## PLATE 17



## Plate 18

Conodonts from the upper part of the Salesville Formation, lower Missourian, Pennsylvanian.

Scale bar = 100 µm, except: fig. 4 = 200 µm.

Fig. 1-2. *Idiognathodus pseudocarinatus* Rosscoe and Barrick 2013, P elements, 1013 section. 1 – sample 1013-2; 2 – sample 1013-4.

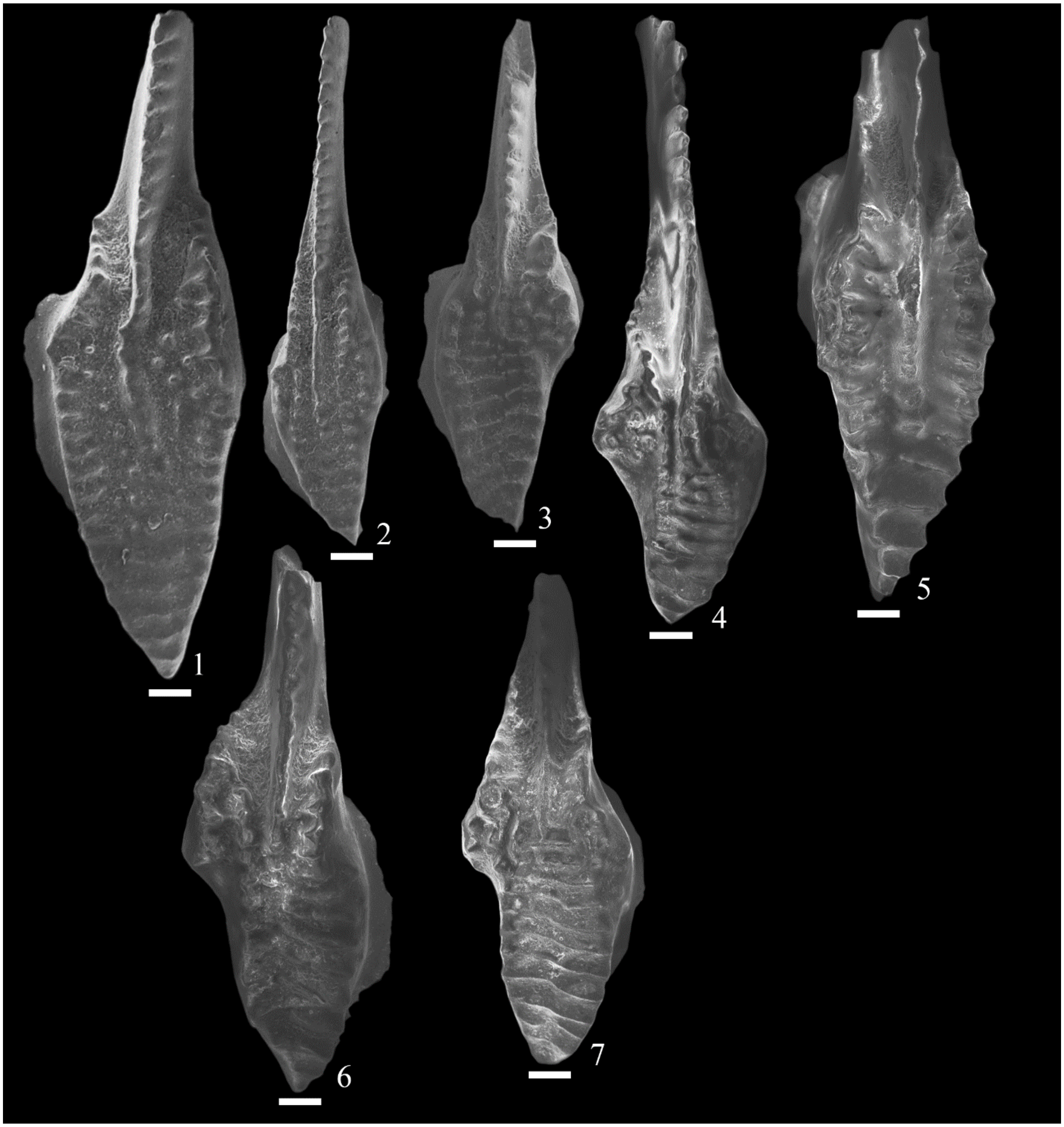
Fig. 3. *Idiognathodus gemmiformis* Gunnell 1933, P element, 1013 section, sample 1013-3.

Fig. 4. *Idiognathodus heckeli* Rosscoe and Barrick 2013, P element, 1013 section, 1013-5.

Fig. 5. *Idiognathodus* cf. *I. neverovensis* (Goreva and Alekseev 2006), P element, 1013 section, sample 1013-2.

Fig. 6-7. *Idiognathodus* cf. *I. corrugatus* Gunnell 1933, P elements. 6 – 1013 section, sample 1013-3; 7 – 1117 section, sample 1117-6.

# PLATE 18



## 2.6 Holothurian Sclerites

Holothurian sclerites from the Strawn Group in North-Central Texas have never been illustrated in any publication, yet they are found in two samples, 1013-0 and 1013-9, from the upper part of the Salesville Formation in the 1013 section. Holothurian sclerites are relatively abundant in sample 1013-0 where five species of four genera are found: *Achistrum brownwoodensis* (Croneis in Croneis and McCormack 1932), *Microantyx permiana* Korniker and Imbrie 1958, *Clavallus spicaudina* (Gutschick, Canis and Brill 1967), *Eocaudina septaforminalis* Martin 1952, and *Eocaudina* sp. (Pl. 19, figs. 1-2, 5-13). The two species of *Eocaudina* are the most common in the sample with all the other species being uncommon to rare. Only a few specimens of the species *Thalattocanthus consonus* Carini 1962 are recovered from the higher sample, 1013-9 (Pl. 19, figs. 3-4). Holothurian sclerites from both samples are generally well-preserved, but occasionally plate and wheel forms are broken.

Overall, the holothurian sclerite assemblage is relatively diverse consisting of wheel, table, hook, and plate forms. They are not known to have biostratigraphic utility but based on their distribution from the current study there is potential for them to contribute as environmental indicators. Notably, the only two samples, 1013-0 and 1013-9, that contain calcareous small foraminifers, also contain holothurian sclerites. The holothurian sclerites present in sample 1013-0 occur with small foraminiferal species *Apterinella grahamensis*, *Brunsia* sp. A, and *Brunsiella* sp. A (Figure 23), but in sample 1013-9 they occur with endothyrids: *Endothyra media*, *E. pauciloculata*, and *E. watersi*.

## Plate 19

Holothurian sclerites from the upper part of the Salesville Formation, Lower Missourian, Pennsylvanian. Scale bar = 150 µm, except: figs. 2-6 and 11-13 = 100 µm.

Fig. 1. *Achistrum brownwoodensis* (Croneis 1932), hook element, 1013 section, sample 1013-0.

Fig. 2. *Microantyx permiana* Kroniker and Imbrie 1958, wheel element, 1013 section, sample 1013-0.

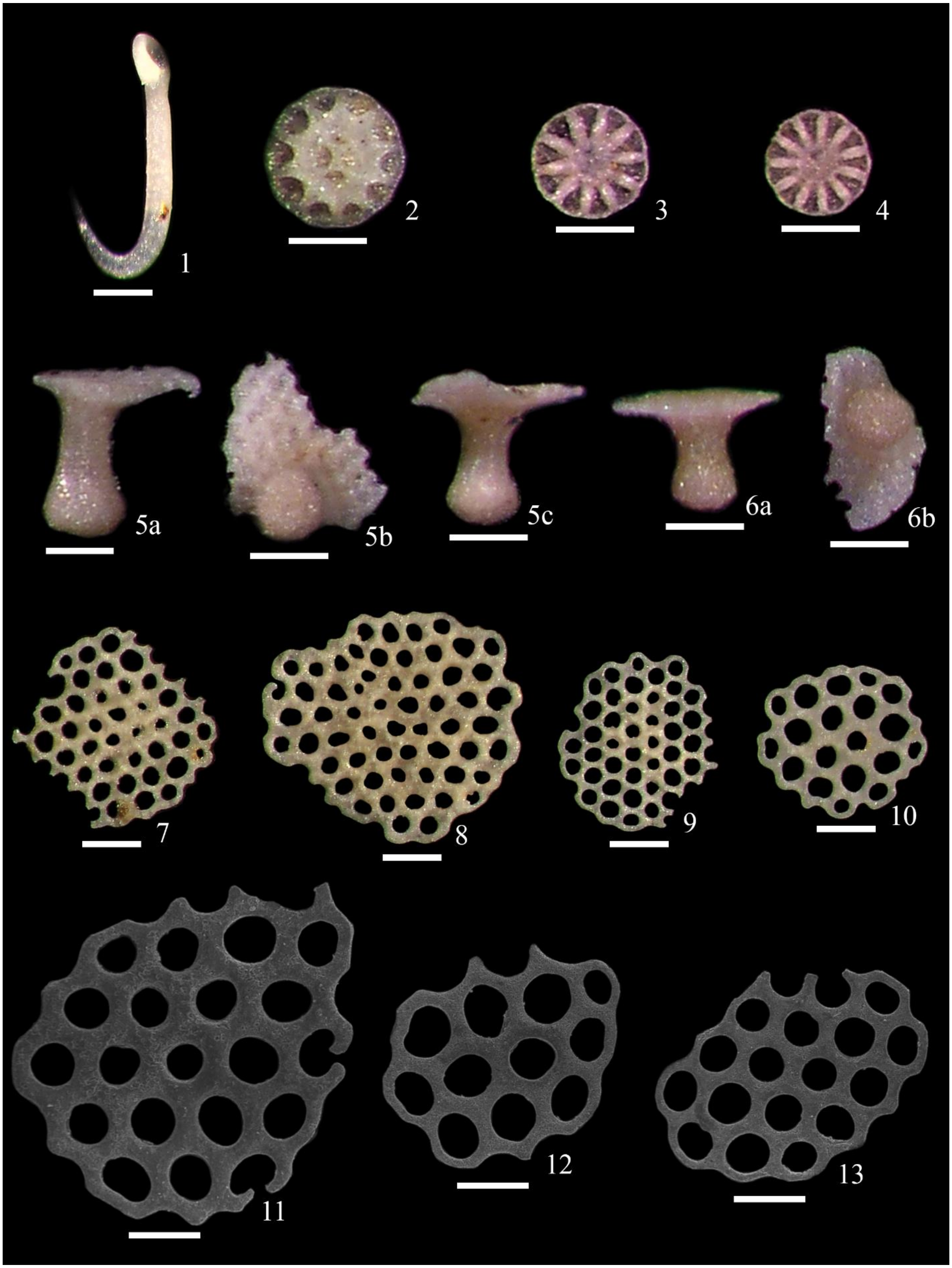
Fig. 3-4. *Thalattocanthus consonus* Carini 1962, wheel elements, 1013 section, sample 1013-9.

Fig. 5-6. *Clavallus spicaudina* (Gutschick, Canis and Brill 1967), table elements, 1013 section, sample 1013-0.

Fig. 7-9. *Eocaudina* sp., plate elements, 1013 section, sample 1013-0.

Fig. 10-13. *Eocaudina septaforminalis* Martin 1952, plate elements, 1013 section, sample 1013-0.

# PLATE 19



## 2.7 Trace Fossils, Macrofossils, and Phosphate Nodules

The trace fossils and macrofossils found in the upper part of the Salesville Formation were not originally intended to be a component of the current study, but several important specimens, particularly from the microfossil-absent Devil's Hollow Sandstone, were found to be important to the correct interpretation of the sections.

### 2.7.1 Trace Fossils

One unit of the Devil's Hollow Sandstone at the 1117 section contains abundant worm feeding borrows that possibly belong to the ichnogenus of either *Protopaleodictyon* or *Unarites* (Figure 19A). These worm borrows suggest that the Devil's Hollow Sandstone is a very shallow

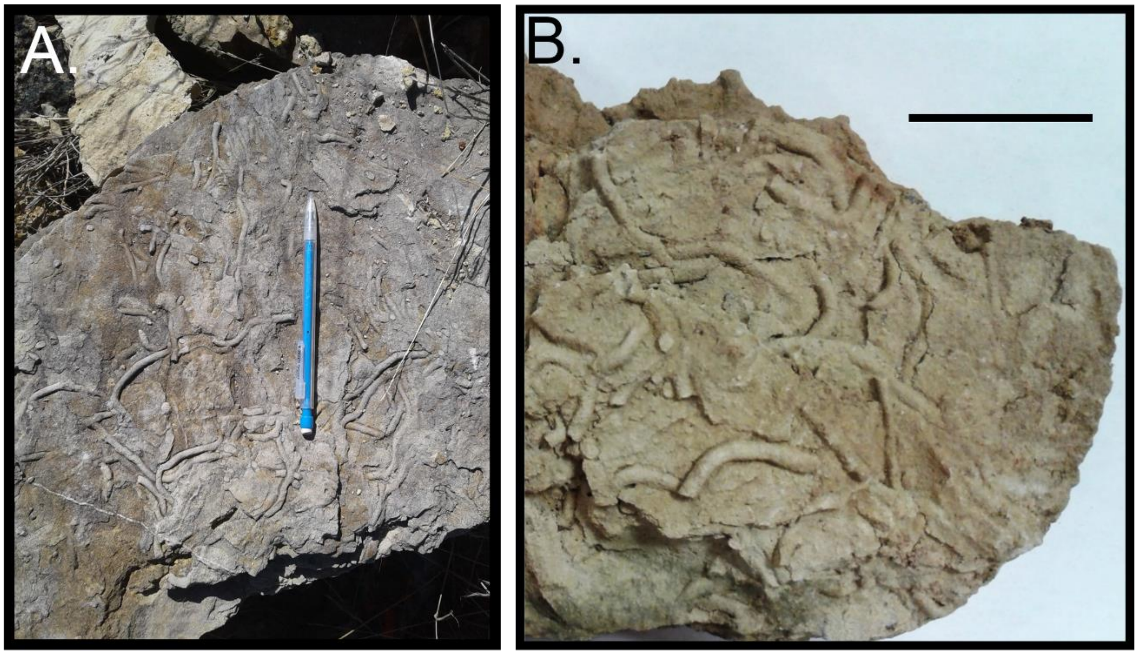


**Fig. 19. A.** A photograph of worm borrows on the weathered surface of an *ex-situ* boulder from the Devil's Hollow Sandstone from the 1117 section. Pencil for scale is 15 cm long. **B.** A Photograph of worm tubes on a fresh surface from the same unit taken from about 2 meters above the base of the section. Scale bar = 5 cm.

marine to deltaic sandstone rather than a marginal to terrestrial sandstone as had been previously hypothesized (Williams et al. 2020). This is an important distinction because it opposes the view that a disconformity is located at the Devil's Hollow Sandstone-Salesville Shale contact. The worm borrows are relatively consistent in their concentration throughout the one unit that contains them and maintain a very similar diameter (Figure 19B). The range of diameter among 13 measured worm borrows is from 4.3 mm to 5.7 mm.

### 2.7.2 Macrofossils

The most interesting of the macrofossils is found at the upper most part of the Devil's Hollow Sandstone at the 1117 section just below the contact with the Salesville Shale. This part of the sandstone contains occasional "twiggy" stenolaemate bryozoans that possibly belong to the genus *Rhombopora*. A well-preserved specimen of *Agassizocrinus*, a rare crinoid, was also recovered from the upper most part of the Devil's Hollow Sandstone (Figure 20A).

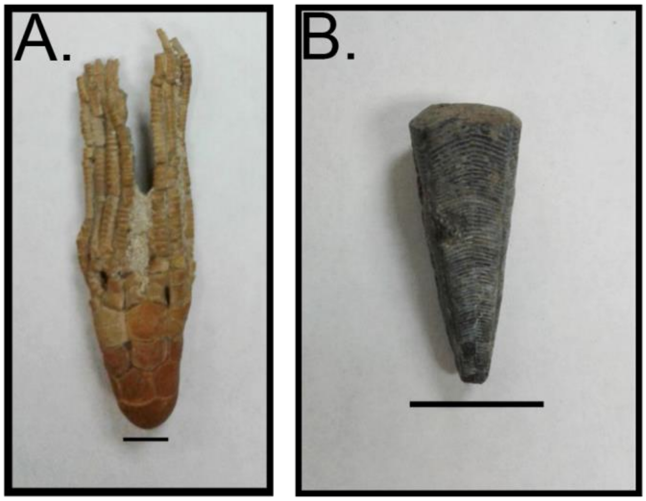


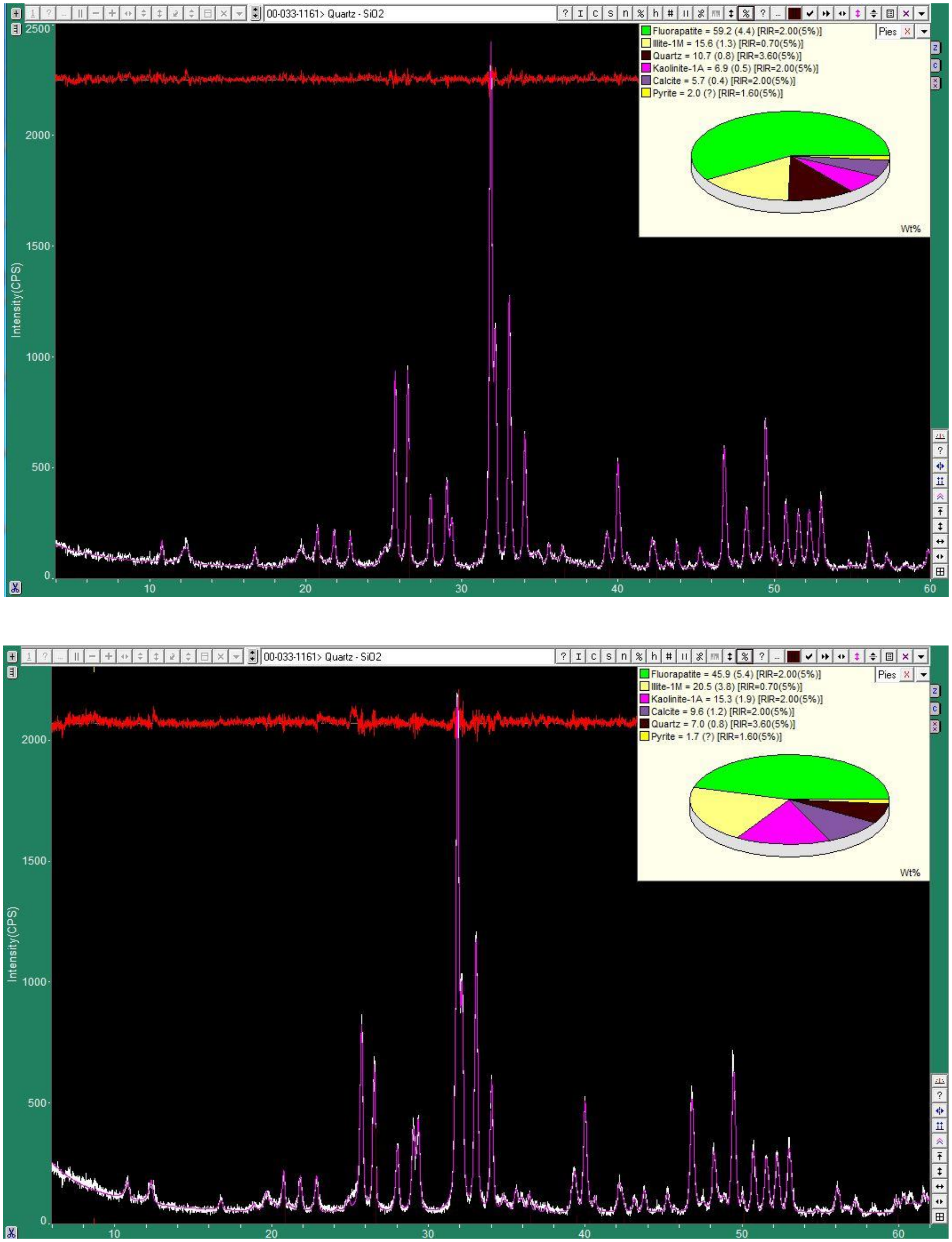
**Fig. 20. A.** A photograph of a crinoid belonging to the genus *Agassizocrinus* from the top part of the Devil's Hollow Sandstone, 1117 section. Scale bar = 1 cm. **B**. A photograph of a conulariid from the upper part of the Salesville Formation, 1013 section, sample 1013-7.6

This specimen was found by Scott Taylor and reconstructed from many pieces. The mudstone units of the sections above the sandstone contain sparse macrofossils with gastropod, bivalve and crinoid debris accounting for the vast majority. Conulariids, both fragments and whole specimens, can be found occasionally in both sections (Figure 20B).

### 2.7.3 Phosphate nodules

Phosphate nodules are recovered from the interval where sample 1013-2 was taken and they are common and typically a few centimeters in size. Four phosphate nodules were analyzed using x-ray fluorescence (XRF) to determine their chemical composition (Figures 21, 22). The primary constituent of all four nodules is fluorapatite, accounting for 45.9-72.5% of the total composition. In three out of the four nodules, the second highest constituent is illite, accounting for 15.6-21.0% of the total composition for the nodules that contained it. One nodule contained no illite, and instead had a much higher percentage of fluorapatite compared to the other nodules (Figure 22A). Quartz and kaolinite accounted for the next highest percentages but varied from sample to sample. Small numbers of pyrite and calcite accounted for the remainder of the composition of the nodules. The composition of the phosphate nodules recovered from the upper part of the Salesville Formation contain much higher numbers of fluorapatite than phosphate nodules from the Pennsylvanian in the Midcontinent where fluorapatite accounts for about 30% (Kidder 1985). The reasons for the higher concentration of fluorapatite is not currently known.

Phosphate nodules precipitate primarily in water depths near the boundary of the minimum-oxygen zone where the upwelling of phosphate-rich, dysoxic-anoxic bottom water is prevalent (Kidder 1985; Heckel 1991). Phosphate nodules occur in black shale units that were



🟩 Fluorapatite = 59.2 (4.4) [RIR=2.00(5%)]
🟨 Illite-1M = 15.6 (1.3) [RIR=0.70(5%)]
🟫 Quartz = 10.7 (0.8) [RIR=3.60(5%)]
🟪 Kaolinite-1A = 6.9 (0.5) [RIR=2.00(5%)]
🟪 Calcite = 5.7 (0.4) [RIR=2.00(5%)]
🟨 Pyrite = 2.0 (?) [RIR=1.60(5%)]

🟩 Fluorapatite = 45.9 (5.4) [RIR=2.00(5%)]
🟨 Illite-1M = 20.5 (3.8) [RIR=0.70(5%)]
🟪 Kaolinite-1A = 15.3 (1.9) [RIR=2.00(5%)]
🟪 Calcite = 9.6 (1.2) [RIR=2.00(5%)]
🟫 Quartz = 7.0 (0.8) [RIR=3.60(5%)]
🟨 Pyrite = 1.7 (?) [RIR=1.60(5%)]

**Fig. 21.** XRF analysis results for phosphate nodule from the upper part of the Salesville Formation. **A.** (Top) nodule #1. **B.** (Bottom) nodule #2.

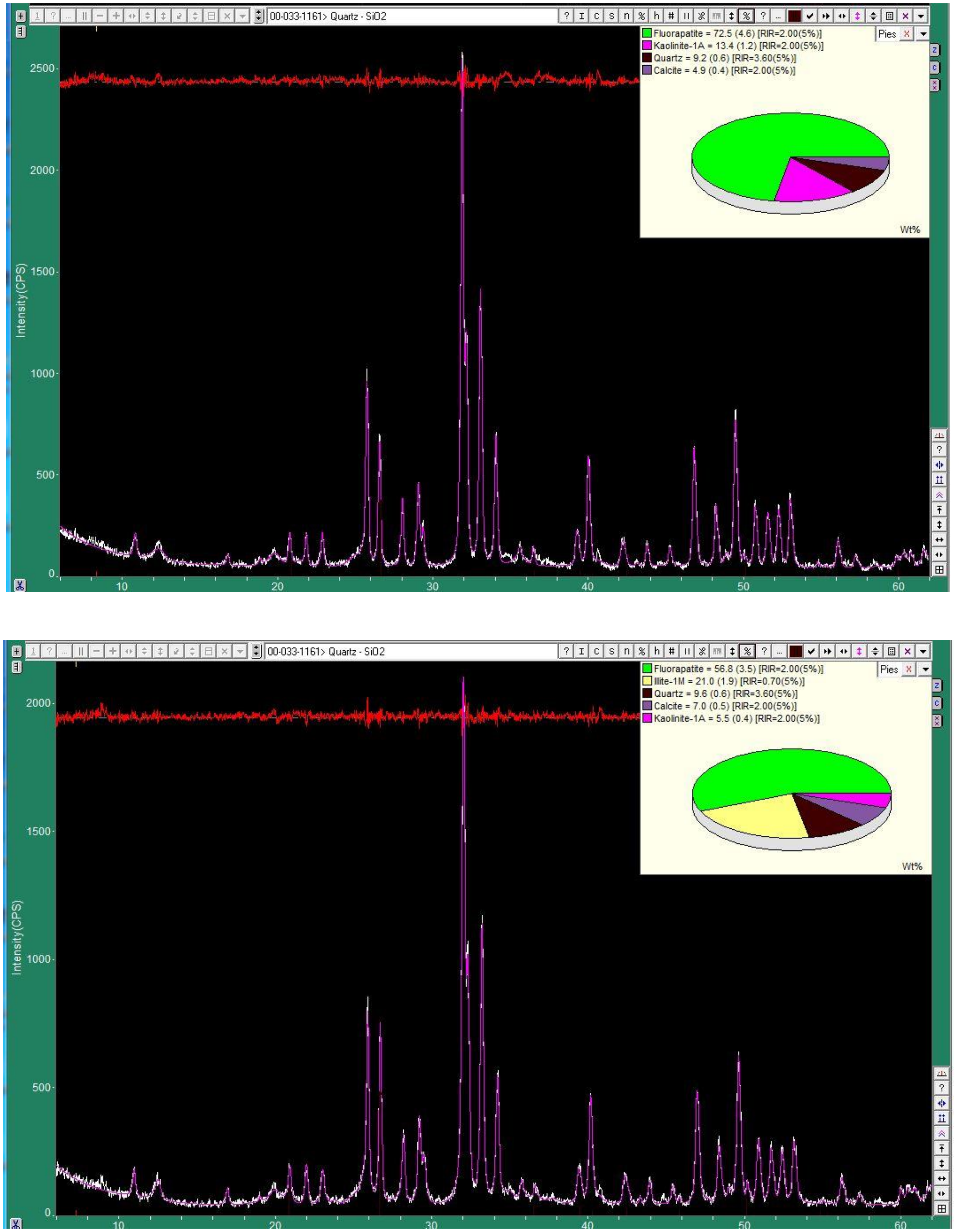


**Fig. 22.** XRF analysis results for phosphate nodules from the upper part of the Salesville Formation. **A.** (Top) nodule #3. **B.** (Bottom) nodule #4.

deposited when the boundary of the minimum-oxygen zone was near the sea floor at that time (Kidder 1985). Because the boundary of the minimum-oxygen zone can move with a rising or falling sea level, phosphate nodules will tend to form near the top of black shale units as sea level falls (“regressive type”), and, less often, at the base of the units as sea level rises (“transgressive type”) (Heckel 1991). Phosphate nodules form at the base of units less often due to the relatively rapid nature of transgressions during the Pennsylvanian that occur too quickly to allow for the phosphate-generating processes to develop (Kidder 1985).

The phosphate nodules in sample 1013-2 correspond to “regressive type” phosphate nodules that formed as the boundary of the minimum-oxygen zone was lowered to near the sea floor during the time of deposition. This observation is evidenced by the continued regression above the sample where the black to dark gray shale quickly transitions to a much lighter gray shale. The “transgressive” type phosphate nodules that would have formed as the boundary of the minimum-oxygen zone encroached on the area from the deeper adjacent Midland Basin as sea level rose are not present. Phosphate nodules were not seen at the 1117 section, possibly due to that section being deposited in shallower water depths.

## 2.8 Depositional Environment Interpretation

The depositional environment interpretation of the studied units are explained herein by dividing the upper part of the Salesville Formation into six informal lithologic “units”. The characteristic features of each unit are based on all the data presented previously in the chapter to provide an all-encompassing summary for each of the different environments and the coinciding microfossil assemblages represented within (Figures 23, 24). Units 1-6 are numbered so that unit 1 is the lowest stratigraphically and unit 6 is the highest stratigraphically (Figure 25).

### 2.8.1 Unit 1

Unit 1 (sample 1013-0) consists of a shallow marine crinoidal siltstone below the Devil's Hollow Sandstone (Unit 2) that was only studied at the 1013 section. This unit contains abundant numbers of the calcareous foraminiferal species *Apterrinella grahamensis*, *Brunsia* sp. A, and *Brunsiella* sp. A along with rare fusulinds *Eowaeringella joyitaensis* and *Fusiella Texana*. Unit 1 also contains diverse ostracodes with a particular abundance of the species *Amphissites centronotus* and is the only unit to contain more than a trivial amount of holothurian sclerites. This unit was deposited towards the end of a marine regression and represents the deposits of a carbonate-rich shallow marine environment.

### 2.8.2 Unit 2

Unit 2 is the Devil's Hollow Sandstone. This unit is devoid of microfossils, but the 1117 section does contain several types of macrofossils and one interval with abundant worm borrows. The presence of the worm borrows and few macrofossils is evidence that this sandstone is a shallow to marginal marine sandstone probably closely associated with the Perrin delta system prevalent at that time. The lithology of this unit varies greatly between the two localities. At the 1013 section the Devil's Hollow Sandstone is thin and poorly consolidated, whereas at the 1117 section the unit is thick, well consolidated and with some bedded intervals. The less developed sandstone at the 1013 section is possibly due to the section being located basinward relative to

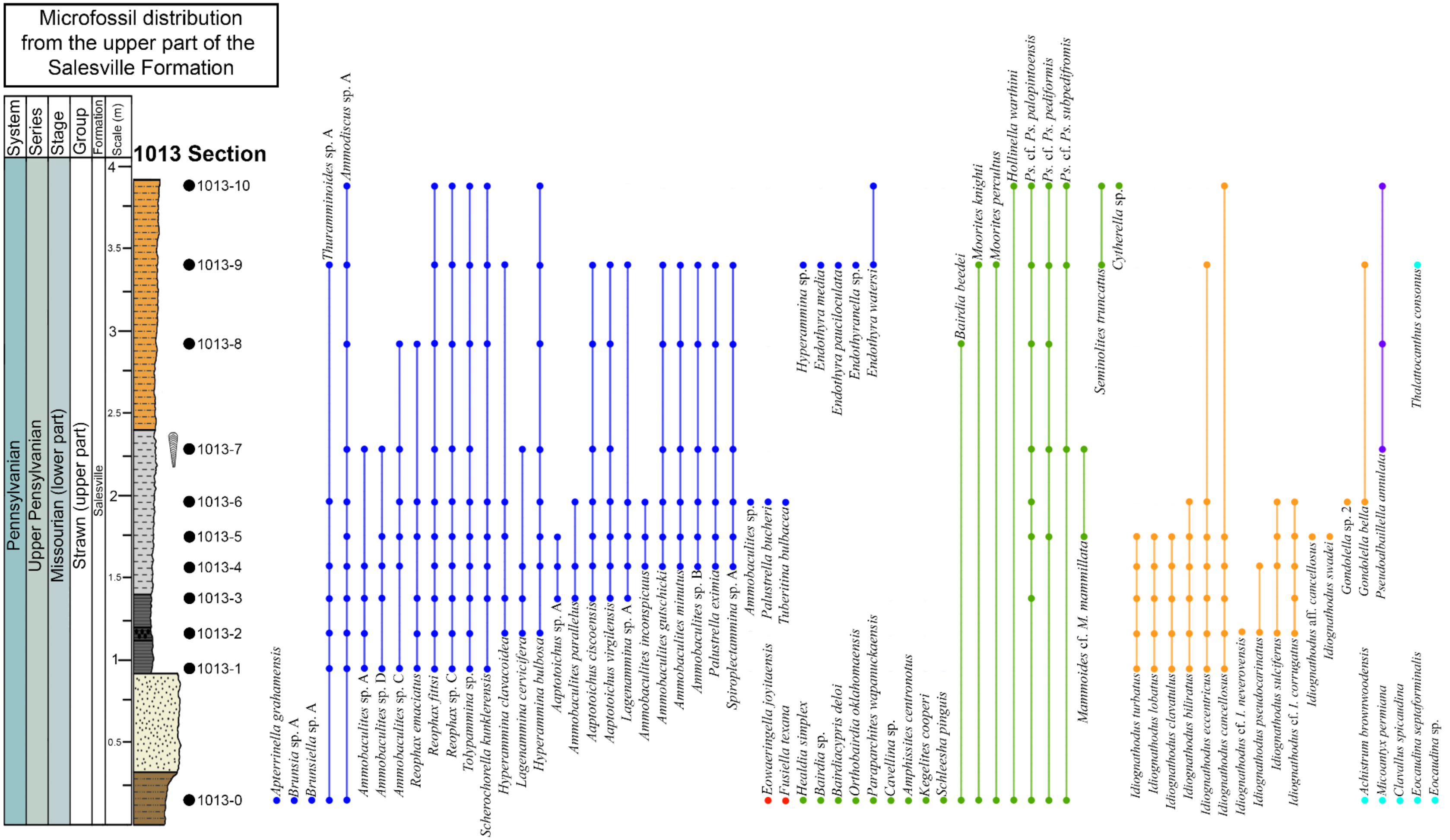


**Fig. 23.** A figure showing the ranges of all species recovered from the 1013 section. The color of the line corresponds to the type of microfossil: Blue = small foraminifers; Red = fusulinids; Green = ostracodes; Orange = conodonts; Purple = radiolarians; Cyan = holothurian sclerites. *Ps.* = *Pseudobythocypris*. For lithologic and faunal symbols see Fig. 8.

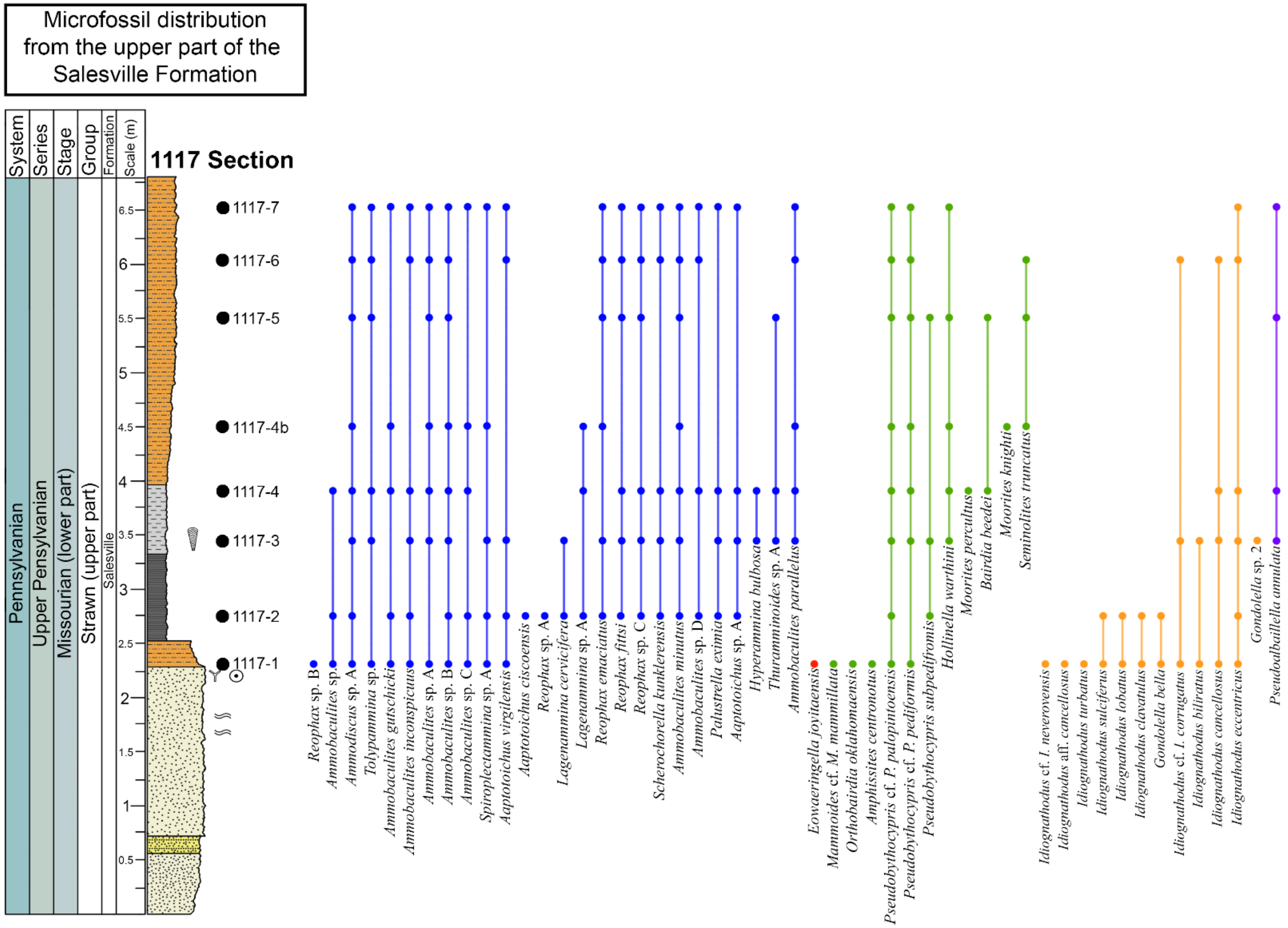


**Fig. 24.** A figure showing the ranges of all species recovered from the 1117 section. The color of the line corresponds to the type of microfossil: Blue = small foraminifers; Red = fusulinids; Green = ostracodes; Orange = conodonts; Purple = radiolarians. For lithologic and faunal symbols see Fig. 8.

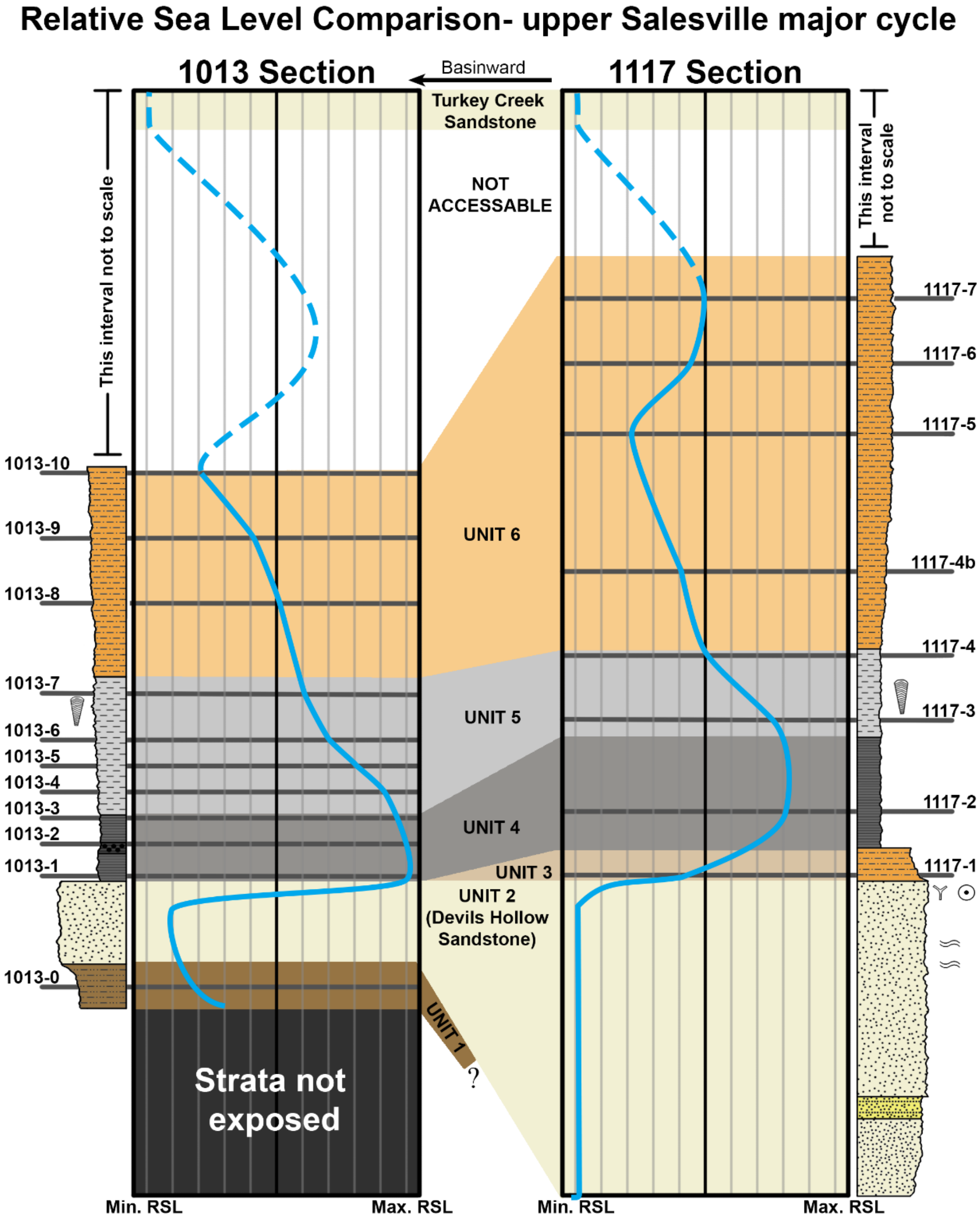


**Fig. 25.** A relative sea level comparison between the two sections of the current study. The solid blue line shows the relative sea level interpreted based on lithology and microfossils. The dashed blue line shows the predicted relative seal level for the remainder of the upper Salesville major cycle. ? = unknown lateral continuity. Max. RLS = maximum relative sea level, Min. RSL = minimum relative sea level. For lithologic and faunal symbols see Fig. 8.

the 1117 section and was thus deposited in deeper water and further away from the sediment source. This unit is considered to be the end of a regression.

### 2.8.3 Unit 3

Unit 3 (sample 1117-1) is a quartz-rich sandy mudstone directly overlaying the Devil’s Hollow Sandstone at the 1117 section. This unit is not laterally continuous and is not present at the 1013 section. Unit 3 is characterized by the agglutinated foraminiferal species *Reophax* sp. B, and the fusulinid species *Eowaeringella joyitaensis* along with rare to uncommon ostracodes. The presence of fusulinids and the high amount of sand sized grains in this unit suggest a shallow marine environment with relatively high energy. However, the abundance of conodonts found in sample 1117-1 would seem to suggest otherwise and their context within this unit is not well understood. This unit represents the beginning of the transgression phase of the upper Salesville major cycle. Unit 3’s absence from the 1013 section can be attributed to either erosion during the early parts of the transgression, or a lack of sand sized sediment input due to being located basinward and thus further away from the sediment source.

### 2.8.4 Unit 4

Unit 4 (samples 1013-1 to 1013-3, and 1117-2) is a black to dark gray fissile mudstone directly overlaying the Devil’s Hollow Sandstone (unit 2) at the 1013 section and overlaying unit 3 at the 1117 section. This unit is characterized by the agglutinated foraminifers: *Thuramminoides* sp. A, *Reophax emaciatus, R. fittsi, R.* sp. C, *Ammobaculites* sp. A, and *A.* sp. D as well as rare to absent ostracodes. The conodont species *Idiognathodus eccentricus* and *I.*

*cancellosus* are generally common in this unit along with lesser numbers of other species of the genus *Idiognathodus*. Unit 4 encompasses the transgressive and deepest part of the upper Salesville major cycle and is characteristic of an open shelf marine environment.

### 2.8.5 Unit 5

Unit 5 (samples 1013-4 to 1013-7, and 1117-3 to 1117-4) is a grey fissile mudstone. This unit is characterized by the agglutinated foraminifers: *Aaptotoichus virgilensis, Ammobaculites gutschicki*, *A. minutus, Hyperammina bulbosa*, *Palustrella eximia*, and *Spiroplectammina* sp. A. The species *Reophax emaciatus*, *R. fittsi*, and *R*. sp. C are still common in this unit, but not as abundant as compared to unit 4. Overall, unit 5 contains a more diverse agglutinated foraminiferal assemblage compared to unit 3. This interval is also characterized by the presence of the ostracode species *Pseudobythocypris* cf *P. palopintoensis*. This unit contains a relatively diverse conodont fauna in the lower samples (1013-4, 1013-5, 1013-6, 1117-3), but the conodont diversity and abundance sharply decrease in the highest samples (1013-7, 1117-4). This unit represents the beginning part of the regressive phase of the upper Salesville major cycle, and the effects of which can be clearly seen in the decline in conodont diversity and abundance in the upper parts and the greater diversity of agglutinated foraminifers.

### 2.8.6 Unit 6

Unit 6 (samples 1013-8 to 1013-10, and 1117-4b to 1117-7) is a brown and gray variegated mudstone This unit is characterized by absent to rare conodonts, a gradual increase in diversity of ostracodes with a continued abundance of *Pseudobythocypris* cf *P. palopintoensis,* and an increase in abundance of the radiolarian *Pseudoalbaillella annulata*. The distribution of small foraminifers in this unit is less consistent as compared to previous units. In the 1013 section, the small foraminiferal assemblage of samples 1013-8 and 1013-9 resembles that of unit 5 except for the presence of *Endothyra media*, *E. pauciloculata*, and *E. watersi* in sample 1013-9. The diversity and abundance of small foraminifers sharply declines in sample 1013-10 that corresponds to a similar trend in the small foraminifers of the 1117 section in samples 1117-4b and 1117-5. The highest two samples of the 1117 section (1117-6, 1117-7) show increased fissility and grayer in color as compared to lower samples, and also contains an increased abundance and diversity of small foraminifers similar to the assemblage in unit 5. Based on the slight change in lithology and the small foraminiferal assemblage, samples 1117-6 and 1117-7 are thought to represent a somewhat deeper marine setting compared to samples 1117-4b and 1117-5. Overall, unit 6 represents the deposits of a shallowing open shelf marine environment and is associated with continued regression of the upper Salesville major cycle. Above this unit, the strata were not studied due to coverage and inaccessibility, but the section is predicted to continue to regress going up section until the base of the Turkey Creek Sandstone that marks the end of the upper Salesville major cycle (Figure 25).

# CHAPTER 3: CONCLUSIONS

Small foraminifers, fusulinids, radiolarians, ostracodes, conodonts, and holothurian sclerites have been studied from two exposures of the upper part of the Salesville Formation near Mineral Wells, North-Central Texas. Small foraminifers are present in all units of the studied sections (1013 and 1117) except in the Devil’s Hollow Sandstone. Thirty-seven species of small foraminifers belonging to 17 genera are identified and illustrated. Among them nineteen species are described, from which 12 species are new: *Thuramminoides* sp. A, *Lagenammina* sp. A, *Ammodiscus* sp. A, *Reophax* sp. C, *Ammobaculites* sp. A, *A.* sp. B, *A.* sp. C, *A.* sp. D, *Spiroplectammina* sp. A, *Aaptotoichus* sp. A, *Brunsia* sp. A, and *Brunsiella sp. A.*

Fusulinids are found in the strata below the Devil’s Hollow Sandstone in the 1013 section, and directly above it in the 1117 section. Two fusulinid species, *Eowaeringella joyitaensis* and *Fusiella texana*, are described from the studied sections. The presence of *E. joyitaensis* allows for the assignment of the upper part of the Salesville to the fusulinid Eowaeringella Zone of Wahlman (2013).

Poorly preserved radiolarians are found in three samples (1013-7, 1013-8 and 1013-10) of the 1013 section, and four samples (1117-3, 1117-4, 1117-5, and 1117-7) of the 1117 section. Only one species *Pseudoalbaillella annulata* is identified. The presence of *P. annulata* in the upper part of the Salesville Formation suggests that the range of the *Pseudoalbaillella desmoinesiensis-P. annulata* radiolarian zone of Nestell et al. (2012) should be extended to the lower Missourian.

Ostracodes occur unevenly in both studied sections and are represented by 19 species of 15 genera and are illustrated. The presence of species *Bairdia beedei*, *Healdia simplex*, and

*Pseudobythocypris subpedifromis* allows for the assignment of the upper part of the Salesville Formation to the ostracode Kegelites dattonensis Zone of Melnyk and Maddocks (1988). It is suggested that the species *Mammoides mammillata* and *Pseudobythocypris palopintoensis* are good indicators for the Missourian.

Most conodonts are found in the black and gray shale units of the studied sections. Fourteen species of conodonts belonging to two genera, *Gondolella* and *Idiognathodus*, are identified and illustrated. The presence of the conodont species *Idiognathodus cancellosus* allows for the assignment of the upper part of the Salesville Formation to the conodont Idiognathodus cancellosus Zone of the Kasimovian standard conodont zone.

Holothurian sclerites are found in two samples, 1013-0 and 1013-9, of the 1013 section, and are represented by six species of the genera *Achistrum*, *Microantyx*, *Clavallus*, *Eocaudina*, and *Thalattocanthus* that are illustrated for the first time.

Distribution and abundance of the microfossil species identified is discussed within the context of the changing lithofacies in both sections. The biostratigraphic zones of the different groups of microfossils support the early Missourian age of the upper part of the Salesville Formation. The microfossil association support the correlation of the upper part of the Salesville Formation with nine other units of early Missourian age in other regions of North America, and one unit in the Moscow Basin of Russia.

The presence of abundant worm borrows in one interval of the Devil’s Hollow Sandstone is discussed and their presence supports the Devil’s Hollow Sandstone to be of marine origin. Other macrofossils found in the sections such as the crinoid *Agassizocrinus*, bryozoans and conulariids are also noted.

An interval with phosphate nodules occurs in the black shale unit, sample 1013-2, of the 1013 section. XRF analysis shows that the chemical composition of these nodules has a higher concentration of fluorapatite than published by Kidder (1985) from the Pennsylvanian of the Midcontinent.

Using all data gathered in the current study, the upper part of the Salesville Formation is divided into six informal "units" based on lithology used to characterize the changing microfossil association and relative sea level in the upper Salesville major cycle. Microfossils that seemed representative of a particular unit were specified, and depositional environment interpretations are suggested.

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