FORAMINIFERS OF THE CLARITA FORMATION (WENLOCK, SILURIAN), FROM THE ARBUCKLE MOUNTAINS, OKLAHOMA

by

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Abstract

FORAMINIFERS OF THE CLARITA FORMATION (WENLOCK, SILURIAN)

FROM THE ARBUCKLE MOUNTAINS, OKLAHOMA

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The study, identification, and classification of Silurian foraminifers from the Arbuckle Mountains in Oklahoma have attracted little attention since the work of Moreman and Ireland in late 1930's. These authors described 48 new species and several new genera, some of which are synonyms in recent taxonomy. Besides foraminifers, diverse shelly faunas have been described from Silurian strata in the Arbuckle Mountain region, especially brachiopods, trilobites, and conodonts, as well as corals, bryozoans, and rare graptolites. Rich assemblages of foraminifers occur in the Fitzhugh Member of the Clarita Formation of the Hunton Group, in association with abundant and diverse conodont faunas. Based on these conodont faunas, the Clarita Formation has been shown to range in age from the late Telychian (latest Llandovery) through the Wenlock into the early Gorstian (earliest Ludlow). A cryptic, but significant unconformity that coincides with the early Homerian Mulde Event separates the Sheinwoodian sequence of the lower part of the Fitzhugh Member from the overlying Homerian to early Gorstian sequence of the upper part of the Fitzhugh Member. Foraminifers have been studied from residues processed for conodonts allowing the conodont species to be used as a key reference to the age of foraminiferal assemblages. Thirty seven species of 12 genera of well preserved and relatively abundant agglutinated foraminifers have been identified in samples from five stratigraphic sections located in the Arbuckle Mountains area. The genera identified include Lagenammina, Thurammina, Colonammina, Shidelerella, Sorosphaera, Psammosphaera, Glomospira, Ammodiscus, and Hyperammina. A modern study of Silurian foraminifers recovered from conodont producing strata in the Arbuckle Mountains area provides an updated taxonomy and platform for correlation to Silurian strata in the United States and other countries.

Table of Contents

List of Illustrations

List of Tables

Chapter 1

Introduction

The study, identification, and classification of Silurian foraminifers from the Arbuckle Mountains area of Oklahoma have attracted little attention over the years since Moreman's work on Silurian and Ordovician foraminifers (Moreman 1930). Most of the fossil data recovered from Silurian strata in the Arbuckle Mountains has been based mainly on conodonts, brachiopods, and graptolites. As a result of little work on foraminifers from this area, their taxonomy is out of date and needs revision. Although a few papers have been published on the Silurian foraminifers of Oklahoma, none have been published in almost half of a century. In fact, very few studies have been published on Silurian foraminifers in North America which would account for the poorly defined or outdated taxonomy. A modern study of Silurian foraminifers recovered from conodont producing strata in the Arbuckle Mountains area will provide an updated platform for correlation to other similar aged strata in the United States and other countries.

1.1 Silurian Foraminifers Previously Studied in North America

In North America, Silurian foraminifers have been studied from Ohio, Indiana, Illinois, Missouri, Indiana, Tennessee, Kansas, Kentucky, Wisconsin and Oklahoma.

1.1.1 Ohio and Indiana

Priddy (1939) discovered agglutinated foraminifers in insoluble residues collected from Wenlock-aged rocks from southwestern Ohio and southeastern Indiana, and gave them to Stewart to study. The samples collected were from the Dayton Limestone, Osgood Shale, and Massie Shale of Ohio, and additionally from the Osgood Formation and Laurel Limestone of Indiana. From these strata, Stewart and Priddy (1941) described 21 species of foraminifers of which ten species were new and include *Rhabdammina geniculata*, *Rh. triradiata*, *Rh. minuta*, *Marsipella? torta*, *Sorosphaera osgoodensis*, *Psammosphaera subsphaerica*, *Raibosammina irregularis*, *Saccammina aspera*, *Thurammina crescentrica*, and *Trochammina prima*. Additionally, lithologic zones were established in the Laurel Limestone and Osgood Formation of Indiana and in the Cedarville Dolomite, Springfield Dolomite, Euphemia Dolomite, Massie Shale, Laurel Limestone, Osgood Shale, and Dayton Limestone of Ohio (Stewart and Priddy 1941). These lithological zones were established based on "color of the fresh rock, the color when weathered, the amount of crystallization, texture, relative hardness and bedding" (Stewart and Priddy 1941, p. 367). Seven zones (zones A – G) were established in the Laurel Limestone based upon the above listed criteria and six zones (zones A – F) were established in the Osgood Formation of Indiana. Similarly, the Cedarville Dolomite and Springfield Dolomite were divided into an upper and lower member as a result of these lithological zones. Foraminifers were identified in samples from the Dayton Limestone, Osgood Shale and Massie Shale in Ohio and the Osgood Formation and Laurel Limestone in Indiana. The most prolific location for foraminifers identified was from the Osgood Formation in Indiana. *Ammodiscus exsertus*, *Ammodiscus incertus* and *Lituotuba exserta* were the most widespread and abundant species present in samples.

Mound (1961) studied agglutinated foraminifers from 23 outcrops of the Brassfield Limestone (Llandovery) in Franklin, Ripley, Jefferson, and Clark Counties of southeastern Indiana and from two outcrops in Ohio. Foraminifers were present in only eight of the 23 outcrops, all from Indiana. The insoluble residues from eight of the localities formed the basis of Mound's study and 26 species of 14 genera of foraminifers were described. Two new genera of agglutinated foraminifers, *Stomasphaera* and *Amphicervicis*, were identified, in addition to three new species, *Stomasphaera brassfieldensis*, *Amphicervicis elliptica*, and *A. hemisphaerica*. Based on the assemblage of foraminifers, Mound concluded that the Indiana Brassfield Limestone foraminiferal assemblage is similar to the Osgood and Niagarian faunas. Several years later, Mound (1968) studied Silurian foraminifers from cores of five wells and drill holes in Allen, Delaware, Howard, Marion, and Newton Counties located in northern Indiana. Eighty two species of 31 genera of Silurian foraminifers were identified by him. Four new species were described and include: *Ammodiscus constrictodilatus*, *Lituotuba recurva*, *Tholosina phrixotheca*, and *Psammonyx ceratospirillus*. Three biostratigraphic assemblage zones were also established by Mound (1968). These assemblage zones, in ascending order, are: the *Turritellella* Assemblage Zone, the *Ammodiscus-Thurammina* Assemblage Zone, and the *Ammodiscus-Lituotuba* Assemblage Zone. The *Turritellella* Assemblage Zone was based on the presence of the agglutinated foraminifer *Turritellella fisheri* in core samples and corresponded to the Lower Salamonie Dolomite (upper Llandovery – lower Wenlock). The *Ammodiscus–Thurammina* Assemblage Zone was based on the presence of *Ammodiscus exsertus* and *Ammodiscus incertus* in addition to 13 species of *Thurammina* and corresponded to the Middle and Upper Salamonie Dolomite (Wenlock) in Allen, Delaware, Howard, and Newton counties, and to the upper part of the Osgood Limestone and the Laurel Limestone in Marion County, Indiana. The third assemblage zone, the *Ammodiscus-Lituotuba* Assemblage Zone was based on the presence of the *Ammodiscus exsertus*, *A. incertus*, *Lituotuba exserta* and *L. inflata* and corresponded to the Louisville Limestone and Wabash Formation (Middle-Upper Wenlock) (Mound 1968).

Browne and Schott (1963) studied foraminifers from the Osgood Limestone (Wenlock) in the Ripley County Construction Company quarry at Osgood, Indiana. In this study, 65 species of 24 genera were identified, of which, one new genus, *Metamorphina*, and 12 new species, *Rhabdammina bifurcata*, *Ammodiscus biconvexus*, *A. compressus, A. moundi*, *Psammonyx campbelli*, *Lituotuba gallowayi*, *L. laticervis*, *Proteonina perryi*, *Tholosina acinaciforma*, *Th. acuta*, *Th. rostrata*, and *Th. corniculata* were described.

1.1.2 Illinois, Missouri, Tennessee, and Kentucky

Grubbs (1939) studied the invertebrate fauna found in calcium carbonate nodules of Wenlock-aged dolomite in Illinois. The samples studied by him were collected from the Federal Stone Company Quarry located on the western edge of Chicago. One new genus, *Arenosiphon*, and seven new species *Arenosiphon gigantea*, *Sorosphaera irregularis*, *Lagenammina cornuta, Thurammina unitubula*, *Th. cylindrica*, *Th. globula*, and *Placopsilina? lineata* were described from these samples.

Dunn (1942) described Silurian agglutinated foraminifers from the Mississippi basin area of Illinois, Missouri, Indiana, and Tennessee, and he identified and described 79 species of Silurian foraminifers of which 57 species of foraminifers were new. Dunn also confirmed the presence of the Osgood Limestone based upon the presence of index Silurian foraminifers in the samples that were compared with index foraminifers from known Osgood Limestone in northern Illinois and Missouri. Another important contribution made by Dunn was that he recognized that Silurian strata could be identified based on the foraminifers present within certain stratigraphic intervals, and he was able to identify Osgood equivalent age strata in northern Illinois and Missouri based on the foraminifers present in the section.

McClellan (1966) identified 33 species of 16 genera of agglutinated foraminifers from ten localities situated in southeastern Indiana and one locality in northern Kentucky. All samples were collected from the Waldron Shale (Wenlock). Of 33 species of 16 genera of agglutinated foraminifers identified, one new genus, *Sorostomasphaera*, and seven new species *Sorostomasphaera waldronensis*, *Stegnammina contorta*, *Hemisphaerammina casteri*, *Metamorphina imbricata*, *Webbinelloidea hattini*, *W. globulosa*, and *W. ventriquetra* were described. In terms of paleoenvironmental factors, McClellan (1966) noted that the lack of variation within the lithology of the Waldron Shale limited his ability to make definite comparisons between the faunas and their environments. In general, from the diversity of species present within the Waldron Shale, the paleoenvironment was thought to be a moderate shallow marine environment associated with low energy and slow sedimentation rate. McClellan (1966) also noted the presence of calcareous lenses within the Waldron Shale. He suggested that the presence of these calcareous lenses indicated the possible location of bottom water currents.

1.1.3 Kansas

Miller (1956) described two new species of agglutinated foraminifers, *Ammodiscus leei* and *Arenosiphon rugosa* from subsurface samples from wells in Wabaunsee, Shawnee, and Riley Counties of Kansas collected by Lee, who worked for the Kansas Geological Survey. Also, two new genera, New Genus A and New Genus B, of foraminifers were described but not named, because they were found in subsurface samples from rotary drilled wells in unknown stratigraphic levels.

Ireland (1966) continued the studies began by Miller (1956). Residues of samples from oil wells in the Salina and Forest City basins of Kansas were studied for Silurian foraminifers from the Hunton Group. From these samples, Ireland was able to describe one new genus, *Hyperbathoides*, and two new species, *Hyperbathoides schwalmi* and *Glomospirella ellipsoidalis*. Foraminifers studied by Ireland (1966) were also used to explain structural and geological features that were previously unexplained, such as faulting, and thickness changes. For example, the horizontal and vertical distributions of foraminifers within Hunton strata were used to determine the presence of repeated zones within a well drilled through a fault plane in Nemaha County of Kansas, and thus account for thickness changes attributed to faulting (Ireland 1966).

1.1.4 Wisconsin

Watkins et al. (1999) presented the first study of Silurian (Llandovery/Wenlock) foraminifers from southeastern Wisconsin detailing the stratigraphy and paleoenvironment of the western part of the Michigan basin. The sections sampled include Sussex, Lannon, Dropshaft KK-1, Dropshaft LM-S, and the Voree Quarry located in Kenosha, Racine, Milwaukee, Waukesha, and Walworth counties, respectively. The samples were initially processed primarily for conodonts, but sponge spicules and the macrofauna were also evaluated (Watkins et al. 1999). From these sections, foraminifers were described and included nine species of the genera *Ammodiscus, Glomospirella, Hemisphaerammina, Hyperammina, Lagenammina, Psammosphaera, Stomasphaera, Thurammina, and Webbinelloidea*. In addition to identifying foraminifers in the samples, the stratigraphy of this area was also studied in detail including the Burnt Bluff Group, Brandon Bridge Formation, Waukesha Formation, and Racine Formation.

1.1.5 Oklahoma

Silurian foraminifers have been previously studied in the Arbuckle Mountains area of southeastern Oklahoma by Moreman (1930, 1933) and Ireland (1939). The foraminifers studied by Moreman were initially discovered by Ockerman who worked for the Kansas Geological Survey and was interested in the heavy mineral content of samples taken from the Chimneyhill Limestone. He noticed fragments of what were later determined by Moreman to be foraminifers (Moreman 1930). From these samples, Moreman identified 30 species of 13 genera of agglutinated foraminifers, of which, three new genera, *Stegnammina, Raibosammina, Colonammina*, and 27 new species including *Crithionina rara*, *Bathysiphon curvus*, *B. deminutionis*, *B. exiguus*, *Psammosphaera cava*, *Sorosphaera tricella*, *Stegnammina triangularis*, *S. cylindrica*, *S. hebesta*, *Raibosammina mica*, *R. aspera*, *Lagenammina sphaerica*, *L. stilla*, *Thurammina tubulata*, *Th.*

subsphaerica, *Th. irregularis*, *Th. triangularis*, *Th. phasela*, *Th. elliptica*, *Th. arcuata*, *Tholosina convexa*, *Th. elongata*, *Colonammina verruca*, *C. conea*, *Hyperammina minuta*, *Ammodiscus? furca*, and *Lituotuba exserta* were described. Later, Moreman (1933) continued to study foraminifers from the Chimneyhill and Viola Limestones and the Woodford Shale in the Arbuckle Mountains with the purpose of "determining the character and geologic range of agglutinated foraminifers in the Early Paleozoic" (Moreman 1933, p. 393). He described one new genus, *Kerionammina*, and 10 new species *Rhabdammina trifurcata*, *Marsipella aggregata*, *Saccammina biosculata*, *Lagenammina cucurbita*, *Webbinella tholus*, *W. quadripartita*, *Hyperammina hastula*, *Saccorhiza flexiliramosa*, *Glomospira biplana*, and *Kerionammina favus* from these strata.

Ireland (1939) also studied Silurian foraminifers from the Arbuckle Mountains and central Oklahoma. The samples studied by him were collected from 6300 wells and outcrops with the purpose of describing the fauna found. Ireland described one new genus, *Bifurcammina*, and 27 new species *Bathysiphon rugosus*, *Psammosphaera angularis*, *P. gracilis*, *Psammophax bipartita*, *Stegnammina elongata*, *Ceratammina cornucopia*, *Saccammina moremani*, *Lagenammina distorta*, *Thurammina delicata*, *Th. globosa*, *Th. polygona*, *Th. sphaerica*, *Th. subpapillata*, *Th. transversalis*, *Webbinella bipartita*, *W. coronata*, *W. gibbosa*, *Tholosina sedentata*, *Hyperammina harrisi*, *Ammodiscus abbreviatus*, *Glomospira westgatei*, *G. siluriana*, *Lituotuba inflata*, *Psammonyx maxwelli*, *Bifurcammina bifurca*, *B. conjuncta*, and *B. parallela* from the Silurian strata.

1.2 Stratigraphy of the Silurian strata in the Arbuckle Mountains

A shale-carbonate-shale sequence of Upper Ordovician – Upper Devonian strata outcrops in the Arbuckle Mountains area of southeastern Oklahoma. During the Late

Ordovician, an increase in terrigenous material from the active Appalachian belt and the Cordilleran belt led to the deposition of the Sylvan Shale (Upper Ordovician). Very shallow sea levels prevailed and resulted in the deposition of the Keel Formation, which marks the beginning of the Hunton Group (Late Ordovician – Early Devonian). The Hunton Group, detailed below, represents the carbonate interval of the sequence, and is overlain by the Woodford Shale (Late Devonian – Early Mississippian) (Amsden 1967).

1.2.1 The Hunton Group

The Hunton Group was initially named as the Hunton limestone by Taft (1902; 1904) in reference to the thick carbonate sequence that outcrops in the Arbuckle Mountains area of southeastern Oklahoma. The rank of the so-called Hunton limestone underwent several nomenclature changes and it was finally raised to group status (Amsden 1960).The age of the Hunton Group ranges from the Hirnantian Stage of the Late Ordovician through the Emsian Stage of the Early Devonian.In the Arbuckle Mountains, the Hunton Group includes the following formations in ascending order: the Keel Formation, the Cochrane Formation, the Clarita Formation, the Henryhouse Formation, the Haragan Formation, the Bois d'Arc Formation and the Frisco Formation (Amsden 1960). The Silurian part of the Hunton Group includes the Cochrane, Clarita and Henryhouse Formations (Figure 1-1).

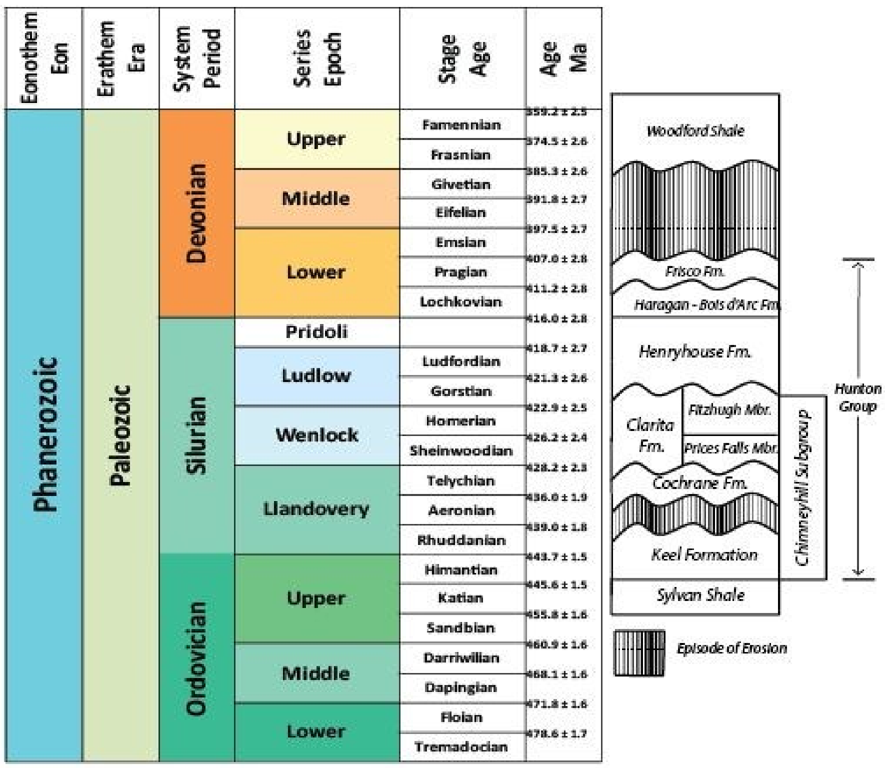
1.2.2 The Clarita Formation

The Clarita Formation includes strata that range in age from the Telychian Stage of the latest Llandovery through the Sheinwoodian and Homerian Stages of the Wenlock Series of the middle Silurian and into the early Gorstian (earliest Ludlow). The Clarita Formation is typically underlain by the Cochrane Formation (Aeronian to Telychian Stage) with a major unconformity separating the two formations, and overlain by the

Henryhouse Formation (Ludlow, Pridoli) also with a minor unconformity separating the two formations (Amsden and Barrick 1988).

1.2.2.1 History of nomenclature

The Clarita Formation was first included as a member of the Chimneyhill Formation of the Hunton Group. The Chimneyhill Formation was named by Reeds (1911)based on outcrops of the limestone in Chimneyhill Creek in the northern part of the Arbuckle



Mountains. Reeds (1911) then informally divided the Chimneyhill Formation into three units based upon lithology.

Figure 1-1 Stratigraphic position of the Hunton Group strata in southeastern Oklahoma relative to a recent Geologic Time Scale (after Al-Shaieb et al. 2000).

These three units were named, in ascending order, the oolitic member, the glauconitic member, and the pink-crinoidal member. Later, Maxwell (1931, 1936) formally named the oolitic member as the Hawkins and Keel Members, the glauconitic member as the Cochrane Member, and the pink-crinoidal member as the Dillard Member. Amsden (1957) renamed the members previously named by Maxwell in ascending order, the Keel and Ideal Quarry Members, the Cochrane Member, and the Clarita Member due to possible naming complications with the Hawkins and Dillard Members, in that, these names were already used in naming conventions elsewhere. These members were changed to formations by Amsden (1967), and the lower part of the Clarita Formation was divided by him into the Prices Falls Member and the upper part into the Fitzhugh Member based on lithology and included as a part of the Chimneyhill Subgroup. Outcrops of the Clarita Formation are found in the Arbuckle Mountains and Criner Hills of southeastern Oklahoma (Amsden 1960; 1967; Figure 1-2). The Clarita Formation's type locality is located in Coal County, Oklahoma near the Old Hunton Townsite (Figure 1-3).

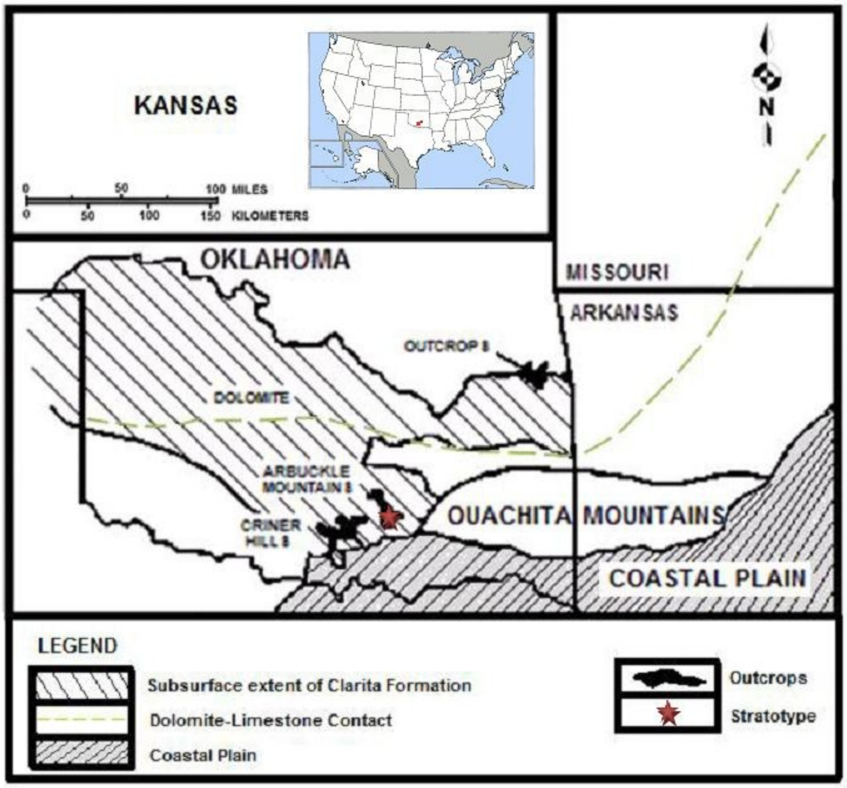


Figure 1-2 Map indicating outcrop locations of the Clarita Formation in the Arbuckle Mountains area of southeastern Oklahoma. The location of the type section of the Clarita Formation is indicated by a red star on the map (modified from Amsden et al. 1980).

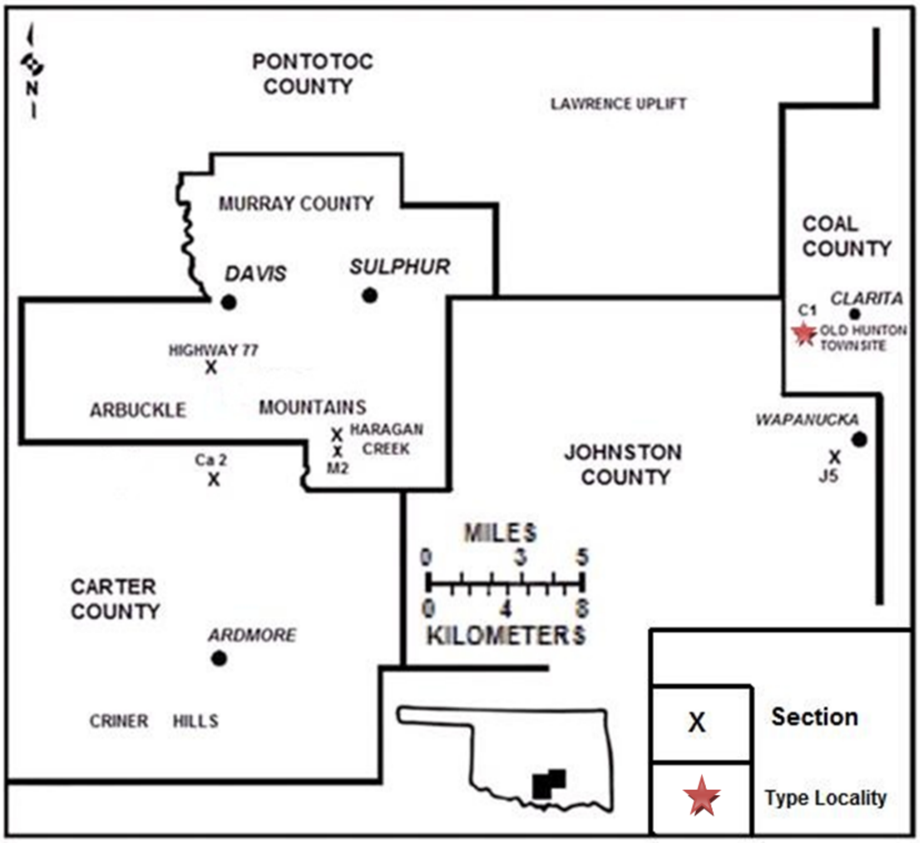


Figure 1-3 Map indicating the location of the type locality of the Clarita Formation, the C1section, at the Old Hunton Townsite near Clarita, Oklahoma (Modified from Barrick and Klapper, 1976).

1.2.2.2 Lithology

The lower member of the Clarita Formation, the Prices Falls Member (upper Llandovery – lower Wenlock, late Telychian – Sheinwoodian Stages), is typically thin (less than 0.5 m thick), shaly and is composed of marl (Amsden et al. 1980). The Fitzhugh Member (Wenlock - Ludlow, Sheinwoodian – Gorstian Stages), the upper member of the Clarita Formation, makes up the majority of the formation and is composed primarily of bioclastic limestone with a thickness of less than 6 m but can range up to approximately 14 m at some locations (Amsden et al. 1980). Within the

Fitzhugh Member, Amsden et al. (1980) recognized three lithofacies-biofacies divisions. The different facies are named according to the primary fossil and matrix content: the crinoid sparite lithofacies, ostracode silty marlstone lithofacies (post Mulde), and the arthropod micrite lithofacies (Amsden et al. 1980). These lithofacies were determined to be directly related to water conditions and the type of material being deposited on the ocean floor.

1.2.2.3 Mulde Event

The Mulde Event is one of three major mass extinction events that took place worldwide in the Silurian in which large changes took place within the biodiversity of marine organisms preserved within the rock record in relation to environmental changes, namely sea level. This event is characterized by a mass extinction of graptolites, changes of biota of acritarchs, chitinozoans, nautiloid cephalopods, conodonts and fish, widespread anoxic conditions, organic-rich shale deposition, and a low sea-level at the beginning of the event followed by rapid sea-level transgression (Calner 2008). The Mulde unconformity is located within the early Homerian and is aptly named in reference to the Silurian Mulde Event (Barrick et al. 2009). During the sea level regression that took place during the Mulde Event much of the strata located in southeastern Laurentia was either not deposited or was eroded as a direct result of sea-level fall. According to Barrick et al. (2009), this event coincides with an unconformity at a sequence boundary and as is poorly represented in the Silurian strata in Oklahoma. Since the event, poorly preserved conodonts are utilized as the main source of precisely identifying the exact location of the Mulde Event within the rock record. The timing of the Mulde Event is identified as starting at the last appearance datum of the graptolite *Cyrtograptus lundgreni* in shale sequences and conodont *Ozarkodina sagitta sagitta* in carbonate sequences. The end of the event coincides with the first appearance datum of the graptolite *Colonugraptus praedeubeli* in shale and the conodont *Ctenognathodus murchisoni* in carbonates (Calner 2008).

According to Barrick et al. (2009), in southeastern Oklahoma, the Mulde unconformity divides the Fitzhugh Member of the Clarita Formation into two parts, the lower Fitzhugh and the upper Fitzhugh.

1.2.3 Conodont zonations of the Clarita Formation

Conodont faunas within the Clarita Formation are well preserved and abundant which allowed for detailed identification of species and additionally the definition of conodont zones within this formation that were used to correlate with other conodont zones identified in Clarita-aged formations around the world. Conodont zonations of the Clarita Formation identified by Barrick and Klapper (1976) are used as a key reference to the age of foraminifers identified in the samples. The foraminifers that are identified and described in this thesis are from the same samples from which Barrick identified and described the conodonts that were used to determine the zones found in Barrick and Klapper (1976).

Barrick and Klapper (1976) described Silurian conodonts from the Arbuckle Mountains of south-central Oklahoma. Five conodont zones were established in the Silurian strata based on samples collected from sections located in the Arbuckle Mountains (Figure 1-4).

The primary basis for the formation of the upper four zones was based upon the evolutionary lineage of the conodont genus *Kockelella* (Figure 1-5). The phyletic lineage begins with *K. ranuliformis* which evolves linearly to *K. amsdeni* – *K. stauros* – *K. variabilis*. Off shoots of this lineage include *K. absidata*, *K. walliseri*, and *K. patula*. Barrick and Klapper (1976) described the evolution of this linear relationship as being "characterized by progressive restriction of the basal cavity and increasing development of the lateral processes in the platform (Pa) element”.

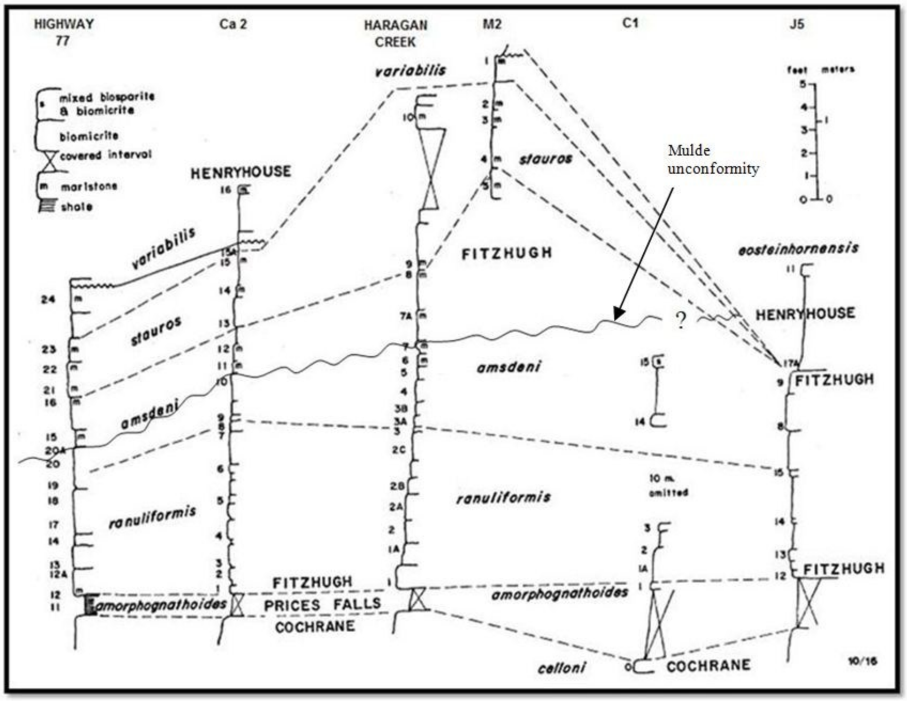


Figure 1-4 Cross sections of the six main sections of the Clarita Formation indicating location of conodont zones and numbers of samples and the location of the Mulde Event in reference to the section and samples (after Barrick and Klapper 1976; Barrick et al. 2009; Barrick, personal communication, 2013).

These changes within the *Kockelella* line allow for determination of age differences among conodonts based upon the development of the elements, and subsequently allow for the establishment of distinct conodont zones within the Clarita Formation. The five conodont zones that subdivide the Clarita Formation are based on the first appearance of key conodonts (Figure 1-6), in ascending order: *Pterospathodus amorphognathoides* conodont zone (Llandovery – Lower Wenlock, Telychian – Sheinwoodian Stages), *Kockelella ranuliformis* conodont zone (Wenlock, Sheinwoodian Stage), *Kockelella amsdeni* conodont zone (Wenlock, Sheinwoodian Stage), *Kockelella* *stauros* conodont zone (Wenlock, Homerian Stage) and the *Kockelella variabilis* conodont zone (Wenlock – Ludlow, Homerian – Gorstian Stages).

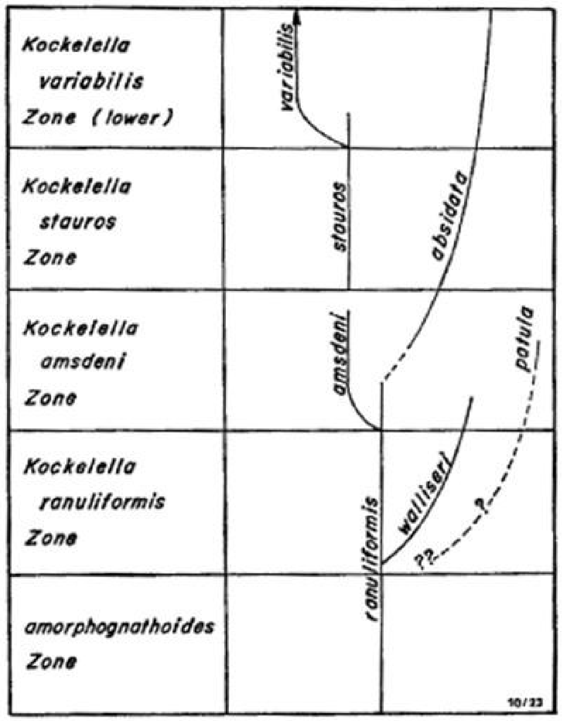


Figure 1-5 Chart illustrating the phyletic lineage of the genus *Kockelella* as identified by Barrick and Klapper (1976).

Of these five zones, the *Pterospathodus amorphognathoides* zone is defined in the Prices Falls Member of the Clarita Formation. The *Kockelella ranuliformis*, *Kockelella amsdeni* and *Kockelella stauros* are identified solely within the Fitzhugh Member of the Clarita Formation (Barrick and Klapper 1976).

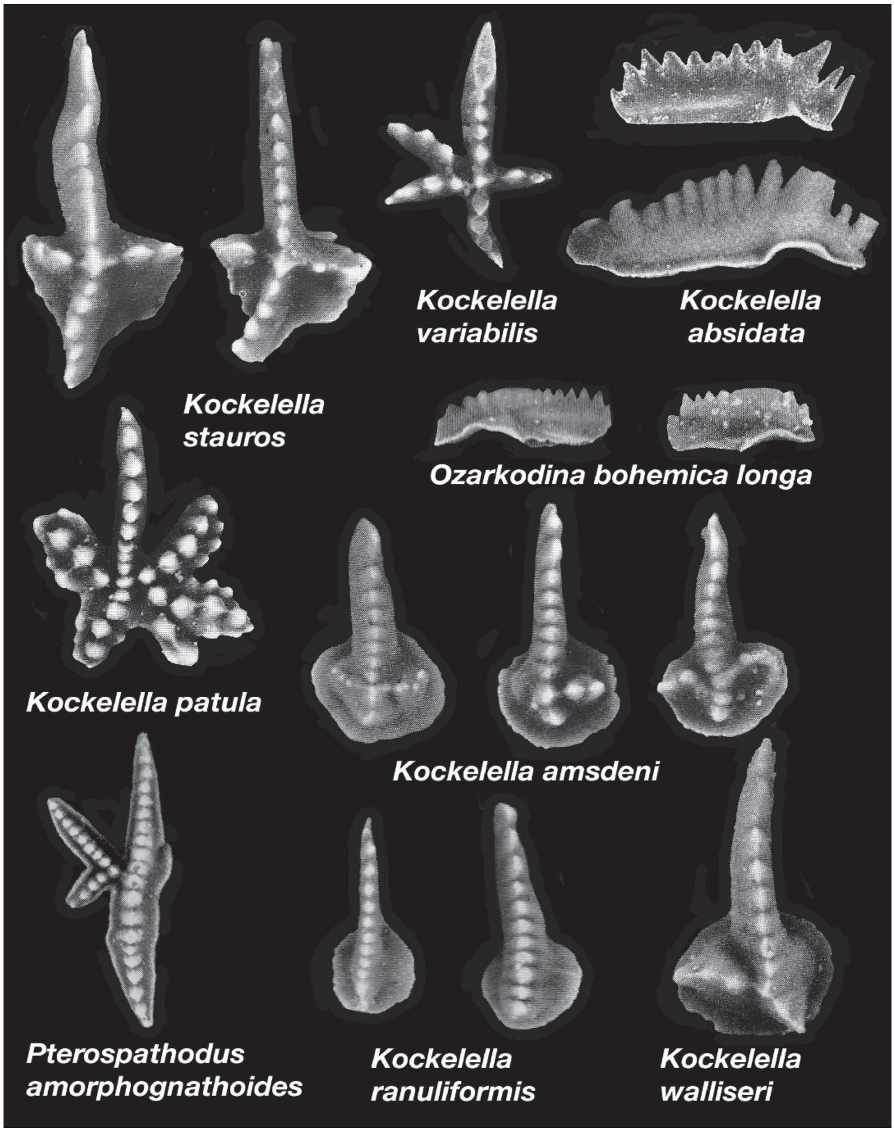


Figure 1-6 Species-indexes of typical conodonts representing each of the conodont zones identified by Barrick and Klapper (1976).

In addition to establishing conodont zones, Barrick and Klapper (1976) assigned the age of the Prices Falls Member and the base of the Fitzhugh Member to the late Llandovery – early Wenlock at the Old Hunton Townsite in the section C1, which is the stratotype section for the Clarita Formation (Figure 1-2). They also identified the base of the Fitzhugh Member, or lower boundary of the *K. ranuliformis* zone, to be early Wenlock, and the uppermost part of the Fitzhugh Member, or the *K. variabilis* zone being latest Wenlock – early Ludlow in age. This age identification of the Clarita strata in terms of conodont zones is important for correlation with similar-aged strata around the world.

Chapter 2

Distribution and Assemblages of Foraminifers

Dr. James Barrick, a professor of geology at Texas Tech University, Lubbock, Texas, provided approximately 55 samples of conodont residues collected from five different sections from the Clarita Formation located in the Arbuckle Mountains area, of southeastern Oklahoma (Figure 1-3).

The distributions of foraminifers throughout the sections were examined to establish possible assemblages or zones and also to determine if the Mulde Event had any influence on the distribution of the foraminifers in the Clarita Formation.

2.1 Methods of studying foraminifers

All foraminifers were picked from the samples and then sorted by genus and species. Specimens were chosen from the complete collection of foraminifers picked to be photographed by the Scanning Electron Microscope (SEM). These specimens were placed on a stub and photographed by the SEM in order to precisely identify the species of the foraminifers and also so that systematic descriptions could be made. Measurements of length, width, and diameter of the test were all used for species identification.

2.2 Distribution of foraminifers in the sections of the Clarita Formation

The sections from which samples were collected are: Haragan Creek section (16 samples), the Ca 2 section (16 samples), M2 section (five samples), Highway 77 section (16 samples), and the J5 section (eight samples) (Figure 1-4). All localities are described in detail in Barrick and Klapper (1976) and in Amsden (1960).

2.2.1 Haragan Creek Section

The Haragan Creek section is one of the most complete sections of the Fitzhugh Member and embraces three conodont zones in ascending order: *ranuliformis*, *amsdeni*, and *stauros* (Figure 1-4). Foraminifers occur in all 16 samples from this section. They are diverse and abundant, and represented by 31 species belonging to 12 genera (Table 2-1). The foraminiferal distribution throughout the section shows that foraminifers are more diverse in the lower part of the section (sample 1 to sample 4) with the stepped first appearance of 27 of the 31 total species including *Lagenammina aspera*, *L. cucurbita, L. sphaerica*, *L. stilla*, *Thurammina echinata, Th. elegans, Th. foerstei, Th. inflata, Th. irregularis, Th. limbata* var. *disciformis, Th. magna, Th. melleni, Th.* aff. *Th. papillata*, *Th. polygona*, *Th. slocomi, Th. sphaerica, Th. subsphaerica*, *Colonammina verruca, Psammosphaera cava*, *Sorosphaera*? *tricella, Sorosphaera multicella, S. subconfusa, Glomospira biplana, Hyperammina curva*, *Ammodiscus furcus*, "*Lituotuba exserta*", and *Shidelerella* sp. 1 first occuring in sample 4. After sample 4, the diversity of species drops but eventually rebounds at the top of the section in samples 9 and 10 with species *Lagenammina cucurbita*, *L. sphaerica*, *L. stilla*, *Thurammina irregularis, Th.* aff. *Th. papillata*, *Th. slocomi*, *Colonammina verruca, Psammosphera cava*, *Sorosphaera*? *tricella, Sorosphaera muticella,* and *Ammodiscus furcus* reappearing. Six species of foraminifers*, Lagenammina sphaerica*, *L. stilla, Thurammina irregularis, Th.* aff. *Th. papillata*, *Psammosphaera cava,* and *Ammodiscus furcus* span the entire section with *Ammodiscus furcus* being the most abundant species of foraminifers found in samples from this section. The only appearance of species *Glomospirella ellipsoidalis* within the Haragan Creek section occurs in sample 7 and likewise the only appearance of *Glomospira inflata* occured in sample 7A. Based upon previous studies of changes within the population and the diversity of species of conodonts from the Clarita Formation, Barrick et al. (2009) estimated the Mulde Event took place in the time interval bounded by strata between samples 7 and 7A in the Haragan Creek section (Figure 1-4).

Table 2-1 Species distribution chart for the Haragan Creek section relative to conodont zones.

Haragan Creek (HC) Section																	
	ranuliformis							***amsdeni***								***stauros***	
Species	**Sample Numbers**																
	1	**1A**	**2**	**2A**	**2B**	**2C**	**3**	**3A**	**3B**	**4**	**5**	**6**	**7**	**7A**	**8**	**9**	**10**
Lagenammina aspera (Stewart and Priddy 1941)	X							X									
Lagenammina sphaerica Moreman 1930	X	X	X	X	X	X	X	X	X	X						X	X
Lagenammina stilla, Moreman 1930	X	X	X		X	X	X	X	X	X						X	X
Thurammina aff. *Th. papillata* Brady 1879	X	X				X	X	X	X	X	X		X			X	X
Thurammina subsphaerica Moreman 1930	X	X		X		X	X	X	X	X			X				
Thurammina irregularis Moreman 1930	X	X	X	X	X	X	X	X	X	X							X
Thurammina magna Dunn 1942	X	X	X	X			X	X									
Thurammina melleni Dunn 1942	X			X		X		X									
Thurammina slocomi Dunn 1942	X				X	X	X	X								X	
Thurammina elegans Dunn 1950	X		X	X	X	X	X	X	X	X	X						
Thurammina inflata Dunn 1942	X			X					X								
Psammosphaera cava Moreman 1930	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X
Hyperammina curva (Moreman 1933)	X																
Ammodiscus furcus Moreman	X	X	X		X	X	X	X	X	X	X		X	X		X	X
Lagenammina cucurbita Moreman 1933		X		X	X		X	X								X	
Thurammina sphaerica Ireland 1939		X	X	X		X	X	X									
Thurammina foerstei Dunn 1942		X	X		X		X										
Colonammina verruca Moreman 1930			X			X	X	X	X	X						X	
"Lituotuba" exserta Moreman 1930			X	X	X	X			X	X	X		X	X			
Sorosphaera? tricella Moreman 1930				X		X	X		X	X						X	X
Thurammina limbata var. Th. disciformis Dunn 1942						X											
Shidelerella sp. 1						X											
Sorosphaera multicella Dunn 1942						X				X						X	
Thurammina echinata Dunn 1942							X	X	X								
Thurammina polygona Ireland,1939										X							
Sorosphaera subconfusa Dunn 1942										X							
Glomospira biplana Moreman 1933										X	X						
Glomospirella ellipsoidalis Ireland 1966													X				
Glomospira inflata (Ireland) 1939														X			
Thurammina sp. 1																	X
Amphitremoida parvituba (Dunn 1942)																	X

Some differences in the foraminifer assemblages are noted between these two samples with six species of foraminifers identified in sample 7, *Thurammina* aff. *Th. papillata*, *Th. subsphaerica*, *Psammosphaera cava*, *Ammodiscus furcus*, *"Lituotuba" exserta*, and *Glomospirella ellipsoidalis*, and only four species, *Psammosphaera cava*, *Ammodiscus furcus*, *"Lituotuba" exserta*, and *Glomospira inflata*, identified in sample 7A. Three species, *Thurammina elegans*, *Th. subsphaerica,* and *Glomospirella ellipsoidalis* were identified in sample 7 from strata deposited prior to the Mulde Event but are not identified in any of the subsequent samples after the Mulde Event. No foraminifers were identified in sample 8. Perhaps the differences in the faunas indicate that the location of the Mulde unconformity should be situated between samples 7A and 8 of this section on the basis of foraminifers. Alternatively, the differences between the locations of the Mulde Event based on conodonts and foraminifers could indicate that the entire fauna was affected differently by environmental fluctuations. Foraminifers were possibly more sensitive to environmental changes, and therefore the diversity and populations were affected before the evidence of changes within the conodont populations could be seen.

2.2.2 Ca 2 Section

The Ca 2 section spans the length of the Fitzhugh Member through the conodont zones *ranuliformis*, *amsdeni*, and *stauros* (Figure 1-4). Foraminifers are found in samples 1 through 14 except samples 2 and 7 in which no foraminifers were present. Twenty nine species of foraminifers of 10 genera were identified in this section (Table 2-2).The overall diversity of foraminifers through section is similar to that of the Haragan Creek section. The stepped first appearance of only two species, *Thurammina irregularis* and *Th. slocomi*, occurs in sample 1. Twelve species of foraminifers such as *Lagenammina aspera*, *L. sphaerica*, *Thurammina elegans*, *Th. foerstei*, *Th. magna*, *Th.* aff. *Th. papillata*, *Th. sphaerica*, *Th. subsphaerica*, *Colonammina verruca*, *Psammosphaera cava*, *Ammodiscus furcus*, and *Shidelerella elongata*, first occur in sample 3 within the *ranuliformis* conodont zone. The foraminifers *Amphitremoida parvituba*, *Lagenammina stilla*, *Thurammina melleni*, and *Shidelerella* sp. 1 first appear in sample 4, and *Lagenammina cucurbita*, *Thurammina tributa*, *Sorosphaera*? *tricella*, and *"Lituotuba" exserta* first occur in sample 5. The first appearance of only two species, *Thurammina polygona* and *Sorosphaera multicella*, is in sample 9, and two species, *Thurammina* sp. 1 and *Sorosphaera subconfusa,* in sample 10. The first and only occurrence of the foraminifer *Thurammina inflata* occurs in sample 11. The first appearance of *Thurammina echinata* is in sample 12, and *Hyperammina curva* in sample 13. Only one species of foraminifer, *Thurammina irregularis*, spans the length of the entire section. Six species of foraminifers are found in only one sample and include *Thurammina foerstei* and *Shidelerella elongata* (sample 3), *Amphitremoida parvituba* and *Shidelerella* sp. 1

Table 2-2 Species distribution chart of the Ca 2 section relative to conodont zones.

Ca 2 Section														
Species	*ranuliformis*								*amsdeni*				*stauros*	
	Sample Numbers													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Thurammina irregularis Moreman 1930	X			X	X	X						X	X	X
Thurammina slocomi Dunn 1942	X			X	X	X								
Lagenammina aspera (Stewart and Priddy 1941)			X		X			X		X		X		
Lagenammina sphaerica Moreman 1930			X	X	X	X		X	X	X		X	X	X
Thurammina elegans Dunn 1950			X	X	X	X		X	X		X	X		X
Thurammina foerstei Dunn 1942			X											
Thurammina magna Dunn 1942			X	X	X			X	X			X	X	X
Thurammina aff. *Th. papillata* Brady 1879			X		X	X		X	X	X		X	X	X
Thurammina sphaerica Ireland 1939			X	X	X	X			X					X
Thurammina subsphaerica Moreman 1930			X					X	X					X
Colonammina verruca Moreman 1930			X		X	X		X	X		X		X	X
Psammosphaera cava Moreman 1930			X	X	X	X		X	X	X	X	X	X	X
Ammodiscus furcus Moreman 1930			X	X	X	X		X	X	X		X	X	X
Shidelerella elongata Dunn 1942			X											
Amphitremoida parvituba (Dunn 1942)				X										
Lagenammina stilla Moreman 1930				X	X	X		X	X			X	X	X
Thurammina melleni Dunn 1942				X	X	X			X					
Shidelerella sp. 1				X										
Lagenammina cucurbita Moreman 1933					X	X		X	X					
Thurammina tributa Dunn 1942					X	X								
Sorosphaera ? tricella Moreman 1930					X			X	X		X	X	X	X
"Lituotuba" exserta Moreman 1930					X	X			X	X		X		
Thurammina polygona Ireland 1939									X		X			
Sorosphaera multicella Dunn 1942									X	X	X		X	X
Thurammina sp. 1										X	X	X	X	X
Sorosphaera subconfusa Dunn 1942										X	X			
Thurammina inflata (Ireland) 1939											X			
Thurammina echinata Dunn 1942												X	X	X
Hyperammina curva (Moreman 1933)													X	

(sample 4), *Thurammina inflata* (sample 11) and *Hyperammina curva* (sample 13). Based on the presence of conodonts in the Ca 2 section, Barrick determined that the Mulde unconformity is situated between sample 10 and sample 11.

There is little difference between these two samples. Nine species of foraminifers such as *Lagenammina aspera*, *L*. *sphaerica*, *Thurammina* aff. *Th*. *papillata*, *Psammosphaera cava*, *Ammodiscus furcu*s, “*Lituotuba*” *exserta*, *Sorosphaera multicella*, *S*. *subconfusa* and *Thurammina* sp. 1 are present in sample 10, and some of them such as *Thurammina elegans*, *Psammosphaera cava*, *Sorosphaera multicella, Thurammina* sp. 1 and *Sorosphaera subconfusa* continued into sample 11. The species *Thurammina elegans*, *Colonammina verruca*, *Sorosphaera*? *tricella*, and *Thurammina polygona* known in sample 9 reappear again in sample 11. The species *Thurammina inflata* appears for the first time in sample 11, *Thurammina echinata* – in sample 12, and *Hyperammina curva* – in sample 13. These three species appear after the Mulde unconformity in the Ca 2 section, whereas these species occur before Mulde unconformity in the Haragan Creek section.

2.2.3 J5 section

The J5 section is represented by five samples that correlate to the *ranuliformis* and *amsdeni* conodont zones (Figure 1-4). Of the five samples, only two samples (samples 12 and 13) actually contained foraminifers. No foraminifers were found from samples 15, 8 and 9 and as a result none of the species span the entire length of the section. Fourteen species of 7 genera of foraminifers are present in the section (Table 2-3). Only four species, *Shidelerella elongata*, *Hyperammina curva*, *Ammodiscus furcus*, and “*Lituotuba*” *exserta* occur in sample 12, and 14 species of foraminifers are present in sample 13.

Table 2-3 Species distribution in the J5 section relative to conodont zones.

J5 Section						
Species	***ranuliformis***				***amsdeni***	
	Sample Numbers					
	12	**13**	**14**	**15**	**8**	**9**
Shidelerella elongata Dunn 1942	X	X				
Hyperammina curva (Moreman 1933)	X	X				
Ammodiscus furcus Moreman 1930	X	X				
"Lituotuba" exserta Moreman 1930	X	X				
Lagenammina aspera (Stewart and Priddy 1941)		X				
Lagenammina sphaerica Moreman 1930		X				
Lagenammina stilla Moreman 1930		X				
Thurammina aff. *Th. papillata* Brady 1879		X				
Thurammina subsphaerica Moreman 1930		X				
Thurammina foerstei Dunn 1942		X				
Thurammina melleni Dunn 1942		X				
Thurammina elegans Dunn 1950		X				
Shidelerella cylindrica Dunn 1942		X				
Psammosphaera cava Moreman 1930		X				

2.2.4 M2 section

The M2 section is represented by five samples that correlate to the *amsdeni*, *stauros*, and *variabilis* conodont zones (Figure 1-4). This section is the shortest section sampled and is represented by 24 species of 9 genera of foraminifers (Table 2-4). Only one species, *Ammodiscus furcus*, spans the entire length of the section. Fourteen species occur in the lowermost sample (sample 5) within the *ranuliformis* conodont zone and include *Lagenammina aspera, L. stilla, L. sphaerica, Thurammina foerstei, Th. limbata* var. *disciformis, Th. magna, Th.* aff. *Th. papillata, Th.* sp. 1, *Th. subsphaerica, Colonammina verruca, Psammosphaera cava, Sorosphaera*? *tricella, Ammodiscus furcus,* and *"Lituotuba" exserta*. Five species first occur in sample 4 and include *Thurammina echinata*, *Th. elegans*, *Th. irregularis*, *Th. sphaerica* and *Th. tributa*. The species *Thurammina inflata*, *Th. polygona*, *Th. slocomi*, *Sorosphaera*? sp. 1, and *Glomospirella ellipsoidalis* first appear in sample 3.

Table 2-4 Species distribution in the M2 section relative to conodont zones.

M2 Section					
Species	***amsdeni***	***stauros***			***variabilis***
	Sample Numbers				
	5	**4**	**3**	**2**	**1**
Lagenammina aspera (Stewart and Priddy 1941)	X	X	X		
Lagenammina stilla Moreman 1930	X	X	X	X	
Lagenammina sphaerica Moreman 1930	X	X	X		
Thurammina foerstei Dunn 1942	X	X	X		
Thurammina limbata var. *disciformis* Dunn 1942	X	X	X	X	
Thurammina magna Dunn 1942	X	X	X		
Thurammina aff. *Th. papillata* Brady 1879	X	X	X		
Thurammina sp. 1	X	X	X	X	
Thurammina subsphaerica Moreman 1930	X	X	X		
Colanammina verruca Moreman 1930	X	X	X		
Psammosphaera cava Moreman 1930	X	X	X	X	
Sorosphaera? tricella Moreman 1930	X	X	X	X	
Ammodiscus furcus Moreman 1930	X	X	X	X	X
"Lituotuba" exserta Moreman 1930	X	X	X	X	
Thurammina echinata Dunn 1942		X	X		
Thurammina elegans Dunn 1950		X	X	X	
Thurammina irregularis Moreman 1930		X	X	X	
Thurammina sphaerica Ireland 1939		X	X		
Thurammina tributa Dunn 1942		X	X		
Thurammina inflata (Ireland) 1939			X		
Thurammina polygona Ireland 1939			X		
Thurammina slocomi Dunn 1942			X	X	
Sorosphaera? sp. 1			X		
Glomospirella ellipsoidalis Ireland 1966			X		

A new conodont zone, *stauros*, begins with sample 4 and continues through sample 2 in the M2 section (Table 2-4). This zone shows the most diversity in terms of foraminifers. The uppermost sample (sample 1) shows a dramatic decrease in number of species of foraminifers with only one species, *Ammodiscus furcus*, identified. This sample also marks the transistion from the *stauros* conodont zone to the *variabilis* conodont zone. The M2 section in its entirety is located stratigraphically above the Mulde unconformity.

2.2.5 Highway 77 Section

The Highway 77 section, much like the previous Haragan Creek section and Ca 2 section is represented by diverse and abundant foraminifers (Figure 1-4, Table 2-5).

Thirty one species of 11 genera were identified from 15 samples within conodont zones*ranuliformis*, *amsdeni*, *stauros*, and *variabilis* (Table 2-5). Foraminifers occur in allsamples with the exception of sample 22.

Table 2-5 Species distribution in the Highway 77 section relative to conodont zones.

Species	Highway 77 Section														
	ranuliformis							*amsdeni*				*stauros*			*variabilis*
	Sample Numbers														
	12	**12A**	**13**	**14**	**17**	**18**	**19**	**20**	**20A**	**15**	**16**	**21**	**22**	**23**	**24**
Thurammina melleni Dunn 1942	X	X	X	X	X										
Thurammina slocomi Dunn 1942	X						X			X					
Thurammina elegans Dunn 1950	X	X			X	X				X		X			
Thurammina tributa Dunn 1942	X	X	X									X			
Thurammina limbata Dunn 1942	X	X	X	X					X	X	X	X		X	
Thurammina foerstei Dunn 1942	X			X	X										
Thurammina aff. *Th. papillata* Brady 1879	X	X	X	X		X	X		X	X	X			X	X
Thurammina subsphaerica Moreman 1930	X	X				X	X		X	X	X			X	X
Thurammina irregularis Moreman 1930	X	X	X	X	X		X		X	X	X	X		X	
Amphitremoida parvituba (Dunn 1942)	X														
Psammosphaera cava Moreman 1930	X	X	X	X	X	X	X		X	X	X	X		X	X
"Lituotuba" exserta Moreman 1930		X	X		X		X		X	X	X	X		X	X
Lagennamina sphaerica Moreman 1930		X	X	X	x	X	X		X	X	X	X		X	X
Lagenammina stilla Moreman 1930		X		X	X		X		X	X	X	X		X	X
Lagenammina aspera (Stewart and Priddy 1941)			X								X	X		X	X
Thurammina sphaerica Ireland 1939			X	X	X	X			X	X				X	
Thurammina polygona Ireland 1939				X											
Thurammina magna Dunn 1942				X		X	X				X				
Colonammina verruca Moreman 1930				X					X	X	X	X			
Ammodiscus furcus Moreman 1930				X	X	X	X	X	X	X	X	X		X	X
Thurammina limbata var. Th. disciformis Dunn 1942									X						
Sorosphaera ? *tricella* Moreman 1930									X	X	X			X	
Glomospirella ellipsoidalis Ireland 1966									X						
Glomospira sp. 1									X						
Lagenammina cucurbita Moreman 1933										X					
Thurammina sp. 1										X	X			X	
Hyperammina curva (Moreman 1933)										X		X		X	X
Glomospira inflata (Ireland) 1939										X					X
Shidelerella sp. 1										X					
Thurammina tubulata Moreman1930															X
Sorosphaera multicella Dunn 1942															X

Only three species, *Thurammina* aff. *Th*. *papillata*, *Th*. *subsphaerica*, and *Psammosphaera cava*, span the length of the entire section. The first appearance of 11 species of foraminifers occurs in the lowermost sample (sample 12) in the Highway 77 section and include *Thurammina melleni, Th. slocomi, Th. elegans, Th. tributa, Th. limbata, Th. foerstei, Th. aff. Th. papillata, Th. subsphaerica, Th. irregularis*, *Amphitremoida parvituba* and *Psammosphaera cava*.

Three species of foraminifers first appear in sample 12A and include *"Lituotuba" exserta*, *Lagenammina sphaerica*, and *L. stilla. Lagenammina aspera* and *Thurammina* *sphaerica* first appear in sample 13. Four species of foraminifers such as *Thurammina polygona*, *Th. magna*, *Colonammina verruca*, and *Ammodiscus furcus* first occur in sample 14. The aforementioned twenty species of foraminifers within the Highway 77 section (samples 12-14) marks the first appearance of a majority of the species within the section and all of them continue to be present in samples 17 through 19. The next stepped first appearances of species of foraminifers occurs in sample 20A where four species of foraminifers, *Thurammina limbata* var. *disciformis*, *Sorosphaera*? *tricella*, and *Glomospirella ellipsoidalis* and *Glomospira* sp. 1, appear for the first time. Barrick determined that the Mulde unconformity based upon conodonts took place in the time represented between samples 20A and 15. Five species of foraminifers first appear in sample 15 and they are *Lagenammina cucurbita*, *Thurammina* sp. 1, *Hyperammina curva*, *Glomospira inflata*, and *Shidelerella* sp. 1. Two more species of the foraminifers such as *Thurammina tubulata* and *Sorosphaera multicella* appear for the first time in sample 24 located within the *variabilis* conodont zone.

Within the Highway 77 section, a drastic reduction in foraminifers occurs between samples 19 and 20, where the number of species diminishes from 10 species (*Thurammina slocomi*, *Th.* aff. *Th. papillata*, *Th. subsphaerica*, *Th. irregularis*, *Psammosphaera cava*, *"Lituotuba" exserta*, *Lagenammina sphaerica*, *L. stilla*, *Thurammina magna*, and *Ammodiscus furcus)* in sample 19 to only one species, *Ammodiscus furcus*, in sample 20. This reduction in foraminifers prior to the Mulde Event and prior to changes within the diversity and populations of conodonts follows the trends of the Haragan Creek section in which the diversity of foraminifers reduces dramatically one to two samples prior to the Mulde Event.

Fifteen species of foraminifers were identified in sample 20A prior to the defined location of the Mulde Event and include *Lagenammina sphaerica*, *L. stilla*, *Thurammina* *irregularis*, *Th. limbata*, *Th. limbata* var. *disciformis*, *Th.* aff. *Th. papillata*, *Th. sphaerica*, *Th. subsphaerica*, *Colonammina verruca*, *Psammosphaera cava, Sorosphaera*? *tricella, Ammodiscus furcus, Glomospirella ellipsoidalis, Glomorspira* sp. 1, and *"Lituotuba" exserta*. Of these 15 species, four species of foraminifers first appear in sample 20A and include *Th. limbata* var. *disciformis*, *Sorosphaera*? *tricella, Glomospirella ellipsoidalis,* and *Glomorspira* sp. 1. Sample 15, post-Mulde Event, shows moderate variation of species from that of sample 20A. Nineteen species of foraminifers are identified in sample 15 and include species known from sample 20A and species which first appear in the sample such as *Lagenammina cucurbita*, *Thurammina* sp. 1, *Hyperammina curva, Glomospira inflata,* and *Shidelerella* sp. 1. Two species, *Glomospirella ellipsoidalis* and *Glomospira* sp. 1, do not occur in sample 15.

2.3 Foraminifers and the Mulde Event

The Mulde Event (or unconformity) appears to have had a small impact on the population and diversity of species of foraminifers in the sections studied, however, possibly not in the same sense as how conodonts were affected by this oceanic event. A general trend throughout the three sections (Highway 77, Ca 2, and Haragan Creek) that were sampled through the Mulde Event shows that foraminifers were affected sooner than conodont populations. In general, the stepped first appearance of a majority of species of foraminifers occurs prior to the Mulde Event with the continuation of some species known before the Mulde Event and with a lesser number of new species appearing after the Mulde Event.

2.4 Foraminiferal Assemblages and Conodont Zones

Two assemblages of foraminifers can be established within the Fitzhugh Member of the Clarita Formation. The first one and the lowest assemblage can be established in the lower part of the *ranuliformis* conodont zone. The first appearance of 21 species of the foraminifers of a total 38 species is seen at the lower boundary of this conodont zone (Table 2-6). Almost all of these species range through the entire Fitzhugh Member, except for the two species, *Shidelerella elongata* and *S. cylindrica*, which occur only in the lower part of the *ranuliformis* conodont zone. Thus, the lower assemblage can be named as the *Shidelerella elongata* assemblage. This assemblage can be traced in all studied sections.

The second assemblage of foraminifers spans from the middle part of the *ranuliformis* through *stauros* conodont zones. The base of this assemblage is marked by the first appearance of foraminifer species such as *Thurammina sphaerica, Th. polygona*, *Th. limbata* var. *disciformis, Colonammina verruca*, *Sorosphaera*? *tricella*, and *Shidelerella* sp. 1. The species *Thurammina echinata*, *Th*. sp. 1, *Sorosphaera multicella*, *S*. sp. 1, *Glomospira biplana*, *G*. *inflata*, *G*. sp. 1, and *Glomospirella ellipsoidalis* first appear in this assemblage and terminate within this assemblage. Besides the mentioned above species, the species *Thurammina inflata*, *Th. melleni*, *Th. foerstei*, *Lagenammina cucurbita*, *Th. tributa*, *Th. polygona*, *Colonammina verruca*, and *Shidelerella* sp. 1 dissappear at the top of the assemblage. The species *Thurammina sphaerica* is very abundant in the assemblage, and thus is named as the *Thurammina sphaerica* asemblage. This assemblage is present in all sections with the exception of the J5 section.

The species of foraminifers known from two underlying assemblages such as *Lagenammina aspera*, *L. sphaerica*, *L. stilla*, *Thurammina* aff. *Th. papillata*, *Th. subsphaerica*, *Psammosphaera cava*, *Hyperammina curva*, *Ammodiscus furcus*, "*Lituotuba*" *exserta*, *Sorosphaera multicella*, and *Glomospira inflata*, continue into the *variabilis* conodont zone, and only one species, *Thurammina tubulata*, first appears in this zone.

Table 2-6 Distribution species of the foraminfers in the Clarita Formation in reference to conodont zones.

Species	Conodont zone			
	ranuliformis	*amsdeni*	*stauros*	*variabilis*
Amphitremoida parvituba (Dunn 1942)	—	—	—	
Lagenammina aspera (Stewart and Priddy 1941)	—	—	—	—
Lagenammina cucurbita Moreman 1933	—	—	—	
Lagenammina sphaerica Moreman 1930	—	—	—	—
Lagenammina stilla Moreman 1930	—	—	—	—
Thurammina elegans Dunn 1950	—	—	—	
Thurammina foerstei Dunn 1942	—	—	—	
Thurammina inflata (Ireland) 1939	—	—		
Thurammina irregularis Moreman 1930	—	—	—	
Thurammina limbata Dunn 1942	—	—	—	
Thurammina magna Dunn 1942	—	—	—	
Thurammina melleni Dunn 1942	—	—		
Thurammina aff. *Th. papillata* Brady 1879	—	—	—	—
Thurammina slocomi Dunn 1942	—	—	—	
Thurammina subsphaerica Moreman 1930	—	—	—	—
Thurammina tributa Dunn 1942	—	—	—	
Psammosphaera cava Moreman 1930	—	—	—	—
Hyperammina curva (Moreman 1933)	—	—	—	—
Ammodiscus furcus Moreman 1930	—	—	—	—
"Lituotuba" exserta Moreman 1930	—	—	—	—
Shidelerella elongata Dunn 1942	—			
Shidelerella cylindrica Dunn 1942	—			
Thurammina limbata var. Th. disciformis Dunn 1942	—	—	—	
Thurammina polygona Ireland 1939	—	—	—	
Thurammina sphaerica Ireland 1939	—	—	—	
Colanammina verruca Moreman 1930	—	—	—	
Sorosphaera? tricella Moreman 1930	—	—	—	
Shidelerella sp. 1	—	—		
Thurammina echinata Dunn 1942	—	—	—	
Sorosphaera multicella Dunn 1942	—	—	—	—
Thurammina sp. 1		—	—	
Sorosphaera subconfusa Dunn 1942		—	—	
Glomospira biplana Moreman 1933		—		
Glomospirella ellipsoidalis Ireland 1966		—		
Glomospira inflata (Ireland) 1939		—	—	—
Sorosphaera sp. 1			—	
Glomospira sp. 1			—	
Thurammina tubulata Dunn 1942				—

Chapter 3

SYSTEMATIC PALEONTOLOGY

The classification of higher protozoan taxa of Cavalier-Smith (2002) and the classifications of agglutinated foraminifers of Kaminski (2000) on order level and Mikhalevich (1995) on class level were used as a systematic approach to classifying the foraminifers in this study. Only some species of foraminifers that are considered to be valid are discussed and described in this study, and the synonymies presented herein should not be considered to be exhaustive or complete. Only significant species were listed in the synonymies in the descriptions of the species of foraminifers

Kingdom PROTOZOA Goldfuss 1817; emend. Owen 1858

Subkingdom GYMNOMYXA Lankester 1878 stat. nov. emend. Cavalier-Smith 2002

Infrakingdom RHIZARIA Cavalier-Smith 2002

Phylum RETARIA Cavalier-Smith 1999 stat. nov. Cavalier-Smith 2002

Subphylum FORAMINIFERA (d'Orbigny 1826) Eichwald 1830 stat. nov. Margulis 1974; stat. emend. Cavalier-Smith 2002 [pro phylum Foraminifera]

Class ASTRORHIZATA Saidova 1981; emend. Mikhalevich 1995; emend. Mikhalevich 1998

Order ASTRORHIZIDA Lankester 1885

Suborder ASTRORHIZINA Lankester 1885

Family HIPPOCREPINELLIDAE Loeblich and Tappan 1984; emend. Mikhalevich 1995

Genus ***Amphitremoida*** Eisenack 1938; emend. Nestell and Tolmacheva 2004 [= *Croneisella* Dunn 1942; = *Pachyammina* Eisenack 1967]

Type species: *Amphitremoida citroniforma* Eisenack 1938.

3.1 ***Amphitremoida parvituba*** (Dunn 1942)

Plate 3, figure 17

Thurammina parvituba DUNN 1942, p. 333, pl. 43, figs. 28-29.

Description: Test free, monothalamous, oval in shape with two necks protruding from each end of the test with a single aperture situated at the end of each neck; white or off-white in color, wall is composed of medium-sized siliceous grains and is rough in appearance. Dimensions (µm): test length including necks 310; length of the test without necks 270; test width 110; length of neck 20.

Material: 7 specimens from the Highway 77 section, Ca 2 section, and Haragan Creek section.

Discussion: Dunn (1942) classified *Thurammina parvituba* due to the fact that this species had more than one projection or neck. Based upon the shape of the test and the presence of two polar apertures this species was placed in the genus *Amphitremoida* Eisenack 1938 by Nestell and Tolmacheva (2004) and followed herein with the placement of *Thurammina parvituba* in the genus *Amphitremoida* due to the aforementioned features.

Occurrence: Silurian, Wenlock to Early Ludlow, late Telychian to early Gorstian, Fitzhugh Member, Clarita Formation. Highway 77 section, samples 12, 14 (*Kockelella ranuliformis* conodont zone); Ca 2 section, sample 4 (*Kockelella ranuliformis* conodont zone); Haragan Creek section, sample 10 (*Kockelella stauros* conodont zone).

Order SACCAMMINIDA Lankester 1885

Suborder SACCAMMININA Lankester 1885

Family SACCAMMINIDAE Brady 1884

Subfamily SACCAMMININAE Brady 1884

Genus *Lagenammina* Rhumbler 1911

Type species: *Lagenammina laguncula* Rhumbler 1911.

3.2 ***Lagenammina cucurbita*** Moreman

Plate 1, figures 9 - 11

Lagenammina cucurbita MOREMAN 1933, p. 395, pl. 47, fig. 5.

Lagenammina forma magna (nomen nudum) - AMSDEN et al. 1980, p. 17 (text).

Description: Test free, monothalamous, consists of a large, spherical chamber followed by a tubular neck with a circular aperture at the end of the neck, typically white or off-white in color; wall is agglutinated and composed of very fine-grained siliceous grains and is smooth in appearance. Dimensions (μm)*:* test length not including neck (L) 220 - 360, test width (W) 250 – 290, length of neck 80-150, width of neck 100- 120.

Material: 46 specimens from various sections.

Discussion: The diagnostic characteristics of this species are a large, spherical chamber with a neck, rounded aperture situated at the end of the neck, and very fine-grained and smooth agglutinated wall. Based on such features *Lagenammina cucurbita* can be easily distinguished from other species of the genus *Lagenammina*. By the spherical shape of the chamber, *L. cucurbita* is similar to *L. sphaerica* Moreman (1930, p. 47, pl. 5, fig. 15), but differs from it by two times larger chamber. Amsden et al. (1980) makes a reference to *Lagenammina forma magna*, but gave no formal description. *L. cucurbita* and *L. forma magna* are probably the same species, and thus *L. forma magna*, a nomen nudum, should be put into the synonymy of *L. cucurbita* because it has the same shape and size of the test.

Occurrence: Silurian, Wenlock to Early Ludlow, late Telychian to early Gorstian, Fitzhugh Member, Clarita Formation. Haragan Creek section, samples 1A, 2A, 2B, 3 (*Kockelella ranuliformis* conodont zone), 3A (*Kockelella amsdeni* conodont zone), 9 (*Kockelella stauros* conodont zone); Highway 77 section, sample 15 (*Kockelella amsdeni* conodont zone); Ca 2 section, samples 5, 6, 8 (*Kockelella ranuliformis* conodont zone), 9 (*Kockelella amsdeni* conodont zone).

3.3 ***Lagenammina sphaerica*** Moreman

Plate 1, figures 3 - 5

Lagenammina sphaerica MOREMAN 1930, p. 48, pl. 5, fig. 15.

Lagenammina distorta IRELAND 1939, p. 196, figure A - 20-21.

Lagenammina uniformis DUNN 1942, p. 328, pl. 43, fig. 4.

Description: Test free, monothalamous, consists of a spherical chamber followed by a relatively long tubular neck with a circular aperture at the end of the neck, typically white or off-white in color; wall is agglutinated and composed of medium-sized siliceous grains and is generally rough in appearance. Dimensions (μm): test length including neck (L): 200-300, test width (W) 150-200, neck length 80-100, width of neck 20 – 50.

Material: Abundant in all samples.

Discussion: Lagenammina sphaerica differs from other species of *Lagenammina* due to its delicate appearance, larger grain size of the wall, spherical shape of the chamber and generally smaller test size. By comparison, *Lagenammina stilla* Moreman has a shorter neck and an ellipsoidal initial chamber that is typically larger than in *L. sphaerica*. *Lagenammina cucurbita* Moreman is larger in size and typically has a finer grain size of the wall. In this study, *Lagenammina distorta* Ireland is considered as a synonym of *L. sphaerica,* although the two species have been separated into two different species in the past based upon the distorted nature of the neck. The distortion of the neck alone could be the product of deformation during burial or an environmental adaptation. *Lagenammina uniformis* Dunn is also considered to be a synonym of *L. sphaerica*. Dunn (1942) described *L. uniformis* as 'urn-shaped' based upon the flattened nature of the upper portion of the test. This flattened appearance leading to an urn-shaped description could have resulted from deformation during burial much like the distortion seen in *L. distorta* Ireland. The size and general appearance of *L. uniformis* suggests placing this species within *L. sphaerica*. Mound (1968) places the species *Lagenammina sphaerica* and *L. cucurbita* as synonymies of *Lagenammina sphaerica* based on general appearance of the test. Herein such a unification of these species is not followed and *L*. *sphaerica* and *L*. *cucurbita* are considered as separate species. In fact, *L. cucurbita* is typically two times larger than *L. sphaerica* and has a finer grain size of the wall.

Occurrence: Silurian, Wenlock to Early Ludlow, late Telychian to early Gorstian, Fitzhugh Member, Clarita Formation. Haragan Creek section, samples 1, 1A, 2, 2A, 2B, 3 (*Kockelella ranuliformis* conodont zone), 3A, 3B, 4 (*Kockelella amsdeni* conodont zone), 9, 10 (*Kockelella stauros* conodont zone); Highway 77 section, samples 12A, 13, 14,18, 19 (*Kockelella ranuliformis* conodont zone), 15, 16 (*Kockelella amsdeni* conodont zone), 21, 23 (*Kockelella stauros* conodont zone), 24 (*Kockelella variabilis* conodont zone); Ca 2 section, samples 1, 3, 4, 5, 6, 7, 8 (*Kockelella ranuliformis* conodont zone), 9, 10, 12 (*Kockelella amsdeni* conodont zone),13, 14 (*Kockelella stauros* conodont zone); J5 section, sample 13 (*Kockelella ranuliformis* conodont zone); and M2 section, samples 5 (*Kockelella amsdeni* conodont zone), 4, 3 (*Kockelella stauros* conodont zone).

Subfamily THURAMMININAE Miklukho-Maklay 1963

Genus ***Thurammina*** Brady 1879

Type species: *Thurammina papillata* Brady 1879.

3.4 ***Thurammina* sp. 1**

Plate 2, figure 10

Description: Test free, monothalamous, spherical, typically white or off-white in color; with very small, subtle projections scattered on surface of the test with oval apertures situated at the end of the projections; wall is agglutinated and composed of medium sized, subangular grains lending to rough appearance of the test. Dimensions (µm): diameter of the test 600.

Material: 12 specimens from the Highway 77 section, Haragan Creek section and Ca 2 section.

Discussion: The length and characteristics of the projections differentiate this species from other species of the genus *Thurammina* and species *Psammosphaera cava* Moreman. *Thurammina* sp. 1 has very short, subtle projections that are evenly spaced on the surface of the test. *Thurammina papillata* Brady identified by Moreman (1930), and now considered as *Th*. aff. *Th. papillata*, tends to have longer projections that are more defined and larger in size as compared to *Thurammina* sp. 1. The appearance of the projections found on *Thurammina tubulata* Moreman is similar in appearance to those of *Thurammina* sp. 1 with the exception of the length of the projections. *Th. tubulata* has long, slender projections evenly spaced over the surface of the test whereas the projections are very miniscule in size on *Thurammina* sp. 1. *Psammosphaera cava* could easily be confused with *Thurammina* sp. 1 if the projections are not observed on *Thurammina* sp. 1. Both species have a spherical test shape with the lack of projections in *P. cava* being the primary difference between it and *Thurammina* sp. 1.

Occurrence: Silurian, Wenlock to Early Ludlow, late Telychian to early Gorstian, Fitzhugh Member, Clarita Formation. Highway 77 section, samples 15, 16 (*Kockelella amsdeni* conodont zone), 23 (*Kockelella stauros* conodont zone); Ca 2 section, samples 10, 11, 12 (*Kockelella amsdeni* conodont zone),14 (*Kockelella stauros* conodont zone); Haragan Creek section, sample 10 (*Kockelella stauros* conodont zone).

3.5 ***Thurammina* aff. *Th. papillata*** Brady

Plate 2, figures 1 - 2a

Thurammina papillata Brady – MOREMAN 1930, p. 51, pl. 5, fig. 13; DUNN 1942, p. 330, pl. 43, fig. 9; IRELAND 1966, p. 226, pl. 1, fig. 18; MOUND 1968, p. 103, pl. 6, figs. 32-34.

Description: Test free, monothalamous, spherical with numerous short, nipple-like projections evenly distributed over the surface of the test; typically white or off-white in color; wall is agglutinated and composed of very fine-grained siliceous grains and is smooth in appearance; rounded apertures located at the end of each projection. Dimensions (μm): test diameter 720 – 820, height of projections 20-50.

Material: Abundant in all samples.

Discussion: Brady (1879) originally described *Thurammina papillata* from ten stations in the Atlantic and Pacific Oceans at depths from 350 to 2000 fathoms (640 to 3657 meters) during an expedition on the "Challenger". The level of the samples described by Brady is Holocene. In the original description of the species, Brady pointed out that *Th*. *papillata* occasionally can have one or two or more chambers attached to each other, single chamber can sometimes have an elongate neck, and irregularly located (and frequently, according to the illustrations) perforate "papillae" with obscure apertures. Silurian forms identified as *Th*. *papillata* by many authors (Moreman 1930; Dunn 1942; Ireland 1966; Mound 1968) have distinctly different features and actually represent a different species. For example, papillae are much widely and evenly distributed and are fewer in number on the surfaces of the Silurian tests. Thus, the Silurian species are assigned herein to *Thurammina* aff. *Th*. p*apillata* because of some similarities to the Holocene forms.

By comparison, *Thurammina* aff. *Th. papillata* differs from *Thurammina tubulata* Moreman and *Th. subpapillata* Ireland due to differences in size and shape of projections. *Thurammina tubulata* has long, slender projections that range in size from 50-60 µm, whereas *Thurammina* aff. *Th. papillata* has shorter and wider projections. *Th*. *subpapillata* has very minute almost indistinguishable projections, whereas *Thurammina* aff. *Th. papillata* has much more pronounced and prominent projections.

Occurrence: Silurian, Wenlock to Early Ludlow, late Telychian to early Gorstian, Fitzhugh Member, Clarita Formation. Haragan Creek section, samples 1, 1A, 2C, 3 (*Kockelella ranuliformis* conodont zone), 3A, 3B, 4, 5, 7 (*Kockelella amsdeni* conodont zone), 9, 10 (*Kockelella stauros* conodont zone); Highway 77 section, samples 12, 12A, 13, 14, 18, 19 (*Kockelella ranuliformis* conodont zone), 20, 15 , 16 (*Kockelella amsdeni* conodont zone), 23 (*Kockelella stauros* conodont zone), 24 (*Kockelella variabilis* conodont zone); M2 section, samples 5 (*Kockelella amsdeni* conodont zone), 4, 3 (*Kockelella stauros* conodont zone); Ca 2 section, samples 1, 3, 5, 6, 8 (*Kockelella ranuliformis* conodont zone), 9, 10, 12 (*Kockelella amsdeni* conodont zone), 13, 14 (*Kockelella stauros* conodont zone); and J5 section, sample 13 (*Kockelella ranuliformis* conodont zone).

Family PSAMMOSPHAERIDAE Haeckel 1894

Subfamily PSAMMOSPHAERINAE Haeckel 1894

Genus ***Sorosphaera*** Brady 1879

Type species: *Sorosphaera confusa* Brady 1879.

3.6 ***Sorosphaera***? ***tricella*** Moreman

Plate 4, figures 5 - 8

Sorosphaera tricella MOREMAN 1930, p. 47, pl. 5, figs. 12, 14.

Sorosphaera bicella DUNN 1942, p. 325, pl. 42, figs. 17-18.

Description: Test free, consists of one or more spherical chambers in a range of different configurations from individual chambers, to clusters of two, three chambers or up to 6 chambers to linear rows of spherical chambers (up to 5 chambers) connected by strings of organic material (plate 4, figs. 5 – 5a); typically white or off-white in color; wall is agglutinated; composed of very fine-grained siliceous grains and is smooth in appearance. Each spherical chamber has at least one aperture but generally two apertures are apparent. Dimensions (µm): diameter of individual chamber 310 – 390; length of linear rows 590 – 910; diameter of clusters 400 – 600; diameter of apertures 20-30.

Material: 67 specimens from Highway 77 section, Haragan Creek section, Ca 2 section, and M2 section.

Discussion: The genus *Sorosphaera* was established by Brady in 1879. Brady originally described *Sorosphaera* with the lacking of any aperture being one the diagnostic or “most striking features” of the genus. This same idea was replicated in Moreman’s description of the new species *Sorosphaera tricella* in 1930. He describes this species and notes “apertures not apparent”. It has been discovered in this study that *Sorosphaera tricella* Moreman does indeed have an apparent aperture and in some cases two apertures. It appears that in the early stage of life for this foraminifer only one aperture is present but, perhaps as a result of budding or later life stage, each spherical chamber contains two apertures. In previous studies, the species of *Sorosphaera* were identified by the number of spherical chambers present in an individual specimen. In turn, *Sorosphaera tricella* and *Sorosphaera bicella* Dunn have been identified based upon the strategy of using this variable feature as the primary diagnostic tool of identification. Herein, it is considered that the species *Sorosphaera tricella* and *Sorosphaera bicella* are the same species. They are identical in appearance but may consist of a varying number of spherical chambers in different arrangements. *Sorosphaera tricella* has been assigned questionably to the genus *Sorosphaera* due to the presence of at least one aperture. All other morphological features are similar to those described by Brady for the genus *Sorosphaera*.

Occurrence: Silurian, Wenlock to Early Ludlow, late Telychian to early Gorstian, Fitzhugh Member, Clarita Formation. Haragan Creek section, samples 2A, 2C, 3 (*Kockelella ranuliformis* conodont zone), 3B, 4 (*Kockelella amsdeni* conodont zone), 9, 10 (*Kockelella stauros* conodont zone); Highway 77 section, samples 15, 16 (*Kockelella amsdeni* conodont zone), 24 (*Kockelella variabilis* conodont zone); M2 section, samples 5 (*Kockelella amsdeni* conodont zone), 4, 3, 2 (*Kockelella stauros* conodont zone); Ca 2 section, samples 5, 8 (*Kockelella ranuliformis* conodont zone), 9, 11, 12 (*Kockelella amsdeni* conodont zone), 13, 14 (*Kockelella stauros* conodont zone).

Order AMMODISCIDA Mikhalevich 1980

Suborder AMMODISCINA Mikhalevich 1980

Family AMMODISCIDAE Reuss 1862

Subfamily AMMODISCINAE Reuss 1862

3.7 Genus ***Ammodiscus*** Reuss 1862; emend. Bornemann 1874; emend. Rhumbler 1895; emend. Loeblich and Tappan 1954; emend. Gerke 1960; emend. Loeblich and Tappan 1961 [= *Bifurcammina* Ireland 1939; = *Grzybowskiella* Myatlyuk 1970; = *Rectoammodiscus* Reitlinger in Vdovenko et al. 1993]

Type species: Involutina silicea Terquem 1862, erroneously identified as *Ammodiscus infimus* by Bornemann 1874 (non *Orbis infimus* Strickland 1846) and emended by Gerke 1960 and Loeblich and Tappan 1961.

Remarks: The genus *Ammodiscus* was first described by Reuss in 1862 and its systematic position has long been an area of controversy among paleontologists because no type species was designated at the time the genus was first established. Schellwien (1898) first designated the species Operculina incerta d'Orbigny 1839 as the type species for the agglutinated genus *Ammodiscus*, but later the species was assigned to the calcareous genus *Cornuspira* by Loeblich and Tappan (1954). Bornemann (1874) was the second person who designated a type species for the genus *Ammodiscus* after revision of the genus *Involutina*. After his revision, the species *Involutina silicea* should be accepted as the type species of the genus *Ammodiscus* as pointed out by Gerke (1960). However, according to Gerke, Bornemann erroneously identified *I. silicea* as the earlier described species *Orbis infimus* Strickland, not knowing that the latter species represents calcareous spirillinas, and he included *I. silicea* in the synonymy of *Orbis infimus*. Thus, the agglutinated species *Involutina silicea* accepted by Bornemann as a type species for the genus *Ammodiscus*, and illustrated by him under the uncorrected name *Ammodiscus* *infimus* (Strickland), should be named as *Ammodiscus siliceus* (Terquem) (Gerke 1960). The history of this matter is discussed by Gerke (1960) and Loeblich and Tappan (1961) both of whom independently re-evaluated the genus *Ammodiscus* in an attempt to eliminate any confusion as to which species was designated as the type species. After the choice of the type species, many reference books (Loeblich and Tappan, 1964, 1987; Subbotina et al. 1981) consider the type species to be *Ammodiscus infimus* Bornemann 1874 (non *Orbis infimus* Strickland 1846) /= *Involutina silicea* Terquem 1862/. In this study, following Ireland (1966) and Vdovenko et al. (1993), *Involutina silicea* Terquem is considered as the type species of the genus *Ammodiscus*. Ireland (1939) added to the problems of the synonomy of the genus *Ammodiscus* when described a new genus, *Bifurcammina* with the type species *Bifurcammina bifurca* and other new species *Bifurcammina conjuncta* and *B. parallela* from Silurian strata of Oklahoma that were similar in morphologic features with the genus *Ammodiscus* with the exception of a branching second chamber on the last whorl. Based on the similar morphology between two genera, Loeblich and Tappan (1964) first united these two genera and assigned genus *Bifurcammina* as a junior synonym of the genus *Ammodiscus*, but later these authors (Loeblich and Tappan 1987) separated them again by considering that both of them are valid genera. In this study, *Bifurcammina* is considered as a synonym of the genus *Ammodiscus* based on similar morphology of the test such as a bichambered test, planispiral coiling, and an agglutinated wall. The only difference between the two genera is the aberrant last whorl which sometimes splits into two tubes in *Bifurcammina* and which probably represents teratologic forms depending on the changing of some parameters of the environment. Also, the genus *Rectoammodiscus* established by Reitlinger (in Vdovenko et al. 1993) as the subgenus of the genus *Ammodiscus* also is a junior synonym of the latter genus because the difference between these two forms is only in the uncoiled last whorl in *Rectoammodiscus*. In the Silurian material one can trace in a single sample transitions from completely planispiral forms (*Ammodiscus*) to planispiral forms with an uncoiled straight or curved in different degree last whorl (*Rectoammodiscus*) and also to planispiral forms with double tubes of the last whorls (*Bifurcammina*) that illustrated on plate 5, figures 1-7. Loeblich and Tappan (1987) assigned the genus *Grzybowskiella* described by Myatlyuk (1970) as the synonym of the genus *Ammodiscus* based on the same morphology of the test and the difference in the structure of the wall – in *Grzybowskiella* the wall is siliceous crypto-crystalline and composed of fine grains of chalcedony, which coincides with the different wall ultrastructure of the genus *Ammodiscus*. Herein, the opinion of Loeblich and Tappan (1987) is followed and the genus *Grzybowskiella* is assigned to *Ammodiscus*.

3.8 ***Ammodiscus furcus*** Moreman; emend. herein

Plate 5, figures 1 - 7

Ammodiscus? *furca* MOREMAN 1930, p. 59, pl. 7, figs. 9, 10.

Ammodiscus abbreviatus IRELAND 1939, p. 200, pl. B, figs. 32, 33.

Ammodiscus exsertus var. minutus IRELAND 1939, p. 200, pl. B, figs. 20, 21.

Ammodiscus constrictus DUNN 1942, p. 339, pl. 44, fig. 27.

Ammodiscus diminutivus DUNN 1950 in Thalmann 1950 [= *A. minutus* DUNN 1942, p. 339, pl. 44, fig. 28].

Bifurcammina bifurca IRELAND 1939, p. 199, pl. B, figs. 38, 39.

Bifurcammina conjucta IRELAND 1939, p. 199, pl. B, fig. 36.

Bifurcammina parallela IRELAND 1939, p. 199, pl. B, fig. 37.

Description: Test free, bichambered, consisting of a rounded proloculus with the second tubular chamber with 6 -7 whorls planispirally coiled around the initial chamber, typically a neck is present that uncoils at right angles to the final whorl; in some specimens the final whorl branches into two necks that uncoil at right angles to the final whorl (plate 5, figures 4-5, 7); in some specimens no neck is present, an aperture is located at the opened end of the second chamber; white or off-white in color, wall consists of very fine siliceous grains and is smooth in appearance. Dimensions (μm): diameter of the test 300 – 400, width of whorls 20 – 50, length of neck 70 – 150, diameter of initial chamber 30 – 40.

Material: Abundant in all samples.

Discussion: In an attempt to organize the many different species (and one new genus *Bifurcammina*) of the genus *Ammodiscus* described by various authors from the Silurian including Moreman (1930), Ireland (1939), and Dunn (1942), as a part of this study it was decided to put into the synonymy of *Ammodiscus furcus* Moreman all planispirally coiled *Ammodiscus* species including *Ammodiscus constrictus* Dunn, *Ammodiscus abbreviatus* Ireland, *Ammodiscus exsertus var. minutus* Ireland and *Ammodiscus minutus* Dunn. These species all vary slightly from one another mainly in how the uncoiled portion of the second chamber behaves. More specifically, *A. constrictus* uncoils at 45° to the main body of the test. *A. abbreviatus* has a very short or abbreviated uncoiled portion that is at right angle to the coiling of the test. Previously, Ireland (1939) designated *Bifurcammina* as a new genus based upon the nature of the last whorl which typically branches into two tubes. Herein, this genus is placed in the synonymy of *Ammodiscus*. *Bifurcammina parallela, Bifurcammina conjucta,* and *Bifurcammina bifurca* (Ireland 1939) have all been placed in the synonymy of *Ammodiscus furcus* Moreman based on similar morphologic features such as test shape and size, coiling pattern, and wall structure. The only apparent difference between the genus *Ammodiscus* and *Bifurcammina* is the branching nature of the final whorl. This difference could be reflective of environmental variations leading to a branching final whorl. All other features of *Bifurcammina* are identical to those of *Ammodiscus*.

Occurrence: Silurian, Wenlock to Early Ludlow, late Telychian to early Gorstian, Fitzhugh Member, Clarita Formation. Ca 2 section, samples 3, 4, 5, 6, 8 (*Kockelella ranuliformis* conodont zone), 9, 10, 12 (*Kockelella amsdeni* conodont zone),13, 14 (*Kockelella stauros* conodont zone); J5 section, samples 12, 13 (*Kockelella ranuliformis* conodont zone); Haragan Creek section, samples 1, 1A, 2, 2B, 2C, 3 (*Kockelella ranuliformis* conodont zone), 3A, 3B, 4, 5, 7, 7A (*Kockelella amsdeni* conodont zone), 9, 10 (*Kockelella stauros* conodont zone); M2 section, samples 5 (*Kockelella amsdeni* conodont zone), 4, 3, 2 (*Kockelella stauros* conodont zone), 1 (*Kockelella variabilis* conodont zone); Highway 77 section, samples 14, 17, 18, 19 (*Kockelella ranuliformis* conodont zone), 20, 20A, 15, 16 (*Kockelella amsdeni* conodont zone), 21, 23 (*Kockelella stauros* conodont zone), 24 (*Kockelella variabilis* conodont zone).

Order LITUOLIDA Lankester 1885

Suborder LITUOLINA Lankester 1885

Family LITUOTUBIDAE Loeblich and Tappan 1984

Genus ***Lituotuba*** Rhumbler 1895

Type species: Trochammina lituiformis Brady 1879, designated by Cushman 1910.

Remarks: The genus *Lituotuba* was first described by Rhumbler in 1895 without establishing of the type species. Schellwien (1898) made an attempt to designate the type species for the genus as *Serpula filum* Schmid, but according to Ireland (1966), it was not a valid designation. Later, Cushman (1910) designated the species *Trochammina lituiformis* Brady as a type species for the genus *Lituotuba*, and since it has been used in all reference books on the foraminifers. Loeblich and Tappan (1987) follow the Ireland's point of view and confirmed that Cushman's designation of *Trochammina lituiformis* Brady as the type species for *Lituotuba* is valid.

3.9 **"*Lituotuba*" *exserta*** Moreman

Plate 5, figures 8 - 10, 16

Lituotuba exserta MOREMAN 1930, p. 59, pl. 7, figs. 5, 6.

Description: Test free, bichambered, an initial chamber with a tubular second chamber with 4 or 5 whorls that coil around the initial chamber in different planes; in some specimens the end of the second chamber uncoils at right angles to the other whorls creating a very short neck; other specimens exhibit no neck at the end of the second chamber; a single aperture is generally oval or circular in shape and is located at the opened end of the tubular second chamber; wall is white or off-white in color, composed of fine-grained siliceous grains, and is smooth in appearance. Dimensions (μm): diameter of the test 210 – 260, width of whorls 20 – 40, height of neck 50, diameter of initial chamber 40 – 50.

Material: 127 specimens from all sections.

Discussion: Moreman (1930) first described the species *Lituotuba exserta* from the Silurian strata of Oklahoma and illustrated two figures under the same name (Moreman 1930, pl. 7, figs. 5 and 6). Unfortunately, he did not designate the holotype of the species. It is not evident that this species belongs to the genus *Lituotuba* based on different morphology. Moreover, Ireland (1966) stated that most of Paleozoic forms described by Moreman (1930), Ireland (1939), Dunn (1942), Mound (1968) and others as *Lituotuba* should be assigned to the genus *Glomospirella* Plummer based on similar type of coiling. It is possible that the species *L. exserta* belongs to the genus *Glomospirella*, and for now the name of the genus is placed in quotation marks as *"Lituotuba" exserta.*

Occurrence: Silurian, Wenlock to Early Ludlow, late Telychian to early Gorstian, Fitzhugh Member, Clarita Formation. Ca 2 section, samples 5, 6 (*Kockelella ranuliformis* conodont zone), 9, 10, 12 (*Kockelella amsdeni* conodont zone); J5 section, samples 12, 13 (*Kockelella ranuliformis* conodont zone); Haragan Creek section, samples 2, 2A, 2B, 2C (*Kockelella ranuliformis* conodont zone), 3B, 4, 5, 7, 7A (*Kockelella amsdeni* conodont zone); M2 section, samples 5 (*Kockelella amsdeni* conodont zone), 4, 3, 2 (*Kockelella stauros* conodont zone); Highway 77 section, samples 12A, 13 17, 19 (*Kockelella ranuliformis* conodont zone), 20A, 15, 16 (*Kockelella amsdeni* conodont zone), 21, 23 (*Kockelella stauros* conodont zone), 24 (*Kockelella variabilis* conodont zone).

Chapter 4

Conclusions

Foraminifers from the Clarita Formation of south-central Oklahoma have been studied from five sections located in the Arbuckle Mountains. These sections are: Haragan Creek section, the Ca 2 section, M2 section, Highway 77 section, and the J5 section. 55 samples from these sections were collected by Dr. Barrick for conodonts and then were given to us for studying foraminifers. Conodonts previously studied by him from the same residues have been used as the key reference to the age of foraminifers from the Clarita Formation.

Foraminifers are very abundant in all samples and represented by 37 species of 12 genera of agglutinated foraminifers.

Seven species of Silurian foraminifers were revised as a result of this study. The species *Thurammina parvituba* Dunn 1942 was placed into the genus *Amphitremoida* Eisenack 1938 based on the presence of two apertures located on each polar end of the test which is a characteristic feature for the genus *Amphitremoida*.

The species *Lagenammina cucurbita* Moreman was redescribed to include *Lagenammina forma magna* Amsden (in Amsden et al. 1980) in its synonymy.

The species *Lagenammina sphaerica* Moreman 1930 was revised to include *Lagenammina distorta* Ireland 1939 and *Lagenammina uniformis* Dunn 1942 as synonyms because of very similar morphologic features and possible deformation of the tests of the latter two species during burial.

The species *Thurammina papillata* Brady 1879 was first described from Holocene deposits with a description that is not consistent with the forms referred to *Thurammina papillata* found in Silurian strata. The Silurian species are thus renamed as

Thurammina aff. Th. papillata due to similarities to the recent species but to distinguish them from recent foraminifers as described by Brady.

The species *Sorosphaera tricella* Moreman 1930 has been placed questionably into the genus *Sorosphaera* due to the presence of at least one aperture. The species *Sorosphaera bicella* Dunn 1942 has been placed in the synonymy of *S. tricella* due to identical morphologic features but varying numbers of chambers.

Planispirally coiled species such as *Ammodiscus abbreviatus* Ireland 1939, *Ammodiscus exsertus var. minutus* Ireland 1939, and *Ammodiscus constrictus* Dunn 1942 were placed in the synonymy of the species *Ammodiscus furcus* Moreman 1930.

The genus *Bifurcammina* was placed in the synonymy of the genus *Ammodiscus* based on similar morphologic features such as test shape and size, coiling pattern, and wall structure with the exception of a branching final whorl that could be the result of environmental variations.

The Mulde Event appears to have affected foraminiferal populations but differently than the conodont populations. In general, the first occurrence of a majority of the species of foraminifers tends to occur prior to the Mulde Event with fewer new species appearing after the event.

Two assemblages of foraminifers can be established in the Clarita Formation: the lowest one, *Shidelerella elongata*, in the lower part of the *ranuliformis* conodont zone and overlying it, the *Thurammina sphaerica*, in the upper part of the *ranuliformis*, *amsdeni* and *stauros* conodont zones.

Appendix A

Plates

Plate 1

Silurian foraminifers from the Clarita Formation, Arbuckle Mountains, Oklahoma.

Figures 1, 2, 8, 12. *Lagenammina stilla* Moreman 1930. 1 – sample 12, Highway 77 section; 2 – sample 12, Highway 77 section; 8 – sample 14, Ca 2 section; 12 – sample 14, Ca 2 section.

Figures 3 – 5. *Lagenammina sphaerica* Moreman 1930. 3 – sample 12, Highway 77 section; 4 – sample 15, Highway 77 section, 4a – enlarged view of fig. 4 showing the surface of the test; 5 – sample 13, J5 section.

Figures 6, 7, 13, 14. *Lagenammina aspera* (Stewart and Priddy 1941). 6 – sample 13, J5 section; 7 – sample 13, J5 section, 7a – enlarged view of fig. 7 showing coarse surface of the test with subangular to subrounded grains; 13–14 – sample 12, Highway 77 section, 14a – enlarged view of fig. 14 showing the surface of the test.

Figures 9 – 11. *Lagenammina cucurbita* Moreman 1933. 9 – sample 9, Ca 2 section; 10 – compressed test showing unusual shape, sample 5, Ca 2 section, 10a – enlarged view of fig. 10 showing the surface of the test with fine and well-sorted grains; 11 – test from the apertural view showing the rounded aperture, sample 15, Highway 77 section.

Scale bar – 100 μm, except figs. 4a, 7a, 10a – 10 μm, 11 – 1000 μm.

Plate 1

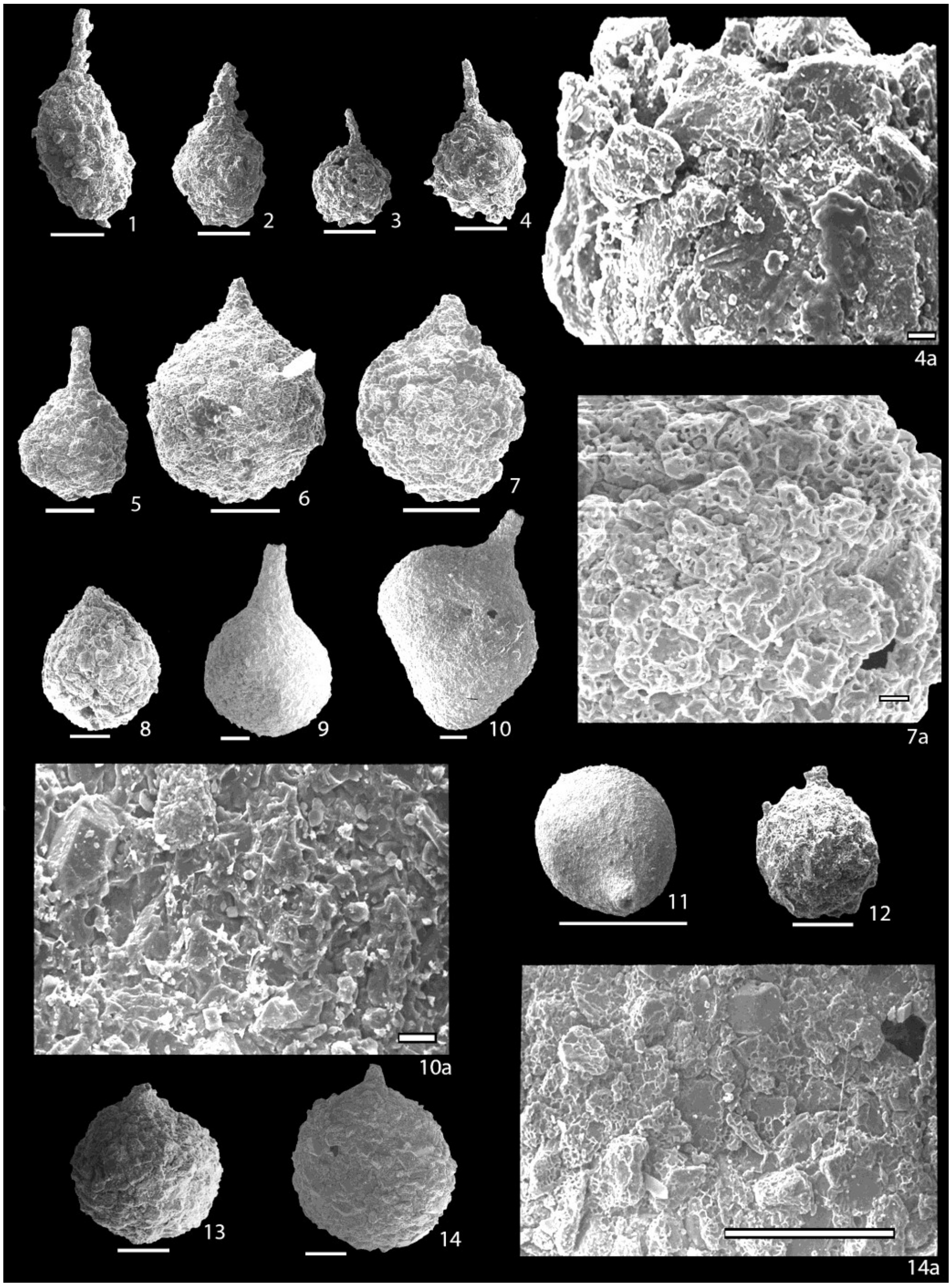


Plate 2

Silurian foraminifers from the Clarita Formation, Arbuckle Mountains, Oklahoma.

Figures 1 - 2. *Thurammina* aff. *Th. papillata* Brady 1879. 1 – sample 24, Highway 77 section, 1a - enlarged view of fig. 1 showing the surface of the test with fine and well-sorted grains and small, nipple-like projections with rounded aperture at the end of the projection; 2 – sample 12, Highway 77 section, 2a - enlarged view of fig. 2 showing the aperture at the end of the nipple-like projection.

Figure 3. *Thurammina tubulata* Moreman 1930, sample 24, Highway 77 section, 3a - enlarged view of fig. 3 showing the smooth surface of the test and the tube-like projection.

Figure 4. *Thurammina subsphaerica* Moreman 1930, sample 12, Highway 77 section, 4a - enlarged view of fig. 4 showing the aperture at the end of the nipple-like projection.

Figure 5 – 7. *Thurammina irregularis* Moreman 1930. 5 – sample 1, Ca 2 section; 6 – sample 15, Highway 77 section; 7 – sample 19, Highway 77 section.

Figure 8. *Thurammina polygona* Ireland 1939, sample 9, Ca 2 section.

Figure 9. *Thurammina sphaerica* Ireland 1939, sample 9, Ca 2 section.

Figure 10. *Thurammina* sp. 1, sample 15, Highway 77 section, 10a - enlarged view of fig. 10 showing the smooth surface of the test and conical-shaped projection with the aperture located at the end of the projection.

Figure 11. *Thurammina echinata* Dunn 1942, sample 3, Haragan Creek section, 11a - enlarged view of fig. 11 showing the aperture at the end of the conical-shaped projection with strings of an organic material stretched from the projection to the main portion of the test.

Scale bar - 100 µm, except figs. 2a, 4a, 11a – 10 µm.

Plate 2

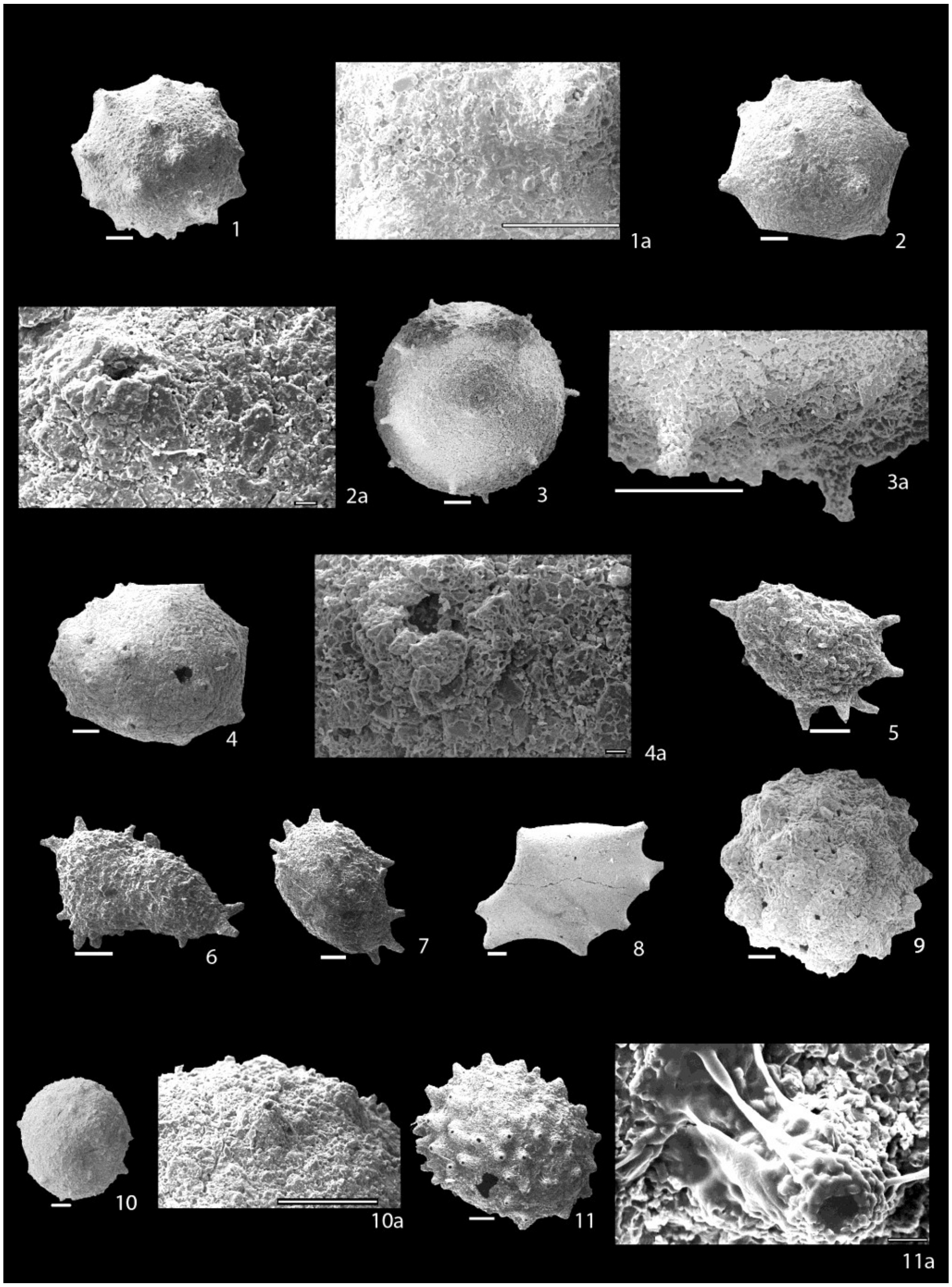


Plate 3

Silurian foraminifers from the Clarita Formation, Arbuckle Mountains, Oklahoma.

Figure 1. *Thurammina foerstei* Dunn 1942, sample 12, Highway 77 section.

Figure 2. *Thurammina inflata* Dunn 1942, sample 3B, Haragan Creek section, 2a - enlarged view of fig. 2 showing rounded aperture at the end of the tube-like projection.

Figure 3. *Thurammina limbata* Dunn 1942, sample 2, M2 section.

Figures 4 – 5. *Thurammina magna* Dunn 1942. 4 – sample 12, Highway 77 section; 5 – sample 12, Ca 2 section.

Figures 6 – 9. *Thurammina melleni* Dunn 1942. 6 – lateral view, sample 2C, Haragan Creek section; 7 – lateral view, sample 12, Highway 77 section; 8 – top view, sample 9, Ca 2 section; 9 – sample 12, Highway 77 section.

Figure 10. *Thurammina slocomi* Dunn 1942, sample 12, Highway 77 section.

Figures 11 – 12. *Thurammina elegans* Dunn in Thalmann,1950. 11 – sample 1, Ca 2 section, 11a – enlarged view of fig. 11 showing coarse-grained surface of the test and conical-shaped projections; 12 – sample 2C, Haragan Creek section.

Figures 13 – 14. *Thurammina tributa* Dunn 1942. 13 – sample 15, Highway 77 section; 14 – sample 12, Highway 77 section, 14a – enlarged view of fig.14 showing the surface of the test and large, poorly sorted grains.

Figures 15 – 16. *Thurammina limbata var. disciformis* Dunn 1942. Sample 20A, Highway 77 section.

Figure 17. *Amphitremoida parvituba* (Dunn 1942), sample 12, Highway 77 section.

Scale bar – 100 µm, except figs. 2a, 11a – 10 µm.

Plate 3

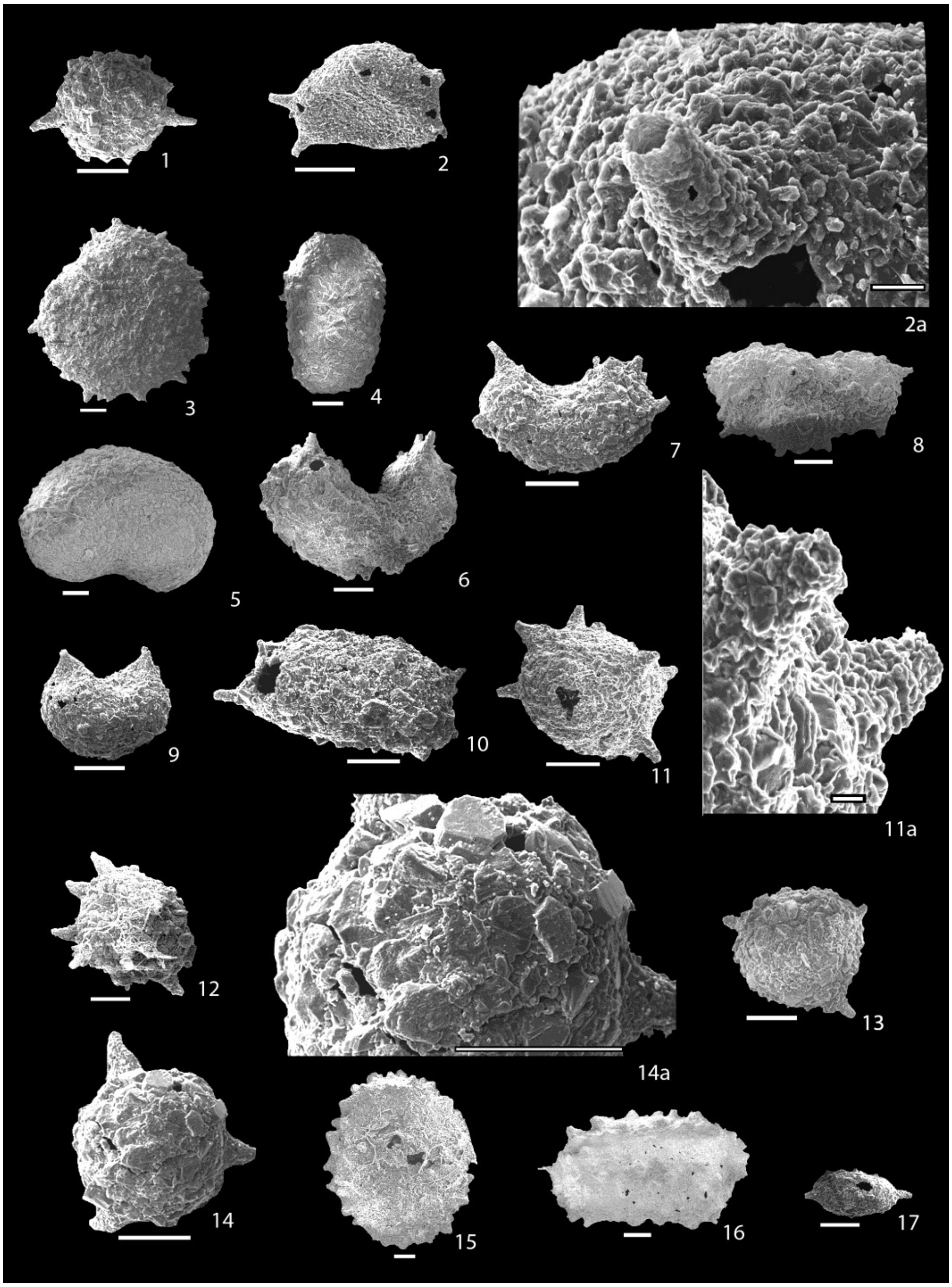


Plate 4

Silurian foraminifers from the Clarita Formation, Arbuckle Mountains, Oklahoma.

Figures 1 – 2. *Colonammina verruca* Moreman 1930. 1 – sample 8, Ca 2 section; 2 – sample 20A, Highway 77 section.

Figures 3 – 4. *Psammosphaera cava* Moreman 1930. 3 – sample 10, Ca 2 section; 4 – sample 12, Highway 77 section.

Figures 5 – 8. *Sorosphaera*? *tricella* Moreman 1930. 5 – sample 12, Ca 2 section, 5a – enlarged view of fig. 5 showing conjunction of three chambers; 6-7 – sample 20A, Highway 77 section; 8 – sample 2, M2 section, 8a – enlarged view of fig. 8 showing two apertures per spherical chamber.

Figure 9. *Sorosphaera subconfusa* Dunn 1942, sample 10, Ca 2 section.

Figures 10 – 11. *Sorosphaera multicella* Dunn 1942. 10 – sample 10, Ca 2 section, 10a – enlarged view of fig. 10 showing a single aperture per chamber and the surface of the test; 11 – sample 14, Ca 2 section, 11a – enlarged view of fig. 11 showing the surface of the test and two apertures per spherical chamber.

Figure 12. *Sorosphaera?* sp. 1, sample 3, M2 section.

Figures 13 – 15. *Hyperammina curva* (Moreman 1933). 13 – sample 1, Ca 2 section; 14 – sample 12, Highway 77 section; 15 – sample 13, J5 section, 15a – enlarged view of fig. 15 showing fine and well-sorted grains on the surface of the test.

Scale bar – 100 µm, except figs. - 10a, 15a – 10 µm.

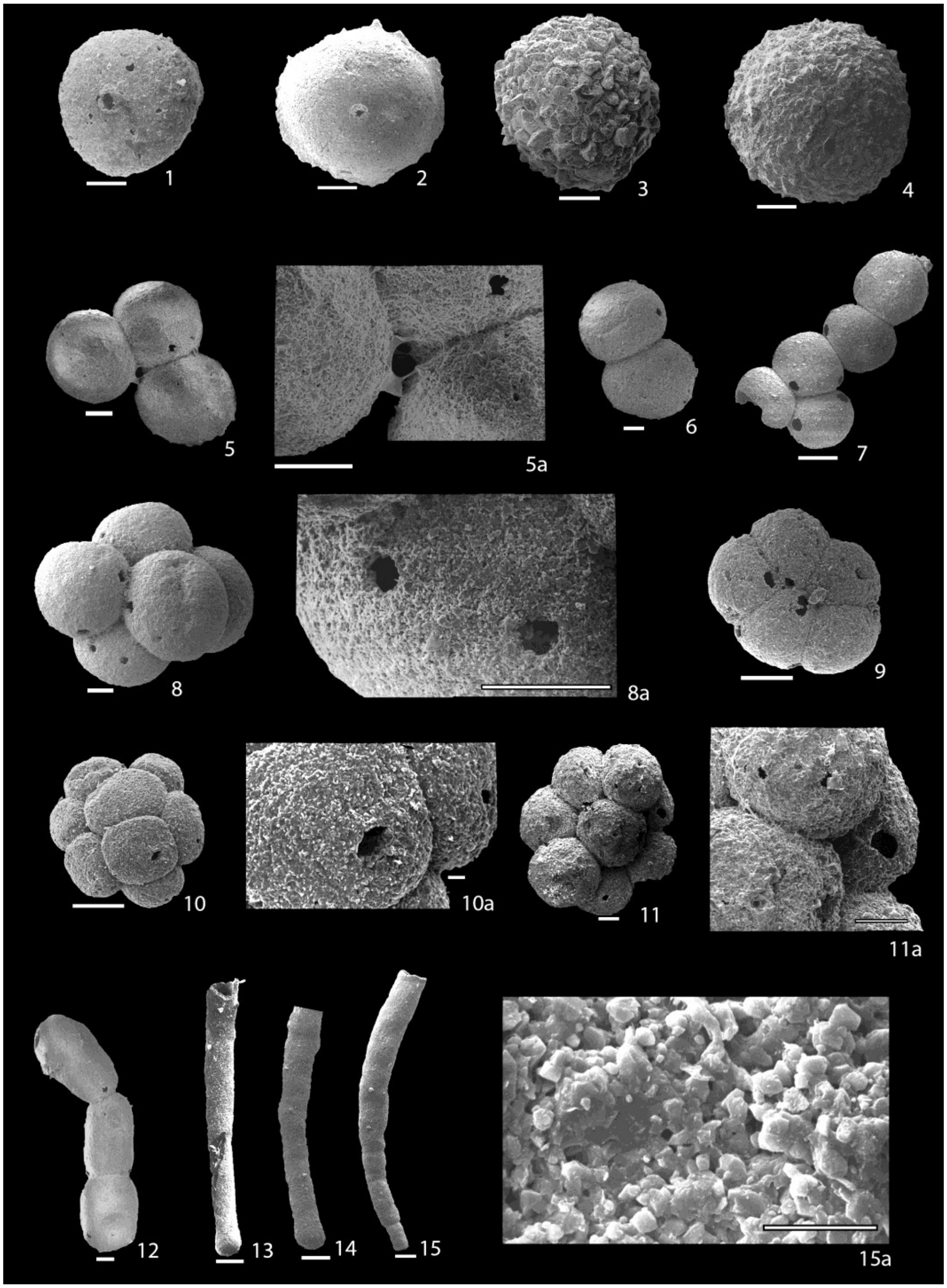

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Plate 5

Silurian foraminifers from the Clarita Formation, Arbuckle Mountains, Oklahoma.

Figures 1 – 7. *Ammodiscus furcus* Moreman 1930. 1 – 6 – sample 20A, Highway 77 section; 2a – enlarged view of fig. 2 showing fine and well-sorted angular grains on the surface of the test and pores located along the sutures; 7 – sample 2, M2 section.

Figures 8 – 10, 16. "*Lituotuba*" *exserta* Moreman 1930. 8 – 10 - sample 12; 16 – sample 20A; Highway 77 section.

Figure 11. *Glomospira biplana* Moreman 1933, sample 12, Highway 77 section.

Figures 12 – 14. *Glomospira inflata* (Ireland 1939). 12 – 13 – sample 15; 14 – sample 24; Highway 77 section.

Figures 15, 17 – 18. *Glomospirella ellipsoidalis* Ireland 1966. Sample 20A, Highway 77 section.

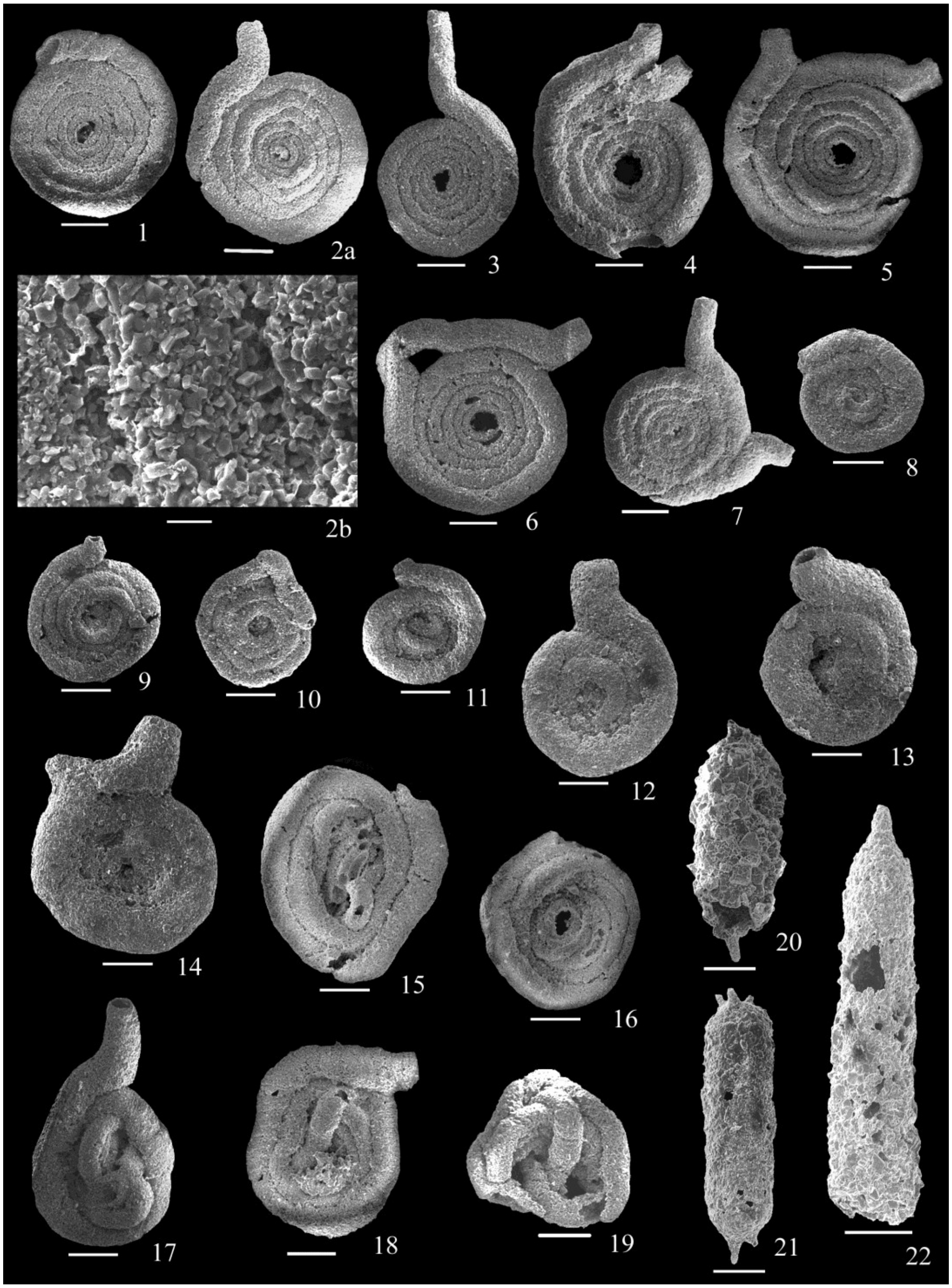
Figure 19. *Glomospira* sp. 1, sample 20A, Highway 77 section.

Figure 20. *Shidelerella elongata* Dunn 1942, sample 3, Ca 2 section.

Figure 21. *Shidelerella* sp. 1, sample 4, Haragan Creek section.

Figure 22. *Shidelerella cylindrica* Dunn 1942, sample 13, J5 section.

Scale bar – 100 μm, except fig. 2a – 10 μm.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Biographical Information

Melinda began studying geology at Tarleton State University and transferred to Stephen F. Austin State University in Nacogdoches, TX to earn her Bachelor of Science in Geology with a minor in mathematics in 2008. In 2009, she resumed her collegiate career by attending the University of Texas at Arlington in pursuit of a Master of Science degree in Geology with a micropaleontology focus. While in graduate school, Melinda began working full-time as a geologist in the mining industry. Upon completion of her degree, Melinda plans to pursue a career in the oil and gas industry.