LATE SILURIAN (LUDLOW, PRIDOLI) AND EARLIEST DEVONIAN (LOCHKOVIAN) COLONIAL AGGLUTINATED FORAMINIFERA OF THE HENRYHOUSE AND HARAGAN FORMATIONS, ARBUCKLE MOUNTAINS, OKLAHOMA

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BACKGROUND

Foraminifers are single-celled organisms that have lived in the Earth's oceans since at least the Cambrian Period 500 million years ago. Agglutinated foraminifers form "skeletons" called tests by cementing sand grains or other objects together with organic material. Many species have uniquely shaped tests that make it possible to date the rocks in which they are found. The species imaged on plates (1 - 9) are between 426 and 415 million years old. They lived along a Late Silurian shelf sea bordering the Oklahoma Aulacogen (Fig. 1).

Foraminifers within the Class Monothalamea are defined by their tendency to construct single-chambered tests. However, the Paleozoic Monothalamid genera *Sorostomasphaera* and *Webbinelloidea* produced tests composed of multiple chambers. Mikhalevich 1995 hypothesized the apparent colonies of *Sorosphaera* and *Webbinelloidea* were primitive pseudo-chambered pseudocolonial tests produced within individual foraminifers. However, this hypothesis can be revisited given the large number and morphological variety of *Sorostomasphaera* and *Webbinelloidea* tests found in the Henryhouse and Haragan Formations. These tests are constructed of chambers of equal size that are generally not centrally organized—chambers are deposited as strings, attached mats, or free ellipsoids. Importantly, the chamber apertures of *Sorostomasphaera* and *Webbinelloidea*, wherever they are visible, always point outward away from the other chambers. The simplest explanation for this growth pattern is that the tests of *Sorostomasphaera* and *Webbinelloidea* are colonies of individuals with fused agglutinated walls. Colonial lifestyles are well-documented for both single- and multi-cellular organisms such as bacteria, algae, corals, graptolites, siphonophores, etc. Genetically identical foraminifers living alongside one another cooperatively would fit the biological understanding of a colony (Hiebert et al 2020). The record of these Oklahoma stratigraphic sections is notable because no other site in the world has yielded such an abundance and diversity of colonial foraminifers.

ABSTRACT

The Ludlow and Pridoli Henryhouse Formation (Hunton Group, Silurian) in the Arbuckle Mountains and Lawrence Uplift of south-central Oklahoma consists of argillaceous wackestone and mudstone with some beds of skeletal wackestone and packstone. The Henryhouse Formation contains foraminifers that have never been systematically described. This work characterizes colonial agglutinated foraminifers found in samples originally collected for conodont study from the Henryhouse Formation and the lower 2.5 meters of the Haragan Formation. The foraminifers were deposited alongside stratigraphically significant conodont species, establishing their relative age. These specimens are notable for their colonial lifestyle, which is unusual among foraminifers. Colonial species belonging to the genera *Sorostomasphaera* and *Webbinelloidea* have been observed in seven roadcut and outcrop localities: Highway 77, Dougherty West, Ca2, 9-10, P1, Hickory Creek, and Goddard Youth Camp. The most complete lithological and faunal sequence comes from the Section Highway 77, in which *Sorostomasphaera* and *Webbinelloidea* are especially abundant in an interval from Units 16-20 (samples 336A-349CC which belong to the conodont zones *Ozarkodina crispa*, *Oz. eosteinhornensis*, and *Oulodus elegans detorta*). Colonial individuals increase their chamber size within this interval, especially evident in the genus *Sorostomasphaera*. In Units 20-21 (the top 2.8 meters of the Henryhouse at Section Highway 77) *Webbinelloidea* species exhibit strings of increasingly boxy chambers. This morphological transition culminates in the Haragan Formation with the appearance of rectangular tests like those defined as the genus *Thekammina* (Dunn 1942). In this work the colonial foraminifers from this interval are illustrated and changes in test morphologies analyzed. Information provided by foraminiferal assemblages such as these may prove useful in future Silurian biostratigraphy or paleoenvironmental characterization.

LOCALITIES

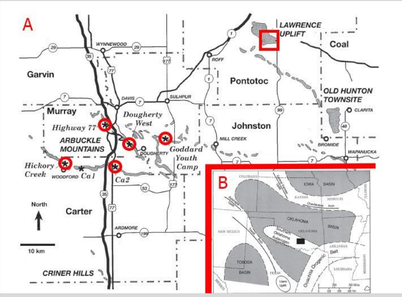

Figure 1. **A** - Map of southern Oklahoma showing the Hunton Group outcrop belt as thin shaded grey patches. The asterisks in red circles show the locations of five sampled sections in the Arbuckle Mountains. Sections 9-10 and P1 are located to the northeast in the Lawrence Uplift within the small red rectangle (modified from Barrick et al. 2010). **B** - Regional tectonic features during the Paleozoic, showing the study area position along the Oklahoma Aulacogen (after Barrick et al. 2010).

PLATES

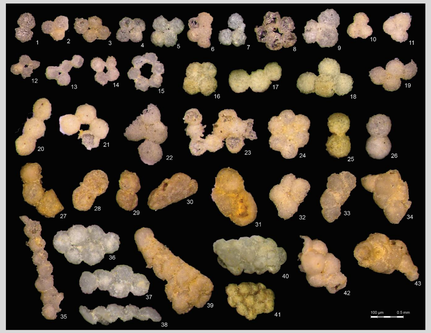

Plate 1: **1-8** Morphological group B1. **10-11** Morphological group B2. **16-19** Morphological group B3. **33-41** Morphological group SB. **1,** 14 DW624 **2** 9-10 **8** H77 **345** **4, 9** Ca2 525 **5, 7, 19** H77 343 **6** 9-10 9A **8** DW623 **10** H77 354 **11** H77 355 **12** 9-10 **10** 13 H77 348 **15** Ca2 548 **16-18** H77 349C **20** H77 350 **21** H77 350A **22** H77 349B **23** H77 341 **24** H77 353 **25, 28** H77 349C **26** H77 349A **27** DW626C **29-30** H77 349CC **31** DW626B **32** 9-10 4 **33-35, 42-43** DW622 **36-39** H77 337A **40-41** H77 334.

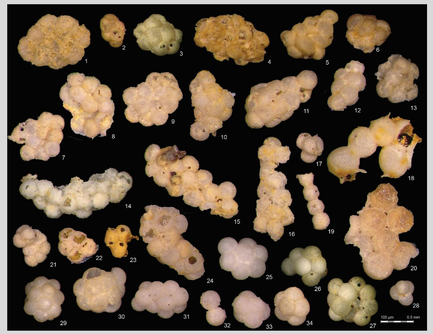

Plate 2: **2-6, 11-13** Morphological group SM-0. **15** An example of morphological group SA-2. **24-34** Morphological group SM-1. **1** H77 337 **2, 4** H77 345A **3, 9, 11, 26-27, 32-33** H77 349B 5 H77 349 **6** DW613 7 H77 351 **8** H77 334 **10, 14, 24** H77 336A **12, 28** H77 349AA **13** Ca2 548 **15** H77 354 **16** H77 333 **17, 19** H77 352 **18, 20** Hickory Creek 12 21 H77 355 **22** DW625 **23** 9-10 7A **25, 29, 31** H77 349AC **30, 34** Ca2 550.

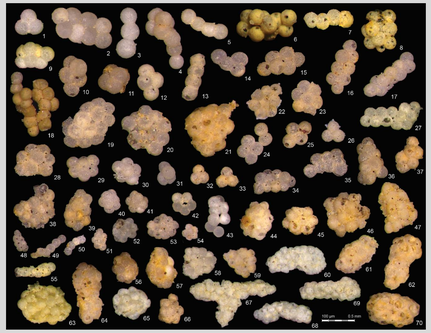

Plate 3: **1-31** Morphological group SM-1. **40-43, 48-55** Morphological group SM-2. **58-62, 65-70** Morphological group SC. **1** H77 349AA **2, 5, 42-43** Ca2 550 **3** H77 349AC **4** H77 349A **6, 10** 9-10 7A **7-8, 15** 9-10 8A **9, 27, 29, 32** 9-10 **10, 21** DW625 **12-13** H77 349AA **14, 25, 34-36** DW624 **16, 23** 9-10 11B **17** H77 344 **18** H77 345A **19, 48, 53-54** 9-10 12 **20** H77 349A **22** H77 345 **24, 28, 37-38** DW623 **26** H77 349B **30, 45** Hickory Creek 12 31 H77 343 **33** 9-10 5 **39** 9-10 8 **40** 9-10 9B **41** 9-10 9A **44** CYC 36 **46** DW611A **47** DW611AA **49** 9-10 9 **50** 9-10 11 51 9-10 13 **52** Ca2 525 **56, 64** DW613 **57** DW12 **58** H77 340A **59** H77 339A **60** H77 338 **61, 67-68** H77 336A **62, 66, 70** DW622 **63** DW11 **65** H77 341 **69** H77 337A.

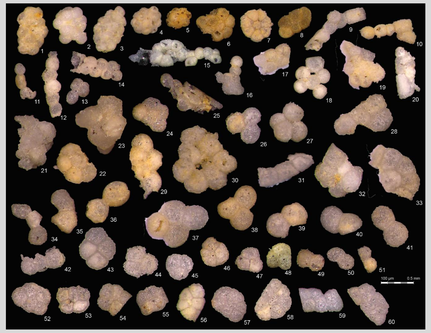

Plate 4: **1-5** Morphological group SC. **9-10, 14-20, 25** Morphological group SW. **26-42** Morphological group WM-0. **43-60** Morphological group WM-1. **1-2** H77 341A **3, 56** H77 340A 4 H77-338 5. **22, 29** DW622 **6, 8** H77 346 7, **33** H77 346A **9** H77 350AA **10** H77 350A **11, 34-35, 41, 57** 9-10 12 **12, 59** 9-10 10 **13-14, 25, 52** DW624 **15-17** H77 343 **18, 20** Ca2 550 **19, 37** H77 342 **21** H77 348A 23 H77 345 **24, 48-49** 9-10 6A **26** H77 336A **27** H77 341 **28** H77 349AC **30-31, 44** H77 348A **32** H77 349A **36** H77 347A **38, 47** 9-10 9 **39, 46** 9-10 9A **40** 9-10 9B **42, 60** H77 344 **43** H77 348 **45, 58** 9-10 11 **50** 9-10 6 **51** 9-10 5 **53** DW623 **54** H77 345 **55** 9-10 13.

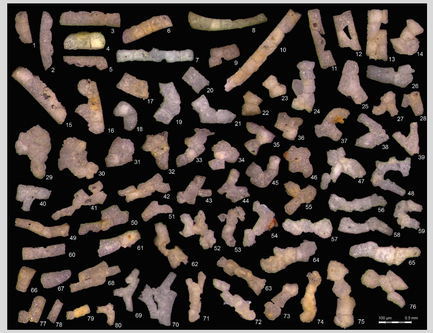

Plate 5: **1-20** Morphological group WM-1. **24-76** Morphological group WM-2. **1, 36, 46, 48-49, 51, 60, 63** 9-10 12 2 9-10 11 3 H77 348 4 9-10 10 **5, 77, 79** 9-10 7A **6, 37** 9-10 9A **7, 13** H77 341 **9, 55, 73** 9-10 11B **10** H77 338A **11, 41-42, 66, 78, 80** 9-10 9 **12, 15-17, 35, 43-45** DW624 **14, 71-72, 76** H77 349B **18-19, 26, 40, 47, 56, 58, 70** Ca2 548 **20, 69** Ca2 525 **21** Ca2 550 **22** H77 349 **23, 39** H77 349AC **24** H77 343 **25** H77 342A **27-28, 74** 9-10 8 **29, 52, 64, 68** H77 345 **30** 9-10 10 **31-33** DW623 **34** DW625 **38, 57, 65, 75** H77 349AA **50, 61** 9-10 13 **53, 67** 9-10 9B **54** H77 348 **59** H77 340A **62** H77 348A.

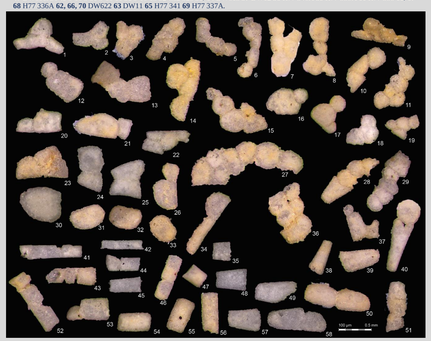

Plate 6: **7-33** Morphological group WT-1. **34-35, 38-58** Morpological group WT-2. **1, 3** H77 349A **2, 6, 20, 52-53, 55** H77 350B **4** H77 350AA **5, 12-13** H77 349B **7-8, 38, 40** H77 350A 9 H77 349CC **10, 21** H77 350AA **11, 19** H77 350 14 H77 349D **15, 24-26, 33, 36** H77 354 **17** H77 349C **18** H77 347 **22, 32, 34, 37, 49** H77 352 **23** H77 351 **27-28, 30, 39, 43, 50, 57-58** H77 353 **29** H77 348 **31, 56** H77 350C **41** Ca2 548 **42, 44-47** H77 356 **35, 48, 51** H77 355.

Plate 7: Selected specimens shown at greater magnifications. **1** H77 346 2 DW613 **3** DW611AA **4** CYC36 **5** DW11 **6** H77 340A **7** H77 344 **8** H77 343 **9** 9-10 11 **10-12, 16, 20, 25-27** 9-10 12 **13-14, 18** Ca2 525 **15, 19** Ca2 550 **17, 22** H77 343 **21** 9-10 9A **23** H77 346 **24** H77 348 **28** Ca2 515 **29** H77 353 **30** H77 350B **31, 34** H77 352 **32** H77 354 **33** H77 351.

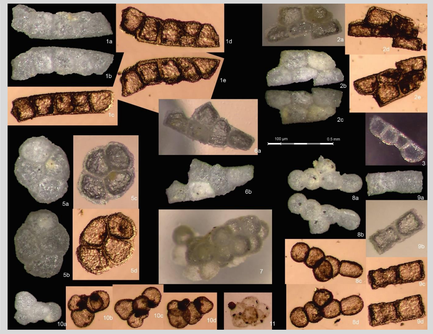

Plate 8: Reflected and transmitted light images. **1-6, 9** Attached *Webbinelloidea* colonies feature hemispherical and boxy chambers with thicker walls composed of coarser grains. The boundaries between chambers walls are often visible in transmitted light. **7-8, 10-11** Free *Sorostomasphaera* colonies feature spherical chambers composed of finer grains. Apertures were visible in specimens 2, 5, 6, 8, and 10. The walls between chambers are without holes. **1-2, 5-11** Section 9-10, sample 11. **3** Section 9-10, sample 11A.

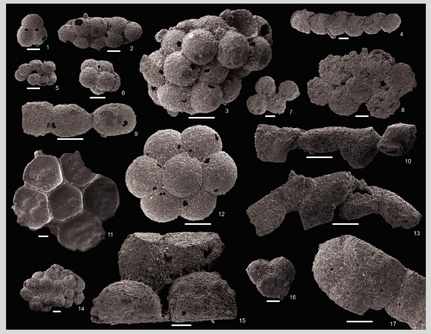

Plate 9: Scanning Electron Microscope images of assorted colonial morphologies. **1-6, 9, 11-12, 14** Round and ellipsoidally chambered *Sorostomasphaera*. **7-8** Coarse-grained more loosely-attached chambers of *Webbinelloidea*? **10, 13, 15-17** Attached hemispherical or boxy chambers of *Webbinelloidea*. 1 9-10 11A **2-3** 9-10 8 **4** P1 B11 **5-8** 9-10 11A **9, 13** 9-10 13 **10** 9-10 9B **11** Hickory Creek 12 **12** 9-10 11A **14** DW 611AA **15** 9-10 6 **16** Ca2 506 **17** 9-10 11A.

STRATIGRAPHIC SECTIONS AND MORPHOLOGICAL DISTRIBUTIONS

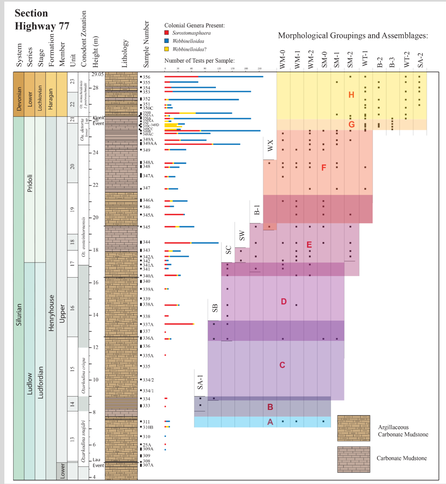

Figure 2. Stratigraphic column of section Highway 77 (left, units after Stanley 2001, conodont information from Barrick and Klapper 1992 and recent communications with Barrick). Generic identifications (middle) were determined according to chamber shape and grain size. Morphological groups (right) are subgeneric divisions based upon shared characteristics such as chamber size and shape, chamber number, chamber arrangement within the colony, and wall thicknesses. Foraminiferal assemblages (A-H, right) are co-occurrences of these morphological groups specific to restricted intervals at Section Highway 77.

DISCUSSION

Colonial morphologies are uncommon in the lower units of Section Highway 77, however, this pattern changes in Unit 16 and above. Colonial tests are especially abundant within Units 18-23, totaling 30-225 tests per two kg rock sample. In Units 15 and 16 most of the colonial species belong to genus *Sorostomasphaera*, but from Unit 17 up to Unit 23, *Webbinelloidea* generally increases in abundance. Coarse-grained *Webbinelloidea*? (morphological groups B1-B3) are minor constituents of the colonial fauna throughout but become dominant within a lower diversity interval spanning samples 349CC to 350XA and are notably present in sample 350B. The major faunal shift between samples 349B and 349CC may be best explained by a shift in sea level. The conodont elements recovered from this short interval are contemporaneous with the estimated beginning of the end-Silurian and earliest Devonian Klonk Oceanic Event (Spiridonov et al 2020). Lithofacies of Units 22 and 23 indicate a return to an environment enriched with *Webbinelloidea* and secondary *Sorostomasphaera*. However, whereas *Sorostomasphaera* species retain planar and ellipsoidal morphologies of tightly bound colonies, the remaining *Webbinelloidea* in Units 22 and 23 differ morphologically from those below, exclusively displaying rectangular and cylindrical strings of chambers. Some species were apparently capable of disaggregation of the colonial strings. In these forms, individual rectangular chambers are observed apart from colonies, they appear morphologically like the holotype of the genus *Thekammina*, Dunn 1942.

Seventeen practical subgeneric colonial morphological groups have been identified based upon characteristics such as chamber size and shape, chamber number, chamber arrangement of the colony, wall thicknesses, and grain size. *Webbinelloidea*? (morphological groups B1-B3) are attached forms characterized by especially coarse-grained round chambers loosely attached to one another. The morphological group WM-0 is most similar to the described species *W. quadripartita* (Moreman 1933) or perhaps *W. tholus* (Moreman 1933). The morphological group WM-1 has numerous smaller and more tightly bound chambers than WM-0 but is otherwise similar. Morphological group WM-2 is similar to WM-1 but exhibits unattached and branching chambers. Group SW features spherical chambers alongside attached chambers similar to WM-1 and WM-2. Morphological group WX is a large, rare, and unusually blocky *Webbinelloidea* species. Morphological groups SA-1, SA-2, SB, SC, SM-0, SM-1, and SM-2 are similar to *S. multicella* Dunn 1942 and *S. tricella* Moreman 1930, but differ in numerous respects, including often having 2-8x as many chambers as any described species. Group WT-1 exhibits wide but flat semi-rounded chambers attached in strings with little shared wall between chambers. Group WT-2 represents rectangular *Thekammina*-like chambers.

An analysis of the co-occurrences of these morphological groups suggests eight provisional foraminiferal faunal assemblages corresponding to the following lithological units at the Highway 77 Section: (A): Unit 13; (B): Unit 14; (C): Units 15 to lower Unit 16; (D): Unit 16 and lower Unit 17 perhaps including sample 341A; (E): Units 17-18; (F): Units 19-20 up to and including sample 349B; (G): Upper Unit 20 (sample 349CC and above) and Unit 21; (H): Units 22-23.

Similar foraminiferal assemblages (A-E/F) can be found in the same vertical distribution at other nearby Henryhouse sections such as 9-10 and Dougherty West. Preliminary observations suggest these foraminifer assemblages vary predictably over this interval in this local region. It remains to be investigated whether the assemblages can be used as precise biostratigraphic indicators. In a future work, data on Henryhouse and Haragan foraminifer assemblage distributions will be compared against the record of biostratigraphically significant conodonts. Notably, agglutinated foraminifers are benthic organisms preferring certain environmental conditions—some assemblages have been observed to thrive at particular depths. For this reason, the foraminiferal record deposited at a locality within any interval is a function not only of evolutionary shifts in the foraminiferal fauna but also of changes in sea level. Globally, much research still remains to be done to properly characterize the foraminiferal assemblages of the Ludlow, Pridoli, and Lochkovian.

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