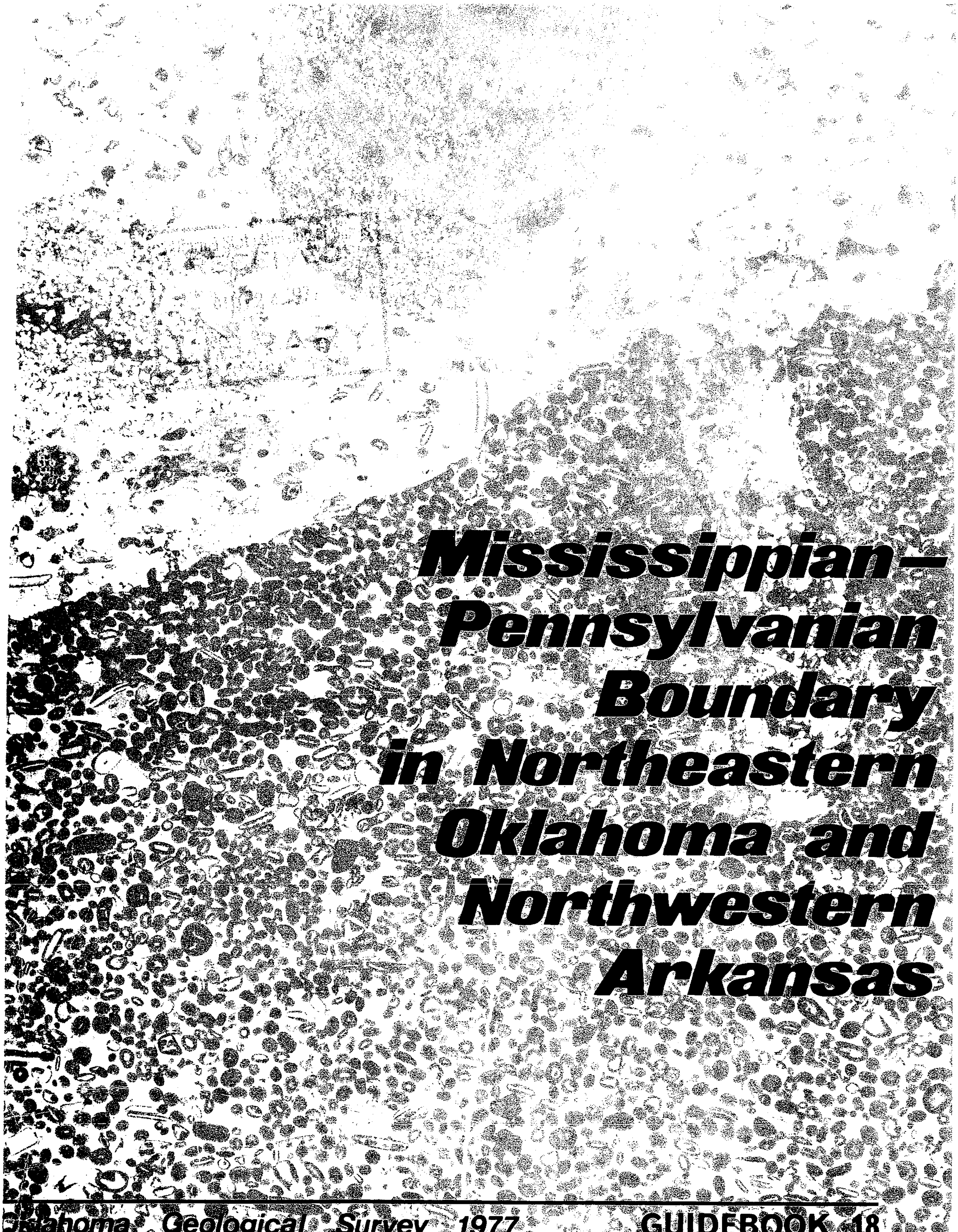
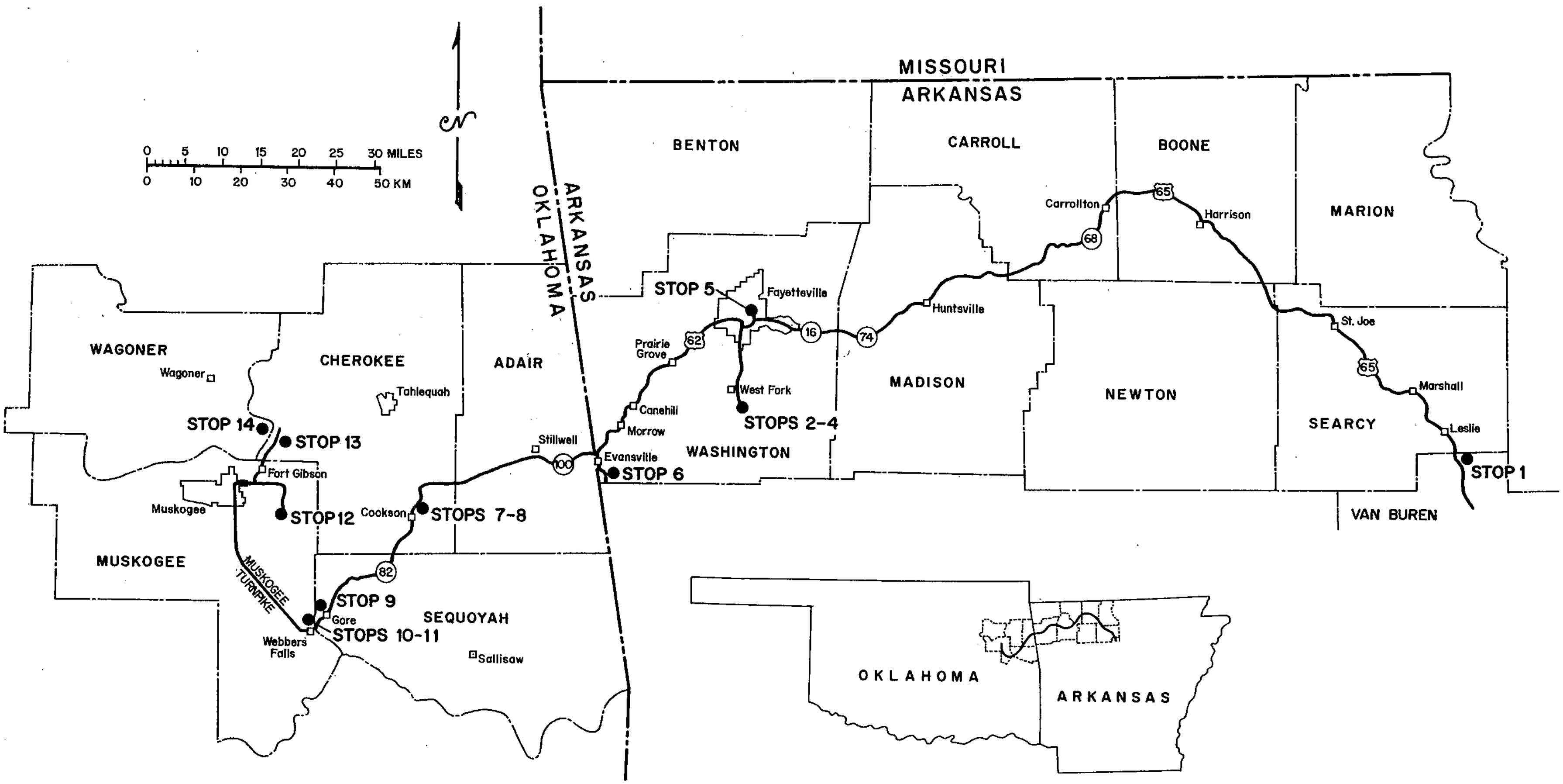


Mississippian–Pennsylvanian Boundary in Northeastern Oklahoma and Northwestern Arkansas

Oklahoma Geological Survey 1977 GUIDEBOOK 18



LOCALITY AND ROUTE MAP

OKLAHOMA GEOLOGICAL SURVEY
Charles J. Mankin, *Director*
GUIDEBOOK 18

UPPER CHESTERIAN-MORROWAN STRATIGRAPHY AND THE MISSISSIPPIAN-PENNSYLVANIAN BOUNDARY IN NORTHEASTERN OKLAHOMA AND NORTHWESTERN ARKANSAS

PATRICK K. SUTHERLAND and WALTER L. MANGER, *Editors*

School of Geology and Geophysics, The University of Oklahoma; and Department of Geology and University Museum, University of Arkansas

Guidebook for Field Trip No. 5, August 5-7, 1977, preceding North American Paleontological Convention II

The University of Oklahoma
Norman
1977

Front Cover

Photomicrograph of unconformable contact between Mississippian Pitkin Formation and Pennsylvanian Sausbee Formation. Stop 12, Braggs Mountain (compare with Stop Descriptions — Third Day, fig. 2).

Lower half, Pitkin Formation; oolitic packstone. Fine- to medium-grained, micritic, oolitic calcarenite; ooids, coated grains, and skeletal fragments set in matrix of micrite and microspar. A typical facies of Pitkin Formation, separated from upper part by sharp contact; note boring at right, filled with material from overlying unit.

Upper half, Sausbee Formation; quartz-sandy, conglomeratic grainstone. Fine- to coarse-grained skeletal, quartz-sandy, pebble-bearing calcarenite. Pebbles of medium-grained, mature, calcite-cemented quartzarenite.

Back Cover

Table of formations and members of upper Chesterian (Mississippian) and Morrowan and Atokan (Pennsylvanian) Series in northeastern Oklahoma and northwestern Arkansas.

This publication, printed by the University of Oklahoma Press, Norman, Oklahoma, is issued by the Oklahoma Geological Survey as authorized by Title 70, Oklahoma Statutes 1971, Section 3310, and Title 74, Oklahoma Statutes 1971, Sections 231-238. 700 copies have been prepared for distribution at a cost to the taxpayers of the State of Oklahoma of $10,762.

PREFACE

This guidebook was prepared for a field trip held prior to the North American Paleontological Convention II at The University of Kansas, Lawrence, August 8-10, 1977. The 2½-day trip examined the lithostratigraphy and biostratigraphy of upper Chesterian and Morrowan strata in northwestern Arkansas and northeastern Oklahoma, with emphasis on the Mississippian-Pennsylvanian boundary.

Since 1960, scores of papers have been published on various aspects of the Chesterian-Morrowan succession in the southern Midcontinent. The editors felt that the occasion of this field trip would provide an opportunity to summarize the present state of knowledge concerning this succession and to identify areas for further research. Contributions were solicited from specialists on the Carboniferous for inclusion with the road logs and stop descriptions. These papers are expected to provide, in addition to their general interest, a foundation and framework for continued investigations beyond the immediate goals of this field trip.

We wish to thank William D. Rose, editor for the Oklahoma Geological Survey, who served as technical editor for this guidebook. His enthusiasm for the project is greatly appreciated, and the quality of the final product is a tribute to his care and attention to detail. We wish also to thank Charles J. Mankin, director of the Oklahoma Geological Survey, for his continued interest in the project and for his willingness to publish this guidebook. Many of our students have helped with aspects of the field trip and guidebook preparation. We wish to acknowledge Jeffrey Hall, Jeffrey Liner, Robert Liner, Tom McGilvey, and Steven Terry of the University of Arkansas; and Robert Grayson, April Hoefner, Mark Orgren, and Grant Zimbrick of The University of Oklahoma. Ronald R. West, Kansas State University, Manhattan, coordinated all field-trip activities in his capacity as field-trip chairman for the convention.

Patrick K. Sutherland
Walter L. Manger
May 31, 1977

CONTENTS

ROAD LOG—FIRST DAY

Walter L. Manger[1]

The field excursion begins in Harrison, Boone County, Arkansas, and proceeds southeastward to the vicinity of Leslie, Searcy County (see trip map), to view exposures of the Imo Formation (uppermost Chesterian) at the famous Peyton Creek road cut (Gordon, 1965; Saunders, 1973). The trip will then return via the previous route to Harrison and continue to Fayetteville, Washington County. Here we will examine Chesterian strata of the upper Fayetteville and Pitkin Formations and Morrowan strata of the Hale (Cane Hill and Prairie Grove Members) and Bloyd (Brentwood Limestone Member) Formations. A lithostratigraphic column (inside front cover) is provided to illustrate the context of each stop. Road logs for day 1 were prepared with the assistance of J. D. Hall, J. L. Liner, R. T. Liner, T. A. McGilvery, M. R. Shinn, and S. H. Terry, Department of Geology, University of Arkansas.

Segment 1—Harrison to Peyton Creek

Mileage begins at junction of Harrison By-pass and U.S. Highways 62 and 65, on southeast side of Harrison.

Total mileage

0.0 Junction of Harrison By-pass and U.S. 62-65. Proceed southeast on U.S. 62-65.

0.9

0.9 Harrison city limit (southeast).

0.9

1.8 Cross Brush Creek (intermittent), which exposes St. Joe-Boone contact in stream bed.

0.4

2.2 Bellefonte city limit (west).

0.2

2.4 Cross intermittent tributary of Dry Branch.

0.1

2.5 Junction of Arkansas 206 and U.S. 62-65. Continue on U.S. 62-65.

0.4

2.9 Cross Huzzah Creek.

0.1

3.0 Bellefonte city limit (southeast).

0.5

3.5 Junction of U.S. 62 and 65. Proceed southeast on U.S. 65.

1.9

5.4 Scattered exposures of upper Boone Formation on northeast side of road for next 0.5 mile. Note lack of extensive chert development.

0.6

6.0 Quarry in upper Boone Formation on southwest side of highway.

0.6

6.6 Valley Springs city limit (northwest).

0.3

6.9 Cross Elm Branch of Hog Creek.

0.3

7.2 Valley Springs city limit (southeast).

0.6

7.8 Cross Plum Branch of Hog Creek. Ordovician strata exposed in stream bed.

0.9

8.7 Junction of U.S. 65 and Arkansas 206. Continue on U.S. 65.

0.2

8.9 Scattered exposures of Boone Formation on both sides of road for next mile.

1.1

10.0 Newton-Boone County line. Scattered exposures of Boone Formation.

0.6

10.6 Western Grove city limit (northwest; may be unmarked).

0.1

10.7 Junction of U.S. 65 and 65B.

0.5

11.2 Cross highway overpass.

0.5

11.7 Junction of U.S. 65 and 65B with Arkansas 123. Western Grove city limit (southeast; may be unmarked).

0.7

12.4 Boone Formation poorly exposed on north side of highway.

0.4

12.8 Boone Formation exposed on both sides of highway.

0.2

13.0 Newton-Searcy County line marker (actually highway crosses this line twice, but it is marked only once).

0.7

13.7 Hillsides covered by chert rubble typical of Boone.

[1]Department of Geology and University Museum, University of Arkansas, Fayetteville, Arkansas.

1.5

15.2 Turnoff to Hurricane River Cave, developed in St. Joe Formation.

0.4

15.6 Hillsides covered by typical Boone regolith.

1.6

17.2 Pindall city limit (west). Boone exposures on north side of highway.

0.5

17.7 Pindall city limit (east).

0.8

18.5 Cross Clear Creek (intermittent).

0.1

18.6 Junction of U.S. 65 and Arkansas 235.

0.1

18.7 Typical Boone regolith exposed in low hills to north of highway.

1.7

20.4 Rubbly-weathering Boone Formation on south side of highway.

0.7

21.1 Weathered Boone regolith quarried for road metal on east side of highway as it descends hill.

0.3

21.4 Another quarry for road metal in Boone regolith.

0.6

22.0 Series of scattered, poor exposures of Boone Formation for next 0.6 mile.

0.8

22.8 Cross northeast-trending fault, downthrown to southeast (no fault plane visible).

0.2

23.0 Fayetteville Shale exposed on east side of highway along bluff of small stream.

0.3

23.3 Fayetteville Shale exposed on east side of road.

0.3

23.6 St. Joe city limit (west).

0.1

23.7 Junction of U.S. 65 and County Road 374.

0.2

23.9 Turnoff of County Road 374.

0.2

24.1 St. Joe city limit (east).

2.8

26.9 Junction of U.S. 65 and Arkansas 333. Entering drainage of Buffalo River. Extensive, scattered exposures of Boone Formation on northeast side of highway for next mile.

1.4

28.3 Quarry for road metal in Boone regolith on northeast side of highway. Begin crossing Buffalo River; note extensive exposures of Boone (up river) and St. Joe–Silurian (down river).

0.5

28.8 Extensive exposures on west side of highway on Boone Formation as road ascends hill.

0.8

29.6 Silver Hill city limit (northwest).

0.2

29.8 Silver Hill city limit (southeast).

0.7

30.5 Begin descent of hill through Boone regolith. Extensive exposures of Boone Formation on east side of highway for next 2 miles.

1.0

31.5 Cross Holder Creek. Continued extensive Boone exposures on southwest side of highway.

0.7

32.2 Boone Formation forms bluffs across valley of Bear Creek.

0.4

32.6 Cross Bear Creek. Large Boone exposures on southwest side of highway.

0.7

33.3 Begin massive exposures of weathered Boone on northeast side of highway for next mile.

0.6

33.9 Junction of U.S. 65 and Arkansas 74.

0.9

34.8 Boone exposed on northeast side of highway for next 1.5 miles.

1.1

35.9 Continued massive exposures of Boone Formation on both north and south sides of highway for next mile.

0.6

36.5 Abandoned quarry in Boone on north side of highway.

0.4

36.9 Junction of U.S. 65 and Arkansas 333.

0.4

37.3 Marshall city limit (west).

1.8

39.1 Junction of U.S. 65 and Arkansas 27.

0.4

39.5 Junction of U.S. 65 and Arkansas 27.

0.2

39.7 Marshall city limit (east).

0.1

39.8 Begin extensive road cuts and exposures of Fayetteville Shale.

0.6

40.4 Continue in Fayetteville Formation, upper interbedded limestone and shale facies.

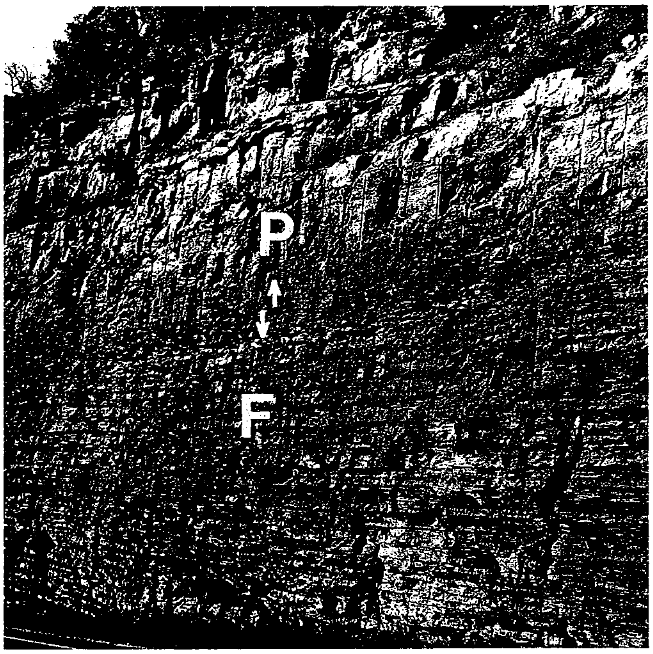


Figure 1. Upper Fayetteville Formation *(F)* contains interbedded dark micritic limestone and black shale. Its conformable contact with overlying Pitkin Limestone *(P)* is drawn at change to light-colored bioclastic, oolitic grainstones and packstones (arrows).

0.2

40.6 Top of hill, Pitkin-Fayetteville contact.

0.1

40.7 Descend hill through similar sequence of Pitkin and Fayetteville.

0.6

41.3 Leave interbedded facies and return to black-shale facies of Fayetteville (mostly covered).

0.8

42.1 Fayetteville black shale exposed intermittently in road cuts and on hills on west side of highway for next mile.

1.8

43.9 Fayetteville sporadically exposed on slopes to east of highway.

1.3

45.2 Cross Cove Creek.

0.1

45.3 Fayetteville poorly exposed on east side of highway for next 0.4 mile.

0.9

46.2 Leslie city limit (west). Cross east-west-trending fault downthrown to south.

0.1

46.3 South-dipping, faulted upper Fayetteville Formation exposed on west side of highway.

0.1

46.4 Junction of U.S. 65 and Arkansas 66.

0.2

46.6 Leslie city limit (south; may be unmarked).

0.2

46.8 Exposures of Pitkin Formation on west side of highway for next mile.

0.7

47.5 Cross Middle Fork of Little Red River.

1.0

48.5 Begin extensive exposures of Pitkin limestone and shale on west side of highway.

0.8

49.3 Exposures of Pitkin limestone and shale developed across valley in bluffs along Middle Fork of Little Red River to east of highway.

0.1

49.4 Phosphate quarry visible to southeast on bluff above Peyton Creek.

0.2

49.6 Searcy-Van Buren County line.

0.2

49.8 Cross Peyton Creek bridge.
STOP 1—Peyton Creek road cut.
Retrace route to Harrison By-pass.

Segment 2—Harrison to West Fork

Mileage begins at junction of Harrison By-pass and U.S. 62-65, on southeast side of Harrison.

Total mileage

0.0 Junction of Harrison By-pass and U.S. 62-65. Proceed northeast on Harrison By-pass (U.S. 62-65).

0.4

0.4 Typical Boone regolith exposed on west side of highway.

0.4

0.8 Contact of St. Joe (red) and Boone Formations exposed in bluff along Crooked Creek to north.

0.4

1.2 Cross Crooked Creek. Extensive Boone exposures along bluffs.

0.5

1.7 Junction of Arkansas 7 and U.S. 62-65.

0.1

1.8 Junction of Arkansas 7N and U.S. 62-65.

0.2

2.0 Traffic light.

0.2

2.2 Boone limestone and chert exposures.

1.1

3.3 Typical Boone regolith on northeast side of highway.

0.3

3.6 Junction with Harrison By-pass (northwest). Proceed northwest on U.S. 62-65.

0.5

4.1 Junction of U.S. 62-65 and Arkansas 43.

1.7

5.8 Turnoff for Boone County Airport.

0.4

6.2 Harrison city limit (northwest).

0.8

7.0 Boone exposed on northeast side of highway.

0.7

7.7 Boone exposed on northeast side of highway.

0.1

7.8 Boone poorly exposed on northeast side of highway.

0.2

8.0 Poorly exposed Boone on east side of highway.

0.2

8.2 Cross Dry Fork of Bear Creek.

0.1

8.3 Junction of U.S. 62 and 65. Abandoned quarry through lower Boone and upper St. Joe limestone. Turn northwest on U.S. 62.

1.9

10.2 Boone poorly exposed on northeast side of highway.

1.1

11.3 Batesville Sandstone exposed in road cut on both sides of highway.

0.1

11.4 Cross old railroad grade and dry tributary of Lick Branch.

0.1

11.5 Junction of U.S. 62 and Arkansas 206. Continue on U.S. 62.

0.1

11.6 Batesville exposed on north side of highway.

0.3

11.9 Poorly exposed Boone Formation on south side of highway.

2.3

14.2 Cross Long Creek.

0.4

14.6 Alpena city limit (east).

0.5

15.1 Junction of Arkansas 68 and U.S. 62. Turn southwest on Arkansas 68.

0.2

15.3 Alpena city limit (west; unmarked).

0.7

16.0 Poorly exposed Batesville on west side of highway.

0.5

16.5 Batesville on both west and east sides of highway.

0.8

17.3 Dipping Boone Formation on east side of highway.

0.1

17.4 Dipping Batesville on east side of highway.

0.3

17.7 Dipping Batesville on west side of highway.

0.1

17.8 Enter Old Carrollton.

The Carrollton town site was settled in 1833 and served as the Carroll County seat from 1834 to 1875. Carrollton was located on the old Carrollton-Forsyth-Springfield road and was a leading trading and political center during that time. It is notable for two events. In 1857, 17 children who had survived the famous Mountain Meadows Massacre in Utah were returned to settle with families here. During the Civil War, Carrollton served initially as a training center for Confederate troops. Herron's army camped here in January 1863, during the retreat from the battle of Prairie Grove, December 7, 1862. Skirmishes occurred here in January 1863 and March and April 1864. The town was completely destroyed during these battles but was rebuilt. It ceased to be of importance when the Carroll County seat was moved to Berryville in 1875.

0.1

17.9 Cross Long Creek. Boone Formation exposed in stream bed.

0.1

18.0 Boone Formation can be seen (in winter) forming bluffs along Long Creek to west of highway.

0.1

18.1 Batesville Sandstone exposed on both sides of road.

0.5

18.6 Cross tributary of Long Creek. Batesville Sandstone exposed on east side of road.

1.0

19.6 Batesville Sandstone poorly exposed on west side of highway.

0.5

20.1 Batesville and Fayetteville poorly exposed on west side of highway.

0.4

20.5 Hills to west and east capped by massive ledge of middle Bloyd sandstone.

0.5

21.0 Batesville Sandstone exposed on east side of highway.

0.2

21.2 Hills to west capped by massive ledge of middle Bloyd sandstone.

0.3

21.5 Intermittent exposures of Batesville Sandstone and Fayetteville shale along either side of highway for next 0.9 mile.

0.8

22.3 Exposure of thin-bedded, flaggy Batesville Sandstone on west side of highway.

0.3

22.6 Exposure of Hindsville Limestone on east side of highway.

0.1

22.7 Poorly exposed Batesville Sandstone on west side of highway.

0.5

23.2 Poorly exposed Boone on west side of highway.

0.1

23.3 Poorly exposed Boone in stream on east side of highway.

1.7

25.0 Intermittent exposures to northwest of Boone limestone and chert through next mile. Hills to southeast are capped by massive ledge of middle Bloyd sandstone.

0.7

25.7 Junction of Arkansas 103 and 68. Continue on 68.

0.7

26.4 Cross Osage Creek (intermittent).

1.0

27.4 Poorly exposed Boone forming hills on north side of highway.

0.1

27.5 Ascend hill through poorly exposed Boone regolith with scattered outcrops. Hindsville Limestone and Hindsville-Batesville contact exposed on north side at hilltop.

0.8

28.3 Batesville Sandstone poorly exposed on north side of highway for next 0.5 mile.

0.6

28.9 Junction of Arkansas 68 and 103. Batesville exposed in several road cuts in this vicinity. Continue on 68.

0.4

29.3 Batesville Sandstone in flaggy beds exposed intermittently on southwest side of highway for next 0.5 mile.

0.7

30.0 Hills in distance to northwest are capped by massive ledge of middle Bloyd sandstone.

0.2

30.2 Batesville Sandstone exposed on both sides of highway.

0.8

31.0 Boone Formation exposed in road cut on northwest side of highway.

0.8

31.8 Cross unnamed tributary to Dry Fork Creek.

0.3

32.1 Enter-leave Dry Fork.

0.2

32.3 Cross Dry Fork Creek (intermittent).

0.2

32.5 Boone exposures can be seen across valley to north.

0.2

32.7 Cross unnamed intermittent tributary to Dry Fork Creek.

0.6

33.3 Poorly exposed Boone forms bluff along Dry Fork Creek on north side of highway.

0.4

33.7 Begin intermittent exposures of Boone Formation on south side of highway for next mile.

1.0

34.7 Ascend hill through Boone Formation.

0.3

35.0 Boone-Hindsville contact on south side of highway.

0.1

35.1 Batesville Sandstone with no upper Hindsville Limestone on south side of highway.

0.1

35.2 Gently dipping Fayetteville Shale on both sides of highway.

0.1

35.3 Exposure of Batesville Sandstone on north side of highway.

0.4

35.7 Junction of Arkansas 68 and 21. Continue on 68.

0.4

36.1 Carroll-Madison County line. Boone exposures on north side of highway. Junction of Arkansas 68 and 21. Continue on 68.

0.2

36.3 Begin scattered exposures of Boone Formation on north side of highway for next mile.

1.5

37.8 Cross Kings River. Good exposure of Boone Formation in abandoned quarry on north side of highway.

0.3

38.1 Marble city limits (east; unmarked).

0.1

38.2 Marble city limits (west).

0.3

38.5 Cross intermittent stream.

1.9

40.4 Begin exposures of Boone Formation in road cuts on north side of highway, capped by typical regolith at tops of hills (0.5 mile).

0.6

41.0 Poorly exposed Boone Formation on south side of highway.

1.2

42.2 Poorly exposed Fayetteville on south side of highway.

0.3

42.5 Hindsville-Fayetteville contact exposed at road level on north side of highway.

0.1

42.6 Upper Hindsville Limestone exposed on south side of highway.

0.1

42.7 Exposures of Batesville Sandstone Tongue on north side of highway.

0.1

42.8 Hindsville Limestone and Batesville Sandstone Tongue exposed in abandoned quarry on north side of highway.

0.2

43.0 Hindsville Limestone exposed on south side of highway.

0.2

43.2 Fayetteville Shale exposed on north side of highway.

1.0

44.2 Junction of Arkansas 68 and 127. Continue on 68.

0.2

44.4 Extensive exposures of Boone Formation for 1 mile on northwest side of road. Note that limestone is resistant unit in these exposures.

0.9

45.3 McClinton Brothers Quarry on southeast side of highway. Extensive exposures of Boone Formation on northwest side of highway.

0.1

45.4 Cross War Eagle Creek.

0.7

46.1 Typical Boone regolith.

0.5

46.6 Boone Formation forms escarpment on south side of highway (winter).

0.3

46.9 Massive weathering of middle Bloyd sandstone on north side of highway (winter).

0.2

47.1 Bloyd shales poorly exposed on southeast side of highway.

0.8

47.9 Huntsville city limit (east). Hale shales (Cane Hill Member) exposed on east side of highway.

0.3

48.2 Junction of Arkansas 68 and 23. Continue on 68.

0.2

48.4 Hale sandstone and shale (Cane Hill Member) exposed on east side of road behind Frederick's gas station.

0.2

48.6 Junction of Arkansas 68 and 23. Continue on 68.

0.6

49.2 Junction of Arkansas 68 and 74. Proceed southwest on 74.

0.3

49.5 Float blocks and poor exposures of Brentwood Limestone Member of Bloyd Formation on slopes to north of highway.

0.3

49.8 Huntsville city limits (west).

0.3

50.1 Descend hill through series of thin-bedded, faulted Hale sandstones on north side of highway for 0.3 mile and in stream valley to south of highway.

0.5

50.6 Bluff to north held up by massive ledge of middle Bloyd sandstone.

0.2

50.8 Highway turns southwest to follow Drakes Creek fault system, a major northeast-southwest fault downthrown to southeast.

0.1

50.9 Hale-Bloyd boundary exposed in road cut on southeast side of highway.

0.4

51.3 Cross Holman Creek (intermittent).

0.1

51.4 Large float blocks of middle Bloyd sandstone to northwest (winter).

0.2

51.6 Road cut on southeast side of highway exposes *Arkanites-Cancelloceras* ammonoid fauna in upper Prairie Grove Member of Hale Formation.

0.6

52.2 Bluffs to northwest held up by middle Bloyd sandstone (winter).

0.1

52.3 Begin poorly exposed middle Bloyd section in road cuts on southeast side of highway for next 0.5 mile.

0.8

53.1 Well-exposed section of middle Bloyd on southeast side of highway.

1.0

54.1 Bloyd exposures intermittently on northwest and southeast sides of highway for next 0.9 mile.

0.2

54.3 Ascend hill for 0.4 mile through middle Bloyd exposures on southeast.

0.4

54.7 Poorly exposed middle Bloyd on northwest side of highway.

0.3

55.0 Atoka Formation exposed along stream bluffs to southeast.

0.4

55.4 Poorly exposed Atoka on northwest side of highway.

0.3

55.7 Intermittent exposures of dipping middle Bloyd and Atoka strata on northwest side of highway for next 0.5 mile.

0.4

56.1 Float blocks of middle Bloyd sandstone on northwest side of highway (winter).

0.4

56.5 Abandoned quarry in Pitkin limestone on northeast side of highway.

0.1

56.6 Faulted Cane Hill Member of Hale Formation to northwest of highway.

0.1

56.7 Intermittent exposures for next 0.9 mile of shale and sandstone mapped as Atoka on *Geologic Map of Arkansas* (Haley, 1976).

1.0

57.7 Draketown.

0.1

57.8 Junction of Arkansas 295 and 74. Road cut to southeast exposes dipping Morrowan strata reflecting part of Drakes Creek fault system. Highway 74 turns northwest out of the fault system. Poorly exposed Fayetteville Shale on slope to north.

0.1

57.9 Begin series of slopes for next 1.6 miles with intermittent exposures of Fayetteville Shale with Wedington rubble at road level. Bluffs to north formed by Pitkin Limestone capped by Cane Hill Member of Hale Formation.

1.7

59.6 Junction of Arkansas 303 and 74. Continue west on 74.

0.4

60.0 Cross Pigeon Creek.

0.3

60.3 Hill to north formed by Pitkin Limestone, capped by Cane Hill Member of Hale Formation.

0.3

60.6 Boone Formation exposed to north of highway.

0.2

60.8 Poorly exposed Boone and regolith to north of highway.

0.4

61.2 Poorly exposed Boone and regolith to north of highway.

0.2

61.4 Wesley city limit (east).

0.3

61.7 Junction of Arkansas 74 and 295. Continue on 74.

0.3

62.0 Wesley city limit (west).

0.3

62.3 Cross Richland Creek. Boone Formation exposed along stream to southwest.

0.7

63.0 Boone exposed on both sides of highway.

0.3

63.3 Washington-Madison County line.

0.1

63.4 Begin poor exposures of Boone and regolith on south side of highway for next 1.1 miles.

1.2

64.6 Cross Tuttle Branch of Richland Creek.

0.3

64.9 Tuttle, junction of Arkansas 74 and Washington County Road 70. Poorly exposed Fayetteville Shale.

0.2

65.1 Poorly exposed Fayetteville Shale for 0.02 mile on slopes to north of highway.

0.4

65.5 Ascend hill through Fayetteville Shale and Wedington Sandstone Member on south side of highway.

0.4

65.9 Continue ascent through poorly exposed Pitkin Limestone. Poorly exposed Cane Hill slope at top of hill.

0.1

66.0 Good Pitkin ledge exposed on hill to north of highway.

0.4

66.4 Lower Fayetteville-Wedington contact in road cut on north side of highway. Note that Wedington is quite thin here.

0.1

66.5 Descend hill through poorly exposed lower Fayetteville Shale.

0.2

66.7 Fayetteville Shale with concretions exposed in intermittent stream to north of highway.

0.3

67.0 Hindsville Limestone in ditch on both sides of highway and in gulley to south.

0.1

67.1 Fayetteville Shale poorly exposed on south side of highway for 0.2 mile.

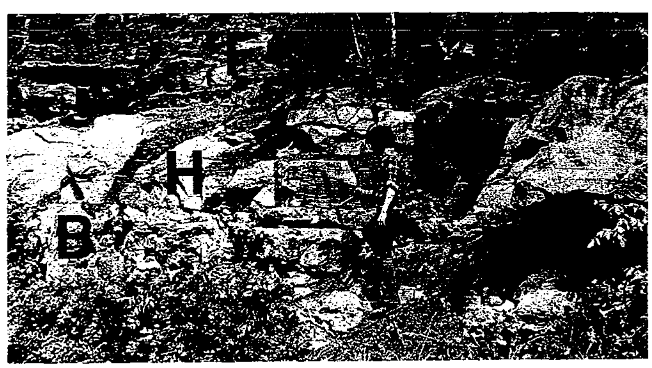


Figure 2. Chert-bearing carbonates of Osagean Boone Formation *(B)* are unconformably overlain by 3 feet of grainstones representing Chesterian Hindsville Formation *(H)*. Hindsville lacks development of basal breccia of reworked Boone chert at this locality. Lower Fayetteville Formation *(F)* is composed of black shales and succeeds Hindsville conformably.

0.3

67.4 Boone-Hindsville-Fayetteville contact.

0.2

67.6 Boone Limestone and chert exposed in road cut to north of highway.

0.2

67.8 Cross White River. Boone exposed at water level to north.

0.1

67.9 Elkins city limit (northeast).

0.2

68.1 Junction of Arkansas 74 and 16. Proceed northwest on 16.

1.7

69.8 Elkins city limit (northwest; unmarked).

0.1

69.9 Fayetteville city limit (southeast).

0.1

70.0 Cross Middle Fork of White River, impounded by Lake Sequoyah.

0.6

70.6 Poorly exposed Fayetteville on slopes to southwest of highway for next 0.3 mile.

0.2

70.8 Lake Sequoyah visible to north. Hills in distance capped by Bloyd Formation.

0.1

70.9 Poor Boone exposure on south side of highway.

0.4

71.3 Baldwin community (east; unmarked). Turn off to Lake Sequoyah.

0.8

72.1 Baldwin community (west; unmarked).

1.0

73.1 Cross West Fork of White River.

1.3

74.4 Junction of Arkansas 16 and 265. Poor Fayetteville exposure on corner to north.

0.5

74.9 Eastgate Shopping Center. Fayetteville Shale exposed on bank on north side of highway. Arkansas 16 turns south.

1.9

76.8 Junction of Arkansas 16 and U.S. 71B. Turn south on U.S. 71B.

0.1

76.9 Cross tributary of Town Branch.

0.1

77.0 Cross railroad spur.

0.3

77.3 Junction of U.S. 71B and Arkansas 265.

0.8

78.1 Poorly exposed Fayetteville slope on east side of highway.

0.1

78.2 Junction of U.S. 71 and 71B (Fayetteville By-pass).

0.3

78.5 Poorly exposed Fayetteville slope on east side of highway.

0.2

78.7 Junction of Arkansas 156 and U.S. 71.

0.5

79.2 Greenland city limit (north).

0.5

79.7 Entrance, Fayetteville Municipal Airport.

0.7

80.4 Cross tributary of West Fork of White River.

0.2

80.6 Traffic blinkers.

0.5

81.1 Greenland city limit (south).

0.3

81.4 Cross tributary to West Fork of White River.

0.6

82.0 Very poorly exposed Fayetteville in ditches and embankments to east for next 0.9 mile.

0.9

82.9 Cross Rock Creek.

0.2

83.1 Poor Fayetteville exposure on embankment to east.

0.1

83.2 West Fork city limit (north).

0.3

83.5 Sporadic poor exposures of Fayetteville Shale and Wedington Sandstone Member on east side of road for next mile.

1.0

84.5 Cross Dye Creek.

0.4

84.9 Pitkin caps hill to east.

0.3

85.2 Junction of U.S. 71 and Arkansas 170, blinking light.

0.5

85.7 West Fork city limit (south).

0.2

85.9 Fayetteville Shale and Wedington Sandstone Member exposed on east side of highway.

0.1

86.0 **STOP 2—Pitkin quarry.**

0.2

86.2 Fayetteville Shale slope with Pitkin float blocks on east side of highway.

0.1

86.3 **STOP 3—Pitkin bluff.**

0.1

86.4 Large continuous bluff of Pitkin Limestone on east side of highway. Fayetteville-Pitkin contact on east bluff.

0.1

86.5 "Ten Mile Rock."

Figure 3. Black shales of upper Fayetteville Formation *(F)* are overlain by 42 feet of Pitkin Limestone *(P)* with apparent conformity. Cane Hill Member *(C)* of Hale Formation (Morrowan) forms Mississippian-Pennsylvanian unconformity at top of exposure.

0.2

86.7 Cross east-west-trending fault, downthrown to south.

0.4

87.1 Cane Hill Member of Hale Formation forms embankment on east side of highway.

0.1

87.2 Cross small fault. Contact of Cane Hill and Prairie Grove Members of Hale Formation exposed on slope to east.

0.1

87.3 Cross small fault. Upper Prairie Grove exposed on east side of road.

0.1

87.4 Contact of Prairie Grove and Brentwood Limestone Member of Bloyd Formation (base of shale) exposed on both sides of road.

0.2

87.6 Cross Mill Creek.

0.1

87.7 Upper Prairie Grove exposed in road cut on east side of road.

0.1

87.8 **STOP 4—Type Brentwood.**
Retrace route to City of Fayetteville.

Fayetteville (population 34,036) was founded as the Washington County seat in 1828 following the partitioning of Lovely County. The city was occupied by Union cavalry under the command of Col. M. L. Harrison on July 14, 1862, without resistance. Harrison was attacked by Confederate troops under the command of Gen. W. L. Cabell on October 28, 1862, and April 18, 1863. The Union force was so well fortified that these attempts were unsuccessful, but they led to the withdrawal of Union troops on April 25, 1863. However, Union forces returned to occupy Fayetteville on September 22, 1863, for the remainder of the war. The University of Arkansas was founded in 1871 as The Arkansas Industrial University. The first class was graduated in 1876. Fayetteville is the main campus of the four-school University of Arkansas System, and it served 13,026 students during the 1976-77 academic year.

STOP 5—Fayetteville railroad cut.
TOTAL MILEAGE FOR FIRST DAY: 197.4 miles.

STOP DESCRIPTIONS—FIRST DAY

Walter L. Manger[1]

STOP 1—PEYTON CREEK ROAD CUT
NE¼ sec. 11 and NW¼ sec. 12, T. 13 N., R. 15 W. Van Buren County, Arkansas

The field excursion begins at the famous Peyton Creek road cut, exposing Chesterian strata of the upper Pitkin and Imo Formations overlain by presumed Morrowan-age strata of the Witts Springs? Formation. The type locality for the Imo Formation is in Sulphur Springs Hollow, a tributary to Bear Creek, in adjacent Searcy County (Gordon, 1965). However, the Peyton Creek exposure has produced the bulk of the Imo fossils, and understanding of the age and correlation of the unit is based primarily on this exposure.

The upper Pitkin Limestone comprises a series of oolitic-crinozoan grainstones with minor dark shale (figs. 1, 2). These beds are significant in that they have yielded biostratigraphically sensitive assemblages of conodonts and calcareous foraminifers. The conodonts, described by Lane (1967) and Lane and Straka (1974), are referable to the *Adetognathus unicornis* Zone of the standard Mississippian succession. This occurrence indicates equivalence of the Pitkin at Peyton Creek to the Grove Church Shale and thus to the top of the type Chesterian Series (Lane, 1967). Smaller calcareous foraminifers from the Pitkin are reported by Brenckle (this guidebook) to be dominated by eosigmoilinids characteristic of Mamet Zone 19. Re-collection of the type Chesterian has produced similar assemblages supporting the correlations based on conodonts (Brenckle, 1977). No ammonoids have been recovered from the Pitkin at this locality. At Leslie, 5 miles north, the Pitkin yields an ammonoid assemblage with *Eumorphoceras bisulcatum* and *Cravenoceras richardsonianum* (Saunders and others, this guidebook). This assemblage may be correlated intercontinentally with Arnsbergian zone E_2a of the standard Namurian succession. The conodonts and foraminifers support this correlation. Ammonoids are not known from type Chesterian strata in this interval.

The Imo succeeds the Pitkin with apparent conformity at the Peyton Creek locality. The bulk of the formation is fossiliferous gray to black shale with scattered beds of sandstone and conglomeratic limestone (figs. 1, 3). Well-known ammonoid assemblages from the Imo provide a basis for precise intercontinental correlation. The assemblage is dominated by *Anthracoceras discus* but includes more sensitive taxa such as *Fayettevillea, Eumorphoceras, Delepinoceras,* and *Cravenoceras* (Saunders, 1973). These forms suggest equivalency to the upper Arnsbergian Stage (E_2b-c) of the standard Namurian succession (Saunders and others, this guidebook). The basal black shale of the Imo also contains an assemblage of crushed ammonoids characterized by *Eumorphoceras bisulcatum erinense.* This occurrence suggests that the lower portion of the Imo Formation is equivalent to E_2a of the standard Namurian succession. Conodonts of the *Adetognathus unicornis* assemblage zone have been recovered from limestone and calcareous sandstone zones extending through the primary ammonoid-bearing zone (Lane, this guidebook). These occurrences suggest that the *Adetognathus unicornis* zone is equivalent to most of the Arnsbergian Stage (E_2) of the standard Namurian succession. Limestones of the Imo yield Mamet Zone 19 foraminifers (Brenckle, this guidebook). Data from the ammonoids, conodonts, and calcareous foraminifers suggest that the Imo Formation is in part younger than the youngest type Chesterian formation (Grove Church Shale). Biostratigraphic relationship to other youngest Chesterian strata such as the Bird Spring Limestone of Nevada cannot be established precisely at this time because of the lack of sensitive faunal elements in common.

At the Peyton Creek exposure, the highest dark shales in the road cut still yield Mississippian palynomorphs (T. Beach, University of Texas-Dallas, personal communication, 1973). Above this zone is an extensive covered interval with no indicative float. The next exposures exhibit an apparently gradational contact of dark shale and quartz sandstone overlain by a thick sequence of flaggy sandstone (fig. 1). The top of the Imo Formation has not been adequately defined, and the boundary is arbitrarily placed at the base of the first massive sandstone. This contact is also presumed to coincide with the Mississippian-Pennsylvanian boundary in this area.

Assignment of these sandstones above the Imo to a formation is unclear. The name Imo was initially withdrawn by Gordon (1965), to be replaced by the term Cane Hill Formation of Chesterian and Morrowan age (Glick and others, 1964). Usage of Cane Hill as a formation in north-central Arkansas was questioned by Quinn (1966) and Saunders (1973); and the name Imo has continued in recent literature (e.g., Gordon, 1970), although it does not appear on the newly published *Geologic Map of Arkansas* (Haley, 1976). The Witts Springs Formation of Morrowan age was proposed for strata overlying the "Cane Hill Formation" in north-central Arkansas (Glick and others, 1964). Since the relationship of the top of the Imo Formation to Morrowan strata has not been clearly established, the sandstone sequence above the Imo is assigned questionably to the Witts Springs to avoid confusion with the name Cane Hill. Although it is common practice to show the Imo Formation overlain by the strata referred to the Cane Hill Member of the Hale Formation (type Morrowan), this relationship has never been demonstrated. In addition, the Mississippian-Pennsylvanian boundary has never been assessed faunally in the region of Imo exposures in north-central Arkansas.

The Imo ammonoid assemblage has received the bulk of taxonomic and biostratigraphic attention (Furnish and others, 1964; McCaleb and others, 1964; Gordon, 1965; Saunders, 1966, 1973, 1975; Manger and Quinn, 1972). However, the fauna is actually dominated by gastropods and and bivalves; yet neither of these groups has received taxonomic treatment. Published studies of other Imo fossils include crinoids (Burdick and Strimple, 1973), phyllocarids (Copeland, 1967), plant petrifactions (Taylor and Eggert, 1967), and palynomorphs (Sullivan and Mischell, 1971).

[1]Department of Geology and University Museum, University of Arkansas, Fayetteville, Arkansas.

STOP 1 — PEYTON CREEK ROADCUT

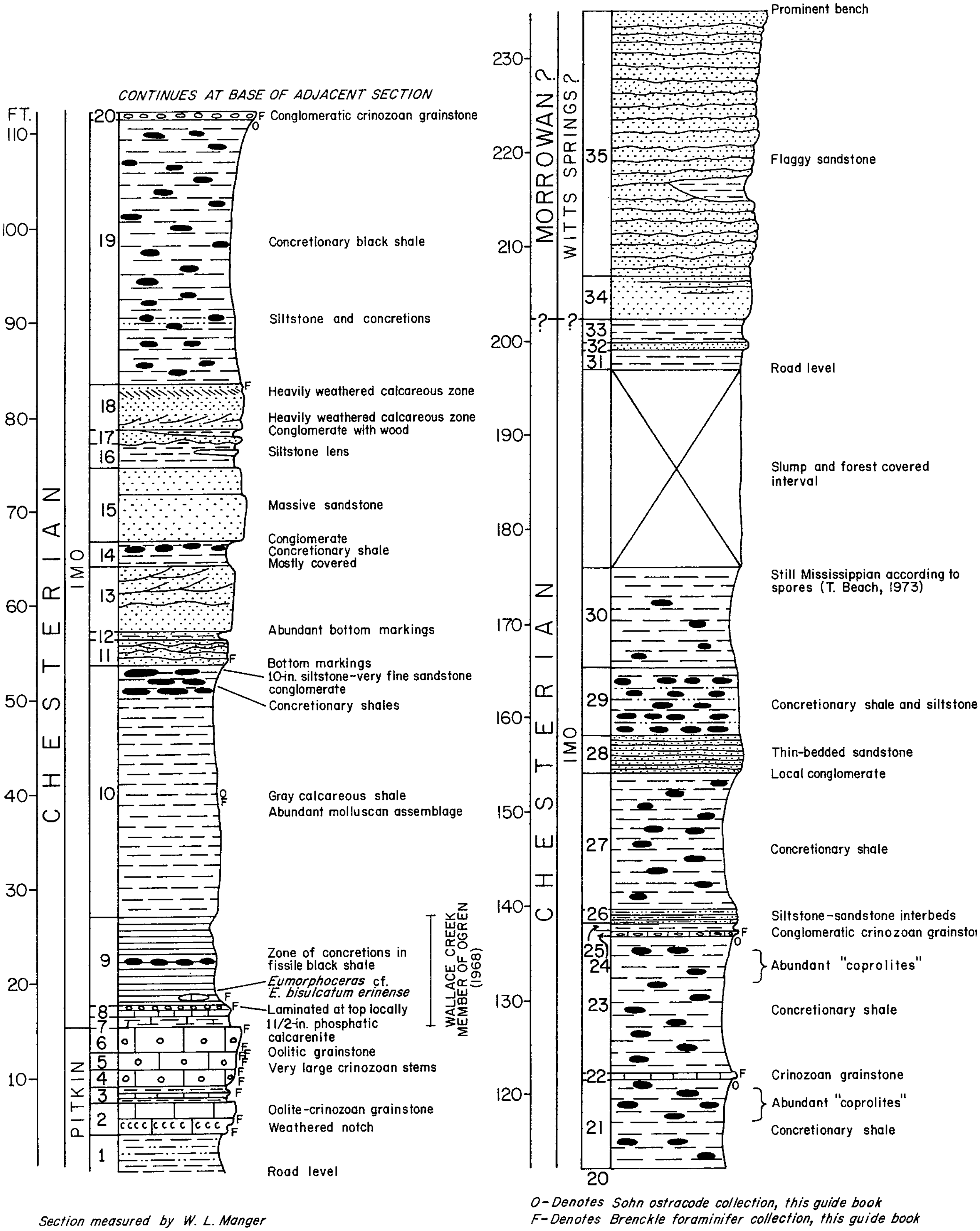


Figure 1. Graphic columnar section for Stop 1.

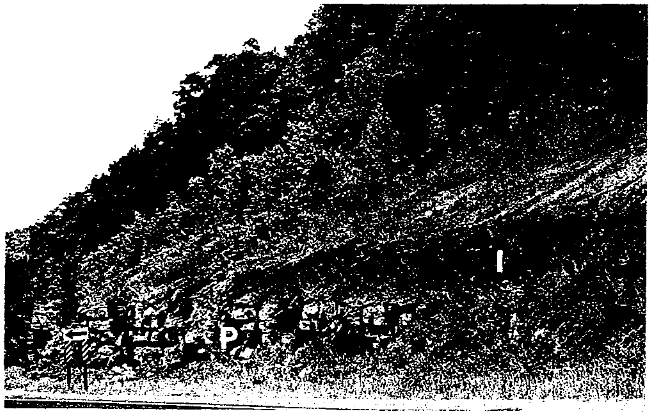


Figure 2. Oolitic grainstones of Pitkin Formation *(P)*, overlain by black and gray shale of lower Imo Formation *(I)*.

Figure 3. Dark shales and interbedded limestones *(L)* of primary fossil-bearing zone in upper Imo Formation.

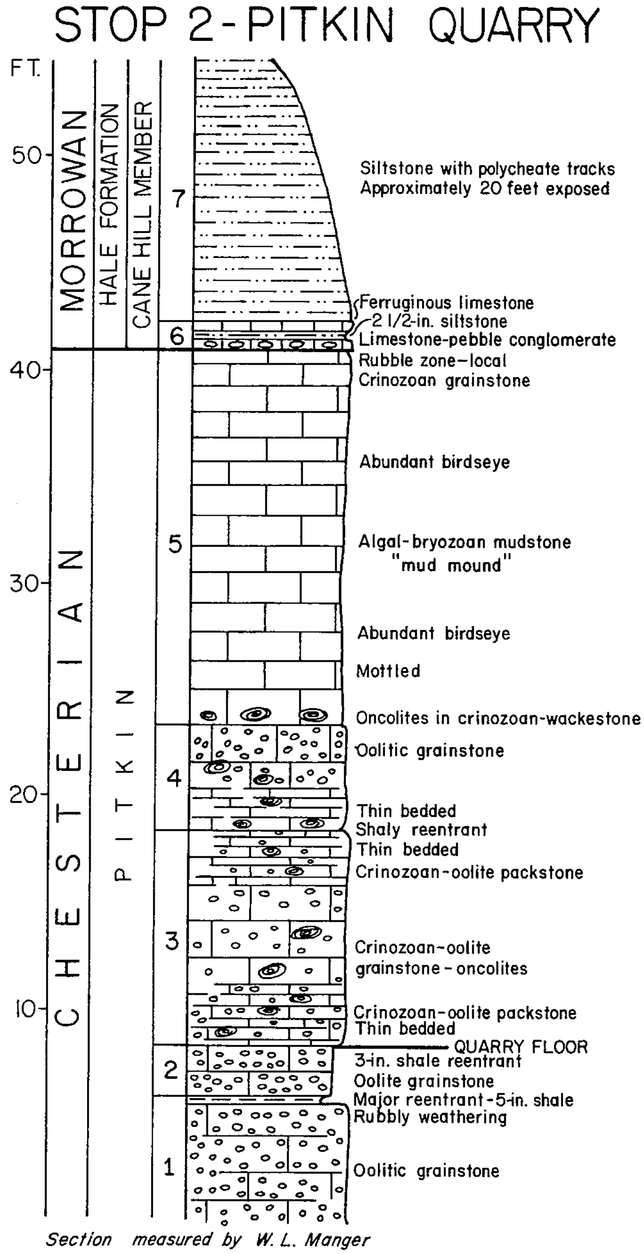


Figure 4. Graphic columnar section for Stop 2.

STOP 2—PITKIN QUARRY
NE¼NW¼SW¼ sec. 4, T. 14 N., R. 30 W.
Washington County, Arkansas

The Pitkin Limestone was proposed by Adams and Ulrich (1904) to replace the "Archimedes Limestone" of Owen (1858). Henbest (1962) designated as type this bluff on the east side of the West Fork of the White River at the base of Bloyd Mountain. Two stops (2 and 3) are planned along the type locality to provide an opportunity to examine the lithostratigraphy of the Pitkin and its contacts with adjacent units.

The Pitkin Limestone is a complex of shallow-water, shelf carbonates. Oolitic and crinozoan grainstones predominate, but muddy facies are also present. Dark shale, which is a common component of the formation in north-central Arkansas, is scarce in the type region. At this stop, the lower portion of the Pitkin represents high-energy, wave-base accumulations of oolite and crinozoan detritus (fig. 4). This interval is succeeded by algal-bryozoan mudstones described by Tehan and Warmath (this guidebook) as lime-mud mounds (fig. 5). Mounds of this type are common and characteristic of the Pitkin in northwestern Arkansas. Girvanellid blue-green algae and fenestrate bryozoans are thought to trap carbonate mud in low mounds that expand and are reduced as a reflection of the energy-level changes during accumulation. Crinozoans provide a current baffle that aids in accumulation of mud (Tehan and Warmath, this guidebook).

The Pitkin-Cane Hill contact (Mississippian-Pennsylvanian boundary) is well exposed at the top of the working face of this quarry (fig. 5). The top of the Pitkin is a rubble zone of highly weathered carbonate and soft clay shale. Overlying this rubble is a thin ferruginous, sandy carbonate and conglomerate bearing rounded cobbles and boulders of typical Pitkin lithology. The conglomerate also contains pebbles of phosphate and pyrite grains. Similar conglomerates mark the base of the Cane Hill elsewhere, even if the Pitkin is absent (e.g., Stop 5). The conglomerate is succeeded by thin-bedded, ripple-marked, essentially unfossiliferous siltstone with polycheate tracks on the upper bedding surfaces. Upper

Figure 5. Pitkin Limestone exhibiting a variety of carbonate facies overlain by platy siltstone of Cane Hill Member, Hale Formation (Morrowan) *(C)*. Contact is marked by resistant ledge of sandy, ferruginous conglomerate containing rounded cobbles of Pitkin lithology (arrow).

Chesterian fossils are abundant in the Pitkin, particularly the cryptostomous bryozoan *Archimedes wortheni*. The fauna has been described by Easton (1942, 1943), who listed 208 species dominated by bryozoans, brachiopods, and molluscans.

Conodonts obtained from the upper Pitkin in northwestern Arkansas are referable to the *Kladognathus-Cavusgnathus naviculus* Zone of the standard Chesterian succession (Lane, 1967; Lane and Straka, 1974). This occurrence indicates that the top of the type Pitkin is older here than in north-central Arkansas (Stop 1), presumably because of increased pre-Cane Hill erosion. Mamet Zone 19 foraminifers occur in abundance in the Pitkin (Brenckle, this guidebook), but no ammonoids have been recovered from exposures in northwestern Arkansas.

STOP 3—PITKIN BLUFF
NE¼SW¼SW¼ sec. 4, T. 14 N., R. 30 W.
Washington County, Arkansas

The Pitkin-Fayetteville contact and adjacent strata are well exposed at this locality. The uppermost Fayetteville Formation contains calcareous shale with lenses and nodules of carbonate (figs. 6, 7). The entire interval is highly fossiliferous, being dominated by shelly fauna. This occurrence is in marked contrast to other Fayetteville exposures in northern Arkansas of dark to black shale and dense concretions yielding only a pelagic fauna, predominantly cephalopods. Knowledge of Fayetteville faunal elements, except for cephalopods, is based primarily on occurrences near the base of the unit. Some of these belong lithostratigraphically to the underlying

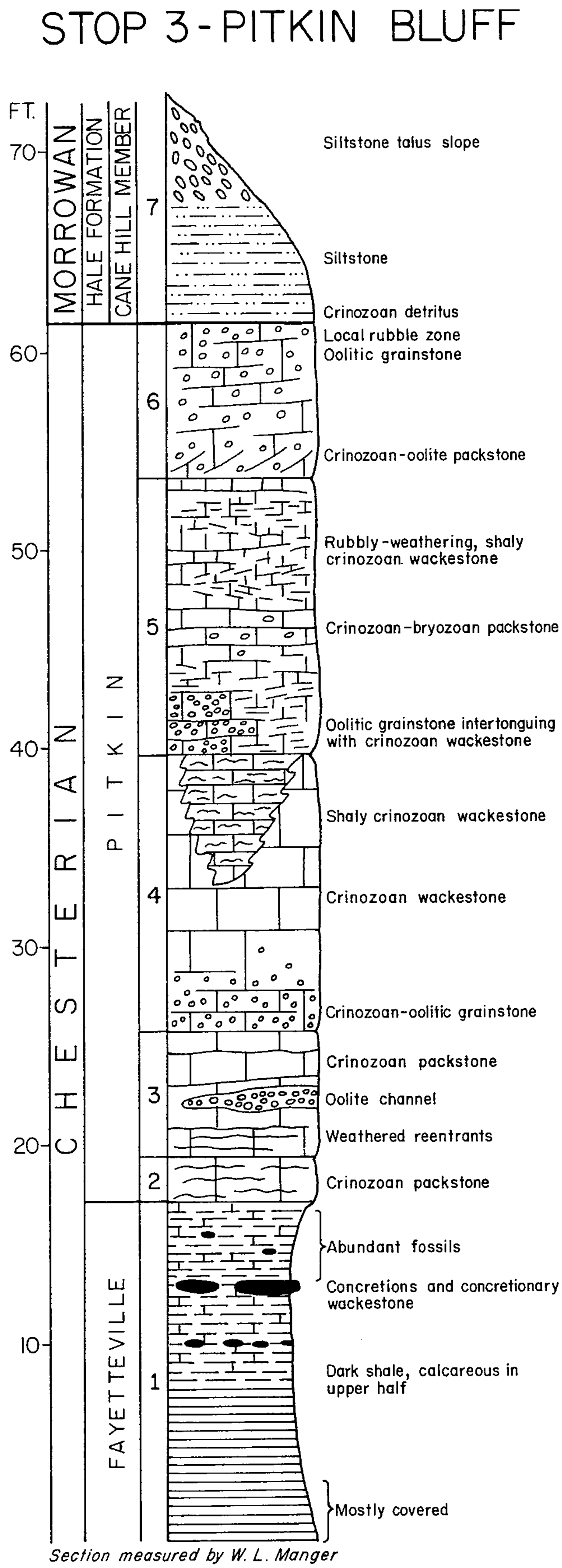


Figure 6. Graphic columnar section for Stop 3.

Hindsville Formation (Chesterian). The fossils at this stop have not been studied in detail, although Brenckle (this guidebook) recovered calcareous foraminifers similar to those of the Pitkin from the uppermost Fayetteville shale. The Fayetteville is succeeded by the Pitkin Limestone, with a sharp but apparently conformable contact.

The Fayetteville Formation has been correlated with the Pendleian Stage (E_1) of the standard Namurian succession, based on its cravenoceratid-eumorphoceratid cephalopod assemblage (Saunders and others, this guidebook).

The Pitkin Limestone is similar though not identical to exposures at Stop 2. No mud mounds are present here, and rubbly-weathering carbonates with shale partings are more commonly developed (fig. 7). Oolitic- and crinozoan-dominated lithologies are similar to those previously seen.

The Cane Hill Member of the Hale Formation exhibits characteristic siltstone lithology, which may rest directly on the Pitkin without conglomerate development in this immediate area.

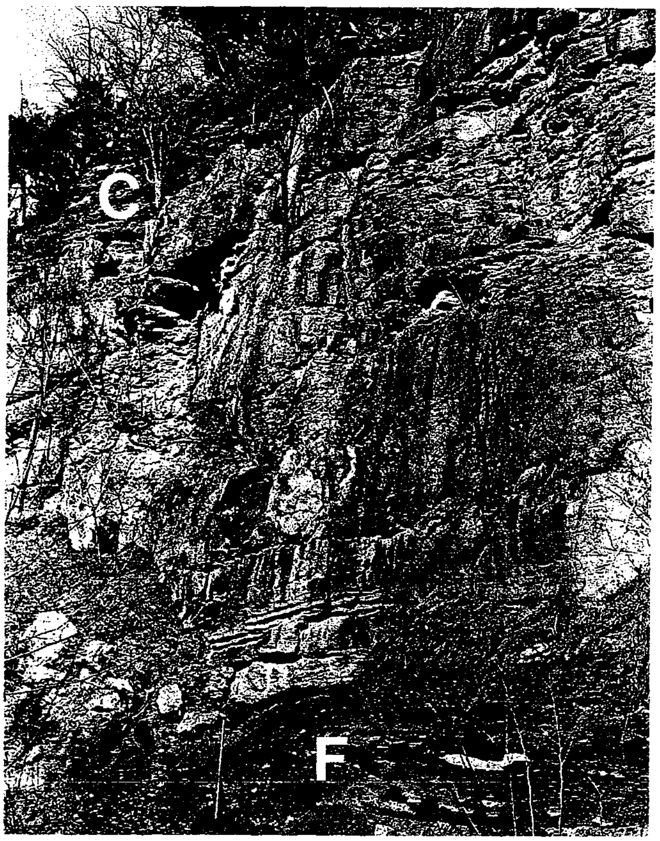


Figure 7. Fossiliferous calcareous shale and carbonate lenses in upper Fayetteville Formation *(F)*, overlain by massive Pitkin Limestone. Cane Hill Member of Hale Formation (Morrowan) *(C)* rests unconformably on Pitkin at top of bluff.

STOP 4—TYPE BRENTWOOD
SW¼NE¼ sec. 16, T. 14 N., R. 30 W.
Washington County, Arkansas

These exposures on the east side of Highway 71 were designated the type section for the Brentwood Limestone Member, basal Bloyd Formation (Morrowan), by Henbest (1962). The unit is represented by an alternation of dark, sandy crinozoan grainstones and dark shales (figs. 8, 9). The

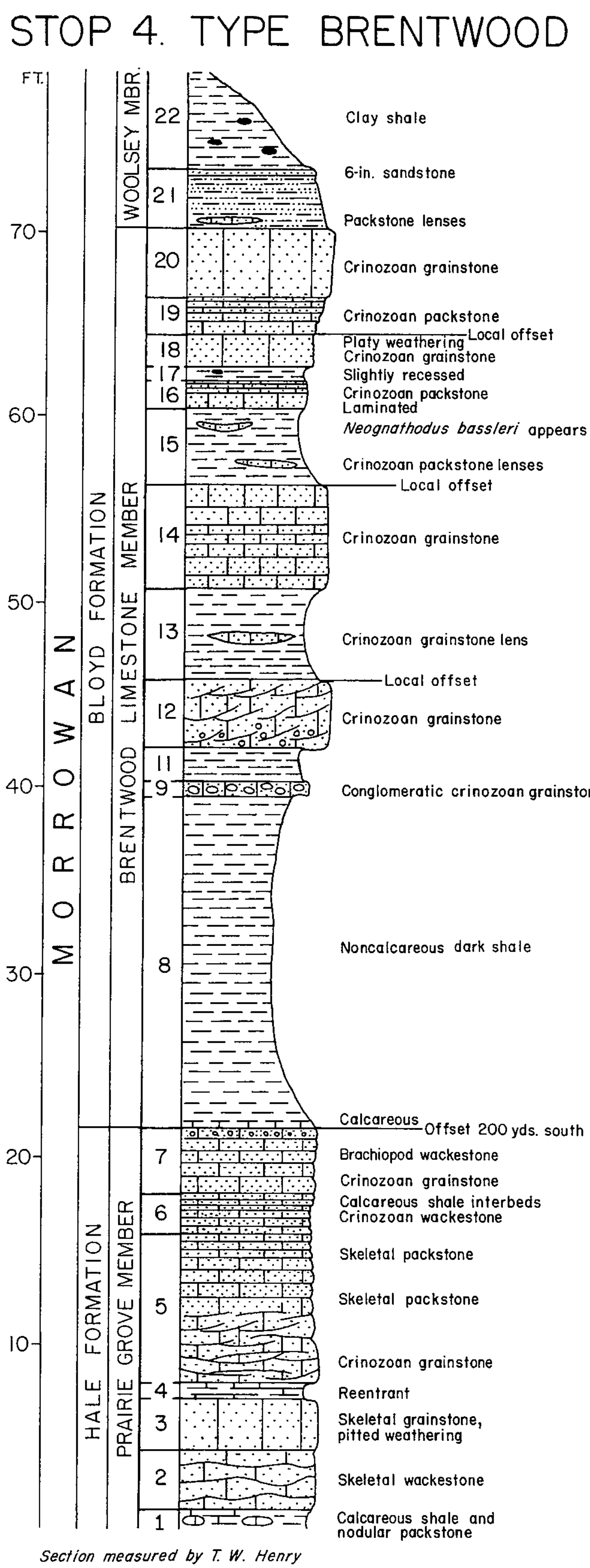


Figure 8. Graphic columnar section for Stop 4.

Brentwood overlies the Prairie Grove Member of the Hale Formation conformably and is overlain by the Woolsey Member of the Bloyd Formation with apparent unconformity (fig. 9).

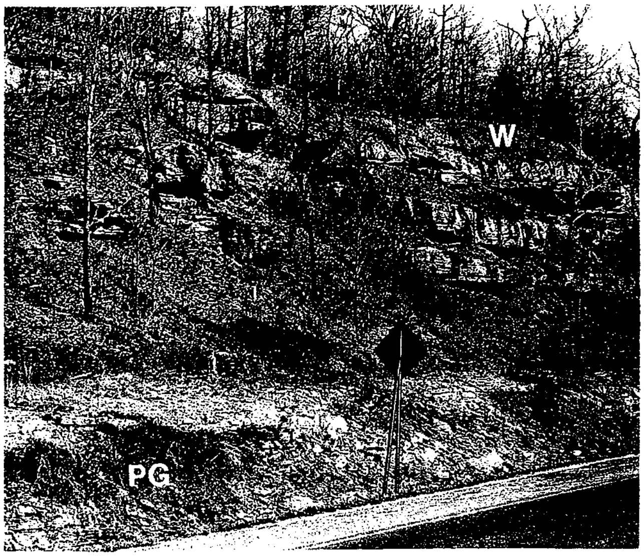


Figure 9. Upper Prairie Grove Member, Hale Formation *(PG)*, succeeded conformably by dark shales and sandy, crinozoan grainstones of type Brentwood Limestone Member, Bloyd Formation. Highest part of this bluff exposes shale of Woolsey Member, Bloyd Formation *(W)*.

The Brentwood Limestone Member was originally described as the "Pentremital Limestone" by Owen (1858). The abundance of this echinoderm influenced correlation of the interval with the Chesterian until well past the turn of the century. Blastoids occur in profusion in local lenses through northern Arkansas and eastern Oklahoma. They are not abundant at this locality, but large collections of well-preserved specimens can be made from equivalent strata in the upper Braggs Member of the Sausbee Formation at Stop 9. The blastoid *Pentremites rusticus* is the only species recognized in Morrowan strata of this region (Horowitz and Macurda; Katz and Sprinkle, this guidebook). Crinoids are common in the Brentwood Member. *Arkacrinus* and *Metacromyocrinus* are common, the latter taxon being recognizable from disarticulated plates by its characteristic ornament. The assemblage is well known through the report by Moore and Strimple (1973). Occurrences are summarized by Strimple (this guidebook).

Biostratigraphic studies of the Brentwood Limestone Member have concentrated on ammonoids, conodonts, and brachiopods. The contact of the Prairie Grove Member of the Hale Formation and the Brentwood is gradational both lithostratigraphically and faunally. Zones based on sensitive taxa span the lithostratigraphic boundary without change. Thousands of ammonoids have been collected from the Brentwood Member throughout northern Arkansas. The most distinctive member of the Brentwood assemblage is *Branneroceras branneri*, which, with the appearance of true *Gastrioceras*, marks the beginning of Westphalian A (G_2). The *Branneroceras* zone occurs in the upper half of the member at this locality (McCaleb, 1968). Consequently, the Namurian-Westphalian boundary falls within the Brentwood Member. The basal part of the Member contains the *Verneuilites-Cancelloceras* assemblage also characteristic of the top of the Prairie Grove Member of the Hale Formation (Saunders and others, this guidebook). The diverse ammonoid assemblage from the Brentwood was monographed by McCaleb (1968).

The Brentwood Member begins in the *Neognathodus symmetricus* Conodont Zone and ranges through a part of the *Idiognathodus sinuosis* Zone of Lane and Straka (1974). At this locality, the top of the Brentwood falls within the *Neognathodus bassleri* Zone, but regionally it may become as young as the *Idiognathodus sinuosis* Zone (Lane and Straka, 1974), as can be seen at the Evansville Mountain section (Stop 6).

Brachiopods of the upper Prairie Grove and the Brentwood fall within the *Plicochonetes*? *arkansanus* Zone of Henry and Sutherland (this guidebook). In addition to the name bearer, species of *Beecheria, Rhyncophora, Tesquea, Linoproductus, Echinaria,* and *Anthracospirifer* are common.

STOP 5—FAYETTEVILLE RAILROAD CUT
SE¼SW¼ sec. 9, and NW¼NE¼ sec. 16
T. 16 N., R. 30 W., Washington County, Arkansas

A cut for the St. Louis and San Francisco Railroad through the city of Fayetteville has been a well-known and important fossil locality for more than 10 years. Here, strata of the Cane Hill Member of the Hale Formation rest unconformably on black shale of the upper Fayetteville Formation (figs. 10, 11).

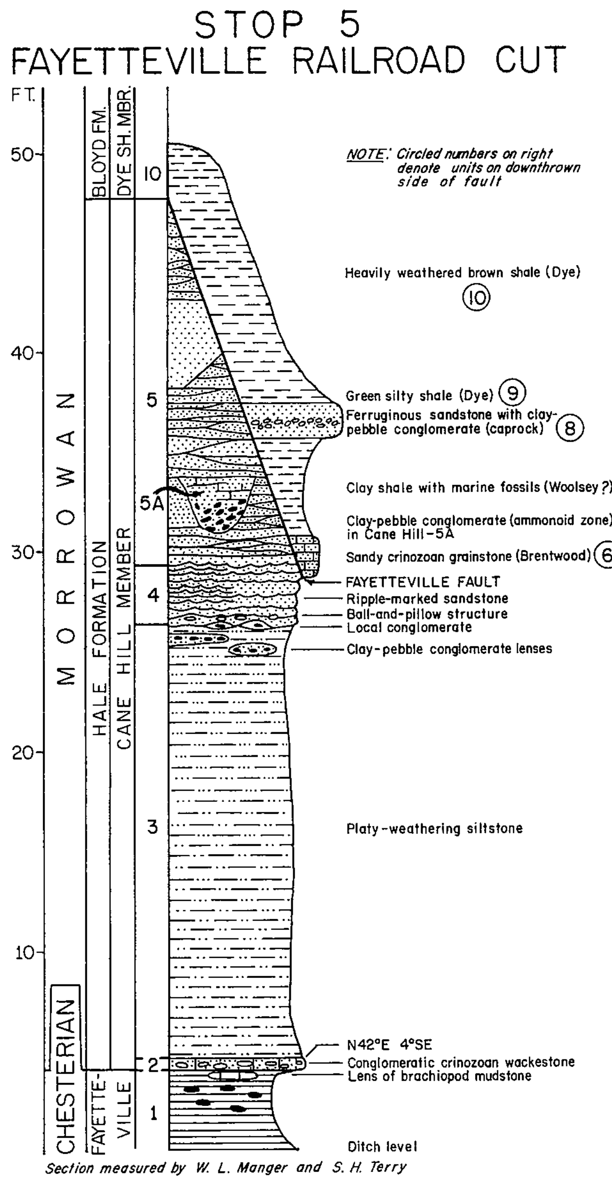


Figure 10. Graphic columnar section for Stop 5.

The Pitkin Formation has been removed by erosion, and its former presence is indicated only by rounded cobbles of characteristic lithologies in a basal Cane Hill conglomerate (fig. 11). The Fayetteville Shale at this locality yields a typical lower Namurian–upper Chesterian palynomorph assemblage (James Urban, University of Texas-Dallas, personal communication). However, the basal Cane Hill conglomerate and succeeding siltstone are devoid of biostratigraphically sensitive fossils. Similar conditions also have been seen at the Pitkin quarry (Stop 2) and are common elsewhere, precluding precise biostratigraphic definition of the Mississippian-Pennsylvanian boundary in northwestern Arkansas.

The basal Cane Hill conglomerate is overlain by approximately 22 feet of unfossiliferous, ripple-marked siltstone with shale partings similar to the lithology seen at the Pitkin quarry (Stop 2) (fig. 11). This siltstone is succeeded by irregularly bedded, fine- to medium-grained sandstone, which is also unfossiliferous for the most part. However, within this sandstone succession is a lens of highly fossiliferous, calcareous, clay-pebble conglomerate with a quartz-sand matrix. This lens yields a rich assemblage of ammonoid cephalopods characterized by the index taxa *Retites semiretia, Reticuloceras tiro, Reticuloceras wainwrighti,* and *Hudsonoceras moorei.* These and other Cane Hill ammonoid taxa have been described in papers by Gordon (1965, 1969), McCaleb (1965), Quinn (1966), and Quinn and Saunders (1968). The ammonoid assemblage provides precise correlation to zone $R_{1}a$ of the Kinderscoutian Stage, Namurian Series, of Europe (Saunders and others, this guidebook). This ammonoid zone also represents the lowest occurrence of biostratigraphically sensitive fossils in type Morrowan strata.

Conodonts of the *Rachistognathus primus* Zone of Lane and Straka (1974) have been recovered from the ammonoid-bearing lens (Straka, 1972; erroneously reported as basal Cane Hill). This assemblage zone is regarded by Lane (Lane and Straka, 1974; this guidebook) as equivalent to parts of the *Homoceras* interval (Chokierian and Alportian Stages H_1-H_2) of Europe in apparent conflict with the correlations based on ammonoids. The lens also yields a diverse fauna of other invertebrates.

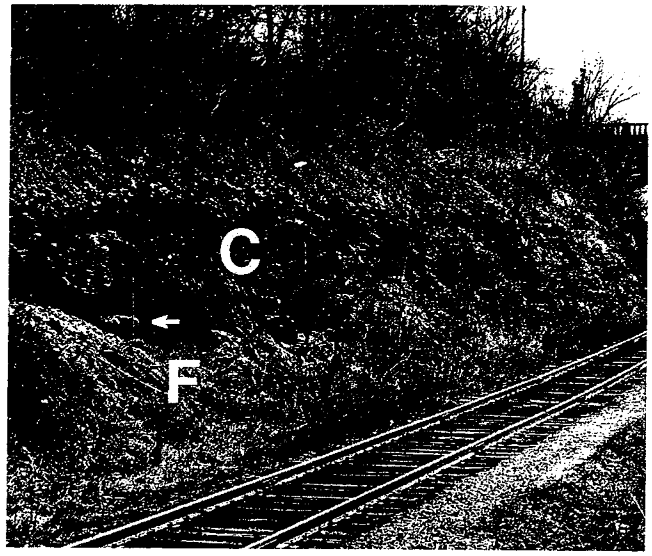


Figure 11. Unconformable contact of Chesterian Fayetteville Formation *(F)* and Morrowan Cane Hill Member of Hale Formation *(C)*. Contact is marked by thin basal conglomerate (arrow) succeeded by platy-weathering siltstone. Jacob staff is 5 feet long.

The Fayetteville fault, a major northeast-trending lineament, intersects the south end of the exposure. The fault is downthrown to the southeast and brings Brentwood through Dye strata of the Bloyd Formation into juxtaposition with the Cane Hill Member of the Hale Formation (fig. 10).

ROAD LOG—SECOND DAY

Patrick K. Sutherland[1]

The road log for the second day begins in Fayetteville, Arkansas, and proceeds southwestward, via the towns of Prairie Grove, Cane Hill, and Morrow, to examine what is considered to be the primary Morrowan reference section, located near Evansville, Arkansas. The route then proceeds westward across Adair County, Oklahoma, to Cherokee and Muskogee Counties, Oklahoma. The new Morrowan formations and members recently described by Sutherland and Henry (1977, and this guidebook) will be examined.

Road logs and stop descriptions for the second day were prepared with the assistance of W. L. Manger, University of Arkansas, and R. C. Grayson, Jr., A. J. Hoefner, M. D. Orgren, and G. D. Zimbrick, The University of Oklahoma.

Total mileage

0.0 Beginning point in southwestern Fayetteville, at junction of U.S. 71 and 62B. Go west on U.S. 62B.

0.4

0.4 Go under railway overpass.

0.5

0.9 Arkansas 112 to north.

0.8

1.7 Go under 4-lane overpass of U.S. 71 By-pass.

1.7

3.4 Farmington city limit (east).

1.1

4.5 Junction of Arkansas 170.

1.2

5.7 Farmington city limit (west). Proceed westward over poorly exposed terrane of Boone Formation. Hills to south are capped by Atoka Formation.

2.9

8.6 Junction of Arkansas 170, paved road to east.

0.7

9.3 Cross Illinois River bridge.

1.0

10.3 Prairie Gove city limit (east).

0.2

10.5 Entrance to Battle Field Park and Musuem.

0.7

The Battle of Prairie Grove marked the final attempt by the Confederates, commanded by General T. C. Hindman, to drive the Union army, commanded by General J. G. Blunt, from northern Arkansas. As the battle plan to attack Blunt was formulated, Hindman learned that troops commanded by General F. J. Herron had arrived by forced march from Harrison, Arkansas, to reenforce Blunt at Cane Hill. Hindman elected instead to attack Herron on December 7, 1862, hoping to disperse that army before it could unite with Blunt. The battle raged throughout the day with an intense artillery duel followed by charges and countercharges. Blunt appeared on the field in the early afternoon and inflicted heavy losses on the Confederate forces. Both sides retreated during the night, leaving 339 killed and 1,630 wounded. Following this battle, Union forces occupied all of southern Missouri and northwestern Arkansas to the Arkansas River and were never again challenged.

11.2 Stoplight. Highway turns west through Prairie Grove.

0.2

11.4 Stop sign; center of Prairie Grove.

0.5

11.9 Prairie Grove city limit (west).

0.3

12.4 Cross Muddy Fork Creek.

1.0

13.4 Poorly exposed Fayetteville Shale on south side of road.

0.5

13.9 Hill to north capped by Wedington Sandstone Member of Fayetteville Shale.

0.5

14.4 Cross Budd Kidd Creek.

0.5

14.9 Extensive exposures of Wedington Sandstone for 0.5 mile on north side of road.

0.5

15.4 Turn south (left) on Arkansas 45. Wedington Sandstone exposed in low road cut.

2.3

17.7 Pitkin Limestone forms bluffs on either side of road.

0.4

18.1 Abandoned quarry in bluff on east side of road is type locality of Pitkin.

0.3

18.4 Cane Hill city limit (north).

The village of Cane Hill was founded in the early 1800's and served as an important mill site for nearly 100 years. Cane Hill College was founded in 1852 by the Presbyterian Church and was active through the Reconstruction. The principal building of the college still stands, and it was used as a hospital following the Battle of Prairie Grove. Cane Hill was a major marshaling area for troops of both the North and South. It was also the focus of several major cavalry engagements during the fall of 1862.

[1]School of Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma.

0.8

19.2 Cane Hill city limit (south).

0.3

19.5 Bluffs of Pitkin Limestone overlying poorly exposed Fayetteville Shale.

0.7

20.2 Church in village of Clyde.

1.0

21.2 Poorly exposed Pitkin Limestone behind houses on hillside south of road.

1.2

22.4 Poorly exposed Fayetteville Shale in east ditch for next 0.4 mile.

0.1

22.5 Top of Hindsville Formation poorly exposed in east ditch. Formation is well exposed in abandoned quarry, out of sight 100 yards south of road.

0.2

22.7 Leave pavement; turn south on county road to Morrow, Arkansas.

1.1

23.8 Cross Fly Creek bridge; exposures of Hindsville in stream bed.

0.1

23.9 Town of Morrow.

0.1

24.0 Exposures of Hindsville form low ridge across creek on west side of road.

0.4

24.4 Poorly exposed Fayetteville Shale on both sides of road for next 0.5 mile.

0.4

24.8 Wedington Sandstone poorly exposed in ditch on west side of road and forms rubble slopes.

0.8

25.6 Poorly exposed Cane Hill Member of Hale Formation in road cut on east side.

0.2

25.8 Dye Shale Member of Bloyd Formation in ditch on west side.

0.1

25.9 Limestone ledge of Kessler Limestone Member of Bloyd Formation in west ditch.

0.3

26.2 Contact of Trace Creek Shale Member of Bloyd Formation and overlying cross-bedded sandstones of Atoka Formation.

1.2

27.4 Church at top of Hale Mountain. Just north of church is head of hollow that begins descent to type locality of Hale Formation. There are spectacular exposures of Prairie Grove Member.

0.3

27.7 Blacktop pavement ends.

0.5

28.2 Poorly exposed Atoka Formation in east ditch.

0.2

28.4 Poorly exposed Dye Shale in west ditch.

0.6

29.0 Fayetteville and Pitkin Formations can be seen in distance at base of hill to south across broad valley.

0.3

29.3 Cane Hill poorly exposed in north ditch.

0.2

29.5 Scattered blocks and low exposures of Brentwood(?) limestone in both ditches.

0.6

30.1 Cane Hill exposed in low bluff south of road.

0.2

30.3 Cross Evansville Creek; road then turns abruptly right (westward).

0.3

30.6 Junction from south of unimproved road.

0.2

30.8 Prairie Grove Member of Hale Formation exposed in bluff along Evansville Creek to north as well as across broad valley to south.

0.6

31.4 Unimproved road joins from south.

0.2

31.6 Float and poorly exposed Brentwood on either side of road.

0.7

32.3 Junction with Arkansas 59; turn south on 59 through town of Evansville.

0.3

32.6 Cane Hill exposed in east ditch; county road joins from east. Cane Hill exposures continue intermittently in east ditches for 0.2 mile.

0.3

32.9 Prairie Grove sandstone exposed in east road cut and at 33.0.

0.4

33.3 Brentwood Limestone exposed in east ditch.

0.7

34.0 Upper Brentwood Member and "caprock" unit of basal Dye Shale Member of Bloyd Formation exposed in west road cut; no Baldwin coal has been observed at this locality.

0.2

34.2 Scattered exposures of Dye Shale continue in west ditch for next mile.

0.8

35.0 Kessler Limestone in west road cut. This exposure occurs near top of important Evansville Mountain reference section. This section is included in road cuts for next 1.3 miles to south.

0.1

35.1 Large slump block of Kessler Limestone in west road cut.

0.1

35.3 Poorly exposed Dye Shale.

0.1

35.4 Low road cut to west exposes upper Brentwood-Woolsey-basal Dye Members.

0.1

35.5 Thin-bedded limestone and shale in upper Brentwood Member in west ditch.

0.1

35.6 Large west road cut at curve in road exposes Prairie Grove-Brentwood contact. West road cuts expose Prairie Grove sandstones for next 0.5 mile.

0.5

36.1 Contact of Cane Hill and Prairie Grove Member of Hale Formation to west of road.

0.1

36.2 Slumped Prairie Grove Sandstone blocks in west road cut.

0.1

36.3 Upper Cane Hill Member well exposed in west road cut.

0.1

36.4 Top of Pitkin Limestone overgrown in ditch west of road.

0.2

36.6 Washington-Crawford County line. Turn around and retrace route northward.

0.1

STOP 6—Evansville Mountain Section. Three different road cuts will be examined, Stops 6A, 6B, and 6C.

36.7 **STOP 6A.** Pull off highway on east side. Upper Cane Hill and Lower Prairie Grove Members of Hale Formation.

0.1

36.8 Slumped Prairie Grove sandstone blocks in west road cut.

0.1

36.9 Contact of Cane Hill and Prairie Grove Members of Hale Formation to west of road.

0.1

37.0 Beginning of several road cuts on west side in Prairie Grove sandstone. Observe characteristic "honeycomb" weathering pattern.

0.3

37.3 **STOP 6B.** Pull off highway on east side. Large road cut exposes upper Prairie Grove and lower Brentwood Members.

0.3

37.6 Upper Brentwood-Woolsey-Lower Dye Members. "Caprock" is well exposed; thin Baldwin coal can be exposed by digging.

0.2

37.8 Large slump block to west of Kessler Limestone.

0.1

37.9 **STOP 6C.** Kessler Limestone and Trace Creek Shale Members of Bloyd Formation.

0.3

38.2 Brentwood and Dye Members of Bloyd Formation.

0.5

39.7 Brentwood exposed east of road.

0.2

39.9 Brentwood-Prairie Grove contact. Continue northward in Prairie Grove.

0.6

40.5 Town of Evansville, Arkansas.

0.5

41.0 Junction. Turn west on Arkansas 156.

0.2

41.2 Hindsville exposed in stream bed, a tributary of Evansville Creek.

0.2

41.4 Arkansas-Oklahoma State line. Arkansas 156 replaced by Oklahoma 100. Proceed westward.

0.3

41.7 Fayetteville Shale poorly exposed in south road cut.

1.3

43.0 Prairie Grove Member caps low hills to south.

0.7

43.7 Fayetteville Shale poorly exposed in south ditch.

2.9

46.6 Poorly exposed Boone Chert in low north road cut.

0.7

47.3 Poorly exposed Boone Chert.

0.2

47.5 High bluff to north formed by Prairie Grove Member.

1.3

48.8 Weathered surface of Boone Formation.

0.1

48.9 Junction of Oklahoma 100 and U.S. 59. Curve right on U.S. 59 to north, go under railroad overpass, and enter city of Stillwell.

0.6

49.5 Turn west in Stillwell on Oklahoma 100.

2.2

Note: Central Adair County is the transition area between the Arkansas Morrowan facies of the Hale and Bloyd Formations, as seen at Evansville Mountain, and the Oklahoma Morrowan carbonate facies, as typically observed along the Arkansas River at the town of Gore, Oklahoma. West of Stillwell the Morrowan has been subdivided into the Sausbee and McCully Formations.

51.7 Weathered Boone Chert in fields to south. Hills to north capped by Sausbee Formation.

1.0

52.7 Fayetteville Shale exposed by excavation for stock pond south of road.

0.3

53.0 Hindsville Limestone in south ditch.

1.7

54.7 Junction with paved road south to Bunch, Oklahoma.

0.7

55.4 Fayetteville exposures scattered on both sides of road for next 2 miles.

2.0

57.4 Thin-bedded shales and sandstones of Sausbee Formation in north road cut.

0.2

57.6 Pass between Gittin' Down and Hungry Mountains. Upper Sausbee Formation exposed in scattered cuts.

0.4

58.0 Lower Pitkin Limestone bench on southeast side of road.

0.1

58.1 Mississippian limestones poorly exposed for next 0.5 mile.

0.8

58.9 Boone Chert poorly exposed in road cuts for next 3 miles.

0.1

59.0 Power-line cut up side of Jackson Mountain, to north of road, exposes Hindsville (lower bluff), Fayetteville (slope), and Pitkin-Braggs (main bluff). Crest of mountain capped by lower Atoka Formation.

0.5

59.5 Boone Chert forms low hills and is exposed along stream south of road.

0.3

59.8 Poorly exposed Boone Chert for next 0.5 mile.

0.9

60.7 Fayetteville-Pitkin contact well exposed in both road cuts on Adair-Cherokee County line. Descend hill and proceed westward, observing poor exposures of Boone Chert on hillsides and in road cuts for next 4.5 miles.

4.5

65.2 Cross approximate trace of Cookson fault (cross from Boone Chert to Atoka Sandstone).

0.1

65.3 Atoka Formation in north road cut.

0.4

65.7 Cross bridge over Caney Ridge arm of Lake Tenkiller.

0.1

65.8 Continue in Atoka Formation. Prominent sandstone bluffs on far side of Lake Tenkiller, to northwest, are formed by Atoka Formation.

0.4

66.2 Junction. Turn left (southeast) on Oklahoma 82.

0.1

66.3 Shales and limestones of Sausbee Formation crop out along both sides for next 0.2 mile.

0.2

66.5 Large road cut in Sausbee Formation.

0.2

66.7 Cross fault (cross from Sausbee Formation, Morrowan, to Boone Chert).

0.1

66.8 Princess Drive-In. Boone Chert seen as rubble and in road cuts for next 0.7 mile.

0.7

67.5 Boone-Hindsville contact in west road cut.

0.3

67.8 Cross approximate trace of Barber fault (cross from Boone Chert to Sausbee Formation).

0.2

68.0 Pitkin-Sausbee contact poorly exposed in east road cut. This exposure is of interest, as Pitkin Formation is missing 0.4 mile to south, at Stop 9.

0.2

68.2 Basal Morrowan sandstones in east road cut and lower Morrowan limestones on west side (overlying sandstone). Limestones on west side continue for 0.2 mile.

0.2

68.4 **STOP 7—Elk Creek section.** Pull off highway to left (east), onto unused gravel road, 100 yards before reaching bridge.

0.1

68.5 Cross Elk Creek bridge.

0.8

69.3 Limestones of lower Sausbee Formation exposed in east road cut.

0.4

69.7 **STOP 8—Cookson section.** Pull off to right (west) side road, in parking area at Fort Chickamauga. Fort Chickamauga is not only a tourist attraction but is also headquarters for both the Fourth United States Cavalry, Special Veterans Reserve, and headquarters for the Fifth Military District, S.V.R. By virtue of S.V.R., acting under Congressional approval, this is the only horse cavalry post still active as such within the borders of the United States.

Stop 8 is on southeast side of highway, beginning in ditch opposite fort entrance and extending westward along road cuts for one-quarter mile to top of hill.

0.3

70.0 Poorly exposed contact of McCully Formation (Morrowan) and Atoka Formation in south ditch.

0.3

70.3 Intersection in village of Cookson. Continue south on flat surface of Atoka Formation. Scattered poor exposures of sandstone and shale in road cuts for next 2.2 miles.

0.4

70.7 Unnumbered paved road to southeast leads to Cookson Hills Game Reserve and Marble City.

1.8

72.5 Highest limestone of McCully Formation poorly exposed in west road cut; Morrowan limestone and shale exposures continue for 0.8 mile.

0.8

73.3 Cross Terrapin Creek; Morrowan limestones and shales exposed on south side of creek and in road cuts for next 0.7 mile.

0.8

74.1 Cross Chicken Creek and approximate trace of Blackgum fault. Boone Chert poorly exposed in road cuts beyond (south of) fault.

0.1

74.2 Limestone in Boone Formation in northwest road cut.

0.2

74.4 Lower Sausbee sandstones poorly exposed in southeast road cuts for next 0.2 mile.

0.5

74.9 Scenic lookout to northwest; distant view of Lake Tenkiller. At this point, and for next 1.4 miles, road parallels strike of Morrowan limestones and shales, seen intermittently in east road cuts.

0.4

76.5 Pitkin Limestone poorly exposed in east road cut.

0.3

76.8 Enter Seqoyah County; leave Cherokee County.

0.1

76.9 Cross Snake Creek.

0.1

77.0 Limestone of Sausbee Formation in east road cut.

0.1

77.1 Paved road to west leads to Blackgum Landing.

0.1

77.2 Sequence of Morrowan limestones and shales in series of west ditch exposures; road climbs through section.

0.3

77.5 Lower Atoka sandstones in west road cuts; road climbs through section.

1.7

79.2 Junction with paved road from east; highway swings due west.

0.6

79.8 Junction: Oklahoma 82 and 100. Continue west on Oklahoma 100.

0.8

80.6 Village of Blackgum.

0.7

81.3 Road traverses flat-lying Atoka sandstones and shales.

1.6

82.9 Enter Tenkiller Lake and Illinois River Flood-control and Hydroelectric District. Distant view of Lake Tenkiller to west.

0.3

83.2 Enter Tenkiller State Park.

0.2

83.4 Road descends onto Tenkiller Dam; note major bluffs of Atoka sandstones above water of lake, to right of road.

0.8

84.2 View across lake, to west, to high bluffs of lower Atoka sandstones below and west of dam.

0.3

84.5 Spillway for lake.

0.4

84.9 U.S. Army Corps of Engineers office to right.

0.2

85.1 Scattered exposures of Atoka sandstones in road cuts.

0.6

85.7 Junction of Oklahoma 100 and 10A; continue south on 100.

0.5

86.2 Paved road to left goes to powerhouse; along that road a basal Atoka channel can be seen that cuts into Morrowan McCully Formation.

0.3

86.5 Leave Tenkiller Hydroelectric District.

0.1

86.6 Shangri-La Motel on right.

0.8

87.4 Poorly exposed Atoka sandstones and shales.

3.1

90.5 Palladino's Restaurant and Motel on right.

1.1

91.6 Junction in town of Gore of Oklahoma 10 and 100; turn north on 10.

1.8

93.4 Enter Muskogee County, then cross creek.

0.1

93.5 Junction. Go straight ahead, west, toward lock and dam, as Oklahoma 10 curves to right (north).

0.9

94.4 Turn right (northwest) on gravel road just before railroad track.

0.6

95.0 Turn left (west) at crossroad.

0.5

95.5 Enter Chisum Quarry (inactive); proceed north and northwestward, generally parallel and east of railway.

0.3

95.8 **STOP 9—Chisum Quarry section.** Section is exposed on north side of central quarry. Exposure on bluff at Stop 10 can be seen looking westward, across Arkansas River. Retrace route to Gore.

4.2

100.0 Junction of Oklahoma 10 and 100, in east part of Gore. Proceed westward on Oklahoma 10 through Gore, from point on earlier log at mile 91.6.

0.3

100.3 Junction in west part of Gore of Oklahoma 10 (it turns south) and U.S. 64. Go straight ahead (west) on U.S. 64.

0.7

101.0 East end of big arched bridge over Arkansas River Navigation route. From crest of bridge look north to lock and dam.

0.4

101.4 West end of bridge. Note broad exposure ahead of rich farm land on Arkansas River terrace.

0.3

101.7 Road south to Webbers Falls.

0.9

102.6 Junction of Oklahoma 100 and U.S. 64; turn right (west) on U.S. 64.

1.1

103.7 Turn right (north) at sign to "Webbers Falls Lock and Dam."

0.2

103.9 Poor exposures in Atoka Formation.

2.7

106.6 Turn right down hill on paved road; curve left along embankment of Arkansas River.

0.6

107.2 **STOP 10—Webbers Falls Lock and Dam section.** Section exposed on large bluff on west side of Arkansas River, just below Webbers Falls Lock and Dam 16. Stop 9, in Chisum Quarry, can be seen looking eastward across river. Turn around, and return to main paved road.

0.6

107.8 FOR OPTIONAL STOP, turn right (north). Road ascends hill.

0.3

108.1 Pavement ends at lookout (overlooks river valley); continue northward up steep gravel road.

0.5

108.6 **STOP 11—McCully Mountain locality.** Stop at crest of hill; exposure is in road cut and on hillside to left of road. Turn around, and retrace route southward.

0.5

109.1 Lookout.

5.5

114.6 Junction; turn right (west) on U.S. 64.

0.5

115.1 Junction; turn right (north) just before underpass; go north on Muskogee Turnpike. All road cuts seen on turnpike are Atoka Formation.

14.0

129.1 Tollgate; pay toll.

5.5

134.1 Chandler Road exit in Muskogee.

0.8

134.9 Gibson Street exit in Muskogee.

1.2

136.1 Turn off at second U.S. 62 exit (Muskogee west), after going under overpass.

0.2

136.3 Curve west over turnpike and go west on U.S. 62 into Muskogee.

1.8

138.1 Junction and stoplight; turn right into parking lot of Curt's Inn (formerly Ramada Inn).

STOP DESCRIPTIONS—SECOND DAY

Patrick K. Sutherland[1]

STOPS 6A, 6B, 6C—EVANSVILLE MOUNTAIN

This section is exposed in a series of cuts and natural exposures along Arkansas Highway 59, beginning with the top of the Pitkin Limestone, 100 feet north of the Washington-Crawford County line (C S. line, sec. 35, T. 13 N., R. 33 W.) and continuing northward for 1.3 miles along the road to the Kessler Limestone, at the crest of the gap (near C S½ sec. 26, T. 13 N., R. 33 W.). The beds above the Kessler Limestone will be examined along a steep unpaved road that intersects Arkansas 59 from the east.

The type localities for the various formations and members of the Morrow Group are scattered in Washington County, Arkansas, but the Evansville Mountain section constitutes, for all practical purposes, the primary overall reference section for the Morrowan Series (Henbest, 1953, 1962). All the Morrowan units are well exposed except for the middle part of the Dye Shale and the upper part of the Trace Creek Shale Members of the Bloyd Formation. Henbest (1962) designated the Evansville Mountain sequence as the type section for both the Cane Hill and the Prairie Grove Members of the Hale Formation.

At Evansville Mountain, the Morrow Group is 350.5 feet thick, the Hale Formation, 136.5 feet thick, and the Bloyd Formation, 214 feet thick (arbitrarily including a covered interval at the top).

The Evansville Mountain section begins at the top of the Pitkin Limestone, but that unit is poorly exposed at this locality as is the lower few feet of the Cane Hill Member of the Hale Formation. At Stop 6A (fig. 1) the middle and upper parts of the Cane Hill (type locality) are well exposed (fig. 2). The sandstone layers in the upper part of the Cane Hill are typically noncalcareous (unit 5). At this outcrop, the contact between the Cane Hill and the overlying calcareous sandstones of the Prairie Grove appear to be gradational. However, at an exposure of the contact in a road cut 0.2 mile to the north (mile 36.9 in road log), the contact appears to be unconformable.

The middle part of the Prairie Grove (unit 6) is exposed in a series of road cuts between Stops 6A and 6B (mile 37.0). These exhibit the typical massive bedding, local large-scale cross-bedding, and the pitted, "honeycombed" weathered surfaces that are characteristic of the unit (fig. 3). These rocks are composed of complexly interbedded calcareous sandstones and quartz-sandy crinozoan grainstones, all locally oolitic.

At Stop 6B, the sequence is continually exposed from the top of unit 6 to the top of unit 12 (fig. 1). This interval includes the upper Prairie Grove Member (fig. 4) and the lower part of the Brentwood Limestone Member of the Bloyd Formation (fig. 5). Deposition was continuous from the Prairie Grove (Hale) to the Brentwood (Bloyd). The top of the Prairie Grove Member is marked throughout Washington County by the uppermost thick-bedded calcareous sandstones or quartz-sandy grainstones. The Brentwood Limestone Member is characterized in the county by limestones with lower quartz-sand content and by the first appearance, above the base of the Prairie Grove Member, of shale beds that are more than 2 feet thick. As a consequence of the latter feature, the Brentwood in Washington County does not form the kind of distinctive cliffs characteristic of the Prairie Grove Member. These distinctions cannot be made to the west in Oklahoma, where prominent shales occur much lower stratigraphically (see Stop 8).

The lower part of the Brentwood at Stop 6B consists of laterally changing thin to medium-bedded layers of grainstones and packstones (units 10B, 11, 12). A distinctive local feature is the occurrence of a bed composed of colonies of *Chaetetes* (fig. 6), a problematical organism traditionally considered to be a tabulate coral.

The nonmarine Woolsey Member of the Bloyd (fig. 1) is only 6.2 feet thick at Evansville Mountain and is observable only by digging (mile 37.6). A thin coal, 0.2-foot thick, occurs locally at the top of the unit, directly overlain unconformably by the sandstones and sandy grainstones (Henbest, 1953, "caprock of the Baldwin coal") that form a basal transgressive marine unit of the Dye Shale Member of the Bloyd.

At Stop 6C, the sequence is well exposed from the top of unit 23 to unit 29. Of particular interest here is the Kessler Limestone Member of the Bloyd. This unit is highly variable in character in Washington County. It is characteristically micritic but varies from skeletal wackestones and packstones to oolitic grainstones. At Evansville Mountain, there is a distinctive interval of algal oncolites near the top of the unit. The contact between the Kessler Limestone and the overlying Trace Creek Shale is sharp and undulating (fig. 7).

At Stop 6C, the lower part of the Trace Creek Shale is well exposed (units 26-29). There are dolomitic or sideritic(?) nodules in the lower 9 feet of these noncalcareous shales. The upper part of unit 26, and higher units, can be examined along a steep, unpaved road that intersects Arkansas Highway 59 from the east, at Stop 6. On figure 1, the covered interval at the top of the section (unit 33) has been arbitrarily included in the Trace Creek. Grayson and Sutherland (this guidebook) suggest the possibility, based on conodont occurrences, that the units in this section from 29 upward should be included in the Atokan and not the Morrowan Series.

Lowest occurrences of conodont species that have been used in zonation are shown in figure 1. For distribution of the conodont zones, see Lane (this guidebook).

STOP 7—ELK CREEK
NW¼SE¼ sec. 31, T. 15 N., R. 23 E.
Cherokee County, Oklahoma

STOP 8—COOKSON
SE¼ sec. 1, T. 14 N., R. 22 E.
Cherokee County, Oklahoma

The Elk Creek (Stop 7) and Cookson (Stop 8) sections, 1.2 miles apart, together form an important reference section for the northern Lake Tenkiller Reservoir area (fig. 8). They are 25 miles west of Evansville Mountain (fig. 1) and 23 miles northeast of the type section for the new formations proposed

[1]School of Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma.

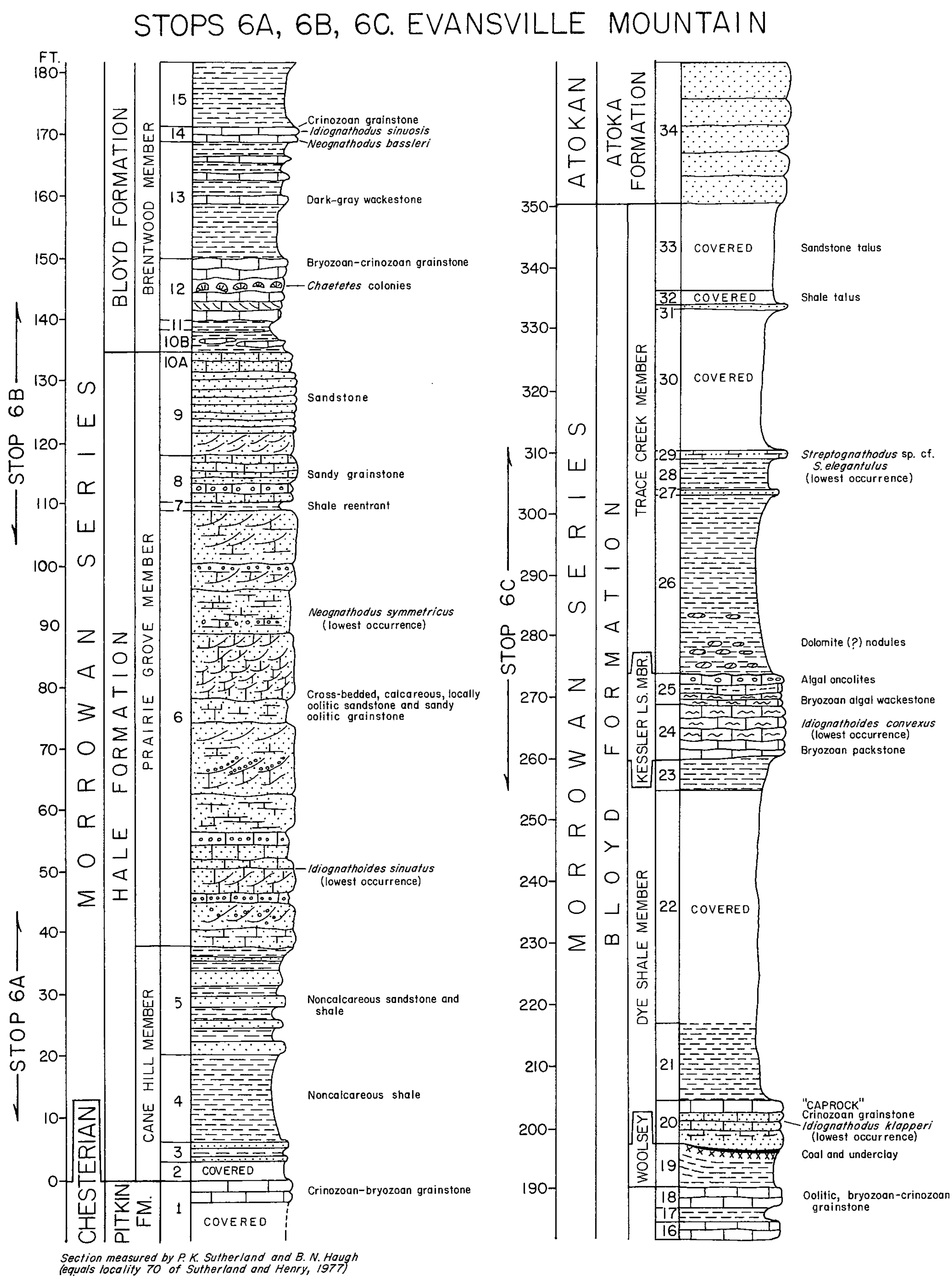


Figure 1. Graphic columnar section for Stops 6A, 6B, and 6C.

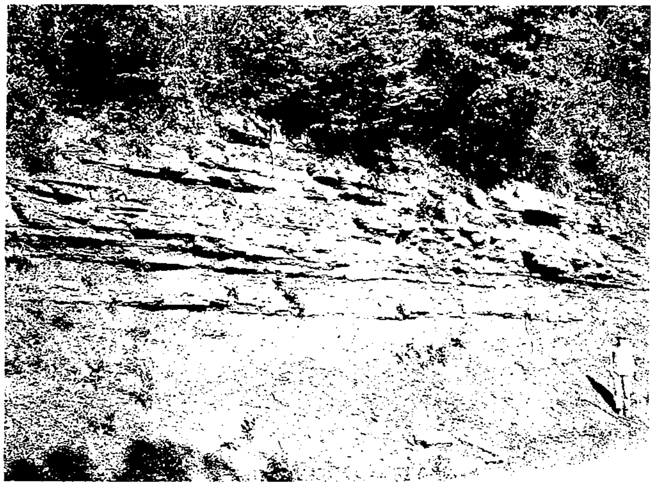


Figure 2. Interbedded shales and sandstones in upper part of Cane Hill Member of Hale Formation at its type locality. Base of Prairie Grove Member of Hale is exposed at top of cut. Picture shows units 4, 5, and base of 6. Stop 6A.

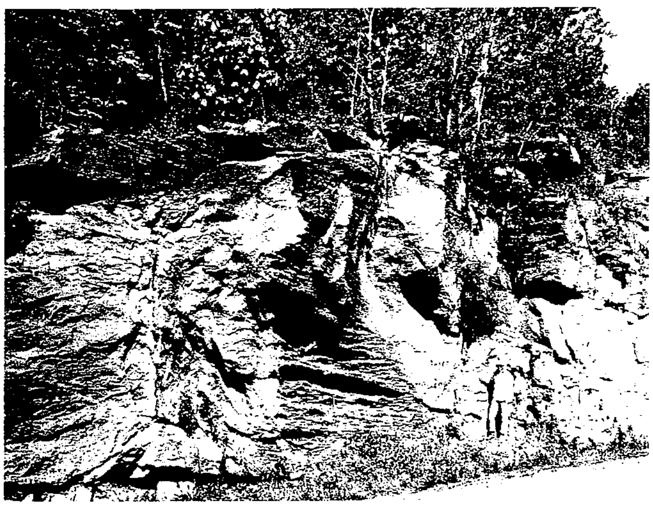


Figure 3. Prairie Grove Member of Hale Formation, showing typical massive cliffs that weather with pitted and "honeycombed" surfaces; upper unit 6. Between Stops 6A and 6B.

Figure 4. Upper Prairie Grove Member of Hale Formation; units 6 (top) to 9. Stop 6B.

Figure 5. Top part of Prairie Grove Member of Hale Formation and lower part of Brentwood Limestone Member of Bloyd Formation; units 10 and 11. Stop 6B.

Figure 6. *Chaetetes* colonies (at hammer) in Brentwood Limestone Member of Bloyd Formation; unit 12. Stop 6B.

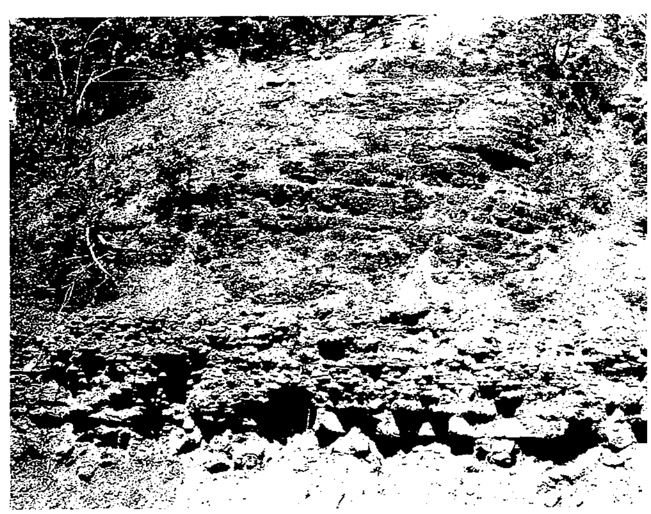


Figure 7. Upper Kessler Limestone and lower Trace Creek Shale Members of Bloyd Formation. Stop 6C.

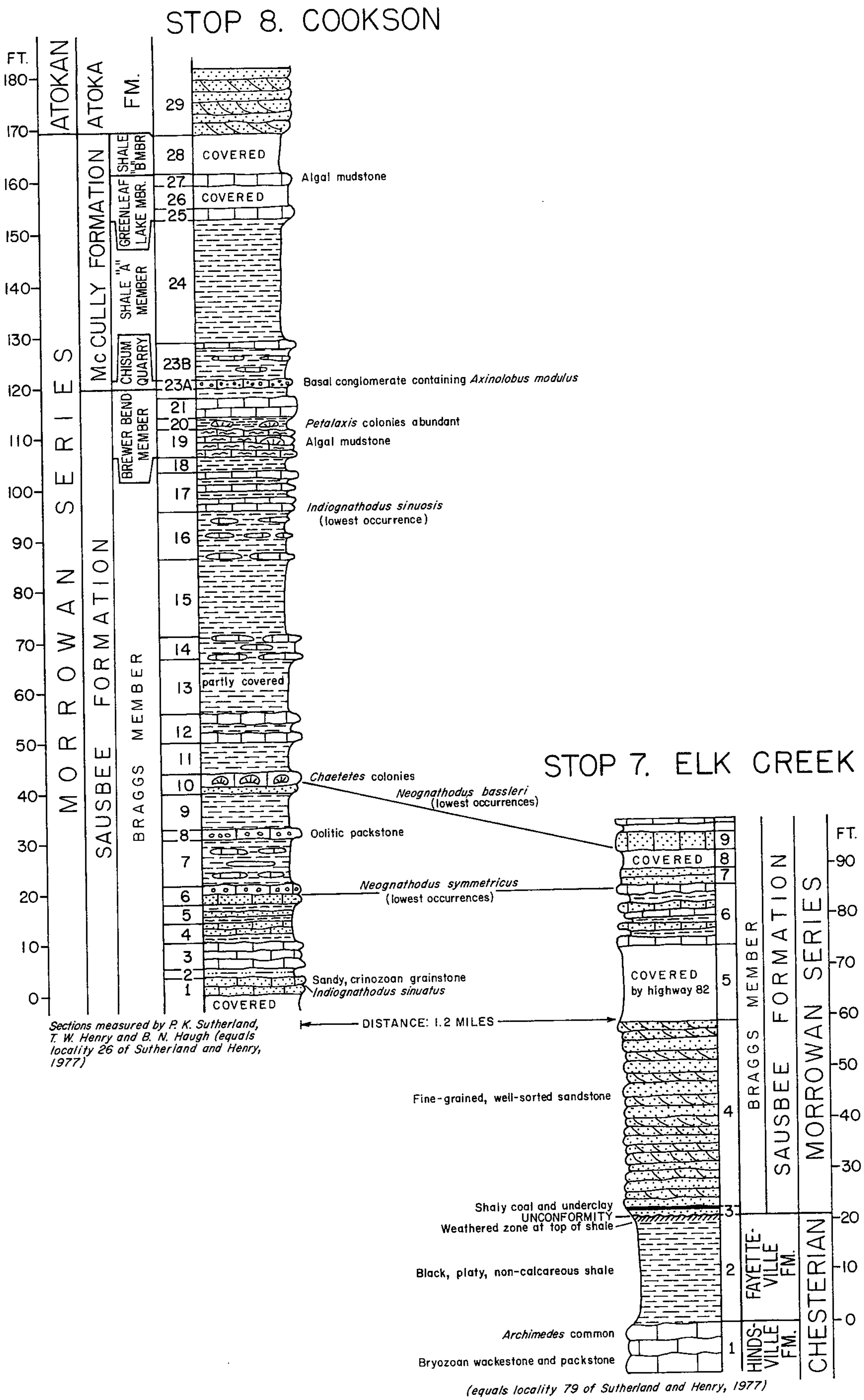


Figure 8. Graphic columnar section for Stops 7 and 8.

by Sutherland and Henry (1977), at the Webbers Falls Lock and Dam on the Arkansas River (Stop 10).

The Elk Creek section is on the north side of Elk Creek, near the steel-girder bridge on Oklahoma Highway 82. Units 1-4 were measured east of the highway, and the section begins at the top of a river bluff formed by the Hindsville Limestone, about 300 yards upstream, to the east of the bridge. Units 6 through 11 were measured in road cuts and natural exposures west of the highway up to 0.2 mile north of the bridge.

At Stop 7, the Pitkin Limestone is missing, and the Sausbee Formation rests directly on the weathered surface of the Fayetteville Formation. A 1- to 2-foot regolith is preserved at the top of the Fayetteville. The irregularity of the pre-Pennsylvanian erosional surface in this area is shown by the presence of the Pitkin Limestone no more than 0.4 mile to the north (mile 68.0).

A 0.2-foot shaly coal and underclay is present at the base of the Braggs Member of the Sausbee Formation, overlain by a thick sequence of fine-grained, well-sorted, cross-bedded sandstone, equivalent to some part of the lower Prairie Grove Member of the Hale Formation in Arkansas.

No equivalent of the Cane Hill shale (Hale Formation) occurs west of central Adair County, nor has the conodont zone *Rachistognathus primus* been found in Oklahoma.

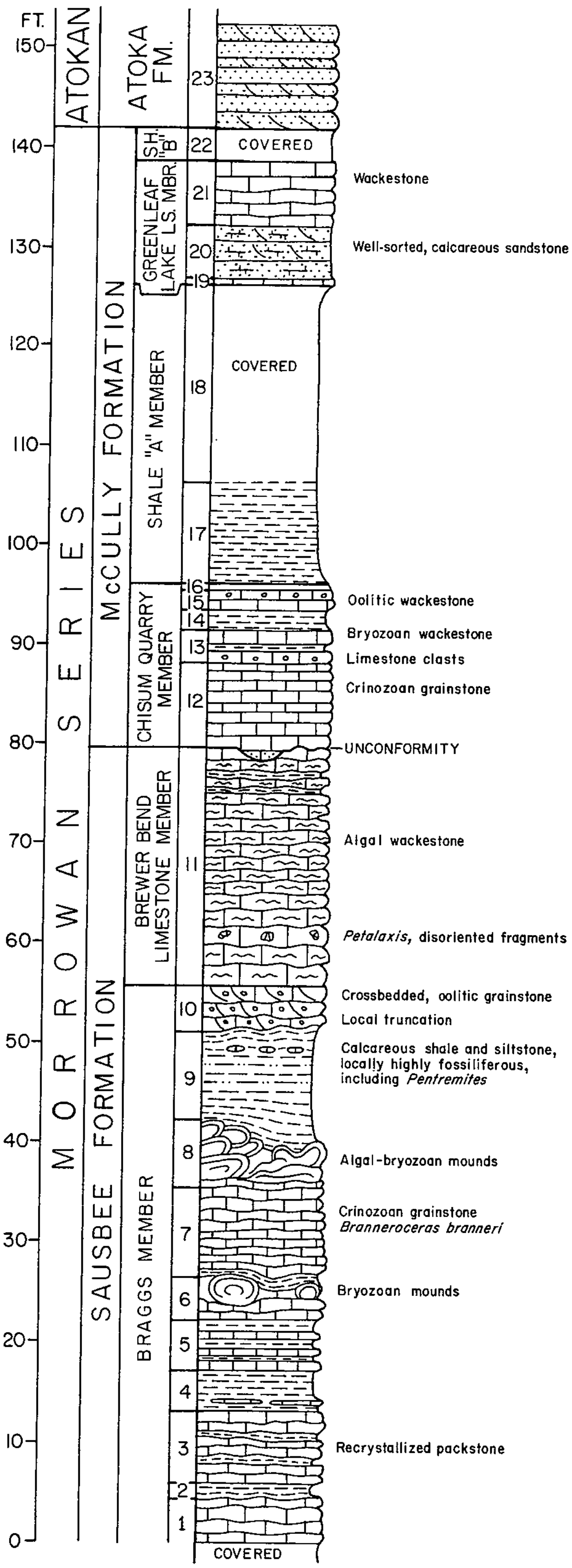
The correlation of the upper part of the Elk Creek with the lower part of the Cookson section is based partly on general lithologic similarity but more importantly on the lowest occurrences in both sequences of two important conodont form-species, *Neognathodus symmetricus* and *Neognathodus bassleri*. Using the base of the *N. symmetricus* zone as a datum gives a composite thickness of 209 feet for the Morrow Group in this area.

The Braggs Member of the Sausbee at Elk Creek and Cookson is equivalent to the Prairie Grove Member of the Hale and the lower part of the Brentwood Limestone Member of the Bloyd at Evansville. Thick shales occur much lower stratigraphically at Cookson than at Evansville (compare figs. 8 and 1).

The Brewer Bend Limestone Member of the Sausbee, which consists primarily of algal wackestones, is the most distinctive lithologic unit in the Morrowan in northeastern Oklahoma (fig. 9). At this locality, it is characterized by the occurrence of the colonial rugose coral *Petalaxis*. In the northern Tenkiller Reservoir area these colonies are invariably found in growth position.

Figure 9. Algal wackestone of Brewer Bend Limestone Member of Sausbee Formation. Picture shows units 16-21. Stop 8.

STOP 9. CHISUM QUARRY



Section measured by P. K. Sutherland and T. W. Henry (equals locality 97 of Sutherland and Henry, 1977)

Figure 10. Graphic columnar section for Stop 9.

STOP 9—CHISUM QUARRY
SW¼NW¼NW¼ sec. 35, T. 13 N., R. 20 E.
Muskogee County, Oklahoma

The base of the Morrowan Series is not exposed in the Chisum Quarry, but the middle and upper Braggs and the Brewer Bend Limestone Members of the Sausbee Formation and the Chisum Quarry Member of the McCully Formation are exceptionally well exposed and accessible (fig. 10).

Of particular note in this quarry is the occurrence of well-developed algal-bryozoan mounds at two intervals, units 6 and 8 (fig. 11). These mounds were studied in detail by Bonem (this guidebook).

The calcareous shale surrounding the mounds in the upper mounding interval (unit 9) are locally highly fossiliferous and contain *Pentremites* (Katz and Sprinkle, this guidebook) and various brachiopod species including *Spirifer goreii.* Also to be found in this quarry in the upper Braggs Member (unit 7) are goniatites of the *Branneroceras branneri* zone, including, in addition to the name bearer of the zone, *Proshumardites morrowanus, Syngastricoceras morrowense, Pseudopronorites arkansiensis,* and *Gaitherites solidum.* This goniatite zone ranges upward through the Brewer Bend Limestone Member. Specimens can be collected from that unit at Stop 11.

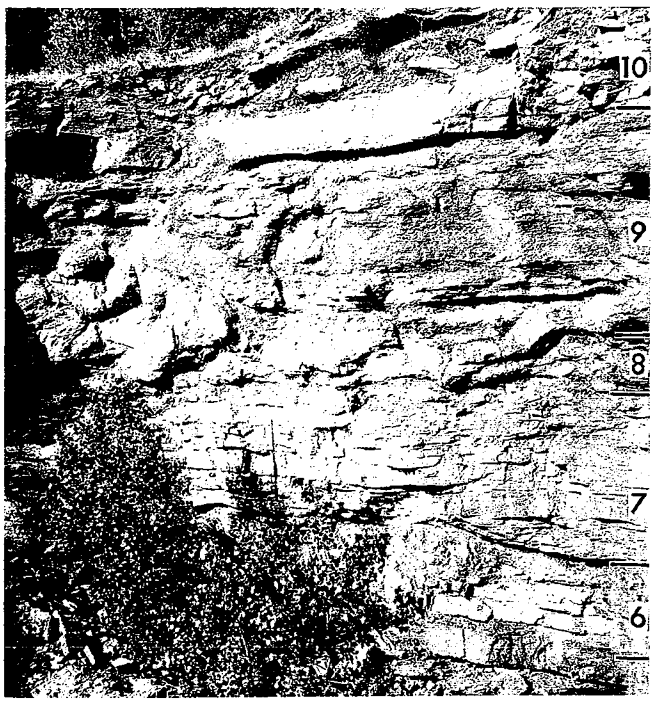
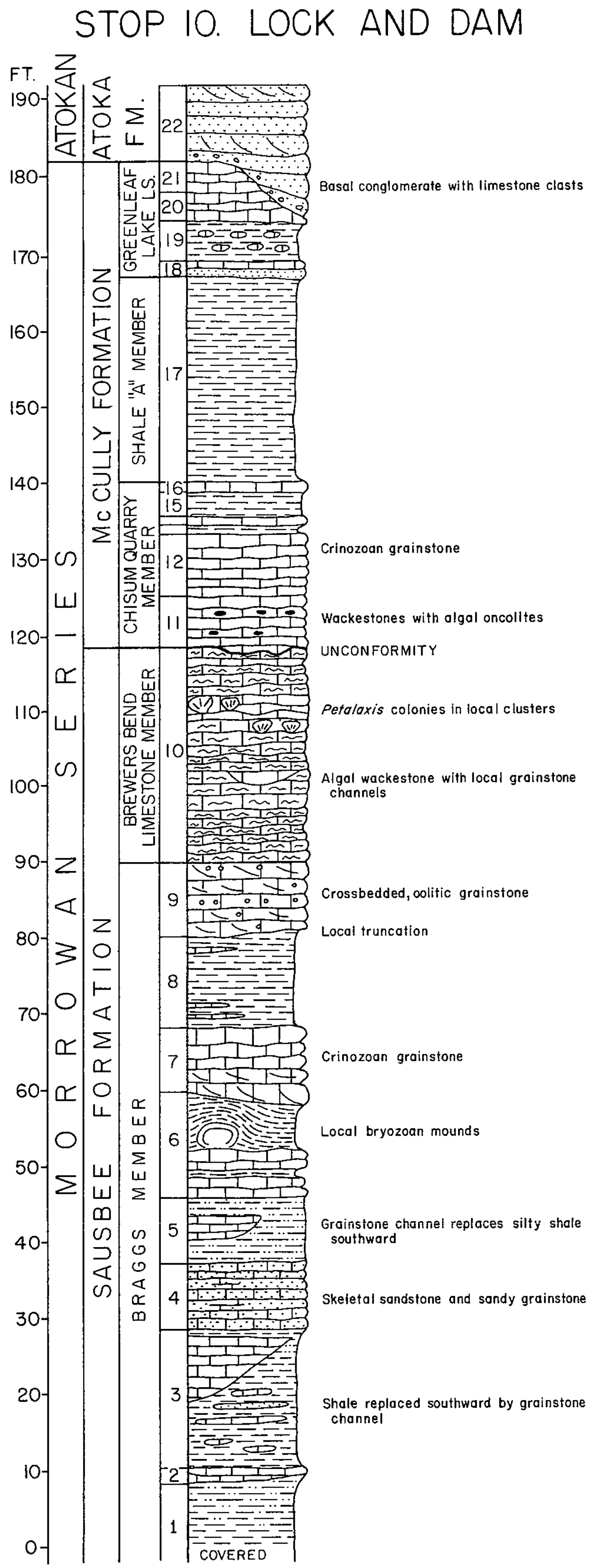


Figure 11. Braggs Member of Sausbee Formation. Note mounds in units 6 and 8. Stop 9.

STOP 10—LOCK AND DAM
Muskogee County, Oklahoma

The exposures at the southwestern end of the Webbers Falls Lock and Dam form the most important Morrowan section in northeastern Oklahoma. This sequence was designated by Sutherland and Henry (1977) as the type section, jointly with the McCully Mountain section 0.3 mile to the northwest, for both the Sausbee and McCully Formations. The lower part



Section measured by P. K. Sutherland and T. W. Henry (equal locality 1 of Sutherland and Henry, 1977)

Figure 12. Graphic columnar section for Stop 10.

(fig. 13) is in SW¼SW¼SE¼ sec. 34, and the upper part (fig. 14) is in SE¼SE¼SW¼ sec. 34, T. 13 N., R. 20 E.

The base of the Sausbee Formation is not exposed at the Lock and Dam. The partial thickness averages 118.5 feet, compared with a total thickness for the formation of 132 feet at the McCully Mountain section, 0.3 mile to the north, where the underlying Pitkin Limestone is exposed. The covered interval at the base of the Lock and Dam section is therefore assumed to be no more than 20 feet. The thickness for the partial Morrowan section at Stop 10 is 182.5 feet.

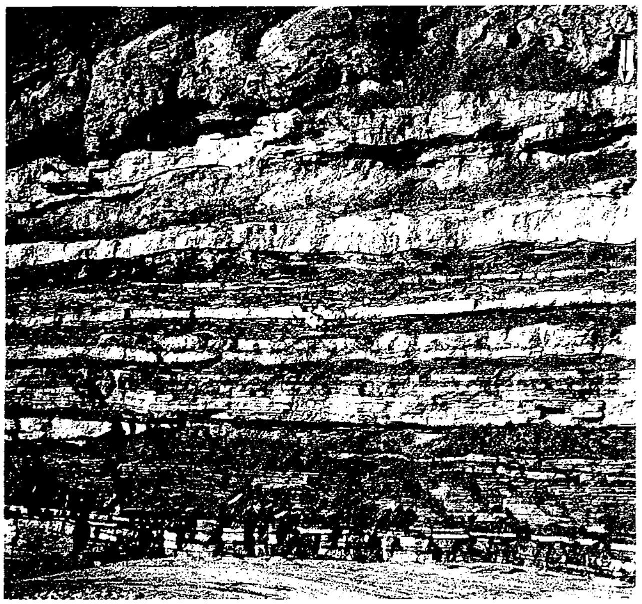


Figure 13. Sausbee Formation: Braggs Member below forms most of cliff; Brewer Bend Limestone Member forms highest rounded cliff. Contact marked by arrow. Exposure is 110 feet high and includes units 1-10. Stop 10.

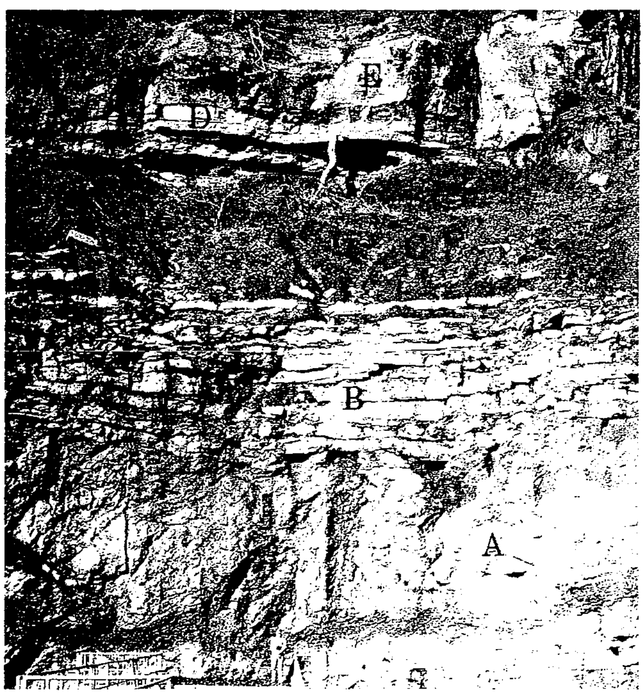


Figure 14. Sausbee Formation: upper part of Brewer Bend Limestone Member *(A)*. McCully Formation: Chisum Quarry Member *(B)*, shale "A" member *(C)*, and Greenleaf Lake Limestone Member *(D)*. Atoka Formation: *(E)*. Arrow to left of *E* points to truncating unconformity at base of Atoka Formation. Unconformity also exists between *A* and *B*.

The Lock and Dam exposure is only 1 mile southwest, across the Arkansas River, from Stop 9 (Chisum Quarry). The small bryozoan mounds in unit 6 at the Lock and Dam correlate with those in unit 6 at Chisum Quarry. No mounds are developed at a higher level equivalent to the large algal-bryozoan mounds that occur in unit 8 at Chisum Quarry.

The unconformities between the Sausbee and McCully and between the McCully and Atoka Formations are well exposed on the bluff west of the west end of Webbers Falls Dam (fig. 14). The lower unconformity is undulating but shows only slight downcutting. The Atoka Formation rests directly on the Greenleaf Lake Limestone Member of the McCully Formation. As can be seen in the upper left part of figure 14, the basal Atoka unconformity, within a lateral distance of less than 15 feet, downcuts locally through 7.5 of the 8.0 feet of limestones making up units 20 and 21.

STOP 11—McCULLY MOUNTAIN
S½NW¼SW¼ sec. 34, T. 13 N., R. 20 E.
Muskogee County, Oklahoma

The McCully Mountain section exposes strata ranging from the Pitkin Limestone (upper Chesterian) to the base of the Atoka Formation (Atokan), including 190 feet of Morrowan beds. This locality is the type section, jointly with the Lock and Dam section (Stop 10), for both the Sausbee and McCully Formations (Sutherland and Henry, 1977). Stop 11, however, is primarily concerned with an examination of the Brewer Bend Limestone Member of the Sausbee Formation. That unit is 24 feet thick at this locality (compared to 28.5 feet at the Lock and Dam). The Brewer Bend Limestone typically consists of algal wackestone and mudstone interbedded with minor shale.

The Brewer Bend Limestone Member is highly fossiliferous, and the biotic diversity is great at localities in the

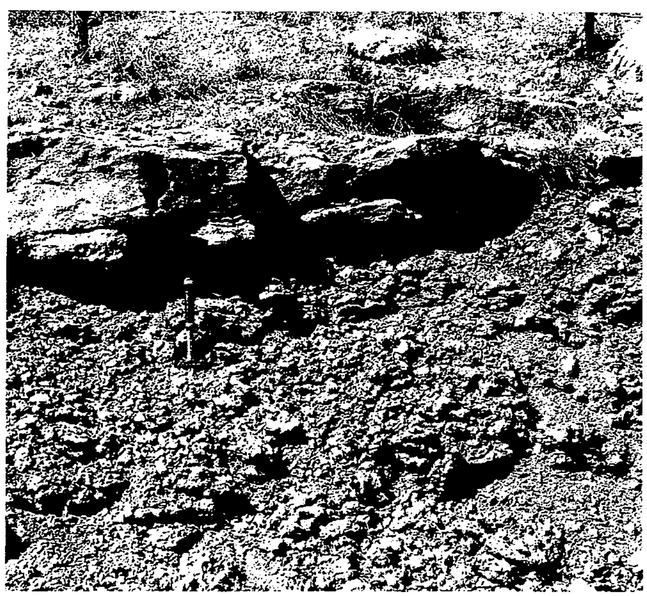


Figure 15. Brewer Bend Limestone Member of Sausbee Formation, showing grainstone-filled channel (base is just above hammer handle) cut in rubbly-weathering algal-carbonate mudstone.

southwestern area of exposures, such as at McCully Mountain. Red algae, particularly *Archaeolithophyllum*, are the most common organic elements, followed by fenestrate bryozoans. Corals and brachiopods are also common. Colonies of the colonial rugose coral *Petalaxis* occur in scattered clusters in the middle and upper parts of the member. The genus *Petalaxis* has been found also in the Middle Carboniferous of the U.S.S.R., Spain, and Japan (Sutherland, 1977).

Rare, sharply defined channel-shaped deposits, composed of skeletal packstone and rare skeletal grainstone, typically 5 to 10 feet across, cut the carbonate-mudstone facies at scattered intervals (fig. 15). Pelmatozoan debris (including much blastoid material) dominates these deposits, but fragments of algae, bryozoans, goniatites, brachiopods, corals, and other fossils are also included. The goniatites occur locally as a coquina. *Gaitherites solidum* dominates the goniatite fauna, but *Branneroceras branneri, Pseudopronorites arkansiensis, Syngastrioceras morrowense,* and *Proshumardites morrowanus* also occur. These forms represent the *Branneroceras branneri* zone.

ROAD LOG—THIRD DAY

Patrick K. Sutherland[1]

The road log for the third day traverses parts of Muskogee, Cherokee, and Wagoner Counties, Oklahoma. The unconformity separating Mississippian and Pennsylvanian strata (Pitkin and Sausbee Formations) will be seen at three important bluff exposures, and the Pitkin, Sausbee, and lower Atoka Formations will be examined.

Road logs and stop descriptions for the third day were prepared with the assistance of R. C. Grayson, Jr.

Total mileage

0.0 Beginning point in northeastern Muskogee, at intersection on U.S. 62 at Curt's Inn. Drive east on U.S. 62.

1.8

1.8 Go over Muskogee Turnpike.

0.4

2.2 West end of big arched bridge over Arkansas River Navigation System.

0.3

2.5 East end of bridge.

0.5

3.0 Bridge over railway.

0.9

3.9 Junction of U.S. 62 and Oklahoma 10. Go straight ahead (east) on 10 across flat terrace of Arkansas River.

1.7

5.6 East edge of Arkansas River terrace.

1.5

7.1 Bridge.

0.1

7.2 Bridge.

0.2

7.4 Poorly exposed Atoka sandstones in south road cut.

0.3

7.7 Lower Atoka sandstones with 6-inch coal in south road cut. Highest Morrowan limestone (McCully Formation) is exposed in ditch at north end of this cut. (Moore, 1947, incorrectly placed this coal in the top of what he termed the Bloyd Formation.)

0.1

7.8 Limestones of McCully Formation exposed on hillside on north side of creek (poorly seen to north through trees). These ledges dip southward below Atoka road cut with coal bed. Limestone crops out along and north of road for next 0.3 mile.

1.0

8.8 Ledges of Moorefield(?) Limestone in east ditch.

0.2

9.0 Fayetteville Shale poorly exposed in ditch.

0.2

9.2 Large bluff southeast of road exposes upper Fayetteville Shale and Pitkin Limestone.

0.2

9.4 **STOP 12—Braggs Mountain section.** Pull off to right of road at scenic overlook; Muskogee in distance to west, across Arkansas River valley. Section exposed in series of road cuts east of highway. For Fayetteville and lower Pitkin formations, walk 0.2 mile down hill to north to last large bluff southeast of road. Turn around and retrace route northward to junction of Oklahoma 10 and U.S. 62 (point on earlier log at mile 3.9).

5.5

14.9 Turn north, right, on U.S. 62. Road traverses flat Arkansas River terrace.

2.0

16.9 Enter town of Fort Gibson.

0.4

17.3 Junction at stoplight in middle of Fort Gibson; turn north (left) on Oklahoma 80.

0.6

17.9 Turn east (right) on Oklahoma 80 past restored log buildings of old Fort Gibson.

Fort Gibson was established in 1824 as the westernmost military outpost after Osage Indians, under Mad Buffalo, wiped out a party of Arkansas trappers on Blue River, to the south, in November 1823.

Located in the Three Forks country where the Verdigris and Grand Rivers join the Arkansas, Fort Gibson had river-boat service to New Orleans. Just to the west of the fort ran the Texas Road that was often jammed with caravans of settlers from Missouri and Illinois headed for Texas.

In 1829, Sam Houston, having resigned the governorship of Tennessee, stopped at Fort Gibson and lived among the Cherokee Indians until 1832. The fort was the base for Washington Irving's visit in 1832, which resulted in his writing *A Tour on the Prairies.*

Turned to the Cherokees in 1857, the fort was taken over by Union troops in 1863 and held by them through the Civil War. It was finally abandoned in August 1890.

The old stockade has been restored, and many of the original buildings still stand. It is a National Historical Monument and is operated by the Oklahoma Tourism and Recreation Department.

0.4

18.3 Junction of Oklahoma 80 and 80A. Turn north (left) at old stone buildings.

[1]School of Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma.

0.4

18.7 Leave Muskogee County, enter Cherokee County; at left is plant processing Pitkin Limestone.

0.8

19.5 Poorly exposed Sausbee Formation in low bluff in trees east of road.

0.1

19.6 Old abandoned Keough Quarry, in Sausbee and McCully Formations, to right. It was once famous as a collecting locality for *Pentremites.*

0.1

19.7 Bluff to east of road exposes Pitkin-Sausbee contact. Contact rises on hillside northward.

0.5

20.2 Side road leading to underground mine in Pitkin Limestone in bluff to east of road. Mine is in massive upper Pitkin Limestone, with roof in lower Sausbee sandstone and limestone.

0.8

21.0 Steep cliffs of Morrowan limestones and shales to east of road (partly hidden in trees). Large sandstone blocks are from overlying Atoka Formation.

0.4

21.4 Pitkin Limestone exposed in small valley to east of road, overlain by Sausbee Formation.

0.2

21.6 View ahead of Fort Gibson Dam.

0.4

22.0 Junction of Oklahoma 80 and Oklahoma 251A. Take sharp right turn up steep grade to south. Lowest road cuts east of road are in Pitkin Limestone. This point is at the base of the sequence at Stop 13. Those who wish may leave bus here and walk up steep roadway to south, observing section in road cuts east of road.

0.2

22.2 Morrowan-Atokan contact in shale near base of high Atoka sandstone bluff east of road.

0.1

22.3 **STOP 13—Fort Gibson Dam section.** Pull off to right at top of steep hill opposite bluff of Atoka sandstone. Walk back down hill (north) to see Morrowan sequence. Retrace route, descend hill northward toward lake.

0.4

22.7 Junction; take Oklahoma 251A to right, toward lake. (This point same as mile 22.0 in earlier log.)

0.2

22.9 High bluff at east end of dam exposes Fayetteville Shale, overlain by high, thick-bedded limestones of Pitkin Formation. Lower Sausbee Formation high on bluff. Most of Fayetteville Shale has been concreted over at east end of dam. Turn left across dam.

0.5

23.4 **STOP 14—west end of Fort Gibson Dam locality.** Turn off into large parking area at west end of dam.

STOP DESCRIPTIONS—THIRD DAY

Patrick K. Sutherland[1]

STOP 12—BRAGGS MOUNTAIN
NW¼NW¼ sec. 28, T. 15 N., R. 20 E.
Muskogee County, Oklahoma

This section (fig. 1) is exposed in a series of cuts along Oklahoma Highway 10 for a distance of about 0.5 mile. The middle and upper parts of the Fayetteville Shale and the whole of the Pitkin Limestone are particularly well exposed. In this area, the upper Fayetteville is characterized by a long sequence of interbedded limestones and shales that form a transitional sequence between the black to dark-gray shales of the lower Fayetteville and the overlying Pitkin. To the east, in Adair County, Oklahoma, and in Washington County, Arkansas, the change from the Fayetteville Shale to the Pitkin Limestone is sharp although gradational. The Pitkin Limestone at Braggs Mountain is highly fossiliferous and contains *Archimedes*, fenestrate bryozoans, and numerous brachiopods. Conodont information is not available for this sequence. The Pitkin-Sausbee unconformable contact is well exposed (fig. 2), and the base of the overlying unit is marked by a thin pebble conglomerate. The limestones in the lowest part of the Sausbee Formation are commonly characterized by the occurrence of quartz sand in contrast to the underlying Pitkin Limestone, which is normally almost quartz free.

The total Morrowan thickness at Braggs Mountain is 142 feet. At this locality the Pitkin Limestone is 60 feet thick, and the Fayetteville Shale is 116 feet thick.

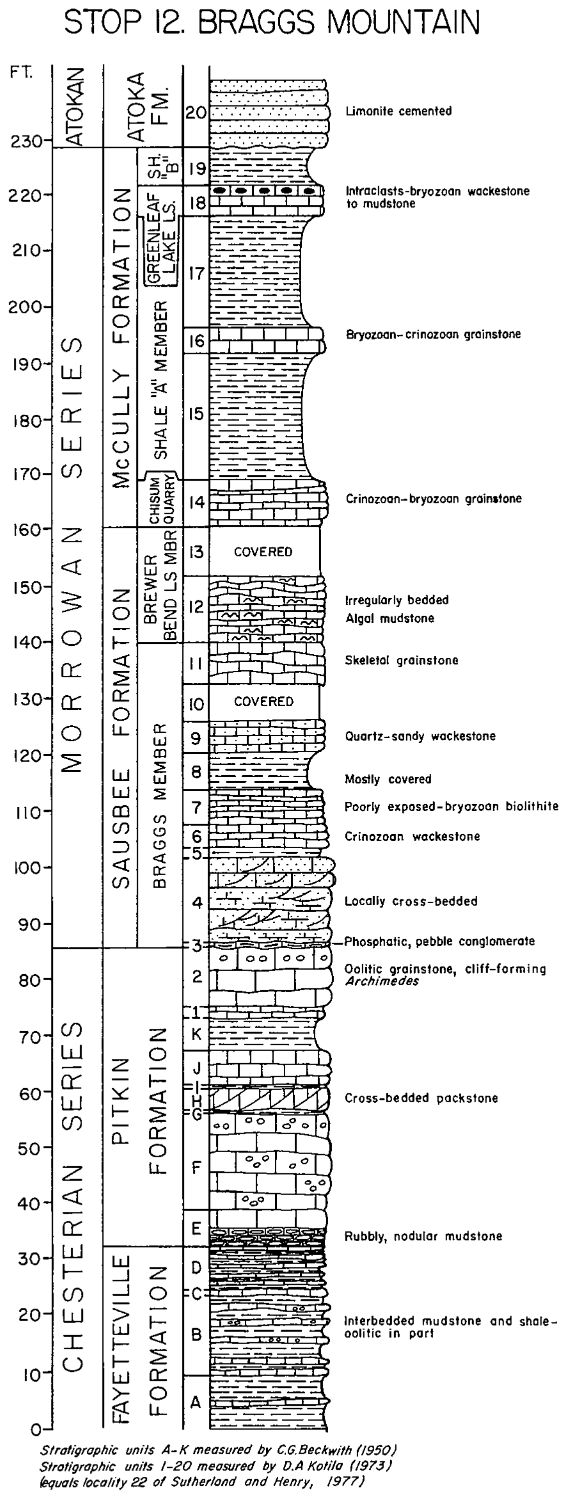


Figure 1. Graphic columnar section for Stop 12.

STOP 13—FORT GIBSON DAM, EAST
N½ sec. 18, T. 16 N., R. 20 E.
Cherokee County, Oklahoma

The purpose of this stop is to demonstrate both the pattern of changing facies within the Sausbee Formation northward from Webbers Falls Lock and Dam (Stop 10) and the regional truncation of the Morrow northward by the unconformity at the base of the overlying Atoka Formation. The distinctive algal mudstone and wackestone facies of the Brewer Bend Limestone Member of the Sausbee, as developed in the Webbers Falls area (Stops 9-11), changes northward into a more open-marine facies typified by the underlying Braggs Member (Sutherland and Henry, 1977). At this section the members of the Sausbee Formation have not been precisely identified because of these facies differences. Conodonts from this sequence, collected and studied by H. R. Lane (Lane and Straka, 1974, fig. 6), indicate that no beds higher than the Sausbee Formation are present in this sequence and that the highest Morrowan strata found here correlate with the Brentwood Limestone Member of the Bloyd Formation at Evansville

[1]School of Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma.

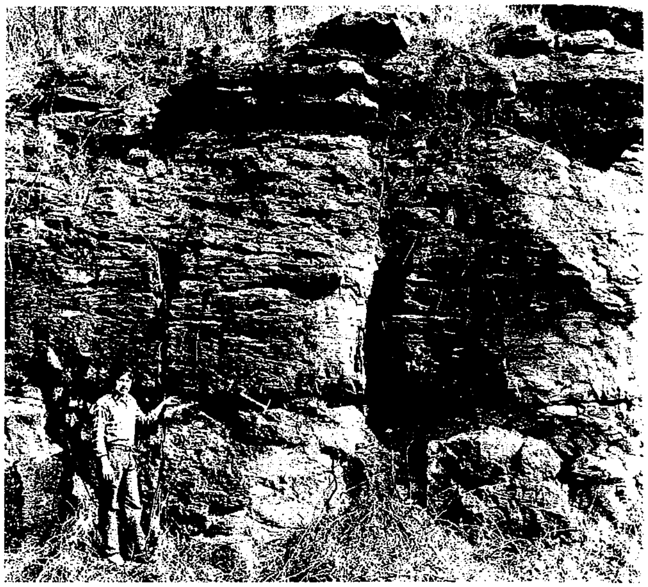


Figure 2. Man points to unconformity between quartz-free Mississippian Pitkin Limestone, below, and sandy, cross-bedded limestone of Pennsylvanian Sausbee Formation, above. Stop 12.

Mountain. More information is needed on the distribution of lithotopes in this northern area.

The whole of the McCully Formation is apparently missing at this locality, and the Atoka Formation rests unconformably on what is presumed to be the upper part of the Sausbee Formation (fig. 3). The unconformity, which occurs within a shale sequence, is well exposed. Figure 4 shows a distant view of the sequence.

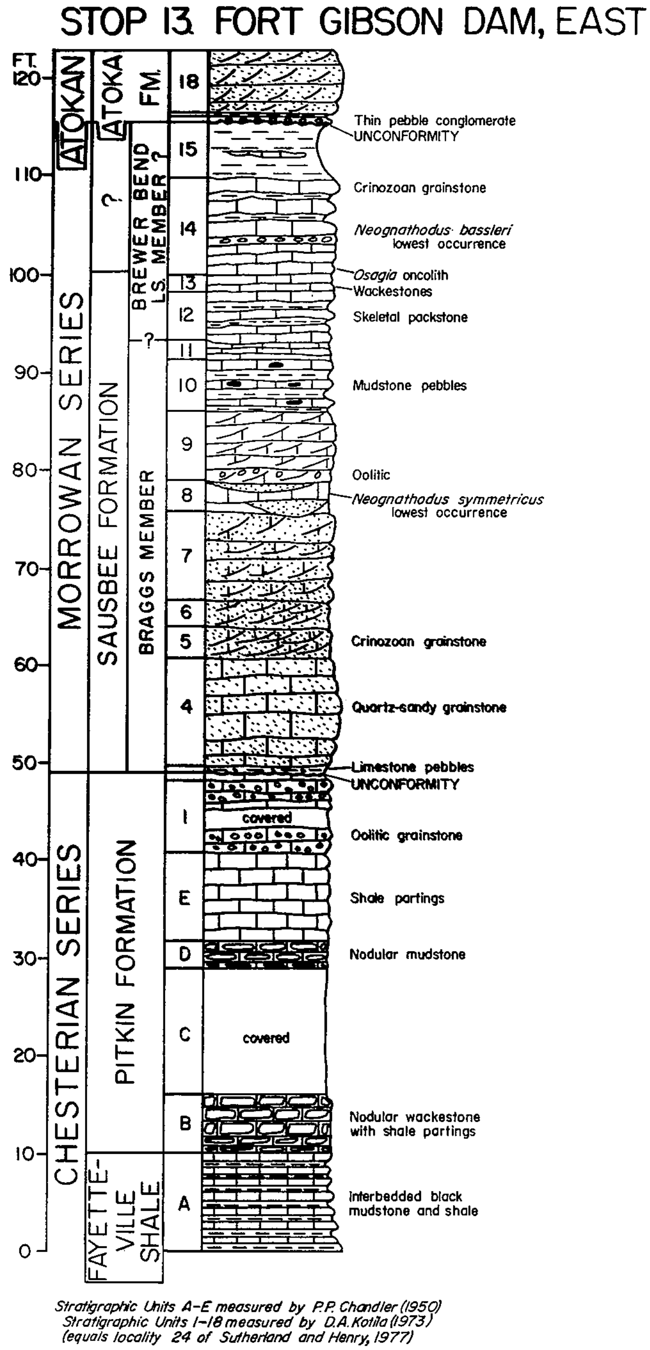


Figure 3. Graphic columnar section for Stop 13.

STOP 14—FORT GIBSON DAM, WEST
NE¼ sec. 13, T. 16 N., R. 19 E.
Wagoner County, Oklahoma

At this locality (fig. 5), 0.5 mile west of Stop 13, the unconformity between the Morrowan Sausbee Formation and the Chesterian Pitkin Limestone is exceptionally well exposed for at least 100 yards along a bluff side. Considerable variation is to be seen laterally in the character of the beds directly above the unconformity.

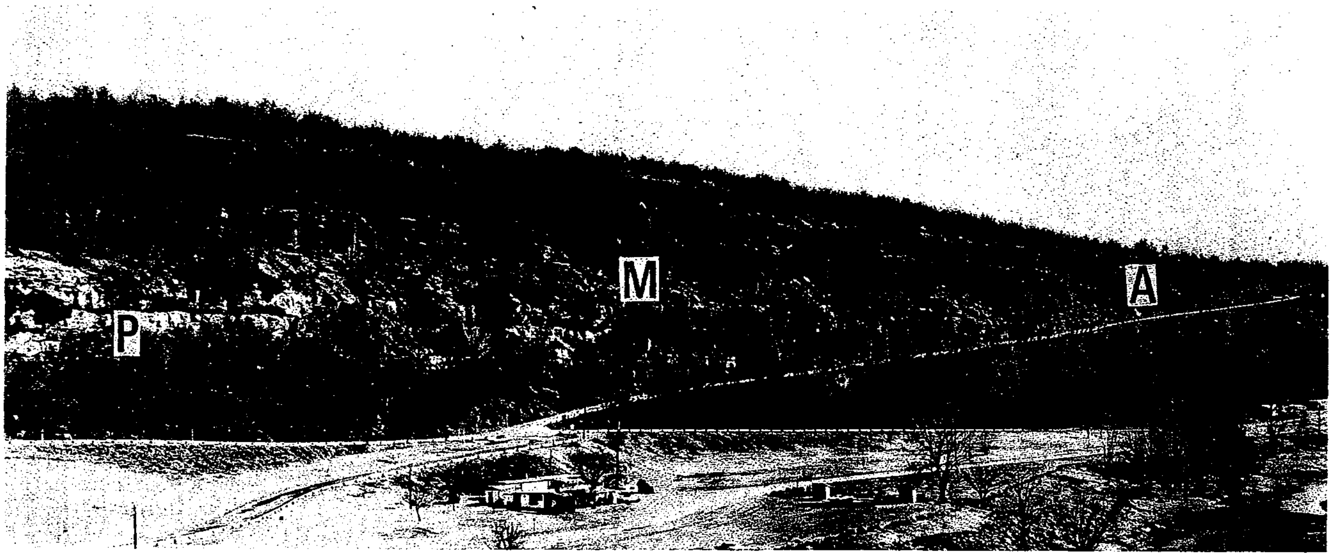


Figure 4. Distant view of sequence east of Fort Gibson Dam along Oklahoma Highway 80. Note location of bluffs, composed of Pitkin *(P)*, Morrowan *(M)*, and Atokan *(A)* units. Stop 13.

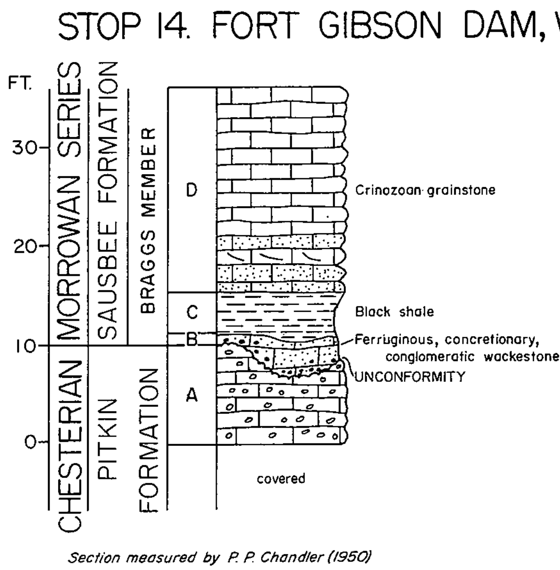


Figure 5. Graphic columnar section for Stop 14.

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STRATIGRAPHY OF UPPERMOST MISSISSIPPIAN AND LOWER PENNSYLVANIAN STRATA IN NORTHEASTERN OKLAHOMA

Patrick K. Sutherland[1] and Thomas W. Henry[2]

Abstract—Both the Chesterian (Mississippian) and Morrowan (Pennsylvanian) Series in northeastern Oklahoma are dominated by shallow-marine limestones and shales. The unconformity between the two series in this area is marked by both physical and faunal changes. There is at least 80 feet of relief on the pre-Morrowan erosional surface. Morrowan strata, which generally rest on the Chesterian Pitkin Formation, locally rest on the Fayetteville or Hindsville Formation.

A regional unconformity within the Morrowan Series occurs at the base of the Dye Shale Member of the Bloyd Shale in northwestern Arkansas and separates the Sausbee Formation from the overlying McCully Formation in northeastern Oklahoma. The Sausbee Formation is subdivided into the Braggs and Brewer Bend Limestone Members. These members correlate eastward with the Hale Formation plus the Brentwood Limestone and Woolsey Members of the Bloyd Shale. The McCully Formation includes the Chisum Quarry, shale "A," Greenleaf Lake Limestone, and shale "B" members, which correlate with the Dye Shale Member, the Kessler Limestone Member, and possibly part of the Trace Creek Shale Member of the Bloyd Shale in Arkansas.

A regional unconformity occurs at the top of the Morrowan sequence in northeastern Oklahoma. In this area, regional tilting to the south resulted in subaerial erosion of the post-Morrowan, pre-Atokan surface.

INTRODUCTION

Rocks of Chesterian (Mississippian) and Morrowan (Pennsylvanian) age are exposed in northeastern Oklahoma as a series of elongate bands that are associated with northeast-trending fault blocks that radiate from the Ozark dome.

The Chesterian Series in this area includes the Hindsville Limestone, the Fayetteville Shale, and the Pitkin Formation, in ascending order. Only the Pitkin will be discussed in this paper.

The Morrowan Series in northeastern Oklahoma has been subdivided by Sutherland and Henry (1977) into two new formations, the Sausbee and the McCully, and each of these into several members (fig. 1).

In this area, both series consist predominantly of shallow-marine limestones and shales. Sandstones form a minor constituent. The unconformity between the two series, marking the local boundary between the Mississippian and Pennsylvanian Systems, is marked by both physical and faunal changes.

CHESTERIAN SERIES

Pitkin Formation

The Pitkin Formation underlies Morrowan strata unconformably in northeastern Oklahoma, except in exposures where it has been removed by pre-Morrowan erosion. The Imo Formation, a Mississippian unit that overlies the Pitkin in north-central Arkansas (see First Day, Stop 1, this guidebook), is not present in northeastern Oklahoma.

The term Pitkin was first used by Adams and Ulrich (1904, p. 109) in Washington County, Arkansas, for strata referred to by previous authors as the "Archimedes Limestone." Henbest (1962, p. 38) designated the extensive cliff exposures along the eastern side of the West Fork of the White River in central Washington County as the type locality (see First Day, Stops 2 and 3, this guidebook).

In northeastern Oklahoma, the Pitkin Formation has an average thickness of 25 to 30 feet and a maximum known thickness of 82 feet (Huffman, 1958, p. 72). It is gradational with the underlying black shales and dark-gray, dense, nodular calcilutites (mudstones and wackestones) of the Fayetteville Formation (Chesterian).

The limestones of the Pitkin Formation in Oklahoma are dominated by light-gray-weathering oolitic calcarenite. For the most part, the calcarenites are oolitic grainstones; a few poorly washed, micritic, oolitic grainstones and packstones occur as interbeds. Skeletal debris generally serves as the nuclei for the ooids, and most of the oolitic limestones contain appreciable skeletal debris in addition to the ooids. Skeletal grainstones and packstones are the second most common lithic type. The skeletal material is varied, although bryozoans, pelmatozoans, and brachiopods are consistently dominant.

Typically, the limestones of the Pitkin Formation are easily distinguished from Morrowan limestones by their lithic character. A noteworthy feature of Pitkin limestones at most localities is the low percentage of quartz sand and silt, a feature that contrasts sharply with the high content of quartz sand in the lower part of overlying Morrowan strata. At most localities abundant *Archimedes,* which does not occur indigenously in overlying Morrowan strata, is also present.

Difficulties in locating the Pitkin-Morrowan contact arise only in the few exceptional areas where limestones that are low in quartz-sand content occur at the base of the Morrowan, such as at measured sections 34 and 78 (fig. 2).

POST-CHESTERIAN EROSION SURFACE

The Pitkin Formation is regionally truncated northward along a highly irregular line (fig. 3). It is present to the northwest, along Fort Gibson Reservoir, and as far north as

[1]School of Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma.
[2]U.S. Geological Survey, Reston, Virginia.

the south edge of Mayes County, in T. 18 N. (Huffman, 1958). To the east, however, there is a marked southwestward indentation in the truncation line, and in southeastern Cherokee County (T. 15 N.) there is an area in which Morrowan strata rest directly on the Fayetteville Formation and locally on the underlying Hindsville Formation (fig. 3). In Adair County the northern limit of the Pitkin Formation lies mostly in T. 16 N. and reaches the southern part of T. 17 N. at the Oklahoma-Arkansas line, at the eastern edge of the county. From that point the line of truncation extends northeastward into Arkansas, to the vicinity of Fayetteville, in the northern part of Washington County.

The unconformity developed on the Mississippian surface in northeastern Oklahoma has a regional relief of up to 80 feet. This conclusion is based on an interpretation of lateral variations in the thickness of the Sausbee Formation and the distribution of sandstone in the lower part of that formation, as shown in figure 4. An interpretation of the magnitude of the relief on the pre-Morrowan surface is dependent on the assumptions that the *Petalaxis* zone and the top of the Brewer Bend Limestone Member of the Sausbee Formation form a reliable regional datum, and that differential compaction of the lower Morrowan sediments is negligible.

It is concluded that a pronounced high on the post-Mississippian erosion surface, elongated in a northwest-southeast direction, is located in the southwestern outcrop area. The axis runs from the southern end of Lake Tenkiller (sec. 19, T. 13 N., R. 23 E.) toward the Braggs Mountain area (sec. 22, T. 15 N., R. 20 E.) and possibly extends farther to the northwest. The feature is herein referred to as the Gore-Braggs Mountain high (fig. 4).

Northeast of the Gore-Braggs Mountain high is a pronounced depression on the post-Mississippian surface, in T. 15 N., R. 23 E., in the vicinity of stratigraphic sections 51 and 79. The precise orientation of this erosional feature cannot be determined. The lower Morrowan stratigraphic interval in this area is exceptionally thick, and the percentage of coarse terrigenous clastics (quartzarenites and conglomerates) is exceptionally high compared to other areas. The absence of both the Pitkin and Fayetteville Formations in this local area also supports the conclusion that a depression exists on the post-Mississippian erosion surface (fig. 3).

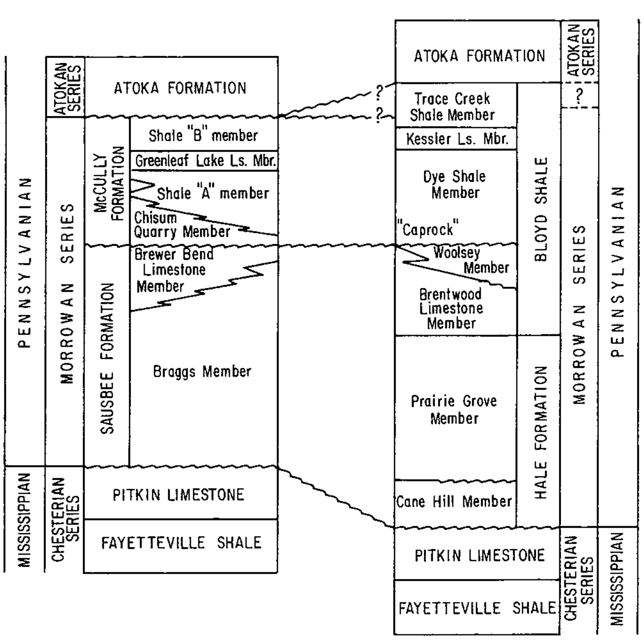


Figure 1. Table of formations and members.

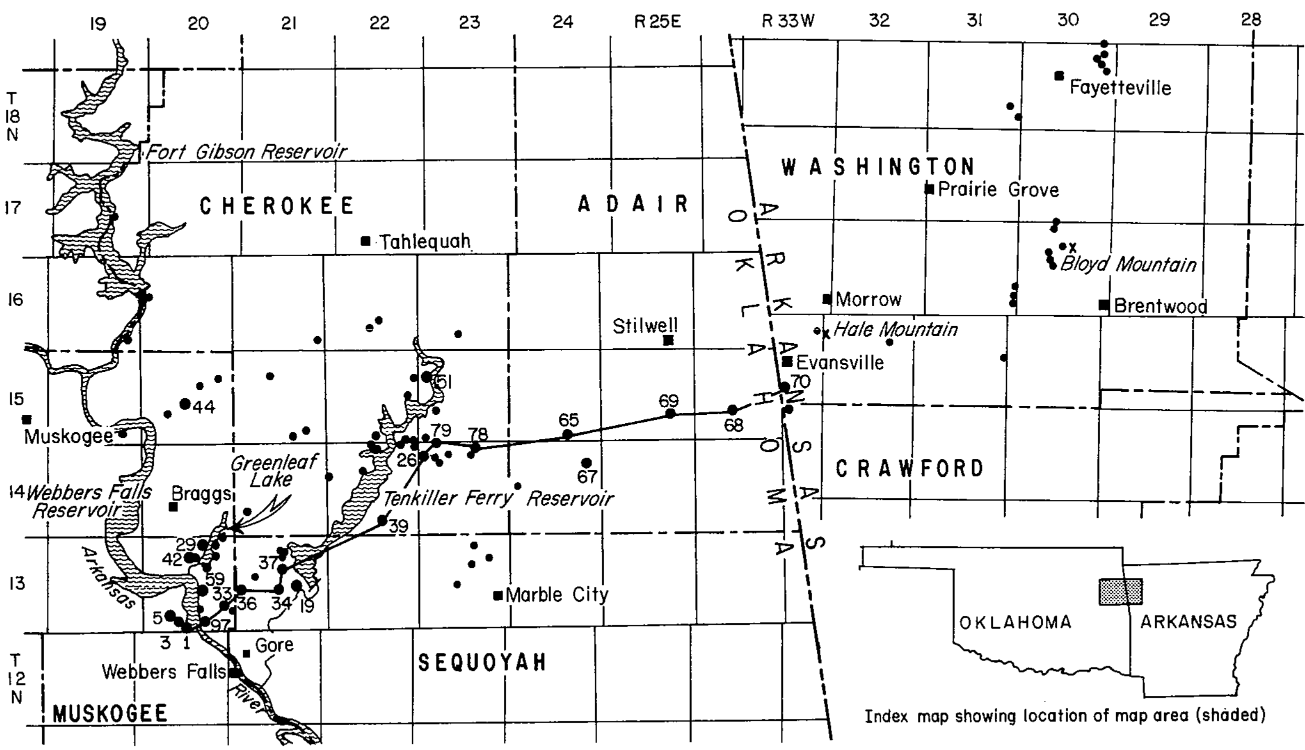


Figure 2. Locality map. Solid circles refer to stratigraphic sections; those numbered are mentioned in text. Line connects sections shown in figure 4. (Figure 1 of Sutherland and Henry, 1977.)

MORROWAN SERIES

Introduction

The Morrowan Series is the basal series of the Pennsylvanian System in central and western North America and has its type area on the southwestern flank of the Ozark dome (fig. 2). Sutherland and Henry (1977) proposed that the type area be extended westward from Washington County, Arkansas, to include the highly fossiliferous carbonate facies in northeastern Oklahoma.

The Morrowan Series in Arkansas is subdivided into the Hale Formation, composed primarily of calcareous sandstone (excluding the basal Cane Hill Member), and an overlying unit, the Bloyd Shale. Limestone forms a secondary lithic component in both formations and is confined primarily to parts of the Prairie Grove Member of the Hale Formation and the Brentwood and Kessler Limestone Members of the Bloyd Shale (fig. 1). Most of the strata in Washington County are shallow-water-marine deposits, excluding the terrestrial Woolsey Member of the Bloyd, but the proximity of the shoreline and a large influx of terrigenous clastic sediments throughout much of Morrowan time inhibited the development of a vigorous and diverse marine megafauna. Only the Brentwood and certain limestone facies of the Prairie Grove consistently yield large and diverse megafaunas.

Morrowan outcrops continue westward into Oklahoma from the Arkansas-Oklahoma line for about 40 miles to the Arkansas River area in eastern Muskogee County (fig. 2). The Morrowan strata abruptly change facies westward into Oklahoma. Moore (1947) and Huffman (1958) claimed ability to differentiate the Hale Formation and the Bloyd Shale in northeastern Oklahoma on the basis of quartz-sand content in the Hale and occurrence of a lowermost shale bed 2 feet or thicker in the Bloyd. Our studies (fig. 4) have shown that the distribution of quartz sand in these rocks is highly irregular and that lowermost shale beds are developed stratigraphically much lower in Oklahoma than in Arkansas. Thus, neither criterion can be utilized satisfactorily as a basis for subdividing the Morrowan strata in northeastern Oklahoma. The terms Hale and Bloyd can be employed for strata as far west as central Adair County (fig. 2), and we use this general area as

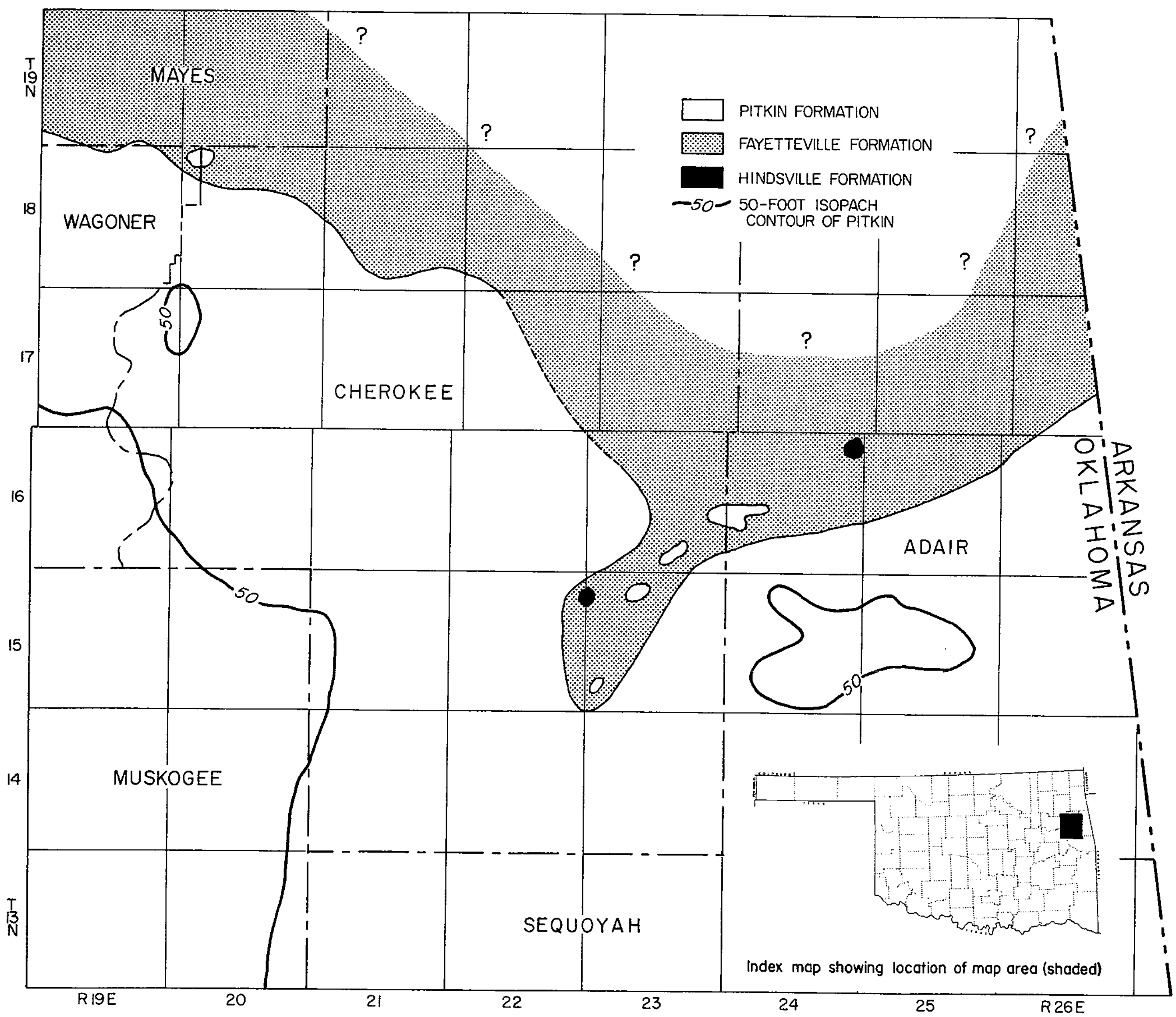


Figure 3. Generalized pre-Morrowan (Pennsylvanian) subcrop map. (Based primarily on an interpretation and modification of maps and stratigraphic sections by Huffman, 1958.)

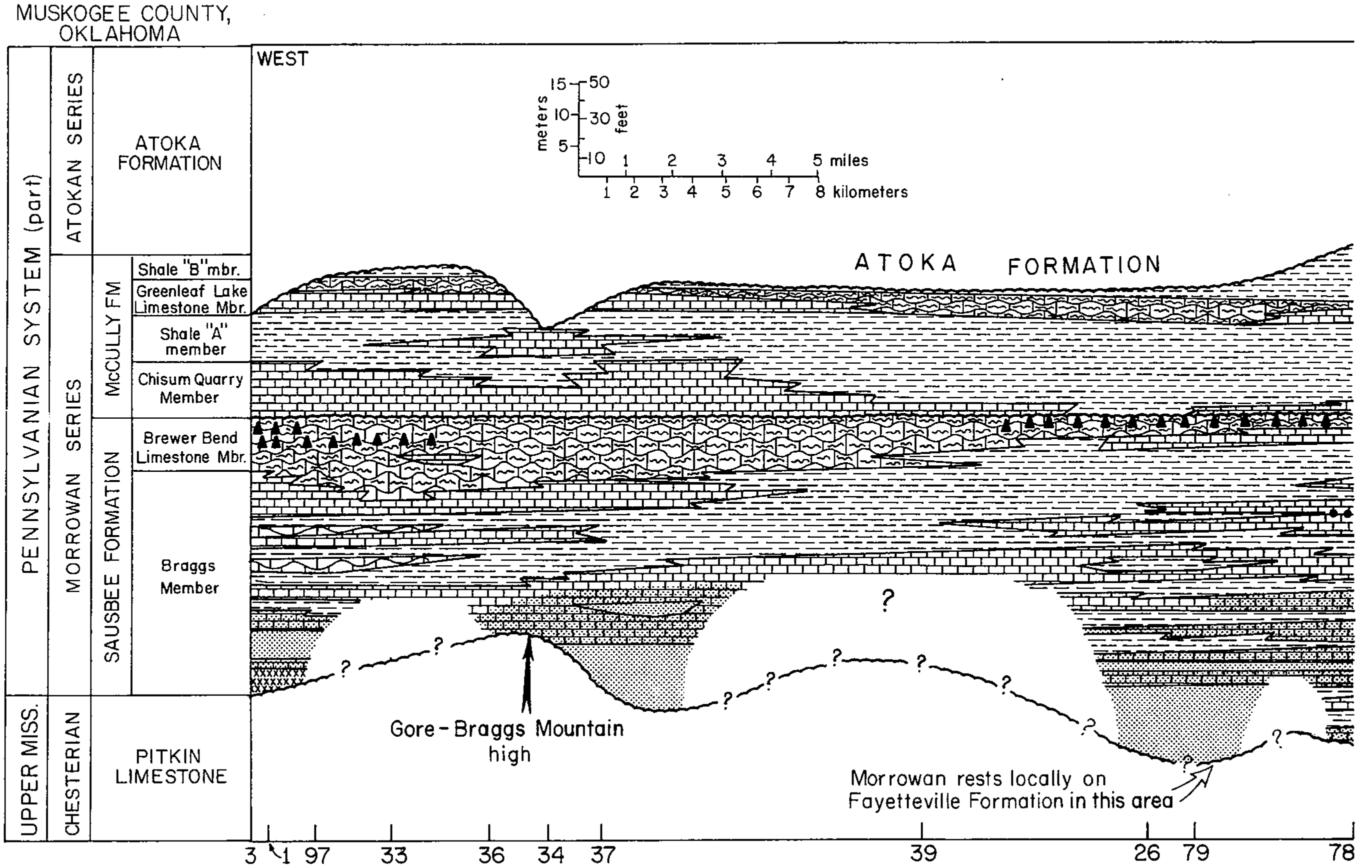


Figure 4. Cross section of Morrowan Series. See figure 2 for location of numbered stratigraphic sections. (Modified from Sutherland and Henry, 1977, figure 3.)

an arbitrary cutoff for employment of both the Arkansas and Oklahoma formation names.

The Morrowan sequence is predominantly limestone in Muskogee, Cherokee, and Sequoyah Counties, and it consists of complexly interfingering carbonate facies. A single distinctive, persistent datum is recognized throughout the area of exposure in northeastern Oklahoma. This datum represents a regional hiatus, and it coincides with the major unconformity at the base of the Dye Shale Member of the Bloyd in northwestern Arkansas. The sequence below this unconformity, the Sausbee Formation, and the sequence above, the McCully Formation, are different lithically, and the contact can be mapped over a large area.

The Morrowan strata thin irregularly westward from Arkansas and are only about 200 feet thick in the westernmost exposures in the vicinity of Webbers Falls Reservoir (fig. 2).

Sausbee Formation

The Sausbee Formation consists predominantly of limestone, with secondary amounts of shale. Sandstones occur only near the base of the formation. A thin basal conglomerate is present locally. The best exposures of this formation are on both sides of the Arkansas River near Webbers Falls Reservoir in southeastern Muskogee County.

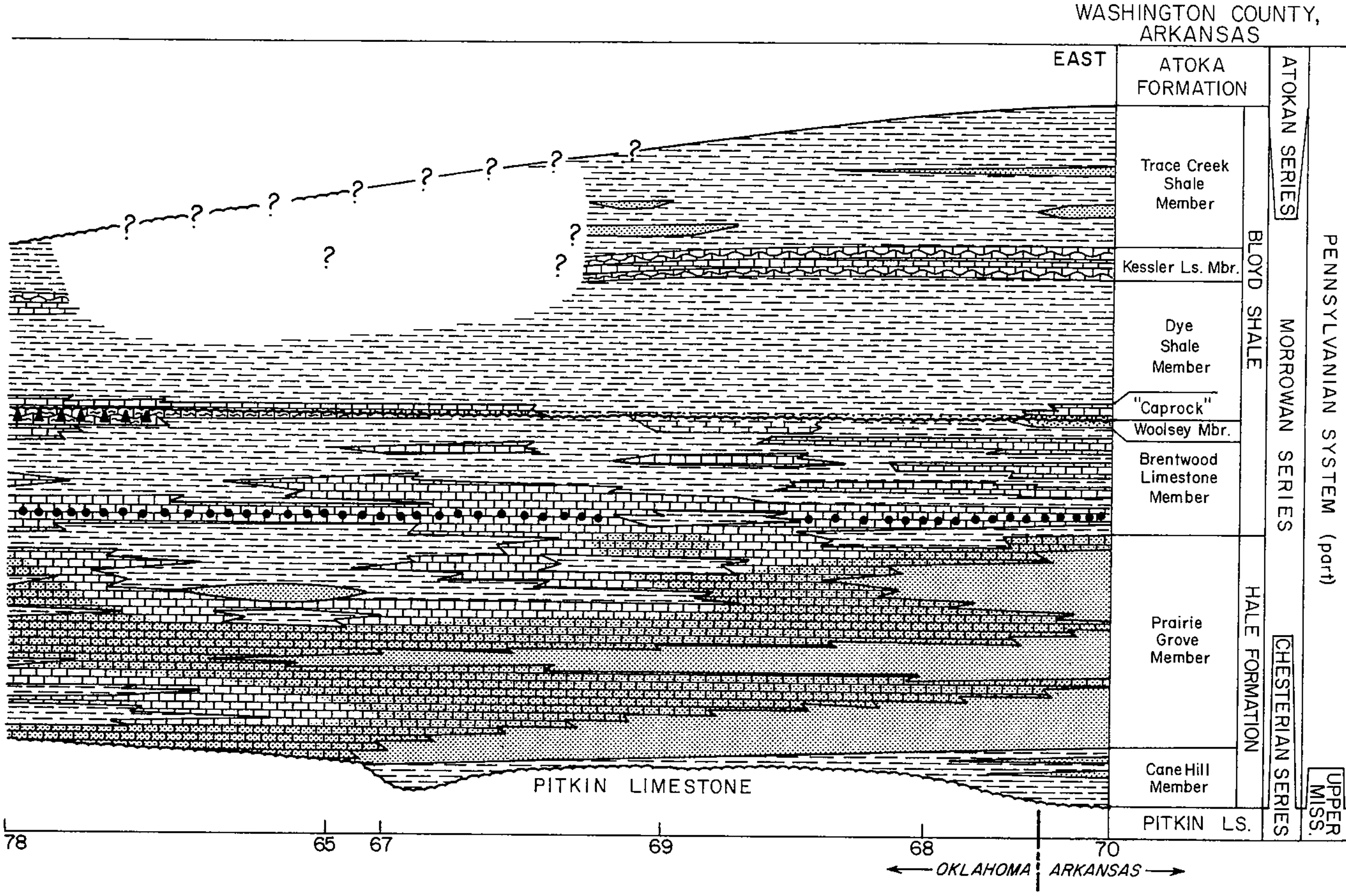
The formation is subdivided into the Braggs Member and the overlying Brewer Bend Limestone Member throughout Muskogee, Sequoyah, and Cherokee Counties. The Sausbee Formation changes facies eastward in Adair County and is stratigraphically equivalent to the Prairie Grove Member of the Hale Formation plus the Brentwood Limestone and Woolsey Members of the Bloyd Shale (fig. 4). Strata equivalent to the basal Cane Hill Member of the Hale in Arkansas are not present in the outcrop area west of Adair County.

The Sausbee Formation varies in observed thickness from 51 to 200 feet. This striking variation results primarily from deposition on a highly irregular erosional surface.

Braggs Member

The Braggs Member is the lower member of the Sausbee Formation. It is heterogeneous and is characterized by abrupt lateral changes in lithic character, reflecting partly the irregularity of the underlying depositional surface and partly the variations in depositional character across the Morrowan carbonate platform. The Braggs Member consists principally of interbedded limestone and shale with irregularly distributed sandstone in the lower part. This member, which constitutes most of the Sausbee Formation, rests unconformably on various Upper Mississippian formations throughout its area of outcrop. It generally overlies the Pitkin Formation. The Braggs Member is conformably overlain by the Brewer Bend Limestone Member, with which it interfingers and intergrades.

The observed thickness of the Braggs Member varies from about 42 to 175 feet, but the thickness of this member has little



EXPLANATION FOR CROSS SECTION

Grain-supported limestone (grainstone, packstone)
Mud-supported limestone (mudstone, wackestone)
Sandstone
Shale, siltstone
Quartz sand in limestone
Algae in mud-supported limestone
Spiculites
Petalaxis
Chaetetes
Unconformity

significance separated from that of the overlying Brewer Bend Limestone Member, which thickens laterally, primarily by facies change at the expense of the upper part of the Braggs Member. The thickness of the Braggs Member at measured section 3 is 103 feet.

The principal lithic constituent of the Braggs Member is limestone, dominantly fine- to coarse-grained skeletal calcarenite (grainstone). Pelmatozoan and bryozoan fragments are the chief grain constituents in the grainstone. Some limestones are quartz rich, particularly in the lower part of the member, where they intergrade with an irregularly distributed basal sequence of sandstones.

Micritic, algal-bryozoan bioherms occur in at least two zones in the upper part of the Braggs Member in the Webbers Falls area, in a stratigraphic interval of 25 to 30 feet. One of these forms a particularly distinctive interval (Bonem, this guidebook).

The lower parts of the Braggs Member, particularly the intervals rich in quartz sand, contain few megafossils, but conodont assemblages indicate that strata as old as the Cane Hill Member are missing in the Arkansas River area. The lowermost fossiliferous strata contain the *Idiognathoides sinuatus* conodont zone, which in Arkansas occupies the lower-middle part of the Prairie Grove Member of the Hale Formation (Lane, this guidebook). The middle and upper parts of the Braggs Member contain the *Neognathodus bassleri* condont zone (unrestricted), which includes in Arkansas both the *N. bassleri* and *N. symmetricus* zones of Lane (this guidebook). Also, the upper third of the Braggs Member in the Arkansas River area contains the *Branneroceras branneri* goniatite zone (Saunders and others, this guidebook), indicating a correlation with the lower Brentwood Limestone Member of the Bloyd Shale in Arkansas. This same goniatite zone occurs in the overlying Brewer Bend Limestone Member. In summary, faunal evidence suggests that the Braggs Member correlates with most of the Prairie Grove Member plus at least the lower part of the Brentwood Limestone Member.

Brewer Bend Limestone Member

The Brewer Bend Limestone Member, the upper member of the Sausbee Formation, is one of the most distinctive stratigraphic units in the entire Morrowan sequence. The top of this member is utilized as a datum for the cross section in figure 4 because of its distinctive petrographic character, unique faunal assemblage, and widespread distribution in northeastern Oklahoma. The Brewer Bend loses its distinctive character by lateral facies changes in the northernmost outcrops in Oklahoma as well as eastward in Adair County. Equivalent strata are present in these areas, but they belong to a different lithofacies.

The Brewer Bend Limestone Member is thickest in the southwestern area of outcrop, with a maximum recorded thickness of 41½ feet at measured section 33 (fig. 4). The long axis of the thick bank sequence is oriented north by northeast. The member thins slightly westward toward the outcrops on the western side of the Arkansas River.

The Brewer Bend Limestone Member typically consists of algal calcilutite (algal wackestone and mudstone) interbedded with minor shale. This limestone is thin to medium bedded and is generally nodular. The Brewer Bend is cliff-forming where its shale percentage is low, but the unit produces a distinctive rubbly outcrop surface where its shale percentage is high (Stop 11, this guidebook).

Algae are the most common organic elements in the Brewer Bend Limestone Member throughout northeastern Oklahoma. The red alga *Archaeolithophyllum*—mostly *A. missouriensis* Johnson—is the most common species, but *A. lamellosum* Wray, *Cuneiphycus texanus* Johnson, and various species of *Girvanella* and *Osagia* are also present (Kotila, 1973). This member is characterized by intensely burrowed algal wackestone and mudstone, which are commonly interbedded with algal boundstone. The principal frame builders of this boundstone are *Cuneiphycus* and *Archaeolithophyllum*. These structures are generally biostromal in nature. Biohermal developments are rare, and small blades in the wackestones, which dominate the skeletal grains, are generally unabraded and were not transported far.

The Brewer Bend Limestone Member is highly fossiliferous, and the biotic diversity is great in the southwest (that is, at measured sections 3 and 5), particularly in the middle and upper parts. Fenestrate bryozoans are the next most common biotic elements after the algae, and corals and brachiopods are also common. Scattered colonies of the colonial rugose coral *Petalaxis*, 1 to 2 feet in diameter, occur in the middle and upper parts of the Brewer Bend in the southwest. The genus *Petalaxis* has been found also in the Middle Carboniferous of the U.S.S.R., Spain, and Japan (Sutherland, 1977).

Scarce, sharply defined channel-shaped deposits, composed of skeletal packstone and rare skeletal grainstone, typically 5 to 10 feet across, cut the carbonate mudstone facies at scattered horizons in the southwest. Pelmatozoan debris (including much blastoid material) dominates these deposits, but fragments of algae, bryozoans, goniatites, brachiopods, corals, and other fossils are also included. The goniatites occur locally as a coquina (Stop 11, this guidebook).

The Brewer Bend Limestone Member thins northeastward, within a distance of 15 miles, from the maximum recorded thickness of 41½ feet at measured section 33 to a thickness of 4 to 12 feet in the northern Tenkiller Reservoir area. The basic lithic type of the member in this latter area is algal wackestone, but the percentage of algae is appreciably lower in this limestone than in that to the southwest. The member in the northern Tenkiller Reservoir area is sparsely fossiliferous and has low biotic diversity, in marked contrast to the profusion and diversity of faunal elements in the southwest. Desiccation cracks are abundant.

The major part of the Brewer Bend Limestone Member, in the northern Tenkiller area (measured section 26), forms a thin interval of algal calcilutite, with clusters of colonies of *Petalaxis* in growth position. These colonies are as much as 2 feet high and as much as 5 feet in diameter (Stop 8, this guidebook).

The Brewer Bend Limestone Member loses its distinctive character farther to the east and is replaced in central Adair County by marine shale at the top of the Braggs Member. The same stratigraphic position is occupied by the nonmarine Woolsey Member of the Bloyd Shale (fig. 4) in extreme eastern Adair County.

The Brewer Bend Limestone Member, in its area of maximum thickness, correlates with the middle and upper parts of the Brentwood Limestone Member plus the Woolsey Member of the Bloyd Shale in Arkansas. It contains many faunal elements that also occur in the Brentwood. Goniatites characteristic of the *Branneroceras branneri* zone of Gordon (1965, 1970) first occur in the upper part of the underlying Braggs Member and extend upward through the Brewer Bend. This member has yielded a variety of goniatite species typical of this zone. Many of these were illustrated by McCaleb (1968). A number of crinoid species, described by Moore and Strimple (1973) and also typical of the Brentwood, are from localities now included in the Brewer Bend Limestone Member. Conodont recoveries from the mud-supported limestone of the Brewer Bend are extremely sparse, and the elements are not diagnostic (Henry, 1970).

Post-Sausbee Unconformity

The boundary between the Sausbee Formation and the overlying McCully Formation is unconformable throughout northeastern Oklahoma; it is a continuation of the regional, subaerially developed unconformity at the base of the Dye Shale Member of the Bloyd Shale (fig. 4) in Arkansas. This is the only major regional break in deposition found within the Morrowan Series in the area and is more correctly termed a disconformity, in that regional truncation of underlying units cannot be demonstrated. The picture is complicated, however, by lateral changes in facies of the units directly below the erosional surface. The contact is invariably sharp, local truncation of less than 3 feet can be seen at several localities, and small fractures in the upper surface of the Brewer Bend Limestone Member are commonly filled with material from the overlying sequence. A thin basal conglomerate consisting of claystone clasts and scattered limestone pebbles is commonly present at the base of the overlying formations.

A significant biostratigraphic change in the composition of both the goniatite and brachiopod faunas also occurs at the boundary between the Sausbee and McCully Formations. It forms the break between the *Branneroceras branneri* and *Axinolobus modulus* goniatite zones (Gordon, 1970) and the boundary between the *Plicochonetes*? *arkansanus* and *Linoproductus nodosus* brachiopod zones (Henry and Sutherland, this guidebook).

McCully Formation

The McCully Formation consists of about equal percentages of limestone and shale in the area near the Arkansas River, but it is predominantly shale eastward from the northern Tenkiller Reservoir area, with limestone distinctly subordinate (fig. 4). Sandstone is scarce in the formation and occurs only locally as thin lenses. The higher limestone percentage generally coincides geographically with the thick development of carbonate mudstone in the underlying Brewer Bend Limestone Member of the Sausbee Formation.

The McCully Formation, like the underlying Sausbee, is best exposed in its type area on the western side of the Arkansas River area near Webbers Falls Reservoir.

In the type area, a basal sequence of limestone (grainstone) and thin interbedded shale, the Chisum Quarry Member, is overlain by an interval dominated by noncalcareous shale, which is informally called the shale "A" member. This shale member in turn is overlain by an interval of predominantly wackestone, the Greenleaf Lake Limestone Member. At the top of the sequence, a thin noncalcareous shale—the shale "B" member—occurs locally where it has not been removed by pre-Atokan erosion.

The thickness of the McCully Formation in type areas (measured sections) 1 and 3 is 64 and 58 feet, respectively. The formation varies greatly in thickness laterally, primarily because of the irregularity of post-Morrowan, pre-Atokan truncation. The maximum thickness recorded in the southwestern area is 75 feet, at measured section 42 (fig.2), 4 miles north of section 3.

The McCully Formation correlates with that part of the Bloyd Shale lying above the base of its Dye Shale Member in Arkansas. Strata equivalent to much of the Trace Creek Shale Member of the Bloyd are lacking in a large area in Oklahoma because of post-Morrowan, pre-Atokan erosion.

Chisum Quarry Member

The Chisum Quarry Member is the lowermost subdivision of the McCully Formation. The sequence in the type area is dominated by grain-supported limestone interbedded with thin shale. The succession is 21½ feet thick at measured section 1 and 19½ feet thick at section 3. In contrast, the Chisum Quarry Member consists of only 5 feet of limestone at an exposure near section 97, only 1 mile northeast of section 1. The short-distance lateral variations in thickness are typical of the highly lensing and discontinuous nature of the limestone layers in the middle and upper parts of this member, and they suggest an interfingering relationship with the overlying shale "A" member.

The limestone of the Chisum Quarry Member in the southwestern area is dominated by grainstone and packstone, with scarce occurrences of wackestone and boundstone.

The Chisum Quarry Member loses its distinctive character farther to the east in Adair County. It thins, the carbonate content decreases, and the sand percentage increases. In central Adair County (measured section 69), a 2½-inch-thick layer of medium- to coarse-grained conglomeratic sandstone with limestone pebbles occurs in the same stratigraphic position and is overlain by a thick shale. These basal strata above the disconformity are the stratigraphic equivalent of the "caprock" of the Baldwin coal, which occurs at the base of the Dye Shale Member of the Bloyd Shale farther east. This stratigraphic correlation is supported by the goniatite fauna collected from the Chisum Quarry Member. An extensive goniatite fauna has been described from the "caprock" in Arkansas (McCaleb, 1968). Gordon (1970) reported that elements of this fauna, which form the *Axinolobus modulus* zone, range from the "caprock," where they occur commonly, upward through the Kessler Limestone Member of the Bloyd, in which they occur rarely.

Shale "A" Member

A sequence consisting primarily of shale conformably overlies the Chisum Quarry Member in the Arkansas River area. Some of this shale is calcareous and contains skeletal debris, but most is noncalcareous and contains no megafossils. Concretions are scarce. A few thin limestone lenses are present, and these are commonly masked by shale talus and are concealed except in fresh cuts and in cores. In the Arkansas River area, the lower part of this unit intergrades and interfingers with the limestone layers of the upper part of the underlying Chisum Quarry Member. As one thickens, the other thins. The interval is 27 feet thick at measured section 1 and 31 feet thick at section 3.

The shale "A" member includes virtually no limestone stringers or layers in eastern Cherokee County. In this area, it is generally a homogeneous, noncalcareous clayey shale that is conformable with the underlying Chisum Quarry Member. The shale "A" member averages approximately 30 feet in thickness in the northern Tenkiller Reservoir area and attains a maximum recorded thickness of 40 feet at measured section 39. This unit is equivalent stratigraphically to the lower and middle part of the Dye Shale Member of the Bloyd Shale in Washington County, Arkansas.

Greenleaf Lake Limestone Member

The Greenleaf Lake Limestone Member is named from the distinctive and persistent interval of limestone that occurs near the top of the Morrowan sequence in Muskogee, Cherokee, and Sequoyah Counties, Oklahoma.

The Greenleaf in its type area consists principally of interbedded micritic, skeletal calcarenite. Wackestone is the most common limestone type, and packstone is locally present, which is partly oolitic. Most of the skeletal grains are fragments of bryozoans, pelmatozoans, and algae. Brachiopod fragments are secondary in abundance. Algal oncolites are present locally in a few beds.

The complete thickness of the Greenleaf Lake Limestone Member is 21 feet at its type section (measured section 42). The greatest recorded thickness, 1 mile to the northeast (section 29), is 30 feet. At both of these localities, the underlying shale "A" member is thinner than usual, suggesting a facies relationship between these units. Physical evidence is limited, since the contact between the two members is commonly covered.

The total depositional thickness of the Greenleaf Lake Limestone Member in the Arkansas River area is unavailable, because the Atoka Formation commonly rests unconformably on the middle or lower part of this member. The member is 15½ feet thick in measured section 1, but laterally the pre-Atokan erosion surface truncates at least 7½ feet of strata within 15 feet to the south (Stop Descriptions—Second Day, fig. 14, this guidebook).

The character of the Greenleaf Lake Limestone Member in the northern Tenkiller Reservoir area is similar to that found in the southwest. Wackestone and packstone are the most common lithic types, and the unit is characterized by abrupt lateral changes in the microfacies. The member is slightly thinner here than to the southwest, and the quartz-sand content is higher, particularly in the lower part of the member.

The thickness of the member in this central area, in sections where it has not been removed by pre-Atokan erosion, varies from 5 feet at measured section 78 to 15 feet at section 51.

The relations of the Greenleaf Lake Limestone Member to the Kessler Limestone Member of the Bloyd Shale in Arkansas is not clear. It seems most likely that the two are stratigraphically continuous, but such a relationship has not been demonstrated, since the upper part of the Morrowan is poorly exposed in western and central Adair County (fig. 4) and there are lateral changes in thickness of the underlying shale units.

Neither the Greenleaf Lake nor the Kessler has yielded a large or diverse conodont fauna (Henry, 1970; Lane and others, 1971). The Greenleaf Lake contains the same brachiopod assemblage as the Kessler, but most of the species range throughout the McCully Formation in northeastern

Oklahoma; only the Kessler has yielded a large brachiopod fauna in northwestern Arkansas. The "caprock" and most of the Dye Shale Member of the Bloyd Shale have yielded only a sparse and low-diversity fauna (Henry, 1973). Goniatites were not found in the Greenleaf Lake Limestone Member. Hence the upper McCully Formation cannot yet be biostratigraphically subdivided.

Shale "B" Member

The uppermost Morrowan unit preserved in Oklahoma is a thin noncalcareous shale preserved only at a few localities above the Greenleaf Lake Limestone Member where it has not been removed by pre-Atokan erosion. It is informally named the shale "B" member. It is similar in lithic character to the shale "A" member, which underlies the Greenleaf Lake. The maximum recorded thickness is 21 feet at measured section 42 (Greenleaf Dam). In the scattered areas where it is preserved it is overlain apparently unconformably by the basal units of the Atoka Formation, but this contact is rarely exposed. Fossils were not found in the shale "B" member, but this unit probably correlates with the lower part of the Trace Creek Shale Member of the Bloyd Shale in Arkansas.

Atoka Formation and Post-McCully Unconformity

In northeastern Oklahoma, the base of the Atoka is regionally truncating. The pre-Atokan surface in that area was tilted toward the south, because the higher Morrowan strata are progressively truncated toward the north. About 40 miles north of Tenkiller Reservoir, in T. 20 N., the Atoka Formation rests directly on various Upper Mississippian formations.

The lower part of the Atoka Formation in Cherokee, Muskogee, and Sequoyah Counties generally consists of noncalcareous sandstone that is locally conglomeratic. The basal part of the sequence is commonly slumped, thus concealing the contact with the Morrowan units. In the Arkansas River area, a 1- to 2-foot sandstone, at the base of thicker Atoka shale, rests directly on the Greenleaf Lake Limestone Member of the McCully Formation. A thin, irregularly developed limestone conglomerate 1 to 2 inches thick occurs directly above the contact. At these localities the conglomerate consists of pebbles of the underlying limestone, abraded solitary corals, michelinid colonies, and other skeletal fragments and scattered chert and phosphate pebbles.

The post-McCully erosion surface is distinctly irregular throughout Cherokee, Muskogee, and Sequoyah Counties. A major pre-Atokan valley was cut into the underlying Morrowan formations. This feature is located along a line from measured section 44 east of Muskogee (fig. 2), southeastward to the southern end of Tenkiller Reservoir, at sections 10 and 34, a distance of at least 15 miles. East of Muskogee, in the bottom of the valley, the entire McCully Formation, as well as the Brewer Bend Limestone Member of the Sausbee Formation, was locally removed, and the Atoka Formation rests on the middle part of the Braggs Member of the Sausbee. The local relief was as much as 120 feet within a lateral distance of less than 5 miles.

The most characteristic feature of the lowest part of the Atoka Formation in northeastern Oklahoma is the marked degree of lateral variation in rock type that results from the irregularity of the underlying depositional surface. The thickest lower Atokan sandstone coincides with these topographic lows.

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LIME-MUD MOUNDS OF THE PITKIN FORMATION (CHESTERIAN), NORTHWESTERN ARKANSAS

Robert E. Tehan[1] and Alex T. Warmath[2]

Abstract—Upper Chesterian lime-mud mounds, which resemble European "Waulsortian" complexes, occur as isolated bioherms scattered throughout the Pitkin Formation in northwestern Arkansas. The Pitkin mounds were rigid features which lacked a framework organism but which were nevertheless wave resistant. These mounds originated as small masses of carbonate mud that were subsequently colonized by bryozoans and crinozoans. The organisms stabilized the buildups by rooting and perpetuated mound growth by baffling currents and trapping lime mud. As mounds in the south developed, they began to influence carbonate deposition shoreward. This allowed subsequent mound development to the north.

Several crude cycles of alternating turbulent and nonturbulent energy phases are reflected as periods of lateral growth and vertical accretion by the mounds. However, overall lateral migration of the mounds was insignificant, even though lateral changes in nonmound facies are abrupt. This indicates that maximum transgression of Chesterian seas occurred during Pitkin sedimentation and also suggests that Pitkin limestone is largely a shoaling-upward sequence.

Cessation of Pitkin deposition is marked by regressing seas that caused subaerial exposure and erosion of the formation.

INTRODUCTION

The youngest Mississippian (Chesterian) unit exposed in northwestern Arkansas is the Pitkin Formation, which lies conformably on black shale of the Fayetteville Formation and is unconformably overlain by terrigenous clastics of the Cane Hill Member of the Hale Formation (Pennsylvanian, Morrowan). Regionally, the formation crops out from Batesville, Arkansas, westward to Muskogee, Oklahoma. In the study area, the limestone is primarily exposed in a narrow outcrop belt that trends across parts of Crawford, Madison, and Washington Counties, Arkansas (fig. 1). It ranges in thickness from zero at its truncated edge in the north to 90 feet in the south.

Deposited as a shallow-water, shelf-carbonate accumulation, the Pitkin is characterized by abrupt lithofacies changes. These lithofacies can be subdivided into a single mound facies and several nonmound facies. Twenty-three lime-mud mounds making up the mound facies occur as isolated bioherms scattered throughout the formation in the northwestern Arkansas study area. The lime-mud mounds are composed of dark-gray to medium-yellow-gray mottled boundstone that contains various amounts of sparry calcite and skeletal allochems. The term boundstone (Dunham, 1962) is expanded in this study to include rocks composed primarily of lime mud that were formed by organisms that baffled currents, trapped lime mud, and held the carbonate mass together by rooting on the buildups. The nonmound facies, which range in composition from mudstone to grainstone, include (1) bioclastic calcarenite, (2) oolithic calcarenite, (3) calcilutite, (4) alternating shale and irregular limestone, and (5) burrowed facies (table 1).

Previously, there have been few regional attempts to delineate lithofacies in the Pitkin. The complex pattern of lithofacies has made an understanding of Pitkin sedimentation difficult. However, recognition of the mounds and the associated facies relationships provides a key for interpreting Pitkin deposition.

[1]Kerr-McGee Corp., Oklahoma City, Oklahoma.
[2]Tenneco, Denver, Colorado.

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STRATIGRAPHY

Stratigraphically, the Pitkin Formation occurs within a sequence of Paleozoic strata 2,000 to 3,000 feet thick that was deposited on the flanks of the Ozark dome, centered in the St. Francois Mountains of southeastern Missouri. These Paleozoic units extend across the northern Arkansas structural platform with a regional dip of less than 1° to the south (Chinn and Konig, 1973). At the platform edge, the dip increases to 4° or 5° as these strata enter the Arkoma basin and attain a thickness of more than 15,000 feet.

Both the Fayetteville Formation and the Pitkin Formation are assigned to the Chesterian Series, based on faunal content and stratigraphic position (Easton, 1943). The Fayetteville-Pitkin contact is abrupt and planar, with basal limestones of the Pitkin commonly containing appreciable shale. This indicates the conformable and slightly transitional nature of the boundary.

The boundary between the Pitkin and the overlying Cane Hill Member of the Hale Formation is commonly slightly hummocky because of subaerial exposure of the limestone prior to Cane Hill deposition. Marine siltstones, sandstones, and

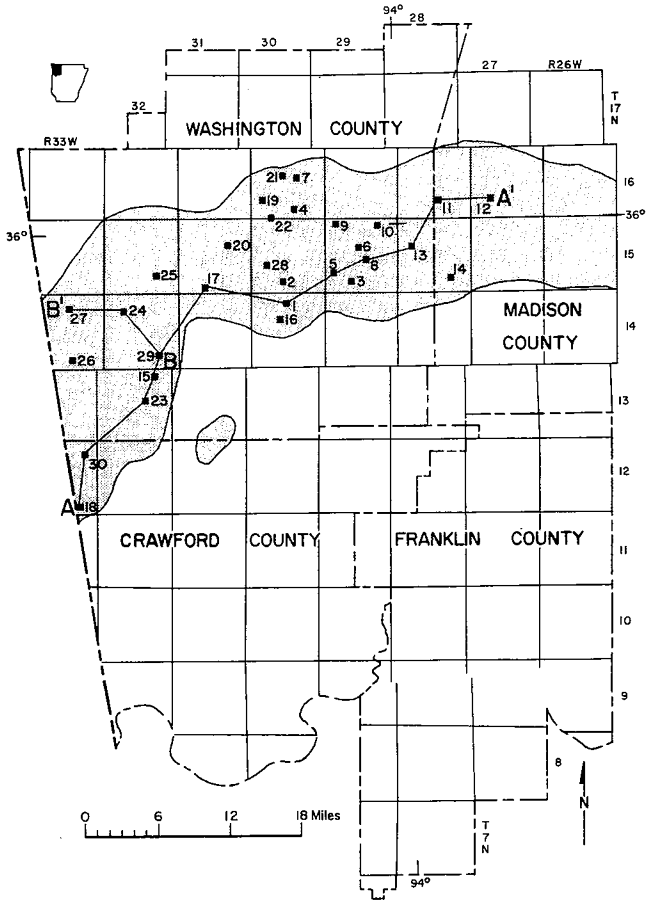

Figure 1. Location of study area in northwest Arkansas showing position of outcrop belt of Pitkin Formation (indicated by stippling) and measured sections (numbered solid squares). Sections connected by line *A-A'* are illustrated in figure 4.

Table 1.—Characteristics of Nonmound Facies

Summary of nonmound facies	Bedding	Rock types
Bioclastic calcarenite: crinozoans, bryozoans, and other skeletal grains	Thick to massive	Wackestone to grainstone
Oolithic calcarenite: ooliths and skeletal grains; several oolite shoals (> 90% ooliths) and spillover lobes exist in study area	Thick to massive	Packstone to grainstone
Calcilutite: micrite, pellets, and skeletal grains	Thin to thick	Mudstone to wackestone
Alternating shale and irregular limestone: oncoliths, intraclasts, and skeletal grains	Wavy lensoid beds to limestone nodules embedded in shale	Mudstone to packstone with intercalated shale
Burrowed: formed by organisms similar to *Callinasa*	Complex system of irregular, anastomosing burrows enclosed in marly matrix	Mudstone

brown to gray shales alternately overlie the Pitkin Formation, although at several localities (sections 7, 18, and 20), the unit is overlain by thin-bedded, sandy, ferruginous, bioclastic calcarenite that infills the "minikarst" surface of the Pitkin. Conodonts derived from this limestone indicate that it belongs to the Lower Pennsylvanian and thus to the Cane Hill. Local ferruginous, phosphatic, limestone or sandstone pebble conglomerates lying directly on the Pitkin Formation contain residuum of Pitkin and possible post-Pitkin strata. These conglomerates indicate an unconformable relationship with the overlying units, which is further enhanced by truncation of the formation northward. In the vicinity of Fayetteville, Arkansas, Cane Hill strata directly overlie the Fayetteville Formation. Studies of foraminifers (Brenckle, this guidebook) and conodonts (Lane, this guidebook) suggest that the unconformity marking the end of Pitkin deposition was not particularly long when compared to standard zonations for those fossils. However, the impoverished nature of basal Cane Hill strata precludes precise faunal dating of this contact.

PREVIOUS INVESTIGATIONS

"Archimedes Limestone" was the first name applied to the Pitkin. Owen and others (1858) borrowed the term, which previously applied to Meramecian strata near St. Louis, Missouri, and erroneously applied it to exposures of Chesterian limestone at Oil Trough in northeastern Arkansas, which also contained an abundance of *Archimedes*. Simonds (1891) used "Archimedes Limestone" for exposures of a similar unit in southern Washington County, Arkansas. (Although actual correlation between these limestone units has never been demonstrated, they are believed to be the same.) Adams and Ulrich (1904) renamed this unit the Pitkin Limestone. Later, Henbest (1962) designated a limestone bluff alongside U.S. Highway 71 between the communities of Woolsey and West Fork, Arkansas, as the type section for the formation. This type section is near the center of the west side of sec. 4, T. 14 N., R. 30 W., where the limestone is approximately 40 feet thick.

The Pitkin Formation has been mentioned in many studies, but only Easton (1942) has published a detailed, regional study. The bulk of this report was devoted to the paleontology of the formation, but Easton (1942) did comment on gross lithologic and stratigraphic relationships. We have published short studies dealing with the lithostratigraphy and petrography of the Pitkin in its type region (Tehan, 1977; Warmath, 1977). Individual bioherms have also been studied for thesis projects at the University of Arkansas (White, 1963; Bennett, 1965; Jackson, 1972). No other data are available for the Pitkin Formation in its type region.

MOUND FACIES

Megascopic Characteristics

The Pitkin lime-mud mounds were rigid structures having wave-resistant capabilities, as indicated by the presence of talus. At one mound location (NE¼NW¼ sec. 34, T. 15 N., R. 28 W.) large clasts containing well-preserved, delicate *Archimedes* fronds were torn from the mound and were deposited adjacently as talus (fig. 2). Some of these bryozoans are up to 7.5 cm in diameter and 17.5 cm in length. The clasts are rounded and the bryozoans have been truncated where they intersect the clast edge, which indicates that the bryozoans have undergone transportation. The talus is present at

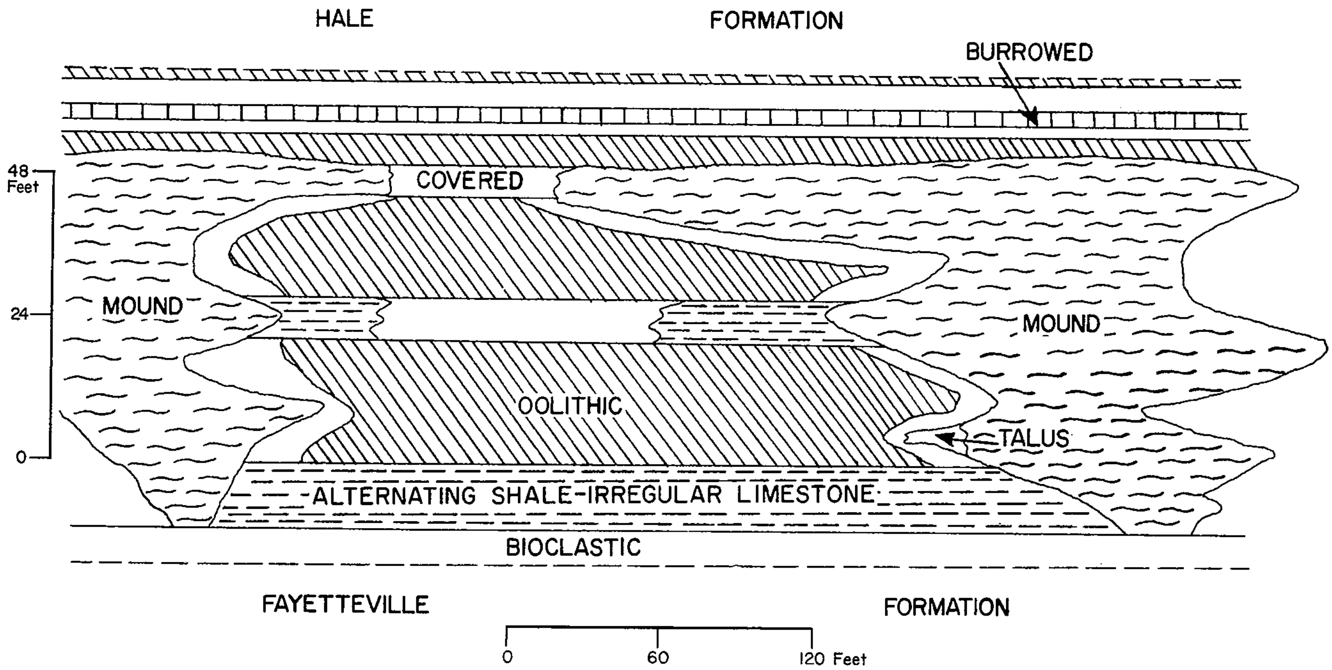

Figure 2. Diagrammatic cross section of Pitkin Formation showing relationship of lime-mud mounds and associated nonmound facies near Durham, Arkansas (section 14).

only one location, which suggests that even though the mounds were capable of wave resistance they were not often subjected to highly turbulent wave action. Oncoliths and intraclasts commonly occur in the alternating-shale, irregular-limestone facies in the vicinity of mounds (sections 20, 23, 28, and 29). These grains are believed to have originated from the mounds and are a further indication of their wave-resistant nature.

The Pitkin mounds are similar to "Waulsortian" complexes of Europe (Parkinson, 1957) and fenestrate-bryozoan bioherms from the Lake Valley Formation (Osagean) of the Sacramento Mountains, New Mexico (Pray, 1958). However, several significant differences are readily apparent (fig. 2). There is no anomalous thickening of the formation in the vicinity of the mound buildups, although the individual facies may thin or thicken against the mounds. Second, beds of the nonmound facies completely encase the mounds with essentially no draping of strata on the mound flanks. Finally, the overall dimensions of the Pitkin mounds are similar, particularly when compared to "Waulsortian" development, than other described mounds. These differences suggest that the Pitkin mounds were developed in particularly shallow water where carbonate deposition was prolific and abrupt lithofacies changes were common. Mounds typical of "Waulsortian" complexes probably occur in more basinward settings than those represented by the Pitkin outcrops in the study area.

Oriented along a northeast-southwest-trending belt parallel to depositional strike, the mounds usually occur in strata greater than 30 feet thick (fig. 3). At Cane Hill, Arkansas, the smallest mound (section 24) is 15 feet long and 10 feet high. The largest mounds are exposed along bluffs paralleling the White River near Durham, Arkansas, and almost span the entire section. One mound complex measures 60 feet vertically and 315 feet horizontally (fig. 2).

Generally, the mounds are lenticular with crude bilateral symmetry about a vertical plane. Texturally, the limestone is ropy or lumpy, resulting from differential weathering of

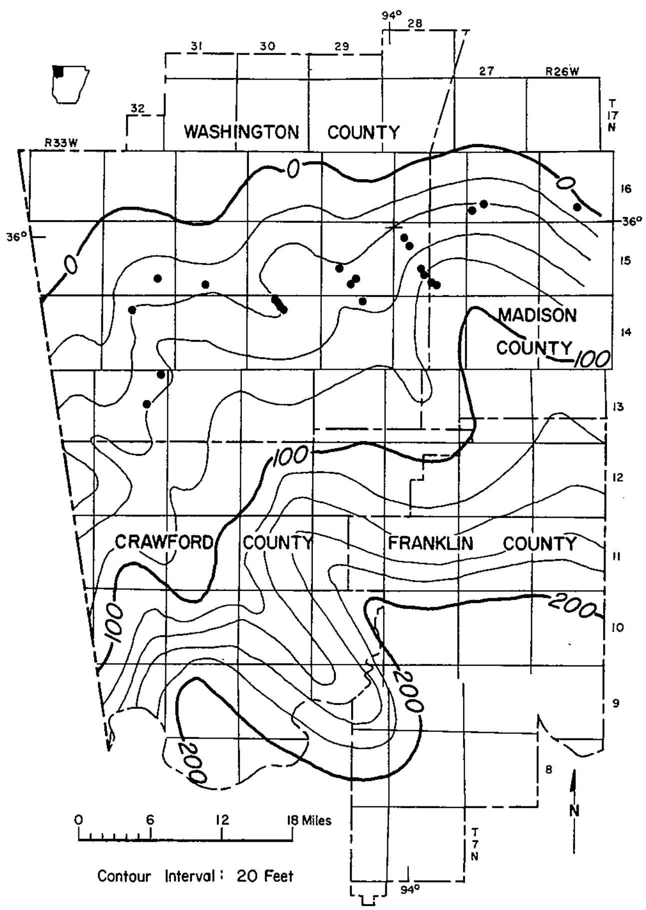

Figure 3. Isopach map of Pitkin Formation showing mound locations (solid circles).

boundstone and sparry calcite. The basal parts of the mounds are composed of nodular boundstone and intercalated shale, which grade laterally into the alternating-shale, irregular-limestone beds. Slight inclination of the alternating-shale, irregular-limestone facies in the vicinity of some mounds indicates that lime-mud boundstone accumulated at a faster rate than the shale. This indicates that the mounds had low topographic relief. During development, however, they were probably less than 2 m high above the surrounding sediment. Contained in this lower zone are a variety and abundance of fauna that is absent in other parts of the mound. Sponges, corals, brachiopods, crinozoans, and both fenestrate and fistuliporid bryozoans characterize this interval. The massive upper regions of the mounds are composed entirely of boundstone and sparry calcite. Faunal diversity decreases upward, with fenestellid and fistuliporid bryozoans and crinozoans constituting the bulk of the skeletal components.

Boundaries between the mound and nonmound facies are abrupt and distinct with the exception of the alternating-shale, irregular-limestone facies, which grades directly into the mounds. As a result of readjustment and shifting of carbonate mud after deposition, skeletal wackestone and calcarenite infilled cavities within the mounds. Much of the skeletal material was derived from organisms occupying the mound proper or which grew in a dense halo on the flanks. Continuity of several of the mounds is interrupted by thick to thin calcarenite beds, which owe their existence to storms or more rapid conditions of sedimentation. As a result, small mounds or parts of larger mounds were drowned.

Microscopic Characteristics

Mound composition is particularly uniform throughout the study area (table 2). The typical mound rock consists of dark-gray to medium-yellow-gray, mottled boundstone with spar-filled voids and small amounts of *Girvanella*, fistuliporid and fenestrate bryozoans, and crinozoans. Microcrystalline spar and micrite (66 percent) compose the matrix of the boundstone. This carbonate may have been derived from green algae similar to *Penicillus*, which has produced much of the lime mud in present-day Florida Bay. Stockman and Ginsburg (1967) indicated that debris from *Penicillus* would not be preseved in lithified rock, as the original structure of aragonite needles is destroyed when inverted to calcite. Dissolution of this type of organism may explain the origin of most of the lime mud composing the mounds.

Bryozoans are the most dominant skeletal grain (7 percent), with fenestrates being more abundant than fistuliporids. However, fistuliporids, several centimeters in length, were observed at several mounds. Delicate fronds of the bryozoans are present in the boundstone, which is an indication that they did not undergo extensive transportation before burial. The bryozoans were partially responsible for creating the cavities now filled by secondary sparry calcite. Crinozoans are preserved as single plates and articulated columns (2 percent). Little abrasion was observed, indicating that transportation was not a major factor in their deposition. Other skeletal matter observed in the thin sections includes bivalves, brachiopods, rugose and tabulate corals, sponge spicules, and foraminifers. *Girvanella* is also sparsely represented in most thin sections.

Sparry calcite has infilled voids within the boundstone (15 percent). These voids have been named "birds-eye" features or stromatactis. They vary in size, and their shape ranges from irregularity to outlines of former skeletal fragments.

Several different origins for the above-described features are proposed. Cavities were created by the accumulation of bryozoan fronds, which, in turn, sheltered the voids from incoming mud. Cavities were also formed by the dissolution of skeletal organisms. Burrowing activity by soft-bodied organisms, perhaps responsible for the mottled coloration of the boundstone, also created voids. Undoubtedly cavities were also formed by reworking, slumping, and desiccation of the mud.

Table 2.—Modal Analysis of Pitkin Mounds, Based on Point-Count Data

Thin-section number	Percentages of constituents					
	Matrix	Spar	Crinozoans	Bryozoans	Pellets	Misc.**
13-1 (M-7)*	63	20	0	13	0	5[†]
14-1 (N-9)	72	20	3	4	0	0
14-2 (N-10)	68	12	3	9	0	9
14-3 (N-11)	72	20	3	4	0	0
14-4 (N-12)	72	20	3	4	0	0
14-5 (N-13)	72	20	3	4	0	0
15-1 (16-20)	70	15	1	4	0	10.5
15-2 (16-21)	68	6	1	15	2	5.5
15-3 (16-22)	85	8	1	2	1	4.5
16-1 (2-8)	19	44	8	19	3	7
16-2 (2-9)	47	14	1	0.5	24	14.5
16-3 (2-10)	48	16	2	6	22	6.5
17-1 (3-5)	75	5	0	3	7	10.5
17-2 (3-6)	69	7	1	11	7	5.5
17-3 (3-7)	74	17	3	3	0.5	2.5
24-1 (10-17)	79	3	0	7	8	5
Averages:	66	15	2	7	5	5

* Original number of thin section as listed in theses.

** This category includes corals, bivalves, sponge spicules, foraminifers, algae, unidentified skeletal grains, and non-skeletal grains.

† Percentages may be more than 100 owing to rounding errors.

RECONSTRUCTION OF PITKIN SEDIMENTATION

Limestone of the Pitkin Formation was deposited as a shallow-water, shelf-carbonate accumulation on a surface of gently sloping shale of the Fayetteville Formation in water depths of less than 20 feet. This transition from shale deposition to carbonate accumulation was caused by a decrease in terrigenous supply. The maximum transgression of Chesterian seas was during Pitkin sedimentation. The strandline was located several miles north of the formation's present truncated edge. Although broad facies patterns are not discernible within the formation, a sequence of sedimentary events can be established by analyzing mound distribution, mound morphology, and lithofacies relationships (fig. 4).

The northeast-to-southwest alignment of mounds is the result of unknown ecological and hydrodynamic factors. The proper mix of water depth, bottom topography, and circulation patterns may have created eddies within the currents, resulting in the deposition of lime mud along this trend (Heckel, 1974). These accumulations formed small masses of carbonate mud that interfingered with sediment of the alternating-shale, irregular-limestone facies. This facies is rich in organic diversification. Bryozoans, crinozoans, brachiopods, corals, bivalves, sponges, and foraminifers are present to some extent. During this slow-sedimentation phase, bryozoans and crinozoans colonized and stabilized the small buildups. Other organisms such as marine plants also may have been present, adding to the stabilization process. Baffling by these organisms caused deposition of additional lime mud. Lateral expansion of the mounds peaked during this time as a result of slow-sedimentation rates and mound colonization (fig. 2). Thick bioclastic calcarenite is commonly opposite lateral mound development, indicating that organic growth was prolific during these relatively quiet-water phases. Evidently, bryozoans were more important in mound building than crinozoans, as bryozoan content in the limestone increases near the mounds whereas crinozoan debris decreases.

Fluctuations in water depth caused by oscillations of sea level or differential subsidence created periods of increased turbulence. Improved circulation patterns further stimulated bryozoan and crinozoan growth by supplying added nutrients. The mounds operated as self-perpetuating features by trapping and binding lime mud deposited as a result of baffling, dissolution of green algae, and diminution of skeletal fragments (Harbaugh, 1957). Mounds developing to the south began to influence carbonate deposition to the north. These mounds were an effective barrier to incoming waves and currents. Quiet-water conditions were therefore created behind this barrier. The mounds also restricted circulation and caused deposition of calcilutite and alternating-shale, irregular-limestone sediments. This created the necessary conditions for additional mound development to the northwest. Widespread oolithic and bioclastic blanket-sand deposits accumulated in the more turbulent intermound areas. The shifting of these intermound deposits commonly inhibited lateral mound development, as a proper substrate for organic growth was not provided. Vertical accretion was more rapid during these turbulent phases, when the flourishing organisms kept pace with the deposition of surrounding sediment.

Apparent at various mound locations are as many as 3 or 4 of these crude energy cycles, which resulted from changes in water depth caused by differential subsidence and oscillating sea level. As water depth increased, some of the mounds were unable to grow and drowned. Other mounds possessed the proper ecological controls to maintain growth through all the cycles. Toward the end of Pitkin deposition, all of the mounds were buried by oolithic and bioclastic beds. Evidently at this time, water depth was extremely shallow, as burrowed deposits overlay some of the mounds. This change marked the beginning of regressing seas and eventual subaerial exposure and erosion of Pitkin and possible post-Pitkin strata.

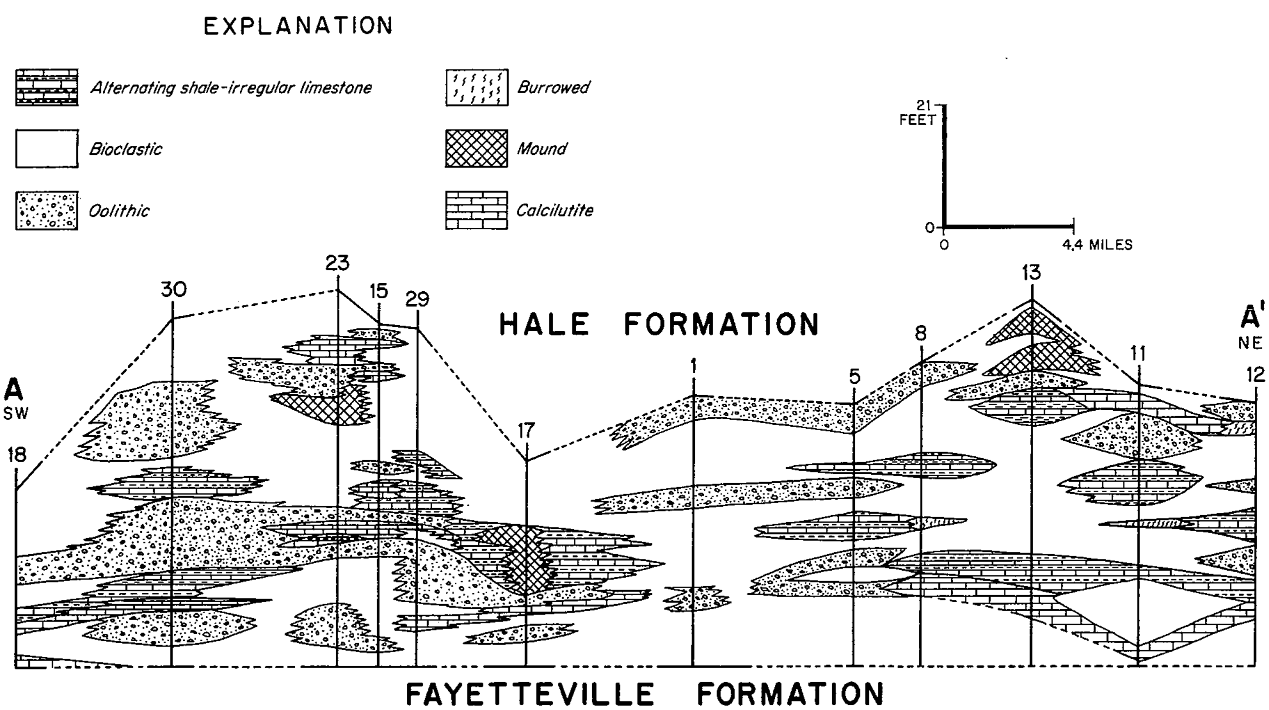

Figure 4. Diagrammatic southwest-northeast cross section along line *A-A'* of figure 1 showing complexity of lithofacies relationships within Pitkin Formation.

SUMMARY

Upper Chesterian lime-mud mounds, similar to "Waulsortian" complexes in structure and composition, occur in the Pitkin Formation of the Midcontinent region. However, several differences are apparent, particularly regarding their relationships with nonmound facies. These differences indicate that the Pitkin mounds were formed in shallower water, where carbonate accumulation was rapid and abrupt lateral changes of lithofacies were common.

Pitkin mud mounds were rigid structures that lacked framework-building organisms, but were nevertheless wave resistant. On the average, these mounds contain 66 percent carbonate mud, from which their name is derived. Sparry-calcite-filled voids (15 percent), various amounts of bryozoans (7 percent), crinozoans (2 percent), and other skeletal and nonskeletal grains compose the remainder of the boundstone.

Carbonate mud deposited as a result of the influence of bottom topography and water depth on circulating water patterns created the mounds. Much of the carbonate mud possibly originated from dissolution of green algae. Bryozoans and crinozoans colonized these buildups, causing additional mud to be deposited by baffling. These organisms stabilized the mounds by trapping the lime mud and rooting on the buildups.

Crude cycles of alternating turbulent and nonturbulent energy phases are reflected as lateral growth and vertical accretion by the mounds. These cycles were influenced by changes in water depth caused by differential subsidence and oscillations of sea level. Several of these cycles are observed at various mound locations (table 3).

As the mounds developed, they began to influence circulation and created quieter conditions in their wake, thus allowing for development of additional mounds shoreward. This is suggested by the decrease in size of the mounds northward and their occurrence higher in the section.

Pitkin limestone accumulated as an overall shoaling-upward sequence. Lateral migration of the mounds was not significant even though lateral changes in the nonmound facies were rapid and abrupt. Water-depth changes of several feet caused lateral migration of the lithofacies. Depending on the slope of the sea floor, which was possibly less than 0.5 foot per mile, this migration could have occurred for several miles or tens of miles. These adjustments in water depth were relatively rapid, as the bulk of the mounds remained in place.

Table 3.—Locations of Readily Accessible Mounds

1 mound complex: NW¼NW¼NE¼ sec. 1, T 13 N., R. 32 W., 7 miles south of Prairie Grove, Arkansas, on Washington County Highway 21, ¾ mile south of Cove Creek Ranch headquarters

5 mounds exposed in quarry: NW¼SW¼ sec. 4, T. 14 N., R. 30 W., 1 mile south of West Fork, Arkansas (Pitkin type section)

4 mounds: SE¼SW¼SW¼ sec. 27, T. 15 N., R. 28 W., 2 miles southeast of Durham, Arkansas; exposed in limestone bluff on White River

1 mound complex: sec. 27, T. 16 N., R. 26 W. (White's reef), 4 miles south of Huntsville, Arkansas, on Arkansas Highway 23 (War Eagle Creek)

Cessation of Mississippian deposition in northwestern Arkansas was marked by regressing seas, which caused subaerial exposure and erosion of the Pitkin. Shallow-water carbonate deposition and resulting lithofacies relationships are usually difficult to interpret. Fortunately, Pitkin mound reaction to the depositional environment and the relationships to other lithofacies provide the data needed for analysis of the formation.

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STRATIGRAPHIC SETTING, CARBONATE LITHOFACIES AND DEVELOPMENT OF LOWER PENNSYLVANIAN BIOHERMS OF NORTHEASTERN OKLAHOMA

Rena M. Bonem[1]

Abstract—Examination of the paleoecology, lithic sequence, and stratigraphy of small bioherms in the Sausbee Formation of the Lower Pennsylvanian Morrowan Series in northeastern Oklahoma permits better understanding of the development and transition in structure and composition of organic mounds through time during the Paleozoic Era in North America. The bioherms are developed in two shale intervals and are composed primarily of bryozoan-algal boundstone with skeletal wackestone and grainstone. Grainstone channel deposits occur adjacent to mound complexes in both intervals, but other bioherms occur as solitary mounds completely surrounded by shale. Description of the lithofacies and biotic associations results in recognition of three phases of biohermal development. These include stabilization of the substrate by stromatolitic blue-green algae (initiation); habitation of the bioherms by a variety of organisms including rugose and tabulate corals, bryozoans, brachiopods, and goniatites (diversification); and domination by encrusting bryozoans or blue-green algae resulting in termination of mound growth.

INTRODUCTION

Small bioherms occur in two stratigraphic intervals within the lower part of the Lower Pennsylvanian Morrowan Series in northeastern Oklahoma. These bioherms are of particular interest because they form a transitional phase in structure and composition between early and late Paleozoic organic mounds.

Several aspects of the bioherms were considered during paleoecologic and stratigraphic analysis. A detailed discussion of the development and paleoecology of the mounds can be found in Bonem (1977a). The paleogeographic setting, lithic sequence, and summary of biohermal development are described herein.

SETTING

The Morrowan bioherms occur at four northeastern Oklahoma localities within a belt that extends north-south for 5 miles (fig. 1). During Morrowan time, this belt paralleled approximately the edge of a shallow-marine, carbonate platform that extended south and southwest from the Ozark dome.

Prior to deposition of the Morrowan limestones and shales, the post-Mississippian erosional surface had approximately 80 feet of relief (Sutherland and Henry, 1977, fig. 3). An elongate topographic high was present northeast of a line along which the bioherms would later form. Although this high was buried before the mounds developed, it may have influenced local current patterns and sedimentation, permitting mound initiation.

LOCATION

The bioherms are best exposed and most accessible in the large central quarry on the Chisum property that provided crushed rock for the Webbers Falls Lock and Dam on the Arkansas River Navigation System. This quarry, now inactive, is located in the SW¼NW¼NW¼ sec. 35, T. 13 N., R. 20 E., Muskogee County, Oklahoma. The section exposed in the central quarry begins in the lower part of the Morrow Group near the southern end of the east quarry wall. Both mounding intervals are exposed and occur within the Braggs Member of the Sausbee Formation (fig. 2).

NATURE OF BIOHERMS

Bioherms in the quarry were plotted on a topographic map of the central quarry (fig. 3). Lithic and faunal composition of the bioherms was examined in detail, utilizing thin sections and polished serial slabs of oriented blocks of boundstone. Bulk samples of shales occurring within and adjacent to the biohermal complexes were also examined.

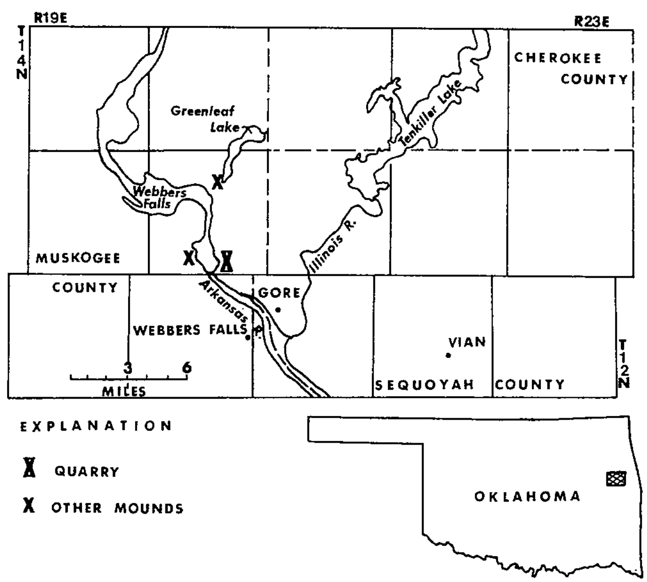


Figure 1. Index map of northeastern Oklahoma showing location of quarry and other biohermal exposures.

[1]Department of Geology, Hope College, Holland, Michigan.

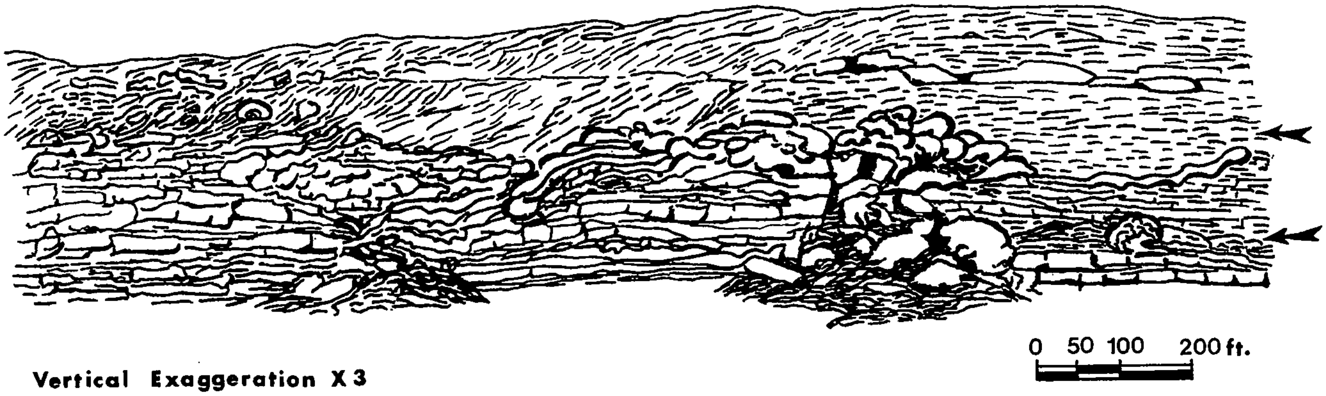


Figure 2. Diagrammatic section of east wall of central Chisum's quarry. Two mounding intervals may be noted at right.

Lower Mounding Interval

The lower 0.8 to 4.0 feet of the lower mounding interval consists of skeletal wackestones containing fragments of pelmatozoan columnals and bryozoans. This interval is overlain by irregularly developed pelmatozoan-bryozoan-algal boundstone mounds that contain local developments of *Garwoodia* (codiacean) algal boundstone. The individual mounds reach a maximum height of 2.5 feet and a width of 9.0 feet on the north wall of the central quarry (fig. 3). Boundstones and wackestones form the central and lower parts of the bioherms that were deposited during initial phases of mound development. Intermediate mound layers are wackestone and grainstone that lack organic binding, whereas the outer layers of the mounds consist of bryozoan boundstones, mudstones, and wackestones. Medium-gray silty shale occurs over, adjacent to, and within the boundstone mounds. The thickness of the shale varies from 0.7 to 1.3 feet on top of the mounds to more than 2.0 feet adjacent to a series of boundstone lobes occurring on the northeast wall. The otherwise parallel bedding of the shales becomes disturbed directly adjacent to mounds as a result of differential compaction of the shale surrounding the mounds.

Silicification of pelmatozoan, bryozoan, and tabulate coral debris is common, as is recrystallization of large skeletal clasts to spar. Dolomitization occurs only in the coarse-grained *Garwoodia* grainstone.

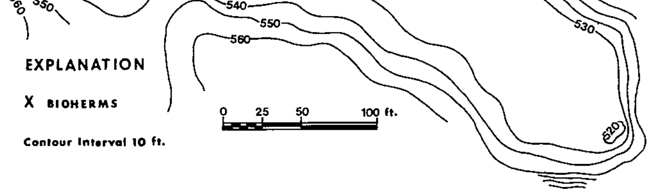


Figure 3. Topographic map of central part of Chisum's quarry, Muskogee County, Oklahoma. Mounds in both intervals are indicated.

Upper Mounding Interval

Eight to 9 feet of interbedded limestones and shales separates the upper mounding interval from the lower interval. The upper interval contains grainstones, packstones, wackestones, and mudstones as well as bryozoan-algal boundstone mounds. The mounds in this interval differ from those in the lower interval in details of composition. In contrast to the mounds of the lower interval, stromatolitic boundstones and wackestones are found in the outer layers as well as in the central and lowest parts of the mounds. Only the intermediate mound layers, which correspond to the diversification phase of mound development, are not completely dominated by stromatolitic algae. Stromatolitic boundstones occur with and intergrade with bryozoan-coral boundstones and wackestones in the intermediate layers of the bioherms. At other nearby localities the intermediate layers of the mounds may be red algal (*Archaeolithophyllum*)-tabulate coral-stromatolitic boundstone and wackestone and goniatitic wackestone.

The mounds of the upper interval also differ from those of the lower interval by being generally larger and more structurally complex with a series of boundstone lobes forming each mound. The mounds reach a maximum height of 6 feet and a width of 10 feet. The mounds in this interval, as in the lower mounding interval, commonly appear to be oriented, having a steep bryozoan-algal roll that faces into dark-gray, calcareous and noncalcareous shales and an elongated "back side" that gradually thins against grainstone channel deposits (fig. 4). Orientation appears to be consistent for all the lobes within a single mound complex but not consistent from one mound to the next within the quarry. The grainstone contains fragments of pelmatozoans, bryozoans, and coelenterates including tabulate corals.

The highest mounds in the upper interval are solitary bioherms that consist of a series of boundstone layers wrapping around each successive layer on at least three sides. The mound margins, in contrast to the lobed mounds, abut against buff-green shale. The only fossils found in the shale are a few abraded pelmatozoan columnals and plant fragments (fig. 5).

All lithic types in the upper interval exhibit partial silicification of pelmatozoan and bryozoan debris and partial recrystallization of large clasts to spar. In addition, nodules occurring in the shales between mounds in this interval consist of dolomitized skeletal (pelmatozoan-spicule) mudstone.

Figure 4. Large, asymmetrical, lobed mound complex (arrow) in upper mounding interval. Vertical exposure about 40 feet.

Figure 5. Solitary bioherm of "jelly-roll" type in upper mounding interval. Vertical exposure about 4.5 feet.

Compaction Features

Vertical micro- and mega-fractures and stylolites are found in lithofacies of both the lower and upper mounding intervals. These features are most common in the stromatolitic and bryozoan boundstones, and, when occurring with dolomitization, fractures through the grains only indicate that compaction preceded dolomitization.

Evidence for Exposure

Associated with the stromatolitic boundstones in the outer layers of the bioherms of the upper mounding interval are bird's-eye structures and desiccation cracks that may have formed as mud cracks on the stromatolitic surface. The cracks are filled with coated grains or ooliths and are associated with anhydrite pseudomorphs and dolomite rhombohedrons. The outer surfaces of the mounds have an irregular "weathered" appearance, stained by iron oxide, while the adjacent and overlying shales contain a nonmarine biota.

BIOHERMAL PALEOECOLOGY

It is useful to examine the paleoecology of the Morrowan bioherms in order to understand the stratigraphic succession associated with the mounds. The bioherms appear to represent a life assemblage that has accumulated in place. Although adjacent pelmatozoan grainstones show indication of transport—including abrasion of fragments, sorting, current orientation, and absence of fragile skeletal material—the mound components do not appear to have been substantially transported. Studies by Chave (1962) indicate that calcareous red algae and fenestrate bryozoans, common in the Morrowan bioherms, are susceptible to mechanical destruction in a short time. Further, the organisms do not appear to have been current oriented or deposited as particulate matter influenced by currents or waves. Instead, the bioherms have a boundstone framework that is formed by a variety of encrusting and cementing organisms and opportunistic accessory organisms, such as brachiopods and rugose and tabulate corals, that found a stable substrate in the mounds. The remains of vagrant organisms, including trilobites, gastropods, nautiloids, and goniatites, may have been transported into the mounds after death, but it is equally possible that they were a part of the normal fauna associated with the mounds, as they show little evidence of transport. Many cavities within the bioherms contain transported debris, but there are also instances where organisms appear to have grown in place within cavities that were present during biohermal growth (Bonem, 1977b). A detailed study of the paleoecology of the bioherms appears in Bonem (1977a), the results of which are summarized below.

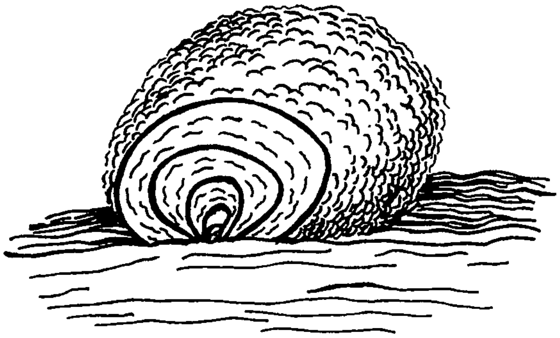
Mound Development

The Morrowan bioherms appear to have begun development above a skeletal wackestone or calcareous shale. The first step in biohermal development, then, must have been sediment stabilization that could have been followed by accumulation of more diverse organisms.

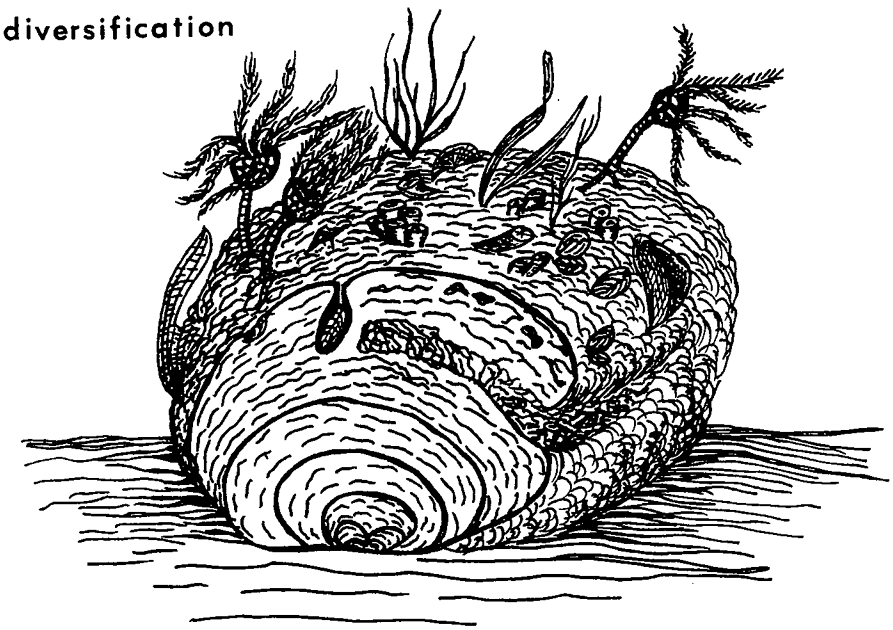
The mounds have a core or lowermost layer that consists of algal material, primarily the blue-green, stromatolitic alga, *Ottonosia.* Comparison with studies of modern environments (Ginsburg and Lowenstam, 1958; Laporte, 1968; Neuman and others, 1970) indicates that stromatolitic algae can form a tough, leathery coating that stabilizes the sediment surface by growing upward and incorporating surface sediments into a mat. Thus, the first phase of mound development can be described as initiation and stabilization of the substrate by blue-green algae (fig. 6).

During the second or diversification phase of mound development the core was generally overlain by a crustlike layer of encrusting or fenestrate bryozoans and encrusting red algae, including *Archaeolithophyllum lamellosum.* These organisms further stabilized and prepared the substrate for habitation by other organisms, including rugose and tabulate corals. Corals require a firm base for initial attachment, but as colonies or individuals grow, they can obtain support by sink-

STAGE 1: stabilization & initiation



STAGE 2: diversification



STAGE 3: domination & termination

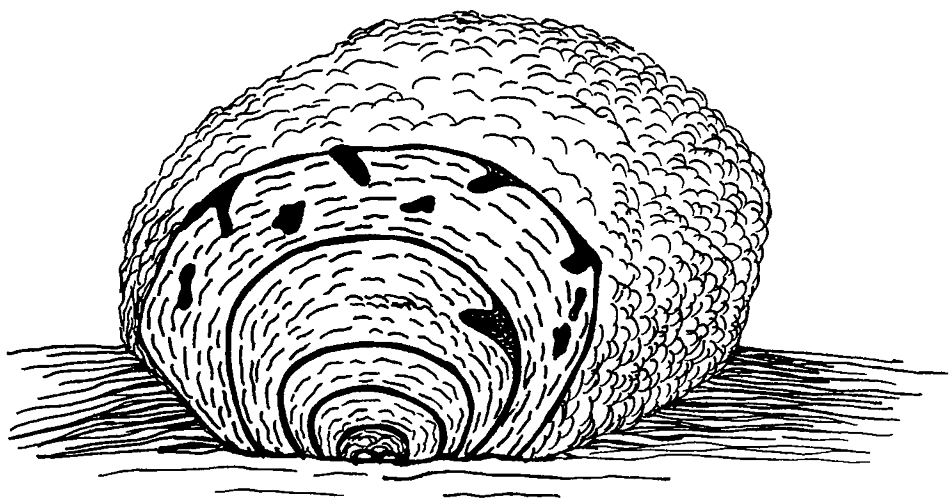


Figure 6. Diagrammatic representation of the three phases of mound development: initiation, diversification, and termination.

ing into the soft algal mud. Debris of bivalves, brachiopods, and pelmatozoans commonly accumulates in irregularities on the bryozoan or algal crust. Thus, above the stromatolitic algae in the Morrowan bioherms, a diverse assemblage of accessory organisms appears (fig. 6). In a favorable environment, it appears that these accumulations of algae and bryozoans with accessory organisms could have flourished and developed relatively large bioherms that may have had little relief above the sediment surface. However, exposures in the upper mounding interval indicate that at least 3.5 feet of relief occurred in the Morrowan bioherms as successive layers were wrapped around the central cores in a "jelly-roll" fashion (fig. 5). This would not have been possible if the structures had been exposed only a few inches above the surrounding substrate.

The final phase or termination of mound development occurred when conditions no longer favored growth of organisms associated with the mounds (fig. 6). This could have occurred for a variety of reasons. Examination of the lithic succession suggests two possible explanations: (1) a sudden influx of clastic sediments, or (2) change in water level resulting either from change in sea level or upward growth of mounds toward the surface. Encrusting growth around the sides as well as the tops of the mounds indicates that the shales encasing the biohermal developments were deposited after mound growth had ceased.

Biotas associated with the shales in the upper and lower mounding intervals indicate different causes for death of the mound biotas. Gradual shallowing during mound development is indicated in the upper mounding interval by ooids and desiccation cracks in the outer mound layers. The shales surrounding these mounds contain scattered abraded marine fossils with fragments of leaves and stems. These factors indicate a shallowing pattern that finally terminated the stromatolitic algal growth of the upper mounding interval.

The dark shales surrounding the bioherms of the lower mounding interval contain a rich, apparently untransported fenestrate and arborescent bryozoan fauna with chonetid brachiopods. There is no evidence of shallowing during mound development as is the case in the mounds of the upper interval. A great change in water depth is not necessary, nor is it indicated by the bryozoan fauna. In order to inhibit growth, it would have been necessary only to increase the influx of clastic sediments across the shallow platform area through increased rainfall or through removal of a barrier to sedimentation such as the high area that initially may have permitted mound development.

CONCLUSIONS

Investigation of the lithic-sequence structure and biotic elements associated with the Morrowan bioherms has resulted in recognition of three phases of mound development: initiation, diversification, and termination. The composition of the Morrowan bioherms of northeastern Oklahoma is significant when compared to earlier or later Paleozoic organic developments. The Morrowan bioherms are small in comparison to later Pennsylvanian and Permian buildups that reach 50 to 100 feet in height and are dominated by phylloid algae (Heckel, 1972; Heckel and Cocke, 1969). In the 4- to 10-foot-high Morrowan bioherms, this algal component was just beginning to be represented by scattered *Archaeolithophyllum*. In fact, the developmental phases represented by the Morrowan bioherms appear to be most similar to those of the Devonian stromatolitic buildups of New York and Canada, which also illustrate stages of initiation, diversification, and termination (Heckel, 1974; Jamieson, 1971; Kloven, 1974). Furthermore, preliminary results of research on modern lagoonal patch reefs suggest that three-phase development may occur within any reef or bioherm subjected to a sudden influx of fine sediments.

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STRATIGRAPHY OF MIDDLE AND UPPER BLOYD STRATA (PENNSYLVANIAN, MORROWAN) NORTHWESTERN ARKANSAS

Doy L. Zachry[1]

Abstract—The Pennsylvanian (Morrowan) Bloyd Formation of northwestern Arkansas is a diverse succession of lithic units deposited in marine and nonmarine sedimentary environments. The nonmarine Woolsey Member accumulated in coastal-plain environments laterally adjacent to an extensive belt of fluvial sedimentation represented by the middle Bloyd sandstone to the east. Marine conditions were established by transgression of the coastal plain. Continued sedimentation produced the terrigenous Dye Shale and Trace Creek Shale Members and the carbonate Kessler Limestone Member of the upper part of the formation. Dye Shale and Trace Creek Shale strata are not differentiated east of western Madison County, where the intervening Kessler Limestone Member is absent.

INTRODUCTION

The Bloyd Formation of northwestern Arkansas is a heterogeneous succession of limestone, sandstone, siltstone, and shale units that accumulated in shallow-marine and nonmarine sedimentary environments during late Morrowan time. The formation overlies the Prairie Grove Member of the Hale Formation (Morrowan) and is overlain by the sandstone and shale succession of the Atoka Formation (Atokan). All surface exposures of the unit in northwestern Arkansas accumulated on a stable structural platform (Chinn and Konig, 1973) north of the Arkoma basin and the Ouachita geosyncline. Lateral variation in the lithic composition of units within the Bloyd Formation is related to the proximity and position of terrigenous-sediment sources and to changes in relative sea level that controlled the shoreline and affected the position of nearshore sedimentary environments.

The Bloyd succession is subdivided into five formally named members in Washington County, Arkansas (fig. 1). Marine carbonate and mudstone sedimentation produced the limestone and shale succession of the basal Brentwood Limestone Member. Marine sedimentation was terminated by an extensive regression, and nonmarine shale, siltstone, and coal accumulated in a variety of flood-plain and coastal-marsh environments to form the Woolsey Member. East of Washington County (fig. 1), thick fluvial sands were deposited by south-flowing braided-stream systems to produce an extensive middle Bloyd sandstone unit. The Dye Shale, Kessler Limestone, and Trace Creek Shale Members reflect a return to normal marine conditions dominated by the deposition of fine terrigenous sediment.

The Bloyd Formation maintains a relatively constant thickness of 175 to 200 feet throughout northwestern Arkansas. Individual members, however, display varied thicknesses, with significant changes recorded over short distances.

BLOYD FORMATION

Brentwood Limestone Member

The Brentwood Limestone Member is a succession of limestone and shale units and ranges from 30 to 50 feet in thickness. Individual limestone units are composed of bioclastic grainstone and packstone and rarely exceed 5 feet in thickness. Single successions contain from 2 to 4 limestone units separated by intervals of dark-gray to black fissile shale. Calcareous sandstone beds occur within the limestone units at several localities and commonly display high-angle cross-stratification. East of Washington County, individual limestone and shale units within the member are thicker and less numerous. The shale units contain more silt and scattered thin beds of sandstone (fig. 2). The lower boundary of the Brentwood Limestone Member is gradational with the underlying Prairie Grove Member of the Hale Formation.

Woolsey Member

The Brentwood Limestone Member is overlain throughout much of Washington County by terrestrial shale and siltstone of the Woolsey Member. The Woolsey Member ranges in thickness from 10 to 40 feet (Henbest, 1962) and is extremely varied in terms of lithic succession. Thicker intervals of Woolsey strata are composed of dark-gray fissile shale (fig. 1). Plant impressions on shale partings are generally abundant. Thinner successions contain units of siltstone interbedded with shale and intervals of dark-gray shale (fig. 1). The siltstone units are thin bedded and display abundant ripple-bed forms. Dark-red stains of iron oxide partially coat the bedding surfaces.

A thin seam of subbituminous coal, the Baldwin coal, occurs persistently within the upper part of the Woolsey succession (fig. 2). The coal ranges from 1 to approximately 8 inches in thickness. The position of the coal within the upper Woolsey Member is varied. At most localities it is present directly beneath the marine caprock of the overlying Dye Shale Member. At these localities a well-developed underclay is usually present. Less commonly the coal occurs within the shale succession of the Woolsey from 4 to 6 feet beneath the caprock. These occurrences are usually thinner, and underclay is less well developed. At two localities in central Washington County the coal is overlain by an interval of plant-bearing nonmarine shale approximately 30 feet thick. The caprock of the overlying Dye Shale is absent at these localities. No regional trends that reflect consistent lateral change in thickness or lithic composition have been recorded for the Woolsey Member.

[1]Department of Geology, University of Arkansas, Fayetteville, Arkansas.

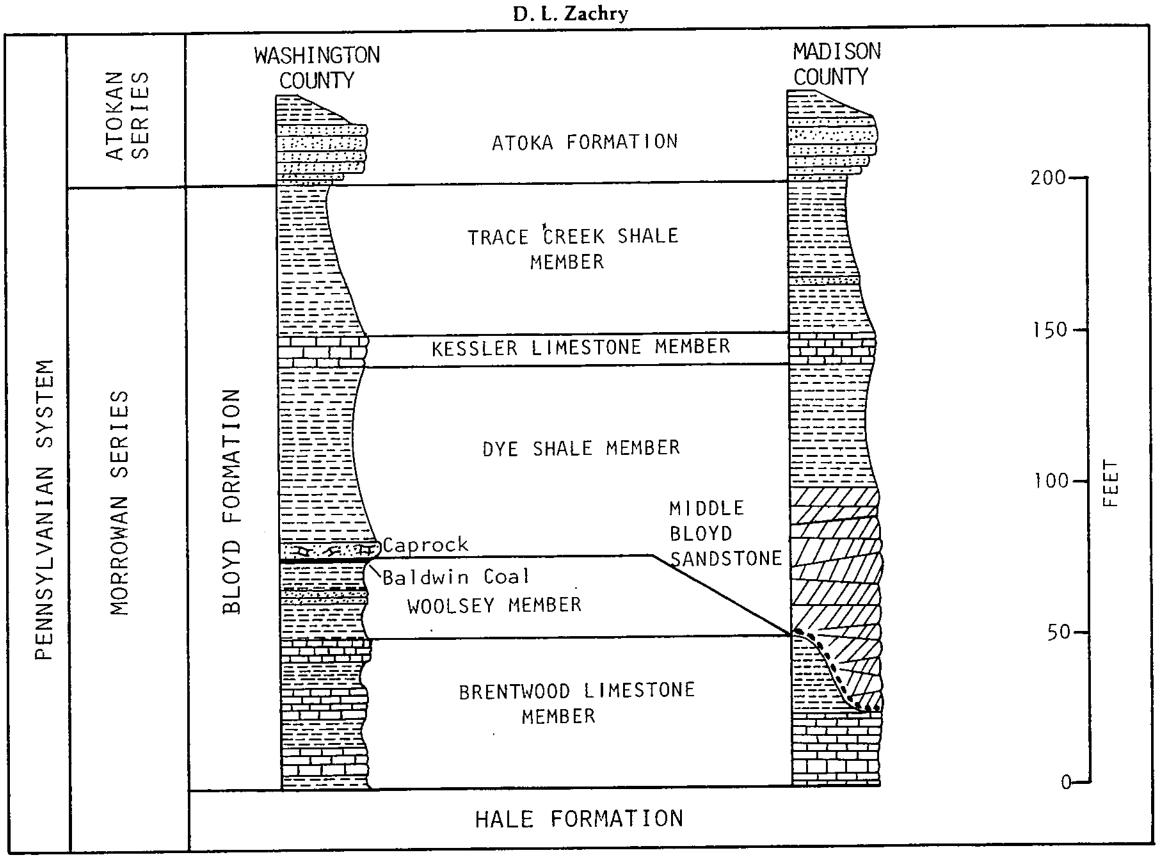

Figure 1. Columnar sections depicting lithic changes within Bloyd Formation in Washington and Madison Counties, Arkansas.

Dye Shale Member

The Dye Shale Member directly overlies the Woolsey Member throughout Washington County (fig. 1). The member is dominantly composed of dark-gray fissile shale with scattered calcareous concretions. It ranges from 60 to 90 feet in thickness. The basal unit of the member, informally designated the caprock, is a bed of calcareous sandstone and sandy limestone from 1 to 4 feet thick (fig. 3). It contains conglomeratic lenses composed of clay pebbles and scattered granules of quartz. Fossil-bearing intervals within the caprock are moderately abundant.

The caprock is relatively persistent throughout Washington County but may be absent at specific localities (fig. 4). Its absence creates difficulties in designating the upper boundary of the Woolsey Member. The caprock represents a return to marine sedimentation succeeding the interval of terrestrial Woolsey accumulation.

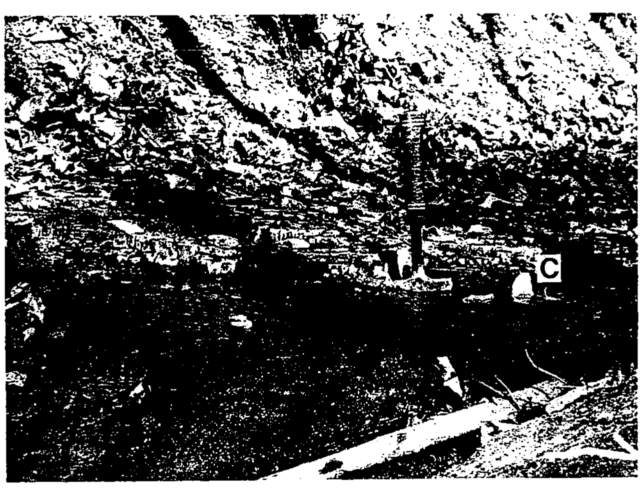

Figure 2. Baldwin coal *(C)* and underlying Woolsey shale. Washington County, Arkansas.

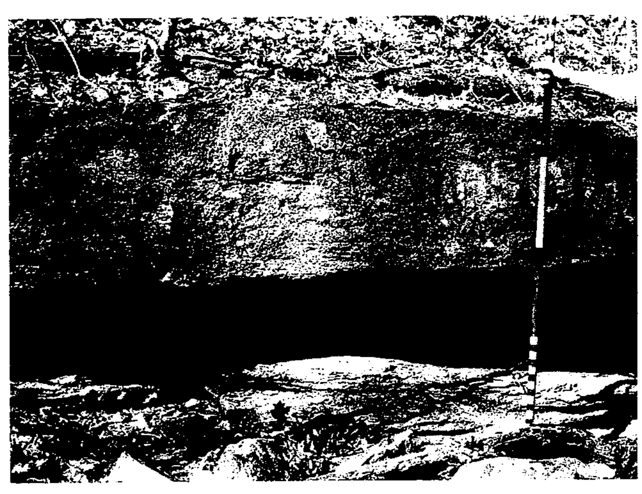

Figure 3. Caprock of Dye Shale Member and underlying Woolsey strata. Washington County, Arkansas.

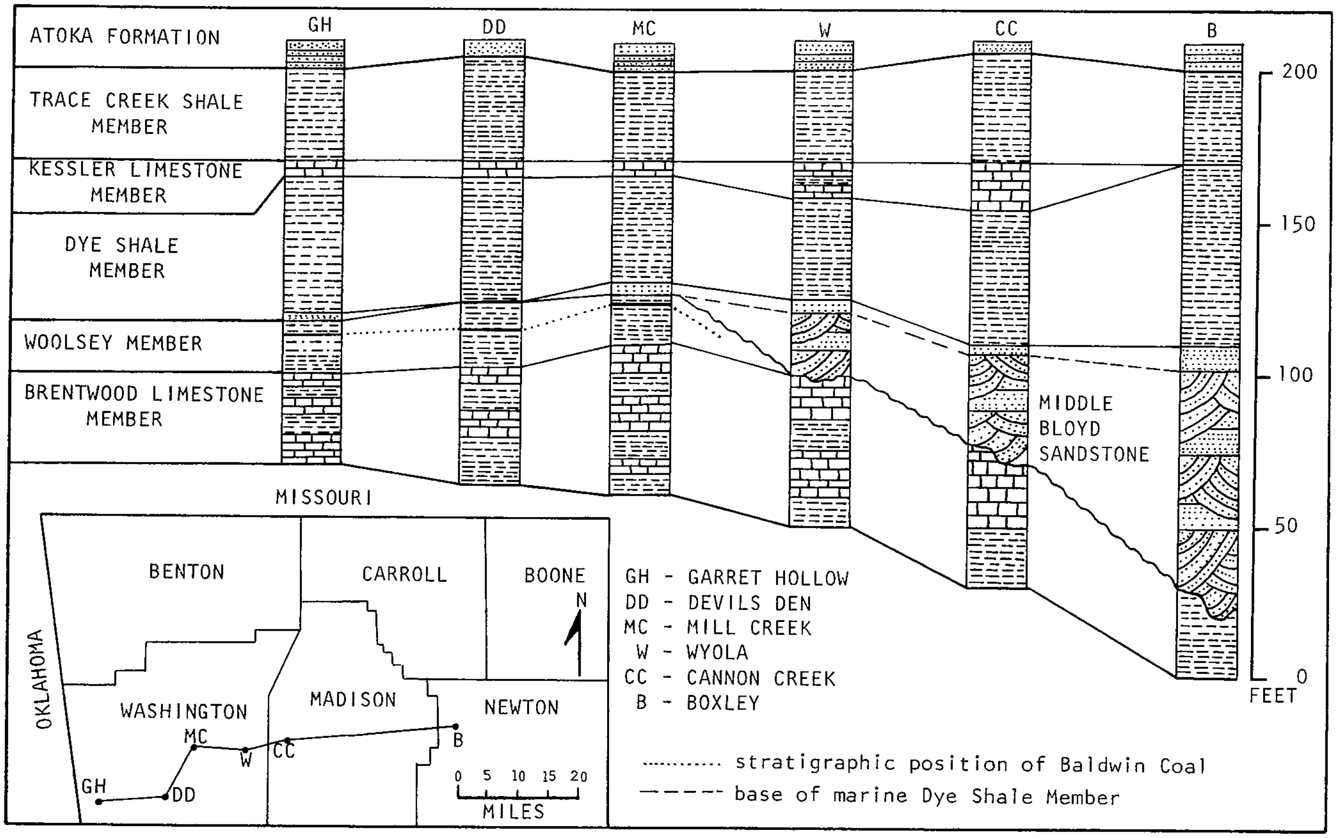

Figure 4. Regional stratigraphic section of middle Bloyd strata in northwestern Arkansas.

Middle Bloyd Sandstone

East of Washington County, the Woolsey Member is replaced by a thick succession of fine- to medium-grained sandstone. The sandstone initially occurs near the Washington-Madison County boundary and thickens eastward into Newton County (fig. 4). The sandstone unit directly overlies strata of the Brentwood Limestone Member and ranges in thickness from 10 feet at its westernmost occurrence to more than 100 feet near Boxley in Newton County (fig. 4). The lower contact of the sandstone with the Brentwood Member is an unconformity that displays up to 6 feet of erosional relief. From locality to locality it rests upon different lithic units within the underlying Brentwood (fig. 5). Evidence of Woolsey strata beneath or above the unit has not been recorded.

Sedimentological Features of Middle Bloyd Sandstone

The middle Bloyd sandstone is externally a blanket-sandstone deposit thickening eastward from 10 feet to over 100 feet through a distance of 40 miles. Internally, the unit is composed of several vertically successive facies recognized by specific grain size, stratification type, and bed-form parameters. Successions of textural and structural features occur in an ordered sequence and are vertically repetitive throughout the unit. Each ordered sequence represents changing flow conditions that occurred repeatedly as the unit was deposited. Most sections through the unit can be subdivided into distinct subunits, each of which represents a genetic entity relevant to an understanding of the depositional environments in which the unit accumulated.

Genetic sequences range from 3 to 15 feet in thickness. They are normally bounded below by a local erosion surface that displays from several inches to more than 1 foot of erosional relief. A thin interval of conglomerate composed of quartz granules and pebbles directly overlies and represents the first deposit on the erosion surface (fig. 6). The conglomerate is overlain by a single or multiple sets of tabular cross-strata. The sets range from 1 to 4 feet in thickness, with foresets that dip 25° to 31° (fig. 7). Individual sets have been traced along

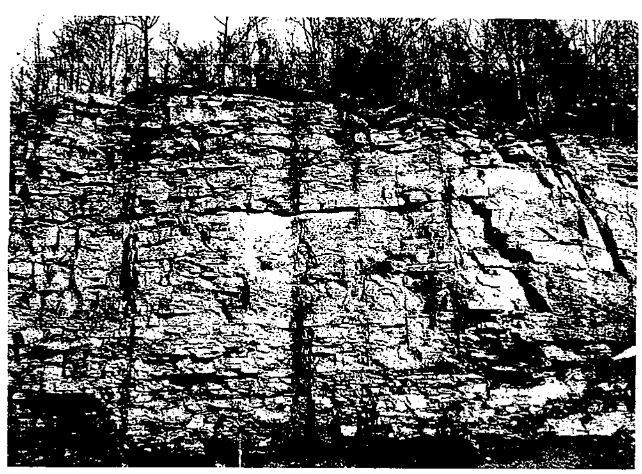

Figure 5. Middle Bloyd sandstone resting unconformably on shale of Brentwood Limestone Member. Near Boxley, Newton County, Arkansas. Sandstone bluff is 35 feet high.

the outcrop for distances of 200 feet (Glenn, 1973). At several localities foreset beds have been overturned in a down-current direction. Bottomset and topset beds are commonly not preserved in the succession. Where bottomset beds occur they are interpreted as the product of higher than normal current velocity with enough competency to carry sand in suspension as far as the toe of the foresets. This produces foresets with steep upper surfaces and tangential surfaces near the base.

Large-scale trough, cross-stratified sets occur in the succession but are less abundant than tabular sets (fig. 7). Where they are present they replace tabular sets in the genetic sequence.

Intervals of large-scale cross-stratification are overlain by thin, small-scale, trough cross-stratified beds ranging from 2 to 12 inches in thickness. Individual beds display ripple-bed forms on their upper surfaces. They are produced by ripple migration under conditions of reduced current competency. The ripple-laminated zone is bounded above by a thin interval of shale, the lower surface of which drapes over ripple-bed forms on the sandstone surface. The shale beds range from 4 to 18 inches in thickness and were deposited by currents of low velocity.

Intervals of shale and ripple-laminated sandstone are commonly truncated laterally by an overlying erosion surface. At some localities this truncation has removed parts of the underlying large-scale cross-stratified sets.

The genetic succession of an erosion surface, quartz-pebble conglomerate, large-scale cross-strata, ripple-laminated beds with ripple-bed forms, and shale is repeated several times through a single vertical section of the sandstone unit.

The average median grain size of individual genetic sequences is 1.42 ϕ unit (0.39 mm). There is a slight overall upward decrease in median grain size and a significant upward decrease in the size of the coarsest percentile. There is no uniform upward gradation in the upward fining trend. In any measured section the grain size and sorting values are somewhat cyclic, with beds of coarse, poorly sorted sediment alternating with beds of finer and better sorted sediment. Locally, finer and well-sorted sediment occurs near the top of specific genetic sequences and generally is volumetrically more important near the top of the major sandstone unit.

Repetitive genetic sequences are interrupted in several sections by poorly bedded intervals of conglomeratic sandstone. Quartz pebbles occur throughout the interval but do not form distinct beds. The basal contacts of these intervals are abrupt but do not display erosional features. They normally overlie ripple-laminated beds of the underlying genetic sequence and are bounded above by an erosion surface.

Paleocurrent measurements obtained from large-scale tabular cross-strata at several localities and measured sections throughout the outcrop belt indicate that the middle Bloyd sandstone was emplaced by unidirectional current systems flowing south and southwestward (fig. 8). Data were analyzed using a method of vector analysis described by Curray (1956). Readings from Madison County produced a vector mean of 194° and a vector magnitude of 81 percent. Boone and Carroll County data have a mean of 203° and a magnitude of 84 percent. Western Newton County readings produced a vector mean of 222° and a vector magnitude of 62 percent. The high vector-magnitude values indicate that the dip directions of foreset strata are highly oriented with low dispersion. Agreement of vector means from the three areas suggests that southwesterly flowing current systems were important in depositing the entire unit.

In measured sections at Wyola, Cannon Creek, and Boxley, the upper 2 to 6 feet of the middle Bloyd unit is composed of fine-grained, horizontally laminated marine sandstone that contains bryozoan fronds and crinozoan debris (fig. 4). The unit is overlain gradationally by shale of the Dye Shale Member.

Sedimentary Environment of Middle Bloyd Sandstone

Repetitive genetic sequences of sedimentary structures and unidirectional current patterns with low dispersion suggest that the middle Bloyd sandstone was emplaced by south-flowing braided-stream systems on a near-strand coastal plain. Each sequence reflects a period of channeling, represented by the basal erosion surface, during periods of high discharge. Subsequent deposits on the erosion surface suggest a continual reduction of current competency, depositing first a lag gravel of quartz pebbles. Further reduction in competency allowed the development of transverse bars and the formation of large-scale tabular cross-strata. Waning flow produced ripple-laminated beds and allowed the preservation of ripple-bed forms.

Figure 6. Large-scale tabular cross-stratified set overlain by erosion surface and quartz-pebble conglomerate. Individual foresets contain quartz granules. Scale is in inches.

Figure 7. Interval within middle Bloyd sandstone showing unit of tabular cross-stratified sets *(A)* overlying trough cross-stratified sets *(B)*. Uppermost tabular set is 2 feet thick. Boone County, Arkansas.

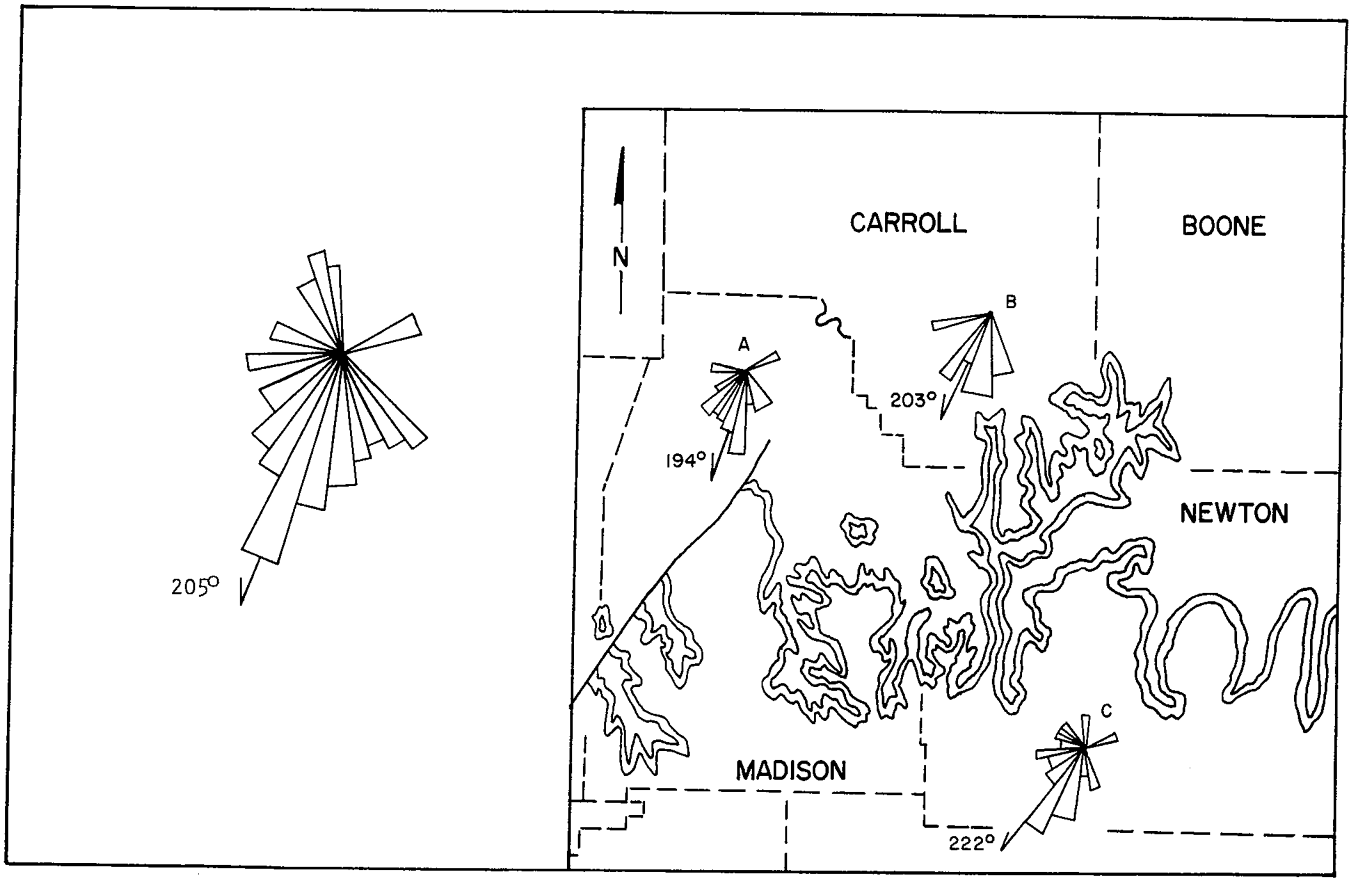

Figure 8. Outcrop belt of middle Bloyd sandstone showing paleocurrent directions (*A*, Madison County; *B*, Boone and Carroll Counties; *C*, Newton County). All measurements taken on large-scale sets of tabular cross-strata. Vector mean indicated in degrees.

Suspended sediment accumulated as flow ceased and channel fill was completed, forming shale laminae as drapes over ripple-bed forms. Reoccupancy of the area by a channel during periods of high discharge caused partial truncation of the uppermost sedimentation units and produced another sequence as flow waned. Units of conglomeratic sandstone with poorly defined interval stratification and nonerosional bases accumulated as braid bars within a system of anastomosing channels.

The unidirectional current system characterized by low dispersion suggests stream systems of low sinuosity typical of braided rivers. The near absence of shale in the succession indicates that the streams transported little suspended material important in bank stabilization and the meandering process. The high bed-load characteristics of the middle Bloyd streams contributed to bank instability and the braided pattern.

The thin interval of marine sandstone at the top of the unit marks the end of fluvial sedimentation as the coastal plain was transgressed by marine seas and the fluvial sediments were reworked and incorporated in beach deposits (fig. 4).

Stratigraphic Relationships of Middle Bloyd Strata

The middle Bloyd sandstone of Madison, Newton, Carroll, and Boone Counties (fig. 4) is assigned to the Dye Shale Member of the Bloyd Formation for stratigraphic and mapping purposes. The fluvial facies that dominates the unit accumulated contemporaneously with Woolsey strata in Washington County. The terrestrial shale, siltstone, and coal of the Woolsey were deposited in flood-plain and coastal-marsh environments west of the major belt of fluvial sedimentation. The transgression that ended nonmarine sedimentation formed the caprock of the Dye Shale Member in Washington County and the thin marine sandstone at the top of the middle Bloyd sandstone east of Washington County. Both intervals were deposited in beach and nearshore environments as the sea advanced. With continued transgression, open marine-shelf environments were established, and clay of the Dye Shale Member accumulated.

Kessler Limestone Member

The Dye Shale Member of the Bloyd Formation is overlain in Washington and western Madison Counties by the Kessler Limestone Member (fig. 9). The Kessler Member ranges in thickness from less than 1 foot in the northernmost exposure to 43 feet in the southernmost exposure. It averages approximately 8 feet throughout most of Washington County, but abrupt changes in thickness have been recorded (Williams, 1975; Fouke, 1976; Puckette, 1976). The unit has not been observed in surface exposures east of central Madison County (fig. 4).

The member occurs as a single unit of limestone and as a succession of units interbedded with shale. It is composed of oolitic and bioclastic grainstone with a minor component of wackestone. Conglomeratic zones composed of clay pebbles

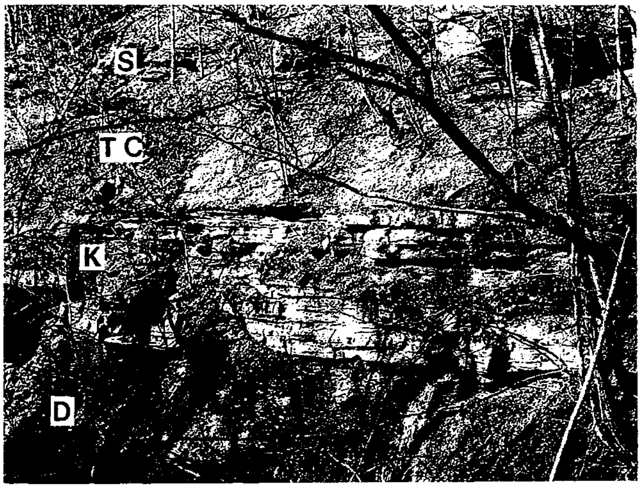

Figure 9. Dye Shale *(D)*, Kessler Limestone *(K)*, and Trace Creek Shale *(TC)* Members of Bloyd Formation, Garrett Hollow, Washington County, Arkansas. Lenticular sandstone *(S)* above Kessler Member is within Trace Creek Shale. Kessler Limestone is 8 feet thick at this locality.

derived from the underlying Dye Shale Member are common near the base. Oncoliths composed of algal-foraminiferal micrite coatings are abundant in the unit and characterize most of its exposures. Thin beds of calcareous sandstone occur within the unit at several localities. Local erosion surfaces are numerous and may laterally truncate beds producing lenticular bed geometry.

Microspar, pseudospar, ferroan dolomite, dolomite, hematite, and secondary-quartz overgrowths are common diagenetic features.

Trace Creek Shale Member

The Trace Creek Shale Member directly overlies the Kessler Limestone Member in Washington and western Madison Counties (fig. 4). It ranges from 50 to 75 feet in thickness and is composed of dark-gray fissile shale. Thin beds of sandstone occur throughout the unit, becoming thicker and more numerous near the top. A single sandstone unit (fig. 9) is present in most sections. It ranges to 8 feet in thickness and is separated from the Kessler by 2 to 10 feet of shale.

East of western Madison County (fig. 4) the Kessler is absent, and the Dye Shale and Trace Creek Shale Members have not been differentiated. At most localities, shale of the Trace Creek Member grades upward into an interbedded shale and sandstone succession assigned to the basal sandstone unit of the overlying Atoka Formation.

SUMMARY

Bloyd strata above the Brentwood Limestone Member accumulated in a variety of marine and nonmarine environments. Limestone, sandstone, siltstone, shale, and coal are represented in the succession. Nonmarine Woolsey strata accumulated in coastal marshes and flood plains in Washington County laterally adjacent to extensive fluvial sedimentation that formed the middle Bloyd sandstone west of Washington County. A major transgression of the fluvial and flood-plain environments produced the caprock of the Dye Shale Member in Washington County and a thin marine sandstone at the top of the middle Bloyd fluvial facies to the east. Open-shelf terrigenous sedimentation was established, forming the Dye Shale and Trace Creek Shale Members. The intervening Kessler Limestone Member marks a temporary reduction of terrigenous supply and the establishment of carbonate environments.

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CHESTERIAN (UPPER MISSISSIPPIAN) BIOTIC DIVERSITY IN ARKANSAS-OKLAHOMA AND ILLINOIS BASIN

Alan S. Horowitz[1]

Abstract—The most striking differences in diversity between the Chesterian of the type area in the Illinois basin and the Arkansas-Oklahoma area are seen in the cephalopods and in the ostracodes. The paucity of ammonoid cephalopods in the type Chesterian is real, but the differences in ostracode diversity are due partly to taxonomic oversplitting and partly to the lack of intensive studies in the Arkansas and Oklahoma region. Arkansas and Oklahoma were closer to the edge of the craton than was the Illinois basin in the Late Mississippian, and open oceanic waters may have affected either directly or indirectly cephalopod diversity. On the other hand, the rich diversity of suspension feeders in the Illinois basin indicates adequate primary producers in this part of the cratonic seaway.

INTRODUCTION

During the past decade I have prepared and maintained several checklists of species reported only in taxonomic studies of Chesterian fossils from the Illinois basin and from the Arkansas-Oklahoma region. The lists are in the form of punch-card decks that can be updated and easily modified, and the decks can be printed in a standard character set (upper-case letters) available at most computer centers. Tabular results of an earlier Illinois basin checklist have been published (Horowitz, 1970). Table 1 presents a current summary of nomenclatorial diversity of Chesterian biotas of the Illinois basin and the Arkansas-Oklahoma region. Each of the major taxonomic categories in table 1 are discussed separately.

STRATIGRAPHIC BOUNDARIES

The latest Chesterian in both the Illinois basin and in the Ozark area of Arkansas and Oklahoma is truncated by a regional disconformity. However, the highest Chesterian beds in both areas are approximately of the same age, i.e., basal *Adetognathus* zone of conodont workers, foraminiferal zone 18 in the Mamet scheme (Mamet and Skipp, 1971; but note that Brenckle, this guidebook, reports zone-19 foraminifers from these same beds), and late *Eumorphoceras* (E_2) zone of the cephalopod zonal scheme developed in Europe and now applied worldwide where information is available.

In the Illinois basin, the base of the Chesterian is marked by the appearance of the crinoid *Talarocrinus* Wachsmuth and Springer. This is the only consistent larger invertebrate marker currently recognized in the Illinois basin at this boundary. The boundary between zones 15 and 16 in Mamet's foraminiferal scheme lies within the lower Chesterian. The conodonts do not show any change across the Ste. Genevieve-Chesterian boundary, and ammonoid cephalopods are almost unknown from the Illinois basin.

The position of the lower Chesterian boundary in Arkansas and Oklahoma is questionable, partly because of conflicting evidence on the age of the Moorefield Formation. At least part of the Moorefield brachiopod fauna, especially that described from the Bayou Manard Member of the Moorefield in Oklahoma, has been regarded as correlative with the Mermecian Salem Limestone of the Illinois basin section. On the other hand, Furnish and Saunders (1971, fig. 1) indicated that the Moorefield of Arkansas is entirely Chesterian and is partly a facies equivalent of the Hindsville Limestone and the Batesville Sandstone. Furthermore, the base of the Moorefield of Arkansas is disconformable and overlies much older beds. The Moorefield fauna of Oklahoma, largely brachiopods, has been omitted from the compilation of nomenclatorial diversity shown in table 1. In southern Oklahoma, deposition was virtually continuous throughout the Chesterian and across the Mississippian-Pennsylvanian boundary. Late Mississippian faunas reported by Elias (1957a, 1957b, 1957c, 1958) and Chamberlain (1971) from southern Oklahoma are included in the diversity reported in table 1.

FORAMINIFERA

Few papers have described the foraminiferal faunas in the Illinois basin or in the Arkansas-Oklahoma area. The Chesterian rocks of the Illinois basin show a reasonable generic diversity; however, many of the reported genera have had only *nomina aperta* assigned to them (Browne and Pohl, 1973). Browne and Pohl (1973, p. 173) indicated that 37 genera were present in the Fraileys Shale fauna they studied, but they described only the calcareous foraminiferal genera. Of the 31 species reported from the Illinois basin, 10 are assigned to *Endothyra* Phillips and 6 to *Zellerina* Mamet.

The significantly lower diversity reported in Arkansas and Oklahoma is due almost surely to the lack of foraminiferal studies in this area. Chesterian foraminiferal diversity at the generic level in the Illinois basin is comparable to that reported by Mamet and Skipp (1971) for the Chesterian of all of North America. Nevertheless, Mamet (oral discussions) believes that the Chesterian foraminiferal faunas of the Illinois basin are impoverished in comparison to the rich faunas of the Cordilleran region of North America or to European and Russian sections of the same age.

RADIOLARIA

Nigrini and Nitecki (1968) reported from the Fayetteville Shale radiolarians that are not specifically or generically determinable. Because radiolarians are usually preserved in rocks interpreted as deep-water sediments in which sedimentation has been slow or intermittent, it is not surprising that they are

[1]Department of Geology, Indiana University, Bloomington, Indiana.

unreported in the shallow-water shelf sediments of the Illinois basin. The proximity of northwestern Arkansas to the edge of the craton and the deeper waters of the structurally active Ouachita belt makes the presence of radiolarians less surprising there.

Table 1.—Comparison of Chesterian Biotic Diversity in Arkansas-Oklahoma and in Illinois Basin

	Chesterian			
	Arkansas-Oklahoma		Illinois Basin	
	Genera	Species	Genera	Species
Animalia	311	627	353	1096
Foraminiferida	7	6	28	31
Radiolaria	present		—	—
Porifera	3	5	present	
Coelenterata	11	13	7	12
Rugosa	10	12	6	11
Conulata	1	1	1	1
Bryozoa	32	105	26	108
Ctenostomata	1	1	—	—
Cystoporata	7	15	8	15
Trepostomata	10	38	6	13
Fenestrata	9	43	9	67
Rhabdomesonida	5	8	3	13
Brachiopoda	45	124	27	63
Vermes	2	2	present	
Mollusca	101	177	57	92
Cephalopoda	47	93	4	13
Ammonoidea	23	47	1	1
Coleoidea	4	5	—	—
Nautiloidea	20	41	3	12
Gastropoda	34	29	40	60
Pelecypoda	18	53	12	17
Scaphopoda	2	2	1	2
Echinodermata	38	54	67	267
Asterozoa and Echinozoa	4	4	10	10
Blastoidea	1	3	3	62
Crinoidea	33	47	47	183
Camerata	1	2	9	56
Flexibilia	1	1	2	8
Inadunata	30	43	32	115
Incertae sedis	1	1	4	4
Edrioasteroidea	—	—	2	3
Holothuroidea	—	—	5	9
Arthropoda	31	67	81	403
Ostracoda	26	61	78	400
Trilobita	2	2	2	2
Other	3	4	1	1
Vertebrata	4	4	33	56
Scales	1	1	—	—
Dermal spines	1	1	7	10
Teeth	2	2	26	46
Crushing and grinding	1	1	13	17
Shearing or nipping	—	—	8	19
Tearing or stabbing	1	1	5	10
Conodontophorida	18	47	17	54
Tracks, trails and burrows	17	21	5	5
Incertae sedis	2	2	5	5
Plantae	65	105	39	83
Non-sporae dispersae	33	58	17	30
Cones, seeds, and sporophylls	12	16	5	5
Leaves	8	20	7	7
Stems and roots	13	22	5	18
Sporae dispersae	32	47	22	53
Totals	376	732	392	1179

PORIFERA

The clearest record of a Chesterian sponge is the description by Nitecki and Rigby (1966) of a demosponge from the Fayetteville Shale of Arkansas. The sponge taxa described by Elias (1957a) from southern Oklahoma are all borings tentatively ascribed to boring sponges. Goldstein and Hendricks (1962, p. 397, fig. 5) illustrated a siliceous shale full of sponge spicules from the Jackfork Formation of southern Oklahoma. The Jackfork is considered both Mississippian and Pennsylvanian in age by Gordon (1973), and the exact age of zones containing sponge spicules is not known. Taxonomic studies of Chesterian sponges in the Illinois basin are lacking. However, Carozzi and Roche (1968) discussed the occurrence of sponge spicules in the carbonate rocks of the type Chesterian in southwestern Illinois.

COELENTERATA

Corals are not very diverse in the Chesterian of the eastern United States. About 15 genera and 30 species have been described in the taxonomic literature. This diversity contrasts strongly with that recorded from much smaller areas in the European Lower Carboniferous. For example, Hill (1938-41) reported 23 genera and 70 species of rugose corals from Scotland. Some of these European forms are associated with reef or near-reef conditions. Rosen (1975, p. 3) suggested that high coral diversities may be related to the collision coasts of some plate-tectonic models. The high diversities in Great Britain would correspond to the active tectonics of this region during Early Carboniferous time and would be a response to the diversity of habitats present in active tectonic areas. Certainly the Illinois basin was a stable area in Late Mississippian (Chesterian) time, but the low diversity of corals in Arkansas and Oklahoma may reflect lack of suitable environments, as the area appears to have been less stable than the Illinois basin (Quinn, 1959).

Sando (1974) recorded from North America 320 Mississippian species, originally assigned to 85 genera; however, many of the genera are now regarded as synonyms, or the genera to which the species were referred are not now believed to occur in the Mississippian. Sando and others (1975) reported that 72 coral genera could be recognized in Mississippian rocks in North America, of which 55 could be used in studies of similarity and endemism. They regarded the Chesterian of the Illinois basin and the Arkansas-Oklahoma area as part of their southeastern zoogeographic province, which exhibited relatively low similarity with other provinces and a rather high endemism. I suspect the taxonomy of the southeastern province is still rather incomplete and that high endemism and low similarity to other regions may be mitigated as the faunas become better known.

With respect to the coral diversity cited in table 1, *Campophyllum gasperense* Butts and *Lithodromus veryi* Greene are considered subjective synonyms and are placed in the genus *Caninia* (Easton, 1944). *Chaetetes* Fischer de Waldheim (or a related genus) is present at several levels in both the Illinois basin and in Oklahoma but is not included in the count of coral diversity because it is unreported in the taxonomic literature; however, the genus has been cited as part of faunal associations (Gutschick, 1965; Sando and others, 1975, p. 664). Sando (1974, p. 1) regarded chaetetids as hydrozoans.

The Conulata, now generally regarded as coelenterates, are represented by a single genus and species in the Illinois basin and in the Chesterian of the Ozark region.

BRYOZOA

The bryozoans have been discussed in a separate paper in this volume. The bryozoan diversity recorded in table 1 represents those generic and specific names reported only in the taxonomic literature. The generic and specific diversity is similar in both the Illinois basin and in the Arkansas and Oklahoma region. Fenestellids, principally species assigned to the genera *Archimedes* Owen and *Fenestella* Lonsdale, dominate the bryozoan diversity, and trepostomes are somewhat more diverse in Arkansas and Oklahoma than in the Illinois basin. The specific diversity of the trepostomes in Arkansas and Oklahoma is greatly inflated by 21 species of *Tabulipora* Lee, surely a case of unwarranted species splitting. Eighteen genera are common to both areas; but the Illinois basin does not have any endemic genera, and only two well-documented genera are restricted to the Arkansas and Oklahoma Chesterian.

BRACHIOPODA

The brachiopod faunas of the Illinois basin contain only three genera not recorded in the larger fauna of Arkansas and Oklahoma, but all three genera (*Protoniella* Bell, a poorly known genus; *Pugnoides* Weller; and *Rhynchopora* King) have been reported beyond North America. Many species are probably incorrectly assigned to genera presently restricted to higher or lower beds. However, the generic diversity would not be much changed, as the species would have to be reassigned to new or to previously established genera not presently recognized in the brachiopod faunas. Of the almost 50 genera from the two Chesterian areas, 20 are recorded as cosmopolitan in Williams and others (1965), and only a few are restricted to North America. The productoid genera constitute about a third of the generic diversity in both Arkansas-Oklahoma (14 genera) and in the Illinois basin (8 genera). Modern revisions might reduce the number of specific names in the Chesterian of the two areas by half, but no reduction has been attempted in the numbers reported in table 1.

VERMES

The calcareous tubes, *Spirobis* Daudin and *Cornulitella* Howell, are generally referred to the worms, although Fisher (1962, p. W137) did not assign the cornulitids to any phylum. Both genera are found as encrusters on hard substrates, usually the shells of other invertebrates. Both genera are present in the Illinois basin, although they have not been reported in the taxonomic literature; and both are present in the Arkansas and Oklahoma Chesterian faunas.

MOLLUSCA

Scaphopods are rare fossils in the Chesterian, and only a few specimens have been reported from either the Illinois basin or from Arkansas and Oklahoma.

As table 1 shows, the generic and specific diversity of the gastropods in the Illinois basin exceeds that in the Arkansas and Oklahoma region, principally because of the publication of the monograph by Thein and Nitecki (1974). Sixteen genera are common to both areas, and the total generic diversity from both areas (58 gastropod genera) compares favorably with the total gastropod generic diversity (73 genera) reported by Batten (1973) for the entire Lower Carboniferous (=Mississippian).

The pelecypod diversity in table 1 includes species assigned to the rostroconch genus *Conocardium* Bronn. The low pelecypod diversity in the Illinois basin is almost certainly due to lack of study. A monograph on pelecypods similar to the gastropod monograph of Thein and Nitecki would probably double the presently known generic diversity and would certainly bring the specific diversity closer to that reported in Arkansas and Oklahoma, where more work has been published on the pelecypods. Only five of the pelecypod genera are reported in both the Chesterian of the Illinois basin and of Arkansas and Oklahoma. The total generic diversity of pelecypods (25 genera) can be compared with the 85 genera and 1,250 species recorded for the entire Lower Carboniferous by Paul (1941).

The cephalopods offer a striking contrast in diversity between the Illinois basin and the Ozark region. More than 150 years of collecting in the Illinois basin has yielded only two specimens of Chesterian ammonoid cephalopods (Furnish and Saunders, 1971), and the reported nautiloid diversity is rather low. In contrast, the area of Oklahoma and Arkansas has produced a rich Chesterian ammonoid and nautiloid fauna, reported by many workers. In addition, the earliest known belemnoids are from the Chesterian of Arkansas and represent at least 4 genera and 5 species. Apparently shallow nearshore epicontinental seas represented by the Chesterian series in the Illinois basin were not a preferred habitat for ammonoids or for cephalopods in general.

ECHINODERMATA

Neither edrioasteroids nor holothurians have been reported in the taxonomic literature from the Chesterian of the Ozark region. Although several taxa of holothurians have been reported from the Chesterian of the Illinois basin, Lane (1976) recently suggested that some disarticulated plates previously assigned to holothurians may be spicules embedded originally in the flexible anal sacs of some Paleozoic inadunate crinoids.

The species diversity among Chesterian blastoids is largely the result of excessive taxonomic splitting in *Pentremites* Say (Galloway and Kaska, 1957). Nevertheless, *Pentremites* shows a considerable variability in form, and Chesterian rocks probably contain a dozen or so well-defined taxa.

Although echinoid spines are a common biotic constituent of Paleozoic limestones, identifiable echinoid or asterozoan remains suitable for taxonomic studies are not very common. Consequently, the diversity shown in table 1 reflects the paucity of articulated asterozoan and echinozoan skeletons, and the modest generic diversity is probably an underestimate of the true diversity.

Currently about 300 specific names have been proposed for crinoids from the Ste. Genevievan and Chesterian rocks in the eastern half of the United States, including exposures in Arkansas, Oklahoma, and central Texas. Excluding about 25 generally recognized subjective synonyms, the remaining species are distributed as follows (number of genera is followed by number of species): Camerata (10, 65), Flexibilia (2, 8), Inadunata (55, 196), Incertae Sedis (5,5). These figures can be compared with the data for the Arkansas-Oklahoma region and the Illinois basin given in table 1.

The principal difference in the crinoid faunas of Arkansas-Oklahoma and the Illinois basin is the diversity of the camerate faunas, including the large number of species in the genera *Talarocrinus* Wachsmuth and Springer (16 species, none of which occur in Arkansas-Oklahoma) and *Pterotocrinus* Lyon and Casseday (32 species, of which 2 are reported from Arkansas-Oklahoma). In addition, the inadunate genera *Agassizocrinus* Owen and Shumard (14 species), *Aphelecrinus* Kirk (13 species), *Intermediacrinus* Sutton and Winkler (9 species), and *Zeacrinites* Troost (13 species) either are much less diverse or are absent in Arkansas and Oklahoma. On the other hand, several inadunate genera have been reported almost exclusively in the Chesterian of Arkansas and Oklahoma and may represent an endemic fauna. Most of the Chesterian crinoid diversity in the eastern United States is represented by the 67 genera and over 200 species recorded in the Illinois basin and in the Ozark region of Arkansas and Oklahoma.

ARTHROPODA

The ostracodes exhibit a significant generic diversity in the Chesterian of the Illinois basin (Cooper, 1941), but the species diversity is probably artificial because the principal taxonomic studies were conducted before the use of growth series and moult stages demonstrated population variability in fossil ostracodes. The lesser diversity of ostracodes in the Chesterian of Arkansas and Oklahoma is probably due largely to lack of intensive investigation.

Trilobites are a minor and ubiquitous element in Chesterian faunas, but their generic and specific diversity is very low. A few additional arthropods have been described from the Chesterian and include borings ascribed to barnacles (Elias, 1958). The special preservation of fossils found in some nodules or concretions in the Fayetteville Shale in the Ozark region (Nitecki and Rigby, 1966) suggests that additional otherwise rarely preserved forms will eventually be described from the Chesterian.

CONODONTOPHORIDA

Individual conodonts have long been recognized as part of a complex apparatus containing elements each of which may have been given a separate taxonomic name. Although efforts are increasing to reconstruct each individual conodont apparatus, little has been published on Chesterian associations in North America. C. B. Rexroad (oral communication) currently recognizes 15 single-element genera and 48 single-element species in the Chesterian of the Illinois basin. In unpublished work, Norby (1976) placed about half of the Chesterian single-element species from the Illinois basin into 8 multielement species and 6 multielement genera. This work also applies to the Arkansas and Oklahoma region, with comparable results. Parts of several other multielement species are also present in both areas.

TRACKS, TRAILS, AND BURROWS

Tracks, trails, and burrows are no less abundant in the Chesterian than elsewhere in the Phanerozoic, but very little formal work has been published on these structures in the Chesterian anywhere in the United States east of the Mississippi River. Consequently, only a few distinctive tracks and trails have received taxonomic names. On the other hand, Chamberlain (1971) reported a diverse assemblage of Late Mississippian tracks, trails, and burrows from the flysch deposits in southern Oklahoma. Most of the taxa are forms generally ascribed to deep waters and are usually absent in deposits of comparable age on the craton in the Ozark area and in the Illinois basin.

VERTEBRATA

Neither the Chesterian of the Arkansas-Oklahoma region nor that of the Illinois basin has yielded any articulated vertebrate skeletons, and the diversity of the vertebrate fauna is based exclusively on the remains of teeth and dermal spines of fishes. Most of the vertebrate remains were described in the last century, and very little work on these fragmentary materials has been attempted in this century. All skeletal remains are presumably those of acanthodian or chondrichthyan fishes. Dermal spines are represented in the Chesterian of the Illinois basin by the genera *Asteroptychius* M'Coy, *Cosmacanthus* Agassiz, *Ctenacanthus* Agassiz, *Glymmatacanthus* St. John and Worthen, *Gyracanthus* Agassiz, *Oracanthus* Agassiz, and *Physonemus* M'Coy. Chesterian vertebrate teeth can be assigned to 1 of 3 categories, based on the inferred function of the teeth. Shearing or nipping teeth are represented by the genera *Antliodus* Newberry and Worthen, *Chomatodus* Agassiz, *Ctenoptychius* Agassiz, *Fissodus* St. John and Worthen, *Peltodus* Newberry and Worthen, *Petalodus* Owen, *Polyrhizodus* M'Coy, and *Tanaodus* St. John and Worthen. Crushing and grinding teeth have been referred to the genera *Cochliodus* Agassiz, *Copodus* Davis, *Deltodopsis* St. John and Worthen, *Deltodus* Morris and Roberts, *Deltoptychius* Davis, *Orodus* Agassiz, *Platyxystrodus* Hay, *Poecilodus* M'Coy, *Psammodus* Agassiz, *Psephodus* Morris and Roberts, *Taeniodus* St. John and Worthen, *Vaticinodus* St. John and Worthen, and *Venustodus* St. John and Worthen. Finally, tearing or stabbing teeth are assigned to the genera *Cladodus* Agassiz, *Hybocladodus* St. John and Worthen, *Lambdodus St. John and Worthen*, *Periplectrodus* St. John and Worthen, and *Stemmatias* Hay.

The number of species represented by these remains probably is considerably exaggerated, because more than one kind of tooth can be present in the same jaw. The impoverished vertebrate diversity presently known in the Arkansas-Oklahoma region may be due to lack of study. Three of the four vertebrate genera reported from Arkansas-Oklahoma occur in the Chesterian of the Illinois basin. *Holmesella* Gunnell, reported by Elias (1956) from the Chesterian equivalents in southern Oklahoma, is possibly an acanthodian scale or dermal denticle. Scales apparently have not been reported from the Illinois basin, although small dermal denticles are commonly encountered in washed residues of fossiliferous shales.

INCERTAE SEDIS

Nomina aperta for the genera *Asterosphaera* Reitlinger, *Calcisphaera* Williamson, *Diplosphaerina* Derville, and *Rauserina* Antropov were referred to the calcareous foraminifers by Browne and Pohl (1973) but now are considered *incertae sedis* or calcareous algae by Mamet (1974) and his coworkers. These genera are placed in *incertae sedis* in table 1. The genera *Ascodictyon* Nicholson and Etheridge, *Marcusodictyon* Bassler, and *Vinella* Ulrich, which have been referred to the ctenostome bryozoans since about 1890, are regarded as *incertae sedis* in table 1.

PLANTAE

The diversity of plants is greater in the Chesterian of the Ozark and Ouachita regions because of the monographic studies of White (1937a, 1937b). Comparable studies have only recently been undertaken in the Illinois basin (Jennings, 1970). Plant diversity is somewhat augmented by the different names given to different parts of the same plant. In addition, the figures for plant diversity utilize synonymies proposed by Janssen (1940) and Lacey and Eggert (1964) for Chesterian taxa in the Illinois basin. Twelve plant-organ genera are common to both the Illinois basin and to Arkansas, and both areas contain the remains of lycopods, sphenopsids, pterophytes, and cycadophytes.

The diversity of sporae dispersae is based principally on single papers from Oklahoma (Felix and Burbridge, 1967) and from the Illinois basin (Hoffmeister and others, 1955). The Oklahoma study represents material from a rapidly deposited basinal facies rather than from a cratonic sequence.

Useful future work on Chesterian plants should include additional descriptive studies as well as a review of the relations of the various kinds of organ genera to one another. Jennings (1976) provided an example of such work in his study of *Rhodea* Presl and its associated organ genera from a locality in the Illinois basin.

DISCUSSION

The diversity given in table 1 represents nomenclatorial diversity because only a few names have been synonymized. Nomenclatorial diversity somewhat overstates taxonomic diversity, especially at the specific level. On the other hand, taxonomic revisions would have very little effect on generic diversity. Reductions in nomenclatorial diversity resulting from monographic revisions may eventually be offset by many taxa yet to be described in the Chesterian of the Illinois basin and of Arkansas and Oklahoma. Assuming that present nomenclatorial diversity represents the ultimate taxonomic diversity to be recorded in the Chesterian of each area, and that a quarter to a half of the fauna had preservable hard parts, the original diversity of life in the Chesterian in the Illinois basin was of the order of 2,000 to 4,000 species. Similar computations for Arkansas and Oklahoma yield 1,250 to 2,500 species.

In the Illinois basin, the Chesterian sequence consists of an alternating marine and nonmarine sequence that probably was deposited farther from the cratonic margin than the Arkansas-Oklahoma area and closer to sources of detrital sediments derived from the craton.

The primary producers during Chesterian time did not leave a fossil record, but they are inferred to have been plentiful because of the diversity of epifaunal suspension feeders (crinoids, blastoids, bryozoans, brachiopods, and some pelecypods). Most of the gastropods, some pelecypods, ostracodes, and trilobites are inferred to have been browsers or detritus feeders. Cephalopods are regarded as predators, and they may have fed upon soft-bodied plankton and nekton that left little fossil record. The differences in cephalopod diversity between the Illinois basin and the Arkansas-Oklahoma area may reflect the differences in abundance of suitable food. The plankton and nekton utilized by cephalopods may have been concentrated in open oceanic water masses associated with deep seas near the edges of the Late Mississippian continental shelf where upwelling of nutrient-rich waters might also have occurred. Acanthodian and chrondichthyan fishes were predators probably at the top of the food pyramid. Low-lying lands near the sea were covered by vegetation, but associated faunas are unknown.

ACKNOWLEDGMENTS

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FORAMINIFERS AND OTHER CALCAREOUS MICROFOSSILS FROM LATE CHESTERIAN (MISSISSIPPIAN) STRATA OF NORTHERN ARKANSAS

Paul Brenckle[1]

Abstract—The top of the Fayetteville Shale, the Pitkin Limestone, and the Imo Formation of northern Arkansas contain approximately 25 genera of calcareous foraminifers and approximately 10 genera of calcareous algae and *incertae sedis*. This biota correlates to the Menard through Grove Church sequence in the type Chesterian region of southern Illinois, part of the *Eumorphoceras* Zone of western Europe, part of the Serpukhovian Stage in the Donets Basin of the Soviet Union, and most or all of Mamet foraminiferal Zone 19. Microfossils of Mississippian age have been recovered at one locality in northwestern Arkansas from Pitkin clasts incorporated in the basal conglomerates of the Early Pennsylvanian Hale Formation.

INTRODUCTION

The lack of detailed taxonomic and biostratigraphic studies on Mississippian calcareous foraminifers and algae in the Midcontinent is striking. Girty (1915) alone illustrated Chesterian foraminifers from Arkansas, and taxonomic works from the type Chesterian region in the Mississippi River Valley are limited almost entirely to those by Cooper (1947), E. Zeller (1950), and D. Zeller (1953). These publications have concentrated primarily on describing members of the families Endothyridae and Eostaffellidae, which represent only part of the foraminiferal fauna present in these rocks. Browne and Pohl (1973) figured a variety of foraminifers from the Chesterian Fraileys Shale in central Kentucky.

In this study of the late Chesterian of northern Arkansas, approximately 25 genera of calcareous foraminifers and approximately 10 genera of calcareous algae and *incertae sedis* were discovered. The foraminifers belong to the families Archaediscidae, Earlandiidae, Endothyridae, Eostaffellidae, Palaeotextulariidae, Pseudoammodiscidae, Tetrataxidae, and Tuberitinidae. Although a rigorous treatment of the taxonomy is beyond the scope of this paper, comparison with other areas shows that the northern Arkansas assemblages are comparable in diversity to late Chesterian biotas from western North America (e.g., Mamet, 1975) and have close affinities to Eurasian microfossils of the same age (Brazhnikova and others, 1967).

[1]Amoco Production Co., Research Center,Tulsa, Oklahoma.

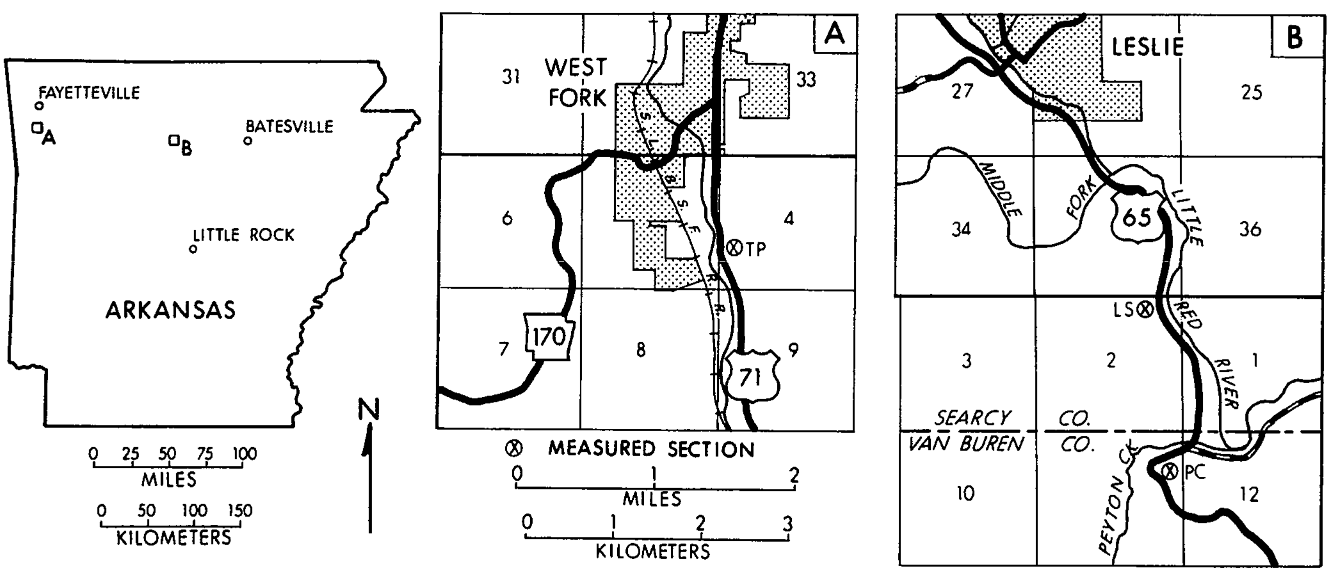

Figure 1. Locality map.

***A*, type Pitkin *(TP)* measured section, SW1/4 sec. 4, T. 14 N., R. 30 W., Washington County. Base map: Washington County General Highway Map 200-72, scale 1:62,500, Arkansas Highway Department, 1969.**

***B*, Leslie South *(LS)* measured section, NE1/4 sec. 2, T. 13 N., R. 15 W., Searcy County; and Peyton Creek *(PC)* measured section, NE1/4 sec. 11, T. 13 N., R. 15 W., Van Buren County. Base maps: Searcy County General Highway Map 200-64, scale 1:62,500, Arkansas Highway Department, 1973, and Leslie quadrangle, scale 1:24,000, U.S. Geological Survey, 1963.**

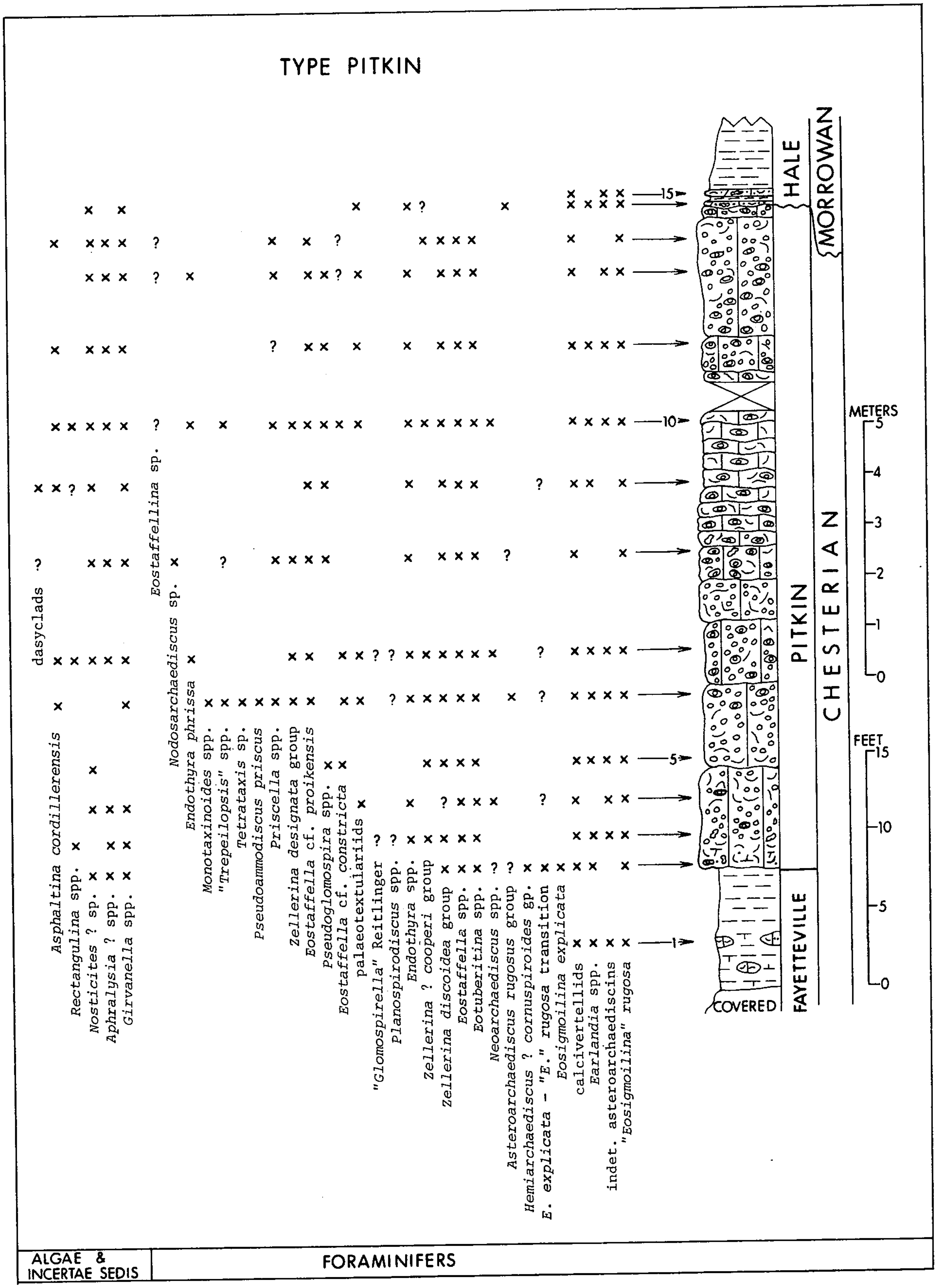

Figure 2. Distribution of microfossils and lithology of type Pitkin measured section. Explanation is on figure 5.

MEASURED SECTIONS

Data for this report came from three measured sections. In northwestern Arkansas (figs. 1A, 2), the top of the Fayetteville Shale, the Pitkin Limestone, and the basal Hale beds were measured near the type locality of the Pitkin as designated by Henbest (1962). The upper Pitkin, the Imo Formation, and the base of the Witt Springs Formation (Morrowan) were studied at the Leslie South and Peyton Creek localities in north-central Arkansas (figs. 1B, 3-5).

The type Pitkin is a medium- to thick-bedded limestone composed mostly of oolith, algal *(Girvanella)* nodule and fossil-fragment grainstones and packstones. In north-central Arkansas, the limestones of the upper Pitkin have allochems similar to those in the type area but are interbedded with calcareous shales. The Imo Formation is a heterogeneous unit composed of marine and nonmarine shales, sandstones, and siltstones with a few interbedded limestones.

TAXONOMY AND CORRELATION

Sampling intervals and fossil occurrences are presented in figures 2-5, and the microfossils are figured on plates 1-4. The most important faunal elements in the assemblages are the eosigmoilinid foraminifers *(Eosigmoilina explicata, "Eosigmoilina" rugosa)*, which are considered to be latest Mississippian indicators in other parts of North America but have heretofore not been reported from this area (Sando and others, 1969; Mamet, 1975). These foraminifers are known from Eurasia (Brady, 1876; Brazhnikova, 1964) and, thus, are useful for global correlations. Eosigmoilinids are found in the basal Hale beds at the type Pitkin section, but these occurrences, as well as those of most other taxa, are restricted to Pitkin clasts incorporated into the Pennsylvanian sediments. The "Chesterian aspect" of the fauna is also shown by the presence of *Planospirodiscus, Neoarchaediscus, Asteroarchaediscus, Hemiarchaediscus*? of the group *H.*? *cornuspiroides, Eostaffellina*?, *"Trepeilopsis,"* calcivertellids, *Monotaxinoides*, and a variety of zellerinids. Although most of these organisms range into the Pennsylvanian, they are joined at that level by *Millerella* and other Pennsylvanian forms (Mamet, 1975).

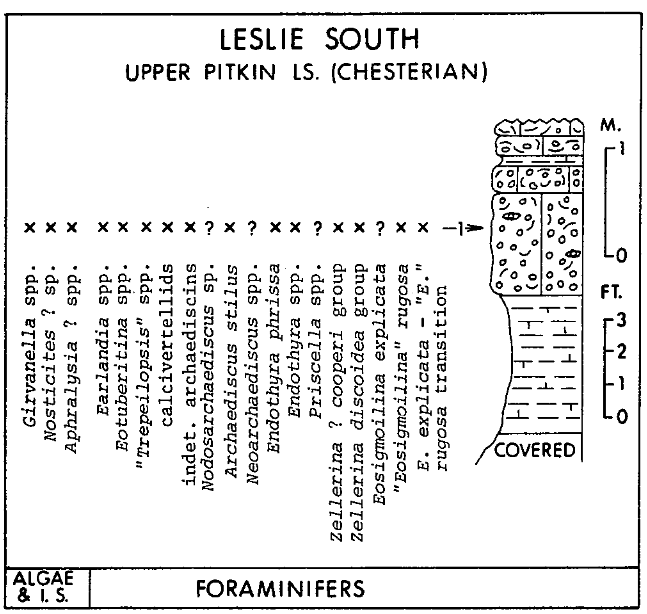

Figure 3. Distribution of microfossils and lithology of Leslie South measured section. Explanation is on figure 5.

The first appearance of the genus *Millerella* has been attributed to both Late Mississippian and Early Pennsylvanian strata. This discrepancy apparently stems from differing interpretations of the concept of the genus (Mamet, 1975). Some specimens (pl. 3, figs. 16-20), which I have questionably assigned to slightly skew-coiled *Zellerina* of the group *Z. discoidea* (Girty), seem to be approaching the coiling pattern of *Millerella* of the group *M. pressa* Thompson. Although these specimens may not be true *Millerella*, it is not unreasonable to expect that primitive millerellids exist in some late Chesterian faunas. Rather than relying on the first appearance of the genus to indicate Pennsylvanian strata, attempts should be made to define species that are characteristic of only the Pennsylvanian.

Correlation of these measured sections to the type Chesterian region of southern Illinois and to foraminiferal and conodont faunas is shown in figure 6. The Chesterian beds also correlate to part of the *Eumorphoceras* Zone (late E_1?-E_2) of western Europe, part of the Serpukhovian Stage (Zones $C_1^n a_2$-$C_1^n d_1$) in the Donets Basin of the Soviet Union and most or all of Mamet foraminiferal Zone 19. A more complete discussion of late Chesterian correlations is presented in Brenckle and others (in press).

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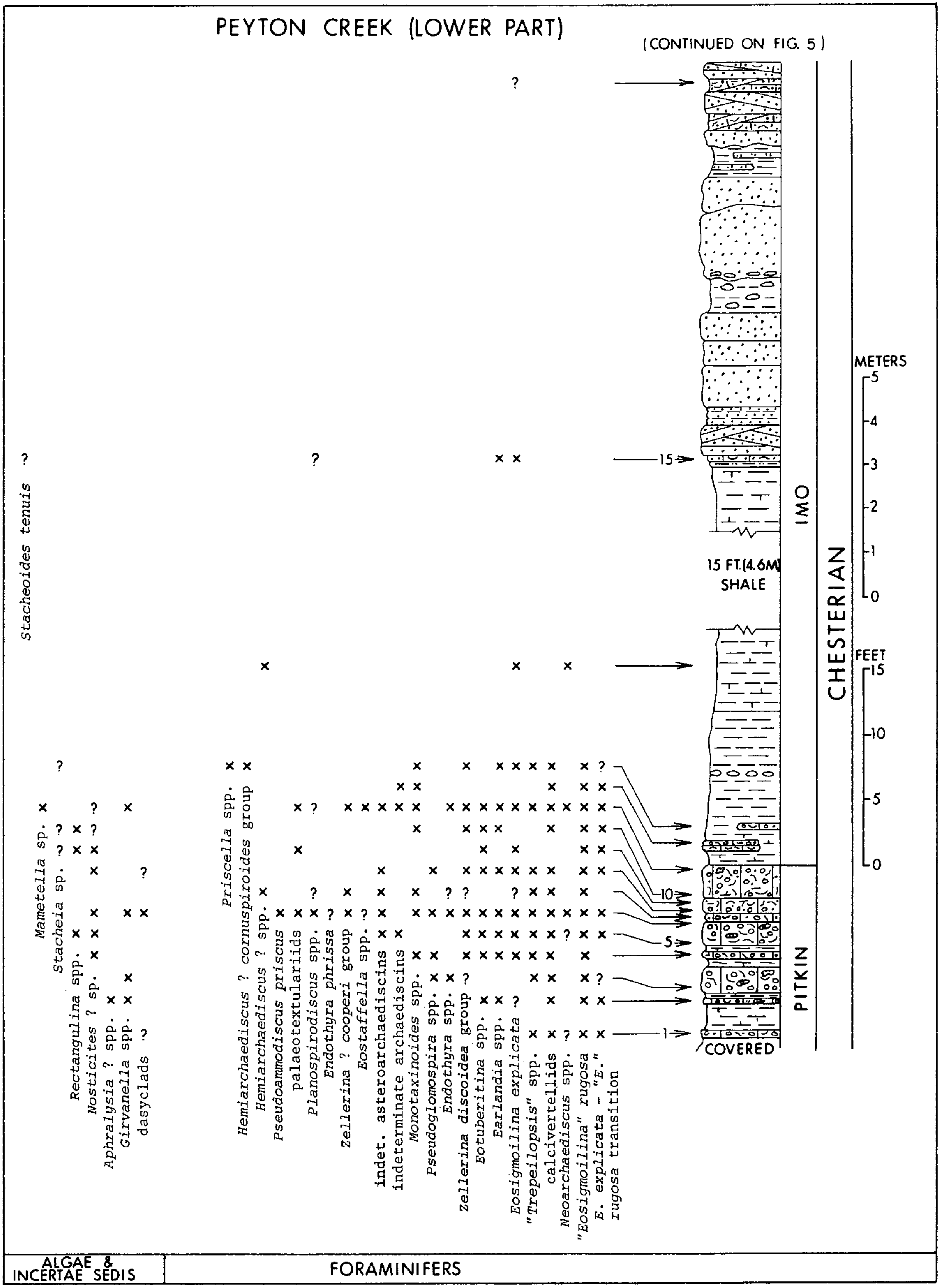

Figure 4. Distribution of microfossils and lithology of lower part of Peyton Creek measured section. Explanation is on figure 5.

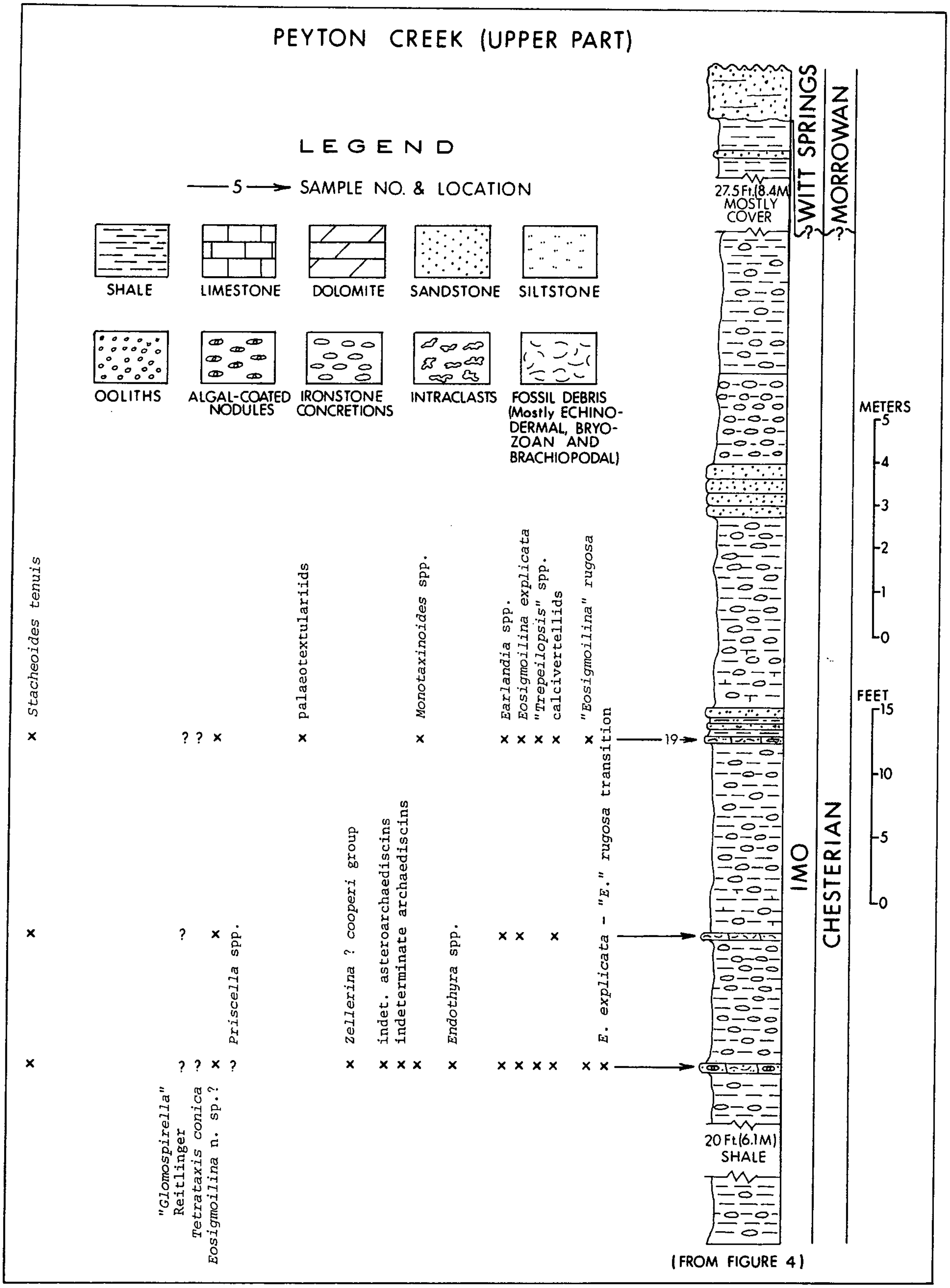

Figure 5. Distribution of microfossils and lithology of upper part of Peyton Creek measured section.

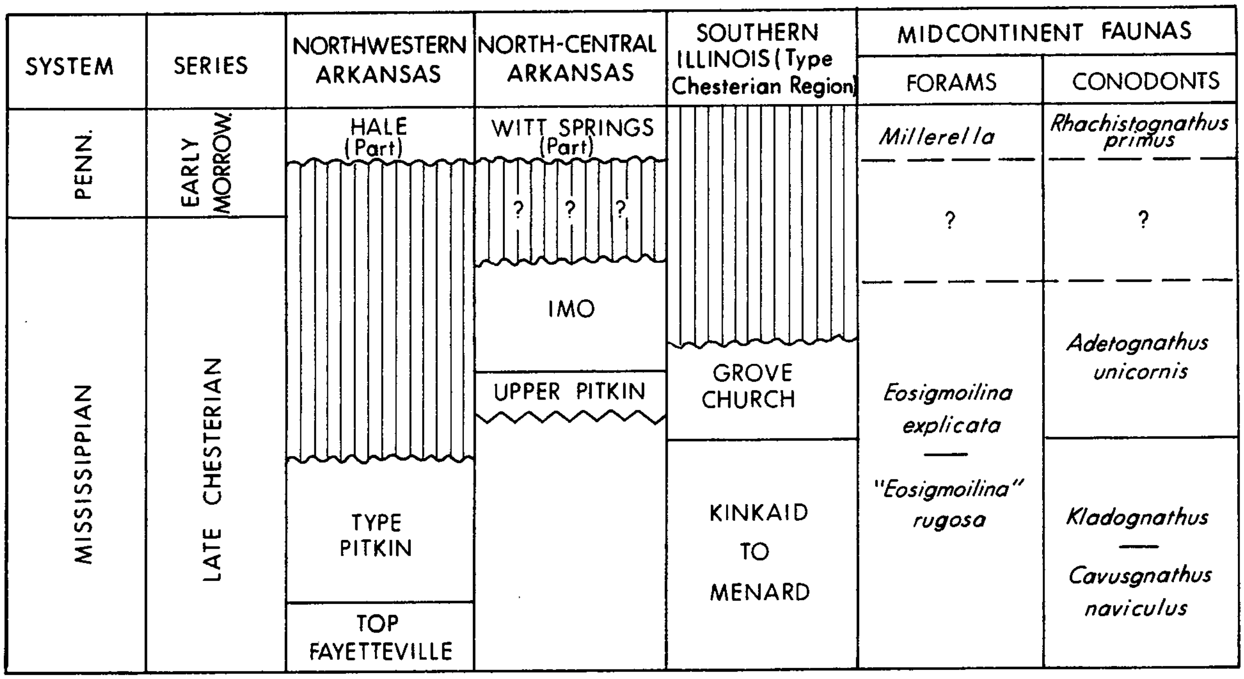

Figure 6. Correlation of Arkansas measured sections to type Chesterian region of southern Illinois, based on foraminiferal and conodont faunas. *Adetognathus unicornis* is now recognized within uppermost limestones (samples 17-19, fig. 5) of Imo Formation at Peyton Creek (H. R. Lane, 1977, personal communication).

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Plate 1

Specimens are reposited at the University of Arkansas Museum; repository numbers are in parentheses. Localities and sample numbers refer to the measured sections in figs. 2-5. Magnifications are approximate on all plates.

All figures x200.

Figs. 1-6.— *"Eosigmoilina" rugosa* Brazhnikova, 1964. *1* (UA 77-204-1), sagittal section, type Pitkin, sample 7; *2* (UA 77-204-2), sagittal section, type Pitkin, sample 5; *3* (UA 77-204-3) and *4* (UA 77-204-4), axial sections, *5* (UA 77-204-5), sagittal section, Peyton Creek, sample 6; *6* (UA 77-204-6), transverse section, type Pitkin, sample 11.

Figs. 7-17.— *Eosigmoilina explicata* Ganelina, 1956 (? = *"Trochammina" robertsoni* Brady, 1876). *7* (UA 77-204-7), axial section, *10* (UA 77-204-10) and *11* (UA 77-204-11), sagittal sections, *17* (UA 77-204-17), transverse section, Peyton Creek, sample 17; *8* (UA 77-204-8) and *9* (UA 77-204-9), sagittal sections, *14* (UA 77-204-14), axial section, *16* (UA 77-204-16), transverse section, Peyton Creek, sample 14; *12* (UA 77-204-12), sagittal section, *15* (UA 77-204-15), transverse section, Peyton Creek, sample 18; *13* (UA 77-204-13), sagittal section, type Pitkin, sample 2.

Figs. 18-22.— *Eosigmoilina explicata-"Eosigmoilina" rugosa* transition. Inner whorls closed as in *"E." rugosa*; outer whorls open as in *E. explicata*. Similar specimens have been described by Brazhnikova (1964) under the name *E. rugosa* form *tenuissima*. *18* (UA 77-204-18), *22* (UA 77-204-22), Peyton Creek, sample 17; *19* (UA 77-204-19), Leslie South, sample 1; *20* (UA 77-204-20), Peyton Creek, sample 10; *21* (UA 77-204-21), Peyton Creek, sample 11; all sagittal sections.

Figs. 23, 29, 30.— *Eosigmoilina* n. sp.? *23* (UA 77-204-23), axial section; *29* (UA 77-204-29), sagittal section; *30* (UA 77-204-30), transverse section; Peyton Creek, sample 17.

Figs. 24, 25.— *Hemiarchaediscus*? of the group *H.*? *cornuspiroides* (Brazhnikova and Vdovenko *in* Brazhnikova and others, 1967). *24* (UA 77-204-24), Peyton Creek, sample 13; *25* (UA 77-204-25), type Pitkin, sample 2; both axial sections.

Fig. 26.— *Archaediscus stilus* Grozdilova and Lebedeva *in* Dain and Grozdilova, 1953, (UA 77-204-26), axial section, Leslie South, sample 1.

Fig. 27.— *Nodosarchaediscus* sp. (UA 77-204-27), axial section, type Pitkin, sample 8.

Fig. 28.—Indeterminate archaediscid (UA 77-204-28), axial section, Peyton Creek, sample 12.

Figs. 31-33.— *Neoarchaediscus* spp. *31* (UA 77-204-31), *N. postrugosus* (Reitlinger, 1949), and *33* (UA 77-204-33), *Neoarchaediscus* sp., near-axial sections, sample 7; *32* (UA 77-204-32), *Neoarchaediscus incertus* (Grozdilova and Lebedeva, 1954), axial section, sample 10; all from type Pitkin.

Figs. 34?, 35, 36?, 37?— *Planospirodiscus* spp. *34* (UA 77-204-34), Peyton Creek, sample 11; *35* (UA 77-204-35), Peyton Creek, sample 6; *36* (UA 77-204-36), type Pitkin, sample 6; *37* (UA 77-204-37), Peyton Creek, sample 15; all axial sections.

Figs. 38, 39.— *Hemiarchaediscus*? spp. *38* (UA 77-204-38), axial section, sample 7; *39* (UA 77-204-39), near-sagittal section, sample 14; both from Peyton Creek. Specimens assigned to *Hemiarchaediscus*? differ from *Archaediscus* in having a single-layered, light-colored wall and more evolute coiling.

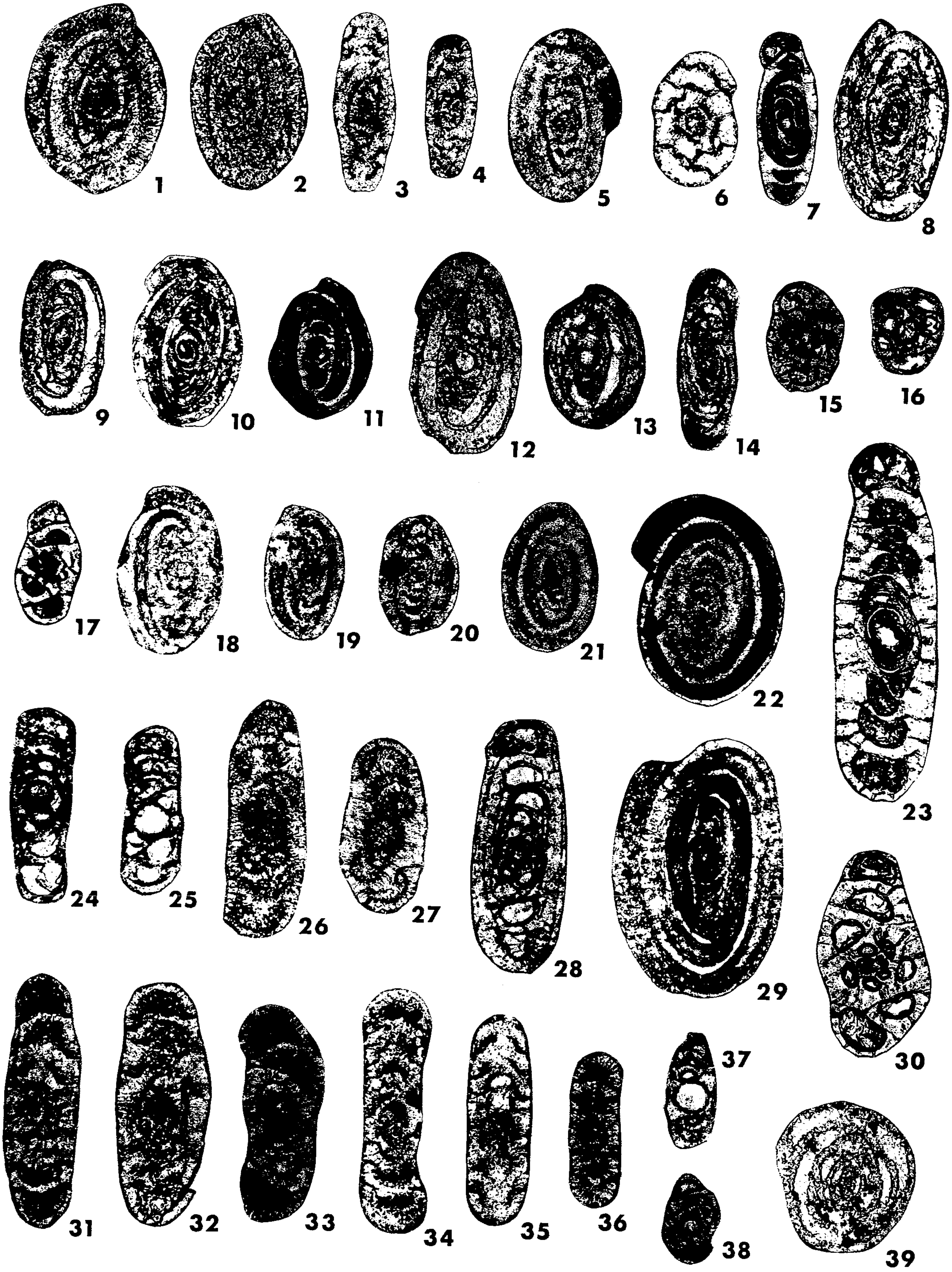
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Plate 2

Figures x100 except as noted.

Figs. 1-3.— *Asteroarchaediscus* of the group *A. rugosus* (Rauzer-Chernousova, 1948), x200. *1* (UA 77-204-40) and *2* (UA 77-204-41), sample 6; *3* (UA 77-204-42), sample 14; all axial sections and from type Pitkin.

Figs. 4, 5.— *Eotuberitina reitlingerae* Miklukho-Maklai, 1958. *4* (UA 77-204-43), Leslie South, sample 1; *5* (UA 77-204-44), type Pitkin, sample 6.

Figs. 6-10.— *Monotaxinoides* spp. *6* (UA 77-204-45), near-axial section, sample 10; *7* (UA 77-204-46), near-axial section, sample 6; *8* (UA 77-204-47), near-sagittal section, sample 19; *9* (UA 77-204-48), near-sagittal section, sample 13; *10* (UA 77-204-49), diagonal section, sample 11; all from Peyton Creek.

Figs. 11-15.— *Earlandia* spp. *11* (UA 77-204-50) and *15* (UA 77-204-54), *Earlandia* of the group *E. elegans* (Rauzer-Chernousova, 1937), Peyton Creek, sample 18; *12* (UA 77-204-51), *Earlandia* of the group *E. minima* (Birina, 1948), Peyton Creek, sample 19; *13* (UA 77-204-52), *Earlandia* of the group *E. minima* (Birina, 1948), type Pitkin, sample 1; *14* (UA 77-204-53), x50, *Earlandia* of the group *E. moderata* (Malakhova, 1954), type Pitkin, sample 6; all longitudinal sections.

Figs. 16-18, 23, 24.—Calcivertellids. *16* (UA 77-204-55), specimen encrusting *"E." rugosa*, and *24* (UA 77-204-63), type Pitkin, sample 10; *17* (UA 77-204-56), type Pitkin, sample 6; *18* (UA 77-204-57), Peyton Creek, sample 11; *23* (UA 77-204-62), Peyton Creek, sample 6.

Figs. 19-22.— *Pseudoammodiscus priscus* (Rauzer-Chernousova, 1948). *19* (UA 77-204-58), axial section, *20* (UA 77-204-59), near-sagittal section, *21* (UA 77-204-60), diagonal section, type Pitkin, sample 6; *22* (UA 77-204-61), axial section, Peyton Creek, sample 6.

Figs. 25, 31, 32.—Palaeotextulariids. *25* (UA 77-204-64), *Palaeotextularia*? sp., diagonal-longitudinal section, and *32* (UA 77-204-71), x25, *Climacammina* sp., longitudinal section, Peyton Creek, sample 6; *31* (UA 77-204-70), x40, indeterminate palaeotextulariid, type Pitkin, sample 7.

Figs. 26?, 27?— *Tetrataxis conica* Ehrenberg, 1854, *emend.* Nestler, 1973. *26* (UA 77-204-65) and *27* (UA 77-204-66), near-axial sections, Peyton Creek, sample 17.

Fig. 28?— *"Glomospirella"* Reitlinger, 1950, (UA 77-204-67), near-sagittal section, type Pitkin, sample 7.

Figs. 29, 30.— *"Trepeilopsis"* spp. *29* (UA 77-204-68), sample 7; *30* (UA 77-204-69), sample 6; both longitudinal sections and from Peyton Creek.

Figs. 33-35.— *Pseudoglomospira* spp. *33* (UA 77-204-72) and *35* (UA 77-204-74), type Pitkin, sample 12; *34* (UA 77-204-73), Peyton Creek, sample 6.

Figs. 36, 37.— *Endothyra phrissa* (D. Zeller, 1953). *36* (UA 77-204-75), near-sagittal section, sample 12; *37* (UA 77-204-76), near-sagittal section, sample 7; both from type Pitkin.

Fig. 38.— *Endothyra* cf. *E. tantala* (D. Zeller, 1953), (UA 77-204-77), near-sagittal section, type Pitkin, sample 7.

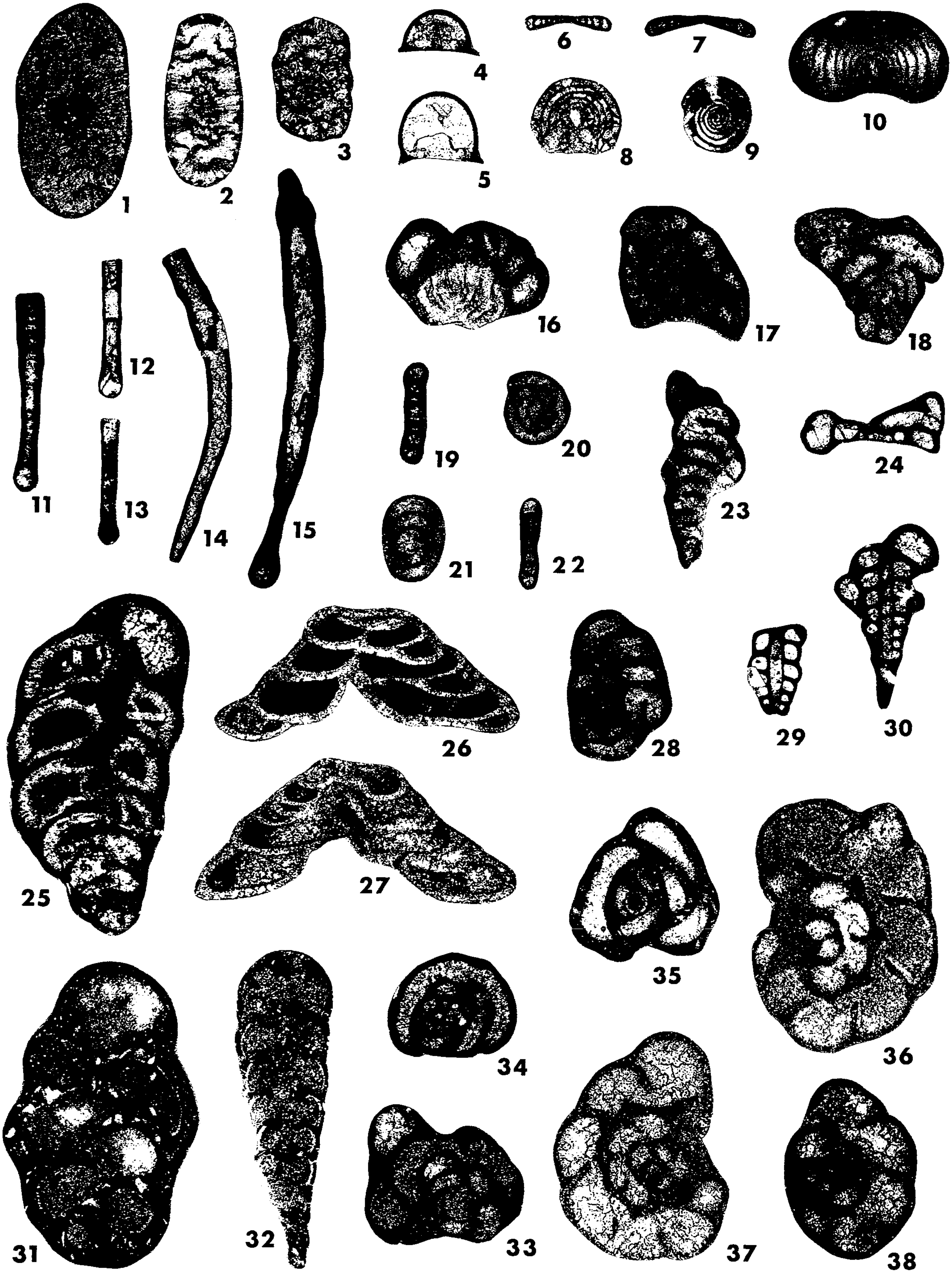
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Plate 3

Figures x100 except as noted.

Figs. 1, 2.— *Endothyra* of the group *E. bowmani* Phillips [1846], *emend.* Brady 1876. *1* (UA 77-204-78) and *2* (UA 77-204-79), sagittal sections, Peyton Creek, sample 6.

Figs. 3-5.— *Priscella* spp. *3* (UA 77-204-80) and *5* (UA 77-204-82), sample 10; *4* (UA 77-204-81), sample 13; all sagittal sections and from type Pitkin.

Figs. 6-15, 16?, 17?, 18?, 19?, 20?— *Zellerina* of the group *Z. discoidea* (Girty, 1915). *6* (UA 77-204-83), axial section, and *17* (UA 77-204-94), sagittal section, type Pitkin, sample 7; *7* (UA 77-204-84), sagittal section, Peyton Creek, sample 11; *8* (UA 77-204-85), near-axial section, and *10* (UA 77-204-87), sagittal section, Peyton Creek, sample 6; *9* (UA 77-204-86), axial section, and *12* (UA 77-204-89), sagittal section, Leslie South, sample 1; *11* (UA 77-204-88), near-axial section, type Pitkin, sample 8; *13* (UA 77-204-90), axial section, type Pitkin, sample 11; *14* (UA 77-204-91), near-axial section, *15* (UA 77-204-92), *16* (UA 77-204-93), *18* (UA 77-204-95), *19* (UA 77-204-96), *20* (UA 77-204-97), axial sections, type Pitkin, sample 2.

Figs. 21-27.— *Zellerina*? of the group *Z.*? *cooperi* (D. Zeller, 1953). *21* (UA 77-204-98), near-axial section, and *22* (UA 77-204-99), sagittal section, Leslie South, sample 1, *23* (UA 77-204-100), axial section, Peyton Creek, sample 11; *24* (UA 77-204-101), axial section, sample 7; *25* (UA 77-204-102), axial section, sample 5; *26* (UA 77-204-103), axial section, and *27* (UA 77-204-104), sagittal section, sample 10; figs. 24-27 from type Pitkin.

Figs. 28-30.— *Zellerina* of the group *Z. designata* (D. Zeller, 1953). *28* (UA 77-204-105), sagittal section, and *30* (UA 77-204-107), axial section , sample 8; *29* (UA 77-204-106), axial section, sample 6; all from type Pitkin.

Figs. 31, 32.— *Eostaffella* cf. *E. constricta* Ganelina, 1951. *31* (UA 77-204-108), sample 6; *32* (UA 77-204-109), sample 10; both axial sections and from type Pitkin.

Fig. 33.— *Eostaffellina*? sp. (UA 77-204-110), axial section, type Pitkin, sample 12.

Figs. 34-40.— *Eostaffella* cf. *E. proikensis* Rauzer-Chernousova, 1948. *34* (UA 77-204-111), x80, sample 8; *35* (UA 77-204-112), sample 10; *36* (UA 77-204-113), sample 11; *37* (UA 77-204-114), *39* (UA 77-204-116), *40* (UA 77-204-117), sample 6; *38* (UA 77-204-115), sample 12; all axial sections and from type Pitkin.

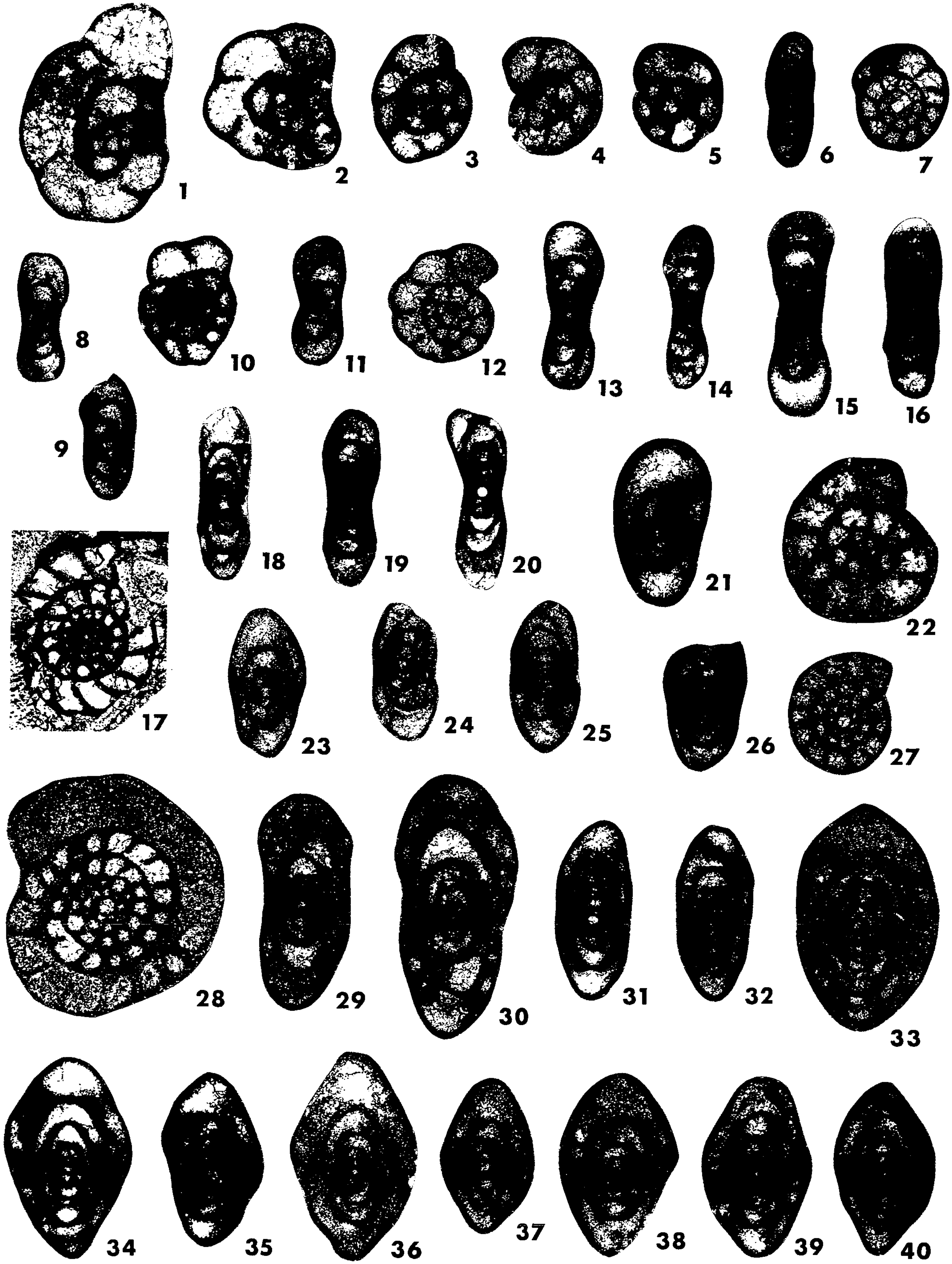
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Plate 4

Figs. 1-3.— *Eostaffella* spp., x100. *1* (UA 77-204-118) and *3* (UA 77-204-120), sample 6; *2* (UA 77-204-119), sample 9; all sagittal sections and from type Pitkin.

Figs. 4, 5.— *Girvanella* spp., x100. *4* (UA 77-204-121), *Girvanella wetheredii* Chapman, 1908, type Pitkin, sample 12; *5* (UA 77-204-122), *Girvanella staminea* Garwood, 1921, Peyton Creek, sample 6.

Figs. 6, 10, 11.— *Nostocites*? sp. (see Rich, 1974). *6* (UA 77-204-123), x65, Peyton Creek, sample 4; *10* (UA 77-204-127), x100, type Pitkin, sample 10; *11* (UA 77-204-128), x50, *Eotuberitina reitlingerae* encrusting surface, type Pitkin, sample 4.

Fig. 7.— *Mametella* sp. (UA 77-204-124), x75, Peyton Creek, sample 11.

Fig. 8?— *Stacheia* sp. (UA 77-204-125), x100, Peyton Creek, sample 10.

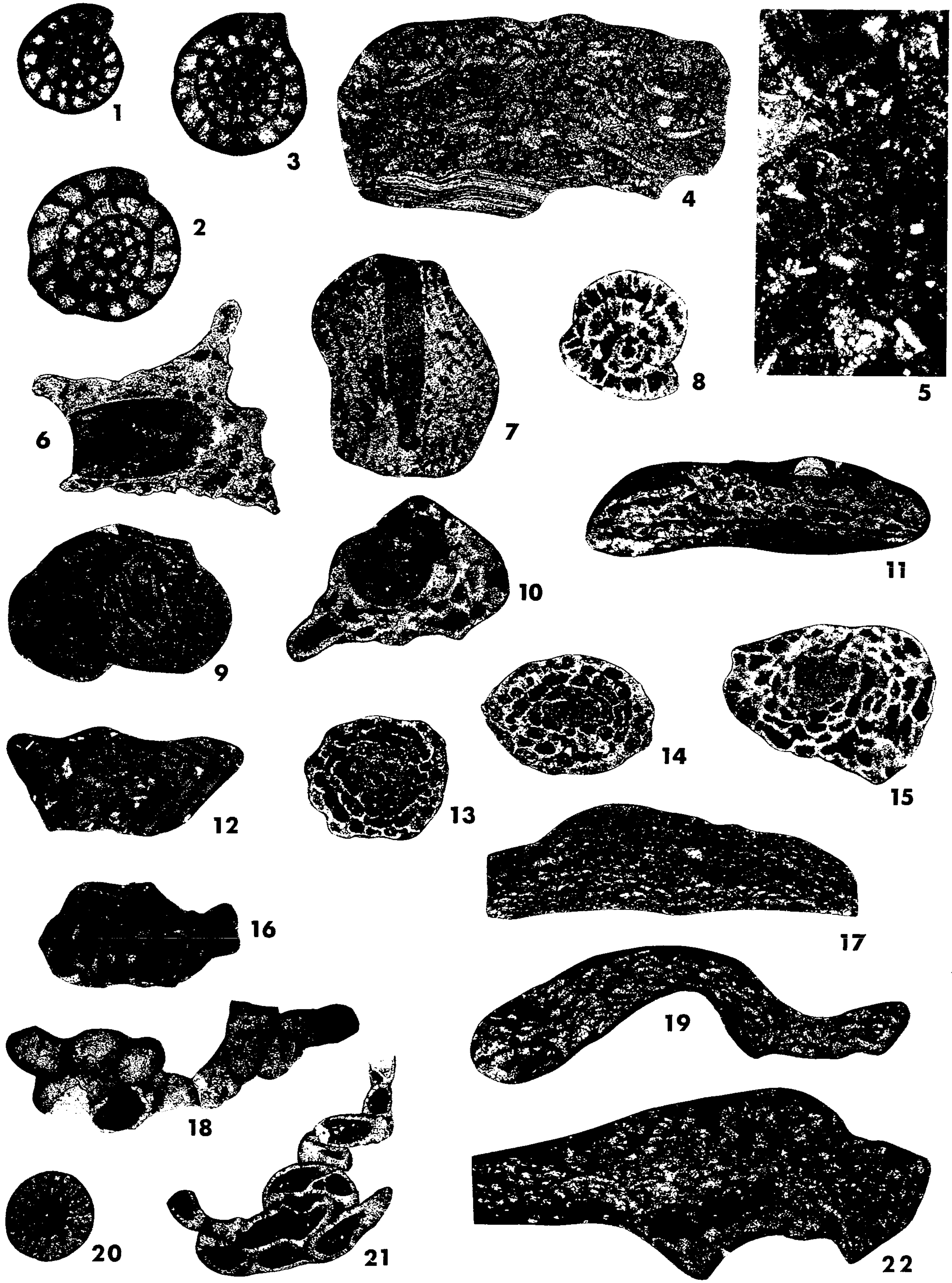
Figs. 9, 12, 16.— *Rectangulina* spp., x50. *9* (UA 77-204-126) and *16* (UA 77-204-133), type Pitkin, sample 7; *12* (UA 77-204-129), Peyton Creek, sample 5.

Figs. 13-15.— *Stacheoides tenuis* Petryk and Mamet, 1972, x100. *13* (UA 77-204-130), *14* (UA 77-204-131), *15* (UA 77-204-132), Peyton Creek, sample 17.

Figs. 17, 19, 22.— *Aphralysia*? spp. *17* (UA 77-204-134), x100, type Pitkin, sample 2; *19* (UA 77-204-136), sample 7, and *22* (UA 77-204-139), sample 8, x50, type Pitkin.

Figs. 18, 21.— *Asphaltina cordillerensis* Mamet *in* Petryk and Mamet, 1972. *18* (UA 77-204-135), x25, and *21* (UA 77-204-138), x20, type Pitkin, sample 10.

Fig. 20.—Dasyclad alga (UA 77-204-137), nanoporid?, x160, Peyton Creek, sample 6.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MICROFAUNA FROM CHESTERIAN (MISSISSIPPIAN) AND MORROWAN (PENNSYLVANIAN) ROCKS IN WASHINGTON COUNTY, ARKANSAS, AND ADAIR AND MUSKOGEE COUNTIES, OKLAHOMA

Doris E. Nodine-Zeller[1]

Abstract—This is a report on the microfauna contained in random thin sections of rocks of Chesterian (Mississippian) and Morrowan (Pennsylvanian) age along a traverse from Evansville, Washington County, Arkansas, to Webbers Falls, Muskogee County, Oklahoma. The limestones of the Morrowan Series represent, for the most part, deposition in a shallow-marine shelf, with both high- and low-energy environments being represented. In general, the microfauna contains *Millerella, Paramillerella, Tetrataxis, "Plectogyra," Ammodiscus, Trepeilopsis, Ammovertella, Endothyranella, Archaediscus, "Eosigmoilina," Tuberatina, "Endothyra," Cuneiphycus, Eostafella, Ozawainella?, Archaeolithophyllum, Girvanella, Lyropora,* pelmatozoan (crinoid-blastoid) remains, goniatites, ophiuroids, encrusting foraminifers, bryozoans, ostracodes, conodonts, holothurian sclerites, corals, brachiopods, echinoid spines, sponges, and sponge spicules.

INTRODUCTION

This is a preliminary report on microfauna of Chesterian and Morrowan age in Arkansas and Oklahoma. The randomly oriented microfossils photographed for this report came from thin sections lent me by P. K. Sutherland, School of Geology and Geophysics, The University of Oklahoma, from a suite he had prepared for stratigraphic and petrographic studies. Locality numbers are those of Sutherland and Henry (1977, figs. 1, 3). In the same paper those authors introduce new formational nomenclature for the Morrowan Series of northeastern Oklahoma. The plates at the end of this paper are collages of the best and most representative specimens from some 400 photomicrographs processed in this study. The intent of this report is to give some idea of the multitude and diversity of the fauna and flora (algae) to be found in Chesterian (Pitkin) and Morrowan rocks in and near the type area. Because of time limitations, the measurements necessary for exact identification of species were not attempted. Detailed lithostratigraphic descriptions have not been included here because they are covered elsewhere in this guidebook.

GEOLOGICAL SETTING

Morrowan rocks of Early Pennsylvanian age were named and described by Adams and Ulrich in 1904 in Washington County, Arkansas, where they have their most complete development. They are 300-400 feet thick (Henbest, 1953) and comprise the Hale Formation below and the Bloyd Shale above. The Morrowan Series includes beds between the underlying Pitkin Limestone, of Late Mississippian age (Chesterian Series), and the sandstones of the Atoka Formation of Middle Pennsylvanian age (figs. 1, 2). These rocks have been exposed by stream erosion along a series of northeast-southwest-trending faults bordering the southwestern edge of the Ozark uplift in northeastern Oklahoma. More local, minor cross faults trend northwest-southeast throughout this area. The Morrowan Series contains sandstones, siltstones, shales, and limestones, but carbonates are the most prevalent rock type in northeastern Oklahoma (Rowland, 1970).

PURPOSE OF STUDY

The endothyrid and paramillerellid foraminifers from the Chesterian Series at its type locality in southern Illinois were described by Nodine-Zeller (1953). They include the small paramillerellas that are considered to be ancestors of the genus *Millerella*.

In working the northern boundary of the Anadarko basin in the subsurface rocks in Meade and Finney Counties, Kansas, and from Texas and Beaver Counties, Oklahoma, problems concerning the lithologic types and age boundaries between rocks of Chesterian, Morrowan, and Atokan age have been encountered. It is hoped that the Morrowan and Atokan rocks in Oklahoma and Arkansas will contain an endothyrid-fusulinid foraminiferal fauna that will help bridge the evolutionary gap between known Late Mississippian and medial Pennsylvanian forms and that these forms can be used for correlation of beds into other regions in North America. It is planned in the future to collect and study, in a more comprehensive way, the foraminiferal faunas in rocks of Morrowan and Atokan age from their type sections in Arkansas and Oklahoma.

MICROFAUNA FROM CHESTERIAN AND MORROWAN ROCKS IN ARKANSAS AND OKLAHOMA

Pitkin Limestone, Chesterian Series (Mississippian), Arkansas and Oklahoma

The Pitkin Limestone contains fine- to coarse-grained, oolitic grainstones and poorly washed micritic oolitic grainstones, with skeletal debris serving as nuclei for the ooids. Terrigenous clastics are scarce in this formation (Rowland, 1970).

Tetrataxis corona Cushman and Waters, *Archaeolithophyllum* sp., *"Plectogyra"* sp., *Paramillerella* sp.,

[1]State Geological Survey of Kansas, Lawrence Kansas.

Endothyra kleina Woodland, *"Eosigmoilina"* sp., *Endothyranella* sp., *Girvanella* sp., pelmatozoan plates, and bryozoans were found in thin sections of the Pitkin Limestone.

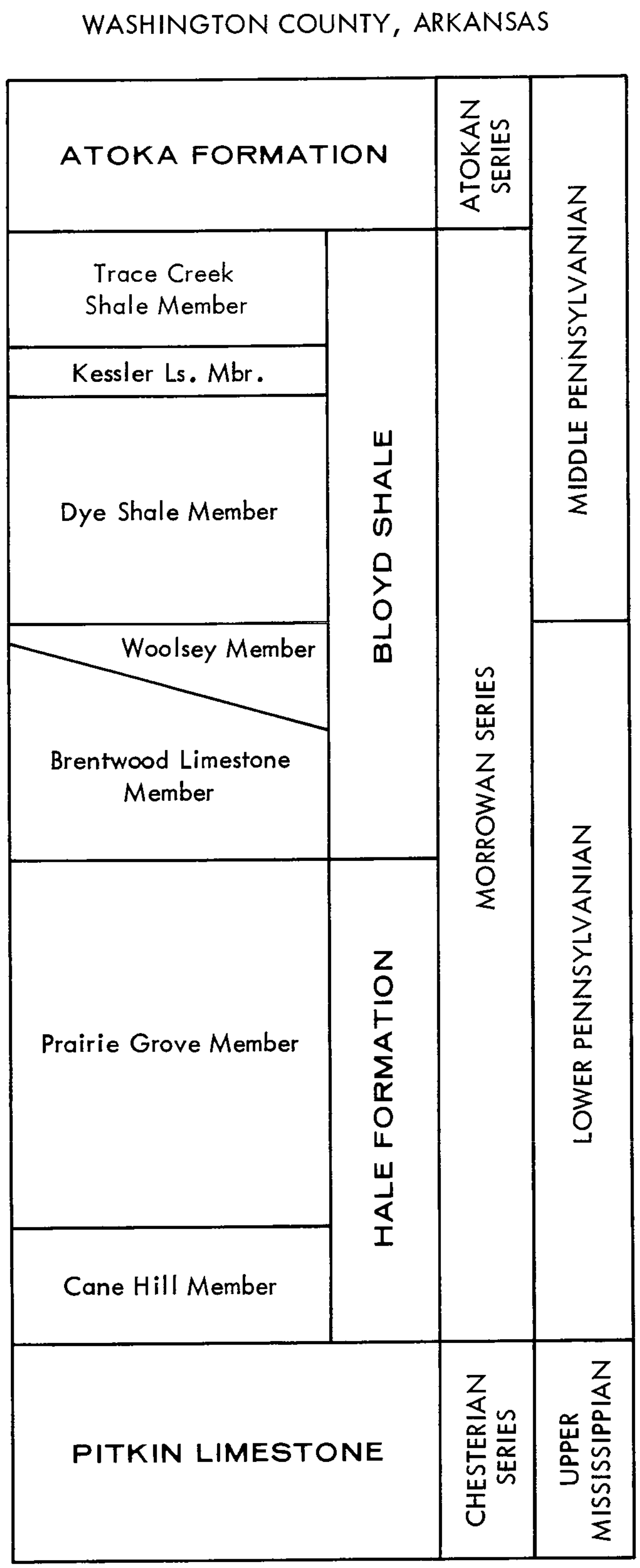

Figure 1. Stratigraphic position of Morrowan Series in western Arkansas.

Lower Morrowan Rocks, Undifferentiated Double Head Mountain, Oklahoma

In a number of places, a conglomerate from a few inches to 1 foot thick lies above the contact of the Pitkin Limestone and the overlying Morrowan rocks. The conglomerate consists of pebbles and cobbles of Pitkin origin. "In section 63 a channel of sandstone occurs in the lower Morrowan, with the Pitkin missing for a length of about 50 yards" (Rowland, 1970, p. 57).

At the base of this group of rocks is a fossiliferous sandstone with angular grains, of which some exhibit oolitic coatings, individual oolites, and encrusting foraminifers. A microfauna

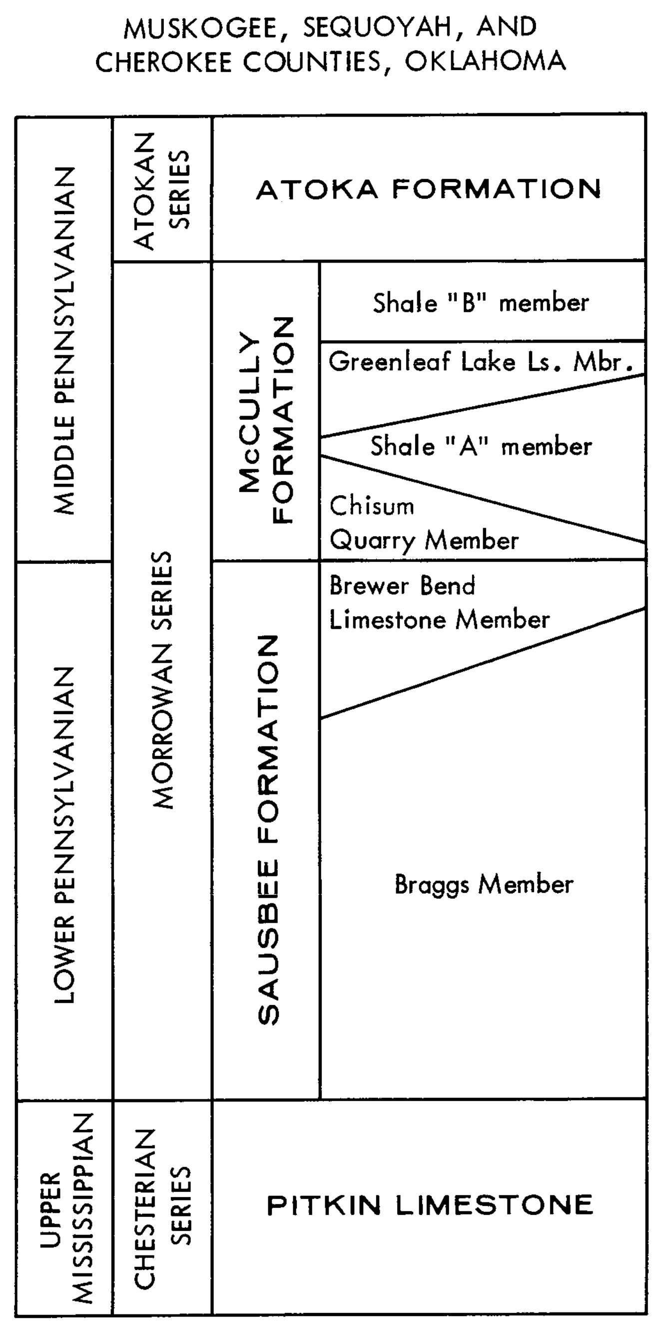

Figure 2. Stratigraphic position of Morrowan Series in northeastern Oklahoma.

including *Millerella* sp., *Paramillerella*? sp., *Ammodiscus* sp., *Tetrataxis* sp., *"Plectogyra"* sp., *Tuberatina* sp., *Endothyra kleina* Woodland, *Archaediscus* sp., *Lyropora* sp., and *Ammovertella* sp., associated with other fossil allochems, is found in sample M69-2-23. Other discrete units are a highly recrystallized skeletal limestone (M69-8-10), a fenestellid hash in a micritic algal base (M69-14), sponge beds, and an extremely fine-grained sponge-foraminiferal micrite (ooze) (M69-17).

The upper Morrowan rocks, identified as the Kessler Limestone Member of the Bloyd Shale, are mostly a fossiliferous micrite with tiny endothyrids, tournayellids, and *E. kleina* Woodland. Beds of the Trace Creek Shale Member of the Bloyd seen in thin section were bitumen-stained, organic-rich sandstones.

Cane Hill Member of Hale Formation Morrowan Series (Lower Pennsylvanian) Arkansas-Oklahoma

The Cane Hill is composed of silt, silty sandstone, and fine-grained sandstone (Henbest, 1953). No identifiable microfossils were found in thin sections from this member in Oklahoma. The thin sections (M68-2) of fossiliferous sandstones contained fragmented organic debris.

Prairie Grove Member of Hale Formation Morrowan Series (Lower Pennsylvanian) Arkansas

The Prairie Grove Member is composed largely of calcareous medium- to fine-grained sandstone (Henbest, 1953). The Prairie Grove microfauna contains *"Plectogyra"* sp., *P. tantala* Nodine-Zeller, *Paramillerella* sp., *P. pinguis* (Thompson), *Millerella* sp., and *M. pressa* Thompson. The macrofauna consists of brachiopods, corals, pelmatozoan (crinoid-blastoid) plates, bryozoans, ostracodes, echinoid spines, algae, and sponges.

Brentwood Limestone Member of Bloyd Shale Morrowan Series (Lower Pennsylvanian) Arkansas-Oklahoma

Beds making up the Brentwood Limestone Member are so variable that no description will be attempted here.

By far the richest fauna occurs in the Brentwood Member. It contains a prolific microfauna that includes *"Eosigmoilina"* sp., *Ammodiscus* sp., *Millerella* sp., *M. marblensis* Thompson, *M. advena*? Thompson, *Paramillerella* sp., *P. pinguis* (Thompson), *Tuberatina* sp., *Ammovertella* cf. *A. inversa* (Schellwein), *Tetrataxis* sp., *Endothyranella* n. sp., *Trepeilopsis* sp., *"Plectogyra"* sp., *Tournayella*? sp., *"Endothyra"* cf. *E. kleina*? Woodland, *Archaediscus* sp., *Climacammina* sp., *Eostafella* cf. *E. ovoidea* (Rauzer-Chernousova), associated with abundant fossil allochems (M68-25b). There are encrusting foraminifers on fossil debris and also clasts encrusted with foraminifers. Samples M68-16 and 17 are sponge-spicule chert containing a foraminiferal fauna.

Woolsey Member and Dye Shale Member of Bloyd Shale, Morrowan Series (Lower and Middle Pennsylvanian) Arkansas-Oklahoma

The Woolsey Member of the Bloyd Shale consists of a succession of terrestrial sediments, including the Baldwin coal bed. A "caprock" overlies this coal.

The Dye Shale Member is predominantly shaly siltstone and claystone. Thin limestone beds and calcareous zones are present locally (Henbest, 1962).

No specimens were obtained from these members. The "caprock" below the Dye Shale Member is a highly recrystallized, oil-stained limestone, with fragments of bryozoans, blastoids, cephalopods, crinoids, brachiopods, and a very small species of *"Endothyra."*

Kessler Limestone Member of Bloyd Shale Morrowan Series (Middle Pennsylvanian) Arkansas-Oklahoma

A microfauna consisting of *"Plectogyra"* sp., *Tuberatina* sp., *Tetrataxis* sp., *Millerella* sp., *Endothyranella* sp., *Paramillerella* sp., *"Endothyra"* sp., *Lyropora* sp., and *Girvanella* sp. is found in the Kessler Limestone Member. A significant occurrence of pyritized endothyrids was encountered in this member (sample M68-27) in Oklahoma. Similar pyritized endothyrids are found in mineralized Mississippian rocks in the Tri-State lead and zinc fields (Nodine-Zeller and Thompson, 1977). Girvanellid or *Osagia* algal balls with fossil-fragment centers (commonly gastropods) occur here in a coarse-grained micritic base with *Tetrataxis* and *Trepeilopsis.*

Trace Creek Shale Member of Bloyd Shale Morrowan Series (Middle Pennsylvanian) Arkansas

Thin sections from this member contained oil-stained fossiliferous sandstones.

Braggs Member of Sausbee Formation Morrowan Series (Lower Pennsylvanian) Oklahoma

The Pitkin Limestone (Mississippian), already described, underlies the Sausbee Formation in Oklahoma.

The Braggs is largely an algal micrite with skeletal debris and mixed oolites; it includes intervals of sandstone containing subrounded grains, oolites, and mixed (reworked) oolites. In some places it is oil stained.

This member contains a prolific microfauna. It consists of *Millerella* sp., *M. extensus* King, *M. marblensis* Thompson, *Paramillerella* sp., *P. pinguis* (Thompson), *"Plectogyra"* sp., *Endothyra* sp., *E. kleina* Woodland, *Bradyina* sp., *Tetrataxis corona* Cushman and Waters, *Tetrataxis* sp., *Ammodiscus* sp., *Archaeolithophyllum* sp., *Lyropora* sp., *Ammovertella* sp., *Climacammina* sp., *Tournayella* sp., *Tuberatina* sp., *Aulopora* sp., *Archaediscus* sp., *Cuneiphycus* sp., and other fossil allochems. A species of extremely large *"Plectogyra"* occurs in core 82-7, and an equally large species of *Millerella* in sample M26-15. *Bradyina* is found in sample M97-5b.

Brewer Bend Limestone Member of Sausbee Formation, Morrowan Series (Lower Pennsylvanian), Oklahoma

The Brewer Bend Limestone Member is an algal limestone or micrite, highly recrystallized, with algal blades and bryozoans and paramillerellids, plectogyrids, and other foraminifers. It contains a fauna of *"Plectogyra"* sp., *Tournayella* sp., *Paramillerella* sp., *Tuberatina* sp., *Archaeolithophyllum* sp., *Tetrataxis corona* Cushman and Waters, *Tetrataxis* sp., *Millerella* sp., *Globivalvulina* sp., *Polytaxis* sp., *Ammodiscus* sp., *Cuneiphycus* sp., and a number of encrusting foraminifers and algae. An extremely large species of *Millerella* is found here, also, and seems to be the same species as that in the Braggs Member below.

Chisum Quarry Member of McCully Formation Morrowan Series (Middle Pennsylvanian) Oklahoma

The foraminiferal fauna found in the Chisum Quarry Member consists of *Paramillerella* sp., *P. cooperi* (Nodine-Zeller), *"Plectogyra"* sp., *Millerella* sp., *M. pressa* Thompson, *M. extensus* King, two species of *Tetrataxis*, *Ammodiscus* sp., *Climacammina* sp., *Ammovertella* sp., *Globivalvulina* sp., *Ozawainella*? cf. *O. ciscoensis*? (Harlton), and *Tuberatina* sp. In addition, it contains *Lyropora* sp., *Archaeolithophyllum* sp., *Osagia*, *Cuneiphycus* sp., and *Girvanella*-coated fossil fragments. Pyritized endothyrids occur in core 80-19 and core 82-12 and 14.

Shale "A" Member of McCully Formation Morrowan Series (Middle Pennsylvanian) Oklahoma

This unit contains *"Plectogyra"* sp., *Millerella pressa* Thompson, *Paramillerella* sp., and prominent bladed algae, mainly *Archaeolithophyllum* sp. and *Anchicodium*(?) sp. Pyritized plectogyrids are found in core 80-27.

Greenleaf Lake Limestone Member of McCully Formation, Morrowan Series (Middle Pennsylvanian), Oklahoma

The foraminifers *"Plectogyra"* sp., *Endothyra kleina* Woodland, *Millerella* sp., *Ozawainella*? sp., *Tetrataxis* sp., *Endothyranella* cf. *E. panderi* (Moller), *Globivalvulina* sp., *Paramillerella* sp., *Lyropora* sp., and *Archaediscus* sp. are present in this member.

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——1948, Studies of American fusulinids: University of Kansas Paleontological Contributions, Protozoa, Article 5, 226 p., 52 pls.

Plate 1

All photographs are uniform in scale, as shown in fig. 21, except for fig. 2, which is shown at a reduced scale.

Fig. 1.— *Paramillerella* sp., enclosed and preserved from recrystallization in concentric oolite, vertical axial section. M70-1, Pitkin Limestone, Mississippian, Evansville Mountain, Arkansas.

Fig. 2.— *Archaeolithophyllum* sp., longitudinal section of thallus, showing cellular structure. M70-1, Pitkin Limestone, Mississippian, Evansville Mountain, Arkansas.

Fig. 3.— *"Eosigmoilina"* sp. M70-1, Pitkin Limestone, Mississippian, Evansville Mountain, Arkansas.

Fig. 4.— *Paramillerella* sp., showing secondary deposits or chomata and slightly keeled final volution. M70-1, Pitkin Limestone, Mississippian, Evansville Mountain, Arkansas.

Fig. 5.— *Endothyra kleina* Woodland, horizontal axial section, 1–1½ volutions. M70-1, Pitkin Limestone, Mississippian, Evansville Mountain, Arkansas. Elongate objects in photograph are echinoid spines.

Figs. 6, 7.— *Paramillerella* sp., approximate vertical axial sections, one with keeled final volution and one with rounded periphery. M70-1, Pitkin Limestone, Mississippian, Evansville Mountain, Arkansas.

Fig. 8.— *Endothyranella*? sp., with final chambers broken off. M70-1, Pitkin Limestone, Evansville Mountain, Arkansas.

Fig. 9.— *"Plectogyra"* sp. M69-19, Brentwood Limestone Member, Bloyd Shale, Double Head Mountain, Oklahoma.

Figs. 10-13.— *Millerella* sp., vertical axial sections. M69-19, Brentwood Limestone Member, Bloyd Shale, Double Head Mountain, Oklahoma.

Fig. 14.— *Paramillerella*? sp., vertical axial section, or juvenile form? M69-19, Brentwood Limestone Member, Bloyd Shale, Double Head Mountain, Oklahoma.

Fig. 15.— *"Plectogyra"* cf. *P. tantala* Nodine-Zeller, horizontal axial section, concentric-coated, in oolite with quartz-accretion centers (white areas). M68-6, Prairie Grove Member, Hale Formation, Muskrat Mountain, Oklahoma.

Fig. 16.— *Millerella* sp. cf. *M. pressa* Thompson, approximate vertical axial section, about 0.6 mm high, encased in radial oolite distorted by impinging recrystallization pressures. M68-10A, Prairie Grove Member, Hale Formation, Muskrat Mountain, Oklahoma.

Fig. 17.— *Paramillerella* cf.? *P. pinguis* (Thompson), vertical axial section, showing large proloculus, oolitic coating on specimen, radial oolite with quartz-accretion center, and interpenetration of grains by recrystallization. M68-6, Prairie Grove Member, Hale Formation, Muskrat Mountain, Oklahoma.

Fig. 18.— *Millerella* sp., horizontal axial section, interpenetrating grains. Almost all fossils are coated in this bed. M68-6, Prairie Grove Member, Hale Formation, Muskrat Mountain, Oklahoma.

Fig. 19.— *Millerella* cf. *M. marblensis* Thompson, well-oriented horizontal axial section, showing proloculus, juvenarium, chomata, and tunnel. M70-13b, Brentwood Limestone Member, Bloyd Shale, Evansville Mountain, Arkansas.

Fig. 20.— *Millerella* sp., vertical axial section. M70-13b, Brentwood Limestone Member, Bloyd Shale, Evansville Mountain, Arkansas.

Fig. 21.—Tiny individual sponges, still amber colored. M68-23A, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.

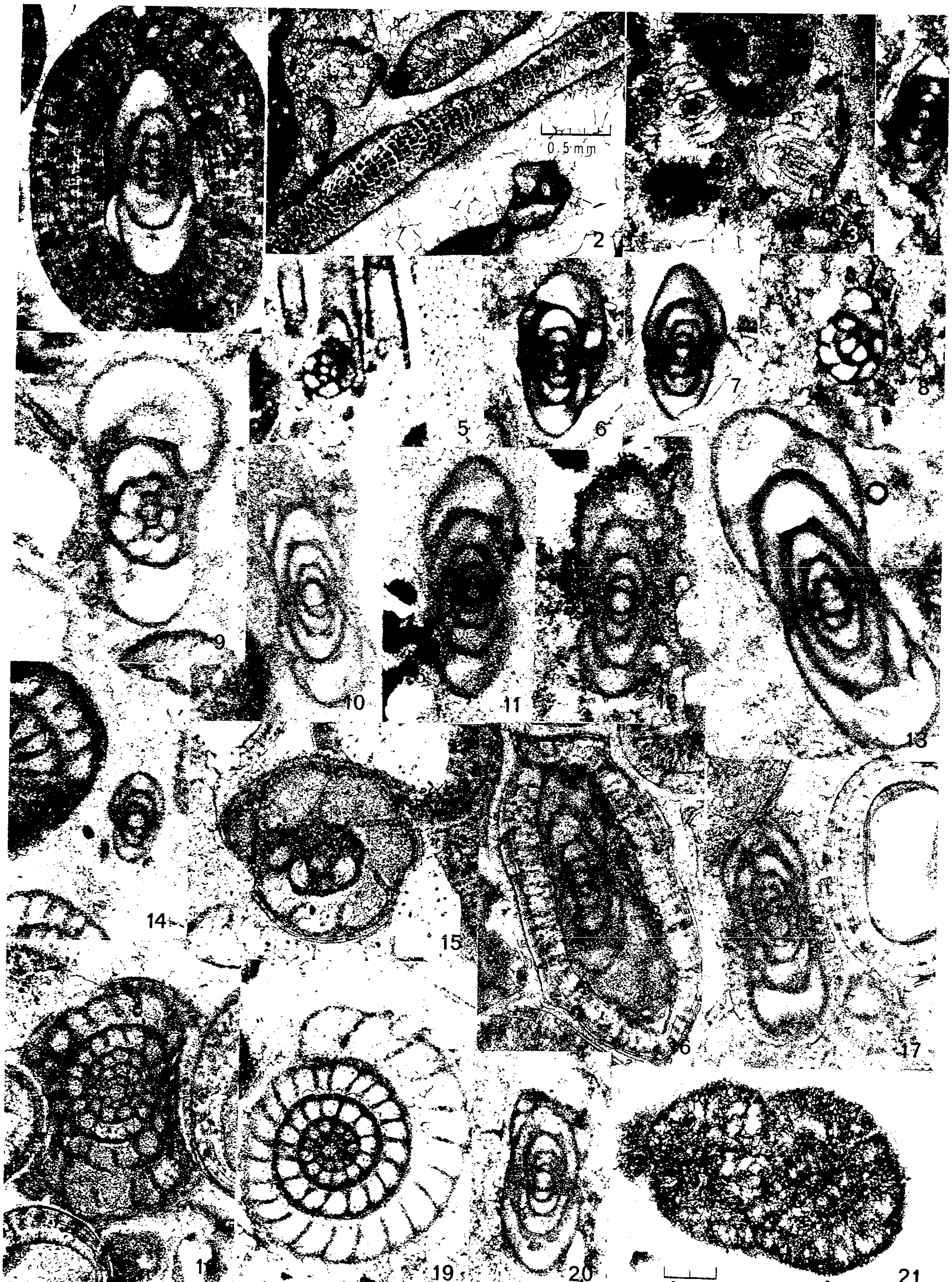
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Plate 2

All photographs are uniform in scale, as shown in fig. 26, except for fig. 20, which is shown at a reduced scale.

Fig. 1.— *Millerella marblensis* Thompson, perfectly oriented horizontal axial section, showing proloculus and juvenarium. M68-15, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 2.— *Millerella marblensis* Thompson, vertical axial section. M70-13b, Brentwood Limestone Member, Bloyd Shale, Evansville Mountain, Arkansas.
Fig. 3.— *Ammovertella* cf. *A. inversa* (Schellwein), an excellent section showing even globular initial chamber. M70-13b, Brentwood Limestone Member, Bloyd Shale, Evansville Mountain, Arkansas.
Fig. 4.— *Archaediscus* sp., equatorial section, with black pyritic? coating. M70-13b, Brentwood Limestone Member, Bloyd Shale, Evansville Mountain, Arkansas.
Fig. 5.— *Millerella* sp., vertical axial section. M68-18, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 6.— *Millerella marblensis* Thompson, vertical axial section, slightly off-center. M68-18, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 7.— *Eostafella* cf. *E. ovoidea* (Rauzer-Chernousova) of King (1973), well-oriented vertical axial section. M70-13b, Brentwood Limestone Member, Bloyd Shale, Evansville Mountain, Arkansas.
Fig. 8.— *"Plectogyra"* sp., vertical axial section. M68-25A, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 9.— *Paramillerella* sp., well-oriented vertical axial section, form distinctly evolute. M68-25A, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 10.— *"Plectogyra"* sp., showing a high angle of rotation of each half-volution plane. M68-18, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 11.— *"Plectogyra"* sp. cf. Pennsylvanian forms, horizontal axial section. M70-18, Brentwood Limestone Member, Bloyd Shale, Evansville Mountain, Arkansas.
Fig. 12.— *Millerella* sp., horizontal axial section, tightly compressed coiling. M68-25A, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 13.— *Endothyra kleina* Woodland, horizontal axial section, 1½-2 volutions. M26-12c, Braggs Member, Sausbee Formation, Cookson Section, Oklahoma.
Fig. 14.— *Tuberatina* sp., showing wall structure with pores. M68-16, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 15.— *Trepeilopsis* sp. M68-17, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 16.— *Endothyranella* n. sp. M68-23b, Brentwood Limestone Member, Bloyd Shale, Muskrat Mountain, Oklahoma.
Fig. 17.— *Millerella* cf. *M. marblensis* Thompson, tangential horizontal axial section. Core 82-4 (U.S. Army Corps of Engineers core Q-139), Braggs Member, Sausbee Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.
Fig. 18.— *Millerella marblensis* Thompson, slightly rotated vertical axial section, showing chomata. M26-3A, Braggs Member, Sausbee Formation, Cookson Section, Oklahoma.
Fig. 19.— *"Endothyra"* cf. *E. kleina*? Woodland, horizontal axial section, showing proloculus, 1-1½ volutions. M70-13b, Brentwood Limestone Member, Bloyd Shale, Evansville Mountain, Arkansas.
Fig. 20.— *Cuneiphycus* sp.; note reduced scale. Core 80-10 (U.S. Army Corps of Engineers core Q-126), Braggs Member, Sausbee Formation, NE NW SE sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.
Fig. 21.— *Paramillerella* sp., horizontal axial section, showing proloculus. M70-13b, Brentwood Limestone Member, Bloyd Shale, Evansville Mountain, Arkansas.
Figs. 22, 24.— *Millerella* cf. *M. extensus* King, horizontal axial section, showing proloculus and tightly appressed coil of 5 volutions. Core 82-3 (U.S. Army Corps of Engineers core Q-139), Braggs Member, Sausbee Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.
Fig. 23.— *Paramillerella* sp., vertical axial section. M97-4, Braggs Member, Sausbee Formation, Chisum Quarry, Oklahoma.
Fig. 25.— *Millerella* cf. *M. marblensis* Thompson, vertical axial section through proloculus, showing chomata. Core 82-3 (U.S. Army Corps of Engineers core Q-139), Braggs Member, Sausbee Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.
Fig. 26.— *Millerella marblensis* Thompson, horizontal axial section, showing proloculus and juvenarium; note logarithmic coiling. M26-10, Braggs Member, Sausbee Formation, Cookson Section, Oklahoma.

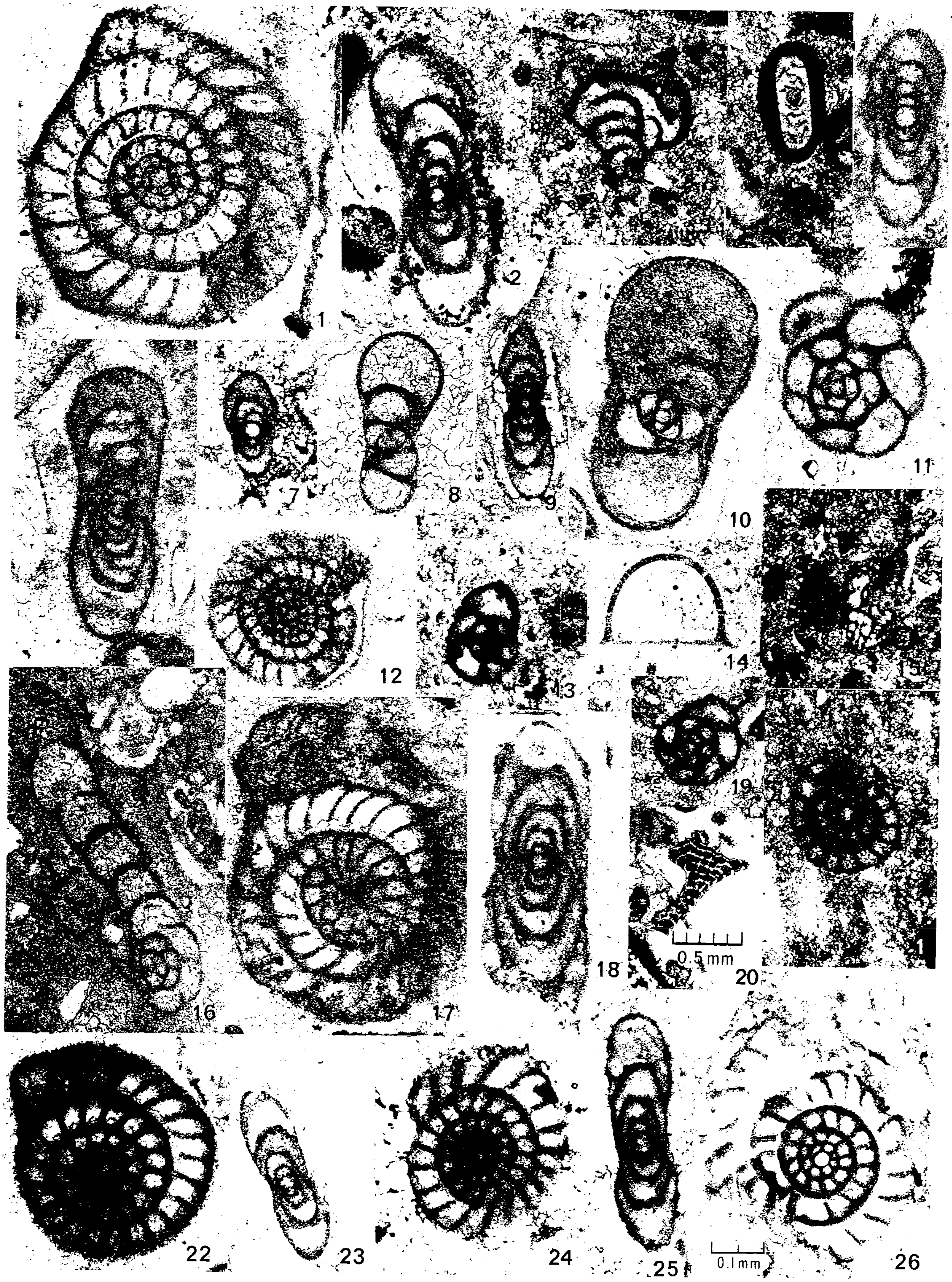
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Plate 3

All photographs are uniform in scale, as shown in fig. 24, except for figs. 3, 5, 12, 13, and 25, which are shown at a reduced scale (see fig. 5).

Fig. 1.—*Millerella marblensis* Thompson, horizontal axial section, showing proloculus and juvenarium. M97-4, Braggs Member, Sausbee Formation, Chisum Quarry, Oklahoma.

Fig. 2.—*Millerella* sp., vertical axial section through proloculus. M97-6 Station F, Braggs Member, Sausbee Formation, Chisum Quarry, Oklahoma.

Figs. 3, 4.—Unidentified alga, transverse sections. *4* is an enlargement of upper portion of specimen on far left in *3* (to orient, compare dark area in alga on both photographs). Core 82-9, at 60 feet (U.S. Army Corps of Engineers core Q-139), Brewer Bend Limestone Member, Sausbee Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 5.—*Archaeolithophyllum* sp., longitudinal section of thallus, showing cellular structure. M65-16a, Brewer Bend Limestone Member, Sausbee Formation, Lyons Mountain, Oklahoma.

Fig. 6.—*Paramillerella* sp., horizontal axial section. Core 82-9, at 60 feet (U.S. Army Corps of Engineers core Q-139), Brewer Bend Limestone Member, Sausbee Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 7.—Gigantic millerellid, tangential section. Core 82-9, at 59.5 feet (U.S. Army Corps of Engineers core Q-139), Brewer Bend Limestone Member, Sausbee Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Figs. 8, 9.—*Millerella* cf. *M. extensus* King. *8*, horizontal axial section with small proloculus and tightly appressed coil of 5 volutions; *9*, vertical axial section, showing chomata and evolute nature of test. Both M65-18, Chisum Quarry Member, McCully Formation, Lyons Mountain, Oklahoma.

Fig. 10.—*Millerella* cf. *M. pressa* Thompson, vertical axial section. M65-18, Chisum Quarry Member, McCully Formation, Lyons Mountain, Oklahoma.

Fig. 11.—*Archaeolithophyllum* sp., longitudinal section of thallus, showing cellular structure, greatly enlarged over that shown in specimen in fig. 5. Core 82-14, at 4.5 feet (U.S. Army Corps of Engineers core Q-139), Chisum Quarry Member, McCully Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 12.— *Tetrataxis corona* Cushman and Waters. Core 82-9, 60 feet (U.S. Army Corps of Engineers core Q-139), Brewer Bend Limestone Member, Sausbee Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 13.— *Tuberatina* sp., encrusting on a blade of *Archaeolithophyllum*. Core 82-9, at 60 feet (U.S. Army Corps of Engineers core Q-139), Brewer Bend Limestone Member, Sausbee Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 14.— *Tournayella* sp. (in a typical pose), horizontal axial section. Core 82-9, at 59.5 feet (U.S. Army Corps of Engineers core Q-139), Brewer Bend Limestone Member, Sausbee Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 15.— *Paramillerella cooperi* (Nodine-Zeller), horizontal axial section of 2¼ volutions, showing proloculus and juvenarium. Core 80-22 (U.S. Army Corps of Engineers core Q-126), Chisum Quarry Member, McCully Formation, NE NW SE sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 16.—Gigantic millerellid, probably same species as fig. 7, horizontal axial section through tiny proloculus, showing chomata. Core 80-27 (U.S. Army Corps of Engineers core Q-126), Shale "A" member, McCully Formation, NE NW SE sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 17.— *"Plectogyra"* sp., vertical axial section. Core 80-26 at 27 feet (U.S. Army Corps of Engineers core Q-126), Shale "A" member, McCully Formation, NE NW SE sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 18.— *Millerella pressa* Thompson, vertical axial section through proloculus, showing evolute nature of test. Core 80-26 at 27 feet (U.S. Army Corps of Engineers core Q-126), Shale "A" member, McCully Formation, NE NW SE sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 19.— *Ozawainella*? sp., vertical axial section close to proloculus, showing sharply angular shape of all volutions, except first one, and uneven chomata. Core 84-24, at 16.5 feet (U.S. Army Corps of Engineers core Q-144), Greenleaf Lake Limestone Member, McCully Formation, NE SE NE sec. 32, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 20.— *Endothyra kleina*? Woodland, horizontal axial section, showing 1½ volutions. M97-19, Greenleaf Lake Limestone Member, McCully Formation, Chisum Quarry, Oklahoma.

Fig. 21.— *Ozawainella*? cf. *O. ciscoensis*? (Harlton), peripheral view of primitive form, encased in oolitic coating, simulating a three-dimensional effect, showing aperture at base of final chamber and slightly inflated rim of apertural face. Core 80-26 (U.S. Army Corps of Engineers core Q-126), Chisum Quarry Member, McCully Formation, NE NW SE sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

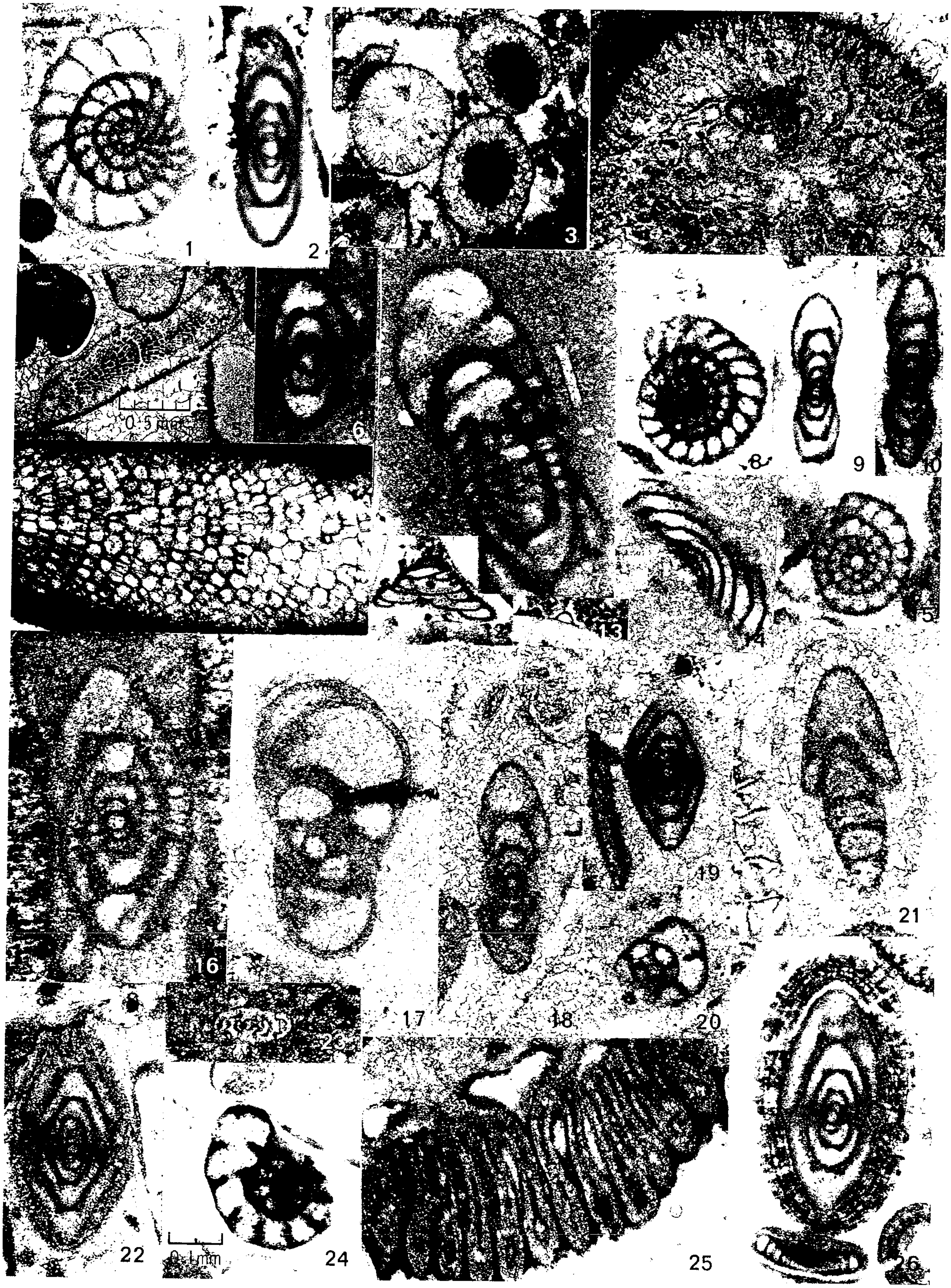
Fig. 22.— *Ozawainella*? sp., vertical axial section, near proloculus, showing sharply angular shape of all volutions, with exception of first volution, and irregular chomata. Core 84-24, at 16.5 feet (U.S. Army Corps of Engineers core Q-144), Greenleaf Lake Limestone Member, McCully Formation, NE SE NE sec. 32, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 23.— *Archaediscus* sp., equatorial section. M97-19, Greenleaf Lake Limestone Member, McCully Formation, Chisum Quarry, Oklahoma.

Fig. 24.— *Endothyranella* cf.? *E. panderi* (Moller), horizontal axial section, showing tunnel through to monoserial portion of test and rounded apertural face. Core 84-18, at 54.5 feet (U.S. Army Corps of Engineers core Q-144), Chisum Quarry Member, McCully Formation, NE SE NE sec. 32, T. 13 N., R. 20 E., Muskogee County, Oklahoma.

Fig. 25.— *Pentremites godoni* (Defrance), hydrospire folds beneath ambulacral area, showing 6 paired, indicative of late Morrowan age. M97-19, Greenleaf Lake Limestone Member, McCully Formation, [location?] Arkansas.

Fig. 26.— *Ozawainella*? sp., vertical axial section slightly off-center, encased in oolite, showing sharply pointed keel, small proloculus, and irregular chomata. Core 82-22? (U.S. Army Corps of Engineers core Q-139), Chisum Quarry Member, McCully Formation, NW SE NW sec. 33, T. 13 N., R. 20 E., Muskogee County, Oklahoma.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LATE MISSISSIPPIAN AND EARLY PENNSYLVANIAN BRYOZOAN FAUNAS OF ARKANSAS AND OKLAHOMA: A REVIEW

Alan S. Horowitz[1]

Abstract—A survey of the literature that includes taxonomic and stratigraphic papers reveals that 32 genera and 127 species of bryozoans have been reported from the Late Mississippian rocks of Oklahoma and Arkansas. A less extensive review of Morrowan bryozoans from the same area yields 15 genera and 53 species of bryozoans. Although several Chesterian genera apparently are endemic, the Chesterian and Morrowan bryozoan faunas generally are geographically and stratigraphically cosmopolitan at the generic level. Too few species have been studied by current standards to permit precise chronologic correlations.

HISTORY OF CHESTERIAN BRYOZOAN STUDIES IN ARKANSAS AND OKLAHOMA

The earliest bryozoan described from the Carboniferous area of Arkansas and Oklahoma appears to be the description and figure of *Archimedipora archimedes* by Shumard (1853, p. 201, pl. 1, fig. 6). This species is considered unrecognizable by Easton and Duncan (1953), who reviewed the history of this generic and specific name as well as the various editions of the Shumard report in which the name appeared. However, the axis figured by Shumard is comparable to that subsequently described from Arkansas as *Archimedes moorei* Condra and Elias (1944, pl. 20, figs. 6, 7). No further formal descriptions of bryozoans from the Carboniferous area of Arkansas and Oklahoma were made for half a century. However, the genus *Archimedes* Owen is one of the most distinctive of fossils, and its presence is indicated in all major geologic reports on the area as witnessed by the use of "Archimedes Limestone" in numerous early reports for what is now regarded as the Pitkin Limestone.

In Washington County, Arkansas, Simonds (1891, p. 55-57) figured three specimens of *Archimedes*, including one having a heavy axis similar to that figured by Shumard (1853, pl. 1, fig. 6), but no specific names were applied. Simonds (1891, p. 68) recognized that other types of bryozoans were associated with *Archimedes*, but no generic names were cited. Indeed, *Pentremites* Say and *Orthoceratites* Gesner (possibly a large *Rayonnoceras* Croneis) were the only other fossils designated generically. Simonds (1891, p. 83-92) did not report any bryozoans from the Pentremital Limestone (now equivalent to the Pennsylvanian Brentwood Limestone Member of the Bloyd Formation) in Washington County, Arkansas.

Weller (1897, p. 254), who, after Shumard, published the first formal report of Mississippian invertebrate fossils in Arkansas, noted only that several genera and species of bryozoans (Polyzoa) were present in the Batesville Sandstone but that their preservation as impressions in the sandstone did not permit accurate identifications. Williams (1900) reviewed the Carboniferous faunas collected by Branner and his associates in the '80's and '90's of the last century and reported *Archimedes* and *Fenestella* Lonsdale from a number of sites, which include beds that would now be assigned to the Batesville Sandstone, Wedington Sandstone, and Pitkin Limestone.

Girty (1910) published the first comprehensive descriptions of Mississippian bryozoans from Arkansas. Unfortunately none of his 35 newly described bryozoan species, including the type species of 8 newly proposed bryozoan genera, were figured. Bassler (1941) subsequently illustrated and discussed Girty's Fayetteville Shale bryozoan genera. None of the types of the remaining bryozoan species described by Girty from the Fayetteville Shale has ever been figured. Gordon (1969, p. 1) noted that those Fayetteville species (including bryozoans) figured subsequently by Girty (1911, 1915) were not based on the original specimens from the Fayetteville Shale, and Gordon also indicated that most of Girty's Fayetteville material came from the limestone at the base of the formation (Gordon, 1969, p. 3). This unit has been referred to the Hindsville Limestone by numerous subsequent authors (e.g., Huffman, 1958, p. 61; Furnish and Saunders, 1971, p. 5). Girty prepared faunal lists of bryozoans from the Hindsville, Batesville, Fayetteville, and Pitkin of north-central Arkansas (Purdue and Miser, 1916). These lists contain 15 bryozoan species assigned to 9 genera.

In 1911 Girty described 5 specific taxa assigned to 3 genera from the Moorefield Shale of Arkansas. However, only the two species of *Batostomella* Ulrich were figured. Girty (1915) discussed 17 specific taxa, identified with variable levels of confidence, that were assigned to 9 genera from the Batesville Sandstone. Only borings questionably referred to the ctenostome bryozoan *Ropalonaria* Ulrich were figured. The bryozoan identifications by Williams (1900) and Girty (1911, 1915) were included by Crôneis (1930, p. 53, 63, 64, 75) in his faunal lists for the Late Mississippian formations in Arkansas. In addition, Croneis cited other faunal lists by Girty (*in* Purdue and Miser, 1916) and unpublished-thesis identifications. Curiously, Croneis (1930) did not cite Girty's 1910 Fayetteville paper, perhaps because a discussion of the fauna of the Fayetteville probably was presented in an unpublished thesis by Croneis (1930, p. 69).

Faunal lists published by Croneis for the Fayetteville, Wedington, and Pitkin include 5 genera and 15 species, of which only *Archimedes swallovanus* (Hall) is figured (Croneis, 1930, pl. 19, fig. 32). *Batostomella parvula* Girty was recognized by Croneis, probably on the basis of material figured by Girty (1911) from the Moorefield Shale. Bassler (1936) described from Arkansas a single species of a new genus of bryozoan whose stratigraphic position was imperfectly known. McKinney (1971) redescribed Bassler's material.

In his faunal list of the Pitkin Limestone, Easton (1942, p. 84) recognized 15 genera assigned to 29 specific taxa, of which

[1]Department of Geology, Indiana University, Bloomington, Indiana.

12 were previously described species. In the following year Easton (1943) published the description and figures of 11 new species assigned to 7 genera. No further work on the bryozoans from the Late Mississippian of Arkansas appears to have been published.

Apparently no formal studies of bryozoans have been published for the northeastern Oklahoma Mississippian belt of outcrop, and the only published formal study from southern Oklahoma is by Elias (1957). Taff (1905, 1906) published faunal lists for the Fayetteville Shale in northeastern Oklahoma that contained 4 genera and 7 species of bryozoans. The largest faunal list of bryozoans was publised by Snider (1915), who recorded 19 species assigned to 7 genera and indicated that 8 additional genera and perhaps twice that number of species were also present in the Chesterian rocks of northeastern Oklahoma (Snider, 1915, p. 74).

Huffman (1958) listed the bryozoan fauna from the various Late Mississippian formations in northeastern Oklahoma. These materials were collected during mapping projects in the area and included 15 bryozoan species assigned to 4 genera. Ten of the species were assigned to *Archimedes.* In southern Oklahoma, Elias assigned the Late Mississippian bryozoans from the Redoak Hollow Formation to 42 species and 18 genera.

SUMMARY OF RESULTS OF CHESTERIAN BRYOZOAN WORK IN OKLAHOMA AND ARKANSAS

Not less than 32 genera and 127 species of bryozoans have been reported from the Late Mississippian rocks of Oklahoma and Arkansas. However, 1 genus and 24 species are documented only in faunal lists. The remaining 31 genera and 102 species have been formally described from this area, but 27 species of Girty (1910) have not been figured. Omission of the 4 genera and 31 species reported by Elias (1957) from the Redoak Hollow Formation of southern Oklahoma would reduce the bryozoan list to 27 genera and 72 species documented for the Late Mississippian from the flanks of the Ozark dome in northwestern Arkansas and northeastern Oklahoma. Half of the reported species are assigned to the genera *Archimedes* (24 sp.), *Fenestella* (19 sp.), and *Tabulipora* Young (21 sp.).

The bryozoan list (table 1) was compiled using the literature cited above with the following changes. Generic names are spelled in accordance with current usage. All species of *Cystodictya* Ulrich were assigned to *Sulcoretepora* D'Orbigny. All species of *Stenopora* Lonsdale were assigned to *Tabulipora*, which Girty (1915, p. 30) noted was necessary to accord with the revisions of Lee (1912). *Batostomella* is now regarded as an Ordovician genus, and the Late Mississippian species assigned to *"Batostomella"* will have to be reassigned to one or more other genera. Blake (1976) recently showed that *Coeloconus* Ulrich is a synonym of *Rhabdomeson* Young and Young, and his conclusions have been followed in table 1. The genera *Condranema* Bassler, *Marcusodictyon* Bassler, and *Vinella* Ulrich are regarded as unknown calcareous encrusters, not boring ctenostome bryozoans, and are excluded from the compilation. Nevertheless, some of the material assigned by Elias (1957) to these genera may represent borers, possibly ctenostomes. *Ropalonaria* is regarded as a boring ctenostome bryozoan and is included in the list. All species described by Girty (1910) are recorded as having been collected from the Hindsville Limestone.

In the following discussion, data on generic ranges and occurrences were taken from Bassler (1953), McKinney (1974), Newton (1971), and the *Zoological Record.* Girty (1910) created eight new genera (*Amphiporella, Callocladia, Coeloclemis, Dyscritella, Idioclema, Pycnopora, Stenocladia,* and *Syringoclemis*), of which *Idioclema* and *Pycnopora* do not appear to have been recorded beyond Arkansas or Oklahoma. *Amphiporella* is now regarded as a synonym of *Tabulipora* (Gautier, 1970). *Dyscritella* is a widely distributed genus with several dozen species that are Devonian to Triassic in age. Pushkin (1976) reviewed the genus *Callocladia* and assigned to the genus nine species of Silurian through Mississippian age. He excluded the Permian species from Australia assigned to *Callocladia* so that the genus is recorded from North America and Europe. In North America *Callocladia* occurs in the Chesterian Fayetteville Shale of Arkansas and equivalent Late Mississippian beds in Alabama (McKinney, 1972). *Coeloclemis* is known from the Fayetteville Shale of Arkansas and the Permian of Japan. *Stenocladia* is recorded from the Late Mississippian of Arkansas and Oklahoma and questionably from the Upper Carboniferous (Pennsylvanian) beds in Australia. *Syringoclemis* has been reported from the Fayetteville Shale of Arkansas and the Lower Permian of Kansas.

The generic assemblage in table 1 is a typical upper Paleozoic one; nine genera range from Devonian to Permian (*Archimedes, Dichotrypa* Ulrich, *Eridopora* Ulrich, *Penniretepora* D'Orbigny, *Rhombopora* Meek, *Streblotrypa* Vine. *Sulcoretepora,* and *Tabulipora*) or Triassic (*Dyscritella*), and all but *Dichotrypa* are common and contain numerous species distributed around the world. An additional eight genera have even longer ranges, beginning in the Ordovician or Silurian and continuing to the Permian (*"Batostomella," Cheilotrypa* Ulrich, *Fenestella, Fistulipora* M'Coy, *Meekopora* Ulrich, *Polypora* M'Coy, *Ropalonaria,* and *Thamniscus* King). Seven genera have Mississippian to Permian ranges (*Coeloclemis, Glyptopora* Ulrich, Leioclema Ulrich, *Lyropora* Hall, *Rhabdomeson, Septopora* Prout, *Stenocladia,* and *Syringoclemis*), of which *Stenocladia* has not been reported below the Upper Mississippian (Chesterian). *Stenoporella* Bassler is questionably recorded from the Devonian and the Late Mississippian. The only endemic genera are apparently *Fenesteverta* Elias, *Idioclema, Pycnopora,* and *Strebloplax* Elias. F. K. McKinney (personal correspondence) has examined the type of *Fenesteverta,* which is an impression in coarse-grained sediment, and considers it unrecognizable.

CHESTERIAN BRYOZOAN CORRELATIONS

Bryozoans are not commonly used for direct correlations in Mississippian rocks, and no general bryozoan zonal scheme has been proposed for the Late Mississippian in North America, although a few bryozoan species were used by Weller (1926) to zone the Chesterian in the Illinois basin. Horowitz and Strimple (1974, p. 216) noted that the ranges of two species cited by Weller have been extended and no longer represent very narrow stratigraphic intervals. Four bryozoan species, listed in a table by McFarlan (1942), were restricted to the lower Chesterian in the Illinois basin. Of these, *Sulcoretepora labiosa* (Weller) was listed in a faunal chart by Snider (1915) for the Fayetteville Shale, and a form related to *Glyptopora punctipora* Ulrich was recorded by Girty (1915) from the Batesville Sandstone.

Elias (1957, p. 426, table 7) published a comparison of the ranges of species of *Archimedes* in the Chesterian of the Illinois basin and the Pitkin and Redoak Hollow formations of Arkansas and Oklahoma. Most species common to both areas range throughout much of the Chesterian. A late Chesterian age for the Pitkin and Redoak Hollow formations is consistent

Table 1.—List of Bryozoan Species Reported in Late Mississippian Formations of Arkansas and Oklahoma

a, affinities; *B*, described and figured; *c*, refer to; *D*, described only; *F*, figured only; *N*, neither described nor figured (faunal lists); *unidif.*, undifferentiated; *X*, reported as present

		Moorefield Fm. undif.	Bayou Manard Mbr.	Batesville Ss.	Hindsville Ls.	lower Fayetteville Sh.	Wedington Ss.	upper Fayetteville Sh.	Fayetteville undif.	Pitkin Ls.	Redoak Hollow Fm.
Archimedes sp.	F	—	—	—	X	—	—	—	—	X	—
A. ardmorensis Elias	B	—	—	—	—	—	—	—	—	—	X
A. communis Ulrich	N	—	—	—	X	X	—	X	X	X	—
A. compactoides Condra & Elias	N	—	—	—	—	—	—	—	—	X	—
A. compactus Ulrich	N	—	—	—	—	—	X	X	X	X	—
A. confertus Ulrich	N	X	—	?	?	?	—	—	X	—	—
A. distans Ulrich	B	—	—	—	X	X	—	—	X	X	X
A. fosteri Condra & Elias	B	—	—	—	—	—	—	—	—	X	—
A. fragilis Condra & Elias	B	—	—	—	—	—	—	—	—	X	—
A. inflatus Huffman *(nomen nudum)*	N	—	—	—	—	—	—	—	X	—	—
A. intermedius Ulrich	F	—	—	—	X	—	—	X	X	X	—
A. invaginatus Ulrich	F	—	—	—	—	—	—	—	X	X	—
A. lunatus Condra & Elias	B	—	—	—	—	—	—	—	—	X	—
A. magnus Condra & Elias	B	—	—	—	—	—	—	—	—	X	—
A. meekanus (Hall)	B	—	—	—	—	—	X	—	—	X	X
A. meekanoides McFarlan	B	—	—	—	—	—	—	—	—	—	X
A. moorei Condra & Elias	B	—	—	—	—	—	—	—	—	X	—
A. owenanus (Hall)	N	—	—	—	—	—	a	X	—	—	—
A. perminimus Ulrich	B	—	—	—	—	—	—	—	—	—	a
A. pitkinensis Elias	B	—	—	—	—	—	—	—	—	X	X
A. proutanus Ulrich	B	X	—	—	—	—	X	X	X	X	X
A. proutanus var. Ulrich	N	—	—	X	—	—	—	—	—	—	—
A. pseudoswallovanus Elias	B	—	—	—	—	—	—	—	—	—	X
A. rigidus Elias	B	—	—	—	—	—	—	—	—	—	X
A. sublaxus Ulrich	B	—	—	—	—	—	—	—	X	X	—
A. swallovanus (Hall)	B	—	—	—	—	—	X	X	X	X	—
A. terebriformis Ulrich	N	—	—	—	—	—	X	—	—	X	—
"Batostomella" sp.	N	—	—	X	—	—	?	X	—	—	—
"B." anomala Girty	D	—	—	—	X	—	—	—	—	—	—
"B." (?) *armata* Girty	D	—	—	—	X	—	—	—	—	—	—
"B." dubia Girty	B	X	—	—	—	—	—	—	—	—	—
"B." parvula Girty	D	X	—	X	X	X	X	—	—	—	—
"B." spinulosa Ulrich	N	—	—	—	?	—	—	—	—	—	—
Callocladia elegans Girty	B	—	—	—	X	—	—	—	—	—	—
Cheilotrypa distans Elias	B	—	—	—	—	—	—	—	—	—	X
C. regularis (Easton)	B	—	—	—	—	—	—	—	—	X	—
Coeloclemis tumida Girty	B	—	—	—	X	—	—	—	—	—	—
Dichotrypa levis Easton	B	—	—	—	—	—	—	—	—	X	—
Dyscritella inaequalis Girty	D	—	—	—	X	—	—	—	—	—	—
D. robusta Girty	B	—	—	—	X	—	—	—	—	—	—
Eridopora (Discotrypella) radiata Elias	B	—	—	—	—	—	—	—	—	—	X
E. (D.) stellata Elias	B	—	—	—	—	—	—	—	—	—	X
Fenestella sp.	N	—	X	X	X	—	—	X	—	—	—
F. cestriensis Ulrich	B	—	—	—	X	—	—	X	X	—	X
F. chesterensis Condra & Elias	B	—	—	—	—	—	—	—	—	—	X
F. compressa Ulrich	N	—	—	—	—	—	—	X	—	—	—
F. cumingsi Condra & Elias	B	—	—	—	—	—	—	—	—	X	X
F. elevatipora Ulrich	N	—	—	—	—	—	—	—	X	—	—
F. exigua springerensis Elias	B	—	—	—	—	—	—	—	—	—	X
F. frutex M'Coy	B	—	—	—	—	—	—	—	—	—	c
F. matheri Condra & Elias	B	—	—	—	—	—	—	—	—	X	—
F. morrowensis Mather	B	—	—	—	—	—	—	—	—	—	X
F. multispinosa Ulrich	D	a	—	—	—	—	—	—	—	—	—
F. ovatipora Elias	B	—	—	—	—	—	—	—	—	—	X
F. paradisensis Condra & Elias	B	—	—	—	—	—	—	—	—	—	X
F. paradisensis ardmorensis Elias	B	—	—	—	—	—	—	—	—	—	X
F. rara Elias	B	—	—	—	—	—	—	—	—	—	X
F. rectangularis Condra & Elias	B	—	—	—	—	—	—	—	—	X	—
F. rudis Ulrich	D	a	—	—	—	—	—	—	—	—	—
F. serratula Ulrich	B	—	—	a	X	X	X	X	X	X	X
F. tenax Ulrich	B	—	—	X	—	—	—	—	—	X	X
F. triserialis Ulrich	N	—	—	—	—	—	—	—	X	—	—
Fenesteverta nicklesi Elias	B	—	—	—	—	—	—	—	—	—	X
Fistulipora excelens Girty	N	—	—	—	X	—	—	—	—	—	—
F. excelens harrisonensis Girty	D	—	—	—	X	—	—	—	—	—	—
F. excelens williamsi Girty	D	—	—	—	X	—	—	—	—	—	—
F. introspinosa Easton	B	—	—	—	—	—	—	—	—	X	—
Glyptopora crassa Easton	B	—	—	—	—	—	—	—	—	X	—
G. michelinia (Prout)	N	—	—	X	a	—	—	—	—	X	—
G. plumosa (Prout)	D	—	—	a	—	—	—	—	—	—	—
G. punctipora Ulrich	D	—	—	a	—	—	—	—	—	—	—
G. sagenella (Prout)	D	—	—	a	—	—	—	—	—	—	—
Idioclema insigne Girty	B	—	—	—	X	—	—	—	—	—	—
Leioclema sp.	D	—	—	X	—	—	—	—	X	—	—
Lyropora solida Easton	B	—	—	—	—	—	—	—	—	X	—
Meekopora abrupta Easton	B	—	—	—	—	—	—	—	—	X	—
M. tenuis Easton	B	—	—	—	—	—	—	—	—	X	—
Penniretepora ardmorensis Elias	B	—	—	—	—	—	—	—	—	—	X
Polypora sp.	D	—	—	X	—	—	—	—	—	—	—
P. cestriensis Ulrich	N	—	—	—	—	—	—	—	X	—	—
P. corticosa Ulrich	N	—	—	—	—	—	—	X	—	—	—
P. debilis Elias	B	—	—	—	—	—	—	—	—	—	X
P. mesleriana Girty	D	—	—	—	X	—	—	—	—	—	—
P. (Polyporella) ovicellata Elias	B	—	—	—	—	—	—	—	—	—	X
P. spinulifera Ulrich	N	—	—	—	—	—	—	—	X	—	—
Pycnopora bella Girty	D	—	—	—	X	—	—	—	—	—	—
P. hirsuta Girty	D	—	—	—	X	—	—	—	—	—	—
P. ovatipora Elias	B	—	—	—	—	—	—	—	—	—	X
P. regularis Girty	B	—	—	—	X	—	—	—	—	—	—
Rhabdomeson (Rhombopora) foerstei Elias	B	—	—	—	—	—	—	—	—	—	X
R. (R.) rogersi Elias	B	—	—	—	—	—	—	—	—	—	X
R. tubum (Girty)	D	—	—	—	X	—	—	—	—	—	—
R. (R.) ulrichi Elias	B	—	—	—	—	—	—	—	—	—	X
Rhombopora persimilis miseri Girty	D	—	—	—	X	—	—	—	—	—	—
R. tabulata Ulrich	N	—	—	—	—	—	—	—	X	—	—
Ropalonaria sp.	B	—	—	?	—	—	—	—	—	—	—
Septopora cestriensis Prout	N	—	—	—	?	—	—	X	—	—	—
S. pinnata Ulrich	B	—	—	—	—	—	—	—	—	—	c
S. pustilifera Girty	D	—	—	—	X	—	—	—	—	—	—
Stenocladia (?) *bassleri* Elias	B	—	—	—	—	—	—	—	—	—	X
S. frondosa Girty	B	—	—	—	X	—	—	—	—	—	—
Stenoporella romingeri Bassler	B	stratigraphic position unknown									
Strebloplax crustacea Elias	B	—	—	—	—	—	—	—	—	—	X
Streblotrypa nicklesi Ulrich	N	—	—	—	X	X	—	—	—	—	—
S. nicklesi robusta Girty	D	—	—	—	X	—	—	—	—	—	—
S. subspinosa Ulrich	N	—	—	—	—	—	—	—	X	—	—
Sulcoretepora sp.	D	—	—	?	—	—	—	—	—	—	—
S. americana (Ulrich)	N	—	—	—	—	—	—	—	X	—	—
S. labiosa (Weller)	N	—	—	—	—	—	—	—	X	—	—
S. nitida (Ulrich)	N	—	—	—	—	X	—	—	X	—	—
S. pustulosa arcta Girty	D	—	—	—	X	—	—	—	—	—	—
Syringoclemis biserialis Girty	B	—	—	—	X	—	—	—	—	—	—
Tabulipora sp.	D	X	—	X	X	—	—	—	—	—	—
T. cestriensis (Ulrich)	N	—	—	—	—	—	—	—	—	X	—
T. emaciata arkansana (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. emaciata inaequalis (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. emaciata megastyla (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. gracilis (Girty)	D	—	—	a	X	—	—	—	—	—	—
T. inermis (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. intermittens harrisonensis (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. longicamerata (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. macnairi Elias	B	—	—	—	—	—	—	—	—	—	X
T. maculosa (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. microfistulata Easton	B	—	—	—	—	—	—	—	—	X	—
T. miseri (Girty)	D	—	—	X	X	—	—	—	—	—	—
T. miseri tubulata (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. mutabilis (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. perattenuata (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. poculoformis Easton	B	—	—	—	—	—	—	—	—	X	—
T. ramosa fayettevillensis (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. reflexa Easton	B	—	—	—	—	—	—	—	—	X	—
T. simplex Elias	B	—	—	—	—	—	—	—	—	—	X
T. simulans (Girty)	D	—	—	—	X	—	—	—	—	—	—
T. subtilis Easton	B	—	—	—	—	—	—	—	—	X	—
T. tuberculata (Prout)	B	—	—	—	—	—	—	—	—	—	c
Thamniscus erectus Elias	B	—	—	—	—	—	—	—	—	—	X
T. furcillatus Ulrich	N	—	—	—	—	—	—	—	X	—	—

with the ranges of *Archimedes* species but is not conclusive. Based on presently published information, the same results can be reached by comparing the Chesterian ranges in the Illinois basin given in McFarlan (1942) with those in table 1.

Clearly, the Arkansas-Oklahoma Late Mississippian bryozoan faunas are dominated by genera widely distributed in space and time. Many species (33, or about a quarter of the reported species) were first described from the Chesterian of the Illinois basin, principally by Ulrich (1890). Endemism is a very minor aspect of the bryozoan faunas of the Late Mississippian in North America. On the other hand, species variability is not well documented for most of the Chesterian bryozoan species, and too few faunas have been described and figured from individual formations to evaluate either the variability or the ranges of many Chesterian bryozoan taxa.

FUTURE WORK

Until the unfigured species of Girty are made known and the morphologic variability and stratigraphic ranges of all Chesterian bryozoan species are better established, bryozoans will continue to provide only the most general of correlations in the Late Mississippian.

EARLY PENNSYLVANIAN BRYOZOA IN ARKANSAS AND OKLAHOMA

No attempt has been made to review all papers containing bryozoan faunal lists from the Morrowan rocks and their equivalents in Arkansas and Oklahoma. Mather (1915) described the bryozoans from the type area of the Morrowan and reported 15 genera and 34 species, of which 1 genus and 27 species were new. Previously described species recognized by Mather were about equally divided between typically Late Mississippian and typically mid-Pennsylvanian forms. Mather's faunal list is given in table 2 with the following changes: *Archimedes juvenis* Mather is omitted, as Condra and Elias (1944, p. 13) placed it in synonymy with *A. swallovanus* (Hall) and regarded all Pennsylvanian occurrences as redeposited Mississippian rocks in Pennsylvanian conglomerates. Taxa assigned by Mather to *Coscinium* Keyserling (*non* Endlicher), *Cystodictya, Dictyocladia* Mather (*non* Pomel), and *Stenopora* are assigned respectively to *Coscinotrypa* Hall and Simpson, *Sulcoretepora, Matheropora* Bassler, and *Tabulipora*. Moore and Dudley (1944) reported one new species of *Cyclotrypa* Ulrich (herein placed in *Fistulipora*) from the Morrowan rocks of northeastern Oklahoma.

In southern Oklahoma, Coryell (*in* Morgan, 1924) and Harlton (1933) described and figured bryozoans from beds equivalent to the Morrowan. These bryozoan occurrences are also entered in table 2 with the following changes: *Leioclema* Ulrich for the variant spelling *Lioclema*, and *Sulcoretepora* and *Tabulipora* for *Cystodictya* and *Stenopora*.

With respect to Coryell's species of *Tabulipora* (originally *Stenopora*), Cuffey (1967, p. 39) suggested that *T. circinna* (Coryell) be questionably placed in *Tabulipora, T. bullata* (Coryell) is a synonym of *T. hispida* (Coryell), and *T. wapanuckensis* (Coryell) is a synonym of *T.*? *ohioensis* (Foerste). These changes are recorded in table 2.

Currently 15 genera and 53 species have been documented from Morrowan rocks in Arkansas and Oklahoma. This diversity is less than half of the diversity recorded from the Late Mississippian rocks in the same area. All the genera are long-ranging late Paleozoic forms, although *Matheropora* and *Acanthocladia* King are probably more characteristic of Pennsylvanian and later rocks than of earlier beds, and *Anisotrypa* Ulrich is typically Mississippian.

Table 2.—List of Bryozoan Species Reported in Early Pennsylvanian Morrowan Formations of Arkansas and Oklahoma

Symbols and abbreviations as in table 1

	Morrow Group					
		Bloyd Shale				
	Hale Fm.	Brentwood Ls. Mbr.	Kessler Ls. Mbr.	Morrow undif.	Johns Valley Sh.	Wapanucka Ls.
Acanthocladia sp.	—	—	—	X	—	—
Acanthocladia ouachitensis Harlton	—	—	—	—	X	—
Anisotrypa sp.	—	X	—	—	—	—
Coscinotrypa fayettevillensis (Mather)	—	X	X	X	—	—
C. gracilens (Mather)	—	X	—	X	—	—
Fenestella bendensis Harlton	—	—	—	—	X	—
F. grandis Harlton	—	—	—	—	X	—
F. granularis Harlton	—	—	—	—	X	—
F. kosomensis Harlton	—	—	—	—	X	—
F. mimica Ulrich	—	—	—	—	—	X
F. morrowensis Mather	X	X	—	X	—	—
F. oklahomensis Harlton	—	—	—	—	X	—
F. serratula Ulrich	—	X	—	X	—	—
F. sevillensis Ulrich	—	—	—	—	—	X
F. venusta Mather	X	X	X	X	—	X
Fistulipora sp.	X	X	—	X	—	—
Fistulipora matheri (Moore & Dudley)	X	—	—	—	—	—
Glyptopora crassitoma Mather	—	X	—	X	—	X
G. incrustans Coryell	—	—	—	—	—	X
Leioclema pushmatahensis (Harlton)	—	—	—	—	X	—
Matheropora triseriata (Mather)	X	X	—	—	—	—
Polypora anastomosa Mather	X	X	—	—	—	—
P. anastomosa spinicarinata Mather	X	—	—	—	—	—
P. cestriensis Ulrich	—	—	—	—	—	X
P. constricta Mather	X	X	—	X	—	—
P. elliptica Rogers	—	X	—	X	—	—
P. halensis Mather	X	—	—	—	—	—
P. kesslerensis Mather	—	—	X	—	—	—
P. magna Mather	X	X	—	—	—	—
P. purduei Mather	X	X	—	X	—	—
P. reversispina Mather	X	—	—	—	—	—
P. spinulifera Ulrich	—	—	—	—	—	X
P. triseriata Mather	X	X	—	—	—	—
P. washingtonensis Mather	X	X	—	X	—	—
Phyllopora cribosa Mather	—	—	X	—	—	—
P. perforata Mather	X	—	—	—	—	—
Prismopora concava Mather	—	—	X	—	—	—
Rhombopora attenuata Ulrich	—	—	X	X	—	—
R. johnsvalleyensis Harlton	—	—	—	—	X	—
R. lepidodendroides Meek	—	—	X	X	—	X
R. nitidula Harlton	—	—	—	—	X	—
R. persimilis Ulrich	—	—	—	—	—	X
R. snideri Mather	—	—	—	X	—	X
R. tabulata Ulrich	—	—	—	X	—	—
Septopora crebripora Mather	X	—	—	—	—	—
S. implexa Mather	—	X	—	—	—	—
S. reversispina Mather	—	X	—	—	—	—
Sulcoretepora brentwoodensis (Mather)	X	X	—	—	—	X
S. elegans (Harlton)	—	—	—	—	X	—
S. flexuosa (Mather)	—	—	—	X	—	—
S. morrowensis (Mather)	—	—	—	X	—	—
S. sinuomarginata (Mather)	X	X	—	—	—	—
Tabulipora sp.	—	X	—	—	—	—
T. ? circina (Coryell)	—	—	—	—	—	X
T. hispida (Coryell) [= *T. bullata* (Coryell)]	—	—	—	—	—	X
T. micropora (Coryell)	—	—	—	—	—	X
T. tuberculata (Prout)	—	X	—	X	—	X
T. ? ohioensis (Foerste) [= *T. wapanuckensis* (Coryell)]	—	—	—	—	—	X

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BRACHIOPOD BIOSTRATIGRAPHY OF MORROWAN SERIES (PENNSYLVANIAN) IN NORTHWESTERN ARKANSAS AND NORTHEASTERN OKLAHOMA

Thomas W. Henry[1] and Patrick K. Sutherland[2]

Abstract—The Morrowan Series in northwestern Arkansas and northeastern Oklahoma is a highly fossiliferous sequence of predominantly marine strata, and it has been used as the standard of reference for the lower part of the Pennsylvanian System in central and western North America. The Morrowan Series in this area is divided into three brachiopod zones. The *Sandia welleri* Zone and the *Plicochonetes*? *arkansanus* Zone are range zones based, in the first case, on the lowest occurrences and, in the second case, on the highest occurrences of a number of brachiopod species. The highest zone, the *Linoproductus nodosus* Zone, is both a range zone and an assemblage zone.

The biostratigraphic resolution provided by the brachiopods in the Morrowan Series is about half that of the goniatites and conodonts. The brachiopod zones are important, however, because the brachiopods are the most commonly and widely occurring phylum recoverable from these strata; also, many stratigraphic intervals lack some or all of the other faunal groups in question.

The Morrowan Series in its type area contains approximately 49 genera, at least 2 of which are new, and approximately 80 species, of which about one-quarter have not as yet been described.

INTRODUCTION

The Morrowan Series in its type area in northwestern Arkansas and northeastern Oklahoma (fig. 1) is composed principally of marine limestone, sandstone, and shale that contain an abundant, well-preserved, and diverse invertebrate fauna initially studied by Mather (1915). Terrestrial sedimentary rocks form a minor proportion of the total stratigraphic succession.

The Morrowan Series is divided into the Hale Formation and the Bloyd Shale in northwestern Arkansas and into the Sausbee and McCully Formations in northeastern Oklahoma (fig. 2). The Hale Formation is further subdivided into the Cane Hill and Prairie Grove Members, and the Bloyd Shale consists of the Brentwood Limestone, Woolsey, Dye Shale, Kessler Limestone, and Trace Creek Shale Members. The Sausbee Formation is separated into the Braggs and Brewer Bend Limestone Members, and the McCully Formation contains the Chisum Quarry Member, the shale "A" member, the Greenleaf Lake Limestone Member, and the shale "B" member. For further discussion, refer to Sutherland and Henry (1977) and to this guidebook.

Our continuing investigation of the brachiopod faunas of the Morrowan Series is concentrated in an area lying on the southwestern flanks of the Ozark dome in northwestern Arkansas and northeastern Oklahoma (fig. 1). This area in Arkansas encompasses Washington, Madison, Newton, and Searcy Counties; the southern parts of Benton, Carroll, and Boone Counties; and northwestern Crawford County. In Oklahoma, it includes Adair and Cherokee Counties and parts of Sequoyah, Muskogee, Wagoner, Mayes, and Delaware Counties. The region for which we have the most densely spaced invertebrate collections and the most physical stratigraphic control is shown by the stippling in figure 1.

[1]U.S. Geological Survey, Reston, Virginia.
[2]School of Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma.

This paper is a progress report of our investigations to date. The specific and generic names presented in this paper have been used historically, but our recent studies indicate that several commonly known names will have to be relegated to synonymy and others reassigned taxonomically. However, these problems are beyond the scope of this paper. Some of the more common brachiopod species are figured in plates 1 and 2.

IMPORTANCE OF FAUNAS OF MORROWAN SERIES

The Morrowan Series is the basal series of the Pennsylvanian System in central and western North America, and for many years it was considered synonymous with the "Lower Series" of the Pennsylvanian System. Recent studies demonstrated that the lower part of the Kanawha Formation in the proposed type area for the Middle Series of the Pennsylvanian System in central West Virginia bears a late Morrowan invertebrate fauna (Gordon, 1976; Henry, 1976; Henry and Gordon, 1977). If the proposed stratotype ultimately is adopted, the upper part of the Morrowan Series in its type area (e.g., that part from the "caprock" at the base of the Dye Shale through the Trace Creek Shale Members of the Bloyd Shale in northwestern Arkansas and the entire McCully Formation in northeastern Oklahoma) would be Middle Pennsylvanian in age.

Furthermore, the Pocahontas and New River Formations (Lower Pennsylvanian) in southern West Virginia and southwestern Virginia—the proposed area for the stratotype of the Lower Series—are predominantly coal-bearing, terrestrial deposits. A single, thin marine bed that bears poorly preserved invertebrates occurs near the base of the New River Formation (Englund, 1974; Henry, 1976; Henry and Gordon, 1977). Knowledge about the invertebrate faunas of the type Morrowan Series is particularly significant, therefore, since, for all practical purposes, the lower and middle parts of the type Morrowan would continue to serve as the standard of reference for marine invertebrate faunas.

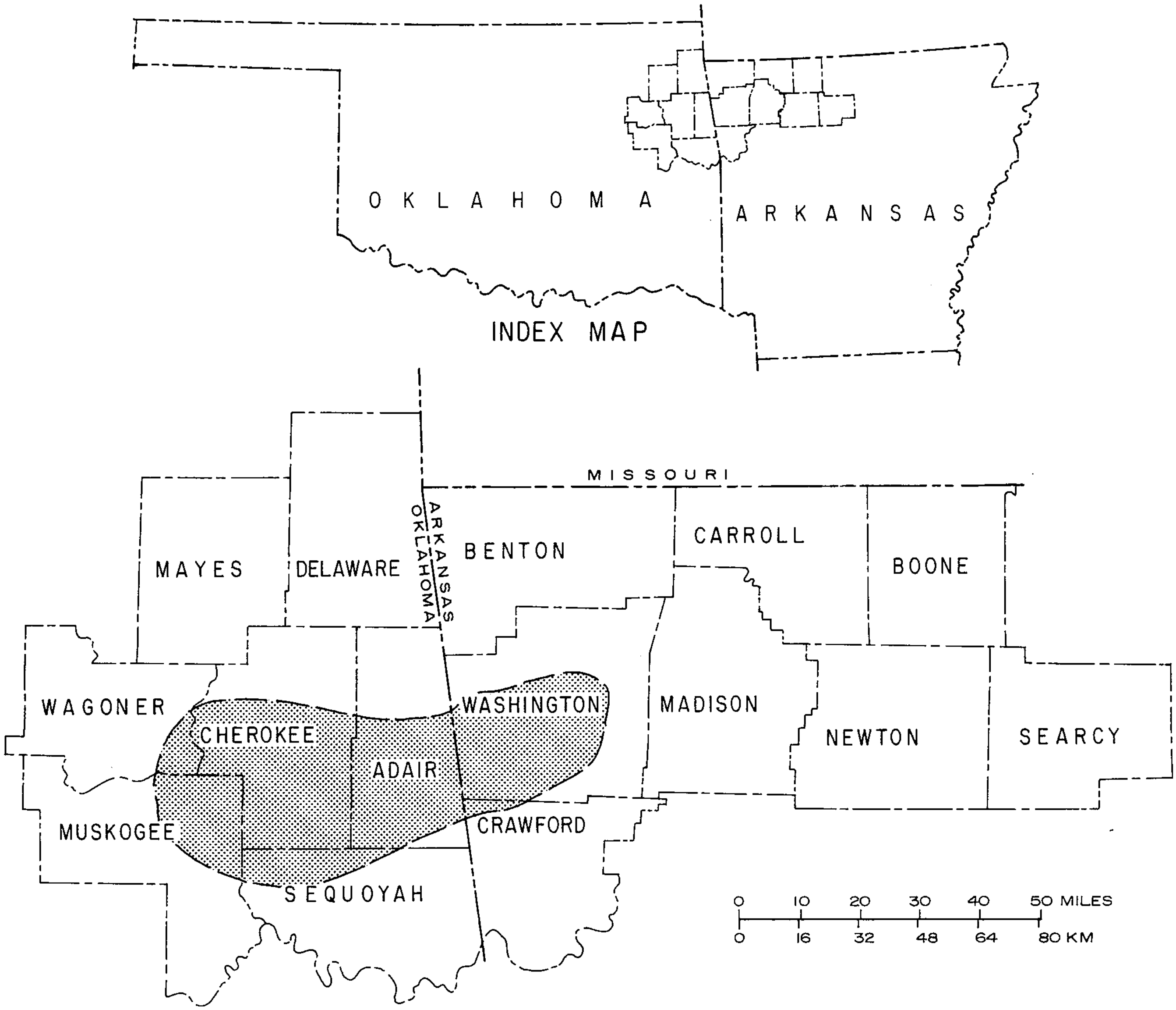

Figure 1. Index map showing area of investigation in northwestern Arkansas and northeastern Oklahoma; stippling shows region of greatest stratigraphic control.

BRACHIOPOD BIOSTRATIGRAPHY

The biostratigraphic usefulness of Pennsylvanian brachiopods was considered for many years to be minimal. This conclusion was derived primarily from the classic investigation of the widely distributed Pennsylvanian faunas in the Midcontinent—principally those from the upper Desmoinesian, Missourian, and Virgilian Series—by Dunbar and Condra (1932). Slow evolutionary rates were inferred for most brachiopod stocks during the late Middle and Late Pennsylvanian. This was clearly not the case during the Early and early Middle Pennsylvanian. Our studies of large collections of brachiopods from measured stratigraphic sequences in the Morrowan of Arkansas and Oklahoma; investigations of late Morrowan through early Desmoinesian equivalents in northern New Mexico (Sutherland and Harlow, 1973); and analysis of the Amsden Formation (Mississippian and Pennsylvanian) in Wyoming by Gordon (1975), including Morrowan and Atokan equivalents, have revealed that many brachiopod species within this interval possess restricted stratigraphic ranges and excellent biostratigraphic application.

The biostratigraphic resolution provided by the study of brachiopods is about half that of the goniatites and conodonts in the Morrowan Series and of the fusulinids in the Atokan and lower Desmoinesian (Henry, 1974; Sutherland and Henry, 1975, and in press). Nevertheless, analysis of these brachiopod faunas and the integration of this information with that presented by other faunal groups are important for two reasons: (1) brachiopods form by far the most commonly occurring phylum in most Pennsylvanian marine assemblages, and (2) many stratigraphic sequences may not have some or all of the other faunal groups in question.

Brachiopods dominate the invertebrate assemblages from the type Morrowan Series, particularly those in the more highly carbonate area in northeastern Oklahoma. We have examined approximately 50,000 specimens from about 600 separate collections from the Morrowan Series. These specimens are reposited at The University of Oklahoma, in the U.S. Geological Survey collections, and in the U.S. National Museum. It appears that the Morrowan Series in its type area contains approximately 80 species, of which about one-fourth have not been described previously. These species are assigned to 49 genera, 2 of which are new.

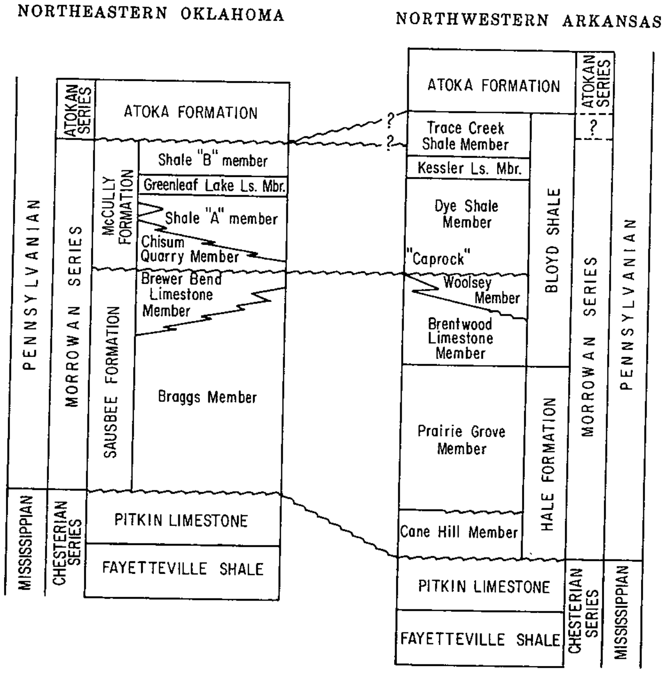

Figure 2. Correlation of Morrowan Series and adjacent strata in northeastern Oklahoma and northwestern Arkansas (after Sutherland and Henry, 1977, fig. 2).

CHESTERIAN BRACHIOPOD FAUNAS

The Chesterian faunas of the Ozark Mountains region have been the subject of a number of investigations. G. H. Girty studied the faunas of the Batesville Sandstone (1915), the Moorefield Shale (1911), and the Fayetteville Shale (1910). The latter work was reevaluated by Gordon and others (1969). The brachiopods of the Chesterian Series of northeastern Oklahoma, including those of the Pitkin Limestone, were studied by Snider (1915), and the Pitkin faunas of northern Arkansas by Easton (1943).

The Pitkin brachiopod faunas are typical late Chesterian assemblages and consist of such common elements as *Orthotetes kaskaskiensis* (McChesney), *Eolissochonetes tumscens* (Easton), *Rugosochonetes oklahomensis* (Snider), *Inflatia adairensis* (Drake), *Diaphragmus cestriensis* (Worthen), *Eumetria vera* Hall, and *E. pitkinensis* Snider.

COMPARISON OF PITKIN AND MORROWAN FAUNAS

Our recent work has extended the ranges of three "typical" Mississippian brachiopod genera, *Flexaria, Torynifer,* and *Inflatia,* well up into the Morrowan Series. The genus *Spirifer,* a similar case, was previously recorded by Sutherland and Harlow (1973) from the Morrowan Series of New Mexico, and it occurs commonly in our Morrowan collections. In addition, *Ovatia, Eumetria,* and *Girtyella,* also typical Mississippian genera, are each represented questionably in the Morrowan Series by a single species. The *Flexaria, Torynifer, Inflatia,* and *Spirifer,* as well as the questionable *Ovatia, Eumetria,* and *Girtyella,* are distinctly different species than their counterparts in the Late Mississippian in the Ozark region.

A number of "typical" Pennsylvanian genera first occur in the Morrowan Series in the Ozarks. These include *Meekella, Neochonetes, Desmoinesia, Sandia,* and *Tesuquea.* All of these genera first occur in the lower part of the Morrowan sequence, but none of these are known to range downward into the Late Mississippian strata.

MORROWAN BRACHIOPOD ZONES

The Morrowan Series in the Ozark region is divided into three brachiopod zones (Henry, 1973, 1974; Sutherland and Henry, 1975, and in press; and this paper, fig. 3). The *Sandia welleri* Zone and the *Plicochonetes*? *arkansanus* Zone are range zones based, in the first case, on the lowest occurrences and, in the second case, on the highest occurrences of a number of brachiopod species. The highest zone, the *Linoproductus nodosus* Zone, is both a range zone and an assemblage zone.

Sandia welleri Zone

The *Sandia welleri* Zone (pl. 1) includes about 35 species of brachiopods, none of which is known to occur in rocks older than the Morrowan. Thirty-four species do range into the overlying *Plicochonetes*? *arkansanus* Zone. The *Sandia welleri* Zone corresponds to the Cane Hill Member (although brachiopods have not been recovered from the lower portion) through the lower half of the overlying Prairie Grove Member of the Hale Formation in northwestern Arkansas and to the lower approximately one-third of the Braggs Member of the Sausbee Formation in northeastern Oklahoma (fig. 3). It may be possible to recognize a subzone in the lower part of the *Sandia welleri* Zone when larger collections of brachiopods are available from the Cane Hill Member.

This zone commonly contains *Orthotetes* n. sp. A, *Schizophoria altirostris* (Mather), *Sandia welleri* (Mather), *Tesuquea formosa* Sutherland and Harlow, *T. morrowensis* (Mather), *Linoproductus eastoni* Gordon, *Echinaria* n. sp. A, *Anthracospirifer matheri* (Dunbar and Condra), *Hustedia miseri* Mather, *H. brentwoodensis* Mather, *Hustedia* n. sp. A, *Flexaria* n. sp., and *Beecheria bilobatum* (Mather).

The *Sandia welleri* Zone is equivalent to the *Rhachistognathus primus* and the *Idiognathoides sinuatus* Conodont Zones of Lane (this guidebook) and to the *Retites semiretia*, the *Reticuloceras henbesti*, and the basal part of the *Arkanites relictus* Goniatite Zones of Saunders and others (this guidebook).

Plicochonetes? *arkansanus* Zone

The lower boundary of the *Plicochonetes*? *arkansanus* Zone, and thus the upper boundary of the *Sandia welleri* Zone, is defined by the lowest occurrence of 11 species of brachiopods. The more common and important of these species are *Plicochonetes*? *arkansanus* (Mather), *Rhynchopora magnicosta* Mather, *Punctospirifer morrowensis* (Mather), *Schizophoria oklahomae* Dunbar and Condra, *Scholoconcha*? *globosa* (Mather), *Desmoinesia nambeensis* Sutherland and Harlow, *Spirifer goreii* Mather, and *Composita biplicata* Mather.

The fauna of the *Plicochonetes*? *arkansanus* Zone (pl. 2) is the most diverse of the 3 zones and includes a minimum of 60 species of brachiopods.

The upper boundary of the *Plicochonetes*? *arkansanus* Zone is defined by the highest occurrence of 12 brachiopod species and the 1st occurrence of an additional 10 species. Of the commonly occurring lower Morrowan species, *Linoproductus* n. sp. A, *Eolissochonetes* n. sp. A, *Anthracospirifer matheri*

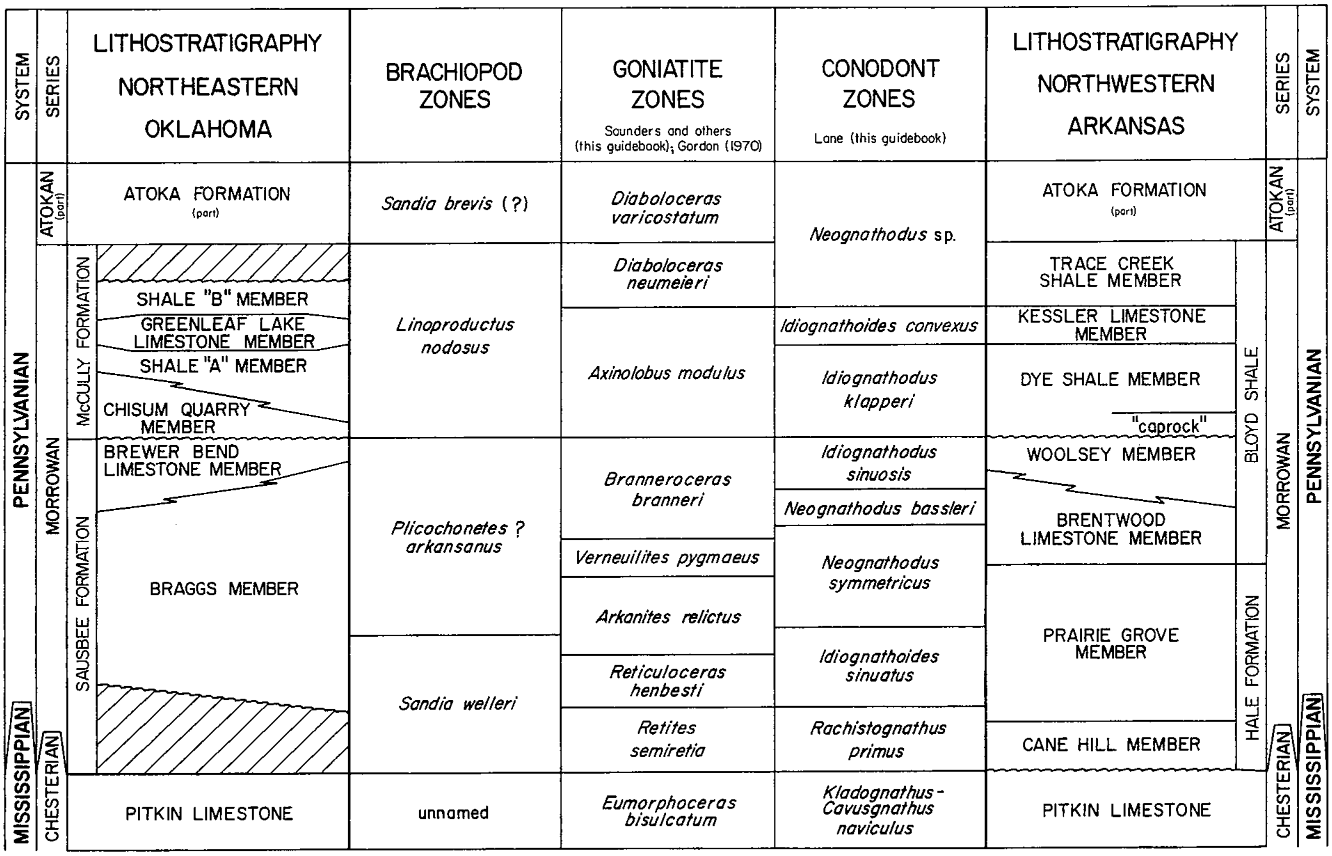

Figure 3. Comparison of brachiopod zones with goniatite and conodont zones.

(Dunbar and Condra), and *Hustedia miseri* Mather do not occur in higher strata.

The interval defined by this zone corresponds to the upper one-half of the Prairie Grove Member of the Hale Formation and to the Brentwood Limestone and Woolsey Members of the Bloyd Shale in Arkansas and to the upper two-thirds of the Braggs Member and the entire Brewer Bend Limestone Member of the Sausbee Formation in northeastern Oklahoma (fig. 3).

The *Plicochonetes*? *arkansanus* Zone is equivalent to the interval from the *Neognathodus symmetricus* Conodont Zone through the *Idiognathodus sinuosis* Conodont Zone of Lane (this guidebook) and to the interval from the middle and upper parts of the *Arkanites relictus* Goniatite Zone through the *Branneroceras branneri* Goniatite Zone of Saunders and others (this guidebook).

Linoproductus nodosus Zone

This zone is named after one of the most easily recognized brachiopod species in the Morrowan Series. *Linoproductus nodosus* (Newberry) is characterized by a single row of large body spines located on the venter of the pedicle valve (pl. 2, figs. 13, 14). This upper Morrowan species is widespread in North America and has been identified from Arizona, Arkansas, Idaho, Kentucky, Montana, New Mexico, Nevada, Oklahoma, Texas, Utah, and West Virginia. *L. nodosus* also occurs in South America in Bolivia, Colombia, and Venezuela. Its ancestor, herein referred to as *Linoproductus* n. sp. A (pl. 2, fig. 5), occurs in the underlying *Plicochonetes*? *arkansanus* Zone. This unnamed linoproductid is characterized by a distinctive, alternating, double row of ventral spines instead of the central row.

In addition to the name bearer, the *Linoproductus nodosus* Zone is identified by the more common species *Anthracospirifer newberryi* Sutherland and Harlow, *Anthracospirifer* cf. *A. tanoensis* Sutherland and Harlow, *Pulchratia*? *picuris* Sutherland and Harlow, *P.*? *pustulosa* Sutherland and Harlow, *Antiquatonia coloradoensis* (Girty), and *Neochonetes platynotus* (White). Rarer forms include *Zia* n. sp. A aff. *Z. novamexicana* Sutherland and Harlow, and *Meekella* n. sp. A. Species that occur in the lower Morrowan strata but that are far more common in the *Linoproductus nodosus* Zone include *Schizophoria oklahomae* Dunbar and Condra, *Desmoinesia nambeensis* Sutherland and Harlow, *Buxtonia grandis* Sutherland and Harlow, and *Linoproductus pumilus* Sutherland and Harlow.

The *Linoproductus nodosus* Zone corresponds to the interval from the base of the Dye Shale through the Trace Creek Shale Members of the Bloyd Shale in northwestern Arkansas and to the entire McCully Formation in northeastern Oklahoma.

The base of the *Linoproductus nodosus* Zone coincides with the regional disconformity at the base of the Dye Shale Member ("caprock") in northwestern Arkansas and at the base of the Chisum Quarry Member of the McCully Formation in Oklahoma. It is not surprising therefore that it should represent the most pronounced faunal break within the Morrowan Series in the Ozarks. The *Linoproductus nodosus* Zone contains 10 species of brachiopods that are not known to occur lower stratigraphically and at least 17 species of brachiopods that are not known to occur higher.

The base of the *Linoproductus nodosus* Zone conforms with the break between the *Branneroceras branneri* Goniatite Zone below and the *Axinolobus modulus* Zone above. The upper part of the *Linoproductus nodosus* Zone is equivalent to the

Diaboloceras neumeieri Zone of Saunders and others (this guidebook). The *Linoproductus nodosus* Zone also is equivalent to the interval of the *Idiognathodus klapperi*, the *Idiognathoides convexus*, and the lower part of the *Neognathodus* n. sp. Conodont Zones of the Lane (this guidebook).

Comparison of Morrowan and Atokan Faunas

The upper ranges of the brachiopod species that define the *Linoproductus nodosus* Zone are not firmly established. The highest persistently fossiliferous unit in the Bloyd Shale in northwestern Arkansas is the Kessler Limestone Member, which is roughly equivalent to the Greenleaf Lake Limestone Member in northeastern Oklahoma. The overlying Trace Creek Shale Member and the shale "B" member are predominantly dark-gray shales that bear very sparse and scattered calcareous, fossiliferous shale from which we have recovered nondiverse and poorly preserved brachiopod faunules. The top of the Bloyd Shale in Arkansas corresponds to a regional transition to the terrigenous clastic facies of the Atoka Formation, and the upper Morrowan in northeastern Oklahoma is unconformably overlain by the nonmarine Atokan strata. Only sparse and mostly poorly preserved brachiopods are known from the Atoka Formation in the Ozarks.

A moderately fossiliferous marine facies continues from upper Morrowan strata into rocks of Atokan age in northern New Mexico, however. The upper Morrowan portion of the La Pasada Formation in that area has yielded 41 species of brachiopods, only 4 of which are known to range into the overlying Atokan part of the La Pasada Formation (Sutherland and Harlow, 1973). We have included all of the Atokan equivalents in northern New Mexico in the *Sandia brevis* Zone (Sutherland and Henry, 1975, and in press), which has a closer affinity to the early Desmoinesian brachiopod faunas than to the late Morrowan faunas.

Diagnostic species of the *Sandia brevis* Zone are the name-bearer *S. brevis* Sutherland and Harlow, *S. santafeensis* Sutherland and Harlow, *Neochonetes henryi* Sutherland and Harlow, *N. whitei* Sutherland and Harlow, and *Desmoinesia ingrata* (Girty). This zone in northern New Mexico also contains the following four species that range downward into the *Linoproductus nodosus* Zone in both the Ozarks and northern New Mexico: *Anthracospirifer tanoensis* Sutherland and Harlow, *A. newberryi* Sutherland and Harlow, *Antiquatonia coloradoensis* (Girty), and *Cleiothyridina milleri* Sutherland and Harlow.

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Plate 1

Characteristic brachiopods of *Sandia welleri* Zone.

Fig. 1.— *Sandia welleri* (Mather). OU 7256, loc. M1-6; upper part of Braggs Member of Sausbee Formation; *a,* pedicle, *b,* anterior, *c,* brachial, *d,* right-lateral views of typical unexfoliated mature specimen, x1.

Fig. 2.— *Schizophoria altirostris* (Mather). OU 7228, loc. M97-5; upper part of Braggs Member of Sausbee Formation; *a,* interior, *b,* exterior, *c,* anterior views of pedicle valve of large, mature specimen, x1.

Fig. 3.— *Tesuquea morrowensis* (Mather). USNM 208813, topotype, USGS loc. 2853 (green); lower part of Prairie Grove Member of Hale Formation; *a,* pedicle, *b,* anterior, *c,* right-lateral, *d,* posterior views of mature specimen with missing trail, x1.

Fig. 4.— *Tesuquea formosa* Sutherland and Harlow. USNM 208810, USGS loc. 1207-PC; Brentwood Limestone Member of Bloyd Shale; *a,* pedicle, *b,* anterior, *c,* right-lateral, *d,* posterior views of mature specimen with part of trail intact, x1.

Fig. 5.— *Hustedia brentwoodensis* Mather. USNM 208833, USGS loc. 2849 (green); Brentwood Limestone Member of Bloyd Shale: *a,* pedicle, *b,* right-lateral, *c,* anterior views of mature, exfoliated specimen, x2.

Fig. 6.— *Hustedia miseri* Mather. USNM 208834, USNM loc. 9284; Braggs Member of Sausbee Formation; *a,* pedicle; *b,* right-lateral, *c,* anterior, *d,* posterior views of mature specimen, x2.

Fig. 7.— *Anthracospirifer matheri* (Dunbar and Condra). USNM 208835, topotype, USGS loc. 2810 (green); disarticulated pedicle valve of mature specimen, x1.

Fig. 8.— *Echinaria* n. sp. A. OU 7267, loc. M109-4; upper part of Prairie Grove Member of Hale Formation; *a,* right-lateral, *b,* pedicle, *c,* anterior, *d,* posterior views of mature specimen, x1.

Fig. 9.— *Orthotetes* n. sp. A, aff. *O. occidentalis* N. G. Lane. USNM 297739, USGS loc. 1996B-PC; Brentwood Limestone Member of Bloyd Shale; *a,* pedicle, *b,* left-lateral, *c,* anterior views of mature specimen, x1.

Fig. 10.— *Beecheria*? *bilobatum* (Mather). OU 7323, UA loc. 115 (=OU loc. M110-20); Brentwood Limestone Member of Bloyd Shale; *a,* pedicle, *b,* left-lateral, *c,* anterior views of mature specimen, x1.

The following abbreviations are used in the plates:
USNM, U.S. National Museum (of Natural History); refers either to Register for Invertebrate Paleontology Collections or to Locality Register. *USGS,* U.S. Geological Survey locality registers; *PC* refers to Permo-Carboniferous Locality Register (specimens marked with blue paper tabs); *green* refers to "Old Series" Locality Register (specimens marked by green paper tabs). *OU,* University of Oklahoma Invertebrate Paleontological Repository; locality given after such a register number will be a University of Oklahoma locality, unless otherwise stated. *UA,* University of Arkansas collecting locality. All photographed specimens are plesiotypes unless otherwise indicated.

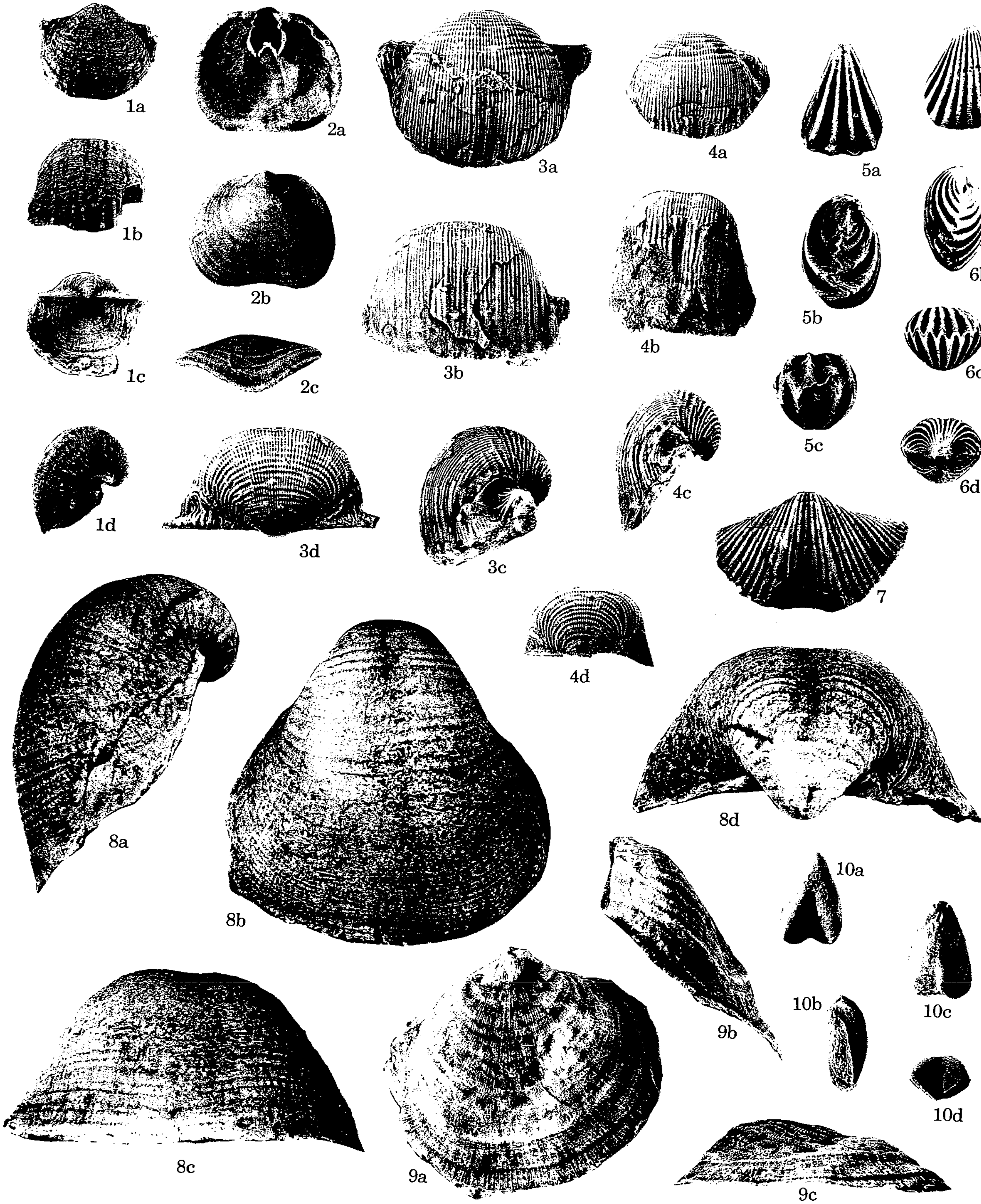
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Plate 2

Characteristic brachiopods of *Plicochonetes*? *arkansanus* Zone and *Linoproductus nodosus* Zone.

Figs. 1-3.— *Plicochonetes*? *arkansanus* (Mather). *1,* OU 7249, loc. M97-5; upper part of Braggs Member of Sausbee Formation; *a,* pedicle, *b,* left-lateral, *c,* posterior, *d,* anterior views of large, mature specimen, x3. *2,* OU 7250, loc. M97-5; upper part of Braggs Member of Sausbee Formation; interior view of brachial valve of large, mature specimen, x3. *3,* OU 7251, loc. M1-5; upper part of Braggs Member of Sausbee Formation; interior of incomplete mature pedicle valve, x3.

Fig. 4.— *Punctospirifer morrowensis* Sutherland and Harlow. OU 7314, loc. M12-8; upper part of Braggs Member of Sausbee Formation; *a,* pedicle, *b,* anterior views of large, gerontic specimen, x2.

Fig. 5.— *Linoproductus* n. sp. A. OU 7430, loc. M100-11; Brentwood Limestone Member of Bloyd Shale; pedicle valve of mature specimen, x1.

Figs. 6-8.— *Eolissochonetes* n. sp. A. *6,* OU 7238, loc. M26-9; middle part of Braggs Member of Sausbee Formation; *a,* pedicle, *b,* anterior views of mature specimen, x3. *7,* OU 7241, loc. M29-6; middle part of Braggs Member of Sausbee Formation; interior of pedicle valve of mature specimen, x3. *8,* OU 7243, loc. M29-6; Braggs Member of Sausbee Formation; interior of brachial valve, x3.

Fig. 9.— *Scoloconcha*? *globosa* (Mather). OU 7254, loc. M1-6; upper part of Braggs Member of Sausbee Formation; *a,* pedicle, *b,* left-lateral, *c,* anterior views of unexfoliated specimen, x3.

Fig. 10.— *Schizophoria oklahomae* Dunbar and Condra. OU 7224, loc. M17-14; Chisum Quarry Member of McCully Formation; interior of pedicle valve of mature specimen, x1.

Fig. 11.— *Rhynchopora magnicosta* Mather. USNM 208831, loc. 8179-PC; Brentwood Limestone Member of Bloyd Shale; *a,* right-lateral, *b,* pedicle, *c,* anterior, *d,* brachial views of typical, mature specimen, x1.

Fig. 12.— *Spirifer goreii* Mather. OU 7441, loc. M99-2; Greenleaf Lake Limestone Member of McCully Formation; pedicle valve of mature, slightly crushed specimen, x1.

Figs. 13, 14.— *Linoproductus nodosus* (Newberry). *13,* OU 7279, loc. M105D-13; Kessler Limestone Member of Bloyd Shale; incomplete pedicle valve, x1. *14,* OU 7280, loc. M30-6; shale "A" member of McCully Formation; pedicle valve of immature specimen, x1.

Fig. 15.— *Desmoinesia nambeensis* Sutherland and Harlow. OU 7442, loc. M29-14; Greenleaf Lake Limestone Member or shale "A" member of McCully Formation; *a,* pedicle, *b,* anterior views of mature specimen, x1.

Fig. 16.— *Antiquatonia coloradoensis* (Girty). OU 7271, loc. M105D-13; Kessler Limestone Member of Bloyd Shale; pedicle view of mature specimen, x1.

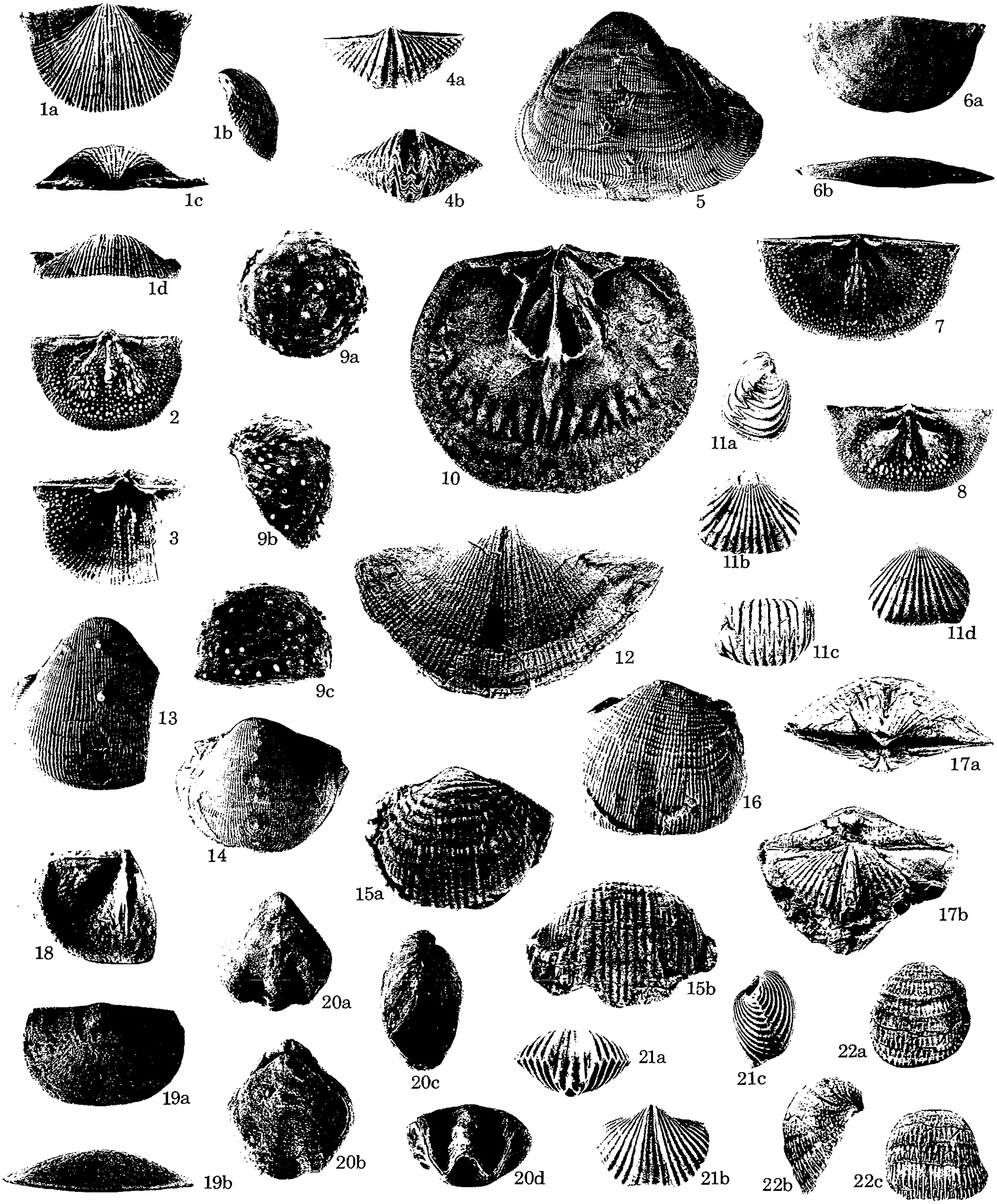
Fig. 17.— *Anthracospirifer newberryi* Sutherland and Harlow. USNM 208832, loc. 8424-PC; basal part of Dye Shale Member of Bloyd Shale ("caprock" of Baldwin coal bed); *a,* posterior, *b,* brachial views of incomplete mature specimen, x1.

Figs. 18, 19.— *Neochonetes*? *platynotus* (White). *18,* OU 7353, loc. M1-20; Greenleaf Lake Limestone Member of McCully Formation; interior view of incomplete mature pedicle valve, x2. *19,* OU 7232, loc. M29-10 or 11; Chisum Quarry Member of McCully Formation; *a,* pedicle, *b,* anterior views of mature specimen, x2.

Fig. 20.— *Composita biplicata* Mather. OU 7440, loc. M12-8, sta. C; upper part of Braggs Member of Sausbee Formation; *a,* pedicle, *b,,* brachial, *c,* right-lateral, *d,* anterior views of mature specimen, x1.

Fig. 21.— *Anthracospirifer* cf. *A. tanoensis* Sutherland and Harlow. OU 7305, loc. M105D-13; Kessler Limestone Member of Bloyd Shale; *a,* anterior, *b,* pedicle, *c,* left-lateral views of typical specimen, x1.

Fig. 22.— *Pulchratia*? *picuris* Sutherland and Harlow. OU 7420, loc. M17-14; Chisum Quarry Member of McCully Formation; *a,* pedicle, *b,* right-lateral, *c,* anterior views of mature, unexfoliated specimen.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UPPER MISSISSIPPIAN AND LOWER AND MIDDLE PENNSYLVANIAN AMMONOID BIOSTRATIGRAPHY OF NORTHERN ARKANSAS

W. Bruce Saunders,[1] **Walter L. Manger,**[2] and **Mackenzie Gordon, Jr.**[3]

Abstract—Upper Mississippian and Lower and Middle Pennsylvanian strata in northern Arkansas contain a rich succession of ammonoid assemblages that provides a firmly based reference for intercontinental correlation. The Upper Mississippian (Chesterian) sequence includes four major ammonoid assemblages, which characterize the upper two-thirds of the Moorefield Formation and Batesville Sandstone (*Goniatites-Girtyoceras-Lusitanites*) and the Fayetteville (*Cravenoceras-Eumorphoceras-Tumulites*), Pitkin (*Cravenoceras-Eumorphoceras*), and Imo (*Fayettevillea-Eumorphoceras-Delepinoceras*) Formations. The Lower-Middle Pennsylvanian (Morrowan) Hale and Bloyd Formations, which unconformably overlie the Chesterian sequence, contain eight distinctive ammonoid assemblages, which are characterized, in ascending order, by combinations of *Retites, Reticuloceras, Arkanites, Cancelloceras,* and *Verneuilites* in the Hale Formation, overlain by *Branneroceras, Axinolobus,* and *Diaboloceras* assemblages in the Bloyd Formation.

In terms of the standard European Carboniferous succession, the base of the Chesterian Series approximates the base of the Upper Viséan $P_{1}c$ Subzone. The Ruddell Shale Member of the Moorefield Formation and the Batesville Sandstone are roughly equivalent to the P_2 Zone. The Viséan-Namurian boundary approximates the base of the Fayetteville Formation at most localities; most of the Fayetteville and the lower part of the Pitkin Formation correlate to the Namurian E_1 Zone. The upper Pitkin is of $E_{2}a$ age; ammonoids of the Imo Formation correlate with Namurian $E_{2}b$ and $E_{2}c$. The H_1 and H_2 intervals are missing, owing to erosion at the Mississippian-Pennsylvanian boundary. The overlying Pennsylvanian Morrowan Series includes a basal $R_{1}a$ assemblage, succeeded by R_1, R_2, and G_1 equivalents in the Hale Formation. The lower part of the Brentwood Limestone Member of the Bloyd Formation is also of G_1 age and represents the top of the Namurian in the Arkansas sequence. The middle and upper Brentwood Limestone, the Dye Shale, and the Kessler Limestone Members of the Bloyd are equivalent to Westphalian A (G_2 Zone), and the Trace Creek Shale Member at the top of the Bloyd is correlated with Westphalian B.

INTRODUCTION

During Late Mississippian and Early Pennsylvanian time, the major ammonoid lineages, which had earlier been sparsely represented, achieved considerable diversity and became a major component of marine faunas. The richest, most complete ammonoid successions of this age occur in the North American Midcontinent, the South Urals, Great Britain, and North Africa. The North American Midcontinent succession constitutes the Upper Mississippian (Chesterian) and Lower Pennsylvanian (Morrowan) in northern Arkansas, where hundreds of ammonoid localities have yielded assemblages from at least 20 different zones. Although work on the Midcontinent successions was begun at the turn of the century (Smith, 1896, 1903; Girty, 1909, 1911), relatively little progress was made in the comprehensive study of these faunas until about 25 years ago. Since that time, scores of separate studies, including a number of monographs, have been based on the ammonoids of this sequence. Efforts in this direction are continuing, although recently increased attention has been given to intercontinental faunal comparisons (Saunders and Manger, 1976) and to the integration and synthesis of biostratigraphic data based on such diverse groups as ammonoids, conodonts, and foraminifers (Brenckle and others, 1977).

[1]Department of Geology, Bryn Mawr College, Bryn Mawr, Pennsylvania.

[2]Department of Geology and University Museum, University of Arkansas, Fayetteville, Arkansas.

[3]U.S. Geological Survey, U.S. National Museum, Washington, D.C.

UPPER MISSISSIPPIAN (CHESTERIAN) AMMONOIDS

The Upper Mississippian of the American Midcontinent is dominantly marine shale and bioclastic, biohermal limestone with only scattered intervals of quartz sandstone. Individually, most of these units are relatively thin, but they are widespread laterally. The Chesterian units in northern Arkansas conform to this pattern, and the nomenclature and stratigraphic relationships are generally well known and agreed upon. The Chesterian formations dealt with herein comprise a cumulative total of approximately 900-1,200 feet (275-365 m) of strata, divided into the Moorefield Formation (upper two-thirds), Batesville Sandstone, Fayetteville Formation, Pitkin Formation, and Imo Formation, in ascending order. Figure 1 shows the locations of the type sections for these units. The base of this interval approximates the base of the upper Viséan $P_{1}c$ Subzone of the northwest European Carboniferous section. The actual base of the upper Visean would correspond roughly with the base of the Moorefield Formation. The Viséan-Namurian boundary lies at or a short distance above the base of the Fayetteville Formation. The top of the Mississippian section in Arkansas varies in age locally, owing to the effects of erosion within the Mississippian-Pennsylvanian unconformity. However, the entire Chesterian thickens markedly in a direction eastward from northwestern Arkansas, and substantially younger Chesterian units are preserved in north-central Arkansas. In the subsequent discussion, the Upper Mississippian ammonoid assemblages (fig. 2; table 1) are treated individually, in ascending order, beginning with the Moorefield Formation.

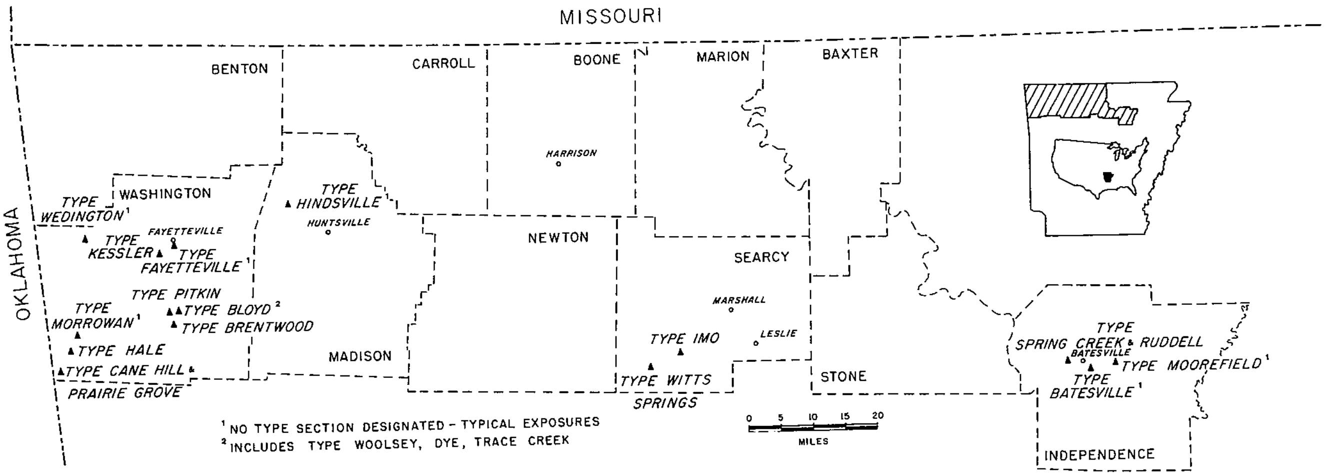

Figure 1. Locations of type localities of Upper Mississippian (Chesterian) and Lower and Middle Pennsylvanian (Morrowan) stratigraphic units in northern Arkansas.

Moorefield Formation

In the type area in Independence County, north-central Arkansas, the Moorefield Formation, roughly 325 feet (100 m) thick, is divided into two members. The lower one, the Spring Creek Member, about 130 feet (40 m) thick, is a dark-gray calcareous siltstone or mudstone, which in places grades into gray-black argillaceous limestone. This contains the typical Moorefield brachiopod-mollusk fauna described by Girty (1911). The upper-middle part also contains ammonoids of the *Goniatites americanus* Zone of Gordon (1970, 1971). The greater part of the Spring Creek Member is Meramecian in age.

Brachiopods are virtually absent in the upper 20 feet (6 m) of the Spring Creek Member at Moorefield, but the pelecypods *Caneyella richardsoni* Girty and *Posidonia becheri* Bronn are common to abundant in some beds, generally associated with fairly large imprints of shells of *Goniatites multiliratus* Gordon. *G. multiliratus* is commonly associated with *Girtyoceras meslerianum* (Girty) in the basal part of the Caney Shale of Oklahoma, constituting the lowest undoubted Chesterian ammonoid assemblage in the United States.

The Ruddell Shale Member of the Moorefield Formation, which is about 195 feet (60 m) thick south of Moorefield, is predominantly a dark-green to gray, soft clay shale containing tan phosphate nodules. The lower part of the member contains some concretionary calcareous siltstone and silty limestone beds, and locally 2 or 3 limestone beds are present near the top. Ammonoids occur almost throughout the shale; they are common in the calcareous siltstone near the base and in nodules near the middle of the member, and are scarce in the upper part.

Common Ruddell species include *Goniatites granosus* Portlock and *Lusitanites subcircularis* (S. A. Miller), both of which characterize the upper *Goniatites* (P_2) Zone of northwest Europe, which is late Viséan in age (pl. 1). *Neoglyphioceras newsomi* (Smith) is limited to the calcareous siltstone and limestone beds in the lower part of the member.

Batesville Sandstone

The Batesville is a tan, medium-grained, calcareous quartzose sandstone, 75 feet (23 m) thick where penetrated by a drill hole at Deane Mountain, Independence County. It contains a fairly abundant invertebrate fauna of Chesterian age (Girty, 1915), including *Goniatites granosus* Portlock and *Neoglyphioceras caneyanum* (Girty). The Hindsville Limestone, commonly regarded as a basal member of the Batesville Sandstone, also yields rare *Goniatites* and *Lusitanites subcircularis* in northwestern Arkansas. These two units, like the Moorefield Formation, correlate with the Viséan P_2 Zone of northwest Europe.

Pre-Namurian Beds in Fayetteville Formation

At Marshall, north-central Arkansas, the Batesville Sandstone–Fayetteville Formation contact coincides precisely with the Visean-Namurian boundary of Europe in that the *Goniatites granosus* assemblage is superseded by the *Cravenoceras-Tumulites* assemblage at this horizon. Not so in Independence County, where the *Cravenoceras-Tumulites* fauna begins about 55 feet (17 m) above the top of the Batesville Sandstone. From the lower 11 feet (3.3 m) of the Fayetteville Formation at localities on the south side of the White River, specimens of *Lusitanites subcircularis* (S. A. Miller), *Neoglyphioceras crebiliratum* Gordon, and *Girtyoceras* cf. *G. ornatissimum* Miller and Youngquist were recovered. This is the highest Visean assemblage in this area.

A similar situation exists in Washington County, northwestern Arkansas, where the lower 15 feet (4.5 m) of the Fayetteville Formation is late Visean in age. Nearly all of the Fayetteville invertebrates described by Girty (1910) came from this pre-Namurian interval. These beds also contain the ammonoids *Goniatites granosus* Portlock and *Lusitanites subcircularis* (S. A. Miller).

Fayetteville Formation

In its type area in Washington County, northwestern Arkansas, the Fayetteville Formation is a black, concretionary marine shale ranging up to 200 feet (60 m) thick. The Fayetteville Formation is informally divided into lower and upper portions by the presence of a persistent, deltaic quartz arenite referred to the Wedington Sandstone Member. The maximum thickness for the Wedington Member is approximately 80 feet (24 m) in surface exposures through northern Arkansas. In some places, the Fayetteville is fossiliferous in the lower part.

The fauna is primarily molluscan, dominated by cephalopods, including 10 ammonoid genera, numerous nautiloids, and several genera of aulococerids (Gordon, 1965, 1966). The cephalopods occur as solitary, pyritized casts in the shale or in ironstone concretions, similar to the "bullion" or calcareous-nodule occurrences in Namurian strata in Europe. The upper portion of the Fayetteville in northwestern Arkansas is only sparsely fossiliferous, except for scattered, thin limestone stringers rich in brachiopods and bryozoans. Going eastward, the Fayetteville Formation thickens to more than 300 feet (90 m) in the vicinity of Marshall, Searcy County, where the upper 100 feet (30 m) are distinguished by regularly alternating layers of shale and sparsely fossiliferous dark, fine-grained limestone.

Although the Fayetteville ammonoid fauna is dominated by cravenoceratids and girtyoceratids, numerous other genera are present (table 1). Fayetteville ammonoids have been included in studies by Gordon (1960, 1965), McCaleb and others (1964), Saunders (1964), Drahovzal and Quinn (1972), and Manger and Quinn (1972). Correlation of the Fayetteville Formation to the basal Namurian Pendleian Stage (E_1) of western Europe is based primarily on the combined presence of *Cravenoceras* and girtyoceratids, notably *Eumorphoceras plummeri* Miller and Youngquist and *Tumulites varians* McCaleb, Quinn and Furnish (pl. 2). The latter species is very close to the European E_1b-c index taxon *Tumulites pseudobilinque* (Bisat). In addition to western Europe, equivalent ammonoid assemblages are represented in the South Urals (Ruzhencev and Bogoslovskaya, 1971), Algeria (Pareyn, 1962), and the geosynclinal shale sequences in the western United States (Miller and Furnish, 1940; Youngquist, 1949; Gordon, 1964, 1970).

Pitkin Formation

The Pitkin Formation is a gray, fossiliferous, biostromal limestone approximately 50 feet (15 m) thick at its type locality in Washington County. In this area, the upper surface of the Pitkin represents the top of the Mississippian, being unconformably overlain by the Lower-Middle Pennsylvanian Morrowan Series. The Pitkin thickens eastward to approximately 300 feet (90 m) near Marshall, Searcy County. In this eastern area of outcrop, the thickened upper portion of the Pitkin has been shown to be younger than the lower portion to the west on the basis of conodonts (Lane, 1967), and this agrees with available ammonoid data.

The ammonoid information available regarding the lower Pitkin in its type area is sparse; only 3 fragments of *Cravenoceras* sp. and 1 *Eumorphoceras* sp. have been recovered, in spite of years of intensive searching. However, approximately 100 miles to the east, on Lick Mountain in Newton County, a rich ammonoid assemblage has been recovered from the lower Pitkin that includes *Cravenoceras, Syngastrioceras, Metadimorphoceras,* and *Trizonoceras.* This fauna most closely resembles that of the underlying Fayetteville Formation and is regarded as being equivalent to the Upper Pendleian Stage (E_1) of Europe.

An important ammonoid fauna described by McCaleb and others (1964) occurs in the upper part of the thickened Pitkin, 1 mile east of Leslie, Searcy County, which includes *Eumorphoceras bisulcatum* Girty and *Cravenoceras richardsonianum* (Girty). This interval, known as the *Eumorphoceras bisulcatum-Cravenoceras richardsonianum* Zone (Saunders, 1973), represents an important and well-established biostratigraphic reference. On the basis of ammonoids, it correlates to the upper Caney (Sand Branch Member) in Oklahoma (Girty, 1909) and to equivalent strata

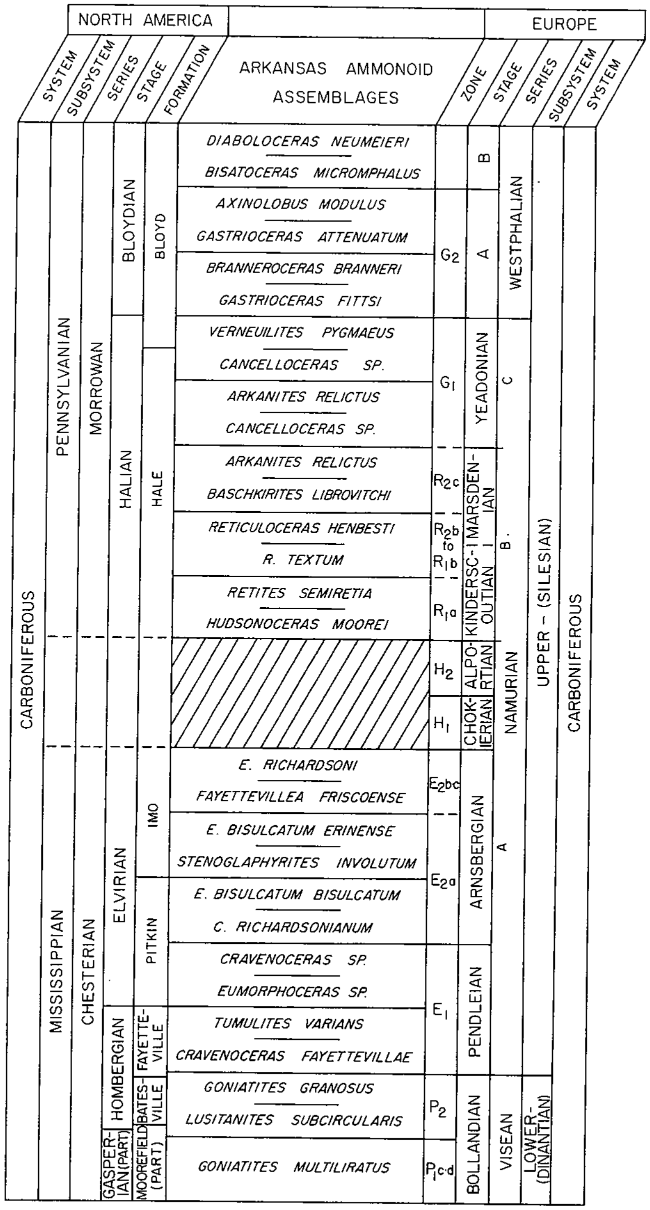

Figure 2. Correlation of Upper Mississippian (Chesterian) and Lower and Middle Pennsylvanian (Morrowan) stratigraphic units in North American Midcontinent with subdivisions of standard European Carboniferous, showing successions of ammonoid assemblages present in northern Arkansas.

in California (Gordon, 1964) and Texas (McCaleb and others, 1964); and on the basis of conodonts (*Adetognathus unicornis* Rexroad and Burton), it correlates to the Grove Church Shale, the youngest interval in the type Chesterian (Lane, 1967). This interval is also widely represented in Europe, as the *Eumorphoceras bisulcatum* s.s. (E_2a) Zone of the Arnsbergian Stage (see Yates, 1962; Korejwo, 1969).

Imo Formation

The upper Pitkin Formation is overlain by a fissile black shale, the "upper Pitkin Shale" of Gordon (1965), which has yielded crushed ammonoids identified as *Eumorphoceras* cf. *E. bisulcatum erinense* Yates. Additionally, a thin, phosphatic

Table 1.—Ammonoid Taxa in Upper Mississippian (Chesterian) Strata in Northern Arkansas

IMO FORMATION

Fayettevillea friscoense (Miller & Owen, 1944)
Fayettevillea bransoni (Saunders, 1973)
Cravenoceras mapesi Saunders, 1973
Rhadinites miseri (Gordon, 1965)
Eumorphoceras richardsoni McCaleb, Quinn & Furnish, 1964
Eumorphoceras imoense Saunders, 1973
Peytonoceras ornatum Saunders, 1966
Anthracoceras discus Frech, 1899
Delepinoceras bressoni Ruzhencev, 1958
Syngastrioceras imprimis Saunders, 1973
Somoholites cadiconiformis (Wagner-Gentis, 1963)
Metadimorphoceras saundersi Manger & Quinn, 1972

"Upper Pitkin Shale"

Cravenoceras sp.
Eumorphoceras cf. *E. bisulcatum erinene* Yates, 1962

Stenoglaphyrites involutum (Gordon, 1965)
Cravenoceras sp.

PITKIN FORMATION

Upper Pitkin member

Eumorphoceras bisulcatum Girty, 1909
Cravenoceras richardsonianum (Girty, 1909)

Lower Pitkin member

Cravenoceras sp.
Eumorphoceras sp.
Arcanoceras furnishi (Saunders, 1964)
Syngastrioceras sp.
Metadimorphoceras aff. *M. saleswheelense* (Moore, 1939)
Trizonoceras n. sp.

FAYETTEVILLE FORMATION

Cravenoceras fayettevillae Gordon, 1965
Cravenoceras lineolatum Gordon, 1965
Eumorphoceras plummeri Miller & Youngquist, 1948
Tumulites varians McCaleb, Quinn & Furnish, 1964
Paracravenoceras ozarkense Gordon, 1960
Fayettevillea planorbis Gordon, 1960
Dombarites mapesi (Drahovzal & Quinn, 1972)
Arcanoceras furnishi (Saunders, 1964)
Cluthoceras glicki Gordon, 1965
Cluthoceras pisiforme (Gordon, 1965)
Pronorites baconi (Miller, Youngquist & Nielson, 1952)
Metadimorphoceras wiswellense (Moore, 1939)

FAYETTEVILLE FORMATION (lower member)

Goniatites granosus Portlock, 1843
Lusitanites subcircularis (S. A. Miller, 1889)
Neoglyphioceras crebriliratum Gordon, 1965
Girtyoceras cf. *G. ornatissimum* Miller & Youngquist, 1948
Girtyoceras cf. *G. jasperense* Gordon, 1965

BATESVILLE SANDSTONE

Goniatites choctawensis Shumard, 1863
Goniatites granosus Portlock, 1843
Neoglyphioceras caneyanum (Girty, 1909)
Lusitanites subcircularis (S. A. Miller, 1889)

MOOREFIELD FORMATION

Middle Ruddell Shale Member

Goniatites granosus Portlock, 1843
Goniatites choctawensis Shumard, 1863
Lusitanites subcircularis (S. A. Miller, 1889)
Girtyoceras limatum (Miller & Faber, 1892)
Ferganoceras elegans Librovitch, 1957
Cravenoceras sp.
Metadimorphoceras wiswellense (Moore, 1939)

Table 1.— *Continued*

Lower Ruddell Shale Member

Goniatites granosus Portlock 1843
Goniatites choctawensis Shumard, 1863
Neoglyphioceras newsomi (Smith, 1903)
Girtyoceras limatum (Miller & Faber, 1892)
Sudeticeras sp.

Upper Spring Creek Member

Goniatites multiliratus Gordon, 1962

pebble bed in this shale has been the source of small, involute ammonoids upon which the taxon *Stenoglaphyrites involutum* (Gordon) is based. The exact age of these ammonoids is uncertain, but they probably correlate to late E_2a or early E_2b of the standard Namurian sequence.

Overlying this shale interval in north-central Arkansas is the Imo Formation, which, in the lower part, comprises sandstones and concretionary shales with lenticular limestones and grades upward into silty shale and sandstone. The lower concretionary shale interval of the Imo has yielded an extremely diverse, well-preserved, molluscan-dominated invertebrate fauna. Most of the fossils occur singly in the shale or in ironstone concretions. The molluscan shell material in most cases has been replaced by calcium phosphate, preserving sculpture and growth lines in exquisite detail. The cephalopods consist primarily of living chambers filled with micritic ironstone that were solidified prior to shale compaction, which, in most specimens, crushed the septate portion of the shell. Unusual, irregular, concretionary masses up to 40 cm long occur in the shale, which are distinguished by three-dimensional ammonoids exposed on the surface. All combinations of Imo ammonoid taxa occur in direct association in these concretionary masses, indicating that this interval probably does not contain a zonal succession of ammonoids. The Imo ammonoids have received considerable scrutiny (Furnish and others, 1964; McCaleb and others, 1964; Gordon, 1965; Saunders, 1966, 1971, 1973, 1975; Manger and Quinn, 1972), but Imo crinoids (Burdick and Strimple, 1973), phyllocarids (Copeland, 1967), nautiloids (Gordon, 1965), plant petrifications (Taylor and Eggert, 1967), and palynomorphs (Sullivan and Mischell, 1971) have also been studied.

The Imo ammonoid assemblage is dominated numerically by *Anthracoceras discus* Frech (approximately 60 percent; Saunders, 1975), a compressed involute form indistinguishable from specimens originally described from the Coal Measures of Silesia (Frech, 1899; Miller and Furnish, 1958). Taxonomically, however, the Imo fauna is characterized by advanced, diverse cravenoceratids (*Fayettevillea, Cravenoceras, Rhadinites*) and girtyoceratids (*Eumorphoceras, Peytonoceras*) (pl. 3). On this basis, this interval has been named the *Eumorphoceras richardsoni–Fayettevillea friscoense* Zone (Saunders, 1973). In addition, rare specimens of the index taxon *Delepinoceras* occur, which are virtually identical to specimens from California, Spain, North Africa, and the South Urals. Early representatives of the Upper Carboniferous to Permian genera *Somoholites* and *Syngastrioceras* also occur in the Imo, as well as specimens of the cosmopolitan genus *Metadimorphoceras.*

The age of the Imo ammonoids is established by the presence of advanced, evolute cravenoceratids (*Fayettevillea friscoense* Miller and Owen) and girtyoceratids

(*Eumorphoceras richardsoni* McCaleb, Quinn, and Furnish), which are similar and equivalent to *F. darwenense* (Moore) and *E. rostratum* Yates, which occur together in Zone E_2c (e.g., Samlesbury Bottoms section, Yorkshire) of Great Britain (Moore, 1946). However, in Europe, Zone E_2b is characterized by *Cravenoceratoides*, and Zone E_2c, by *Nuculoceras*. Neither of these genera has been found in the Imo, and thus the unit has been regarded as E_2b-c undifferentiated (Saunders, 1973, 1975). It should be noted that the Rhoda Creek Formation of southeastern Oklahoma has an ammonoid fauna that is equivalent, although less diverse, than that of the Imo Formation (Saunders, 1973, 1975). Imo equivalents outside North America occur in Great Britain, France, Belgium, Holland, Spain, Germany, Poland, Yugoslavia, the Donets Basin, the South Urals (=Zone $_1C_2$), central Asia, China, and the Algeria-Morocco border area; details of these occurrences can be found in Yates (1962), Korejwo (1969), Ruzhencev and Bogoslovskaya (1971), and Saunders (1973).

MISSISSIPPIAN-PENNSYLVANIAN UNCONFORMITY

The sequence of Upper Mississippian and Lower Pennsylvanian ammonoid assemblages in northern Arkansas comprises a relatively complete ammonoid zonal succession with one notable exception: no representative of ammonoids diagnostic of the *Homoceras* interval has been found in North America. As a result of the Mississippian-Pennsylvanian unconformity, cravenoceratid-dominated Chesterian faunas are succeeded by Morrowan strata characterized by reticuloceratids. In terms of the European Namurian, Arnsbergian (E_2b-c) faunas are overlain by a basal Kinderscoutian (R_1a) assemblage with no record of the intervening Chokierian (H_1) or Alportian (H_2) Stages (fig. 2). However, it should be noted that a few nondiagnostic ammonoids have been found below the first occurrence of reticuloceratids in North America, and that unfossiliferous beds are present above the Imo Formation. Thus, it is possible that additional discoveries may yield *Homoceras*-age ammonoids in northern Arkansas.

LOWER AND MIDDLE PENNSYLVANIAN (MORROWAN) AMMONOIDS

Lower Pennsylvanian (Morrowan) strata contrast markedly with those of the Upper Mississippian, by the predominance of siliciclastic facies. Morrowan sequences of interbedded siltstone, shale, calcareous sandstone, sandy calcarenite, and scattered conglomeratic zones lack a predictable order. In northwestern Arkansas, type Morrowan strata have been subdivided into the Hale and Bloyd Formations, although the Hale and lowermost Bloyd seem to make up a single depositional unit. These formations are further subdivided into numerous members, reflecting alternations of dark shale with other lithologies. Figure 1 shows the locations of the type sections for these units. Individual thicknesses of these Morrowan formations are highly variable, but the cumulative thickness approaches 500 feet (150 m) in northwestern Arkansas.

Recognition of the type Morrowan lithostratigraphic nomenclature has not been possible in the north-central outcrop area because the characteristic member facies are not developed. The Witts Springs Formation has been proposed for the interval equivalent to the upper Hale Formation (Prairie Grove Member) and Bloyd Formation in north-central Arkansas (Glick and others, 1964). The name Cane Hill was elevated from a member of the Hale Formation to designate a single formation that includes all post-Pitkin and pre-Witts Springs strata (Glick and others, 1964). This usage has not been widely accepted, as the name Imo Formation has referred to the highest Chesterian strata above the Pitkin Formation in north-central Arkansas (Saunders, 1973). In addition, no continuity of the Cane Hill interval from the type Morrowan region to north-central Arkansas has been demonstrated. Consequently, at this time, the nomenclature of lowermost Pennsylvanian strata in north-central Arkansas has not been established.

Hale Formation

The Hale Formation is a sequence of variable lithologies constituting the basal portion of the Morrowan Series in its type region, northwestern Arkansas. The Hale is subdivided into a lower Cane Hill Member and an upper Prairie Grove Member (Henbest, 1953; 1962).

Cane Hill strata consist of a distinctive sequence of interbedded siltstone, shale, and fine-grained sandstone with scattered conglomeratic, sandy calcarenite lenses. The member is characteristically a persistent, non-resistant, slope-forming interval averaging 45 feet (14 m) throughout northwestern Arkansas. At the base of the Cane Hill Member is the Mississippian-Pennsylvanian unconformity, which is developed on Chesterian strata and is marked by a thin basal conglomerate. The basal conglomerate contains clasts and reworked fossils from the underlying Chesterian strata, most notably the Pitkin Formation. The interbedded siltstone-shale facies is barren for the most part, except for trace fossils marking both upper and lower surfaces of the siltstone beds. In contrast, fossils, particularly ammonoids and other mollusca, are abundant in the conglomeratic, carbonate-cemented sandstone lenses, which occur unpredictably throughout the unit.

The contact of the Cane Hill and Prairie Grove Members exhibits unequivocal evidence of unconformity in northwestern Arkansas, including basal conglomerate, truncation of strata, reworked faunal elements, and variable contact age. Strata above this contact, referred to the Prairie Grove Member, are much more diverse in lithologic expression than those of the Cane Hill. The Prairie Grove Member is an easily mapped, bluff-forming unit averaging 55 feet (17 m) in thickness in northwestern Arkansas. The most pervasive lithology is carbonate-cemented quartz sandstone, which at some places exhibits a weathered "honeycomb" appearance owing to differential removal of patches of carbonate cement. In addition, light and dark sandy calcarenite occurs within the Prairie Grove interval and at some places makes up the entire member. The Prairie Grove Member also exhibits pebble conglomerates similar to those of the Cane Hill, and lenses of calcirudite are present in the carbonate facies. Fossils, particularly echinoderm detritus, are common to abundant in all Prairie Grove facies. However, ammonoids tend to be restricted to the conglomerate and calcirudite lenses, and they are exceedingly rare in the brachiopod-bryozoan-dominated calcarenites.

Hale Ammonoid Assemblages

Thousands of ammonoids representing 5 assemblages have been collected from localities in the Hale Formation in northwestern Arkansas (table 2). Elements of these assemblages have been described in taxonomic papers by Gordon (1965, 1969), Manger and Quinn (1972), Mather (1915), McCaleb (1964), McCaleb and others (1964), Quinn (1965, 1966a, 1966b), Quinn and others (1962), and Quinn and Saunders (1968). Because most of the Hale ammonoid localities are stratigraphically and geographically isolated, determination of precise biostratigraphic relationships has been difficult. However, through detailed lithostratigraphic studies and correlation of associated conodonts, the succession of these assemblages is now well founded (Manger, 1971). The ammonoid succession is dominated by short-ranging reticuloceratids and gastrioceratids in association with longer ranging forms such as *Syngastrioceras globosum* (Easton), *Pseudopronorites quinni* (Gordon), *Cymoceras*, and *Schartymites* (pl. 4).

The oldest Pennsylvanian ammonoid assemblage in northern Arkansas occurs above the base of the Cane Hill Member. This assemblage is characterized by *Retites semiretia* McCaleb, *Reticuloceras tiro* Gordon, *R. wainwrighti* Quinn, and *Hudsonoceras moorei* Quinn and Saunders, in addition to *Cymoceras, Schartymites,* and *Pseudopronorites* (table 2). This interval, which ranges into strata referable to the basal Prairie Grove Member according to Manger (1971), was referred to as the *Reticuloceras tiro* Zone by Gordon (1969, 1970) and as the *Hudsonoceras* Zone by Quinn (1970). Comparison of the reticuloceratids of this assemblage (*Retites semiretia* McCaleb, *reticuloceras tiro* Gordon, and *R. wainwrighti* Quinn) with those of the British Namurian succession indicates correlation to the lower Kinderscoutian Stage (R_1a). Comparable assemblages are also known from Ireland, West Germany, Belgium, the Donets Basin, and the South Urals (see Bisat and Hudson, 1943; Ruzhencev and Bogoslovskaya, 1975).

An isolated locality in the lower Prairie Grove Member in Washington County has yielded a prolific fauna that apparently has been removed by erosion in most places elsewhere in northern Arkansas. This assemblage is characterized by two similar but distinctive reticuloceratids, *Reticuloceras* ? *henbesti* (Gordon) and *R.*? *textum* (Gordon), in addition to several long-ranging and unidentified forms (table 2). Precise correlation of this interval is unclear at present, but it appears to be equivalent to portions of the late Kinderscoutian (R_1) or early Marsdenian (R_2) Stage.

The most abundant, widespread, and diagnostic ammonoid in the Hale Formation is the advanced reticuloceratid *Arkanites relictus* (Quinn, McCaleb, and Webb). This ammonoid ranges through most of the Prairie Grove Member, but concurrence with other taxa indicates that it is possible to recognize two assemblages within its range. The oldest includes *Arkanites relictus* in addition to the rare but distinctive form *Baschkirites librovitchi* Quinn and Saunders, as well as other characteristic Hale ammonoids. Above this in the Prairie Grove Member an assemblage occurs that combines *A. relictus* with an early gastrioceratid ammonoid, *Cancelloceras*. Although *Arkanites* is not found in the British Namurian succession, it compares favorably with reticuloceratids of the Marsdenian (R_2) and lower Yeadonian (G_1) Stages by possessing deep ventrolateral sulci. This feature progressively becomes more strongly developed upward through the R_2-G_1 succession of Britain. The first appearance of gastrioceratids in the British Namurian occurs in Zone R_2c, with *Gastrioceras lineatum* Wright and *Cancelloceras* marking the beginning of the Yeadonian Stage (G_1). Comparison of the northern Arkansas succession to that of the British Namurian indicates that the older *Arkanites relictus-Baschkirites librovitchi* assemblage correlates to some part of the Marsdenian Stage (R_2) and the *A. relictus-Cancelloceras* assemblage to the upper Marsdenian (R_2c) or the Yeadonian Stage, Zone G_1a. It should be noted that the *Arkanites relictus-Cancelloceras* assemblage has also been recognized in the Golf Course Formation in the Ardmore basin, south-central Oklahoma (Manger and others, 1974).

At the top of the Prairie Grove Member and continuing into the basal Brentwood Limestone Member of the Bloyd Formation is an assemblage consisting almost entirely of *Verneuilites* (Manger, 1971). This genus includes forms assigned to *Pygmaeoceras, P. pygmaeum* Mather, following revision of that genus by Quinn (1965). In addition, the youngest known representative of the genus *Metadimorphoceras, M. subdivisum* Manger and Quinn, as well as rare *Cancelloceras*, occurs there. This interval was referred to as the *Pygmaeoceras pygmaeum* Zone by Quinn (1970), who regarded it as lower to middle Prairie Grove, and as the *Reticuloceras henbesti-Arkanites relictus* Zone by Gordon (1970). However, assignment of this fauna to the top of the Hale by Manger (1971) is confirmed by the occurrence of *Verneuilites* at the top of the Namurian in the South Urals (Zone ${}_2C_1$; Ruzhencev and Bogoslovskaya, 1971) and by the occurrence of *Cancelloceras* at the top of the European Namurian (Ramsbottom and Calver, 1962).

Bloyd Formation

The Bloyd Formation, which constitutes the upper part of the Morrowan Series, contains a variety of rocks of both marine and continental origin, although shale is the most abundant. In its type area in Washington County, this formation is divided into five members, in ascending order: Brentwood Limestone, Woolsey, Dye Shale, Kessler Limestone, and Trace Creek Shale (Henbest, 1953, 1962).

Brentwood strata are typically composed of cross-bedded sandy limestone in ledges alternating with dark shaly mudstone. Channeloid lenses of limestone intertongue laterally, and limestone and dark-colored shale interfinger with little or no lateral continuity. This unit, which averages about 40 feet (12 m) in thickness, is truncated above by a disconformity at the base of the Woolsey Member.

The Woolsey Member, up to 45 feet (14 m) thick, is mostly terrestrial in origin and includes a basal conglomerate locally. At the type locality, however, interbedded black limestone and light-brown sandy shale at the base of the unit have yielded a conodont fauna distinctly younger than that of the Brentwood (Lane, 1967, p. 925). In eastern Oklahoma, where the Woolsey fingers laterally from the base upward into marine beds resembling those of the Brentwood Limestone Member, the megafauna likewise is similar to that of the Brentwood (T. W. Henry, oral communication, 1977). In the typical Woolsey section, shaly, silty sandstone beds predominate in the lower part, and a coal bed is present at or near the top. The underclay of the coal has provided an abundant flora that was assigned by Read and Mamay (1964, p. K6, K7, table 2) to their Upper Paleozoic floral zone 6. Occurrences of this same floral zone in western Virginia were correlated by Jongmans (1937) with Westphalian A.

The coal bed at the top of the Woolsey is overlain by a bluff-forming conglomeratic, calcareous sandstone "caprock," up to 25 feet (8 m) thick, at the base of the Dye Shale Member. This caprock contains a varied invertebrate fauna. The Dye Shale Member ranges in thickness from 60 to 110 feet (18 to 34 m) and is composed mainly of dark-gray to black shaly siltstone and claystone with a few lenticular interbeds of sparsely fossiliferous limestone.

The Kessler Limestone Member is 5 to 30 feet (1.5 to 9 m) thick; it is medium to light gray and oolitic and contains algal-foraminiferal concretions, mainly of *Ottonosia* and *Osagia*. Locally it contains a fairly abundant megafauna.

Table 2.—Ammonoid Taxa in Lower and Middle Pennsylvanian (Morrowan) Strata in Northern Arkansas

BLOYD FORMATION

Trace Creek Shale Member

Diaboloceras neumeieri Quinn & Carr, 1963
Gastrioceras cf. *G. araium* McCaleb, 1968
Phaneroceras compressum (Hyatt, 1891)
Bisatoceras micromphalus McCaleb, 1968
Dimorphoceratoides cf. *D. campbellae* Furnish & Knapp, 1966
Boesites scotti (Miller & Furnish, 1940)
Pseudopronorites arkansiensis (Smith, 1896)

Kessler Limestone and Dye Shale Members

Axinolobus modulus Gordon, 1960
Axinolobus quinni McCaleb and Furnish, 1964
Diaboloceras neumeieri Quinn & Carr, 1963
Gastrioceras araium McCaleb, 1968
Gastrioceras attenuatum McCaleb, 1968
Proshumardites morrowanus Gordon, 1965
Syngastrioceras oblatum (Miller & Moore, 1938)
Phaneroceras compressum (Hyatt, 1891)
Phaneroceras kesslerense (Mather, 1915)
Wiedeyoceras smithi McCaleb, 1968
Pseudopronorites arkansiensis (Smith, 1896)

Brentwood Limestone Member

Branneroceras branneri (Smith, 1896)
Gastrioceras adaense Miller & Owen, 1944
Gastrioceras fittsi Miller and Owen, 1944
Gaitherites morrowensis (Miller & Moore, 1938)
Syngastrioceras oblatum (Miller & Moore, 1938)
Bisatoceras secundum Miller & Moore, 1938
Proshumardites morrowanus Gordon, 1965
Cymoceras miseri McCaleb, 1964
Pseudopronorites arkansiensis (Smith, 1896)

Verneuilites pygmaeus (Mather, 1915)
Cancelloceras sp.
Syngastrioceras globosum (Easton, 1943)
Pseudopronorites quinni (Gordon, 1969)
Metadimorphoceras subdivisum Manger & Quinn, 1972

HALE FORMATION

Prairie Grove Member

Verneuillites pygmaeus (Mather, 1915)
Cancelloceras sp.
Cymoceras sp.
Wiedeyoceras matheri (Gordon, 1965)
Schartymites paynei (Gordon, 1965)
Syngastrioceras globosum (Easton, 1943)
Pseudopronorites quinni (Gordon, 1969)

Arkanites relictus (Quinn, McCaleb & Webb, 1962)
Cancelloceras sp.
Cymoceras sp.
Ramosites sp.
Pseudopronorites quinni (Gordon, 1969)
Schartymites sp.
Syngastrioceras globosum (Easton, 1943)

Arkanites relictus (Quinn, McCaleb & Webb, 1962)
Baschkirites librovitchi Quinn & Saunders, 1968
Schartymites paynei (Gordon, 1969)
Syngastrioceras globosum (Easton, 1943)
Pseudopronorites quinni (Gordon, 1969)
Cymoceras cracens (Gordon, 1965)

Reticuloceras? *textum* (Gordon, 1965)
Reticuloceras? *henbesti* (Gordon, 1965)
Syngastrioceras globosum (Easton, 1943)
Pseudopronorites quinni (Gordon, 1969)
Schartymites paynei (Gordon, 1965)
Cymoceras cracens (Gordon, 1965)

Table 2.— *Continued*

Cane Hill Member and possibly basal Prairie Grove Member

Retites semiretia McCaleb, 1964
Reticuloceras tiro Gordon, 1969
Reticuloceras wainwrighti Quinn, 1966
Hudsonoceras moorei Quinn & Saunders, 1968
Pseudopronorites quinni (Gordon, 1969)
Syngastrioceras globosum (Easton, 1943)
Cymoceras cracens (Gordon, 1965)
Paradimorphoceras sp.
Schartymites paynei (Gordon, 1965)

The Trace Creek Shale Member at the top of the Bloyd Formation ranges in thickness from 20 to 70 feet (6 to 21 m) and is composed principally of gray to black silty to clayey shale. The basal bed consists of chocolate-brown detrital limestone, or in places of channeloid sandstone. Sparse lenticular limestone beds containing some fossils are scattered through the member.

In the type region, the members of the Bloyd Formation are well defined, but eastward the Bloyd grades laterally into a sandy facies and its members cannot be differentiated. Part of the Bloyd is included in the Witts Springs Formation (Glick and others, 1964). In this more easterly region the conglomeratic caprock was misidentified as the base of the Atoka Formation by earlier workers, as shown on the 1929 edition of the Arkansas geologic map (Miser and Stose, 1929). This region has been remapped, and the revised Morrowan-Atokan boundary is shown on the recently published Arkansas geologic map (Haley, 1976).

Bloyd Ammonoid Assemblages

Thousands of ammonoids have been recovered from the Bloyd Formation, most of them from the upper part of the Brentwood Limestone Member and its equivalents in northern Arkansas. Three principal assemblages are recognized, not counting the *Verneuilites pygmaeus* assemblage of the uppermost Hale Formation, which extends upward into the lower part of the Brentwood. Bloyd ammonoids have been treated taxonomically in papers by Smith (1896, 1903), Mather (1915), Miller and Moore (1938), Miller and Owen (1944), Gordon (1960, 1965), Unklesbay (1962), Quinn and Carr (1963), McCaleb (1964, 1968), McCaleb and Furnish (1964), and Quinn (1965).

In northwestern Arkansas, where the five members are typically developed, Bloyd ammonoid localities are well located stratigraphically. Eastward, in the sandy facies, however, correlation by ammonoid assemblages is more dependable than by lithology. The ammonoid succession is dominated by schistoceratids, including the subfamily Axinolobinae, and by gastrioceratids.

Succeeding the *Verneuilites-Cancelloceras* assemblage, the middle and upper parts of the Brentwood contain a distinctive fauna characterized by *Branneroceras* and true *Gastrioceras* (pl. 5). This was designated as the *Branneroceras branneri* Zone by Gordon (1970) but was included in a larger *Gastrioceras branneri* s.l. Zone by Gordon (1965). Typical forms are *Branneroceras branneri* (Smith), *Gastrioceras fittsi* Miller and Owen, *G. adaense* Miller and Owen, and *Gaitherites morrowensis* (Miller and Moore). This assemblage, without *Gaitherites,* is also found in the middle of the Witts Springs Formation and near the base of the Johns Valley Shale in Arkansas, as well as near the top of the Union Valley Sandstone in Oklahoma. The appearance of true *Gastrioceras* and *Branneroceras* in this part of the Morrowan section coincides with the beginning of Westphalian A in Europe.

No ammonoids are known in the predominantly continental Woolsey Member in Arkansas, but the marine caprock overlying the coal bed at the top of this member is characterized by two species of *Axinolobus,* the earliest goniatitid having a 10-lobed suture, and by the first appearance of *Diaboloceras* and *Phaneroceras,* in association with longer ranging genera (pl. 6). Ammonoids are scarce to absent in other parts of the Dye Shale Member, but the overlying Kessler Limestone Member has provided rare specimens of *Axinolobus quinni* McCaleb and Furnish, *Gastrioceras attenuatum* McCaleb, and *Phaneroceras kesslerense* (Mather), indicating that the Kessler belongs in the same ammonoid zone as the underlying shale member. This was called the *Axinolobus modulus* Subzone by Gordon (1965) and was raised to zonal rank by Gordon (1970). The *Axinolobus* assemblage also occurs in the Gene Autry Shale of Oklahoma.

Axinolobus has not been positively identified in Europe, but a well-preserved discoidal shell with triangularly coiled early whorls, described as *Paralegoceras percostatum* Schmidt from Westphalian A strata in northwestern Spain, almost certainly belongs in this genus. This suggests that, like the plant-bearing beds near the top of the Woolsey Member, the Dye Shale and Kessler Limestone Members might be correlated with Westphalian A.

The Trace Creek Shale Member has provided relatively few ammonoids. The largest assemblage was found in a conglomeratic limestone in Washington County, 30 feet (9 m) below the base of the Atoka Formation. It includes *Diaboloceras neumeieri* Quinn and Carr in association with *Dimorphoceratoides,* longer ranging genera, and the earliest appearance of *Boesites.* McCaleb (1968, p. 66-68) also identified *D. neumeieri* from the underlying zone, associated with *Axinolobus,* but stated that these specimens are somewhat more primitive than the holotype. This assemblage was assigned to the *Diaboloceras neumeieri* Zone by Gordon (1970). *Diaboloceras neumeieri* is closely related to *Rodiezmoceras bisati* Wagner-Gentis from Westphalian B strata in northwestern Spain. Nassichuk (1975, p. 149) suggested that *Rodiezmoceras* might be a synonym of *Diaboloceras,* and we are inclined to agree with him. Both species are schistoceratids, at the same stage of suture development. Additionally, both are more primitive than *D. varicostatum* Miller and Furnish, the type species of *Diaboloceras,* which has incipient 9th and 10th lobes in the suture and occurs in the lower part of the overlying Atoka Formation. A correlation of the Trace Creek Shale Member with Westphalian B is suggested.

DURATION OF THE MORROWAN SERIES

Ammonoid-based correlations with European sections indicate that the Morrowan Series is equivalent to a considerable part of the middle Carboniferous, including Namurian B and C, Westphalian A, and part of Westphalian B. Correlation with predominantly continental deposits of the standard Pennsylvanian section of the Appalachian region, based upon faunas from marine tongues, indicates that the Morrowan is equivalent to all of the Lower Pennsylvanian and part of the Middle Pennsylvanian, not merely the Lower Pennsylvanian as previously supposed.

In the Appalachian region, the highest Morrowan ammonoid fauna, characterized by *Diaboloceras neumeieri,* occurs in the Kendrick Shale Member of the Breathitt Formation in eastern Kentucky (Furnish and Knapp, 1966) and indicates a correlation of the Kendrick with the Trace Creek Shale Member of the Bloyd Formation. The brachiopod *Linoproductus nodosus* Newberry is abundant in the Kendrick but is absent in the higher Magoffin Member of the Breathitt Formation; in West Virginia this species is found only in the lower part of the Middle Pennsylvanian Kanawha Formation. *L. nodosus* occurs in the upper Morrowan Dye Shale, Kessler Limestone, and Trace Creek Shale Members of the Bloyd in Arkansas (Henry and Sutherland, this guidebook); this is in agreement with the ammonoids in indicating a Middle Pennsylvanian age for the upper Morrowan.

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Plate 1[1]

Representative ammonoids from the Upper Mississippian (Chesterian) Moorefield Formation, Batesville Sandstone, and basal beds of the Fayetteville Formation and their equivalents. Moorefield specimens are from the vicinities of Moorefield (fig. 18), Howards Wells (figs. 3, 6), and Ramsey Bottom (figs. 1, 2, 7, 8, 10, 11), Independence County, Arkansas. Examples of *Goniatites* are from Caney Shale erratics in the Johns Valley Shale, near Boles, Arkansas (fig. 14), and Johns Valley, Oklahoma (figs. 15, 16), and from the Caney Shale, Delaware Creek Member, 2 miles east of Blanco, Pittsburg County (figs. 12, 13), and 2 miles southeast of Nebo, Murray County (figs. 17, 19), Oklahoma. Basal Fayetteville specimens (figs. 4, 5, 9) are from USGS locs. 14344 and 15920, in Independence County, Arkansas.

Figs. 1-3.— *Lusitanites subcircularis* (S. A. Miller, 1889), Moorefield Formation, Ruddell Shale Member. *1, 2,* USNM 119516, x2; *3,* USNM 119611, x1.

Figs. 4, 5.— *Neoglyphioceras crebriliratum* Gordon, 1965, basal Fayetteville Formation; paratype, USNM 119514, x2.

Figs. 6-8.— *Girtyoceras limatum* (Miller and Faber, 1892), Moorefield Formation, Ruddell Shale Member. *6,* USNM 119612, x1; *7, 8,* USNM 119630, x3.

Fig. 9.— *Girtyoceras* cf. *G. ornatissimum* Miller and Youngquist, 1948, basal Fayetteville Formation; USNM 119632, x2.

Figs. 10, 11.— *Neoglyphioceras newsomi* (Smith, 1903), Moorefield Formation, lower Ruddell Shale Member; USNM 119515, x2.

Figs. 12, 13.— *Neoglyphioceras caneyanum* (Girty, 1909), Caney Shale, Delaware Creek Member; lectotype, USNM 119589, x2.

Fig. 14.— *Goniatites granosus* Portlock, 1843, Caney Shale erratic in Johns Valley Shale; latex cast, USNM 119509, x1.

Figs. 15, 16.— *Goniatites choctawensis* Shumard, 1863, Caney Shale block in Johns Valley Shale; USNM 119502, x2.

Figs. 17-19.— *Goniatites multiliratus* Gordon, 1962. *18,* Moorefield Formation, Spring Creek Member; fragment, USNM 119498, x1; *17, 19,* Caney Shale, Delaware Creek Member; holotype, USNM 119499, x2.

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[1]All figured specimens are reposited at the U. S. National Museum, Washington D. C. (USNM); the Department of Geology, The University of Iowa, Iowa City, Iowa (SUI); and the University Museum, University of Arkansas, Fayetteville, Arkansas (UA).

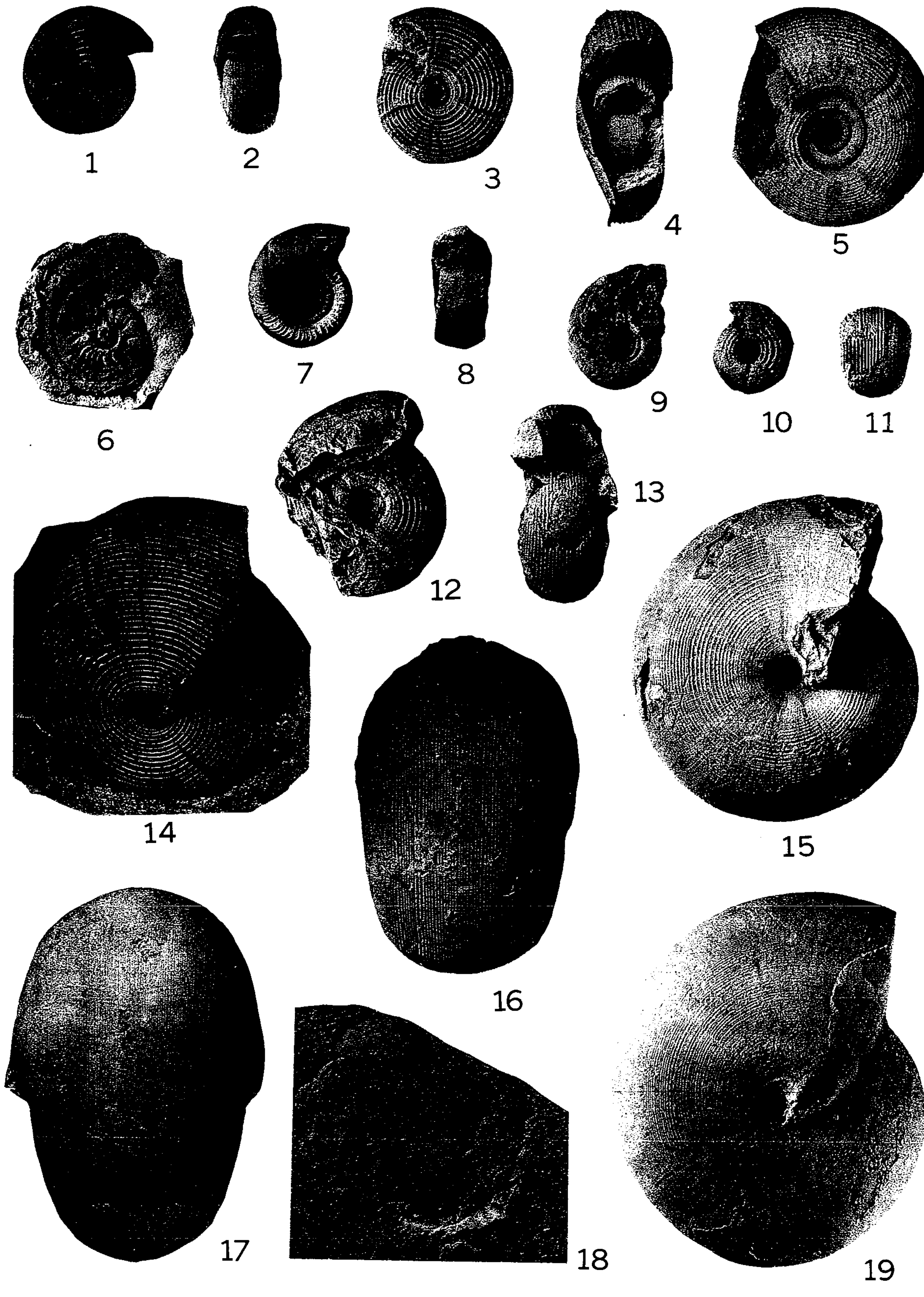
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Plate 2

Representative ammonoids of the Upper Mississippian (Chesterian) Fayetteville, Pitkin, and Imo Formations. All specimens from the Fayetteville Formation (figs. 1, 2, 8-11) are from exposures along Town Branch in the southwestern part of Fayetteville, Washington County; specimens from the upper Pitkin Formation (figs. 4-7) are from 1 mile east of Leslie on Arkansas Highway 65, Searcy County, and the fossiliferous concretion (fig. 3) is from the Imo Formation, same locality as for plate 3.

Figs. 1, 2.— *Cravenoceras fayettevillae* Gordon, 1965, lower Fayetteville Formation; UA 77-205-1, x2.

Fig. 3.—Fossiliferous concretionary mass covered with *Anthracoceras discus* Frech, 1899, Imo Formation; x1.

Figs. 4, 5.— *Eumorphoceras bisulcatum* Girty, 1909, upper Pitkin Formation; UA 77-205-2, x1.

Figs. 6, 7.— *Cravenoceras richardsonianum* (Girty, 1909), upper Pitkin Formation; UA 77-205-3, x2.

Figs. 8, 9.— *Tumulites varians*, McCaleb, Quinn, and Furnish, 1964, lower Fayetteville Formation; UA 77-205-4, x2.

Figs. 9, 10.— *Eumorphoceras plummeri* Miller and Youngquist, 1948, lower Fayetteville Formation; UA 77-205-5, x3.


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Plate 3

Representative ammonoids of the uppermost Mississippian (Chesterian) Imo Formation. All specimens are from exposures near Peyton Creek on Arkansas Highway 65, approximately 5 miles southeast of Leslie, Van Buren County, Arkansas (from Saunders, 1975).

Figs. 1-3.— *Anthracoceras discus* Frech, 1899. *1*, SUI 34725, x1.5; *2*, SUI 34722g, x3; *3*, SUI 34722a, x6.
Fig. 4.— *Delepinoceras bressoni* Ruzhencev, 1958; SUI 34718, x1.
Figs. 5, 18, 19.— *Fayettevillea friscoense* (Miller and Owen, 1944). *5*, spec SUI 34733, x2; *18, 19*, SUI 34729, x1.
Figs. 6, 7.— *Syngastrioceras imprimis* Saunders, 1973; holotype, SUI 34715, x1.
Figs. 8, 9.— *Cravenoceras mapesi* Saunders, 1973; paratype, SUI 34695, x1.25.
Figs. 10, 11.— *Eumorphoceras richardsoni* McCaleb, Quinn, and Furnish, 1964; paratype, SUI 11538, x2.
Fig. 12.— *Somoholites cadiconiformis* (Wagner-Gentis, 1963); SUI 34134, x1.25.
Figs. 13, 14.— *Rhadinites miseri* (Gordon, 1965); SUI 34708, x1.25.
Figs. 15, 16.— *Eumorphoceras imoense* Saunders, 1973; holotype, SUI 34711, x2.
Figs. 17, 22.— *Peytonoceras ornatum* Saunders, 1966; holotype, UA 73-12-1, x3.
Figs. 20, 21.— *Fayettevillea bransoni* Saunders, 1973; holotype, SUI 34701, x1.25.

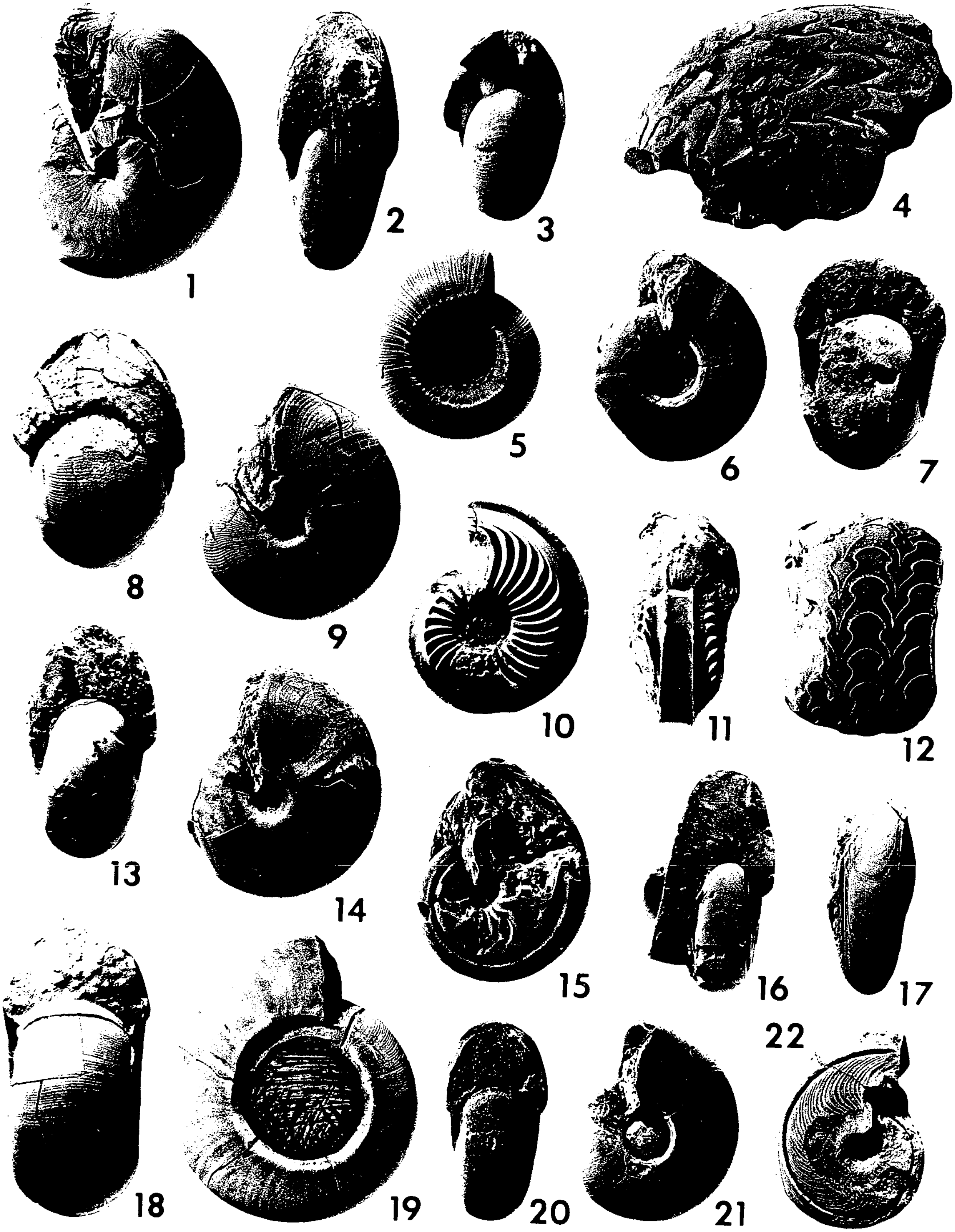
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Plate 4

Representative ammonoids of the Lower Pennsylvanian (Morrowan) Hale Formation. Specimens figured are from the lower Cane Hill Member, railroad cut between Lafayette and Maple Streets in Fayetteville, Washington County (figs. 5, 14, 15), Arkansas, and from a quarry half a mile north of Cane Hill, Washington County (figs. 16, 17); from the middle portion of the Hale Formation, 2 miles south of West Fork, west side of Highway 71, Washington County (figs. 18, 19); from the lower Prairie Grove Member, north side of Bradshaw Mountain, 5 miles southeast of Green Forest, Carroll County (fig. 13), Arkansas; from the upper Prairie Grove Member, along Highway 74, 1.2 miles southwest of Huntsville, Madison County (figs. 6-12), Arkansas; and from the upper Prairie Grove Member (or lower Brentwood Limestone Member, Bloyd Formation), on the east side of Kessler Mountain, Washington County (figs. 1-4).

Figs. 1-4.— *Verneuilites pygmaeus* (Mather, 1915), uppermost Prairie Grove Member. *1, 2,* SUI 35406, x1.5; *3, 4,* UA 77-205-6, x3.

Fig. 5.— *Hudsonoceras moorei* Quinn and Saunders, 1968, lower Cane Hill Member; paratype SUI 34918, x6.

Figs. 6-9.— *Cancelloceras* sp., upper Prairie Grove Member; *6-8,* UA 77-205-7, x1.5; *9,* UA 77-205-8, x2.2.

Figs. 10-12.— *Arkanites relictus* (Quinn, McCaleb, and Webb, 1962), upper Prairie Grove Member; UA 77-205-9, x1.5.

Fig. 13.— *Baschkirites librovitchi* Quinn and Saunders, 1968, lower Prairie Grove Member; paratype SUI 34922, x2.5.

Figs. 14, 15.— *Retites semiretia* McCaleb, 1964, lower Cane Hill Member; topotype, UA 77-205-10, x2.3.

Figs. 16, 17.— *Reticuloceras tiro* Gordon, 1969, Cane Hill Member, Hale Formation; holotype, USNM 146400, x2.5.

Figs. 18, 19.— *Reticuloceras henbesti* (Gordon, 1965), middle portion of the Hale Formation; holotype, USNM 119660, x1.4.

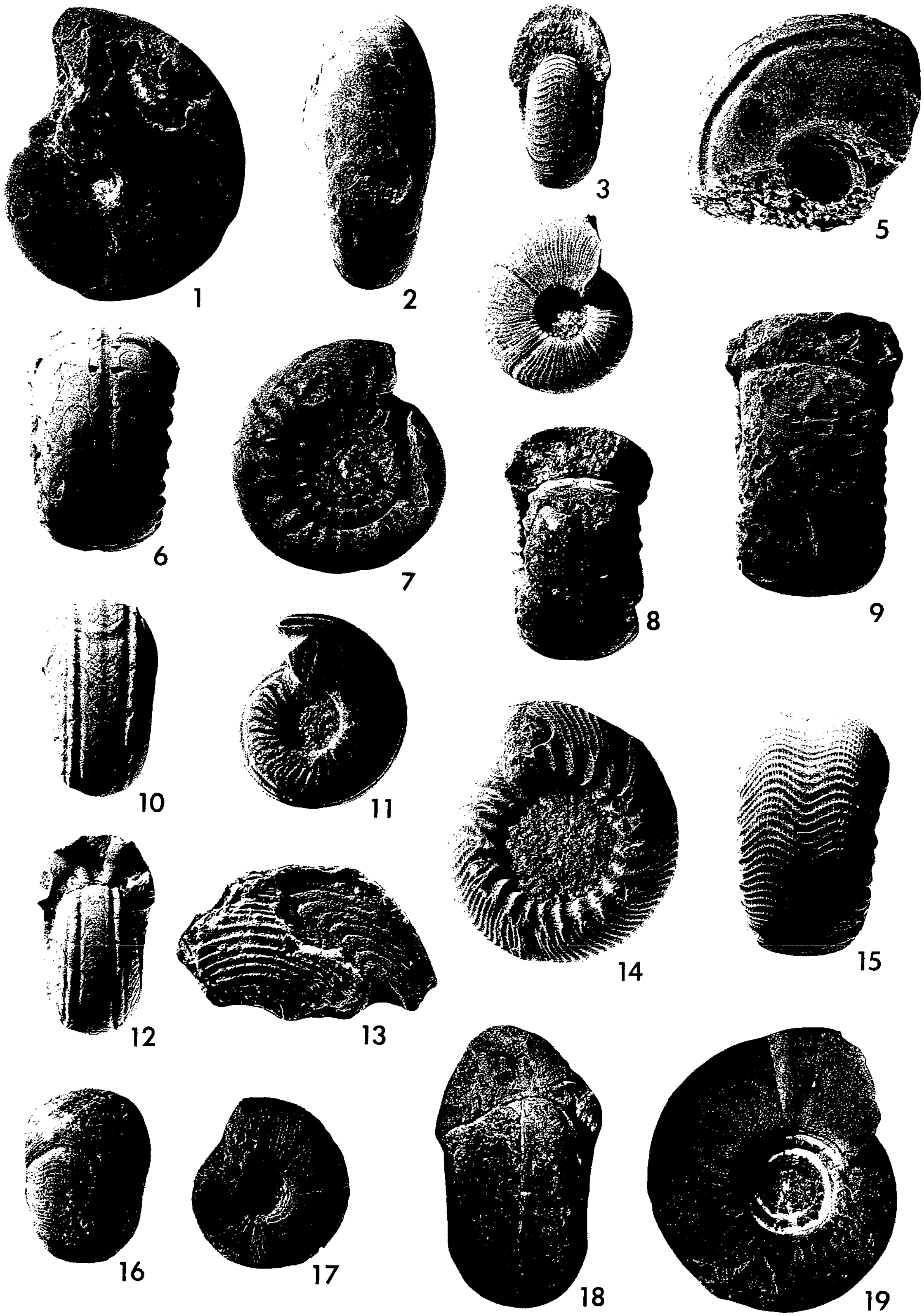
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Plate 5

Representative ammonoids from the Lower Pennsylvanian (Morrowan) Brentwood Limestone Member of the Bloyd Formation and lateral equivalents, including the Witts Springs Formation. Most of these specimens are from Gaither Mountain, 7 miles southwest of Harrison, Boone County, Arkansas (figs. 1, 2, 6-15, 18-21); one is from the same stratigraphic interval at Pilot Mountain, 3.5 miles southwest of Valley Springs, Boone County (figs. 16, 17); one is from the Brentwood Limestone Member, 1¼ miles southeast of Woolsey, Washington County, Arkansas (figs. 4, 5); and one is from the Wapanucka Limestone, 2 miles east of Clarita, Coal County, Oklahoma (fig. 3). Figs. 10-13 are reproduced from Miller and Moore (1938), and figs. 3, 18-21, from McCaleb (1968).

Figs. 1-3.— *Proshumardites morrowanus* Gordon, 1965. *1, 2,* Witts Springs Formation, Brentwood Limestone Member equivalent; *1, 2,* holotype, USNM 119679, x2; *3,* Wapanucka Limestone, SUI 11632, x2.

Figs. 4, 5.— *Cymoceras miseri* McCaleb, 1964, Bloyd Formation, Brentwood Limestone Member; USNM 119654, x3.

Figs. 6, 7.— *Bisatoceras secondum* Miller and Moore, 1938, Witts Springs Formation, Brentwood Limestone Member equivalent; lectotype, SUI 1969, x2.

Figs. 8-11.— *Gaitherites morrowensis* (Miller and Moore, 1938), Witts Springs Formation, Brentwood Limestone Member equivalent. *8, 9,* USNM 119673, x3; *10, 11,* lectotype, SUI 1980, x2.

Figs. 12, 13.— *Syngastrioceras oblatum* (Miller and Moore, 1938), Witts Springs Formation, Brentwood Limestone Member equivalent; holotype, SUI 1972, x1.

Figs. 14-17.— *Branneroceras branneri* (Smith, 1896), Witts Springs Formation, Brentwood Limestone Member equivalent. *14, 15,* USNM 119624, x1; *16, 17,* holotype, USNM 26439, x1.

Figs. 18, 19.— *Gastrioceras fittsi* Miller and Owen, 1948, Witts Springs Formation, Brentwood Limestone Member equivalent; SUI 11644, x1.13.

Figs. 20, 21.— *Pseudopronorites arkansiensis* (Smith, 1896), Witts Springs Formation, Brentwood Limestone Member equivalent; SUI 11701, x1.1.3.

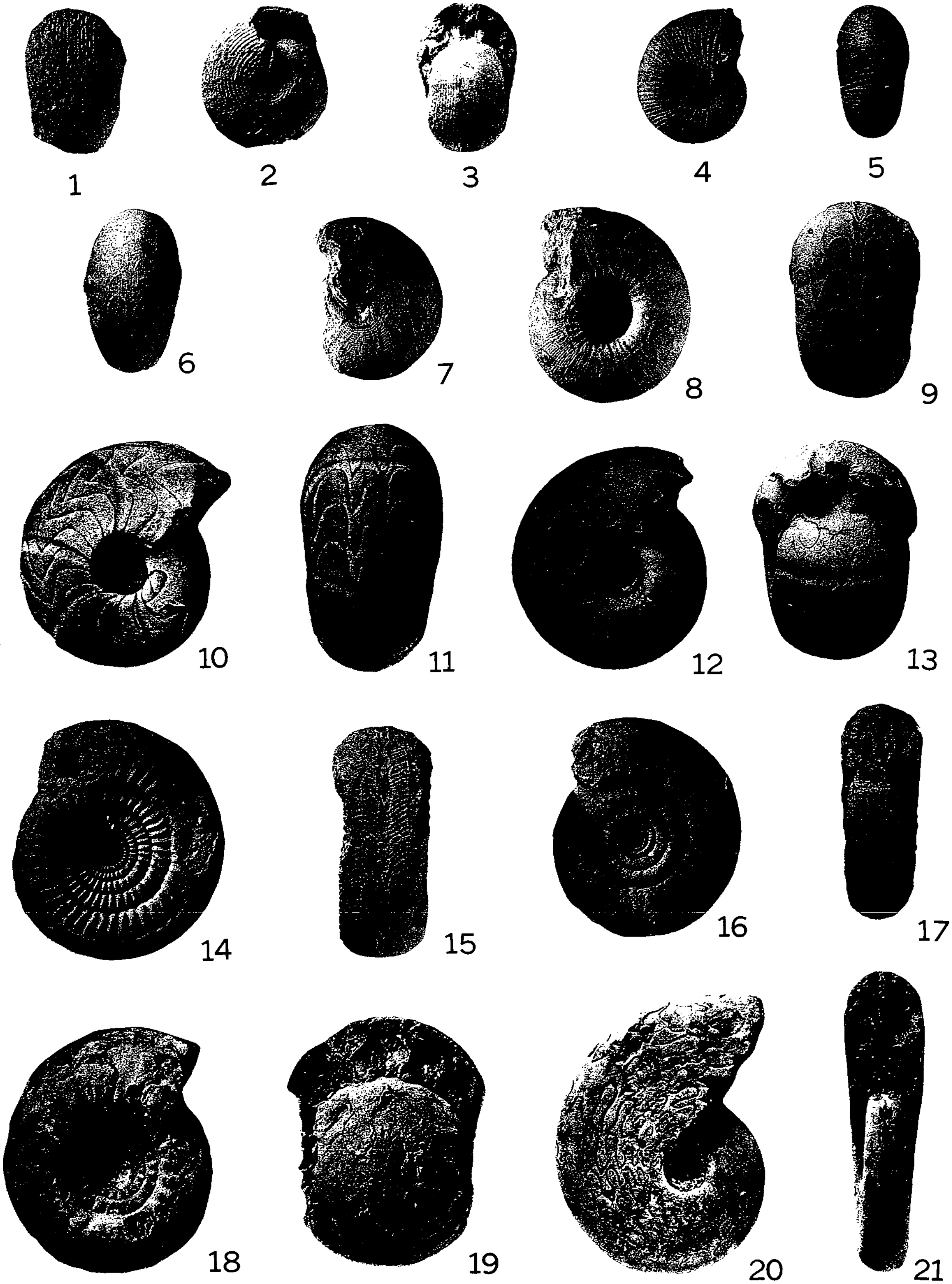
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Plate 6

Representative ammonoids from the Dye Shale, Kessler Limestone, and Trace Creek Shale Members of the Lower-Middle Pennsylvanian (Morrowan) Bloyd Formation. Several specimens are from a lateral extension of the Dye Shale Member at Greers Ferry Dam, 3 miles northeast of Heber Springs, Cleburne County, Arkansas (figs. 1, 2, 4-6); two are from equivalents of the Dye Shale Member near Gene Autry, Oklahoma (figs. 3, 7, 8); and one is from the Bloyd Formation, Trace Creek Member, 2 miles west of Woolsey, Washington County, Arkansas (fig. 9). All figures are from McCaleb (1968).

Fig. 1.— *Axinolobus modulus* Gordon, 1960, Dye Shale equivalent, caprock conglomerate; UA 72-407-2, x1.

Fig. 2.— *Phaneroceras compressum* (Hyatt, 1891), Dye Shale equivalent, caprock conglomerate; UA 72-151-1, x1.1.

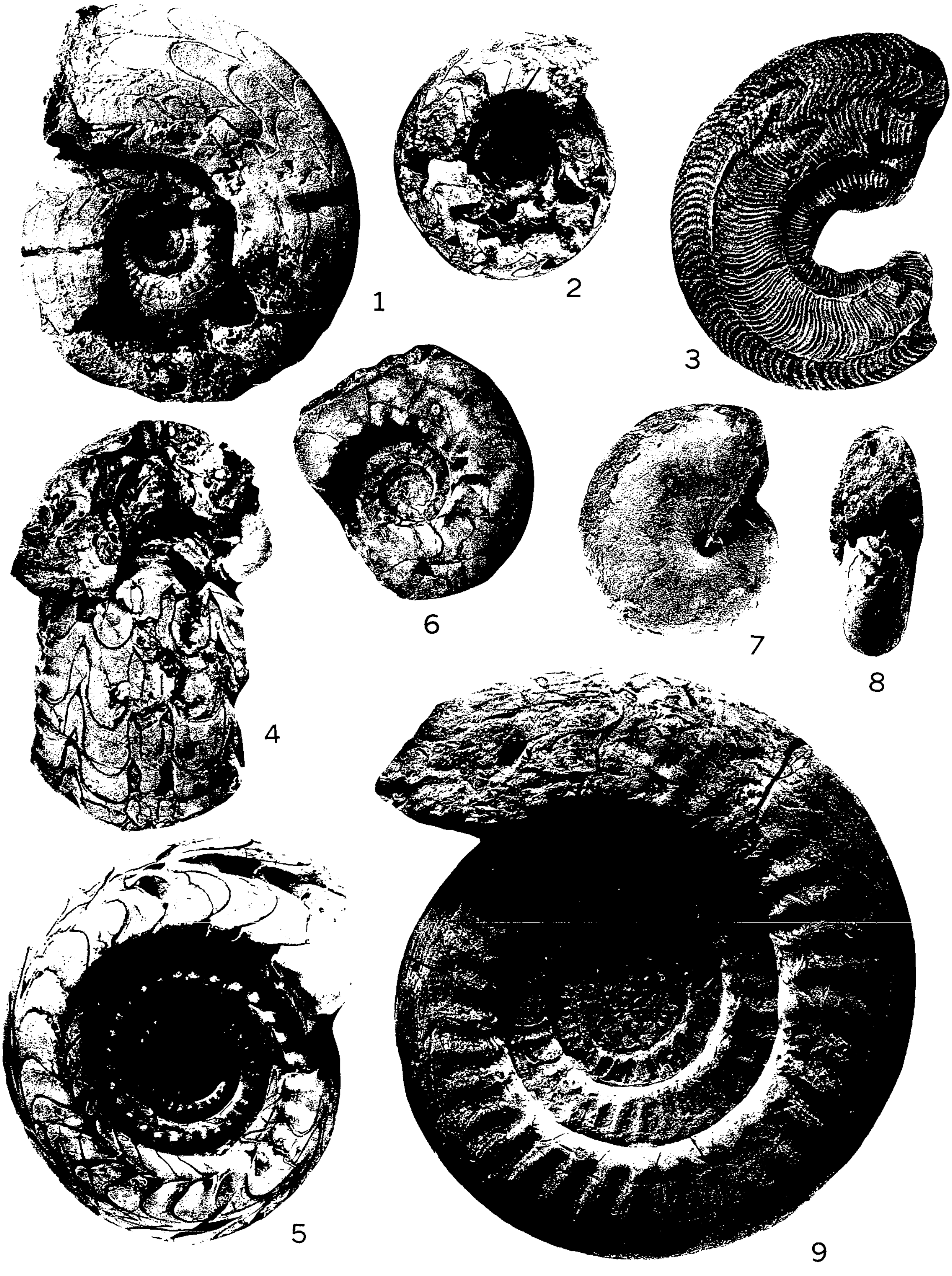
Fig. 3.— *Axinolobus quinni* McCaleb and Furnish, 1964, Gene Autry Shale; SUI 11700, x1.

Figs. 4, 5.— *Gastrioceras attenuatum* McCaleb, 1968, Dye Shale equivalent, caprock conglomerate; SUI 11650, x1.

Fig. 6.— *Gastrioceras araium* McCaleb, 1968, Dye Shale equivalent, caprock conglomerate; paratype, UA 72-151-12, x1.

Figs. 7, 8.— *Wiedeyoceras smithi* McCaleb, 1968, Gene Autry Shale; paratype, SUI 11638, x1.75.

Fig. 9.— *Diaboloceras neumeieri* Quinn and Carr, 1963, Bloyd Formation, Trace Creek Member; holotype, UA 72-350-1, x0.6.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MORROWAN (LOWER PENNSYLVANIAN) OSTRACODES FROM ARKANSAS AND OKLAHOMA

Larry W. Knox[1]

Abstract—Some 44 species of ostracodes distributed among 32 genera were found in the type Morrowan rocks of northwestern Arkansas and the Morrow Group of northeastern Oklahoma. The type Morrowan rocks are herein assigned to one formerly recognized ostracode assemblage zone, the Zone of *Amphissites rothi*. The zone may be divided into a lower subdivision characterized by *Amphissites miseri* Harlton and *Aurikirkbya triseriata* Shaver, and an upper subdivision characterized by the absence of the latter two species. The type Morrowan fauna is particularly noteworthy because it contains many more distinctive ostracodes than have as yet been reported from *Amphissites rothi* faunas that occur in other geographic areas. The correlation of the following rock units and ostracode faunas with the type Morrowan appear firm: the Johns Valley Shale, the Wapanucka Limestone, and the lower part of the Dornick Hills Group, all of Oklahoma; the lower part of the Glen Eyrie Formation of Colorado; the Poverty Run Member (Pottsvillian Series) of eastern Ohio; the Lead Creek Limestone Member of the Mansfield Formation of Indiana; and the Lead Creek Limestone Member of the Tradewater Formation of Kentucky.

Many of the distinctive species of the type Morrowan fauna are more closely allied with Chesterian (Upper Mississippian) ostracode faunas than with post-Morrowan faunas. Phyletic trends that occur along several evolutionary lineages, as proposed herein, and other faunal relationships, serve to confirm the alliance of Chesterian and type Morrowan ostracode faunas.

The significance of the ostracode fauna is enhanced by the paucity of fusulinaceans in the type Morrowan and lower Atokan rocks. *Profusulinella* Rauzer-Chernousova and Belyaev has been found with the *Amphissites rothi* fauna in other areas. Therefore, doubt is cast on the common North American practice of recognizing the Morrowan-Atokan boundary on the basis of the first appearance of *Profusulinella*. The lower part of the Zone of *Profusulinella* is considered herein to be of Morrowan age.

TYPE MORROWAN OSTRACODE FAUNA

Significance and Faunal List

Type Morrowan ostracodes are abundant, morphologically complex, and highly diverse. Many of the species are distinctive and easily recognized. Some of the type Morrowan species have been described from other Lower Pennsylvanian rocks from such widespread geographic areas as Ohio, Indiana, Illinois, Kentucky, Oklahoma, Texas, New Mexico, and Colorado.

The type Morrowan fauna consists of 44 species distributed among 32 genera (Knox, 1974). Two orders, 4 suborders, and 15 families are represented. The families Healdiidae (9 species), Amphissitidae (8 species), Kirkbyidae (5 species), and Cavellinidae (4 species) are the most important faunal constituents in numbers of species. The Amphissitidae, however, dominate all other families in numbers of individuals.

The ostracode species that have been described from the type Morrowan and (or) the associated northeastern Oklahoma interval are listed in table 1. In addition to these species, 4 species and 1 genus that are new and as yet undescribed also occur in the same interval. The most characteristic and distinctive species of the type Morrowan fauna have been figured herein (pls. 1, 2).

Stratigraphic Distribution

Ostracodes were found in the upper part of the Prairie Grove Member (1 sample) of the Hale Formation; the Brentwood Limestone (8 samples), the Dye Shale (1 sample), and the Kessler Limestone (1 sample) Members of the Bloyd Formation; and the upper part of the Morrow Group (16 samples) of northeastern Oklahoma. The Trace Creek Shale Member (5 samples) of the Bloyd Formation and the lower part of the Prairie Grove (9 samples) and the Cane Hill (7 samples) Members of the Hale Formation have not, as yet, yielded ostracodes. The Brentwood Limestone Member of the Bloyd Formation (and the equivalent northeastern Oklahoma interval) proved to be most productive, yielding 70 percent of the samples from which ostracodes were recovered.

Most of the common Morrowan ostracode species range through the productive part of the Morrowan section. A few species appear to have limited ranges within the Morrowan Series, but their value for more detailed biozonation is still uncertain because these species have been found in small numbers of individuals, from a small number of samples, from samples that probably indicate a restricted paleoenvironment, or by a combination of the three conditions. Two species appear to be exceptions to the preceding general stratigraphic distribution: neither *Amphissites miseri* nor *Aurikirkbya triseriata* was found above the Brentwood nor above rocks of the equivalent time interval in northeastern Oklahoma. In the Brentwood and stratigraphically lower rocks, numerous specimens belonging to these two species are associated with many other species that commonly range into rocks that are stratigraphically higher than the Brentwood in the type Morrowan area. This may indicate that *Am. miseri* and *Au. triseriata* are restricted to a lower part of the fauna.

Phyletic Trends and Faunal Alliances

The type Morrowan fauna contains ostracode specimens, referred to several species, that appear to be related phyletically to ostracodes of other than Morrowan age. Many of the most distinctive Morrowan taxa exhibit ancestral-descendant relationships with Chesterian ostracode faunas rather than with later Pennsylvanian faunas. These phyletic

[1]Tennessee Technological University, Cookeville, Tennesee.

Table 1.—Ostracode Assemblage from Type Morrowan Rocks

**Amphissites? confluens* Bradfield
A. marginiferus Roth
**A. miseri* Harlton
**A nodosus* Roth
A. rothi Bradfield
A. rugosus Girty
**Aurikirkbya triseriata* Shaver
Bairdia pompilioides Harlton
**Bairdiolites ardmorensis* (Harlton)
Cavellina cf. *C. pulchella* Coryell
Cavellinella casei Bradfield
**Cornigella pushmatahensis* Harlton
Coryellina capax Bradfield
**Dorsoobliquella bachmani* Sohn
Fabalicypris regularis Cooper
**Glyptopleura whitei* Bradfield
Healdia cf. *H. carterensis* Bradfield
H. glennensis Harlton
H. ornata Morey
H. simplex Roundy
**Healdioides pushmatahensis* (Harlton)
Hollinella (*Hollinella*) *bassleri* (Knight)
Hypotetragona arcuata (Bean)
**Kegelites wapanuckaensis* (Harlton)
**Kirkbya bendensis* Harlton
K. clarocarinata Knight
**K. jolliffana* Bradfield
Monoceratina ardmorensis (Harlton)
Moorites minutus Warthin
Orthobairdia dornickhillensis (Harlton)
**Polytylites* cf. *P. quincollinus* (Harlton)
**Proparaparchites guthreyi* (Bradfield)
Pseudobythocypris tomlinsoni (Harlton)
**Pseudoparaparchites? dornickhillicus* (Bradfield)
P. wapanuckaensis (Harlton)
**Roundyella bellatula* Bradfield
Sansabella laevis (Warthin)
**Seminolites?* cf. *S. perforatus* Harlton
Silenites lenticularis (Knight)
Sulcella sulcata Coryell and Sample

*Species believed to range no higher than the top of the Morrowan Series in the Midcontinent or other areas of North America.

relationships and other faunal alliances between Chesterian and type Morrowan ostracodes may prove to be of value for purposes of correlation. The first appearance of a taxon and phenetic similarities have been utilized to establish phyletic lineages and faunal relationships both within the Morrowan Series and between the Chesterian and Morrowan Series (Knox, 1974).

Polytylites

The evolutionary development of *Polytylites* cf. *P. quincollinus* constitutes a significant evolutionary event and may prove to be very important in the delineation of Morrowan rocks. The discovery of *P.* cf. *P. quincollinus* represents the only occurrence of the common Chesterian genus *Polytylites* in Morrowan rocks. Earlier reported Lower Pennsylvanian occurrences of *Polytylites* have been referred to other genera (Knox, 1974). A phyletic size increase of as much as 20 percent has been demonstrated for *Polytylites quincollinus* during Chesterian time (McGuire, 1966). The belief that size increase is an evolutionary trend for this species is substantiated by the size of adult Morrowan specimens, the largest of which are 10 percent larger than the largest reported specimens from the Chesterian Series. The complete absence of an inner ridge on type Morrowan specimens may also be inferred, but with less assurance, to represent a phyletic trend for the species. Chesterian specimens generally have a normally developed inner ridge, but in Morrowan specimens the inner ridge is replaced by a near-90° bend of the valve surface that produces a swollen area separating the lateral surface from the flat ventral surface. That *P.* cf. *P. quincollinus* is descended from Chesterian *P. quincollinus* seems clear; application of a new name for the Morrowan specimens might tend to obscure this relationship even though morphological differences do exist. In fact, the absence of the inner ridge on the pertinent Morrowan specimens, if Sohn's (1962) generic characters were strictly applied, would restrict them from belonging to the genus *Polytylites* and make phylogenetic relationships even more obscure.

Amphissites

Amphissites miseri, known only from the Lower Pennsylvanian, is an interesting species that is intermediate in phenetic relationships between species of *Polytylites* and *Amphissites. A. miseri* has anterior and posterior nodes, as well as a central node, as do species of *Polytylites;* the species has lateral and dorsal carinae, as do species of *Amphissites.*

Amphissites nodosus occurs in Morrowan rocks of the type area and is associated with *Amphissites bushi* in the Wapanucka Limestone. Both species are restricted to Morrowan rocks. These two species are similar, *A. bushi* differing from *A. nodosus* by having a vertically elongate central node. In other respects, the species are quite similar; they are apparently closely related. In lower stratigraphic levels of the type Morrowan, specimens of *A. nodosus* have inner ridges and lateral carinae that are thinner and more widely separated on the ventromedian surface of the valve, whereas higher Morrowan specimens have these carinae and ridges in closer proximity, perhaps because they are thicker. These phenetic changes may represent a phyletic trend.

The specimens from the type Morrowan that I have referred to *Amphissites rugosus* compare very favorably to *Amphissites golcondensis* Croneis and Gale, from the Upper Mississippian Golconda Formation; I consider the latter to be a synonym of *A. rugosus.* The type Morrowan form also compares very favorably with Lower Pennsylvanian specimens referred by Bradfield (1935) and Shaver and Smith (1974) to *Amphissites marginiferus* Roth; Bradfield's and Shaver and Smith's specimens (not Roth's) are considered to be conspecific with the Morrowan specimens. The species *A. rugosus* has been accorded considerable latitude by many authors, but in a restricted sense the Lower Pennsylvanian (Morrowan) and Upper Mississippian (Chesterian) forms referred to above show greater phenetic affinity than any other of those specimens commonly referred to *A. rugosus.*

Hollinella

It has been proposed that *Hollinella* (*Hollinella*) sp. group *bassleri* was descended from *Hollinella* (*Keslingella*) sp. group *radiata* (Bless and Jordan, 1972). Presumably this would have resulted in a loss of advental spurs in juveniles along this evolutionary lineage. Specimens referred to *H.* (*H.*) *bassleri* from the Kessler have the same characteristic features as adults referred to *H.* (*Hollinella*), but juveniles apparently have a pair of reduced advental spurs considered diagnostic of the subgenus *H.* (*Keslingella*). The Morrowan specimens appear to represent a form intermediate between species belonging to the two subgenera; Bless and Jordan's range chart (1972, p. 15) indicates that the evolutionary transition between the subgenera occurred approximately during Morrowan time.

Roundyella

Other distinctive genera and species from the type Morrowan are known from Upper Mississippian rocks. *Roundyella bellatula* occurs in the type Morrowan fauna and also from the lower part of the Dornick Hills Group (Lower Pennsylvanian). The species has also been reported from the Upper Mississippian Redoak Hollow Formation of the Ardmore basin (Elias, 1958).

Bairdiolites

Bairdiolites ardmorensis occurs in the type Morrowan collections as well as in other Lower Pennsylvanian rocks of Oklahoma. This species is the only species of the genus *Bairdiolites* known from Pennsylvanian rocks of North America; all other species of the genus are restricted to the Upper Mississippian.

Healdioides

The genus *Healdioides* is represented in type Morrowan rocks by *Healdioides pushmatahensis* and by a second, as yet formally undescribed, species. *Healdioides* most commonly occurs in Upper Mississippian rocks of North America.

Incisurella-Tetratylus

The type Morrowan fauna contains specimens belonging to two new species, as yet formally undescribed, that are clearly related phyletically to the genera *Incisurella* Cooper and *Tetratylus* Cooper (Knox. 1974). *Incisurella* is known only from Chesterian strata, and *Tetratylus* is restricted to Mississippian rocks.

WAPANUCKA OSTRACODE FAUNA

Several samples containing ostracodes were recovered from two localities in the Wapanucka Limestone. One locality is an active quarry about 1 mile south of Hartshorne, Oklahoma, and the second locality is at Limestone Gap, about 10 miles northeast of Stringtown, Oklahoma. Twenty-four of the species recovered from the Wapanucka Limestone were also found in the type Morrowan rocks. Two additional species not found in the type Morrowan were recovered from the Wapanucka Limestone: *Amphissites bushi* Harlton and *Healdia caneyensis* Harlton. These two species are very distinctive and are known elsewhere only from rocks of Morrowan age with the possible exception of one reported occurrence of *A. bushi* from rocks of late Atokan or early Desmoinesian age in northern New Mexico. R. H. Shaver (personal communication) has identified this species from a sample sent to him by P. K. Sutherland, who reported it to be from his locality 36-97 in the La Pasada Formation (see Sutherland and Harlow, 1973, p. 7, fig. 7). The species content and faunal ranges of the fauna of Morrowan age from the Wapanucka Limestone corroborate earlier statements made concerning the stratigraphic distribution of the type Morrowan fauna.

ATOKA OSTRACODE FAUNA

Ostracodes were recovered from a single calcareous-shale sample of the Atoka Formation at a road cut 100 yards east of the east end of the bridge on Oklahoma Highway 51 at Fort Gibson Reservoir. This ostracode fauna differs significantly from the fauna of Morrowan age. Eight species from the Atoka fauna also were found in the type Morrowan fauna: *Cavellina* cf. *C. pulchella, Cavellinella casei, Fabalicypris regularis, Hypotetragona arcuata, Moorites minutus, Orthobairdia dornickhillensis, Pseudobythocypris tomlinsoni,* and *Pseudoparaparchites wapanuckaensis.* All but 2 of these 8 species have long ranges (into Desmoinesian rocks of the Midcontinent and elsewhere, and even into younger rocks). The remaining Atoka fauna includes three species that do not occur in rocks of Morrowan age: *Amphissites roundyi* Knight, *Healdia deesensis* Bradfield, and *Monoceratina* cf. *M. bradfieldi.*

This same sample also contained associated fusulinid specimens that were reported by George Sanderson (personal communication from P. K. Sutherland, 1974) to represent "an advanced species of *Fusulinella,* representing a form well above the base of the *Fusulinella* Zone, and also well up in the Atoka Formation."

OSTRACODE BIOZONATION

The Lower and lower Middle Pennsylvanian rocks of the eastern part of the Illinois basin have been assigned previously to two ostracode zones: a lower, formally named Zone of *Amphissites rothi,* and an upper, informally recognized zone characterized by *Amphissites centronotus* (Thompson and Shaver, 1964, p. 19-21). Between these two zones is found a nondiagnostic ostracode fauna (Shaver and Smith, 1974).

Most of the characteristic species of the *Amphissites rothi* fauna are found also in the Morrowan ostracode faunas of the Midcontinent. Further, the *A. rothi* zonal concept is here applied to the type Morrowan rocks with certain modifications. The type Morrowan rocks contain numerous additional species not yet reported from the *A. rothi* fauna of the Illinois basin. These additional type Morrowan species included in the faunal list are here considered part of the *A. rothi* zonal concept Those marked with an asterisk (table 1) are considered to be additional important guide fossils to the *A. rothi* Zone. The species *Amphissites bushi* and *Healdia caneyensis* from the Wapanucka Limestone are here considered to be additional members of the *A. rothi* Zone.

The age limits of the Zone of *Amphissites rothi* as herein modified are unsatisfactorily known. Nearly a score of samples from below the uppermost part of the Prairie Grove have proved to be barren of ostracodes; hence the lower boundary is unknown. The ostracodes of the Atoka Formation (Series) are poorly known, but the fauna from the Atoka Formation on Oklahoma Highway 51 near Fort Gibson Reservoir does not belong to the *A. rothi* fauna; this part of the Atoka Formation constitutes a maximum upper stratigraphic and age limit for the *A. rothi* fauna. The Atoka fauna contains *Amphissites roundyi,* a characteristic species of the *Amphissites centronotus* fauna (Thompson and Shaver, 1964; Shaver and Smith, 1974), but not *A. centronotus.* The Atoka fauna could belong to the *A. centronotus* fauna or to the nondiagnostic fauna that occurs between the *A. rothi* and *A. centronotus* faunas.

Because the *A. rothi* fauna was not found in the Atoka Formation near Fort Gibson Reservoir, nor from rocks of post-Morrowan age anywhere in North America, the most likely explanation seems to be restriction to the Morrowan Series for the fauna.

CORRELATION

The following correlations of rock units and their associated ostracode faunas with the type Morrowan appear firm: the Johns Valley Shale, the Wapanucka Limestone, and the lower part of the Dornick Hills Group (to at least the top of the Otterville Limestone), all of Oklahoma; the lower part of the Glen Eyrie Formation of Colorado: the Poverty Run Member (Pottsvillian Series) of eastern Ohio; the Lead Creek Limestone Member of the Mansfield Formation of Indiana; and the Lead Creek Limestone Member of the Tradewater Formation of Kentucky. With less assurance, correlations have been made with the lower part of the Marble Falls Formation of Texas and the upper part of the Sandia Formation of New Mexico.

BIOSTRATIGRAPHIC PROBLEMS

Evidence derived from the type Morrowan ostracode fauna appears to be in conflict with certain standard North American fusulinid zonal relationships. The *Amphissites rothi* fauna occurs in association with the primitive fusiform fusulinid *Profusulinella* Rauzer-Chernousova and Belyaev in several lower Pennsylvanian rock units of the Illinois basin in Indiana and Kentucky (Thompson and others, 1959; Shaver and Smith, 1974). The Morrowan age of these units has been independently substantiated by conodont occurrences in some of these same units (Taylor, 1974). Fusulinid stratigraphers, however, have generally recognized the first appearance of *Profusulinella* to indicate basal Atokan rocks. Part of the problem is the generally unfossiliferous nature of the Atoka Formation at its type section near Atoka, Oklahoma, and the apparent time-transgressive nature of the Atoka Formation (see discussion by Shaver and Smith, 1974) to the northwest toward Clarita, Oklahoma, from which section the standard fusulinid biozonation of the Atokan Series has developed. Most fusulinid biostratigraphers accept a fusulinid scheme that precisely equates the Morrowan Series to the Zone of *Millerella* Thompson; the Morrowan-Atokan Series boundary is defined by the first appearance of *Profusulinella*; the lower Atokan rocks are assigned to the Zone of *Profusulinella*; higher Atokan rocks belong to the Zone of *Fusulinella*. The rocks above the Brentwood do not contain abundant *Millerella*: Thompson (1944) and Knox (1974, p. 28) found none; Lane and others (1972) reported, but did not figure, *Millerella* from the Kessler. If *Millerella* was restricted from the upper part of the type Morrowan, perhaps for paleoecological reasons, then it seems likely that *Profusulinella* might also have been prohibited by the same factors. Ostracode and conodont faunas from the lower part of the Atoka Formation near Clarita may yet be found. If so, the presence of the *Amphissites rothi* fauna in the lower part of the Atoka Formation would indicate, in my opinion, that the upper part of the Morrowan Series and the lower part of the Atokan Series (as defined by the reference section near Clarita) overlap in a time sense.

The relationships of Lower and lower Middle Pennsylvanian ostracode faunas and their associated stratigraphic ranges are still unkown or imperfectly known from such important sequences as the Ardmore basin of Oklahoma, the type Derryan of New Mexico, and other Pennsylvanian rocks of Nevada and Utah. The ranges and faunal relationships of ostracodes to other fossil groups need to be better established in these sections.

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Plate 1

Numbers following stratigraphic units are Indiana University Department of Geology repository numbers.

Fig. 1.— *Kegelites wapanuckaensis* (Harlton). Left (x50) view of carapace, Morrow Group of Oklahoma, 13502-23.

Fig. 2.— *Amphissites nodosus* Roth. Right (x55) view of carapace, Kessler Limestone Member, Bloyd Formation, 13512-1.

Fig. 3.— *Amphissites rothi* Bradfield. Left (x55) view of carapace, A-1 instar, Kessler Limestone Member, Bloyd Formation, 13512-1.

Fig. 4.— *Amphissites rugosus* Girty. Right (x50) view of adult carapace, Morrow Group of Oklahoma, 13506-15T.

Fig. 5.— *Amphissites miseri* Harlton. Lateral (x55) view of broken right valve, Morrow Group of Oklahoma, 13506-15T.

Fig. 6.— *Polytylites* cf. *P. quincollinus* (Harlton). Lateral (x55) view of right valve, Morrow Group of Oklahoma, 13506-15T.

Fig. 7.— *Amphissites marginiferus* Roth. Left (x50) view of damaged adult carapace, Morrow Group of Oklahoma, 13503-7.

Fig. 8.— *Amphissites*? *confluens* Bradfield. Lateral (x50) view of right valve, Kessler Limestone Member, Bloyd Formation, 13512-1.

Fig. 9.— *Aurikirkbya triseriata* Shaver. Right (x50) view of adult carapace, Morrow Group of Oklahoma, 13503-2.

Fig. 10.— *Amphissites bushi* Harlton. Lateral (x51) view of right valve, Wapanucka Limestone, 13520-4.

Figs. 11-13.— *Hollinella (Hollinella) bassleri* (Knight). *11,* lateral (x51) view of right valve, instar; *12,* lateral (x56) view of right valve, adult female; *13,* lateral (x51) view of left valve, adult male. All specimens from Kessler Limestone Member, Bloyd Formation, 13512-1.

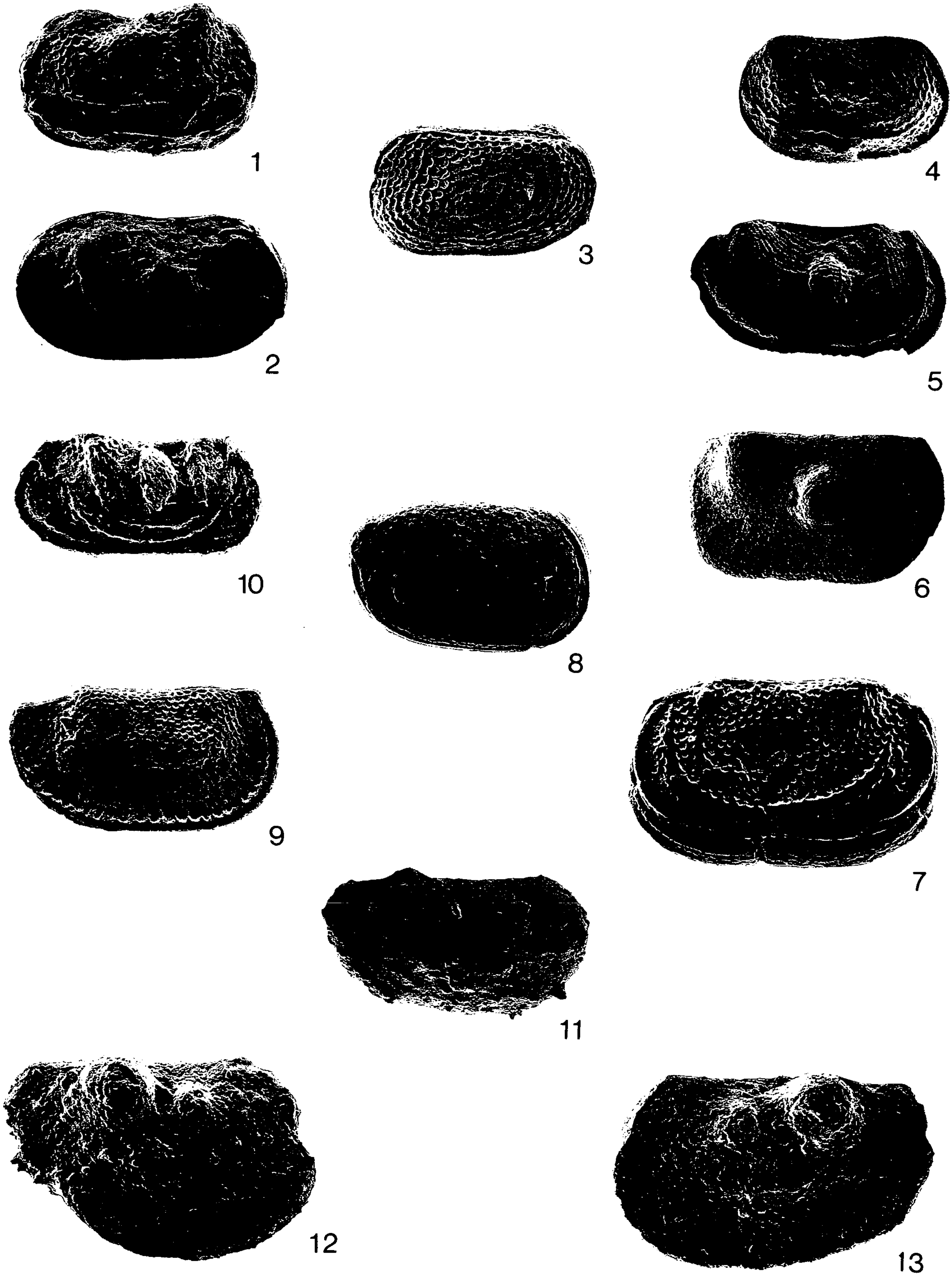
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Plate 2

Fig. 1.— *Kirkbya bendensis* Harlton. Lateral (x50) view of left valve, Dye Shale Member, Bloyd Formation, 13510-1.

Fig. 2.— *Cornigella pushmatahensis* Harlton. Right (x53) view of carapace, Morrow Group of Oklahoma, 13506-15M.

Fig. 3.— *Healdioides pushmatahensis* (Harlton). Right (x48) view of carapace, Morrow Group of Oklahoma, 13506-15T.

Fig. 4.— *Glyptopleura whitei* Bradfield. Left (x53) view of adult carapace, Prairie Grove Member, Hale Formation, 13513-10.

Fig. 5.— *Seminolites*? cf. *S. perforatus* Harlton. Right (x48) view of carapace, Morrow Group of Oklahoma, 13509-1.

Fig. 6.— *Proparaparchites guthreyi* (Bradfield). Right (x50) view of carapace, Morrow Group of Oklahoma, 13509-1.

Fig. 7.— *Kirkbya jolliffana* Bradfield. Left (x52) view of carapace, Kessler Limestone Member, Bloyd Formation, 13512-1.

Fig. 8.— *Pseudoparaparchites*? *dornickhillicus* (Bradfield). Lateral (x52) view of right valve, Kessler Limestone Member, Bloyd Formation, 13512-1.

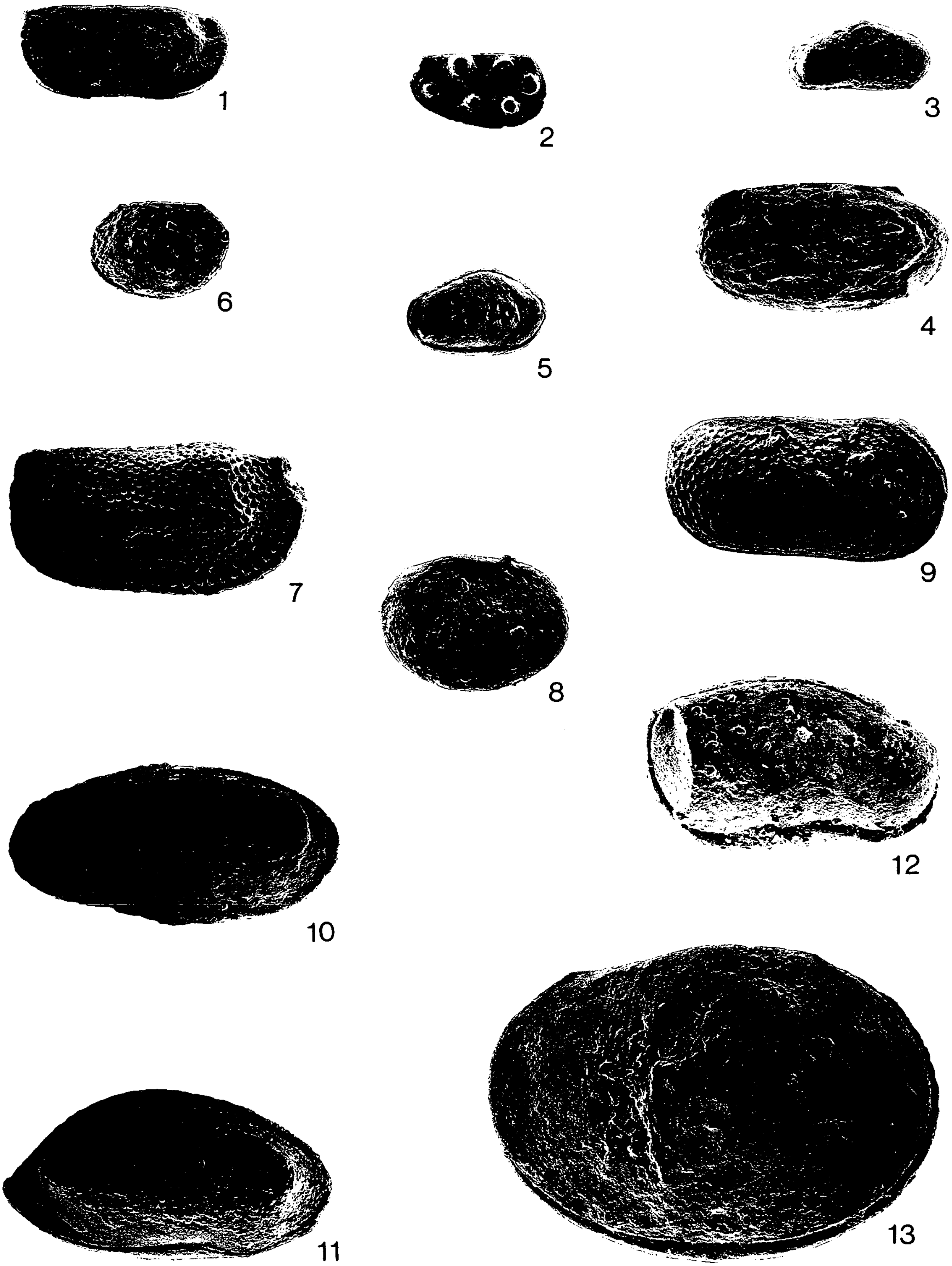
Fig. 9.— *Roundyella bellatula* Bradfield. Lateral (x53) view of right valve, Morrow Group of Oklahoma, 13509-3M.

Fig. 10.— *Cavellinella casei* Bradfield. Left (x53) view of adult male carapace, Morrow Group of Oklahoma, 13503-7.

Fig. 11.— *Bairdiolites ardmorensis* (Harlton). Right (x48) view of adult carapace, Morrow Group of Oklahoma, 13502-23.

Fig. 12.— *Healdia caneyensis* Harlton. Right (x58) view of carapace, Wapanucka Limestone, 13520-2.

Fig. 13.— *Dorsoobliquella bachmani* Sohn. Right (x56) view of adult carapace, Morrow Group of Oklahoma, 13503-2.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LATE MISSISSIPPIAN AND EARLY PENNSYLVANIAN OSTRACODA FROM NORTHERN ARKANSAS—A PRELIMINARY SURVEY

I. G. Sohn[1]

Abstract—Ostracodes from the Lower Pennsylvanian Brentwood Limestone Member of the Bloyd Shale and the Cane Hill Member of the Hale Formation, and from the Upper Mississippian part of the "Imo" Formation and Fayetteville Shale, are illustrated in open nomenclature. A total of 39 taxa are related to 18 known genera and 3 indeterminate genera. Only 2 genera contain more than 1 species. The faunules differ from each other on the specific level but not on the generic level. Because the samples are few, conjectures as to the reasons for these differences are unwarranted at this time.

INTRODUCTION

The Fayetteville Shale ostracodes (Late Mississippian) in Arkansas were described by Girty (1910, 1915a, 1915b), Harlton (1929), and Sohn (1969); the Morrowan ostracodes (Early Pennsylvanian) were described by Harlton (1929) and in an as yet unpublished Ph.D. dissertation in 1974 by Knox. Roth (1929a), Cooper (1941, 1946) and other workers illustrated, identified, or mentioned ostracodes from Arkansas. During the summer of 1976, W. L. Manger, University of Arkansas, Fayetteville, mailed to me two shipments of collections from Upper Mississippian and Lower Pennsylvanian rocks that he made specifically for this study, and Mackenzie Gordon, Jr., U.S. Geological Survey, contributed two collections containing ostracodes, one from the Mississippian part of the "Imo" Formation of Gordon (1964, p. 34) (USGS coll. 15298-PC), the other from the Cane Hill Member of the Hale Formation (Lower Pennsylvanian, Morrowan, USGS coll. 26398-PC). The collections of shale were disaggregated with 15-percent hydrogen peroxide; the one limestone sample was crushed. They yielded a few poorly preserved specimens, which are illustrated and discussed in this report. for example, one collection (USGS 12298-PC) from the top 2 feet (0.61 m) of the Cane Hill Member of the Hale Formation yielded from 31 picked grams one poorly preserved valve of *Rectobairdia*? sp. (pl. 1, figs. 47, 48), the only representative of this genus in the entire study. I am certain that the taxa recovered and illustrated in open nomenclature represent but a fraction of the ostracodes present in the formations. Additional collections will undoubtedly increase considerably the number and variety of ostracodes in the Upper Mississippian and Lower Pennsylvanian rocks in Arkansas.

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[1]U.S. Geological Survey, U.S. National Museum, Washington, D.C.

GENERAL COMMENTS

The paleogeographic framework of Arkansas during Late Mississippian and Early Pennsylvanian time was interpreted by Gordon (1974) as a nearshore shallow shelf that underwent marine transgressions and regressions. The Late Mississippian seas extended farther north in Arkansas (Gordon, 1974, fig. 1B) than they did during the Early Pennsylvanian (Gordon, 1974, fig. 1C), and they deepened toward the south and southeast. The ostracode faunules of the Fayetteville Shale previously recorded (Sohn, 1969) were obtained from limestones that were probably laid down farther from shore than was the material comprising the two samples of Fayetteville Shale containing the ostracodes used in this study. This may explain the fact that the ostracodes illustrated in this study do not represent the previously identified species; it may also explain the presence of the two specimens with adductor muscle-attachment scars similar to Pennsylvanian fresh-water ostracodes (pl. 3, figs. 22, 27).

USGS coll. 26391-PC from the Cane Hill Member of the Hale Formation consisted of limestone that was crushed in order to separate the ostracodes. In addition to the illustrated specimens, the following taxa, too poorly preserved for illustration, were found: *Acratia*? sp., *Silenites*? sp., *Graphiadactyllis* sp., *Amphissites* spp., kloedenellacean genus undet., and fragments and steinkerns undet.

Because of the small number of samples used and the scarcity of ostracodes in each sample, practically every collection yielded different assemblages. Only one species, *Gortanella* sp., was recovered from two different localities of the Mississippian part of the "Imo" Formation of Gordon (1964, p. 34); the illustrated specimens are from Van Buren County (USGS coll. 12941-PC), and the other specimen is from Searcy County (USGS coll. 15298-PC). The sampling of ostracode faunules used in this study are pitifully meager; consequently, Roth's (1929b, p. 6) warning of the danger of drawing conclusions based on inadequate sampling is heeded. Except for *Gortanella* Ruggieri and the undetermined kloedenellacean genus (pl. 2, figs. 14-16), all the other taxa represent genera known in Mississippian, Pennsylvanian, and some in Permian rocks. Consequently, differences among the ostracode faunules, as far as they are represented in this study, are on the specific level only.

UPPER MISSISSIPPIAN

Fayetteville Shale

Two samples from the Fayetteville Shale contained poorly preserved ostracodes, and a few are illustrated here to supplement the known fauna of the Fayetteville Shale (Sohn, 1969, p. 41, 42). Of interest is the shell ultrastructure of Kirkbyacea (this report, pl. 3, figs. 8-10), which is similar to the ultrastructure of the living deep-sea (507-1007 m) myodocopid *Metapolycope hartmanni* Kornicker and Van Morkhoven as illustrated by Kornicker and Van Morkhoven (1976, fig. 7d). Although the carbonate content of the fossil shells undoubtedly has been reorganized, the similarity of the ultrastructure of these shells to that of the shell of a living ostracode merits further investigation. Of further interest are the illustrations of the adductor muscle-attachment scar on steinkerns of an undeterminable genus (pl. 3, figs. 22, 27).

"Kegelites" sp. 2 (pl. 3, figs. 1-3, 9-13)

One right valve with a well-developed dorsal shield and a left valve with some of the dorsal part missing (fig. 12) were recovered. The smaller damaged valve shows the shell ultrastructure near the dorsal shield (figs. 9, 10).

Polytylites? sp. (pl. 3, figs. 4-8)

The broken left valve probably belongs to the common Late Mississippian genus *Polytylites* Cooper, but it is not certain because the posterior terminal shoulder is missing. The damaged specimen, however, shows the ultrastructure of the shell. Cooper (1941, p. 18) recorded *P. quincollinus* (Harlton, 1929) from the Fayetteville Shale, but the specimen on hand is probably not that species.

Sargentina sp. 1 (pl. 3, figs. 28-41)

This relatively abundant species differs from all the known species in this genus in having an umbonate right valve. Figures 28-30 are of a steinkern that retains the umbonate asymmetry of the right valve (compare figs. 28 and 39).

Gen. and sp. undet. (pl. 3, figs. 18-27)

Two steinkerns with preserved casts of the adductor muscle-attachment scars were recovered. One of the muscle scars (fig. 27) resembles those of Pennsylvanian fresh-water ostracodes (Sohn, 1977).

Cavellina sp. 1 (pl. 3, figs. 14-17)

This rather subrounded species is one of several in the Fayetteville Shale that have not yet been described.

"Imo" Formation (in Part)

Five collections from the Mississippian part of the "Imo" Formation of Gordon (1964, p. 34) contained ostracodes.

Monoceratina sp. (pl. 1, figs. 18-21)

Although *Monoceratina* Roth is a common genus in Paleozoic rocks, this minute valve cannot be assigned to any of the described species.

Monoceratina? sp. (pl. 2, fig. 17)

This very minute valve is probably the young of an undescribed species.

Gen. and sp. undet. ex gr. *Monoceratina* Roth 1928 (pl. 1, figs. 14-17)

This unique minute single valve cannot be assigned with certainty to *Monoceratina* Roth, 1928.

Youngiella sp. or spp. (pl. 1, figs. 29-32, 39-46; pl. 2, figs. 1-3)

Youngiella Jones and Kirkby is distinguished from the other genera in the Youngiellacea in having a smooth surface without any rims or ridges. This minute genus is relatively abundant in USGS colls. 12941-PC, and 15298-PC; five poorly preserved specimens that differ in state of preservation and in lateral outline are illustrated. The diagnostic taxodont hinge is suggested, albeit poorly preserved in figures 31 and 39 of plate 1.

Healdia cf. *H. boggyensis* Harlton, 1927 (pl. 1, figs. 11-13)
Healdia sp. (pl. 1, figs. 26-28)
Healdia sp. ex gr. *H. caneyensis* Harlton, 1927 (pl. 2, figs. 4, 5)

The illustrated specimen is about half the length of the holotype of *H. caneyensis*, but it more closely resembles the holotype than do any of the Mississippian and Pennsylvanian specimens subsequently identified as that species. It differs in that the ridge connecting the two spines is straight, whereas this ridge is slightly curved in the type series.

Healdioides? sp. (pl. 1, figs. 22-25)

Healdioides Coryell and Rozanski was described from Upper Mississippian rocks of Illinois. This species differs in lateral and dorsal outlines and in that the end ridges are closer to the end margins.

Healdioides sp. 1 (pl. 1, figs. 6, 7)

This species differs from the species illustrated on plate 1, figures 22-25, in lateral and dorsal outlines and in better development of the crescentic end ridges.

Healdioides sp. 2 (pl. 2, figs. 8-10)

The crescentic ridges are farther removed from the end margins than in the other specimens of this genus illustrated on plates 1 and 2.

Kloedenellacea, gen. undet. (pl. 2, figs. 14-16)

In addition to the 2 illustrated specimens, 1 smaller right valve, about 0.6 mm in greatest length, was recovered from the same sample (USNM 245001).

Hollinella sp. (pl. 2, figs. 12, 13)

The illustrated left valve differs from all the described species of *Hollinella* Coryell in outline, size, shape, and position of the two nodes and in the development and shape of the frill.

Hollinella sp. indet. (pl. 2, figs. 27, 28)

The frill of this poorly preserved right valve is broken; consequently, the species cannot be determined without additional specimens.

Gortanella sp. (pl. 2, figs. 11, 23-26)

Gortanella Ruggieri (type-species, *G. regina* Ruggieri) was described from the Upper Carboniferous of the Carnic Alps as differing from *Hollinella* Coryell in having a subdued anterior node and two strong ventrolateral spines with a connecting frill that terminates at the posterior spine. *Hollinella longispina* (Jones and Kirkby) was referred to the new genus. The specimens on hand fit the description of the genus. One left valve slightly smaller than the one illustrated in figure 11 (USNM 245008) was recovered from USGS coll. 15298-PC (Searcy Co.).

Cornigella sp. (pl. 2, figs. 41, 42)

The specimen is too poorly preserved for identification.

Sargentina spp. (pl. 2, figs. 29-40)

See Sohn (1975, p. G8) for a discussion of the genus. The marginal frills illustrated here have not been previously recorded in species of this genus but are known in other genera of the Sansabellidae. Because of difference in lateral outline, the valve illustrated in figures 31 and 32 may not be conspecific with the other specimens. The specimen illustrated in figures 35-37 has a different subcentral pit and may also represent a separate species.

Cavellina sp. (pl. 2, figs. 18-22)

Note the internal septum in fig. 20 that is indicative of a female.

LOWER PENNSYLVANIAN

Cane Hill Member of Hale Formation

Two collections, one from Washington County (USGS coll. 12938-PC) and one from Stone County (USGS coll. 26931-PC), yielded ostracodes. Although the latter is east of the type area, a few of the species recovered from it are included as a partial indication of the variety present in this formation.

Healdia cf. *H. glennensis* Harlton, 1927 (pl. 1, figs. 3-5)

More than 150 species have been described and included in *Healdia* Roundy, and that genus is badly in need of revision. The variation in morphology illustrated on plates 1 and 2 indicates some of the criteria that could be used to split this genus.

Healdia sp. 1 (pl. 1, figs. 37, 38)

Rectobairdia? sp. (pl. 1, figs. 47, 48)

Only one valve that probably belongs to this genus was recovered.

Shivaella sp. (pl. 1, figs. 6-8)

Although this species is abundant in growth stages in USGS coll. 26391-PC, only one small specimen (USNM 244964) is illustrated in order to record this genus.

Kirkbyella (*Berdanella*) sp. (pl. 1, figs. 9, 10)

Two better preserved valves were found (USNM 245027).

Shleesha? sp. (pl. 1, fig. 53)

This incomplete valve on matrix is closer to *Shleesha* Sohn than to any other genus in the Amphissitidae.

Knightina n. sp. (pl. 1, figs. 56-66)

This species is abundant in USGS coll. 12938-PC and is represented by growth stages. It differs from the known species in *Knightina* Kellett, 1933, in fine-surface reticulation and in lateral outline. The inside rim that is not continuous along the ventral margin in large valves (pl. 1, figs. 58, 61) and that is continuous in younger instars (pl. 1, figs. 62, 66) is due to preservation, because some large specimens have a continuous rim.

Genus undet. 1 (pl. 1, fig. 67)

This steinkern of a young growth stage belonging to a kloedenellid genus is undetermined. It is illustrated to show the probable variety represented in the formation.

Genus undet. 2 (pl. 1, fig. 68)

This larger poorly preserved valve is also an undetermined kloedenellid.

Brentwood Limestone Member of Bloyd Shale

USGS Coll. 12937-PC, upper 2 feet (0.61 m) of shale, yielded a sparse assemblage, representing, in addition to unidentifiable fragments, the following five genera.

Pseudoparaparchites sp. (pl. 1, figs. 1, 2)

Only one valve on matrix was recovered.

Healdia ex. gr. *H. formosa* Harlton, 1928 (pl. 1, figs. 33, 34)

One broken left valve that differs from *H. formosa* Harlton, 1928, in smaller size, shorter dorsoanterior margin, and in being slightly higher relative to the greatest length.

Bairdiolites sp. (pl. 1, figs. 49, 50)

In addition to the illustrated right valve, one poorly preserved left valve was recovered, which may or may not be conspecific with the right valve. Only one Early Pennsylvanian species, *B. ardmorensis* (Harlton, 1929), has been described in North America (Sohn, 1960, p. 17, fig. 12), and I have no record of additional Pennsylvanian species since that study. Knox (1974) identified *B. ardmorensis* in samples from the Bloyd Shale.

Kirkbya sp. (pl. 1, figs. 54, 55)

In addition to the illustrated valve, a more broken left valve was recovered.

"Kegelites" sp. (pl. 1, figs. 35, 36)

In a previous paper (Sohn, 1961), I indicated in a key to the genera in the Amphissitidae (p. 114) that *Kegelites* Coryell and Booth does not have a dorsal shield such as shown here on plate 1, figures 35, 51, and plate 3, figures 3, 12, and I illustrated species including growth stages that do not have this shield (1961, pls. 9, 10). Specimens obtained for this study have a dorsal shield, suggesting that more than one taxon on the generic level may be involved. Because a taxonomic revision is beyond the scope of this paper, I am calling those species that have a dorsal shield *"Kegelites."*

Three steinkerns and fragments too poorly preserved to be identified with the illustrated specimen were recovered.

COLLECTION LOCALITIES

Only those collections that contained ostracodes are listed.

Upper Mississippian

USGS coll. 12939-PC. Van Buren County, Arkansas. "Imo" Formation (in part), black shale 14 feet 6 inches (4.4 m), top 1-foot (0.3-m) interval below 3d limestone, at Peyton Creek locality, N½ sec. 12, T. 13 N., R. 15 W., along U.S. Highway 65, on east side of road, 5 miles (8.0 km) south of Leslie, Arkansas. Collected by W. L. Manger, 1976 (position of this and samples 12940-12942 shown on schematic section for Stop 1).

USGS coll. 12940-PC. Same locality as above. "Imo" Formation (in part), black shale 9 feet 8 inches (2.9 m), top 1-foot (0.3-m) interval below 2d limestone. Collected by W. L. Manger, 1976.

USGS coll. 12941-PC. Same locality as above. "Imo" Formation (in part), black shale 28 feet (8.5 m), top 1-foot (0.3 m) interval below 1st limestone. Collected by W. L. Manger, 1976.

USGS coll. 12942-PC. Same locality as above. "Imo" Formation (in part), gray shale 26 feet 6 inches (8.1 m), sample 23 feet (7.0 m) below 1st "Imo" sandstone layer. Collected by W. L. Manger, 1976.

USGS coll. 12943-PC. Washington County, Arkansas. Fayetteville Shale, black shale aobut 6 feet (1.8 m), top 6 inches (0.15 m). NW¼SE¼NE¼ sec. 9, T. 16 N., R. 30 W., behind Linkway store, west side of Highway 71 N. Collected by W. L. Manger, 1976.

USGS coll. 12944-PC. Washington County, Arkansas. Fayetteville Shale 17 feet (5.2 m), top 5-foot (1.5-m) interval directly below Pitkin Limestone. NW¼SW¼ sec. 3, T. 14 N., R. 30 W., exposed in bluff directly south of type Pitkin Limestone locality. Collected by W. L. Manger, 1976 (position of this sample shown on schematic section for Stop 3).

USGS coll. 15298-PC. Searcy County, Arkansas. "Imo" Formation (in part), fossiliferous shale layer about 20 feet (6.1 m) above base of formation, and about 1 to 2 feet (0.3 to 0.61 m) above base of shale cut bank, near center line between secs. 17 and 18, T. 13 N., R. 18 W., about 200 feet (61 m) up gully east of road, Snowball quadrangle. Collected by M. Gordon, B. Haley, and W. Danilchik, November 1954.

Lower Pennsylvanian

USGS coll. 12937-PC. Washington County, Arkansas. Brentwood Limestone Member of Bloyd Shale, upper 2 feet (0.61 m) of shale near type Brentwood section, SE¼SE¼ sec. 16, T. 14 N., R. 30 W., approximately ½ mile (0.8 km) south of north end of Bloyd Mountain. Collected by W. L. Manger, 1976.

USGS coll. 12938-PC. Washington County, Arkansas. Cane Hill Member of Hale Formation, shale from upper 2 feet (0.61 m), 13 feet, 10 inches (4.2 m), above road level behind IGA store, Evelyn Hills Shopping Center, SW¼NW¼ sec. 10, T. 16 N., R. 30 W. Collected by W. L. Manger, 1976.

USGS coll. 26391-PC. Stone County, Arkansas. Cane Hill Member of Hale Formation, fossiliferous ferruginous siltstone and limestone, prospect pit dug by Mr. Randolph Stair in NE¼ sec. 26, T. 13 N., R. 9 W., 200 feet (60.1 m) stratigraphically above top of Pitkin Limestone (Mississippian) and about 170 feet (50.2 m) above Peyton Creek faunal zone that was collected about 1 mile (1.6 km) to southeast. Collected by E. E. Glick, 1973.

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Plate 1

All scanning-electron micrographs, reduced for publication x½.

Figs. 1, 2.— *Pseudoparaparchites* sp. Dorsal (anterior to right) and outside views of left valve, approx. x45. Brentwood Limestone Member of Bloyd Shale, Washington County. USGS coll. 12937-PC. Figured specimen USNM 244962.

Figs. 3-5.— *Healdia* cf. *H. glennensis* Harlton, 1927. Right, dorsal (anterior to right), and left views of carapace, approx. x45. Cane Hill Member of Hale Formation, Stone County. USGS coll. 26391-PC. Figured specimen USNM 244963.

Figs. 6-8.— *Shivaella* sp. Right, left, and dorsal (anterior to right) views of carapace, approx. x45. Same collection as above. Figured specimen USNM 244964.

Figs. 9, 10.— *Kirkbyella (Berdanella)* sp. Outside views of right and left valves, approx. x45. Same collection as above. Figured specimens USNM 244965, 244966.

Figs. 11-13.— *Healdia* cf. *H. boggyensis* Harlton, 1927. Posterior, right, and dorsal (anterior to right) views of carapace, approx. x60. "Imo" Formation, Searcy County. USGS coll. 15298-PC. Figured specimen USNM 244967.

Figs. 14-17.—Gen. and sp. undet. ex. gr. *Monoceratina* Roth, 1928. Posterior, outside, anterior, and dorsal (anterior to right) views of left valve, approx. x100. Same collection as above. Figured specimen USNM 244968.

Figs. 18-21.— *Monoceratina* sp. Dorsal (anterior to left), outside, posterior, and inside views of right valve, approx. x100. Same collection as above. Figured specimen USNM 244969.

Figs. 22-25.— *Healdioides*? sp. *22, 23*, dorsal (anterior to right) and right views of carapace, approx. x60. Same collection as above. Figured specimen USNM 244970. *24, 25*, dorsal (anterior to right) and right views of carapace, approx. x60. Same collection as above. Figured specimen USNM 244971.

Figs. 26-28.— *Healdia* sp. Dorsal (anterior to right), posterior, and right views of carapace, approx. x45. Same collection as above. Figured specimen USNM 244972.

Figs. 29-32.— *Youngiella* sp. Dorsal (anterior to left) and outside views of right valve, approx. x100; detail of anterior part of hinge, approx. x500, and inside view of same valve, approx. x100. Same collection as above. Figured specimen USNM 244973.

Figs. 33, 34.— *Healdia* ex gr. *H. formosa* Harlton, 1928. Dorsal (anterior to right) and outside views of broken left valve, approx. x45. Brentwood Limestone Member of Bloyd Shale, Washington County. USGS coll. 12937-PC. Figured specimen USNM 244974.

Figs. 35, 36.— *"Kegelites"* sp. Dorsal (anterior to left) and outside views of right valve, approx. x45. Same collection as above. Figured specimen USNM 244976.

Figs. 37, 38.— *Healdia* sp. 1., Dorsal (anterior to right) and right views of carapace, approx. x60. Cane Hill Member of Hale Formation, Searcy County. USGS coll. 15298-PC. Figured specimen USNM 244977.

Figs. 39-46.— *Youngiella* sp. or spp. *39-41*, detail of hinge, approx. x250; inside and outside views of left valve, approx. x100. Same collection as above. Figured specimen USNM 244978. *42, 43*, dorsal (anterior to left) and outside views of abraded carapace, approx. x100. Same collection as above. Figured specimen USNM 244979. *44-46*, dorsal (anterior to left), inside, and outside views of left valve, approx. x100. Same collection as above. Figured specimen USNM 244980.

Figs. 47, 48.— *Rectobairdia*? sp. Dorsal (anterior to right) and outside views of left valve, posterior missing, approx. x30. Cane Hill Member of Hale Formation, Washington County. USGS coll. 12938-PC. Figured specimen USNM 244981.

Figs. 49, 50.— *Bairdiolites* sp. Dorsal (anterior to left) and outside views of abraded right valve, approx. x45. Brentwood Limestone Member of Bloyd Shale, Washington County. USGS coll. 12937-PC. Figured specimen USNM 244982.

Figs. 51, 52.— *"Kegelites"* sp. Dorsal (anterior to right) and outside views of left valve, approx. x100. "Imo" Formation, Searcy County. USGS coll. 15298-PC. Figured specimen USNM 244983.

Fig. 53.— *Shleesha*? sp. Outside view of left valve, approx. x45. Cane Hill Member of Hale Formation, Stone County. USGS 26391-PC. Figured specimen USNM 244984.

Figs. 54, 55.— *Kirkbya* sp. Dorsal (anterior to right) and outside views of left valve, approx. x45. Brentwood Limestone Member of Bloyd Shale, Washington County. USGS coll. 12937-PC. Figured specimen USNM 244985.

Figs. 56-66.— *Knightina* n. sp. *56-58*, dorsal (anterior to right), ventral (anterior to left), and outside views of left valve, approx. x30. Cane Hill Member of Hale Formation, Washington County. USGS coll. 12938-PC. Figured specimen USNM 244986. *59-62*, dorsal (anterior to left), ventral (anterior to left), outside, and posterior views of right valve, approx. x30. Same collection as above. Figured specimen USNM 244987. *63, 64*, outside and dorsal (anterior to right) views of left valve, approx. x30. Same collection as above. Figured specimen USNM 244988. *65, 66*, dorsal (anterior to right) and outside views of left valve of young growth stage, approx. x30. Same collection as above. Figured specimen USNM 244989.

Fig. 67.—Gen. undet. 1. Outside view of internal cast (steinkern) of right valve, approx. x95. Same collection as above. Figured specimen USNM 244990.

Fig. 68.—Gen. undet. 2. Outside view of corroded right valve, approx. x60. Same collection as above. Figured specimen USNM 244991.


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Plate 2

Figs. 1-3.— *Youngiella* sp. 1. *1*, inside view of right valve, approx. x100. "Imo" Formation, Van Buren County, USGS coll. 12941-PC. Figured specimen USNM 244992; specimen broke after photography. *2, 3*, dorsal (anterior to right) and outside views of left valve, approx. x100. "Imo" Formation, Van Buren County. USGS coll. 12940-PC. Figured specimen USNM 244993.

Figs. 4, 5.— *Healdia* sp. ex gr. *H. caneyensis* Harlton, 1927. Dorsal (anterior to right) and right views of carapace, approx. x60. "Imo" Formation, Van Buren County. USGS coll. 12942-PC. Figured specimen USNM 244994.

Figs. 6, 7.— *Healdioides* sp. 1. Dorsal (anterior to right) and right views of carapace, approx. x60, same coll. as above. Figured specimen USNM 244995.

Figs. 8-10.— *Healdioides* sp. 2. Dorsal (anterior to right), right, and left views of carapace, approx. x60. "Imo" Formation, Van Buren County. USGS coll. 12940-PC. Figured specimen USNM 244996.

Fig. 11.— *Gortanella* sp. Outside view of left valve, approx. x45. "Imo" Formation, Van Buren County. USGS coll. 12941-PC. Figured specimen USNM 244997.

Figs. 12, 13.— *Hollinella* sp. Dorsal and outside views of left valve, approx. x30. "Imo" Formation, Van Buren County. USGS coll. 12940-PC. Figured specimen USNM 244998.

Figs. 14-16.—Kloedenellacea, gen. undet. *14, 15*, dorsal (anterior to right) and outside views of left valve, approx. x60. "Imo" Formation, Van Buren County. USGS coll. 12940-PC. Figured specimen USNM 244999. *16*, outside view of right valve of larger individual, approx. x60. Same coll. as above. Figured specimen USNM 245000.

Fig. 17.— *Monoceratina*? sp. Outside view of left valve, approx. x90. "Imo" Formation, Van Buren County. USGS coll. 12941-PC. Figured specimen USNM 245002.

Figs. 18-22.— *Cavellina* sp. *18-20*, dorsal (anterior to right), outside, and inside views of left valve, approx. x45; note incipient interior septum in ventroposterior area on fig. 20 that is diagnostic of females. "Imo" Formation, Van Buren County. USGS coll. 12941-PC. Figured specimen USNM 245003. *21, 22*, dorsal (anterior to right) and outside views of carapace, approx. x30. "Imo" Formation, Van Buren County. USGS coll. 12940-PC. Figured specimen USNM 245004.

Figs. 23-26.— *Gortanella*? sp. *23*, outside view of right valve, approx. x30. "Imo" Formation, Van Buren County. USGS coll. 12941-PC. Figured specimen USNM 245005. *24*, outside view of smaller right valve, approx. x45. Same collection as above. Figured specimen USNM 245006. *25, 26*, dorsal (anterior to left) and outside views of right valve, approx. x30. "Imo" Formation, Van Buren County. USGS coll. 12940-PC. Figured specimen USNM 245007.

Figs. 27, 28.— *Hollinella* sp. indet. Outside and inside views of right valve, approx. x45. "Imo" Formation, Van Buren County. USGS coll. 12941-PC. Figured specimen USNM 245009.

Figs. 29-40.— *Sargentina* spp. *29, 30*, outside and inside views of right valve, approx. x45. "Imo" Formation, Van Buren County. USGS coll. 12940-PC. Figured specimen USNM 245010. *31, 32*, outside and inside views of left valve, approx. x60; note remnant of marginal frill. "Imo" Formation, Van Buren County. USGS coll. 12939-PC. Figured specimen USNM 245011. *33, 34*, outside and inside views of right valve, approx. x45. "Imo" Formation, Van Buren County. USGS coll. 12940-PC. Figured specimen USNM 245012. *35-37*, dorsal (anterior to right), right, and left views of carapace, approx. x45. "Imo" Formation, Van Buren County. USGS coll. 12941-PC. Figured specimen USNM 245013. *38-40*, right, dorsal (anterior to right), and left views of carapace, approx. x45. "Imo" Formation, Van Buren County. USGS coll. 12940-PC. Figured specimen USNM 245014.

Figs. 41, 42.— *Cornigella* sp. Dorsal (anterior to left) and outside views of left valve, approx. x100. Same collection as above. Figured specimen USNM 245015.

Plate 3

Figs. 1-3.— *"Kegelites"* sp. 2. Posterior, outside, and dorsal (anterior to left) views of right valve, approx. x30. Fayetteville Shale, Washington County. USGS coll. 12944-PC. Figured specimen USNM 245016.

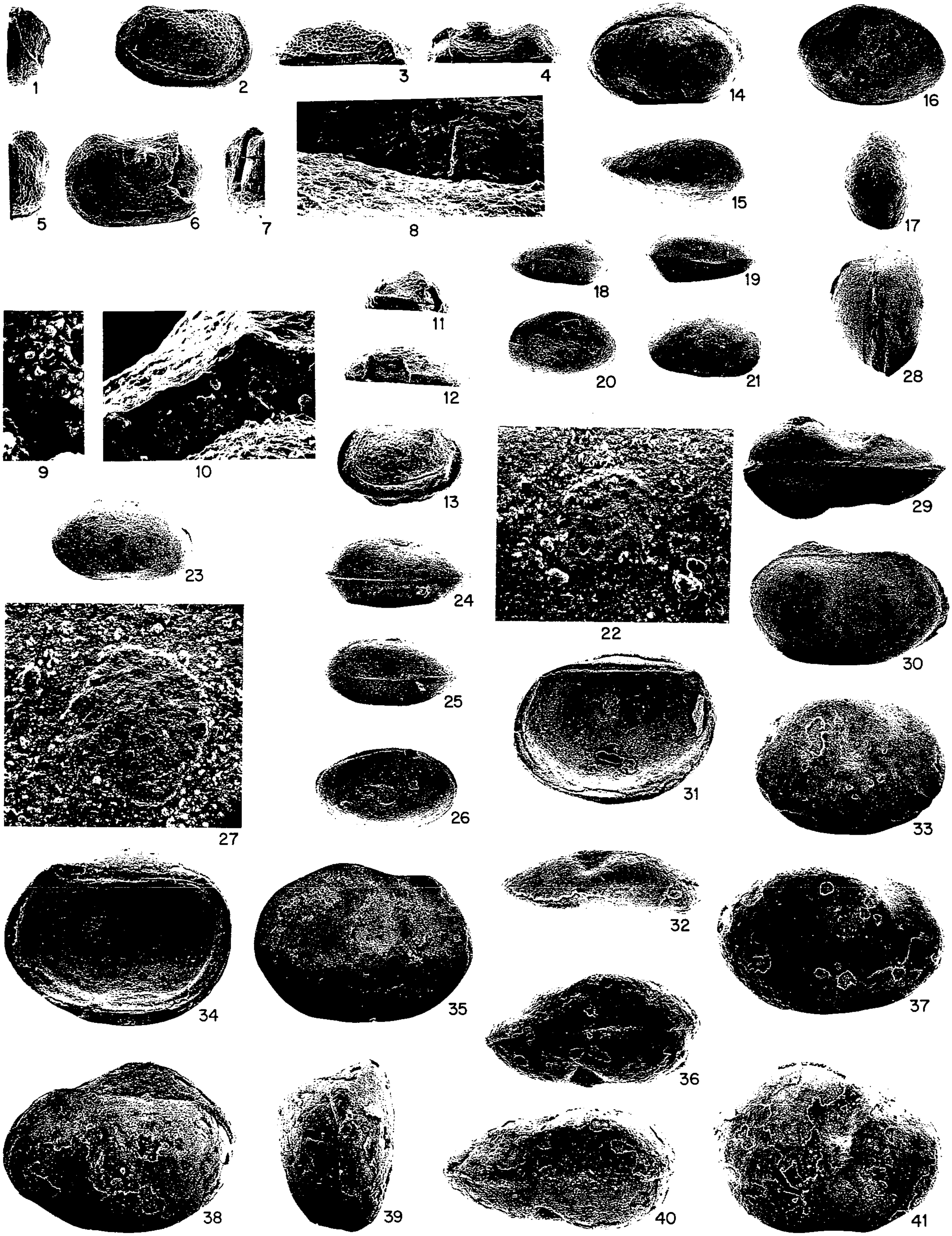
Figs. 4-8.— *Polytylites* sp. Dorsal (anterior to left), anterior, outside, and posterior views of left valve, approx. x30; detail of shell ultrastructure approx. x325 area shown by arrow on fig. 7. Same collection as above. Figured specimen USNM 245017.

Figs. 9-13.— *"Kegelites"* sp. 2. Details of shell ultrastructure, approx. x1050 and 325; area shown by arrow on fig. 11, posterior (dorsal to right), dorsal, and outside views of left valve, approx. x30; note dorsal crest on fig. 10. Same collection as above. Figured specimen USNM 245018.

Figs. 14-17.— *Cavellina* sp. 1. Left, right, dorsal (anterior to left), and posterior views of carapace, approx. x25. Same collection as above. Figured specimen USNM 245019.

Figs. 18-27.—Gen. and sp. undet. *18-22*, dorsal (anterior to left), left, ventral (anterior to right), and right views of internal cast (steinkern), approx. x45, and detail of adductor muscle-attachment scar of right valve, approx. x275. Fayetteville Shale, Washington County. USGS coll. 12943-PC. Figured specimen USNM 245020. *23-27*, left, dorsal (anterior to right), ventral (anterior to right), and right views of steinkern, approx. x45, and detail of adductor muscle-attachment scar of left valve approx. x275; arrow shows probable frontal scar to left of main scar. Same collection as above. Figured specimen USNM 245021.

Figs. 28-41.— *Sargentina* sp. 1. *28-30*, posterior, dorsal (anterior to right), and right views of steinkern, approx. x45. Same collection as above. Figured specimen USNM 245022. *31-33*, inside, dorsal (anterior to left), and outside views of right valve, approx. x45. Same collection as above. Figured specimen USNM 245023. *34, 35*, inside and outside views of right valve, approx. x45. Same collection as above. Figured specimen USNM 245024. *36, 37*, dorsal (anterior to left) and right views of carapace, approx. x45. Same collection as above. Figured specimen USNM 245025. *38-41*, left, posterior, dorsal (anterior to left), and right views of carapace, approx. x45. Same collection as above. Figured specimen USNM 245026.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MORROWAN (LOWER PENNSYLVANIAN) *PENTREMITES* IN OKLAHOMA AND ARKANSAS

Steven G. Katz[1] and James Sprinkle[2]

Abstract—Occurrences of the blastoid *Pentremites* in Morrowan strata in Oklahoma and Arkansas represent the only place in North America where these echinoderms are abundant in Pennsylvanian rocks. Although these *Pentremites* show considerable variation in their calyx shape, amount of deltoid flare, and number of hydrospires, all Morrowan blastoids in this area appear to belong to a single species, *Pentremites rusticus* Hambach. This Morrowan species shows a major morphologic change in the internal respiratory hydrospires along with the development of sexual dimorphism, features not found in any other blastoid. The anal (posterior) hydrospires in females of this species are reduced in number and greatly expanded in shape to serve as brooding chambers for fertilized eggs; the anal hydrospires of males are reduced in number but are otherwise normal. A single female blastoid, out of 658 specimens studied by sectioning, has apparent fossilized eggs still preserved in the expanded anal hydrospires. This modification of the anal hydrospires for brooding in *Pentremites rusticus* would (1) reduce predation on the early ontogenetic stages and (2) keep the larvae from drifting away from the small localized bioherms that provided optimal conditions in the Morrowan of this area. These advantages may have allowed this single species of *Pentremites* to survive into the Pennsylvanian.

INTRODUCTION

Blastoids are an extinct class of middle and late Paleozoic brachiole-bearing stemmed echinoderms. They reached their peak diversity during the Mississippian and were abundant throughout much of North America during this time. However, blastoids became rare in North America during the Pennsylvanian except for those in Morrowan (Early Pennsylvanian) strata in eastern Oklahoma and northwestern Arkansas. These Morrowan blastoids belong to *Pentremites rusticus* Hambach, and this occurrence represents the last remnant of a major Mississippian diversification of this genus. In fact, Galloway and Kaska (1957, p. 46-47, 50) mistakenly believed that these strata were Late Mississippian rather than Early Pennsylvanian because of the abundance of *Pentremites.*

Early Pennsylvanian *Pentremites* are almost unknown elsewhere; some specimens apparently belonging to *P. rusticus* are known from the Wapanucka Limestone of southern Oklahoma. A few specimens of *Pentremites* have also been collected from the Morrowan La Tuna Member of the Magdalena Formation at a locality in the Hueco Mountains of west Texas (Darwin Boardman, personal communication, 1971). Unfortunately, no specimens from this locality were available for study. Macurda (1964, p. 708-710) described *Pentremites crystalensis* from the Morrowan(?) of southern Nevada, but Webster and Lane (1970, p. 276-279) showed that this occurrence of *Pentremites* (plus another new species, *P. aridus*) is Late Mississippian (Chesterian) and not Early Pennsylvanian. No other Early Pennsylvanian occurrences of *Pentremites* are known from North America.

OCCURRENCE OF MORROWAN *PENTREMITES*

Pentremites rusticus occurs throughout the Sausbee Formation in Oklahoma but is abundant only in the upper part of the Braggs Member and in the Brewer Bend Limestone Member. In the overlying McCully Formation, it occurs uncommonly in the Chisum Quarry Member and is extremely rare in the Greenleaf Lake Limestone Member (information provided by P. K. Sutherland, The University of Oklahoma, personal communication; see Sutherland and Henry, 1977, for recently erected stratigraphic nomenclature). This species is also found, but less commonly, in the Prairie Grove Member of the Hale Formation and in the Brentwood Limestone Member of the Bloyd Formation in Arkansas (figs. 1, 2).

Pentremites rusticus was part of a shallow-marine, offshore-shelf community that thrived in the clear, slightly agitated, normal marine water of this area during the Early Pennsylvanian. Its mode of life was probably similar to that of rheophile (current-seeking) crinoids. These blastoids were high-level suspension feeders, forming their long brachioles into a sophisticated downcurrent-opening funnel that filtered planktonic microorganisms from the slow horizontal currents. However, none of the blastoids studied in this investigation have been found with the brachioles, stem, or minute cover plates attached. When the blastoids died, they apparently were exposed long enough before burial for the soft parts to decay and for the fragile brachioles, stem segments, and cover plates to become detached from the calyx and disarticulated, leaving only the compact, tightly sutured calyx and the protected internal calcite hydrospires intact (fig. 3).

Most specimens were not exposed too long before burial, as shown by the relatively undisturbed nature of the hydrospires and the unworn ambulacral and calyx plates. However, a few specimens are an exception to this and appear worn with no hydrospires preserved; others may be flattened or distorted, probably as a result of later diagenetic crushing (Sprinkle and Gutschick, 1967).

Most of the well-preserved specimens have nearly smooth calyx plates with minor or indistinct growth lines (pl. 1, figs. 1-3, 5-8), but a few have pronounced growth ridges (pl. 1, fig. 4). Although Galloway and Kaska (1957, p. 24) attributed this ornamentation to preservation, it is probably a product of local or seasonal variation in growth. Some other blastoids, such as *Belocrinus* from the Devonian of France (Macurda, 1966), have prominent growth ridges.

[1]1001 University Avenue, Columbia, Missouri.

[2]Department of Geological Sciences, The University of Texas, Austin, Texas.

The blastoid skeletal plates and hydrospires were composed of a normal echinoderm meshwork (stereom) of calcite rods (Galloway and Kaska, 1957; Macurda, 1973), with the intervening pores originally occupied by soft tissue (stroma) that has now been filled in with syntaxial overgrowths of secondary calcite. These overgrowths unfortunately make removal of the specimens from the limestone slabs difficult and often impossible, because breaks tend to travel through the specimens along calcite cleavage planes. Many of the better specimens were found already weathered out of the rock and nearly free of matrix.

Besides these syntaxial calcite overgrowths, other calyx-filling materials included brown, yellow, and light-green micrite, gray skeletal biomicrite, "poorly washed" biosparite, ooliths, and dolomite rhombs. Some specimens were not entirely filled and formed miniature geodes.

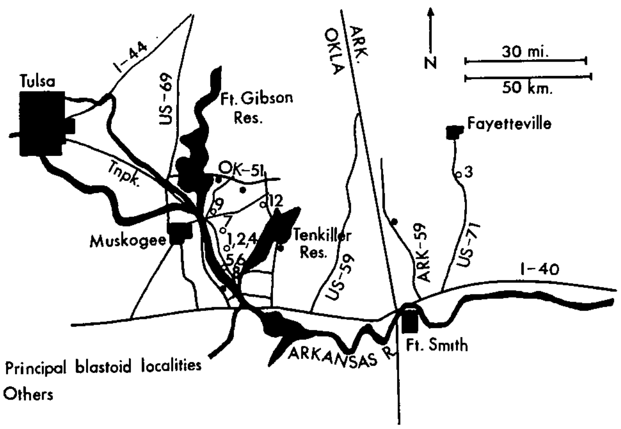

Figure 1. Map of blastoid-collecting localities in eastern Oklahoma and northwestern Arkansas. Numbered collections are listed in table 1.

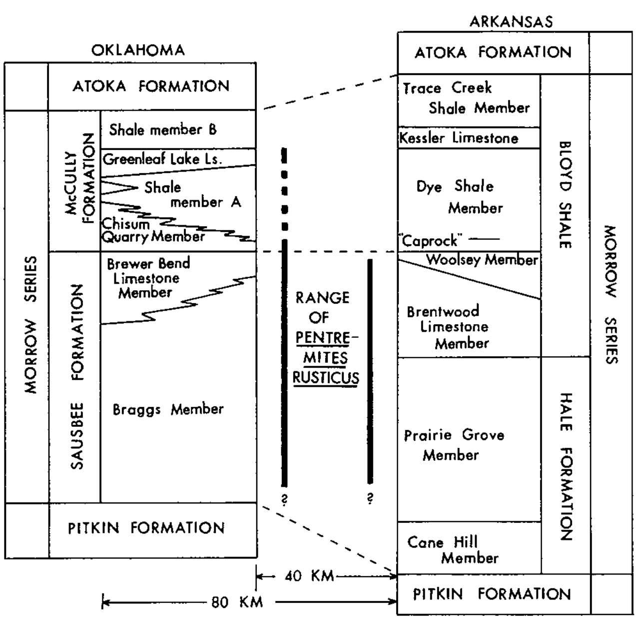

Figure 2. Range of *Pentremites* in Morrowan of eastern Oklahoma and northwestern Arkansas (stratigraphy after Sutherland and Henry, 1977).

TAXONOMY OF MORROWAN *PENTREMITES*

Hambach (1903) was the first to investigate *Pentremites* from the Morrowan of Oklahoma and Arkansas. He distinguished two species, *P. rusticus* and *P. angustus*, based primarily on their different calyx shapes. Katz (1975, and in press) has demonstrated that *P. angustus* is probably not a separate species at all; when Hambach described it, he chose as the holotype a rare specimen having a highly elongated shape.

The problem was further complicated by Galloway and Kaska (1957). They incorrectly assumed a Late Mississippian age for *P. angustus* from Oklahoma and Arkansas and, by comparing external morphology of *P. angustus* with that of the Chesterian species *P. godoni* (Defrance), concluded that *P. angustus* was a variety of *P. godoni*, namely *P. godoni angustus*. In addition to the Oklahoma and Arkansas specimens, they also included elongate *P. godoni* from the Chesterian Paint Creek Formation of Illinois (Galloway and Kaska, 1957, pl. 3, fig. 24, and pl. 13, fig. 1). However, because of the overwhelming evidence that the strata from which *P. angustus* from Oklahoma and Arkansas comes are Morrowan, not Chesterian, and because internal morphology in the two species is significantly different, separation at the species level is warranted. All the *Pentremites* from the Sausbee, McCully, Bloyd, and Hale Formations of eastern Oklahoma and northwestern Arkansas are *Pentremites rusticus*, as previously redefined by Katz (1975, and in press), and not *P. godoni*. *Pentremites rusticus* also differs sufficiently from *P. laminatus*, which occurs in the underlying Pitkin Limestone of these areas, so that these two species can usually be distinguished in the field (Beaver, 1964).

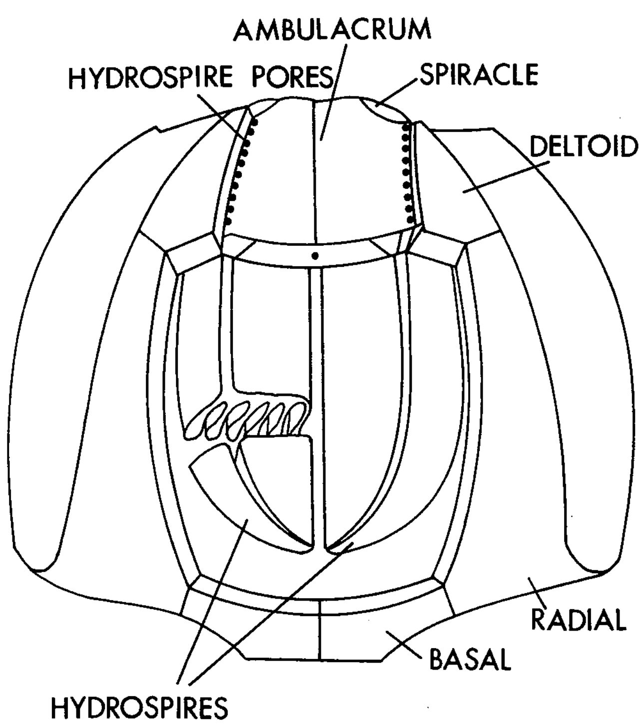

Figure 3. Cutaway view of blastoid calyx showing location of internal hydrospires (modified from Moore and others, 1952).

HYDROSPIRE MORPHOLOGY AND ABNORMALITIES

P. rusticus characteristically has well-preserved internal respiratory hydrospires. They are composed of 10 groups of calcareous pleated folds located under the edges of the ambulacra and exposed to view in transversely sectioned specimens (fig. 3; pl. 1, figs. 9-13. They open to the outside through five spiracles at the summit of the calyx and through numerous tiny hydrospire pores along the ambulacra.

Hydrospires were first named by Billings (1869), who recognized their respiratory function based on similarity with gills. Several authors have inferred that sea water carrying oxygen entered the blastoid via the hydrospire pores and passed through the narrow slits where oxygen was exchanged for carbon dioxide across the thin walls. The spent water was then forced up to the spiracles and expelled (Beaver, 1968; Katz, 1975). Water movement was probably a result of ciliary action rather than hydrospire expansion and contraction (like bellows), because there is no evidence that hydrospires were soft or flexible (Beaver, 1968). Constancy of shape from specimen to specimen and preservation of the original echinoderm stereomic microstructure indicate also that hydrospires were inflexible in the living blastoid.

Although the number of folds in a hydrospire group varies from genus to genus, it is nearly constant within most species of spiraculate blastoids. However, *Pentremites rusticus* has a substantial amount of variation, not only from individual to individual but also from hydrospire group to hydrospire group within a single individual. Five to 7 folds is most common in the non-anal (i.e., non-posterior) positions, although 3, 4, and 8 folds have also been found. The number of hydrospire folds in each of the 2 anal groups in these Morrowan *Pentremites* is usually reduced to 3, 4, or 5. In almost every specimen, no matter what the number of folds in non-anal groups, there are fewer folds in the two anal groups. In addition, the folds in the two anal groups are not always equal in number in any one individual. This reduction in number of anal hydrospire folds is not known in any other species of *Pentremites,* or in any other spiraculate blastoid.

Moreover, the anal hydrospires can be divided into two distinctly different types. In some specimens (designated Type I), the anal hydrospire groups have a reduced number of folds that are expanded and distorted in shape, unlike the normally developed hydrospires in non-anal positions (fig. 4a). This Type I abnormality has never been reported in any blastoids except those from the Morrowan of Oklahoma and Arkansas (Beaver, 1964, 1968; Katz, 1975). Other specimens (designated Type II) show a reduced number of folds just as in Type I, but the shape of the folds is the same as that of non-anal hydrospires (fig. 4b). Nearly all of the sectioned specimens that have preserved anal hydrospires show one of these easily distinguishable types. There are no intermediate forms, and only the anal hydrospires are affected.

Of the 658 sectioned specimens that have preserved anal hydrospires, the Type I pattern occurs in 254 (39 percent) of them (table 1), whereas the Type II pattern occurs in 404 specimens (61 percent). There is no geographic or stratigraphic preference for one type or the other. Both are found at all localities and horizons, and the number of Type I specimens is always less than or equal to the number of Type II specimens (table 1.)

Study of the Morrowan *Pentremites* has yielded evidence that the expanded Type I hydrospires were used for brooding eggs and perhaps larvae (Katz, 1975; Katz and Sprinkle, 1976). Thin sections of University of Oklahoma specimen no. 8372 (pl. 1, figs. 8, 13-15) show that the left anal-hydrospire group is completely filled with hundreds of transparent spheres that are probably preserved eggs. If so, then blastoids with Type I hydrospires were probably females and those with Type II hydrospires were probably males. This is the first evidence of sexual dimorphism in a blastoid; however, no other calyx feature shows this sexual difference. The 39/61 ratio of Type I to Type II specimens therefore implies an uneven sex ratio, but this is not uncommon in the animal kingdom.

The presence of eggs is also the first evidence of internal fertilization and brooding in blastoids. Mississippian species of *Pentremites* show no hydrospires modified for internal brooding. Some advantages of brooding eggs and nonpelagic larvae would be (1) reduction of the chances of predation on these early ontogenetic stages and (2) reduction of the chances of their drifting into unfavorable environments. Many modern predators and suspension or filter feeders prey on pelagic eggs and larvae, and Mather's (1915) faunal list of Morrowan fossils includes several groups feeding in this way. However, few of these animals were present in the Early Pennsylvanian and not in the Late Mississippian, where blastoids show no evidence of egg or larval brooding.

Because pelmatozoans, including blastoids, thrived on isolated small bioherms in the Morrowan (Bonem, 1975; Katz, 1975), these blastoids may have developed brooding and nonpelagic larvae or direct development as a mechanism to prevent the offspring from drifting away from these most favorable areas. Pelagic larvae are wide ranging and have a

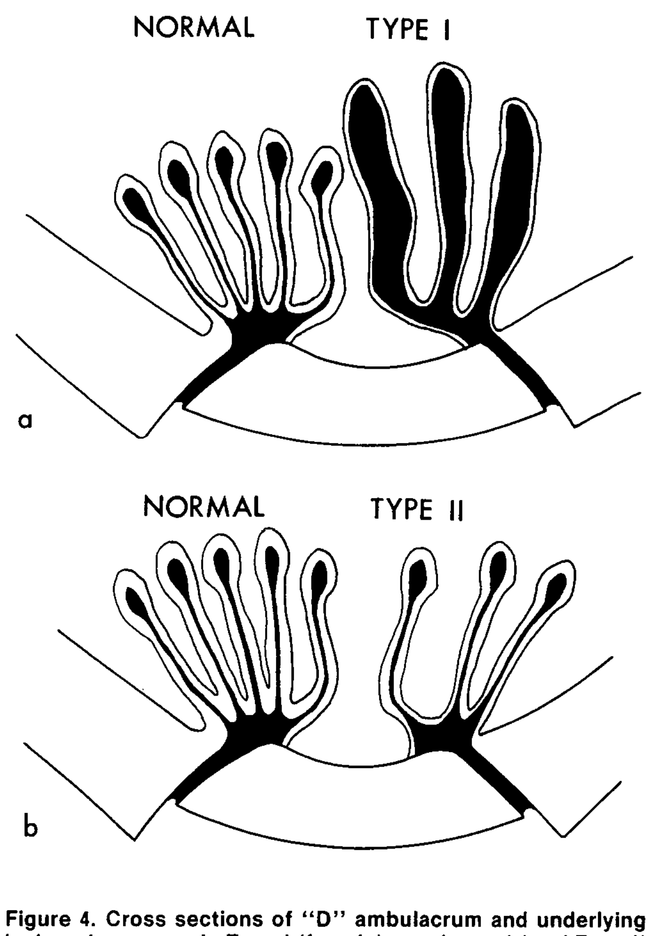

Figure 4. Cross sections of "D" ambulacrum and underlying hydrospire groups in Type I (female) specimen *(a)* and Type II (male) specimen *(b)* of *Pentremites rusticus*, showing how anal hydrospires (at right) differ from normal hydrospires in this species.

Table 1.—Number of Type I and Type II Specimens of *Pentremites rusticus* in Collections from Different Localities

Collection locality (see fig. 1)	No. of specimens	No. of Type I specimens	No. of Type II specimens	Type I/ Type II ratio
1	34	17	17	50/50
2	27	10	17	37/63
3	40	15	25	38/62
4	31	13	18	42/58
5	81	29	52	36/64
6	39	16	23	41/59
7	55	20	35	36/64
8	85	37	48	44/56
9	57	19	38	33/67
10	40	13	27	33/67
11	101	34	67	34/66
12	37	18	19	49/51
Misc. others	31	13	18	42/58
Totals	658	254	404	39/61

long existence (as much as 6 weeks), so that the larvae may be dispersed great distances although they suffer a high rate of mortality during this time. In contrast, forms with nonpelagic larvae or direct development lack widespread dispersal but have much lower mortality. In the Morrowan environment where blastoids flourished, they may have needed the advantages of protection and limited dispersal in localized favorable environments more than the disadvantage of not achieving wide dispersal. Therefore, this change in type of reproductive process may have allowed *Pentremites rusticus* to survive in this region during the Morrowan while other species of *Pentremites* did not.

ACKNOWLEDGMENTS

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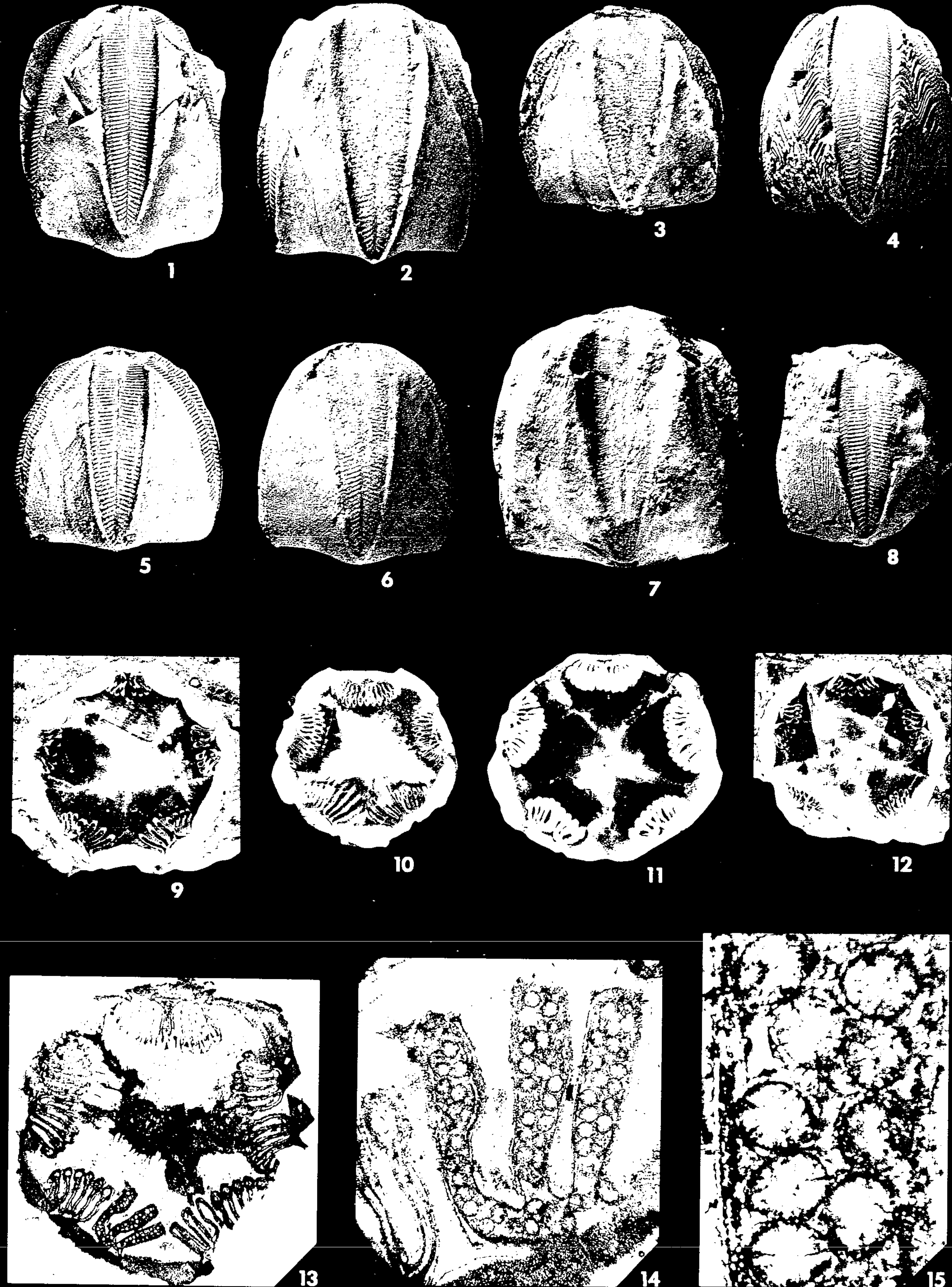
Plate 1

Figs. 1-8.— *Pentremites rusticus* Hambach. A series of specimens before sectioning, showing external preservation, range in calyx shape, and amount of deltoid flare (all x2.7). *1,* U. Texas specimen no. 1211TX-24, Sausbee Formation, Gore, Oklahoma, showing high deltoid flare and elongate barrel shape; *2,* U. Oklahoma no. 8425, Sausbee Formation, Fort Gibson, Oklahoma; *3,* U. Iowa no. 38846, Sausbee Formation, Gore, Oklahoma; *4,* U. Texas no. 1216TX-1, ? formation, Braggs, Oklahoma, showing unusual degree of ornamentation on the radials and deltoids; *5,* U. Michigan no. Penn-3/1969, Sausbee Formation, Fort Gibson, Oklahoma, showing fine growth lines on radials and deltoids; *6,* U. Oklahoma no. 8442, ? formation, typical Arkansas specimen showing very little deltoid flare; *7,* U. Oklahoma no. 8386, Sausbee Formation, Gore, Oklahoma; note squat barrel shape and abraded exterior surface; *8,* U. Oklahoma no. 8372, Sausbee Formation, Jeffries Quarry, Muskogee County, Oklahoma; rather small and poorly preserved specimen that was found to contain possible blastoid eggs (see figs. 13-15, below).

Figs. 9-12.— *Pentremites rusticus* Hambach. A series of transversely sectioned specimens, anal side oriented downward (all x2.7). *9,* U. Texas no. 1213TX-11, Bloyd Formation, Washington County, Arkansas, Type I specimen in matrix; note few hydrospire folds per group; *10,* U. Oklahoma no. 8429, Sausbee Formation, Gore, Oklahoma, Type I specimen with many hydrospires; *11,* U. Oklahoma no. 8370, Sausbee Formation, Jeffries Quarry, Muskogee County, Oklahoma, Type II specimen with light-colored, slightly overgrown hydrospires; *12,* U. Texas no. 1213TX-4, Bloyd Formation, Washington County, Arkansas, Type II specimen showing few hydrospire folds per group.

Figs. 13-15.— *Pentremites rusticus* Hambach. Transverse sections of single egg-bearing, Type I (female) specimen, U. Oklahoma no. 8372, Sausbee Formation, Jeffries Quarry, Muskogee County, Oklahoma. *13,* transverse thin section showing eggs in left anal hydrospire group (x5.0); *14,* enlargement of left anal hydrospire group in *13* showing expanded Type I folds completely filled with eggs (x22); *15,* enlargement of right fold in *14* showing slightly oblong eggs with degraded membranes and radiating contacts internally where calcite crystals have grown together (x90).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LATE MISSISSIPPIAN AND EARLY PENNSYLVANIAN BLASTOIDS FROM NORTHEASTERN OKLAHOMA AND NORTHWESTERN ARKANSAS

Alan S. Horowitz[1] and D. B. Macurda, Jr.[2]

Abstract—Of the 14 species of *Pentremites* reported in the Late Mississippian and Early Pennsylvanian rocks of the Ozark region, 2 are invalid names, and only 2 of the remaining 12 taxa are common: *P. laminatus* Easton from the Pitkin Limestone and *P. rusticus* Hambach from Morrowan rocks. The morphologic characters of *P. laminatus* are consistent with a late Chesterian age for the Pitkin Limestone, but additional work will be necessary both on the Ozark faunas and on a revision of the genus *Pentremites* before further biostratigraphic refinements will be possible.

PREVIOUS INVESTIGATIONS

Shumard (1853, p. 200) apparently published the earliest report of blastoids in northeastern Arkansas. He briefly commented on, but did not figure, *Pentremites florealis* Say (an objective junior synonym of *P. godoni* (Defrance), and *P. sulcatus* (Roemer). As subsequently reviewed by Galloway and Kaska (1957), *P. godoni* is confined to the early Chesterian and *P. sulcatus* to the middle and late Chesterian of the standard Illinois basin Chesterian section. The present repository of Shumard's original materials is unknown, and, because Shumard reported only that his specimens were Carboniferous, we cannot be certain whether the specimens were Mississippian or Pennsylvanian or both.

No further paleontological work on blastoids from this area appears to have been published until the end of the century, when the abundance of blastoids in the Brentwood Limestone Member of the Bloyd Shale led the geologists of the Arkansas Geological Survey to apply the term Pentremital Limestone to these beds. In Washington County, Arkansas, Simonds (1891) did not report any blastoids from beds now regarded as Late Mississippian in age but did report abundant *Pentremites* Say from his Pentremital Limestone (=Brentwood). Simonds' (1891, p. 92) unnumbered figure of *Pentremites* apparently represents a small specimen of the subsequently described species *P. rusticus* Hambach (= *P. angustus* Hambach).

Hambach (1903, p. 53-54) described two species, *P. angustus* and *P. rusticus*, from what he regarded as the Chester Limestone of Washington County, Arkansas. Mather (1915, p. 100) indicated that these species were from the Morrow Formation, principally the Brentwood Limestone. Galloway and Kaska (1957, p. 50) questioned the Pennsylvanian age of these species. Our own collections and those of numerous other workers indicate that both species are of Morrowan, Pennsylvanian, age. The two species are the latest representatives of the genus *Pentremites*, and we agree with Katz and Sprinkle (1976) that they are probably subjective synonyms. *P. angustus* has page priority, but Katz and Sprinkle (1976, p. 1137) apparently prefer to retain the name *P. rusticus*. We will follow their usage as first revisers.

Chesterian blastoids from the Ozark region were first reported in this century by the U.S. Geological Survey mappers preparing folios in Arkansas and Oklahoma (Adams and Ulrich, 1905; Taff, 1905, 1906; Purdue, 1907; Purdue and Miser, 1916). Taff (1905, 1906) reported "*Pentremites* sp. undet. (a large form between *P. godoni* and *P. conoideus*)" from the Fayetteville Shale in Oklahoma. Snider (1915) reported *Pentremites* in the Chesterian formations of northeastern Oklahoma, and Croneis (1930) listed several species from the Fayetteville and Pitkin Formations of Arkansas and followed Mather (1915) in reporting *Pentremites* from the Hale and Bloyd Formations of the type Morrowan in northwestern Arkansas. Easton (1943) created the species *P. laminatus* for forms from the Pitkin Limestone in Arkansas. This species has been found subsequently in Oklahoma and in Alabama (Drahovzal, 1967).

Pentremites is apparently the only blastoid genus reported from the Late Mississippian and Early Pennsylvanian rocks of the Ozark region of Oklahoma and Arkansas. Elsewhere *Diploblastus* Fay is characteristic of early Chesterian rocks in the eastern United States and is present at least as high as the middle Chesterian Glen Dean Limestone, where it is rare in the standard Illinois basin Chesterian section.

At least 14 names have been applied to specimens of *Pentremites* from the Ozark area of Arkansas and Oklahoma. Of these, *Pentremites wedingtonensis* Croneis (1930, p. 71) is a *nomen nudum* and *P. interlineatus* Huffman (1958, p. 73) is an error for *P. laminatus* Easton. Table 1 presents the stratigraphic distribution of 12 species of *Pentremites* as reported in Arkansas and Oklahoma. Most of these are probably misidentifications, *P. laminatus* and *P. elongatus*? being the only species we have encountered in the Pitkin Formation and *P. rusticus* the only species in the Pennsylvanian.

The present model of evolution within the genus *Pentremites* is based on the work of Galloway and Kaska (1957), with some modifications proposed in Horowitz and Strimple (1974). The sulcate ambulacra and flaring deltoid plates of *P. laminatus* would indicate a late middle Chesterian (Glen Dean Limestone) or later age compared with the standard Illinois basin section. This is consistent with, but not as refined as, correlations based on other evidence that suggests a late Chesterian age (Clore through Kinkaid) for the Pitkin Limestone.

P. elongatus Shumard was originally reported from the Burlington Limestone and was reviewed recently by Macurda (1975). Slocum (1955, p. 13) reported the species in a faunal list of the Hindsville Formation in Oklahoma. We have not collected specimens similar to *P. elongatus* from the Hindsville but have collected these very low-pelved forms in the Pitkin Limestone in Oklahoma, as reported in Horowitz and Strimple (1974, p. 210). The presence in the Pitkin of forms com-

[1]Department of Geology, Indiana University, Bloomington, Indiana.
[2]Museum of Paleontology, The University of Michigan, Ann Arbor, Michigan.

Table 1.—Stratigraphic Distribution of Species of *Pentremites* Reported in Late Mississippian and Early Pennsylvanian Rocks of Ozark Region and Illinois Basin

Data from references cited in text						Chesterian		
	Hindsville	*Fayetteville*	*Pitkin*	*Hale*	*Bloyd*	*Lower*	*Middle*	*Upper*
Pentremites angustus Hambach (= *P. rusticus* Hambach)	—	—	—	X		—	—	—
P. elongatus Shumard	X	—	X	—		—	—	—
P. godoni (Defrance)	X	—	X	—		X	—	—
P. godoni pinguis Ulrich	cf.	—	—	—		X	—	—
P. laminatus Easton	—	—	X	—		—	—	—
P. obesus Lyon	—	—	X	—		—	X	—
P. patei Ulrich	X	—	—	—		—	X	—
P. platybasis Weller	—	X	—	—		X	X	—
P. pulchellus Ulrich	—	X	—	—		X	X	X
P. rusticus Hambach	—	—	—	X		—	—	—
P. sulcatus (Roemer)	—	—	—	—		—	X	X

parable in shape to *P. elongatus* and the presence of the conoid species *P. rusticus* in the overlying Pennsylvanian beds indicate that some of the earliest appearing morphologies in the genus *Pentremites* persisted through its chronologic range. This picture contrasts with that initially proposed by Galloway and Kaska (1957). The specimens of *P. elongatus*? occur in a ratio of less than one per thousand specimens of *P. laminatus*.

We are not prepared to make further comments on the usefulness of *Pentremites* in regional correlations until we have completed a review of materials presently in our collections.

OCCURRENCE AND PRESERVATION

Most of the early reports of *Pentremites* in the Ozark region were from Washington County in northwestern Arkansas. Recollection of outcrops in this region has yielded well-preserved material, but the number of specimens is relatively small. Huffman (1958) cited numerous localities in northeastern Oklahoma. Some of these, plus other, more recent exposures in Cherokee and Muskogee Counties, have yielded large populations from both the Mississippian and Pennsylvanian that are well suited for study of ontogenetic and phenotypic variation. Some populations contain more than 1,000 specimens.

The best specimens are preserved in shales interbedded with thin limestones. Individuals consist only of the theca; the column, brachioles, and ambulacral covering plates have been lost prior to final burial. Large populations commonly occur in local lenses one to several meters across; preservation of external ornament and hydrospires is excellent, so transportation has been minimal. The associated fauna is diverse, including brachiopods, crinoids, bryozoans, and mollusks.

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CHESTERIAN (UPPER MISSISSIPPIAN) AND MORROWAN (LOWER PENNSYLVANIAN) CRINOIDS OF NORTHEASTERN OKLAHOMA AND NORTHWESTERN ARKANSAS

Harrell L. Strimple[1]

Abstract—In northeastern Oklahoma and northwestern Arkansas, camerate crinoids are represented in the Chesterian by very few poorly preserved specimens of acrocrinids, dichocrinids, and platycrinitids. The same families are present in the Morrowan; in addition, the Paragariocrinidae make an appearance.

Flexible crinoids are limited to *Onychocrinus* and *Taxocrinus* in the Chesterian, neither of which genera are recognized in younger strata. Five genera of flexibles are found in the Morrowan.

Inadunate crinoids are dominant, and those of the Order Cladida (dicyclic) far surpass those belonging to the Disparida (monocyclic). On a generic level, only seven inadunates survive the transition from Chesterian to Morrowan time. However, numerous lineages are recognized. Thirty-two inadunate genera are known from the Chesterian, and 30 from the Morrowan.

INTRODUCTION

Any survey dealing with crinoids must be tempered with the understanding that complete cups or crowns are preserved only under ideal conditions because of their multiplated endoskeletons. Unless they were buried very quickly upon demise, they disarticulated rapidly, and their identity, with few exceptions, was lost. It is obvious from the vast numbers of disarticulated ossicles present in rock formations that great numbers of crinoids lived during Chesterian and Morrowan time. No species is considered in the present report unless it is known from a dorsal cup or crown (cup with arms attached), with two exceptions: *Stereobrachicrinus pustulosus* is represented only by single fused arms, and *Platyplateium* sp. is known only from a twist nodal of a platycrinitid crinoid. Disarticulated crinoid ossicles are not considered herein.

Stratigraphic terms and concepts used herein are those of Furnish and Saunders (1971, text-fig. 1).

The flexible genera *Cibolocrinus* and *Calycocrinus* first appear in Morrowan rocks of Oklahoma, but these genera have no known antecedents in the Chesterian of North America. *Cibolocrinus* continued throughout the Pennsylvanian into the Permian, but *Calycocrinus* is not represented until the Permian. *Calycocrinus* was not a really successful genus; that is, it was not prolific at any time, but somehow, somewhere, it managed to survive into the Permian. *Taxocrinus* and *Onychocrinus* are fairly common in Chesterian rocks, but neither is found in Morrowan rocks where *Zenocrinus, Paramphicrinus,* and *Euonychocrinus* first appear. The last two genera were rather successful, although never prolific, throughout Pennsylvanian time.

Most camerate lineages disappeared by Chesterian time, and very few representatives of this subclass are present in Morrowan rocks of the subject area. Acrocrinids and dichocrinids (including *Pterotocrinus*) are known from fragmentary remains. An ornate *Dichocrinus* not previously reported, and as yet undescribed, is known to occur in the Hindsville Formation. A single columnal of a platycrinitid (*Platyplateium*) has been reported from the Imo Formation of Arkansas. *Platycrinites* s.s. is common in Genevievian strata east of the Mississippi River but does not persist into the Chesterian in that area. There is a previously unreported calyx of *Platycrinites* sp. (s.l.) from the Morrowan of northeastern Oklahoma. *Megaliocrinus*, a paragariocrinid, appears in Morrowan rocks of northeastern Oklahoma; this genus is unknown elsewhere save in coextensive rocks in Spain. Acrocrinids are not common in the Morrowan but persist into the Missourian (Upper Pennsylvanian).

Inadunate crinoids dominated in Chesterian and Morrowan time, and the order Cladida is the most common. Of crinoids placed in the order Disparida, the superfamily Allagecrinacea is scarce but is represented in the Chesterian by a previously unrecorded *Allocatillocrinus* from the Fayetteville Formation of Oklahoma. *Allocatillocrinus* is rather common in Morrowan rocks. The Belemnocrinacea have not been reported from the Chesterian; however, 2 or 3 specimens of *Synbathocrinus* are known from Middle and Upper Pennsylvanian strata. Among the cladids, the Suborder Cyathocrinina are almost nonexistent in Chesterian and Morrowan rocks. *Lecythiocrinus*, which has obscure affinities, first appears in the Morrowan and was fairly successful in the Missourian of Oklahoma and Kansas. The Suborder Poteriocrinina was by far the most prolific during Chesterian and Morrowan time.

CHESTERIAN

Hindsville Formation

The genera *Agassizocrinus, Staphylocrinus,* and *Cryphiocrinus* are all components of Gasperian faunas, and all save *Agassizocrinus* appear to be restricted to the lower Chesterian. They are usually found as disarticulated cup plates, which are relatively common in some strata in Oklahoma, Illinois, Arkansas, Kentucky, and Alabama (personal observation). The unusually thick cup plates and typical lack of a stem place them in a known eleutherozoic category. They apparently filled an unusual ecologic niche (turbulent conditions?). In any event, isolated basal plates of *Staphylocrinus* are common enough in the Hindsville Formation of northeastern Arkansas and northwestern Oklahoma to serve as indices of the formation. A few cups and one crown of *Cryphiocrinus* have been described from the same area (Strimple, in press).

[1]Geology Department, The University of Iowa, Iowa City, Iowa.

Table 1.—List of Chesterian-Morrowan Crinoid Species, Showing Known Occurrences in Oklahoma and Arkansas

Species	Hindsville	Fayetteville	Pitkin	Imo	Hale	Bloyd	Okla = O Ark = A
Abrotocrinus sp.	*X						*O
Acrocrinus constrictus Burdick & Strimple		X					O
Anchicrinus rugosus (Strimple)						X	O
Affinocrinus grandis Moore & Strimple						X	O
Affinocrinus progressus Moore & Strimple						X	O
Agassizocrinus conicus Owen & Shumard	X	X					O-A
Agassizocrinus patulus Strimple			X				O
Alcimocrinus girtyi (Springer)						X	O
Alcimocrinus ornatus Strimple		X					O
Allocatillocrinus carpenteri (Wachsmuth)		*X					*O
Allocatillocrinus rotundus Moore						X	O-A
Allocatillocrinus rotundus multibrachiatus Moore						X	O
Ampelocrinus erectus Strimple		X					O
Anchicrinus planulatus Moore & Strimple						X	O-A
Anobasicrinus braggsi (Strimple)						X	O
Aphelecrinus planus Strimple		X	X				O
Aphelecrinus exoticus Strimple		X					O
Arkacrinus dubius (Moore & Plummer)						X	O-A
Arkacrinus constrictus Moore & Strimple						X	A
Arkacrinus sp.					*X		*A
Atokacrinus tumulosus Moore & Strimple						X	O
Bronaughocrinus figuratus Strimple			X	*X			O-*A
Bronaughocrinus cherokeensus Strimple	X						O
Calycocrinus furnishi Moore & Strimple						X	O
Calycocrinus symmetricus Moore & Strimple						X	O
Camptocrinus sp.			*X				*A
Carinocrinus stevensi Laudon			X				O
Catillocrinus sp. (= *Allocatillocrinus*)			X				O
Chlidonocrinus trinodus Strimple & Watkins		X					O
Chlidonocrinus sp.				*X			*A
Cibolocrinus circulus Moore & Strimple						X	O
Cibolocrinus regularis Moore & Plummer						X	O
Cibolocrinus spinosus Moore and Strimple						X	O
Cibolocrinus tumidus Moore & Plummer						X	O
Cosmetocrinus eventus (Strimple)			X				O
Cosmetocrinus sp. Laudon			X				O-*A
Cromyocrinus grandis Mather						X	O-A
Cryphiocrinus bowsheri (Strimple)	X						O
Cryphiocrinus girtyi Kirk	X						O-A
Culmicrinus sp.			*X				*A
Cymbiocrinus gravis Strimple		X					O
Dasciocrinus aulicus Strimple		X					O
Dichocrinus girtyi	X						O
Dichocrinus sp.			*X				*A
Dicromyocrinus optimus Strimple						X	O
Dicromyocrinus subaplatus Moore & Strimple						X	O
Diphuicrinus croneisi Moore & Plummer						X	O-A
Diphuicrinus pentanodus Moore & Strimple						X	O
Eirmocrinus sp.					X		A
Endelocrinus matheri (Moore & Plummer)						X	O-A
Globacrocrinus pirum (Moore & Plummer)						X	O-A
Goleocrinus impressus Burdick & Strimple				X			A
Goleocrinus mangeri Burdick & Strimple				X			A
Heliosocrinus aftonensis Strimple		X					A
Intermediacrinus modernus (Strimple)		X					O
Lasanocrinus daileyi (part) (= *L. nodatus* Moore & Strimple)						X	O
Lasanocrinus minutus Moore & Strimple						X	O
Lasanocrinus multinodus Moore & Strimple						X	O
Lasanocrinus nodus Moore & Strimple						X	O
Lasanocrinus strigosus (Moore & Plummer)						X	O
Lecythiocrinus asymmetricus Moore & Strimple						X	O
Linocrinus floweri Laudon			X				O
Linocrinus sp.		*X					O
Mantikosocrinus castus Strimple		X					O
Megaliocrinus aplatus Moore & Laudon						X	O
Megaliocrinus exotericus Strimple						X	O
Metacromyocrinus gillumi Strimple						X	A

Table 1.— *Continued*

Species	Hindsville	Fayetteville	Pitkin	Imo	Hale	Bloyd	Okla=O Ark=A
Metacromyocrinus papulosus (Moore & Plummer)						X	O
Metautharocrinus cockei Moore & Strimple						X	O-A
Metautharocrinus spinifer Moore & Strimple						X	O
Morrowocrinus fosteri Moore & Plummer						X	O
Onychocrinus pulaskiensis Miller & Gortey		X	X				O
Ophiurocrinus hebdenensis Wright		X					A
Paianocrinus aptus Strimple			X				O-*A
Paianocrinus durus Strimple			X				O-*A
Palmerocrinus kesslerensis Moore & Strimple						X	A
Palmerocrinus sp.					X		A
Paracromyocrinus oklahomensis (Moore & Plummer)						X	O-A
Paracymbiocrinus pitkini (Strimple)			X				O
Paracymbiocrinus ormandi Burdick & Strimple				X			A
Paradelocrinus aequabilis (Moore & Plummer)						X	O-A
Paragassizocrinus caliculus (Moore & Plummer)						X	O-A
Paragassizocrinus magnus (Moore & Plummer)						X	O-A
Paramphicrinus magnus Moore & Strimple						X	A
Pelecocrinus stereosma Laudon			X				O
Pentaramicrinus modulus (Strimple)			X				O
Pentaramicrinus nitidus (Miller & Gurley)	*X						*O
Perimestocrinus pumilus Moore & Plummer						X	O
Perimestocrinus teneris Moore & Plummer						X	O-A
Phacelocrinus brevis Moore & Strimple						X	O
Phacelocrinus rosei (Moore & Plummer)						X	O
Phacelocrinus sp.		*X					*O
Phacelocrinus sp.			*X				*A
Phanocrinus alexanderi Strimple		X					O
Phanocrinus cooksoni Laudon			X				O-*A
Phanocrinus cylindricus Miller & Gurley		X					O
Phanocrinus formosus Worthen		X					O
Phanocrinus imoensis Burdick & Strimple				X			A
Phanocrinus irregularis Strimple			X				O-*A
Phanocrinus sp.			*X				*A
Platyacrocrinus brentwoodensis (Moore & Plummer)						X	O-A
Planacrocrinus conicus Moore & Strimple						X	O
Planacrocrinus minutus Moore & Strimple						X	O
Platycrinites sp.						*X	*O
Platyplateium sp.				X			A
Pterotocrinus tridecibrachiatus Gutschick			X				O
Sciadiocrinus cascus Moore & Strimple						X	O
Sciadiocrinus crassacanthus Moore & Plummer						X	O-A
Scytalocrinus aftonensis Strimple		X					O
Scytalocrinus braggsi Laudon			X				O
Scytalocrinus crassibrachiatus Moore & Strimple						X	O
Scytalocrinus dunlapi Laudon			X				O
Scytalocrinus garfieldi Laudon			X				O
Scytalocrinus sp. Laudon			X				O
Scytalocrinus sp. Laudon			X				O
Scytalocrinus sp.			*X				*A
Staphylocrinus sp.	X						O-A
Stenopecrinus ornatus Moore & Strimple						X	O
Stereobrachicrinus pustulosus Mather						X	O-A
Strongylocrinus hansoni Moore & Strimple						X	O
Strongylocrinus ornatus Moore & Strimple						X	O
Taxocrinus cestriensis (Hall)		X					O
Taxocrinus whitfieldi (Hall)			X				A
Telikosocrinus caespes Strimple			X	*X			O-*A
Telikosocrinus residuus Strimple			X				O
Ulrichicrinus chesterensis Strimple		X					O
Ulrichicrinus oklahoma Springer						X	O
Utharocrinus pentanodus (Mather)						X	O-A
Zeacrinites peculiaris (Miller & Gurley)		X					O
Zeusocrinus foveatus (Strimple)			X				O

*Reported for the first time.

Abrotocrinus sp. is reported here from the Hindsville Formation in Craig County, Oklahoma. *Dichocrinus* sp. cf. *D. girtyi* is noted from west of Locust Grove, Mayes County, Oklahoma. The latter species is mainly known from the Renault and Paint Creek Formations (Gasperian) of southwestern Illinois. Huffman (1958, p. 64) reported *Abrotocrinus cymosus, Agassizocrinus conicus, Eupachycrinus spartarius, Phanocrinus nitidus,* and *Mooreocrinus bowsheri* (= *Cryphiocrinus bowsheri*) from the Hindsville Formation of Oklahoma, but the specimens, other than the last mentioned, are not available for verification. However, all of the genera save *Eupachycrinus* (= ? *Intermediacrinus*) are known to occur in the formation. *Pentaramicrinus nitidus* (Miller and Gurley) is reported for the first time from a crown found east of Hulbert, Cherokee County, Oklahoma.

In summary, there are 9 species of crinoids known from the Hindsville Formation, divided among 8 genera (table 1, column 1).

Fayetteville Formation

Crinoids are rare enough to be considered essentially nonexistent in the black shales that make up the Fayetteville Formation in Arkansas. One species, *Ophiurocrinus hebdenensis* Wright, has been reported by Burdick and Strimple (1971). In contrast, a carbonate facies of the formation exposed mainly in Craig and Adair Counties, Oklahoma, has yielded a prolific crinoid fauna consisting of 20 genera with 23 species. To the south, on Braggs Mountain in Muskogee County, limestone beds and intervening shales in the transitional zone between the black-shale facies of the Fayetteville Formation and the massive limestones of the Pitkin Formation contain some well-preserved crinoids (e.g., *Mantikosocrinus castus,* as well as some unstudied species).

Most species and some genera are endemic to the region, but, in general, they can be compared appropriately to faunas of the Hombergian Stage of the Illinois basin. There is some indication that a closer liaison existed with some faunal provinces in northern Alabama, but this is based on unpublished information, primarily a Master's thesis by Dennis Burdick (1971). There is a notable absence of *Pterotocrinus* in the Oklahoma-Arkansas region; the genus is prolific to the east in the Illinois basin.

A small crinoid fauna from northern Georgia described by Broadhead and Bagby (1972) shows some affinity to the Fayetteville fauna. Most notably it includes the only other known Chesterian occurrence of *Ulrichicrinus.* Identified species and occurrences are summarized in table 1 (column 2).

Pitkin Formation

A small crinoid fauna was described by Laudon (1941) from the Pitkin Formation, primarily from Adair County, Oklahoma. A few specimens from the Pitkin have been reported from Braggs Mountain, north of Braggs, Muskogee County, Oklahoma. Most of the Oklahoma Pitkin crinoids are from a single exposure in the bluffs overlooking the Arkansas River in Muskogee County west of Gore. Although poorly preserved specimens have been observed embedded in limestone all along the scarp, almost all of the specimens have been recovered by excavation in shale and thin limestone lentils from an area no more than 500 feet long and about 2 to 4 feet thick. Very few cups are found without at least the lower arm segments attached. The most common as well as the most distinctive species is *Bronaughocrinus figuratus.*

Bronaughocrinus is a derivative of the phanocrinid lineage, in which the arms became equibiserial. This genus very likely gave rise to *Arkacrinus* of Morrowan age. The basic phanocrinid lineage, which has uniserial arms, is also present in the Pitkin Formation and continues into the Pennsylvanian without any change in arm structure. Evolutionary changes are reflected in the reduction of anal plates in the posterior interradius of the cup from a maximum of three in primitive types to none in forms regarded as advanced.

Wing plates of *Pterotocrinus* are notable by their absence in both Oklahoma and Arkansas except for one area near Fort Gibson Dam in Muskogee County, Oklahoma. During construction of access roads on the east side of the dam, some huge blocks of limestone were exposed, and wing plates were seen on their exposed surfaces. These were identified as *P.* sp. cf. *P. tridecibrachiatus* by Burdick and Strimple (1970).

In Washington County, Arkansas, the type area of the Pitkin, the formation is relatively thin and composed of coarsely crystalline, massive limestone beds not conducive to the preservation of identifiable crinoid specimens. To the east the formation thickens, and shaly facies are interposed. South of Huntsville, Madison County, Arkansas, a shelf has been cleared for a park where Arkansas Highway 23 crosses War Eagle Creek. Some crinoids, as well as ophiuroids, echinoids, and starfish, have been recovered from this exposure. The most diagnostic discovery has been *Phacelocrinus* sp., which has very large, long arms. The same species, with even more robust and elongated arms, was found in a concretionary layer lying on limestones of the Pitkin Formation to the east in a quarry on Arkansas Highway 14 west of Locust Grove, Independence County.

Near Locust Grove, Arkansas, *Painocrinus* sp. cf. *P. durus* has been noted in association with the robust-armed *Phacelocrinus* sp., also found south of Huntsville, Arkansas. A large, unreported crinoid fauna was recovered on the upper surface of a thin limestone bed in the upper part of the limestone sequence in the abandoned quarry west of Locust Grove. *Taxocrinus whitfieldi* was reported from this exposure by Strimple (in press). A close affinity with crinoids from Oklahoma is indicated.

Relationship with Elviran crinoid faunas of the Illinois basin is suggested, although no close relationships have been established. To date, 32 species of crinoids have been identified, divided among 22 genera (table 1, column 3).

Imo Formation

Based primarily on ammonoid studies (Furnish and Saunders, 1971; Saunders, 1973), the Imo Formation of northeastern Arkansas is believed to be the youngest known Chesterian unit in the United States east of the Rocky Mountains. Although crinoids are by no means common in the formation, consistent collecting through the years has provided an appreciable number of species (table 1, column 4). A unique occurrence of small colonies of *Parcymbiocrinus ormondi* preserved in a massive sandstone channel fill is present in the stream at the former village of Elba, Searcy County, Arkansas. Most of the described crinoids were found in the deep road cut on U.S. Highway 75 just east of Peyton Creek, a few miles east of Leslie, Searcy County. More recently, a new fauna was found in shale wasted in the excavation of the phosphate mine north of the road cut. Ophiuroids, starfish, and three species of crinoids were recovered from the latter exposure. Preservation in exquisite detail is afforded by this fine-grained, thinly laminated black shale, which is, however, extremely friable and subject to fracture. A new species of *Chlidonocrinus* is the most common crinoid and

Table 2.—Chart Showing Stratigraphic Ranges and Possible Relationships of Selected Genera in Oklahoma and Arkansas

Dashed line indicates lineage is known elsewhere in younger strata; *x's* indicate demise of lineage; *???* designates undetermined affinities or lack of continuity; solid lines indicate continuity

Chesterian	Morrowan	Middle Pennsylvanian
Abrotocrinus	*Plummericrinus*	————————
Acrocrinus	*Globacrocrinus*	————————
Agassizocrinus	xxxxxxxxxxxxxx	
Alcimocrinus	————————	————————
Allocatillocrinus	————————	? *Isoallagecrinus*
Ampelocrinus	*Paragassizocrinus*	*Polusocrinus*
Aphelecrinus	???	
Bronaughocrinus	*Arkacrinus*	xxxxxxxxxxxxxx
Camptocrinus	xxxxxxxxxxxxxx	
Carinocrinus	xxxxxxxxxxxxxx	
Chlidonocrinus	— — — — — — —	————————
Cosmetocrinus	? *Anobasicrinus*	————————
Cryphiocrinus	xxxxxxxxxxxxxx	
Cymbiocrinus	— — — — — — —	*Oklahomacrinus*
Dasciocrinus	? *Anchicrinus*	————————
Dichocrinus	— — — — — — —	————————
Goleocrinus	— — — — — — —	————————
Heliosocrinus	————————	*Stellarocrinus*
Intermediacrinus	xxxxxxxxxxxxxx	
Linocrinus	xxxxxxxxxxxxxx	
Mantikosocrinus	*Cromyocrinus*	— — — — — — —
	Metacromyocrinus	————————
	Parcromyocrinus	————————
	Dicromyocrinus	————————
Onychocrinus	— — — — — — —	? *Euonychocrinus*
Ophiurocrinus	xxxxxxxxxxxxxx	
Paianocrinus	— — — — — — —	*Laudonocrinus*
Paracymbiocrinus	???	
Phacelocrinus	————————	*Hydriocrinus*
Phanocrinus	*Endelocrinus*	————————
	Palmerocrinus	???
	Diphuicrinus	————————
	Paradelocrinus	————————
	Atokacrinus	————————
Pentaramicrinus	???	
Pelecocrinus	???	
Platyplateium	— — — — — — —	————————
Pterotocrinus	xxxxxxxxxxxxxx	
Scytalocrinus	————————	*Erisocrinus*
Staphylocrinus	xxxxxxxxxxxxxx	
Stereobrachicrinus	xxxxxxxxxxxxxx	
Taxocrinus	? *Paramphicrinus*	————————
Telikosocrinus	xxxxxxxxxxxxxx	
Ulrichicrinus	————————	————————
Zeacrinites	xxxxxxxxxxxxxx	
Zeusocrinus	*Lasanocrinus*	???
	Perimestocrinus	————————
	Utharocrinus	xxxxxxxxxxxxxx
	Metautharocrinus	xxxxxxxxxxxxxx
	Affinocrinus	————————
	Stenopecrinus	————————
???	*Megaliocrinus*	— — — — — — —
???	*Eiromocrinus*	————————
???	*Cibolocrinus*	————————
???	*Calycocrinus*	— — — — — — —
???	*Platycrinites*	————————
???	*Lecythiocrinus*	————————
???	*Strongylocrinus*	— — — — — — —

represents the oldest known occurrence of the genus. Although the genus has not been recognized in Morrowan strata, *C. ornatus* Strimple and Moore (1971) is known from the Missourian of Pontotoc County, Oklahoma, and *C. echinatus* Strimple and Watkins (1969) from the Atokan of the Llano uplift of north-central Texas. *Chlidonocrinus* is an unusually important element in that it is thought to represent the lineage leading to the more common stalked crinoids found in present-day oceans (personal observation).

Seven crinoid species divided among six genera have been identified to date.

MORROWAN

There are not enough crinoid specimens (three species: table 1, column 5) known from the Halian Stage in the subject area to make meaningful observations. The following discussion is based on faunas of the Bloydian Stage and equivalent strata in Oklahoma, which comprise 58 species and 1 subspecies divided among 38 genera. A comprehensive report was made by Moore and Strimple (1973). Approximately 62 percent of all known species of Morrowan crinoids are represented in the study area (see table 1, column 6).

Modification of the cup from a high cone shape to a low bowl or saucer shape was well under way in Chesterian time, but the primitive cone shape remained as a substantial proportion of the crinoid population. In the Morrowan of Oklahoma and Arkansas the cone shape almost disappeared; however, this could have been due in part to environmental conditions, because the high cup with upflaring infrabasals persisted throughout the Pennsylvanian into the Permian. A strong trend toward atrophy and even loss of the stem in some lineages was shown by *Agassizocrinus, Cryphiocrinus, Staphylocrinus,* and *Cryphiocrinus* in Gasperian time, during which an adaptation to a bottom-sitting habit was evidenced. I believe that many stalked crinoids of Morrowan age could and did sit on the ocean bottom, at least part of the time.

Some Morrowan cromyocrinids (e.g., *Paracromyocrinus*) developed exceptionally broad basal planes, as did the phanocrinids (e.g., *Arkacrinus, Palmerocrinus, Diphuicrinus*) and pirasocrinids (e.g., *Affinocrinus, Metautharocrinus, Utharaocrinus, Lasanocrinus*). If these crinoids had extended well above the ocean floor on stalks or columns and had been rheophyilic (current seekers), the broad bases of the cups would have been resistant to currents.

Many species developed downward-projecting basals (*Utharocrinus*), downward-projecting radials (*Lasanocrinus*), and the two in combination (*Metautharocrinus*). The projections usually extend below the normal basal plane and could have served as pentapods or decapods to support them on the ocean bottom. Distal parts of some elongated radials of *Arkacrinus* project below the normal basal plane at the point of flexing into the basal concavity and so form a pentapod. The unusually thickened basals and radials of *Arkacrinus* are a feature shared with *Diphuicrinus coneisi* and previously mentioned unquestionably eleutherozoic genera of the early Chesterian.

The absence or paucity of columnar-attachment systems (radicular cirri, holdfasts, roots) strongly suggests a eleutherozoic or semieleutherozoic life style for many or most crinoids of Morrowan age. The columns probably functioned more as tethers, and many were probably bottom runners. In contrast, based on information obtained from some Chesterian and post-Morrowan occurrences, most of the larger flexible crinoids normally are thought to have root systems.

On a generic level, the hiatus between Chesterian crinoids and those of Morrowan age (or post-Morrowan) is severe. *Alcimocrinus, Ulrichicrinus, Allocatillocrinus, Scytalocrinus, Chlidonocrinus, Heliosocrinus, Phacelocrinus,* and *Platyplateium* are the only known genera to have survived the transition. Yet most of the lineages survived into the Morrowan (see table 2), and some proliferated during that time (phanocrinids, pirasocrinids, cromyocrinids). Some genera did not survive beyond the Morrowan (e.g., *Arkacrinus, Utharocrinus, Metautharocrinus*).

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MORROWAN (EARLY PENNSYLVANIAN) CONODONTS OF NORTHWESTERN ARKANSAS AND NORTHEASTERN OKLAHOMA

H. Richard Lane[1]

Abstract—Eight successive conodont faunas occur in the type Morrowan Series of Arkansas and Oklahoma and at Early Pennsylvanian localities in western North America. Correlative faunal sequences occur in Japan, Belgium, Germany, Eire, England, and the Soviet Union.

INTRODUCTION

Over the last decade, I have been studying Early Pennsylvanian conodonts at various localities in central and western North America (Lane, 1967; Lane and others, 1971; Lane and others, 1972; Lane, in press; Brenckle and others, in press). Initial efforts centered on the type Morrowan section in Arkansas and northeastern Oklahoma and the Morrowan exposed on the southern flanks of the Arbuckle Mountains, southern Oklahoma, and culminated in the type Morrowan conodont zonation of Lane and Straka (1974).

During this same period, results of many other Pennsylvanian conodont studies were published by Dunn (1966, 1970a, 1970b, 1976), Koike (1967), Higgins and Bouckaert (1968), Webster (1969), Meischner (1970), Bouckaert and Higgins (1970), Austin (1972), Nemirovskaya (1974), Higgins (1975), and others. Figure 1 illustrates the various areas throughout the world where Early and Middle Pennsylvanian conodont faunas have been described in the literature or collected by this

[1]Amoco Production Co., Research Center, Tulsa, Oklahoma.

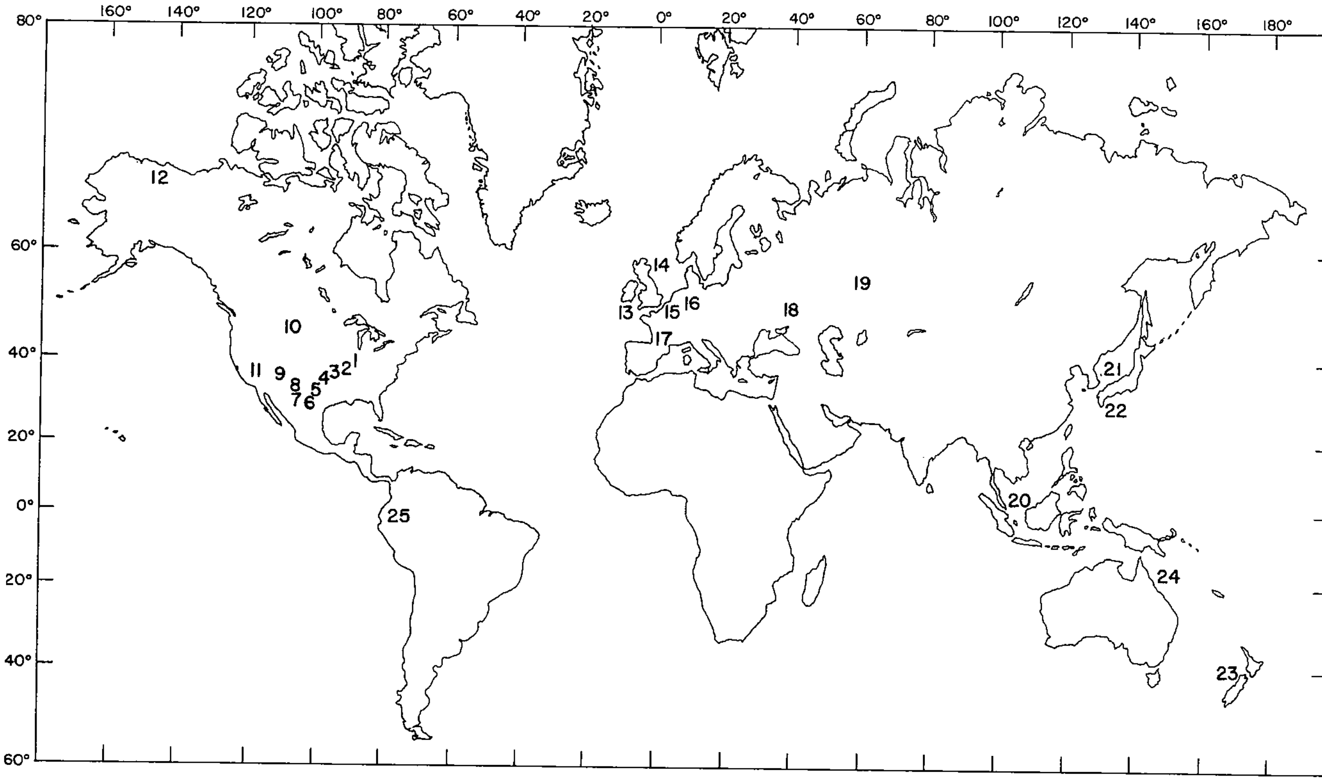

Figure 1. Map showing reported occurrences of Early and early Middle Pennsylvanian conodonts. Numbers on upper right side of each column in figure 2 are same as localities numbered on this figure. Other numbers not listed in figure 2 also are known to contain Early or early Middle Pennsylvanian conodont faunas, and these are listed below with source for information. *Locality 12,* Wahoo Formation, northeastern Alaska, author's collections. *Locality 17,* "Griotte" Limestone, Spain, Higgins (1962), Wirth (1967), Marks and Wensink (1970). *Locality 19,* Bashkirian and Moscovian, southern Urals, U.S.S.R., Furduy (1975). *Locality 20,* brachiopodal limestone, Sungei Lembing area, Thailand, Igo and Koike (1968). *Locality 21,* Omi and Akiyoshi Limestones, southwest Japan, Igo and Koike (1964, 1965), Igo (1974). *Locality 23,* Kakahu Limestone, New Zealand, Jenkins and Jenkins (1971). *Locality 24,* limestones in proximity to Wondai "Series," Queensland, Australia, Palmieri (1969). *Locality 25,* Middle Pennsylvanian (Derryan) limestones, Colombia, Stibane (1967); Ecuador, author's collections.

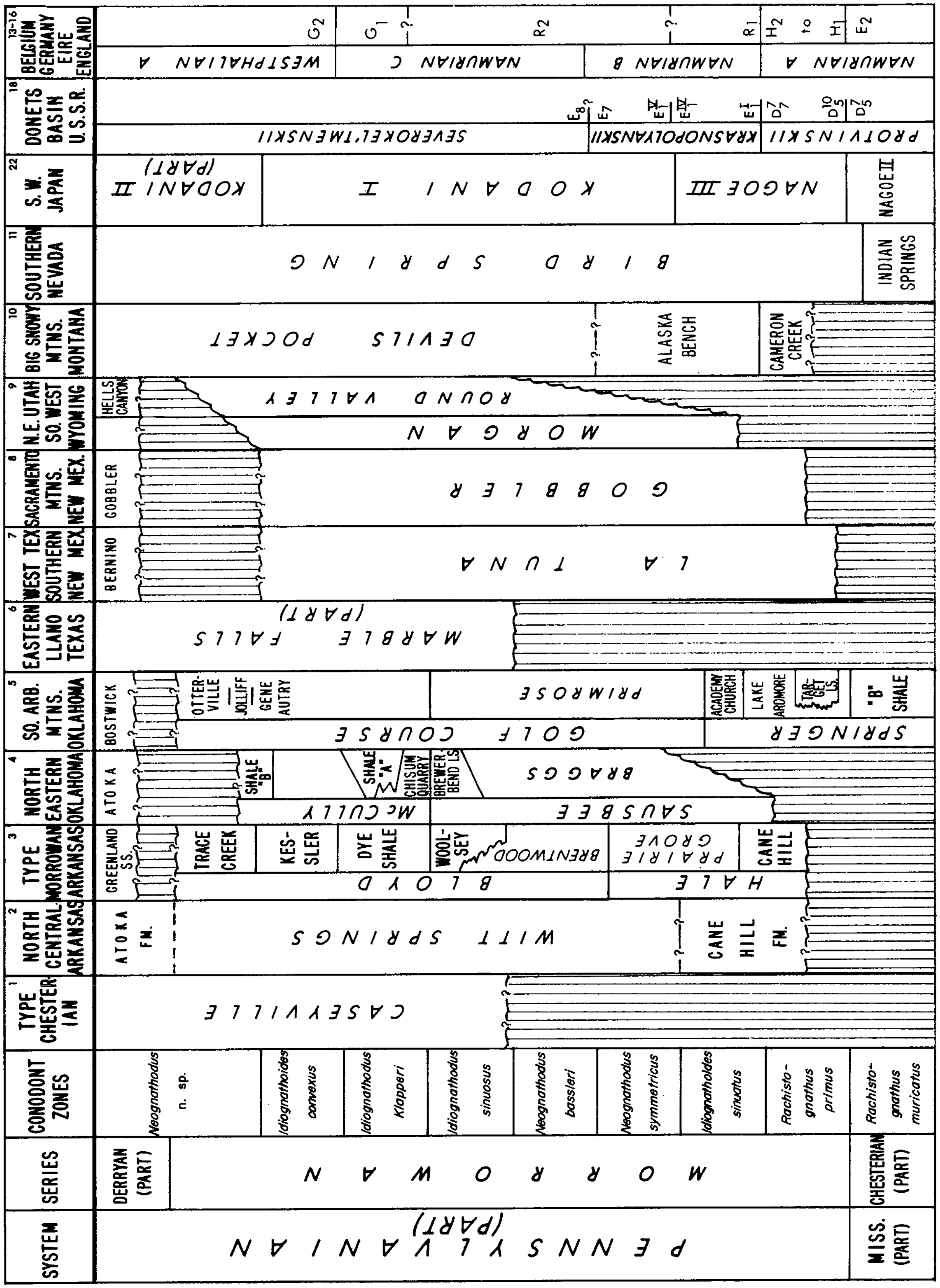

Figure 2. Correlation chart of Early Pennsylvanian stratigraphic units and conodonts from various areas of North America, Europe, and Japan. Numbers at top of columns refer to localities on figure 1.

author. It is the purpose of the present study to summarize my work in the Morrowan of northwestern Arkansas and northeastern Oklahoma and to relate it to these other known occurrences of Early Pennsylvanian conodonts (fig. 2).

TYPE MORROWAN CONODONT SEQUENCE

Rhachistognathus primus Zone

The *R. primus* Zone is the earliest Morrowan conodont zone. It occurs in the Cane Hill Member and the lowest part of the Prairie Grove Member of the Hale Formation in Arkansas and possibly in the basal Braggs Member of the Sausbee Formation (Sutherland and Henry, 1977) in Oklahoma. At least the basal part of the zone correlates with the *Homoceras* Zone, based on comparison of conodont faunas associated with homoceratid ammonoids in Europe (Meischner, 1970; Austin, 1972; Nemirovskaya, 1974; Higgins, 1975). Although *R. primus* has never been found in Europe, the overlap of the lower range of *Declinognathodus noduliferus* with the upper ranges of *Rhachistognathus minutus, Gnathodus bollandensis, G. girtyi simplex,* or *G. nodosus* is sufficient to delineate the lower part of the zone. This same overlap in conodont ranges is seen in western North America associated with *R. primus.* The entire *R. primus* Zone is defined by the range of the name bearer, and therefore it may be as young as R_1 Kinderscoutian, based on its occurrence with certain Cane Hill ammonoid faunas (Gordon, 1970; Manger, 1971) in the type Morrowan. The overlap in range of *Gnathodus bilineatus* and *D. noduliferus* in southwest Japan as reported by Koike (1967) may correlate with part of the *R. primus* Zone.

Idiognathoides sinuatus Zone

The *I. sinuatus* Zone occurs in the lower part of the Prairie Grove Member of the Hale Formation in northwestern Arkansas and in the lower part of the Braggs Member of the Sausbee Formation in northeastern Oklahoma; it corresponds to part or all of R_1. The appearance of the name bearer (left = *I. corrugatus* of Higgins, 1975) marks the base of the zone, and, according to Higgins, the species first appears in basal Kinderscoutian (R_1) strata in England. The definition of this zone in the present study represents an emendation of the *Idiognathoides noduliferus* Zone of Lane and Straka (1974) [= *D. noduliferus* Zone of Lane, in press, and Brenckle and others, in press].

Neognathodus symmetricus Zone

The *N. symmetricus* Zone occurs in the upper Prairie Grove and lower Brentwood of northwestern Arkansas and in the middle Braggs of northeastern Oklahoma. The zone ranges from the appearance of *N. symmetricus* to the first occurrence of *Neognathodus bassleri* and probably corresponds with the upper part of R_1 or the lower part of R_2 (Marsdenian) of western Europe.

Neognathodus bassleri Zone

The base of the *N. bassleri* Zone is defined at the first occurrence of *N. bassleri,* and the top by the first occurrence of *Idiognathodus sinuosus.* The zone occurs in the upper Brentwood in northwestern Arkansas and in the upper Braggs of northeastern Oklahoma, and a fauna that belongs to this zone was reported from bullions yielding *Reticuloceras superbilingue* by Austin (1972, pl. 2, figs. 11-21). However, Higgins (1975, fig. 6) reported that the first occurrence of the important Pennsylvanian conodont genus *Idiognathodus* is probably at the base of R_2. Thus, basal R_2 strata may be as young as the *I. sinuosus* Zone. These conodont correlations do not agree with others suggested on the basis of ammonoid occurrences (Saunders and others, this guidebook).

Idiognathodus sinuosus Zone

The *I. sinuosus* Zone is defined by the overlapping ranges of *N. bassleri* and *I. sinuosus.* The zone occurs in the Woolsey of northwestern Arkansas and in the upper Braggs and Brewer Bend Limestone Members (Sutherland and Henry, 1977) of the Sausbee Formation of northeastern Oklahoma. Although Saunders and others (this guidebook) suggest that the interval yielding this fauna in northwestern Arkansas belongs to G_2 (Westphalian A), conodont evidence suggests an R_2 or possibly a G_1 (Yeadonian) age.

Idiognathodus klapperi Zone

The *I. klapperi* Zone is defined by that portion of the range of the name bearer below the first occurrence of *Idiognathoides convexus.* The zone occurs in the caprock of the Baldwin coal (Dye Shale) of northwestern Arkansas. Saunders and others (this guidebook) suggest that the interval yielding this fauna in Arkansas correlates with G_2 in western Europe, but conodont information suggests an R_2 or a G_1 age. Presently the name bearer of this zone is not known to occur outside of the central and western United States.

Idiognathoides convexus Zone

The *I. convexus* Zone is defined by the range of the name bearer below the first occurrence of *Neognathodus* n. sp. [= *Gnathodus* cf. *G. roundyi* Gunnell, Koike, 1967, p. 299, pl. 1, figs. 27, 28, and *Neognathodus roundyi* (Gunnell), Dunn, 1970a, p. 336, pl. 64, fig. 4]. This zone, which occurs widely over the western United States, is limited to the Kessler in northwestern Arkansas and to the upper part of the Greenleaf Lake Limestone Member of the McCully Formation (Sutherland and Henry, 1977) in northeastern Oklahoma. *Idiognathoides convexus* occurs in strata of G_2 age in Europe, according to Bouckaert and Higgins (1970) and Meischner (1970, fig. 3).

Neognathodus n. sp. Zone

The *Neognathodus* n. sp. Zone probably spans the Early-Middle Pennsylvanian boundary. The zone is defined at the first occurrence of *Neognathodus* n. sp. and *Gondolella clarki.* The fauna occurs at the base of the Trace Creek (Unit 25) at locality M-108 of Henry (1973, p. 411) and near the top of the same stratigraphic unit at the Evansville Mountain Section of Lane and Straka (1974) in northwestern Arkansas. The *Idiognathoides* n. sp. Zone of Lane and others (1972) and Lane and Straka (1974) is abandoned because of the extension of the range of *Neognathodus* n. sp. down into the latter zone. *Idiognathoides* n. sp. is conspecific with *Streptognathodus lanceolatus* Webster and has not been found outside the Cordillera. The first definite Derryan conodont fauna is best recognized at the appearance of *Gnathodus coloradoensis*. However, the occurrence of *G. coloradoensis* in relation to the *N.* n. sp. Zone is not yet fully understood.

CONCLUSIONS

1. Eight conodont zones are recognized in the Morrowan (Early Pennsylvanian) of central and western North America and can be utilized, in a less rigorous manner, for global correlations.

2. Conodonts of Pennsylvanian affinities appear at the base of the *Homoceras* Zone in western Europe, within the Protvinskii Horizon at limestone D_5^{10} in the Donets Basin, U.S.S.R., at the base of Nagoe III in Japan, and at the base of strata traditionally treated as earliest Pennsylvanian in western North America. Ammonoid cephalopods near the base of the standard marine Early Pennsylvanian (Morrowan) in Arkansas are dated as R_1.

3. The R_1-R_2 boundary is at or near the base of the *N. symmetricus* Zone, and the G_1-G_2 boundary is near the appearance of *Idiognathoides convexus*. This latter species first occurs at the base of the Kessler Limestone Member of the Bloyd Formation in the type Morrowan. These correlations do not fully agree with others proposed in this guidebook.

4. *Neognathodus* n. sp. and *Gondolella clarki* span the Morrowan-Derryan boundary. Until more complete information is available, this boundary is best recognized by conodont workers at the appearance of *Gnathodus coloradoensis*.

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CONODONT EVIDENCE FOR UNCONFORMITY WITHIN TRACE CREEK SHALE MEMBER OF BLOYD FORMATION (LOWER PENNSYLVANIAN) IN NORTHWESTERN ARKANSAS AND NORTHEASTERN OKLAHOMA

Robert C. Grayson, Jr.,[1] and Patrick K. Sutherland[1]

Abstract—A paraconformity, marking the local boundary of the Morrowan and Atokan Series in northeastern Oklahoma and northwestern Arkansas, is believed to be present within the Trace Creek Shale Member of the Bloyd Formation. Evidence for this interpretation is based on a gap in the conodont faunas from the Trace Creek Shale as compared with other, more complete, faunal successions in Oklahoma. The paraconformity corresponds to at least the lower portion of the range of *Gnathodus coloradoensis*—below occurrences of *Streptognathodus* sp. cf. *S. elegantulus* and above occurrences of *Idiognathoides convexus* and *Neognathodus kanumai.* Based on the present investigation, the Morrowan-Atokan chronostratigraphic boundary in northeastern Oklahoma and northwestern Arkansas is best recognized by first occurrences of *Streptognathodus* sp. cf. *S. elegantulus.*

INTRODUCTION

A regional unconformity occurs between the Atoka Formation and the underlying Morrow Group in the westernmost areas of the northeastern outcrop belt in Oklahoma, particularly in Muskogee, Cherokee, and Sequoyah Counties (Sutherland and Henry, 1977, fig. 3). Twenty-five to 50 miles to the east, in Washington County, Arkansas, Zachry and Haley (1973) reported that physical evidence for a regional unconformity between type Morrowan strata and the overlying Atoka Formation has not been observed. Sutherland and Henry (1977) assumed that in the intervening 25-mile-wide area of Adair County, Oklahoma, the basal sandstone of the Atoka Formation became a truncating surface (fig. 1). However, an alternative interpretation is possible, based on recently recovered conodont faunas from the Trace Creek Shale, the uppermost member of the Bloyd Formation, in northeastern Oklahoma and northwestern Arkansas. Comparison of these faunas with conodont faunas we have recovered from other Lower Pennsylvanian sequences near the Morrowan-Atokan boundary in Oklahoma indicates the presence of a significant faunal gap in the conodont succession within the Trace Creek in the type Morrowan region (fig. 1). Consequently, it seems probable that the middle and uppermost portions of the Trace Creek Shale in Adair County, Oklahoma, and in northwestern Arkansas are time equivalents to the Atoka Formation in the more westerly part of the northeastern Oklahoma exposures.

Conodont faunas were recovered from acid-insoluble residues of limestone and calcareous sandstone units at two measured sections. The locations of these exposures are shown in figure 2. The two measured sections have considerable stratigraphic significance. The Evansville Mountain section (locality 1) is considered to be the most important reference section of the type Morrowan sequence in northwestern Arkansas (Henbest, 1962). The exposure at Sawney Hollow, Oklahoma (locality 2), 2.8 miles south-southwest of locality 1, is significant because of its geographic proximity to Evansville Mountain, Arkansas, and also because it contains a greater proportion of suitable lithologies (limestones) for acid-insoluble conodont-recovery techniques than found at Evansville Mountain.

[1]School of Geology and Geophysics, The University of Oklahoma, Norman, Oklahoma.

LOCAL STRATIGRAPHY

In extreme northeastern Oklahoma (Adair County) and northwestern Arkansas (Washington County) the highest stratigraphic subdivisions of the Bloyd Formation are, in ascending order, the Kessler Limestone and Trace Creek Shale Members. The Kessler Limestone Member is a laterally persistent but highly variable unit consisting of varying proportions of oncolitic, oolitic, algal, and micritic limestone with scattered thin shales or sandstones. The Kessler Limestone provides a useful datum for physical correlations of the predominantly clastic Bloyd Formation between the measured sections at Sawney Hollow and Evansville Mountain (fig. 3).

The Trace Creek Shale Member is a predominantly shale interval but includes a few thin interbeds of sandstone, calcareous sandstone, and sandy limestone that occur above the Kessler Limestone Member and below massive, cliff-forming sandstone (=Atoka Formation). At Evansville Mountain (fig. 3), interbeds include a dense, siliceous, argillaceous-limonitic limestone (unit 27), a calcareous sandstone (unit 29), and a sparsely fossiliferous sandstone (unit 32). Only unit 29 is sufficiently calcareous to dissolve in formic acid. In comparison, two calcareous units (16, 19) occur at Sawney Hollow in the Trace Creek Shale; these units have yielded conodonts by acid-insoluble techniques (fig. 3). These units consist of sandy, crinoidal grainstone interbedded with calcareous and noncalcareous sandstone. The lower of the calcareous units (16A) contains a few rounded micrite intraclasts and is overlain with an irregular contact by slightly calcareous sandstone (16B). A physical correlation of strata exposed at Sawney Hollow with the important reference section at Evansville Mountain is not demonstrable for individual lithic units within the Trace Creek Shale. However, conodonts provide a basis for a faunal correlation between some parts of the adjacent sections (fig. 3).

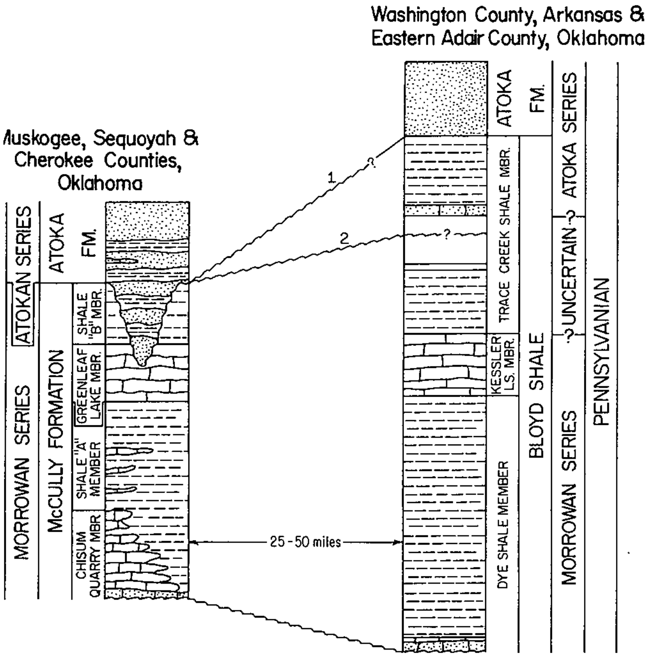


Figure 1. Table of formations and members of upper Morrow Group in northeastern Oklahoma and in northwestern Arkansas, depicting possible interpretations of Morrowan-Atokan boundary relationships: *1*, preliminary interpretation of Sutherland and Henry (1977); *2*, interpretation in this paper, based on conodonts.

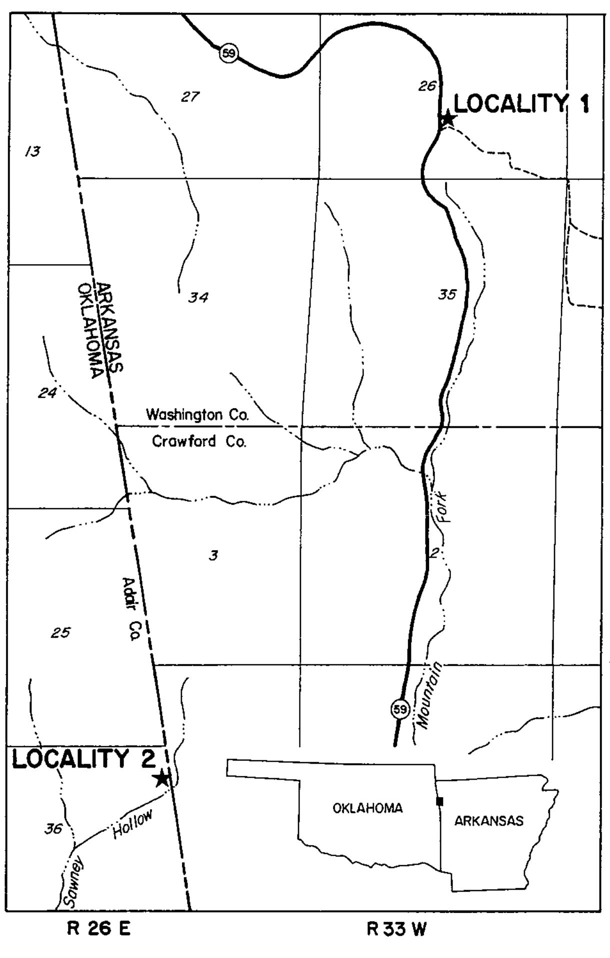


Figure 2. Map showing locations of measured sections: locality 1, Evansville Mountain; locality 2, Sawney Hollow.

CONODONT FAUNA

The stratigraphic distribution of conodont form-species recovered from the exposures at localities 1 and 2 is shown in table 1. The fauna is dominated by platform elements. Nonplatform elements make up a small, biostratigraphically less useful, component of the fauna. The platform fauna is not particularly diverse, but several species have been recorded from the Kessler Limestone and Trace Creek Shale Members for the first time. These form-species include *Spathognathodus minutus, Spathognathodus* n. sp., *Streptognathodus* sp. cf. *S. elegantulus,* and *Streptognathodus suberectus.* Of greatest interest are occurrences of the platform elements *Idiognathoides convexus, Neognathodus kanumai,* and *Streptognathodus* sp. cf. *S. elegantulus.* These elements seemingly have stratigraphic significance.

Idiognathoides convexus is the nominant species for Lane and Straka's (1974) *Idiognathoides convexus* zone. Lane (in press; this guidebook) restricts the *I. convexus* zone to the Kessler Limestone Member. However, based on our faunas containing *I. convexus,* this zone could include the lower portion of the Trace Creek Shale Member at our Sawney Hollow section (table 1, locality 2).

The *Idiognathoides convexus* zone is succeeded by Lane's (in press; this guidebook) *Neognathodus* n. sp. (= *Neognathodus kanumai*) zone. This zone is regarded (Lane, this guidebook) as indicating equivalence to latest Morrowan (Trace Creek) and earliest Derryan (= Atokan) strata because of restriction of this taxon to that interval. However, the range of *N. kanumai* has not been precisely established. Our collections from the Morrowan Jolliff Member of the Golf Course Formation in the Ardmore basin, Oklahoma, contain abundant *N. kanumai.* This unit is correlative with the Dye Shale and Kessler Limestone Members of the Bloyd Formation, based on goniatites. Consequently, known occurrences of this species in northwestern Arkansas and northeastern Oklahoma may represent a local range encompassing only a part of the complete range of this platform element. At present, the local range and stratigraphic significance of occurrences of *N. kanumai* in northwestern Arkansas and northeastern Oklahoma are also uncertain. Lane (personal communication) has recovered this platform element from a thin limestone exposed in Lee Creek, Washington County, Arkansas. This limestone unit is reported by Lane (this guidebook) to belong to the Trace Creek Shale Member. However, Henry (1973) regarded this unit as part of the Kessler Limestone Member. At Sawney Hollow, *N. kanumai* occurs in unequivocal Trace Creek Shale (unit 16B). This occurrence is compatible with the definition of Lane's *Neognathodus* n. sp. zone (= *N. kanumai*). The age of this fauna, however, with respect to the Morrowan-Atokan chronostratigraphic boundary, cannot be determined.

S. elegantulus is generally regarded by most workers as indicating a Desmoinesian age, although Koike (1967) reported an element he referred to *S. elegantulus* from the Atokan portion of the Kodani Formation in Japan. Koike's (1967) figured specimens of *S. elegantulus* closely resemble some of the specimens referred to *S.* sp. cf. *S. elegantulus* in this study. Platform conodont elements referred to *Streptognathodus* sp. cf. *S. elegantulus* occur in the Trace Creek Shale Member at Sawney Hollow (unit 19) and at Evansville Mountain (unit 29). Presumably *Streptognathodus* sp. cf. *S. elegantulus* is an Atokan homeomorph of the Desmoinesian *S. elegantulus,* although this occurrence could represent an extension of its range. The taxonomic status of this platform element is uncertain at present, although a restriction to Atokan age for occurrences of *S.* sp. cf. *S. elegantulus* might be established with further collections.

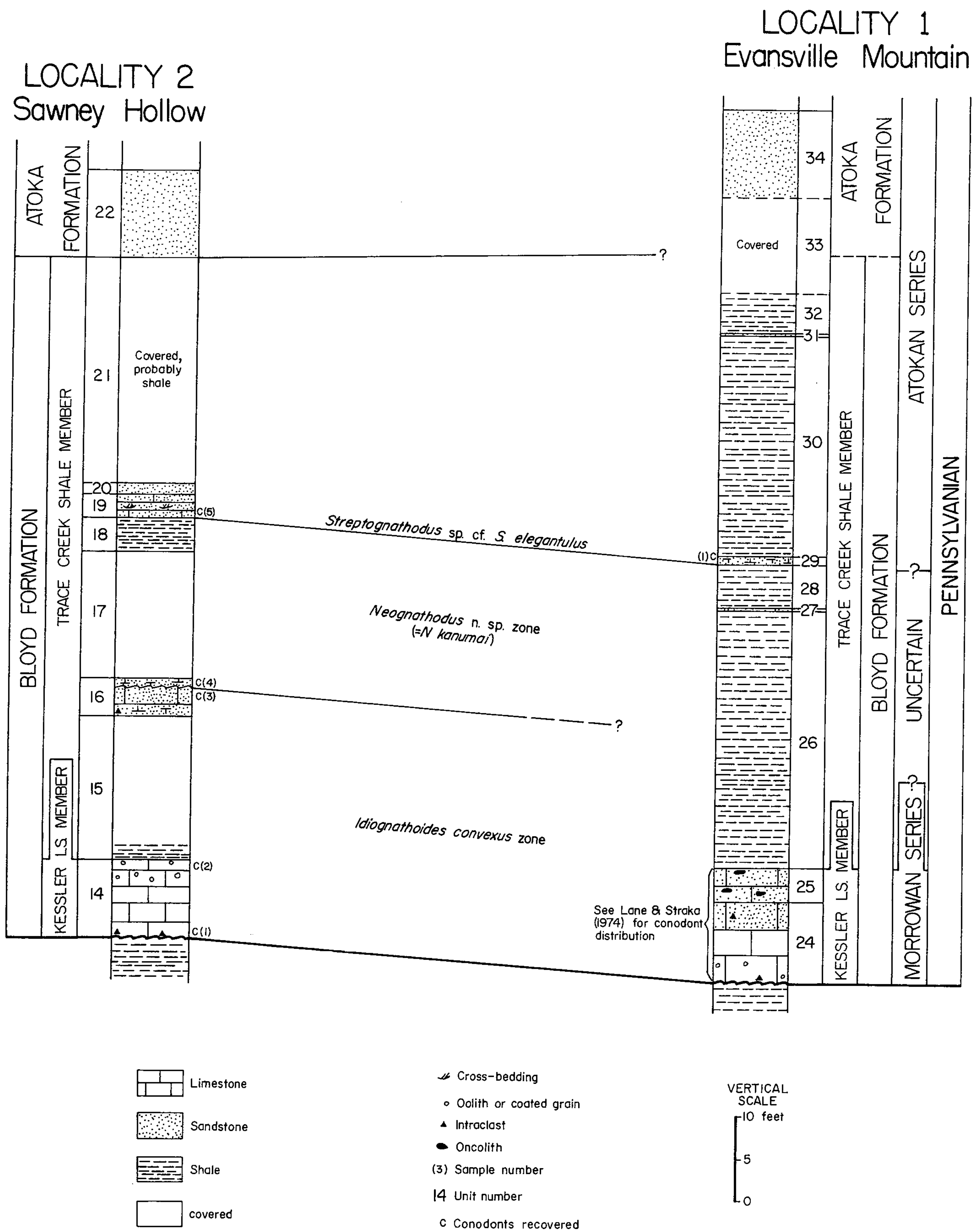


Figure 3. Graphic representation of measured sections, showing conodont-producing intervals.

Table 1.—Distribution of Conodonts at Two Exposures of Upper Bloyd Formation, Oklahoma and Arkansas

	Bloyd Formation					
	Kessler Limestone		Trace Creek Shale			
Localities:			2			1
Sample numbers:	1	2	3	4	5	1
Adetognathus sp.		1	1			
A. gigantus (Gunnell)		3				
A. lautus (Gunnell)	1	2		1	1	2
Hibbardella sp.		1		1	1	
Idiognathodus sp.			2	1		
I. sinuosis Ellison and Graves	5	12	2	1	11	2
Idiognathoides sp.		2			2	1
I. convexus (Ellison and Graves)	4	3	1		2	
Ligonodina typa (Gunnell)	1					
Lonchodina sp.				1		
Metalonchodina sp. A		1				
Neognathodus kunamai				2		
Neoprioniodus sp. A	1				1	
Spathognathodus sp.					1	2
S. minutus (Ellison)						1
S. n. sp. Lane			1			
Streptognathodus sp. cf. *S. elegantulus*					18	3
Streptognathodus suberectus Dunn		2			2	

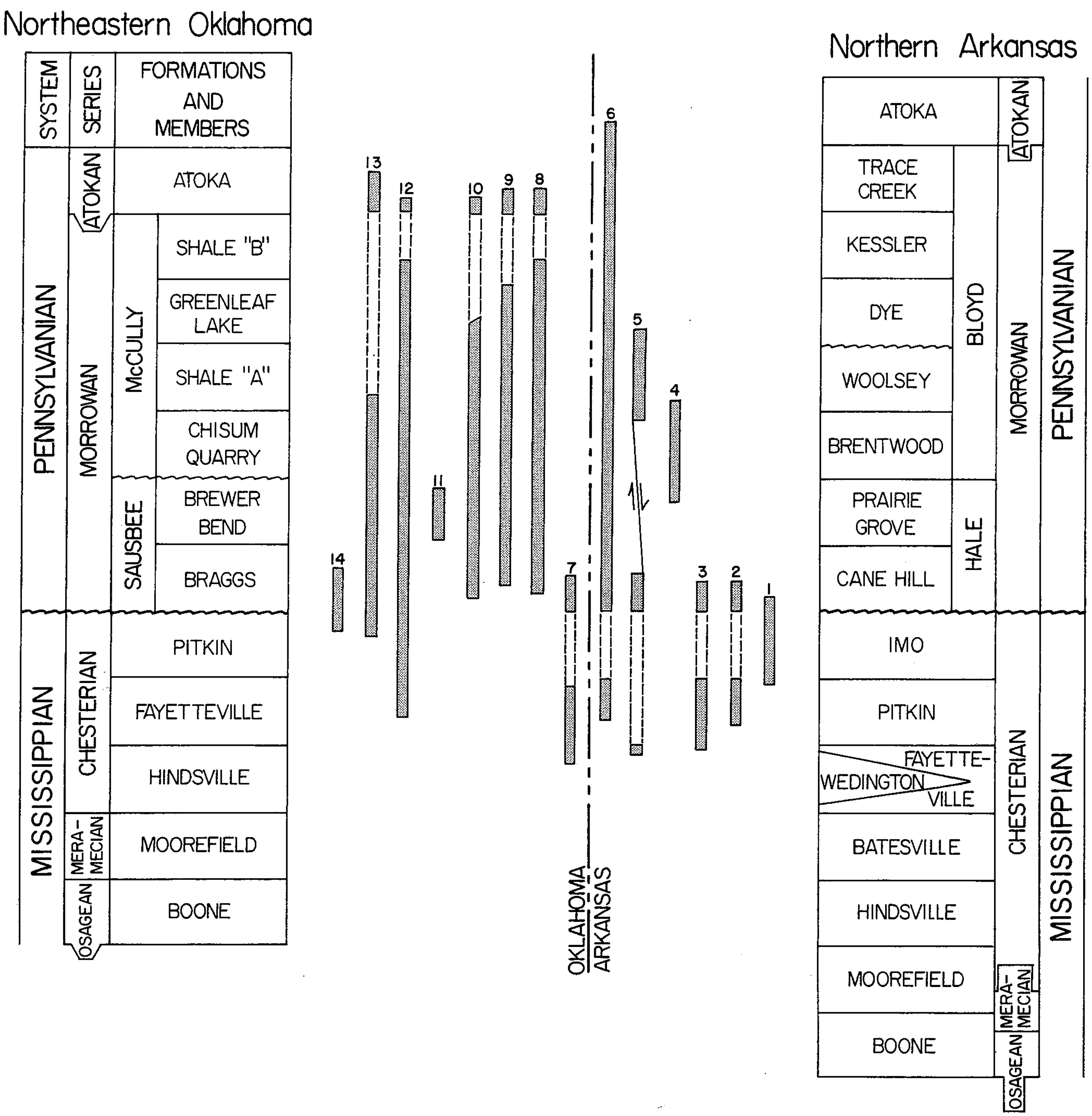
SIGNIFICANCE OF CONODONT FAUNA

The Wapanucka Formation in the frontal Ouachita Mountains, Oklahoma (Morrowan-Atokan age), yields conodont faunas containing *Gnathodus coloradoensis* with *Streptognathodus* sp. cf. *S. elegantulus*. Sutherland and Grayson (1977) reported one locality in the Wapanucka where both occur in a measured unit significantly above the presumed top of the Morrowan Series (Gordon and Sutherland, 1975). However, at other localities in the frontal Ouachita Mountains, *G. coloradoensis* first occurs in the Wapanucka Formation at least 100 feet below *Streptognathodus* sp. cf. *S. elegantulus*. At all Wapanucka localities that have been collected for conodonts, the first occurrence of *G. coloradoensis* is invariably above the stratigraphic interval that contains *N. kanumai*. We have found a similar distribution for these species in the Golf Course (Jolliff-Otterville Members) and Lake Murray (Bostwick Member) Formations in the Ardmore basin, Oklahoma. Specifically, *G. coloradoensis* first occurs at or near the base of the Bostwick Member several hundred feet above occurrences of *N. kanumai*. *Streptognathodus* sp. cf. *S. elegantulus* first appears in the Bostwick Member approximately 200 feet above the base of the unit and about 100 feet above occurrences of *G. coloradoensis*.

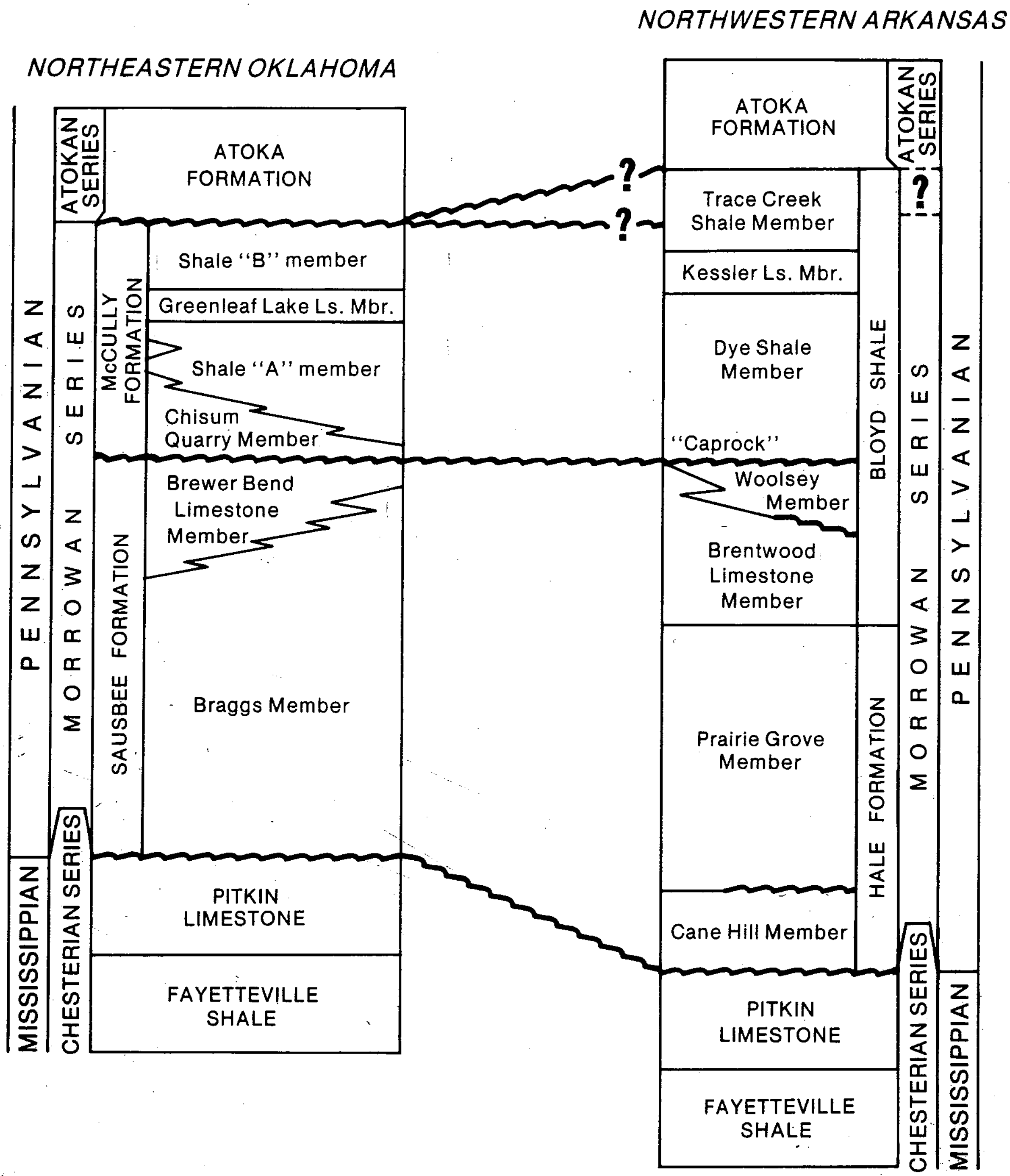
In contrast to these more complete faunal successions, a faunal gap is present in the Trace Creek Shale Member of the Bloyd Formation in northwestern Arkansas and northeastern Oklahoma. The faunal gap is recognized because *G. coloradoensis* is not present below the lowest occurrences of *Streptognathodus* sp. cf. *S. elegantulus* at Sawney Hollow or in any part of the type Morrowan or in Morrowan units in northeastern Oklahoma. We suggest that this faunal hiatus may indicate a paraconformity that corresponds to the regional disconformity observed between the Morrowan strata and the Atoka Formation in the western exposures in northeastern Oklahoma. In the westernmost exposures in northeastern Oklahoma, the Atoka Formation, which bears *Streptognathodus* sp. cf. *S. elegantulus*, can be shown to truncate underlying Morrowan-age units containing conodonts of the *Idiognathoides convexus* Zone (Lane and Straka, 1974; Sutherland and Henry, 1977). Detailed stratigraphic documentation of a paraconformity in the Trace Creek Shale Member is not yet completed, but occurrences of *Streptognathodus* sp. cf. *S. elegantulus* suggest that the upper part of the Trace Creek in eastern Adair County, Oklahoma, and in northwestern Arkansas was deposited contemporaneously with the lower part of the Atoka Formation in more westerly exposures in northeastern Oklahoma.

MORROWAN-ATOKAN BOUNDARY

Correlation of strata of latest Morrowan and earliest Atokan age and placement of the Morrowan-Atokan boundary have been inconsistent because of the poorly fossiliferous nature of the lower part of the Atoka Formation. Consequently, the selection of a Morrowan-Atokan boundary based on faunal evidence must be arbitrary at present. This boundary is placed at the lowest occurrence of *Streptognathodus* sp. cf. *S. elegantulus*, based on two factors: (1) *Streptognathodus* sp. cf. *S. elegantulus* occurs only in the unequivocal Atoka Formation in northeastern Oklahoma; and (2) *Streptognathodus* sp. cf. *S. elegantulus* is restricted to the Bostwick Member of the Lake Murray Formation, a unit generally regarded as Atokan



GENERALIZED STRATIGRAPHIC SUCCESSIONS AND RELATION OF STOPS



NORTHEASTERN OKLAHOMA
NORTHWESTERN ARKANSAS
ATOKAN SERIES
ATOKA FORMATION
PENNSYLVANIAN
MORROWAN SERIES
McCULLY FORMATION
Shale "B" member
Greenleaf Lake Ls. Mbr.
Shale "A" member
Chisum Quarry Member
SAUSBEE FORMATION
Brewer Bend Limestone Member
Braggs Member
MISSISSIPPIAN
CHESTERIAN SERIES
PITKIN LIMESTONE
FAYETTEVILLE SHALE
Trace Creek Shale Member
Kessler Ls. Mbr.
Dye Shale Member
"Caprock"
Woolsey Member
Brentwood Limestone Member
BLOYD SHALE
Prairie Grove Member
Cane Hill Member
HALE FORMATION
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