PALEOENVIRONMENT OF FITZHUGH MEMBER OF CLARITA FORMATION (SILURIAN, WENLOCKIAN) SOUTHERN OKLAHOMA

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Title Page Illustration

Outcrop of the Fitzhugh Member of the Clarita Formation near White Mound in the central part of the Arbuckle Mountains (see pl. 1, fig. 2). Ink drawing by Roy D. Davis from a photograph by D. F. Toomey.

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PALEOENVIRONMENT OF FITZHUGH MEMBER OF CLARITA FORMATION (SILURIAN, WENLOCKIAN) SOUTHERN OKLAHOMA

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Abstract—The Fitzhugh Member of the Clarita Formation (Silurian, Wenlockian) is a low-magnesium, organo-detrital limestone which bears a substantial megafauna and microfauna, the latter with abundant agglutinated foraminifers and conodonts. Lithostratigraphic and lithofacies information has been combined with quantitative faunal data derived from microfossil counts of formic acid residues and thin section point counting to provide an integrated paleoenvironmental model. Three intergrading lithofacies–biofacies divisions are recognized: (1) crinoid sparites, (2) arthropod micrites, and (3) ostracode marlstones.

These lithofacies changes are associated with changes in the sessile and vagrant benthic megafauna. Crinoids are the dominant megafaunal element in the sparites, decreasing in abundance in the micrites, their place being taken by the ostracodes and trilobites; brachiopods, which are moderately common in the sparites, are largely replaced by mollusks in the micrites. The sessile and vagrant megafauna virtually disappear in the marlstones, and only thin-shelled ostracodes remain. This lithofacies–biofacies pattern suggests that bottom conditions were the controlling factor. The firm, clean-washed sands of the sparites represented optimum conditions for a large, varied megafauna, dominated by sessile filter feeders, whereas the increasing siltation and turbidity of the micrites and marlstones increasingly restricted the benthic megafauna. The sessile agglutinated foraminifers and inarticulate brachiopods are present in all three lithofacies, suggesting considerable ecologic tolerance for these organisms. Conodonts are represented in all facies, although minor fluctuations in the relative abundance of certain species occur in each environment.

INTRODUCTION

The Clarita Formation is divided into an upper Fitzhugh Member and a lower Prices Falls Member (Amsden, 1967). The latter is a thin unit, probably nowhere exceeding ½ m in thickness, composed of argillaceous marlstone locally grading into calcareous shale. The Fitzhugh Member, which makes up most of the Clarita Formation, is widely distributed and well exposed in the Arbuckle Mountains and Criner Hills of south-central Oklahoma, where it comprises a distinctive, well-defined limestone unit admirably suited for a lithofacies-biofacies analysis (text-figs. 1, 2). Throughout the outcrop area, it is generally less than 6 m thick, but locally it ranges up to 14 m. It is a uniformly low-magnesium limestone, averaging less than 2 percent $MgCO_3$. All of the Arbuckle Mountains-Criner Hills outcrop area lies well south of the dolomite front (text-fig. 1), and thus dolomitization, regardless of origin, has not obscured the rock texture. The Clarita Formation is generally underlain by the Lower Silurian (Llandoverian) Cochrane Formation (pl. 2, fig. 1) and overlain by the Upper Silurian (Ludlovian) Henryhouse Formation, although locally it rests on the Upper Ordovician (Ashgillian) Keel Formation and is overlain by the Lower Devonian (Gedinnian) Haragan–Bois d'Arc Formations. The Cochrane Formation is a glauconitic, organo-detrital limestone with only minor facies changes throughout its outcrop area in the Arbuckle Mountains–Criner Hills. The Henryhouse Formation is mostly marlstone, exhibiting a progressive increase in lime mud and HCl-insoluble terrigenous detritus from the northeastern end of the Arbuckle Mountains into the central region (Amsden, 1975, p. 24, panel 11; Amsden, 1980). This is similar to the Fitzhugh facies changes discussed in this report, and thus all post-Cochrane Silurian (post-Llandoverian) strata in this region have a similar paleoenvironmental pattern.
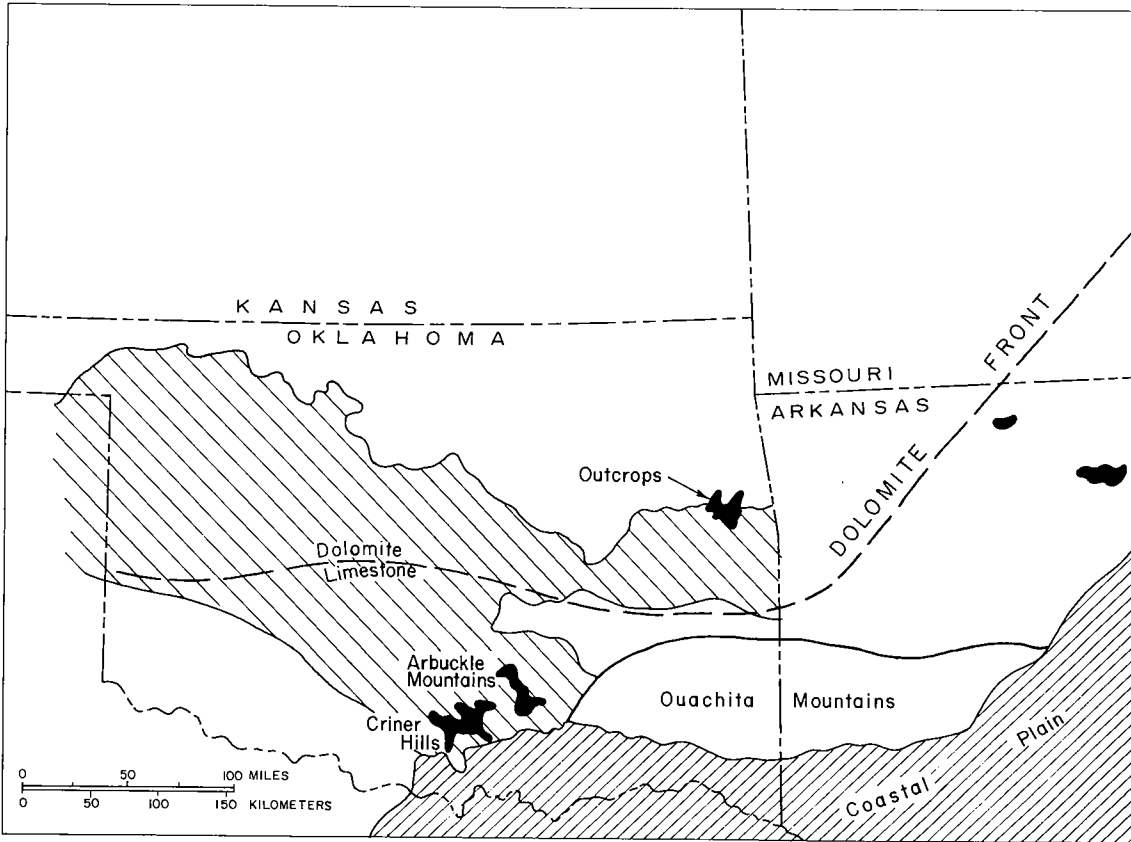
Text-figure 1. Map showing location of Silurian (Wenlockian) outcrops in central United States. Subsurface distribution shown by widely spaced diagonal lines (for Oklahoma only).
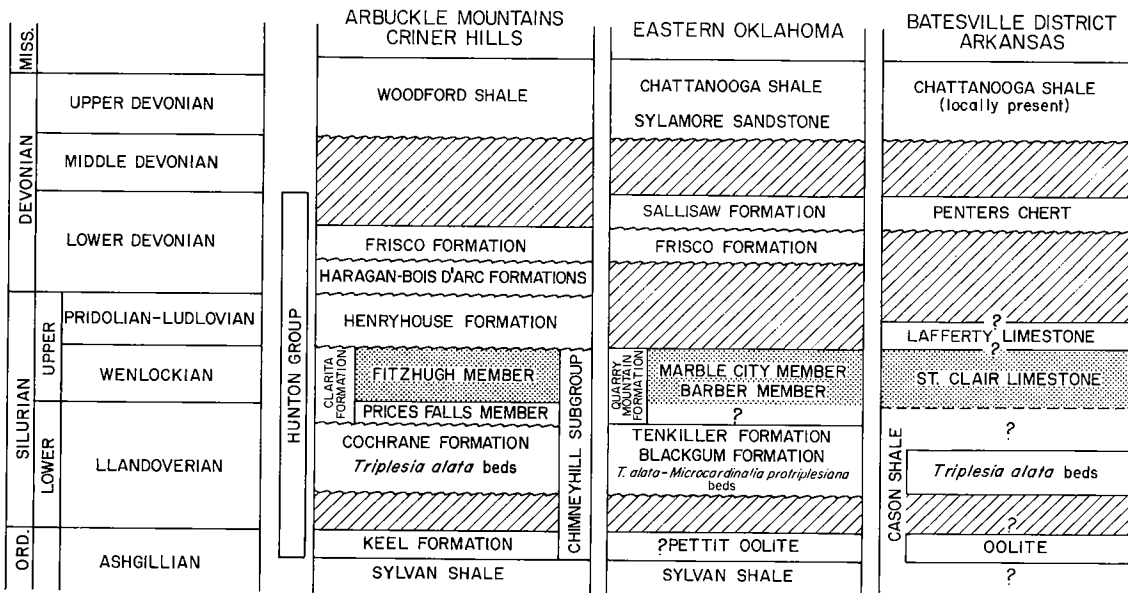
Text-figure 2. Stratigraphic chart showing Silurian strata (Wenlockian formations stippled) in Oklahoma and Arkansas. Not to scale in stratigraphic thickness or time.

General Lithologic and Faunal Characteristics

The Fitzhugh Member throughout its outcrop area is characterized by relatively thin, uniform beds (pl. 1, figs. 1, 2). The crinoid sparite and arthropod micrite facies discussed below comprise organo-detrital limestones with low HCl-insoluble residues, mostly under 10 percent, but in the silty ostracode marlstones the residues range as high as 26 percent (by weight). The HCl insolubles in all lithofacies are almost exclusively clay- and silt-size terrigenous detritus. The coarse fraction of this detritus, that part which can be examined with a standard petrographic microscope, is composed mostly of angular to slightly subangular quartz grains of which very few exceed 0.05 mm in diameter.

No reefs or boundstones have been observed in the Fitzhugh Member, nor have any been found in the belt of Wenlockian strata extending across Oklahoma and Arkansas. No stromatolites have been seen, and calcareous algae are rare or absent. Corals, which are represented mostly by small tetracorals, constitute an insignificant part of the fauna. Disarticulated pelmatozoan plates are abundant to moderately common in the crinoid sparites and arthropod micrites, and these fossils (along with other megafaunal elements such as the trilobites, ostracodes, brachiopods, bryozoans, mollusks, and a large microfauna) make up a large and varied megafauna which contributed an impressive volume of organic material. At least 23 species of brachiopods are present in the sparites (Amsden, 1968), and these, combined with the substantial volume of pelmatozoan plates, show the presence of a prolific sessile benthos. Trilobites are a numerous and taxonomically diverse group, and ostracodes are abundant in all biofacies. These groups, combined with the mollusks and other megafaunal elements (Amsden, 1975) and a large fauna of conodonts (Barrick and Klapper, 1976; Barrick, 1977), agglutinated foraminifers, and inarticulate brachiopods (Toomey, this report), demonstrate that the crinoid sparite and arthropod micrite facies had a richly diverse marine biota.

Fossil Preservation and Megafossil Assemblages

Breakage of the organic material is minimal in all facies, and articulated brachiopod shells are fairly common (Amsden, 1968, pls. 14–19; this report, pls. 3–5).There is some evidence of burrowing (pl. 2, fig. 2), but the effects of bioturbation are scattered and moderate. In some beds the carapaces and shells of certain groups, such as the trilobites, brachiopods, and cephalopods, are concentrated (pl. 3, figs. 1–4), suggesting selective sorting by current and (or) wave action. However, these concentrations are generally small and local, and for the most part the faunal characteristics present in any of the three facies recognized (as determined by point counting) are relatively uniform over fairly large areas. These relationships suggest that the organic material was not moved far before burial and that the present faunal associations are essentially life assemblages.

The preservation of the megafauna is excellent. The microtextures of most fossils are preserved: the original texture of the pelmatozoan plates (pl. 5, fig. 2; pl. 6, figs. 1, 2), trilobites (pl. 4, fig. 4), brachiopods (pl. 4, figs. 1, 3; pl. 5, fig. 2), ostracodes (pl. 4, fig. 1), and bryozoans shows little or no alteration. The only exception is the mollusk shells, which are everywhere altered to sparry calcite (pl. 4, fig. 4; pl. 5, figs. 1, 2; pl. 6, figs. 2, 3). The conodonts (Barrick and Klapper, 1976, pls. 1–4; Barrick, 1977, pls. 1–3) and foraminifers (pl. 7, this report) are also well preserved.

Age and Biostratigraphic Relations

The Fitzhugh articulate brachiopods were studied by Amsden (1968), who assigns them a Wenlockian age; and the conodonts were studied by Barrick and Klapper (1976) and Barrick (1977), who state that this member spans most of the Wenlockian Series, with the uppermost beds possibly including very early Ludlovian equivalents. The articulate brachiopods have their best development in the crinoid sparite facies in the northeastern part of the Arbuckle Mountains, and most of the species described by Amsden (1968) were collected from this area. The four *Kockelella* conodont zones described by Barrick and Klapper (1976) have their best representation in the arthropod micrites and ostracode silty marlstones from the central part of the mountains. The two lower conodont zones, *K. ranuliformis* and *K. amsdeni*, are also present in the northeastern sparites and micrites, but the upper *K. stauros* and *K. var-*

iabilis zones have not been recognized outside the central region (text-fig. 3). It should be noted that all the zone conodonts are non-cone species which make up a very small part of the total fauna, whereas, as noted in the section on Conodonts, about 97 percent of the specimens collected from the Fitzhugh Member are cone species.

The Prices Falls Member has not yielded any megafossils, but conodonts studied by Barrick and Klapper (1976) and Barrick (1977) are assigned to the *Pterospathodus amorphognathoides* zone, which ranges from the Llandoverian (C6) into earliest Wenlockian.

Locality Data

All stratigraphic sections (e.g., P1, etc.) referred to in this report are described in the Appendix of Oklahoma Geological Survey Bulletin 84 (Amsden, 1960), with the exception of section AQL, which is described in Barrick and Klapper (1976, p. 84).

Acknowledgments

In the discussion which follows, the section on Lithofacies and Megafaunal Biofacies was prepared by Amsden, the section on Agglutinated Foraminifers and Inarticulate Brachiopods, by Toomey, and the section on Conodonts, by Barrick.

LITHOFACIES AND MEGAFAUNAL BIOFACIES

This part of our study presents the basic lithofacies and megafaunal biofacies data and discusses the relationship between them. It is concerned primarily with the megafaunal elements, composed largely of sessile and vagrant benthos, but ostracodes are also included. The foraminifers, small inarticulate brachiopods, and conodonts are discussed in later sections. The quantitative HCl-insoluble-residue data, which are composed largely of clay- and silt-size extrabasinal detritus, are derived from chemical analyses prepared by the Oklahoma Geological Survey. Several hundred thin sections were examined, and about 65 were point counted. The quantitative faunal data are derived from the point counting, the counting having been done usually on a 0.8-mm spacing and involving 300 to 600 points per thin section.

Counts were made on the matrix, distinguishing spar and micrite matrix, and on the major fossil components, such as pelmatozoan plates, trilobites, ostracodes, bryozoans, and brachiopods; all data are expressed as a percentage of total rock volume. The specimens from which the thin sections were prepared represent a reasonably detailed geographic and stratigraphic sampling of the Fitzhugh Member, and the consistency of the results obtained indicate that additional sampling would not make any substantive change in the data here presented.

Three lithofacies–biofacies divisions are here recognized within the Fitzhugh Member: (1) crinoid sparites, (2) arthropod micrites, and (3) ostracode silty marlstones, each named for the principal fossil and matrix represented. In their typical expression, each has distinctive characteristics, although they merge one into the other and should be regarded as part of a continuously varying sequence, with the crinoid sparites and ostracode silty marlstones being the end members and the arthropod micrites the transitional facies between them. There is some stratigraphic control to the distribution of these facies. In the northeastern part of the Arbuckle Mountains, crinoid sparites locally dominate the upper part of the Fitzhugh Member; and in the central part of the mountains, the ostracode silty marlstones are best developed in the uppermost strata. However, throughout most of the northeastern region, the sparites are interbedded with, and in part intimately intermingled with, the micrites; in the central area, the arthropod micrites are interbedded with the ostracode silty marlstones (text-figs. 4, 5). These relationships, plus the regional facies pattern, indicate both lateral and vertical gradation of the three facies.

Crinoid Sparite Facies

The principal lithologic character of the crinoid sparites is the dominant spar matrix,
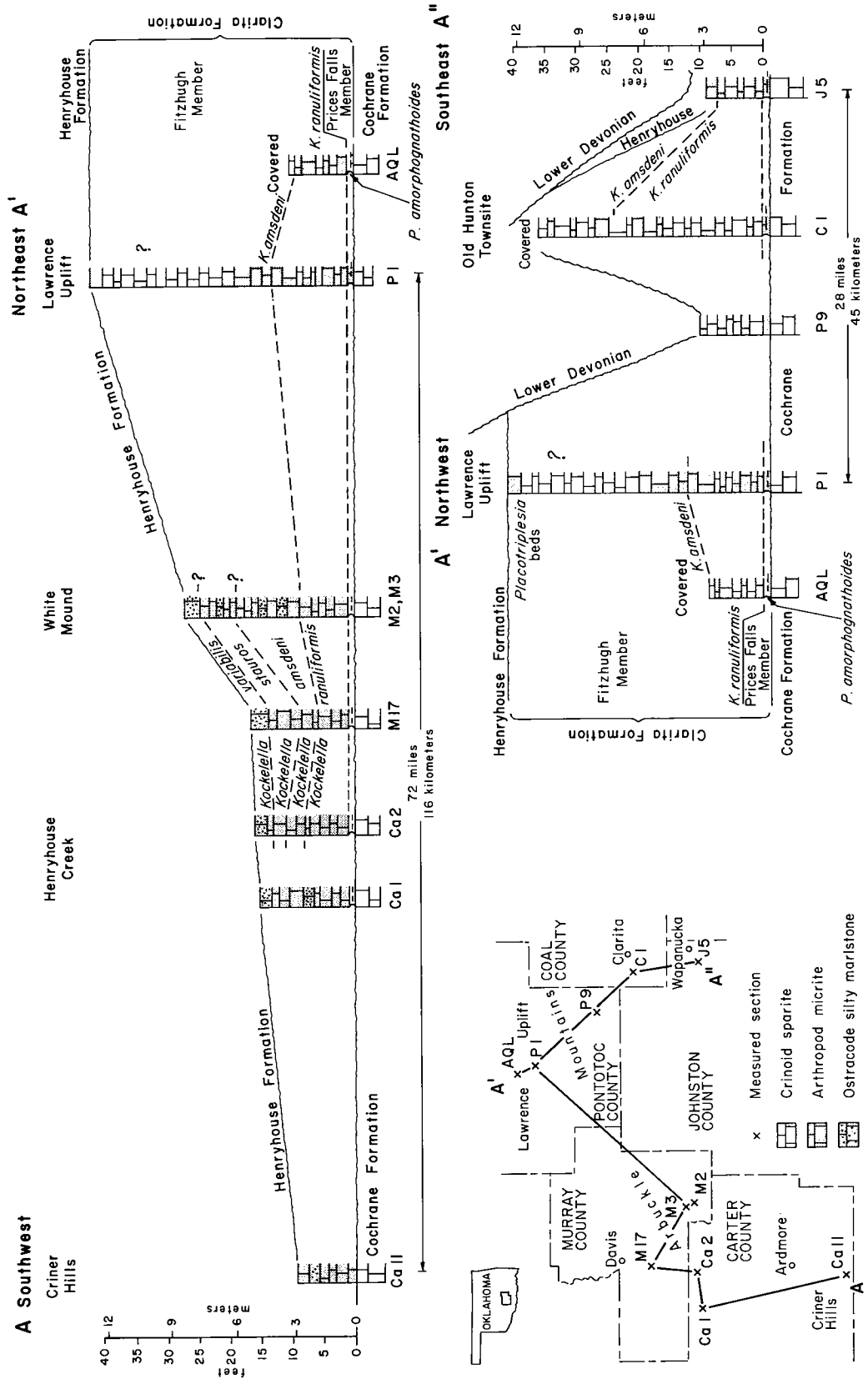
Text-figure 3. Described stratigraphic sections (Amsden, 1960, Appendix; Barrick and Klapper, 1976, p. 84), showing lithofacies–biofacies pattern and presently known distribution of the *Kockelella* conodont zones described by Barrick and Klapper (1976). Based on thin sections prepared from rock specimens collected by Toomey and Klapper from same beds sampled for conodonts and foraminifers.

Text-figure 4. Map with selected columnar sections, showing stratigraphic and geographic distribution of Fitzhugh lithofacies and biofacies recognized in Arbuckle Mountains—Criner Hills. (These stratigraphic sections described in Amsden, 1960, Appendix, and Barrick and Klapper, 1976.)
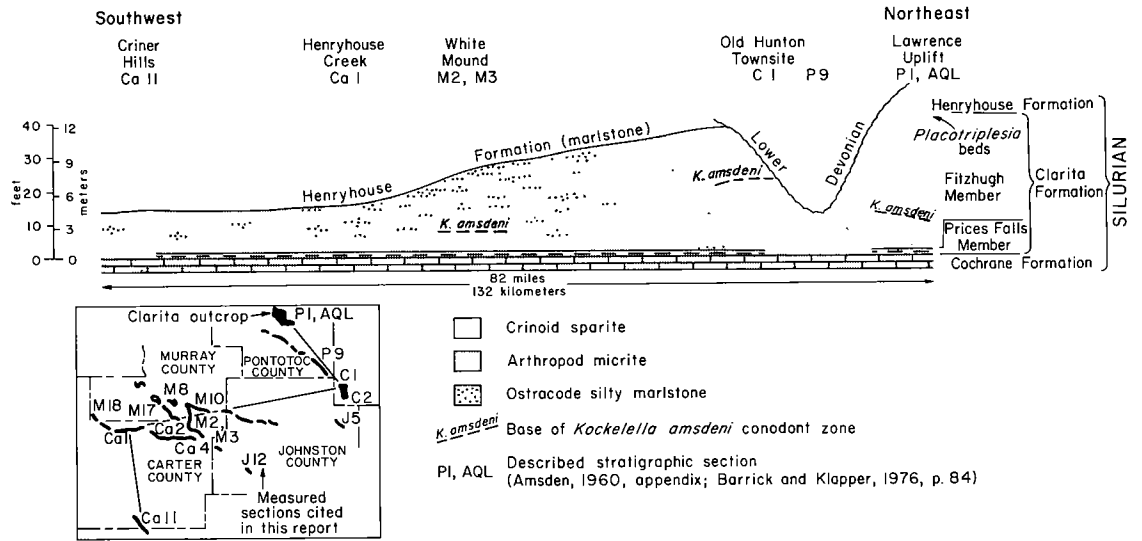
Text-figure 5. Interpretive stratigraphic section showing inferred facies relationships across Arbuckle Mountains and Criner Hills. Based on lithofacies and biofacies data obtained from stratigraphic sections shown on inset map. See also text-figs. 3, 4.

invariably combined with very low insoluble residues averaging less than 1 percent (text-fig. 6). The acid-insoluble residues in the sparites, as well as in the other facies, are largely clay- and silt-size terrigenous detritus (Amsden, 1960, p. 54), although there is probably a minor amount of secondary mineralization in all residues. The total matrix averages about 27 percent, of which on the average only 3 percent is micrite, the remainder being spar. The Fitzhugh micrites are interpreted as lime muds introduced at the time the rock was deposited. Some diagenetic changes, notably a slight enlargement in grain size, appears to have affected parts of the micrite matrix, but we believe that the micrite matrix is a part of the primary depositional fabric of the rock. Organic debris in the sparites ranges from 70 to 80 percent of rock volume, averaging 73 percent (text-fig. 7; pl. 4, figs. 1, 2; pl. 5, fig. 1). This material is believed to be a grain (fossil-clast) supported fabric, with the spar matrix having been introduced at or near the time of deposition. Disassociated pelmatozoan plates are the dominant fossils, ranging from 16 to 30 percent and averaging 25 percent of total rock volume. Next in abundance are ostracodes, mostly thick-shelled types (shell wall exceeding 0.05 mm in thickness), and trilobites, each averaging about 10 percent of rock volume. Bryozoans and brachiopods are the only other common constituents, each averaging approx-

imately 3.5 percent of rock volume. All other groups combined make up less than 1 percent of total rock volume (text-figs. 7, 8). It is noteworthy that corals make up such a small part of the fossil biomass, with only two of the thin sections studied showing any corals: one with 2.3 percent, and the other with 0.4 percent (corals also contribute very little to the other facies). Unidentified fossils average about 20 percent, and it is assumed that most
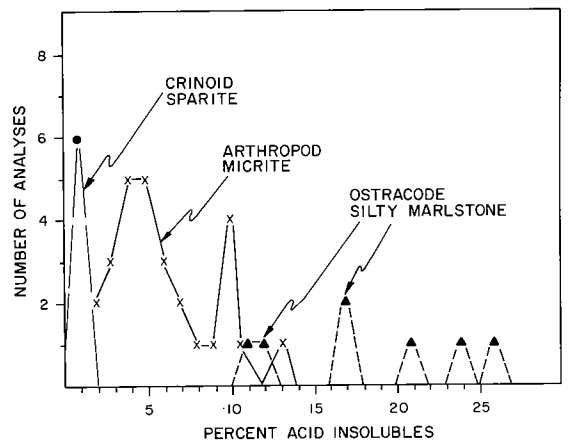
Text-figure 6. Frequency diagram showing distribution of HCl-insoluble residues in three major lithofacies–biofacies divisions recognized in Fitzhugh Member of Clarita Formation, Arbuckle Mountains–Criner Hills. Based on 41 rock analyses prepared by Oklahoma Geological Survey.

of these are representatives of identified
groups which have been broken or cut at such
an angle as to be unrecognizable. The pelmato-
zoan/arthropod ratio ranges from 0.70 to 3.98,
averaging 1.3; and the arthropod/bryozoan
plus brachiopod ratio ranges from 0.78 to
16.37, averaging 2.6 (text-fig. 7).

The crinoid sparites are confined to the
northeastern Arbuckle Mountains outcrops,
being well developed in Pontotoc County and
extending south and east into Coal County
(text-figs. 3–5). On the Lawrence Uplift, at the
northern end of the mountains (Amsden, 1960,
pl. A; text-fig. 4, this report), the lower part of
the Fitzhugh is composed of arthropod micrite
with numerous spar intercalations overlain
by 5 m of crinoid sparite with minor micritic
areas (stratigraphic sections P1 and P3,
Amsden, 1960, p. 268–269).The crinoid sparite
facies is well represented in the Fitzhugh out-
crop belt, extending south and east to old Hun-
ton townsite in Coal County (stratigraphic
section C1, Amsden, 1960, p. 182, panel 2;
text-fig. 4, this report), although throughout
this area it is commonly interbedded with ar-
thropod micrites, and in many beds the two
textures are intimately associated (pl. 4, figs.
3, 4). Elsewhere in the Arbuckle Mountains–
Criner Hills, spar, if present, is a minor part
of the matrix (text-figs. 4, 7).

Placotriplesia Beds

The top 0.6 m of the Fitzhugh Member
that is exposed near the northeastern end of
the Arbuckle Mountains is a richly fossilifer-
ous micrite strongly dominated by brach-
iopods and trilobites (stratigraphic section
P1-F, Amsden, 1960, p. 286; text-fig. 9, this re-
port). These are the Placotriplesia beds, so
named for the dominant triplesid brachiopod
P. praecipta (Ulrich and Cooper), and this is
the only known exposure in the Arbuckle
Mountains–Criner Hills outcrop area. They
carry a distinctive brachiopod fauna which
differs in several respects from that of the un-
derlying crinoid sparites (the biostratigraphic
relations are discussed in Amsden, 1968, p.
17–20, pls. 17–20). This is an unusual Fitz-
hugh biofacies because of its high brachiopod
volume; in fact, it is by far the greatest
brachiopod biomass observed, averaging 15.5
percent. Of particular interest is the high
brachiopod volume combined with a substan-

tial arthropod–mollusk volume, whereas in
the typical arthropod micrite facies, a well
represented arthropod–mollusk fauna is ac-
companied by a low brachiopod count (cf. text-
fig. 9 with text-fig. 7).

With the exception of the Placotriplesia
fauna, almost all of the Fitzhugh brachiopods
collected and described by Amsden are from
the crinoid sparite lithofacies–biofacies, with
only a few obtained from the micrite facies in
the central Arbuckle Mountains at strati-
graphic sections C1 and J5 (Amsden, 1968, p.
14–24, 103). To some extent this is an artifact
of collecting, because the fossils break free of
the spar matrix more readily than from the
micrites. However, the present study clearly
shows that brachiopods are more abundant in
the sparites than in the micrites.

Arthropod Micrite Facies

The major lithologic characteristic of the
arthropod micrite lithofacies–biofacies is the
dominant micrite matrix with only minor,
scattered patches of spar (text-fig. 7; pl. 5, fig.
2; pl. 6, figs. 1, 2). The micrite is believed to
represent a lime mud which provided the sub-
strate for this facies. Clay- and silt-size insol-
uble detritus ranges from 2 to 13 percent, av-
eraging 6.2 percent (text-figs. 6, 7). The total
matrix ranges from 23 to 50 percent, averag-
ing 39.1 percent, and the total organic debris
ranges from 50 to 77 percent, averaging 60.9
percent. This facies has a grain (fossil-clast)
supported fabric, with the lime muds having
been introduced at the time the organic debris
accumulated.

Pelmatozoans average 11 percent of total
rock volume, and the combined ostracodes and
trilobites average approximately 14 percent;
the ostracodes are mostly small, thin-shelled
types (shell wall less than 0.05 mm thick). The
next most abundant group is the mollusks,
which average slightly over 7 percent (gas-
tropods plus cephalopods; pelecypods are an
insignificant part of the identified biota).
Bryozoans and brachiopods are reduced in
volume from the crinoid sparite facies and to-
gether contribute less than 3 percent of total
rock volume (text-fig. 8). Corals are an insig-
nificant part of the biomass; of the 33 sections
counted, corals appear in only three, and in
only one of these do they exceed 0.5 percent
(3.9 percent). Algae are also an insignificant
part of the identified biomass.
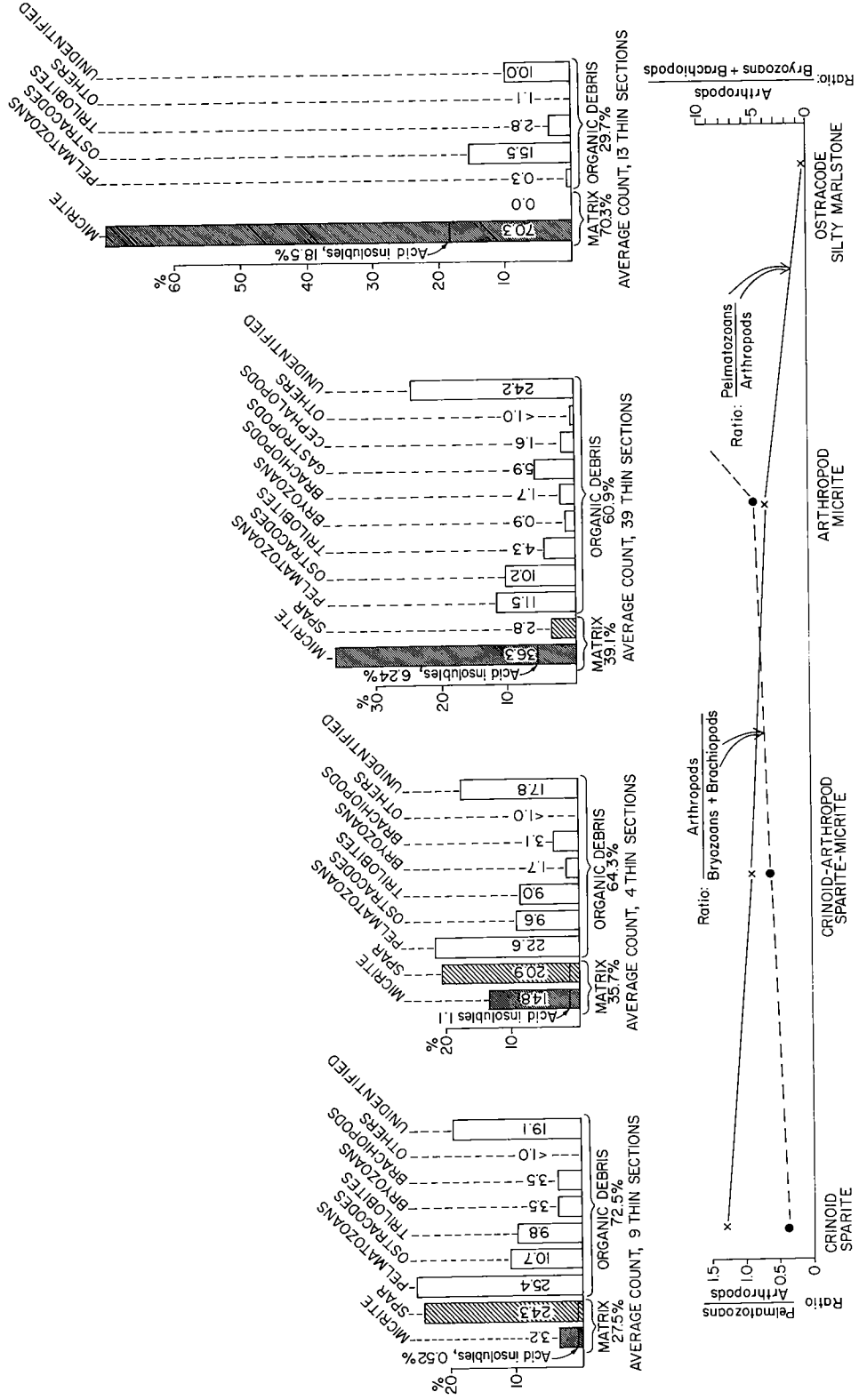
Text-figure 7. Bar graphs (above) showing distribution of matrix components and major fossil groups in lithofacies–biofacies divisions of Fitzhugh Member, including transitional crinoid sparite–arthropod micrite facies. Matrix and fossil data obtained by thin-section point counting, and acid-insoluble residues from chemical analyses by Oklahoma Geological Survey. Lower graph shows pelmatozoan–arthropod ratio and arthropod/bryozoan plus brachiopod ratio for each of facies depicted in overlying graphs.
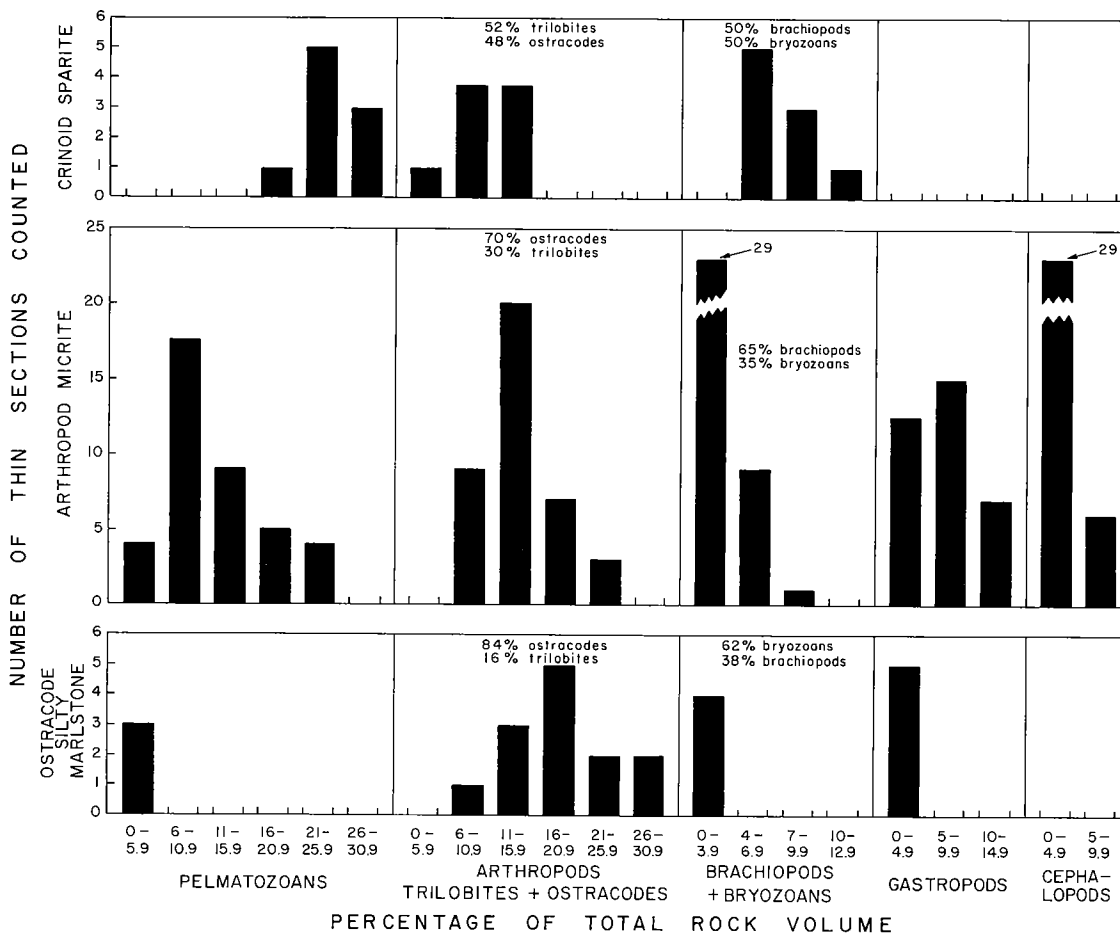
Text-figure 8. Frequency diagrams showing distribution of major megafaunal elements in three Fitzhugh facies as determined by point-counting. These diagrams summarize relative shift in mode for each fossil group that occurs in transition from crinoid sparite to arthropod micrite to ostracode silty marlstone. Compare to graphs shown in text-figure 7.

The micrite facies is present in the northeastern part of the Arbuckle Mountains, where it is associated with the sparite facies, but elsewhere it is dominant. The quantity of insoluble detritus in the micrites is variable; however, it exhibits a fairly well-marked geographic trend. In the northeastern area, insoluble detritus in the micrites generally falls in the 2- to 4 percent range, but in the central and southwestern part of the Arbuckle Mountains this increases to an average of about 6 percent. There is also a stratigraphic concentration in the latter region, and in general the detritus increases irregularly upward, commonly reaching its maximum in the upper part of the Fitzhugh Member. It is in this central region that the micrites locally grade into the ostracode silty marlstones (text-figs. 3–5).

Ostracode Silty Marlstone Facies

The ostracode silty marlstone facies is characterized by micrite matrix with almost no trace of spar (text-fig. 7; pl. 6, figs. 3, 4). Clay- and silt-size insoluble detritus ranges from 11 to 26 percent, averaging 18.5 percent (text-figs. 6, 7). Matrix in the 13 thin sections point-counted ranges from 57 to 87 percent, averaging 70.3 percent, and the total organic debris averages 29.7 percent. This lithofacies has a mud-supported fabric, and its texture is essentially a mixture of lime mud and fine ter-
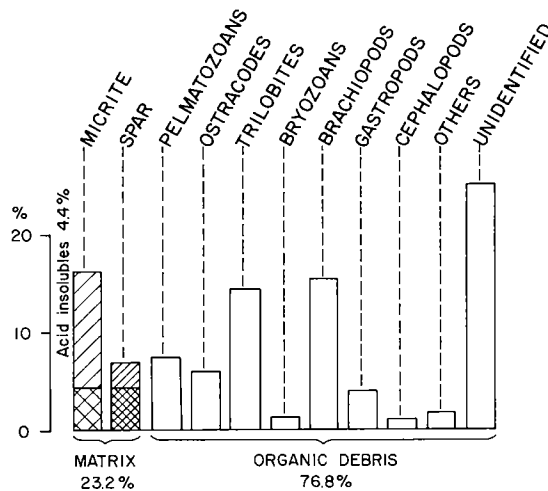
Text-figure 9. Bar graph showing distribution of matrix and major fossil groups in *Placotriplesia* beds of Fitzhugh Member, Clarita Formation. SE¼ sec. 5, T. 2 N., R. 6 E. (stratigraphic section P1-F, Amsden, 1960, p. 268; Amsden, 1968, p. 17–20). Based on point counts from two thin sections; all data given as percentages of total rock volume. Acid-insoluble residues from chemical analyses by Oklahoma Geological Survey.

rigenous detritus enclosing scattered organic debris. Ostracodes, which are almost entirely thin-shelled forms (pl. 6, figs. 3, 4), completely dominate the fauna, ranging from 9 to 23 percent of total rock volume. Trilobites are the next most abundant organism, averaging only 3.3 percent. Pelmatozoans were observed in only two thin sections, with an overall average of 0.3 percent; all other fossil groups combined average about 1 percent of total rock volume (text-figs. 7, 8).

The ostracode silty marlstone is concentrated in the central and southwestern parts of the Arbuckle Mountains, with a few thin beds in the Criner Hills (text-figs. 3, 4). It is best developed in the upper part of the Fitzhugh Member, but some beds are present in the middle and lower parts of this member, within 1½ m of the Cochrane Formation (text-figs. 3–5). It should be noted that the entire Fitzhugh Member has a relatively high concentration of insoluble detritus in this area, and many of the arthropod micrite beds have considerable silt accompanied by a decrease in the volume of organic material. This trend increases upward, causing much of the upper Fitzhugh Member to grade locally into marlstones resembling the overlying Henryhouse Formation. However, even in this

central region, there is a sharply defined lithologic boundary separating the Fitzhugh Member from the Henryhouse Formation. This contact is marked by an increase in insoluble detritus and an abrupt decrease in the microfauna, including ostracodes, at the base of the Henryhouse Formation. The lithologic character of this contact is described and illustrated in Amsden (1976, p. 25, pl. 8, figs. 4a, 4b), and its relationship to the conodont fauna was discussed by Barrick and Klapper (1976, p. 61).

Conclusions

The Fitzhugh facies pattern encompasses a gradation from crinoid sparites to arthropod micrites and finally to ostracode silty marlstones. Lithologically this involves the following: (1) a change from spar matrix to a micrite matrix and a gradual increase in the quantity of terrigenous detritus from less than 1 to more than 18 percent, with an accompanying increase in manganese content from about 100 to 800 ppm and an increase in K_2O from about 0.1 to more than 1.0 percent, both probably related to increases in clay content (text-fig. 10); and (2) an increase in the percentage of matrix from less than 30 to more than 60 percent (and a reciprocal decrease in organic debris), thus producing a change from a grain-supported to a mud-supported fabric.

These lithologic changes can be correlated with the following changes in the organic content: (1) the change from spar to micrite and finally to marlstone is marked by a progressive decrease in pelmatozoan plates from a position of dominance to one in which they are almost totally absent; (2) in the change from spar to micrite, the arthropods increase and surpass the pelmatozoans, and the brachiopods and bryozoans decrease, their position being taken by the gastropods with some cephalopods; and (3) thin-shelled ostracodes make up almost the entire fauna in the silty marlstones, the only other faunal element of any significance being the trilobites. These changes are summarized in the graphs shown in text-figures 6–8, and are illustrated in the photomicrographs on plates 4–6.

These changes in the organic and rock components must certainly reflect changes in the environment. The volume of skeletal material, with organic debris making up well
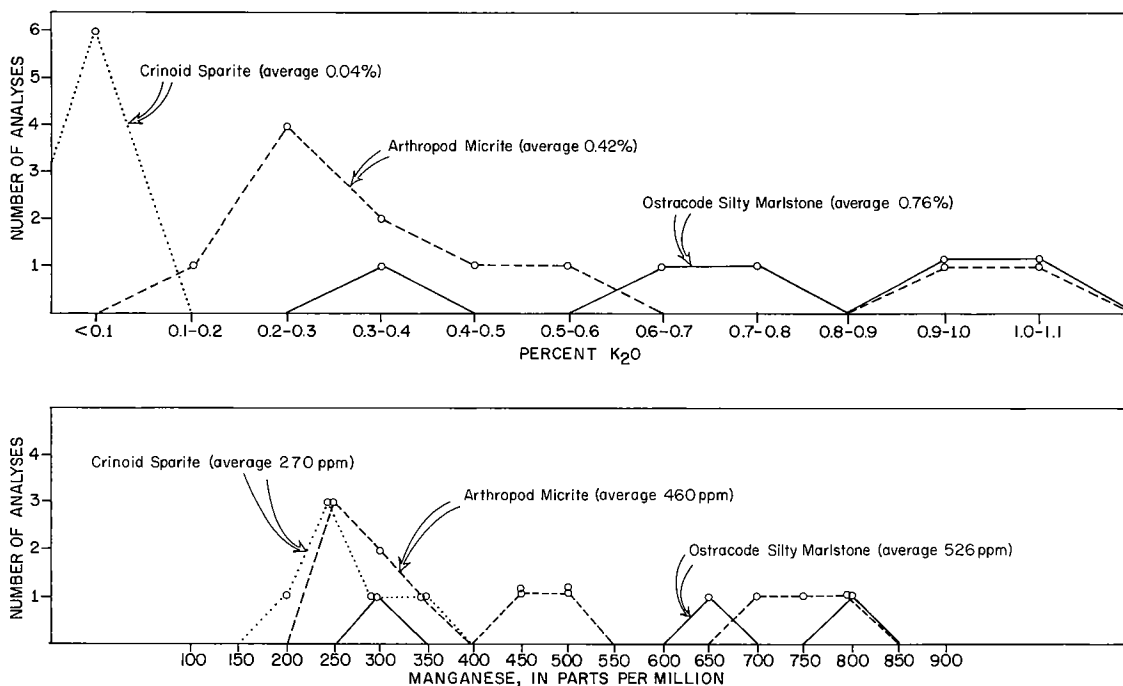
Text-figure 10. Frequency diagrams, Fitzhugh Member, Clarita Formation, Arbuckle Mountains–Criner Hills. Lower diagram compares manganese content (in ppm, rounded to nearest 50 ppm) of crinoid sparite, arthropod micrite, and ostracode silty marlstone (numbers in parentheses represent arithmetic means, in ppm). Upper diagram compares K_2O content (percentage weight) of three facies (numbers in parentheses represent arithmetic means). Analyses by Oklahoma Geological Survey.

over 50 percent of the total rock volume, indicates warm waters of moderate depth. This biofacies appears to represent an offshore carbonate platform with clear water and a firm substrate composed of clean-washed organic debris and an energy level with sufficient agitation to move the organic material moderately before burial. Crinoid thickets were widespread, and the vagrant benthos was well represented by ostracodes, mostly thick-shelled types, and trilobites; brachiopods and bryozoans were widely distributed but of moderate concentration. The increase in lime mud in the micrite facies favored a sharp increase in ostracodes and trilobites as well as a change in the benthos, reducing the crinoid colonies and largely replacing the brachiopods with gastropods (text-fig. 8). This change from a spar to micrite environment represents a moderate decrease in energy level, probably associated with some increase in depth, although there is no indication in the character of the faunas, preservation of fossils, or lithofacies that this increase was of appreciable magnitude.

We regard the sparite, micrite, and marlstone facies as a part of the carbonate-shelf deposition which was so widely developed over the Midcontinent region in middle Paleozoic time. We believe the major factor affecting the faunal change from the sparite to the micrite environment to have been the development of a muddy substrate accompanied by considerable turbidity. Sessile filter feeders such as the crinoids appear to have been especially susceptible to these changes (text-figs. 7, 8), suggesting that turbidity was concentrated near the sea floor, possibly associated with a soft substrate. In the calcareous marlstones, turbidity and accompanying siltation increased sharply, largely eliminating the macrobenthos and leaving primarily small, thin-shelled ostracodes which were probably free-swimming forms. Agglutinated foraminifers, very small inarticulate brachiopods, and conodonts are also present, as discussed elsewhere in this report.

Correlative Wenlockian-age strata are widely distributed in the Midcontinent region. The Quarry Mountain Formation crops out in eastern Oklahoma, in parts of Sequoyah, Cherokee, and Adair Counties

(text-figs. 1, 2). The upper Marble City Member of this formation is an organo-detrital limestone of exceptional purity, averaging about 0.3 percent HCl-insolubles (Amsden and Rowland, 1965, p. 49). Silurian strata in this region lie north of the dolomite front, and, locally, parts of the Marble City are heavily dolomitized. The Marble City Member is similar to the Fitzhugh Member in its general textural characteristics but differs in its faunal composition, being dominantly a crinoid-bryozoan assemblage, the latter mostly fenestellid types. Brachiopods, trilobites, and ostracodes 'make up a small but persistent part of the biota, along with a few mollusks. Corals are rare; no stromatolites have been observed, and the evidence for calcareous algae is meager. This represents a crinoid-bryozoan thicket of impressive dimensions, occupying an area of at least 200 square miles. The sea floor was composed of firm clean-washed, skeletal sands, and the water was clear and of a relatively low energy level (Amsden, 1978, p. 7–9).

Correlative strata also crop out in the Batesville district of north-central Arkansas (text-figs. 1, 2), but here the St. Clair Limestone is dominantly a crinoid-arthropod sparite, similar to the sparite and sparite-micrite facies in the Arbuckle Mountains region (Amsden, 1978, p. 6, text-fig. 5). These strata are also widely distributed in the subsurface of north Texas, Oklahoma, and Arkansas, and this Wenlockian limestone belt extends from the Texas Panhandle to the Mississippi River (text-fig. 1). The thickness is mostly under 200 feet, and, excluding the effects of dolomitization, the strata are almost exclusively organo-detrital carbonates, similar to the sparites and micrites in the Fitzhugh Member and representing a similar shallow-water shelf environment. The silty ostracode marlstone facies has not been observed north of the central Arbuckle Mountains, and this facies is probably present only in areas bordering the Ouachita province. This indicates that the terrigenous detritus in the Fitzhugh Member was derived in large part from the same source as that supplying the Ouachita sedimentary basin. There is, however, no evidence for any strand line in the southern Arbuckle Mountains or Criner Hills, nor does there appear to be any clear evidence for a strand line in any of the Wenlockian belt lying to the north. The northern edge of these strata

appears to be everywhere the result of truncation by later erosion.

The Arbuckle Mountains–Criner Hills are located near a major bend in the Ouachita–Marathon fold belt (text-fig. 11; Flawn and others, 1961, pls. 1, 2). Paleocurrent directions in the late Paleozoic Jackfork, Johns Valley, and "Atoka" sequence show that sediment transport in the Ouachita sedimentary basin was generally westward along the axis of the trough (Briggs and Cline, 1967, p. 985, 992–998; Briggs, 1974, p. 274–279). Information on the lithologic character and distribution of Silurian strata in the Ouachita Mountains is meager, especially for the Oklahoma portion, but in all probability the source and movement of the clastics in the middle Paleozoic were similar to those of the late Paleozoic. The only Silurian fossils from the Ouachita province presently known to us are graptolites from the Blaylock Sandstone of middle Llandoverian age, somewhat older than the Clarita Formation (Berry and Boucot, 1970, p. 123). The geographic distribution of the more clastic lithofacies in the
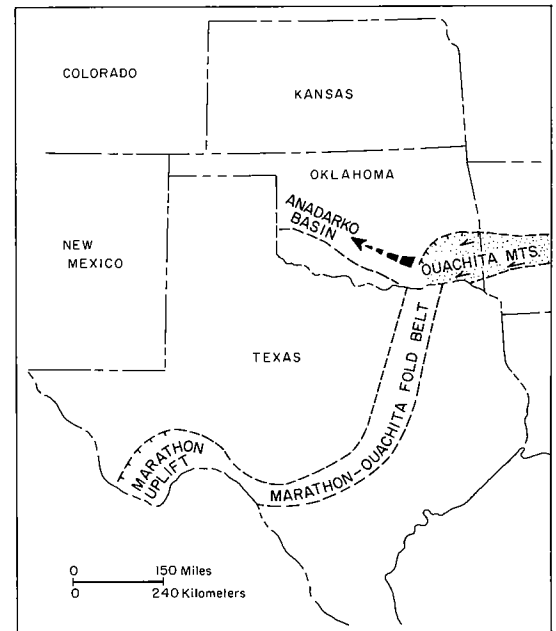
Text-figure 11. Map showing trend of Ouachita–Marathon fold belt. Solid arrows indicate trend of paleocurrent directions for late Paleozoic strata in Ouachita province. Dashed arrow indicates general trend of Silurian (Clarita–Henryhouse) lithofacies–biofacies across Arbuckle Mountains –Criner Hills and into southern part of Anadarko Basin.

Clarita and overlying Henryhouse Formations appears to correlate with the present Ouachita Mountains. Terrigenous detritus in both the Clarita and Henryhouse Formations is concentrated in the central and southeastern parts of the Arbuckle Mountains and in the Criner Hills. The Henryhouse marlstone lithofacies extends for a considerable distance westward along the deep axis of the Anadarko Basin, losing its lithologic identity toward the north and northwest, where it grades into organo-detrital limestones and dolomites with little terrigenous detritus (Amsden, 1976, p. 38–42, panel 11; Amsden, 1980, text-fig. 7).

Thus the regional as well as the local facies patterns suggest that most of the extra-basinal detritus was derived from the Ouachita trough, although its fine grain size and reduced volume indicate that some filtering mechanism was operating between the two basins. Certainly the organic-rich sediments of early and middle Paleozoic strata in the Arbuckle carbonate province must represent a very different environment from that of the sediments present in the Ouachita clastic province only a short distance to the east, but the character of the transition between the two basins is poorly understood.

AGGLUTINATED FORAMINIFERS AND INARTICULATE BRACHIOPODS

Introduction

Agglutinated foraminifers were first described from the Silurian "Chimneyhill limestone" (Clarita Formation, Fitzhugh Member) of the Arbuckle Mountains by Moreman (1930). However, as Moreman indicated (p. 43), the first Oklahoma Silurian foraminifer specimens were discovered by J. W. Ockerman of the Kansas Geological Survey, sometime immediately prior to 1930. These specimens were found in an insoluble residue prepared for heavy-minerals study. Ockerman showed this residue to Moreman, who recognized fragments in the sample as parts of foraminiferal tests.

In his 1930 publication, Moreman described and illustrated 25 "Chimneyhill" species, of which 23 were regarded as new

species. A good many of these new species would now be regarded as synonyms. Moreman's Silurian foraminifers came from samples of the "Chimneyhill limestone" at two locations in the Arbuckle Mountains of southern Oklahoma. These are his locality 2, near Bromide, Oklahoma, and locality 3, situated beside old U.S. Highway 77, between Davis and Ardmore, Oklahoma.

Later, Ireland (1939) studied large collections of foraminifers from insoluble residues prepared from both subsurface and outcrop samples of Silurian rocks of the Arbuckle Mountains and the subsurface of central Oklahoma. From the "Chimneyhill limestone" he described and illustrated 24 species, of which 22 were regarded as new species. In addition, one new genus and two new varieties were also described and illustrated. Again, many of these new species would now be regarded as synonyms.

Since these early works, taxonomic revision on Silurian agglutinated foraminifers has been undertaken by a number of workers, of whom the efforts by Noland (1969) and Conkin and Conkin (1964, 1977) have been most helpful. In essence, these authors have relegated many of the older foraminiferal names to synonymy.

In this study we have closely agreed with the pragmatic approach to taxonomy taken by Noland (1969) and have adopted her concept as to what constitutes a species with regard to Oklahoma Silurian agglutinated foraminifers. This concept specifically recognizes the fact that an objective basis for taxonomic diagnoses must utilize reliable morphologic characters, since only a siliceous agglutinated exoskeleton is present. Hence, one must view fossil foraminiferal assemblages as former living populations that possessed a variable range of morphologic characteristics. These include size, shape, chamber arrangement, test wall thickness, mode of attachment (if an encrusting form), and composition and size of the agglutinating particles. All of these characters must be considered *in toto*, so that the occasional sport does not become the basis of a new species.

Accordingly, we have recognized only six genera and 11 species of agglutinated foraminifers in the Clarita Formation of the Arbuckle Mountains region of southern Oklahoma. The composition of this foraminiferal

TABLE 1.—CLARITA AGGLUTINATED
FORAMINIFERAL ASSEMBLAGE

A. Family Astrorhizidae Brady, 1881

    Genus *Hyperammina* Brady, 1878

        Hyperammina harrisi Ireland

        H. hastula Moreman

B. Family Saccamminidae Brady, 1884

    Genus *Psammosphaera* Schulze, 1875

        Psammosphaera cava Moreman

    Genus *Lagenammina* Rhumbler, 1911

        Lagenammina sphaerica Moreman

        L. forma magna (new species)

    Genus *Thurammina* Brady, 1879

        Thurammina irregularis Moreman

        T. papillata Brady

        T. echinata Dunn

    Genus *Webbinelloidea* Stewart & Lampe, 1947

        Webbinelloidea tholus (Moreman)

C. Family Ammodiscidae Reuss, 1862

    Genus *Ammodiscus* Reuss, 1862

        Ammodiscus exsertus Cushman

        A. siliceus (Terquem)

assemblage is shown in table 1. It will be noted that this microfauna is made up of only three families: Astrorhizidae, Saccamminidae, and Ammodiscidae. Of these, the Ammodiscidae are the most abundant in total numbers of re-trieved specimens.

Acknowledgments

Nature of the Microfauna

Methods and character of residues.—Two samples of 500 gms each from 90 collections were prepared with 10-percent formic acid. Of the residues prepared from these collections, one-third were "picked clean," segregated, and mounted on micropaleontology slides in the customary manner. The residues from the re-maining two-thirds of the collections were prepared as "strewn slides" for ease in micro-scopic examination. The preservation of the Clarita microfauna is excellent, and specimen breakage during preparation was kept to a minimum by repeated treatment with dilute formic acid. The +2 microns size fraction of the insoluble residue seldom exceeds 1 percent of the total sample weight. Of this small per-centage, the residue may be composed almost entirely of agglutinated foraminifers, cono-donts, and inarticulate brachiopods. Literally thousands of microfossils can be concentrated in an individual residue. Other insoluble-residue components include clumps of spongy argillaceous material, shale flakes, quartz silt, pyrite, and hematite.

Microfauna seen in thin section.—Although great numbers of microfossils can be freed by acid etching of the rock matrix, the occurrence of microfossils in thin section, par-ticularly agglutinated foraminifers, is indeed a rarity. Microscopic examination of approxi-mately 200 large thin sections (2 × 3 inches), prepared from most of the collections, yielded only a few identifiable agglutinated forami-niferal specimens. In spite of the fact that a number of different foraminifer types were retrieved from the residues, only a few speci-mens referred to *Ammodiscus* sp. could be recognized in thin section; these are shown on plate 7, figures K–N. No calcareous se-creted foraminifer tests were observed in thin section.

"Sports."—The occurrence of teratologi-cal agglutinated foraminiferal specimens in the Clarita residues is noteworthy. Signifi-cantly, only species of the genus *Ammodis-cus* are affected, most commonly *A. exsertus* Cushman. In this species the occurrence of multiple apertures appears to be the domi-nant teratological aberration. In the past,

specimens with multiple apertures (sports) have been regarded as distinct genera and (or) species. The abundance of these sports is estimated to occur in no more than 12 specimens per every 500 "normal" specimens, or substantially less than 1 percent of the total *A. exsertus* population. Sports of *A. siliceus* (Terquem) manifest themselves in conspicuous offsettings of the inner initial coils. This feature has also led to previous taxonomic misinterpretation.

"Floods."—Residues containing "floods" of agglutinated foraminifers occur at each location; their distribution is shown in text-figures 12–20. These "flood" residues contain literally thousands of agglutinated foraminifer specimens. This microfauna is primarily dominated by species of *Ammodiscus* and in a few instances by specimens of *Hyperammina harrisi* Ireland, or a combination of both forms. Other Clarita agglutinated foraminifers are also relatively more abundant within these ammodiscid floods but are apt to be masked by sheer numbers of ammodiscids.

Paleoecologic comments.—Examination of 90 Clarita collections containing many

thousands of agglutinated foraminifer specimens has allowed us to speculate as to the probable paleoecologic habitat of various forms represented within this assemblage. These data are summarized in table 2.

The Clarita foraminiferal assemblage is composed entirely of benthic agglutinated foraminifers that inhabited various paleoecologic niches within a typical level bottom community. It is thought that there probably existed various levels of habitat stratification within this particular depositional realm. Accordingly, three habitats can be suggested, based on the morphologic features exhibited by some species and comparison with Holocene benthic foraminifer habitats. These are (1) benthic encrusters, (2) benthic browsers, and (3) benthic interstitial forms.

Those forms classified as benthic encrusters can be readily identified by two distinctive morphologic features, i.e., attachment scars or slits, usually on the ventral surface of the test (well shown in some specimens of *Thurammina irregularis* Moreman), and, in the absence of a particular attachment scar, a flat-bottomed test or series of flat-bottomed
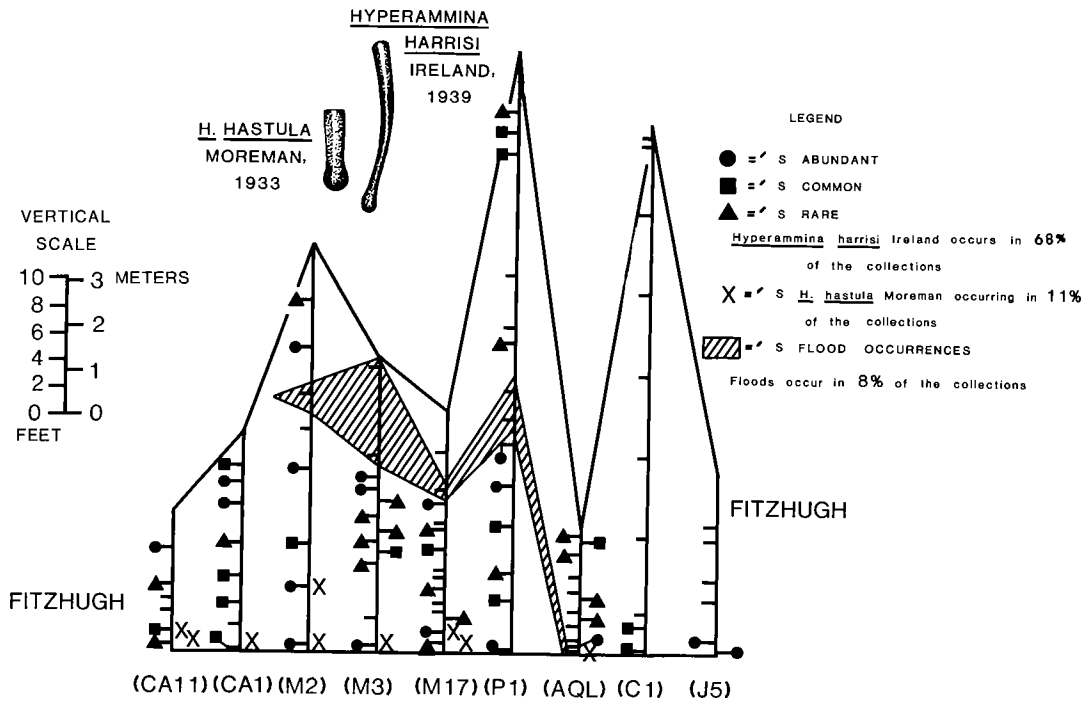
Text-figure 12. Graphic plot showing distribution and abundance of two species of *Hyperammina* present within Fitzhugh interval along outcrop belt; pattern delineates stratigraphic interval with flood occurrences of hyperamminids at five locations (M2, M3, M17, P1, and AQL).
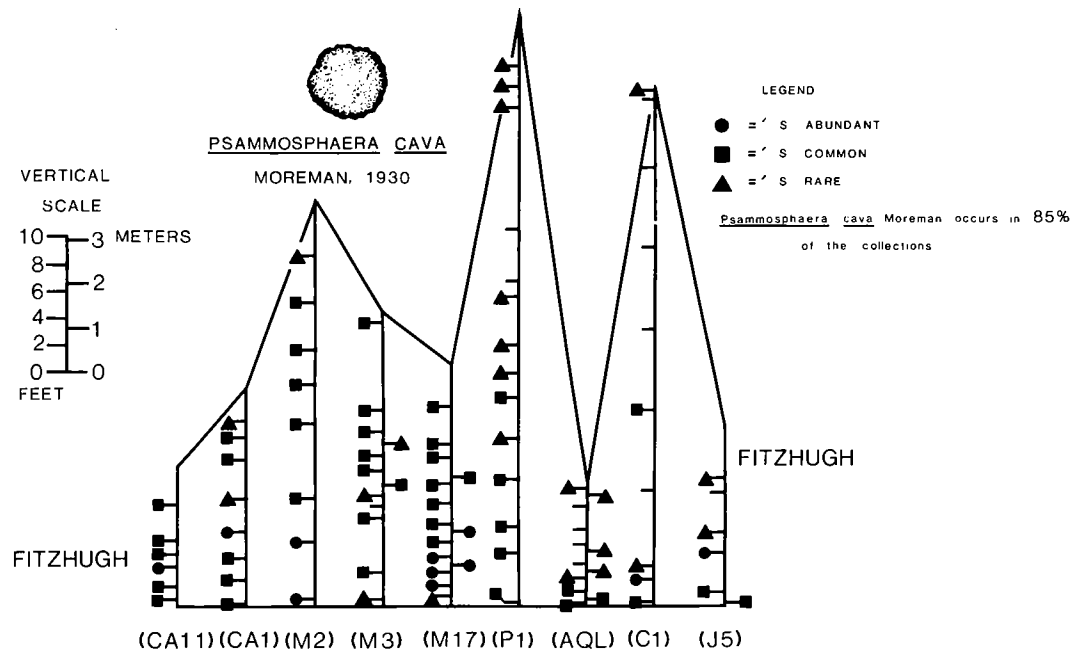
Text-figure 13. Graphic plot showing distribution and abundance of *Psammosphaera cava* Moreman within Fitzhugh outcrop interval.
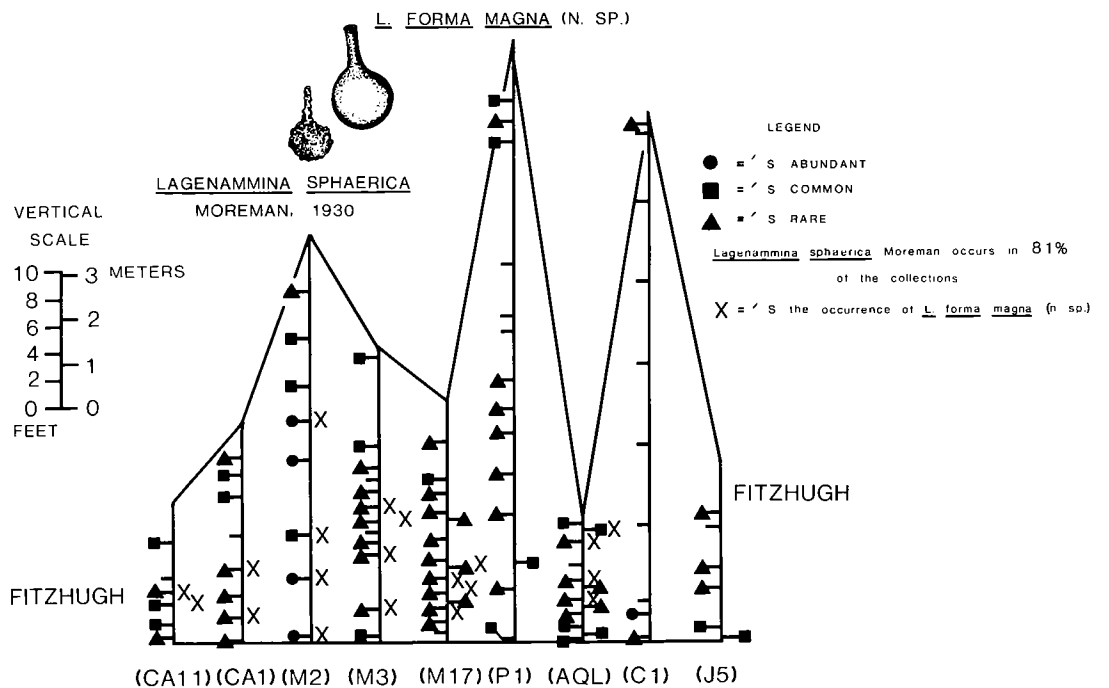
Text-figure 14. Graphic plot showing distribution and abundance of *Lagenammina sphaerica* Moreman within Fitzhugh outcrop interval. Plot of X's indicates occurrences of *Lagenammina forma magna* (n. sp.) and shows relationship to dominant lagenamminid species.
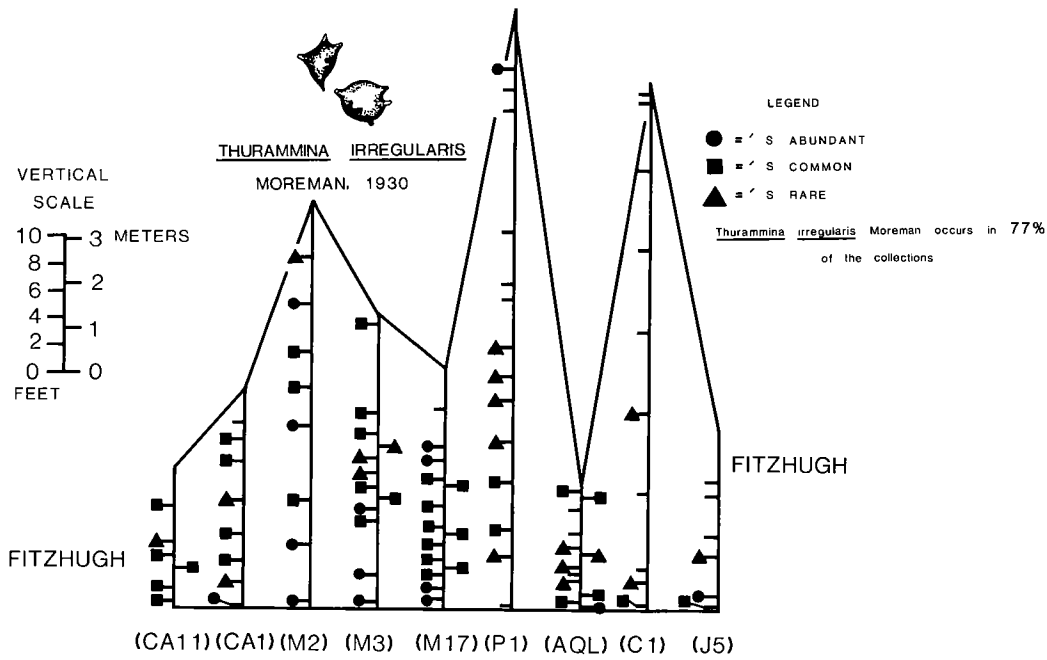
Text-figure 15. Graphic plot showing distribution and abundance of encrusting foraminifer *Thurammina irregularis* Moreman within Fitzhugh outcrop interval.
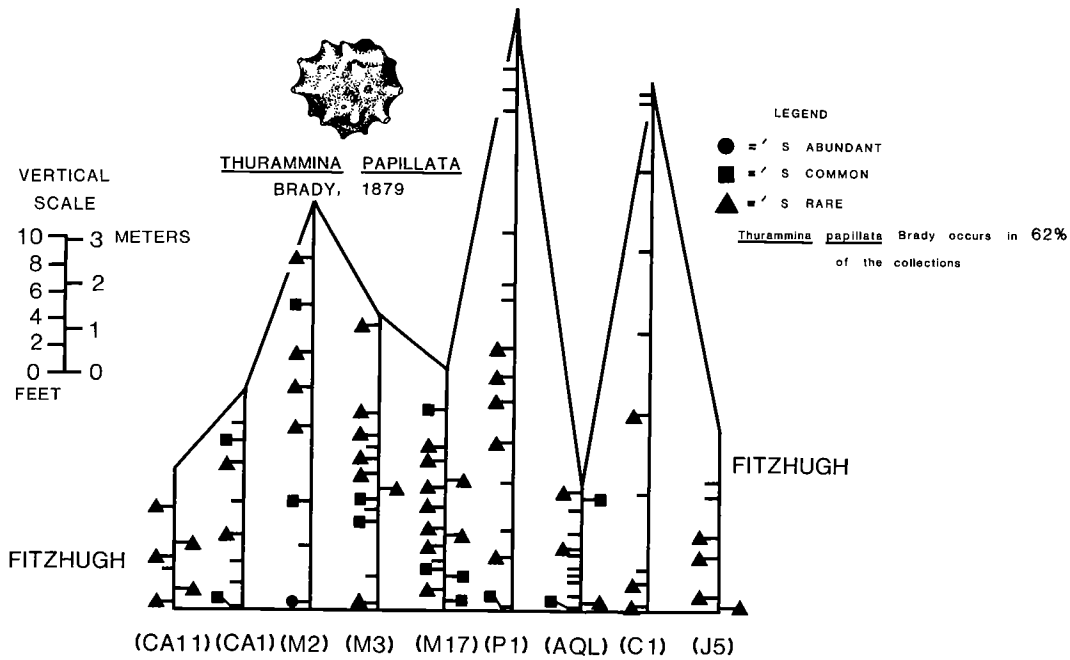
Text-figure 16. Graphic plot showing distribution and abundance of *Thurammina papillata* Brady within Fitzhugh outcrop interval.
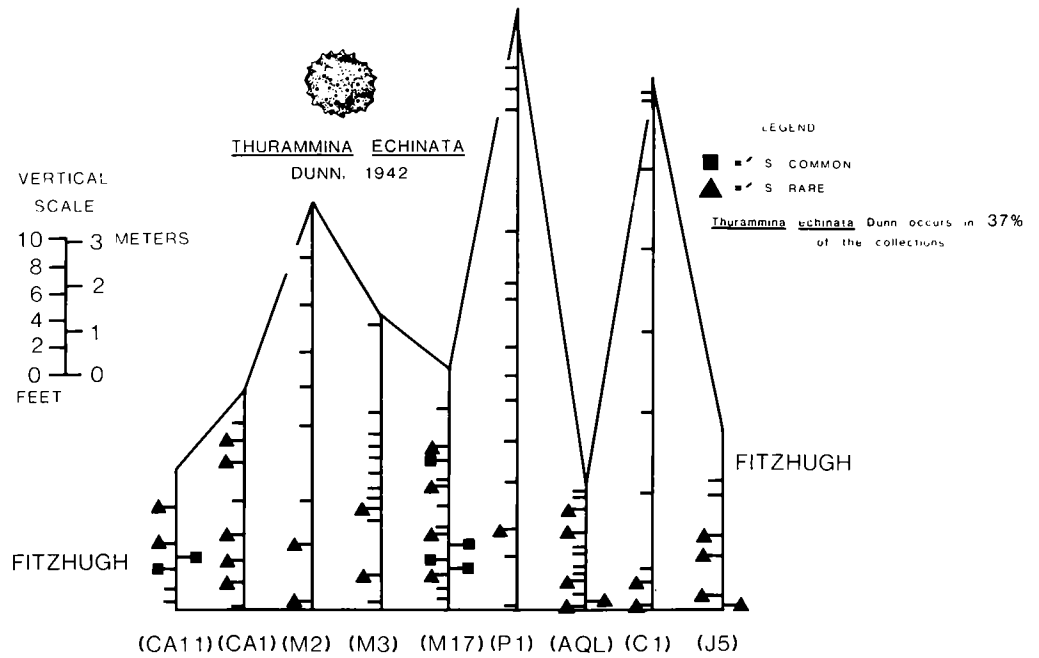
Text-figure 17. Graphic plot showing distribution and abundance of *Thurammina echinata* Dunn within Fitzhugh outcrop interval.
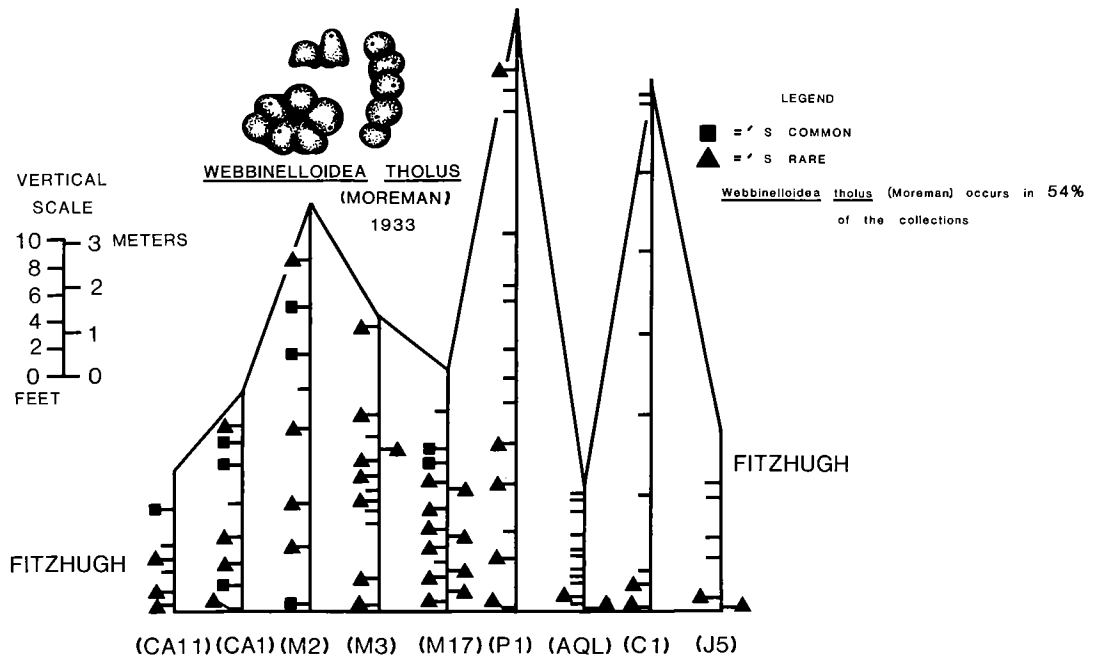
Text-figure 18. Graphic plot showing distribution and abundance of encrusting foraminifer *Webbinelloidea tholus* (Moreman) within Fitzhugh outcrop interval.
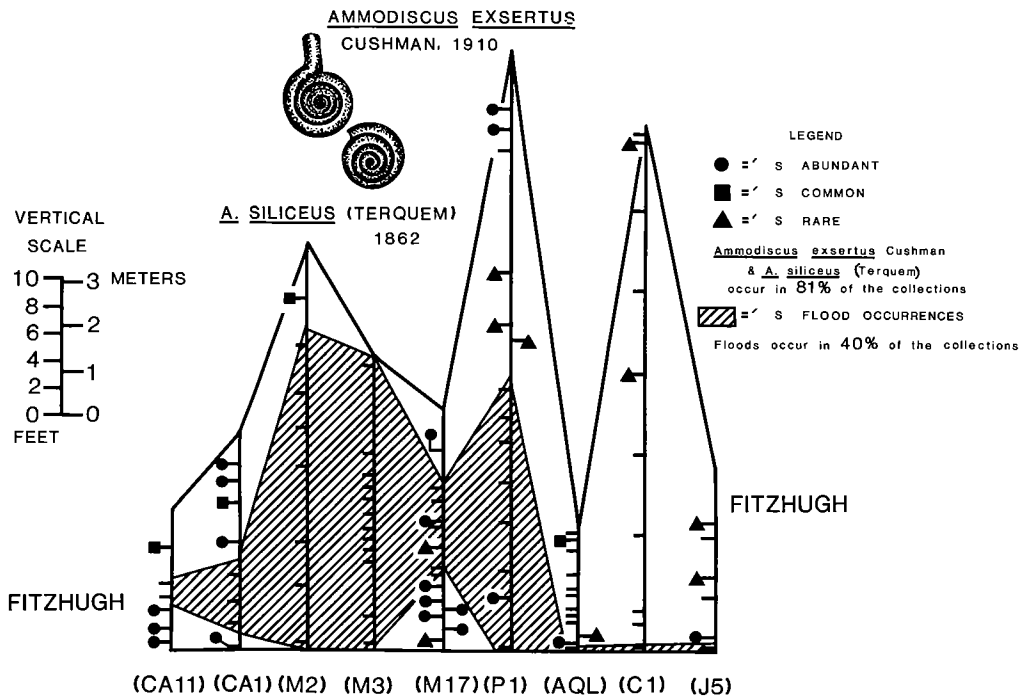
Text-figure 19. Graphic plot showing distribution and abundance of two species of *Ammodiscus* present within Fitzhugh interval along outcrop traverse; pattern delineates stratigraphic interval with flood occurrences of ammodiscids at all locations.
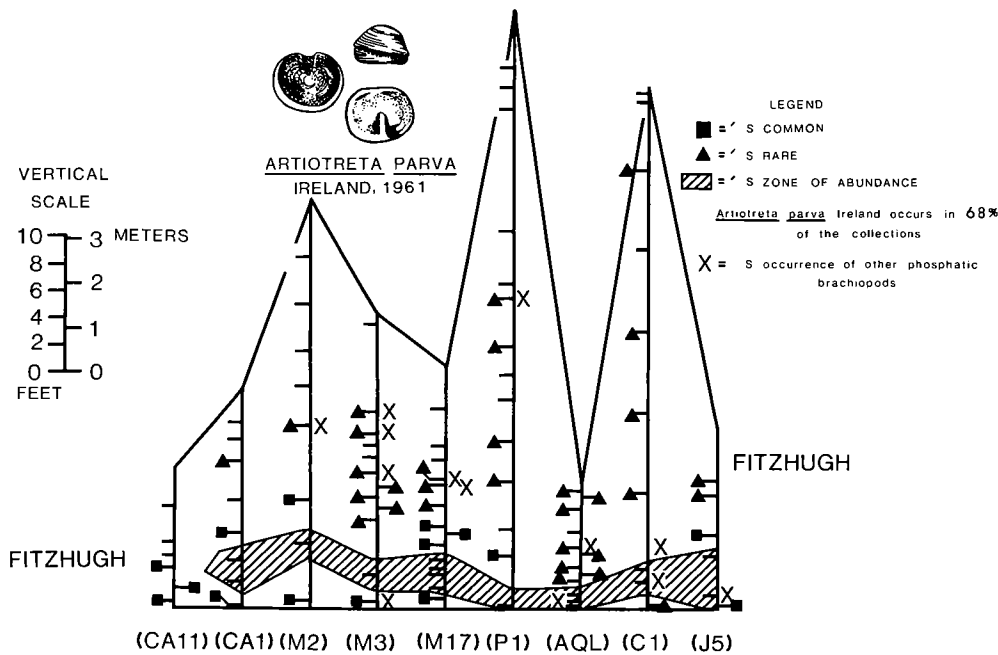
Text-figure 20. Graphic plot showing distribution and abundance of phosphatic inarticulate brachiopod *Artiotreta parva* Ireland within Fitzhugh outcrop traverse; pattern delineates stratigraphic position of zone of abundance present at all localities except CA11. Plot of X's indicates rare occurrences of other phosphatic brachiopods.

tests arranged either randomly or in linear series (exemplified by specimens of *Webbinelloidea tholus* (Moreman)). In addition, most encrusting forms generally show more overall morphologic variability of the test, as a result of what might be termed "plastic adaptation" of the foraminifer test to the encrusted host surface. Considering that most megafossil groups are represented within the Clarita biota, the opportunity to find a suitable attachment host would not appear to be a significant problem. One should also keep in mind the possibility that various soft-bodied algae with a grasslike habitat existed on the sea bottom simultaneously and within the shelly community, and, being perishable, have not left a geological record.

The majority of Clarita agglutinated foraminifers, lacking recognizable attachment surfaces and exhibiting a variety of test morphologies, appear to have carried on their life activities primarily as benthic browsers (see table 2). This browsing activity occurred within different, though probably stratified, habitat levels ranging from the sediment/water interface up to and amongst the varied biotic clusters (crinoids, bryozoans, various shelly forms, and algae or "grasses" mentioned above) that elevated them above the immediate sea-floor level. In a study of Holocene foraminifers of the Florida–Bahama area, Marszalek and others (1969, p. 342) observed that in shallow-water environments most foraminifers carry on their life processes within and on various marine algae. It is suggested that this probably was also the case with some Clarita foraminifers.

Certain Clarita foraminifers also may have lived within the immediate substrate as an integral entity of the interstitial biota. It is thought that species of *Hyperammina*, with their unique test morphology of a solidly constructed tube closed at one end, probably inhabited the uppermost few millimeters of the sea bottom and browsed within this particular habitat.

Interestingly, very little research has been directed toward determining the function of the foraminiferal test, especially ancient foraminifers. Marszalek and others (1969) suggested that the primary function of the foraminiferal test may be simply to serve as a receptacle to function as a chemical buffer protecting the soft-bodied animal against unfavorable environmental changes. However, the great variety of foraminiferal test morphologies suggests that some taxa have evolved unique tests that appear to allow the organism to adapt, rather effectively, within well-defined ecologic niches.

Phosphatic brachiopods.—As noted previously, well-preserved chitino-phosphatic inarticulate brachiopods occur fairly commonly within the Clarita residues, a characteristic recorded by Ireland (1961). Three distinctive forms can be recognized, although only one, *Artiotreta parva* Ireland, occurs in abundance. This particular brachiopod species is characterized by its smallness and the convex, almost hemispherical pedicle valve, along with a prominent internal median unbranched septum in the dorsal valve. Two other forms, *Acrotretella siluriana* Ireland and *Lingula* sp., occur as fragments in a few Clarita residues.

TABLE 2.—POSTULATED PALEOECOLOGIC HABITAT OF
VARIOUS CLARITA FORAMINIFERS

Benthic Encrusters	Benthic Browsers	Benthic Interstitial Forms
Thurammina irregularis Moreman	*Psammosphaera cava* Moreman	*Hyperammina harrisi* Ireland
Webbinelloidea tholus (Moreman)	*Lagenammina sphaerica* Moreman	*H. hastula* Moreman
	L. forma magna (n. sp.)	
	Thurammina papillata Brady	
	T. echinata Dunn	
	Ammodiscus exsertus Cushman	
	A. siliceus (Terquem)	

Distribution of the Microfauna

Agglutinated foraminifers.—In general, agglutinated foraminifers range throughout the entire Clarita interval (Fitzhugh Member), and the typical assemblage reported herein (table 2) is present in most collections across the outcrop belt. For all practical purposes, the distribution of agglutinated foraminifers does not show an apparent biostratigraphic zonation. In fact, identical agglutinated foraminiferal species appear to be long ranging and occur in stratigraphic units both below and above the Fitzhugh Member. Nonetheless, there are two foraminifers whose distribution patterns are confined either to the lower one-third or one-half of the Fitzhugh Member. These are, respectively, *Hyperammina hastula* Moreman and *Lagenammina forma magna* (n. sp.). However, both foraminifers do not occur in substantial numbers and are not present along the entire outcrop belt. Seemingly, the distribution of Fitzhugh Member agglutinated foraminifers appears to be facies controlled rather than biostratigraphically controlled.

Of the three recognized Fitzhugh Member rock facies, agglutinated foraminifers are less common within collections taken from the crinoid sparite facies (localities C1, AQL, and P1). As shown previously, rocks of this facies are well-washed grainstones with the micritic component winnowed out. Rocks of this type, suggesting an originally unstable substrate, do not as a rule contain abundant and diverse foraminiferal biotas. This is well shown in text-figures 12–20 where, in most instances, there is a pronounced reduction in both plotted foraminifer abundance and diversity.

Collections from localities assigned to the arthropod micrite facies (localities J5 and CA11) contain typical Fitzhugh Member foraminiferal assemblages, but these collections seldom attain the overall abundances seen in collections of the ostracode silty marlstone facies. The relatively more muddy and silty substrate seems to reflect somewhat deeper and less turbulent bottom conditions, and it appears to have been more conducive to agglutinated foraminiferal exploitation.

The most abundant and diverse microfaunas occur at those localities where lithology of the ostracode silty marlstone facies is dominant (localities CA1, M17, M2, and M3, the latter near M4 sec.; Amsden 1960, p

235–238). Here also, the more muddy sea bottom, with a pronounced increase in silt, appears to have been ideal for foraminiferal development. As noted previously, each facies possesses its distinctive characteristics, although the varied lithologies merge into one another and are thought to be expressions of a continuously varying sequence, which is (in places) interbedded. This is well shown in the facies map (text-fig. 4), where at Locality P1 the top half of the Fitzhugh Member is classified as a crinoidal sparite. Agglutinated foraminifers are, for the most part, generally less abundant within this interval than in the underlying arthropod micrite interval, where some foraminifers may even reach "flood" abundances (text-figs. 12, 19). The distributional patterns for each of the Fitzhugh Member agglutinated foraminifers are discussed below.

Two species of *Hyperammina* are present within the Fitzhugh collections. The dominant form is *H. harrisi* Ireland, a rather long, slender, slightly curved, delicate tube, closed at one end by a fragile proloculus. In most collections, the proloculus is broken off, resulting in this form's appearing as a delicate, curved, open-ended tube, a feature that has caused some taxonomic difficulty in the past when workers considered this taxon as representing the genus *Bathysiphon*. This species occurs in 68 percent of the collections and is distributed throughout the Fitzhugh interval (text-fig. 12). Floods of this form occur in 8 percent of the collections and are associated with the more micritic lithologies. In contrast, *H. hastula* Moreman is a rather more massive form, though shorter in length and linear shape, having a more pronounced proloculus resembling the head of a wooden match. *H. hastula* occurs sparingly in only 11 percent of the collections, although these occurrences are located only in the lower one-third of the Fitzhugh Member (text-fig. 12). Specimens of this hyperamminid species were not seen in collections from localities J5, C1, and P1. The agglutinating particles of both hyperamminid species are very fine quartz silt embedded in much siliceous cement, imparting a smooth surface to the tests. Thin-section photomicrographs of hyperamminid test walls are shown on plate 7, figs. F–J.

Morphologically, *Psammosphaera cava* Moreman is a typical globular form without any distinctive surficial features and lacking

a discernible aperture. This species is the most widely distributed Fitzhugh foraminifer and occurs in 85 percent of the collections distributed throughout the entire Fitzhugh interval (text-fig. 13). Numbers of specimens range from rare to abundant, with more specimens occurring in the dominantly micritic intervals. Agglutinating particles for this species consist of relatively coarse, though somewhat angular, quartz silt grains with little matrix siliceous cement, thus imparting a rather rough surficial texture to the test.

Two distinctive species of the genus *Lagenammina* occur in 81 percent of the collections (text-fig. 14). The dominant species is *L. sphaerica* Moreman, a small, delicate, flask-shaped form, with a conspicuous but delicate neck extending upward from the main body of the test for variable lengths and ending with an open, circular aperture. This species occurs throughout the Fitzhugh, with numbers of specimens ranging from rare to abundant, although specimens are most abundant within the more micritic intervals. The agglutinating particles of *L. sphaerica* consist of subrounded quartz silt grains with only sparse siliceous cement, imparting a somewhat rough surface texture to the test.

I have referred the other lagenid species as a large form under the genus *Lagenammina*, clearly representing a new species. *L. forma magna* (n. sp.) is characterized by its smooth, massive appearance and large size, being up to three times as large as *L. sphaerica*. Its distinctive smooth appearance is due to the fine nature of the agglutinating quartz-silt particles that are embedded in much siliceous cement. This large lagenid foraminifer occurs only sparsely but is present in some collections from the lower one-half of the Fitzhugh interval (text-fig. 12), although no specimens occur at localities P1, C1, and J5. This form is always associated with *L. sphaerica,* although it only occurs in 22 percent of the collections.

Three distinctive species of *Thurammina* occur within the Fitzhugh collections. The most abundant and widely distributed species is *T. irregularis* Moreman, which occurs in 77 percent of the collections throughout the Fitzhugh (text-fig. 15), but it is most abundant within the more micritic intervals. This species is characterized by its small size, roughly globose though highly variable shape with irregularly distributed protuberances on

the test surface, and, in some instances, an attachment slit on the ventral surface. The agglutinating particles for this encrusting species consist of very fine quartz silt embedded within much siliceous cement.

The second most abundant thuramminid species is *Thurammina papillata* Brady, which occurs in 62 percent of the Fitzhugh collections. This form also is more common within the more micritic intervals (text-fig. 16). This species is distinguished by its relatively large size, smooth massive appearance, and numerous well-developed protuberances regularly distributed over the test surface, which sometimes imparts a distinctive polygonal outline to the test. The agglutinating particles of this species are fine quartz silt embedded in much siliceous cement.

The least abundant thuramminid species is *Thurammina echinata* Dunn, which occurs in only 37 percent of the Fitzhugh collections throughout the outcrop belt (text-fig. 17). It, too, occurs more commonly in the micritic intervals. This distinctive foraminiferal species occurs in rare to common abundance and is characterized by its small to medium size, globose shape, and the test surface covered with numerous protuberances imparting a characteristic spinose appearance. The agglutinating particles are fine quartz silt embedded in a siliceous cement matrix.

The encrusting agglutinated foraminifer *Webbinelloidea tholus* (Moreman) occurs in 54 percent of the Fitzhugh collections across the outcrop area (text-fig. 18). This species occurs in only rare to common abundances and is most apparent in the more micritic intervals. The primary distinguishing feature of this foraminifer is its extreme morphological variability that manifests itself in forms that range from single chambers to clusters of chambers to linear chains of variable length. This extreme variability of test morphology has previously been a definite source of taxonomic confusion, with at least four genera and numerous species erected to describe various ontogenetic forms of this species. In addition, all specimens are flat-bottomed and possess a pronounced peripheral rim, and some may even show an attachment slit, all features emphasizing its encrusting habit. Small, subcircular apertures are sometimes seen on each chamber; these are usually located in an eccentric position. The agglutinating particles of this species consist of very fine quartz silt

embedded in a thin test wall matrix of very fragile siliceous cement.

The planispirally coiled form *Ammodiscus* is the most abundant agglutinated foraminifer represented in the Fitzhugh collections and occurs in 81 percent of the collections throughout the sampled outcrops (text-fig. 19). Two species are represented, *A. exsertus* Cushman and *A. siliceus* (Terquem), and both occur most commonly in the more micritic intervals, although both forms have also been found in the crinoidal sparite facies. Flood occurrences of *Ammodiscus* are conspicuous and occur in approximately one-half (40 percent) of the plotted collections shown in text-figure 19. *A. exsertus* is characterized as a relatively medium-sized planispirally coiled tube that coils for several complete whorls but coils upward with the last whorl, perpendicular to the primary plane of coiling, forming a pronounced neck that ends in an open circular aperture. In contrast, *A. siliceus* is a planispirally coiled tube of from three to eight complete whorls, with the final whorl ending in the same plane of coiling and with a circular aperture at the end of the tube. Thin-section photomicrographs of both species are shown on plate 7, figures A–E. The agglutinating particles consist of very fine quartz silt embedded in a siliceous cement.

Phosphatic brachiopods.—As noted earlier, phosphatic inarticulate brachiopods are also common constituents present in the Fitzhugh residues. One form, *Artiotreta parva* Ireland, is dominant. Significantly, this species occurs in a prominent zone of abundance stratigraphically close to the base of the Fitzhugh Member. This distribution pattern is shown in text-figure 20. It should be noted that this species is present in rare to common abundances across the outcrop belt and occurs throughout the Fitzhugh stratigraphic interval; it has not been found in stratigraphic units below or above the Fitzhugh Member. The very rare occurrences of two other phosphatic inarticulate brachiopods, *Acrotretella siluriana* Ireland and *Lingula* sp., are also plotted in text-figure 18. The zone abundance of *A. parva* appears to be a stratigraphic marker unit of local significance.

Comparison to Other Wenlockian Foraminiferal Assemblages

In attempting to compare the Middle Silurian (Wenlockian) agglutinated foramin-

iferal assemblage of the Clarita Formation (Fitzhugh Member) to other reported Wenlockian microfaunas, we have adopted a realistic approach in assessing the validity of reported stratigraphic occurrences and, in particular, the distinction as to what constitutes valid taxonomic assignments. Accordingly, we have considered many previously described genera and species to be synonyms, in a manner comparable to that set forth by Noland (1969) and Conkin and Conkin (1964, 1977), and we have evaluated other Wenlockian microfaunas within this framework.

Two papers by Ireland (1966, 1967) explored the use of agglutinated foraminifers in attempting to straighten out subsurface Silurian stratigraphic problems in the Forest City and Salina Basins of northeastern Kansas. The goal of these studies was to facilitate regional correlation of Kansas Silurian strata with units of similar age in other areas. The Silurian portion of the subsurface section was subdivided into a fivefold zonation, of which zone 3 was considered to be the Clarita (Fitzhugh Member) equivalent, primarily based on the fact that this was the only zone that yielded agglutinated foraminifers.

This microfauna was described and illustrated with line drawings (Ireland, 1966). Taking into consideration that most of Ireland's described species would now be placed into synonymy, the Kansas agglutinated microfauna does appear to have some species that are identical to those present in the Fitzhugh Member. Species in common include *Ammodiscus exsertus* Cushman, *A. siliceus* (Terquem), *Hyperammina harrisi* Ireland, *H. hastula* Moreman, *Psammosphaera cava* Moreman, and *Thurammina papillata* Brady. Noteworthy differences include the occurrence of the encrusting form *Turritellella* in the Kansas collections, and its absence in the Fitzhugh, and the occurrence of *Webbinelloidea tholus* (Moreman) and *Lagenammina sphaerica* Moreman plus various thuramminid species in the Fitzhugh and their absence in the Kansas subsurface. In both units, specimens of Ammodiscidae dominate the agglutinated foraminiferal assemblages.

Dunn (1942) studied collections of Silurian agglutinated foraminifers from rocks of the Mississippi Basin (Indiana, Illinois, Tennessee, and Missouri) and described and illustrated numerous species and genera from these collections. Unfortunately, the validity of most of his genera and species would now be

questioned and probably placed into synonymy. More importantly, stratigraphic data for Dunn's collections are incomplete and confusing; this, coupled with the fact that his type specimens are no longer available, has led to much confusion. Thus, it is perhaps more prudent to ignore this study and concentrate on later works from the same general area.

Study of the Silurian (Wenlockian) Waldron Shale of southeast Indiana (McClellan, 1966) resulted in a further proliferation of numbers of new species and one new genus of agglutinated foraminifers. We would regard many of these as synonyms of previously described forms. The Waldron microfauna is dominated by species referred under the Astrorhizidae (especially hyperamminids) and the Saccamminidae (in particular, encrusting forms that we would place with the webbinelloidids). Abundant Fitzhugh forms, i.e., the ammodiscids and lagenamminids, along with thuramminids, are common.

In a subsurface study of cored Silurian rocks from five counties in northern Indiana, Mound (1968) identified a number of agglutinated foraminifers from the Louisville Limestone (Wenlockian equivalent) in cores from four of the five counties. Mound noted that the Waldron Formation (also thought to be a Wenlockian equivalent) was mostly barren of agglutinated foraminifers but that the overlying Louisville Limestone (a Wenlockian equivalent) contained forms characteristic of the basal part of his so-called *Ammodiscus– "Lituotuba"* Assemblage Zone. No new forms were described from this interval, and this microfauna appears to be dominated by species referred under the Astrorhizidae (mostly hyperamminids) and Ammodiscidae. Sparse occurrences of saccamminids, i.e., *Thurammina echinata* Dunn, *T. papillata* Brady, lagenamminids, psammosphaerids, and webbinelloidids, were also reported. In general terms of composition, this microfauna closely resembles that reported from the Clarita (Fitzhugh Member) of southern Oklahoma, except that the Fitzhugh contains much greater numbers of foraminiferal specimens.

Residues prepared for this study, from the Wenlockian St. Clair Limestone, collected by Amsden in 1961 (Amsden 1968, p. 22) from Dongolo Hollow, Alexander County, Illinois, also carry a distinctive agglutinated foraminiferal microfauna that is very similar to that of the Clarita (Fitzhugh Member) of southern Oklahoma. St. Clair residues contain flood occurrences of *Ammodiscus exsertus* Cushman and *A. siliceus* (Terquem), abundant specimens of *Hyperammina harrisi,* and rather sparse occurrences of *Thurammina irregularis* Moreman, *Lagenammina sphaerica* Moreman, and *Webbinelloidea tholus* (Moreman), making up a microfauna carrying species identical to those described from the Fitzhugh Member. Residues were also examined from the St. Clair Limestone near Batesville, Independence County, Arkansas, and these, too, were found to carry an almost identical agglutinated foraminiferal assemblage, though not as abundant as that described from the Fitzhugh Member. Amsden (1968), in a study of large collections of articulate brachiopods from both the Fitzhugh and St. Clair intervals, showed that both faunas have a remarkable similarity of bachiopod species and are probably correlative units.

In a report on the Silurian-Devonian biostratigraphy in central Nevada, McClellan (1973) reported the sparse occurrence of Silurian (Wenlockian) agglutinated foraminifers from the Diana and Bastille Formations and from the lower parts of the Masket Shale and Roberts Mountains Formation. Graptolite and brachiopod studies had previously indicated a Wenlockian age for those units from which agglutinated foraminifers had been retrieved. The form *Psammosphaera cava* Moreman appears to be the only species reported in common from all localities. In addition, there are a few occurrences of agglutinated foraminifers we would regard as *Webbinelloidea tholus* (Moreman).

As seen from the above, the published record for Silurian (Wenlockian) agglutinated foraminiferal occurrences in North America is indeed sparse. Most occurrences are isolated and based upon only a few stratigraphically controlled collections, thus making it difficult to compare these microfaunas to those obtained from the ideally stratigraphically controlled collections reported herein from the Clarita Formation (Fitzhugh Member) of southern Oklahoma.

Conclusions

The study of 90 collections of agglutinated foraminifers obtained from 11 stratigraphically controlled outcrop localities of the

Silurian (Wenlockian) Clarita Formation (Fitzhugh Member) in southern Oklahoma has yielded the following results:

1. Examination of literally thousands of specimens derived from formic acid residues has allowed us to recognize a distinctive agglutinated foraminiferal assemblage. This foraminiferal assemblage comprises 11 species, of which one is regarded as new, divided under six genera and comprising three foraminiferal families (Astrorhizidae, Saccamminidae, and Ammodiscidae). Of these, the Ammodiscidae are the most abundant in terms of total number of specimens.

2. Examination of numerous thin sections from each locality has failed to yield any recognizable calcareous secreted foraminifers, and, in fact, even though thousands of agglutinated foraminifers are present in the residues, only a few agglutinated specimens of *Ammodiscus* were seen in thin section.

3. Foraminiferal "sports" occur in less than 1 percent of the population: only species of *Ammodiscus* are affected with teratological aberrations. The most common form of sport is one with multiple apertures.

4. Some residues contain "flood" abundance of agglutinated foraminifers. These "floods" are dominated by *Ammodiscus exsertus* Cushman and *A. siliceus* (Terquem), and more rarely *Hyperammina harrisi* Ireland, or combinations of all three species.

5. Agglutinated foraminifers range throughout the entire Fitzhugh Member and do not show an apparent biostratigraphic zonation. Instead, the overall foraminiferal distribution appears to be facies controlled rather than biostratigraphically controlled.

6. Agglutinated foraminifers are more abundant in the micritic and marly facies of the Fitzhugh intervals and are sparse or absent in the crinoidal sparites, particularly in the northeastern part of the outcrop belt.

7. Phosphatic brachiopods, especially the form *Artiotreta parva* Ireland, occur within the Fitzhugh residues. This species occurs in a prominent zone of abundance stratigraphically situated close to the base of the Fitzhugh and appears to be a good stratigraphic marker.

8. The published record of Silurian (Wenlockian) agglutinated foraminiferal occurrences in North America is sparse, thus making comparisons to the Fitzhugh of limited value.

CONODONTS
Introduction and Methods

The conodont fauna of the Fitzhugh Member of the Clarita Formation is unusually diverse and abundant in comparison with other known Wenlockian conodont faunas. This great abundance suggests that conodont animals formed an important part of the marine ecosystem in which the Fitzhugh was deposited. Analysis of the distribution and abundance of conodont elements with respect to the Fitzhugh facies yields some information on patterns of variation within a single major biofacies but does not permit the certain identification of the controlling ecologic factors.

The problems of bias owing to sampling errors, differential preservation, and sample preparation make individual collections of conodont elements only poor estimates of the true abundance of species in the original conodont biofacies. Still, these estimates constitute the only quantitative information available on the abundance and distribution of conodonts. It is not possible to determine the true number of individuals from collections of disjunct elements, for the number of elements per individual is not known for most species. It has been assumed here that the number of elements produced per individual of a species is constant. This view is held by many conodont workers, but Carls (1977) suggested that it may not be correct. For the purpose of estimating the relative abundance of species within samples, the assumption has been made that the number of elements per individual is the same for all species. Lacking the true ratios for any of the species, this appears to be the simplest procedure to follow.

The data used for this study, except for the number of elements of *Dapsilodus obliquicostatus* (Branson and Mehl) in some samples, were obtained by the identification of disjunct elements from formic acid–insoluble residues retained on a 125-micron sieve. The taxonomy employed is that of Barrick and Klapper (1976) and Barrick (1977). In the vast majority of samples, at least 1,000 elements were identified; the smallest number of elements identified from any sample was 200 (Ca2-7; table 3). The total number of elements of *D. obliquicostatus* was counted directly in only about one-half of the samples (see table 3). For the remaining samples, only the Sa element of

D. obliquicostatus was counted, and the number of M and SbSc elements present in the sample was calculated using the following formulae:

| Number of M elements: | $M = 4.93\,(Sa) + 3.5$ $(N = 147, r = 0.80)$ |
| Number of SbSc elements: | $SbSc = 12.3(Sa) + 23$ $(N = 149, r = 0.86)$ |

These equations were derived by the least-squares method of linear regression using data from the Clarita Formation and coeval portions of the St. Clair Limestone (Arkansas), Wayne Formation (Tennessee), and Bainbridge Formation (Missouri–Illinois). *N* is the number of pairs compared in the derivation; *r* is the product-moment coefficient.

As a consequence of the great dominance of elements of *Dapsilodus obliquicostatus* throughout the Fitzhugh Member, the relative abundance of each of the remaining species constitutes only a few percent or a fraction of a percent of the total fauna. Also, variations in the relative abundance of these species are affected more strongly by minor fluctuations in the abundance of *D. obliquicostatus* than by changes in their own absolute abundance. To better express the behavior of these less abundant species, the relative abundance of each in each sample has been calculated after the sum of elements of *D. obliquicostatus* was subtracted. Unless otherwise indicated, these are the values of relative abundance given for all species except *D. obliquicostatus*.

Two factors enter into the definition of diversity of faunal associations: the number of species present, and the evenness of the species-abundance distribution (Fager, 1972). An increase in either is considered to be an increase in diversity. Since there is little variation in the number of species in each sample, and the same species are usually present, fluctuation in diversity of the conodont fauna is best measured by the evenness of the species-abundance distribution. Because the number of individuals of conodont animals cannot be resolved, the separate elements assigned to each multielement species were treated as if they were individuals in the calculation of the index of evenness.

The measure of evenness employed here is the scaled standard deviation index, SD', whose mode of calculation and properties were reviewed by Fager (1972). The values of SD'

range linearly from 0.0, the most uneven distribution possible for a given number of species and individuals, to 1.0, the most even distribution possible for that number. Unlike many other measures of evenness, such as the Shannon–Weiner equitability index, the distribution of values around 0.5 is relatively uniform, making SD' intuitively more comparable to histograms that display the species-abundance distribution. The most abundant species in the most common species distributions, log-normal and exponential, affect the value of SD' most strongly.

Since the abundance of *Dapsilodus obliquicostatus* appears to affect the value of SD' most strongly, a second calculation of evenness was performed for each sample. This second value, SDO', characterizes the species-abundance distribution of the species after the sum of elements of *D. obliquicostatus* is subtracted from the total for each sample.

The distributions of values of relative abundance for each species and those of SD' and SDO' are strongly skewed for the Fitzhugh Member as a whole and for each of the facies subdivisions. For this reason the median is used as a measure of central tendency or the "average" in the following discussion.

Acknowledgments

Fitzhugh Conodont Fauna

The most striking feature of the conodont fauna of the Fitzhugh Member is the strong dominance of elements of a single simple-cone species, *Dapsilodus obliquicostatus* (Branson and Mehl). Elements of this species constitute an average of 79 percent of all elements recovered per sample. *D. obliquicostatus* fails to be the most abundant species in only six of the 67 samples used in this study. This high level of dominance is reflected in the low average

value of evenness of the species-abundance distribution, SD' = 0.24. The absolute abundance of conodont elements in the Fitzhugh Member is unusually large for Wenlockian microfaunas. The median abundance is 1,540 elements per kilogram of sample, with a maximum value of 9,500 elements per kilogram.

The evenness of the species-abundance distribution after *Dapsilodus obliquicostatus* is removed is considerably higher, SDO' = 0.55. This level of evenness is due to the relative abundance of four simple-cone species and the rarity of the remaining species. *Pseudooneotodus bicornis* Drygant is the most abundant of these, with a median of 23 percent. It is the most abundant species in only one sample of the Fitzhugh. Elements of *Panderodus unicostatus* (Branson and Mehl) and *Decoriconus fragilis* (Branson and Mehl) are almost as common, 21 and 20 percent, respectively. The latter is the most abundant species in four samples. *Walliserodus sancticlairi* Cooper is the fourth most common species; its elements average 10 percent of the fauna. *Ozarkodina excavata excavata* (Branson and Mehl) is the most abundant non-cone species, but its elements constitute only 2 percent of the fauna. Elements of all species of *Kockelella* combined and *Panderodus,* sp. nov., of Barrick (1977) each contribute 1 percent. *Dapsilodus sparsus* Barrick and *D. praecipuus* Barrick occur in slightly less than one-half of the samples from the Fitzhugh Member. The latter, though, is the dominant species in one sample (P1–17; table 3). The remaining species listed by Barrick and Klapper (1976) and Barrick (1977) as occurring in the Fitzhugh are found in only a few samples and in extremely small numbers.

The main objective of the study was to determine whether significant differences in the composition of conodont faunas exist among the facies described in this report. The 67 samples were separated into the following groups: arthropod micrite facies (AM)—21 samples (sections Ca2, J5, and Haragan Creek); interbedded arthropod micrite and crinoid sparite facies (SM)—23 samples (sections AQL, P1, and C1); crinoid sparite facies (CS)—nine samples (sections P1 and C1); ostracode silty marlstone facies (OS)—12 samples (sections Ca2, M2, and Haragan Creek); and the *Placotriplesia* beds (PL)—two samples (section P1). See table 3 for the samples included in each of these groups. The distributions of values of absolute abundance, even-

ness (SD' and SDO'), and relative abundance of the most common species are summarized in text-figure 21 for each facies.

Discussion of Conodont Distribution

One striking difference among the conodont faunas of the major facies is the nearly twofold increase in abundance of elements that corresponds with the transition from the arthropod micrite facies through the interbedded micrite and sparite facies into the crinoid sparite facies (text-fig. 21). The increase in abundance is not a result of unequal rates of sedimentation, for sections bearing the interbedded and sparite facies are somewhat thicker than the equivalent sections of arthropod micrite. Some of the difference in conodont abundance may be due to the concentration of elements under the slightly higher energy conditions that the sparite beds represent. No obvious sorting of elements by size or shape is apparent, however, and a real change in the abundance of conodont animals in the environment responsible for the sparite beds is believed to be the reason. The environments that produced the interbedded micrite and sparite facies and the crinoid sparite facies apparently were able to support a larger number of conodont animals than that of the arthropod micrite facies. This increase in abundance of conodont elements parallels an increase in the abundance of remains of suspension-feeding benthic macrofossils. It is possible that the environment of sparite-bearing sections was characterized by a more abundant suspended food supply which enabled a greater number of suspension-feeding(?) conodont animals to exist. Perhaps the cleaner and more turbulent water conditions represented by the sparite-bearing sections were more favorable for the maintenance of a larger conodont population.

The conodont fauna of the interbedded arthropod micrites and crinoid sparites is the most diverse of the major facies. The evenness of the species-abundance distribution of all species, SD', and after *Dapsilodus obliquicostatus* is removed, SDO', are the highest of all the major facies (text-fig. 21). Although no species attains its greatest relative abundance in this facies, most approach their maximum absolute abundance for any facies. In comparison with the other Fitzhugh facies, the

prevailing environmental conditions apparently did not restrict the abundance of any of these species strongly in favor of another.

The conodont fauna of the crinoid sparite facies, which directly overlies the interbedded micrites and sparites, has the least even of species-abundance distributions. The major difference in fauna composition from the underlying beds is the rarity of elements of *Decoriconus fragilis* in the crinoid sparite facies (text-fig. 21). *Panderodus unicostatus*, *Pseudooneotodus bicornis*, and *Walliserodus sancticlairi* show a slight increase in relative abundance. *Dapsilodus obliquicostatus* is more abundant as well, but the increase is greater than that which can be accounted for just by the rarity of *Decoriconus fragilis*. The absolute abundance of elements of all species except *D. fragilis* is slightly greater than in the interbedded micrite and sparite facies. Since there is no good evidence that elements of *D. fragilis* were selectively winnowed out of the sparite facies, the change in abundance must represent a true scarcity of individuals of this species during the deposition of the sparite. However, the specific environmental conditions that restricted its distribution are not apparent.

Like the crinoid sparite facies, the evenness of the species-abundance distributions of the arthropod micrite facies is relatively low compared with that of the interbedded micrites and sparites. In this case the low level of evenness is due to the low relative abundance of two species, *Panderodus unicostatus* and *Walliserodus sancticlairi* (text-fig. 21). Elements of *Dapsilodus obliquicostatus* and *Pseudooneotodus bicornis* show a corresponding increase in relative abundance. An important aspect of the conodont microfauna of this facies is that nearly all species have their lowest absolute abundance here. Only the relatively uncommon *Dapsilodus sparsus* has a slight increase in both relative and absolute abundance. As noted before, the environment of the arthropod micrite facies did not support a large number of conodont animals compared to the sparite-bearing sections. *P. unicostatus* and *W. sancticlairi* were apparently the species least able to survive in this ecologically more restricted environment.

The changes in conodont fauna in the transition from the arthropod micrite facies into the overlying ostracode silty marlstone facies are more difficult to interpret. *Pseudo-*

oneotodus bicornis and *Panderodus unicostatus* underwent dramatic reciprocal changes in abundance within the marlstone facies. *Pseudooneotodus bicornis* is more common near the base of the marlstone interval, about 30 percent, but starting at a level within the *Kockelella stauros* Zone, its abundance drops to less than 5 percent. *Panderodus unicostatus* constitutes less than 10 percent of the microfauna in the lower interval and increases to nearly 50 percent in the upper beds of this facies. It is difficult to ascertain if these changes were in response to the influx of the fine-grained terrigenous clastics that characterize the facies or were due to some other factor.

The absence of elements of *Walliserodus* in the marlstone may be due to clastic influx, for elements of this genus occur in coeval carbonates in Tennessee and Missouri that lack large quantities of terrigenous clastics (Barrick, 1978). The appearance of *Belodella silurica* in the marlstone is in part a coincidence of stratigraphic range. This species appears within the *Kockelella amsdeni* Zone in Tennessee and Missouri without a corresponding change in lithofacies. Even in the Fitzhugh, the appearance of *B. silurica* only roughly approximates the increase in clastic influx (table 3). The environment of the marlstone, though, surely did favor a moderate abundance of this species, an average of 7 percent. Among the remaining species, only *Ozarkodina excavata excavata* shows a significant increase in abundance compared with the arthropod micrite facies (text-fig. 21). This increase is probably ecologically controlled, but it is not possible to be certain. Assuming no significant change in rates of sedimentation, the slight increase in absolute abundance of elements from the arthropod micrites suggests that there was no significant change in the carrying capacity of the marlstone facies for conodont animals.

The extremely low abundance of *Dapsilodus obliquicostatus* and of conodonts in general in the *Placotriplesia* beds is atypical for the Fitzhugh (text-fig. 21). Otherwise, only the greater abundance of *Decoriconus fragilis* and absence of *Walliserodus sancticlairi* set these beds apart from the major facies. The reason for these changes is not evident but may be related to the factors that produced the unusual megafaunal association of this unit.

A few major variations in the abundance

of *Dapsilodus obliquicostatus* appear to be largely independent of the Fitzhugh facies. In sections of both the arthropod micrite facies (Haragan Creek, Ca2, and J5) and the interbedded micrites and sparites (AQL), elements of *D. obliquicostatus* constitute less than half of the fauna in a short interval near the top of the *Kockelella ranuliformis* Zone (table 3). This is the level at which *Decoriconus fragilis* becomes more abundant in all sections of these facies. A second level of sharply decreased abundance occurs within the upper

TABLE 3.—SUMMARY DATA OF CONODONT ABUNDANCE AND DIVERSITY, BY SAMPLE, OF FITZHUGH MEMBER

Sample	C/kg	S	SD'	DO%	SDO'	PU%	PS%	WS%	DF%	OX%	K%	DS%	DP%	BS%	PSP%	OT%	F
J5-12	1130	12	0.43	57*	0.55	44	9	24	5	4	5	5	t	0	2	2	AM
J5-13	1470	10	0.25	77*	0.60	24	12	13	40	7	1	t	2	0	1	0	AM
J5-14	1390	8	0.20	82*	0.53	17	50	14	17	t	0	0	2	0	t	0	AM
J5-15	640	8	0.35	68*	0.48	7	50	6	32	2	2	0	0	0	1	0	AM
J5-16	150	8	0.54	32*	0.58	31	9	t	54	1	0	0	3	0	1	0	AM
J5-17	1120	10	0.41	61*	0.57	36	23	3	29	2	5	0	1	0	1	t	AM
Ca2-1	2220	9	0.14	87	0.65	20	34	14	23	6	3	0	t	0	1	0	AM
Ca2-2	1870	9	0.13	84*	0.73	18	29	14	15	16	3	4	0	0	1	0	AM
Ca2-3	920	5	0.09	92*	0.12	8	88	0	2	0	0	0	0	0	1	0	AM
Ca2-4	920	8	0.26	76*	0.39	8	62	t	25	0	2	3	0	0	t	0	AM
Ca2-5	670	8	0.19	82*	0.22	3	80	0	3	5	2	t	0	0	0	8	AM
Ca2-6	640	9	0.17	84*	0.49	5	45	2	33	1	0	11	0	0	0	1	AM
Ca2-7	100	5	0.68	20	0.59	9	45	0	40	0	0	7	0	0	0	0	AM
Ca2-8	720	9	0.18	83*	0.54	10	25	1	46	4	1	11	0	0	1	0	AM
Ca2-9	2570	11	0.09	92*	0.72	24	18	6	20	10	13	7	1	0	0	1	AM
Ca2-10	6000	10	0.36	64*	0.40	2	43	t	t	1	t	3	49	0	1	0	AM
Ca2-11	770	7	0.08	93*	0.28	5	71	0	0	16	6	3	1	0	0	0	OS
Ca2-12	1610	9	0.29	74*	0.56	4	43	0	25	21	2	0	0	4	0	2	OS
Ca2-13	1820	10	0.27	74*	0.38	1	8	0	13	65	4	0	0	6	t	3	OS
Ca2-14	3200	9	0.06	94*	0.48	53	2	0	23	9	4	0	0	7	1	t	OS
Ca2-15	600	9	0.23	78*	0.41	62	2	0	3	9	11	0	0	7	6	t	OS
HC-1	2320	11	0.17	84	0.61	30	24	18	23	2	1	0	0	0	1	1	AM
HC-2	3370	7	0.07	94	0.50	5	53	2	20	0	t	19	0	0	0	0	AM
HC-2B	1500	8	0.07	94	0.21	3	75	1	13	0	1	4	1	0	0	0	AM
HC-3	760	10	0.45	20	0.45	8	8	4	71	2	t	5	0	0	t	0	AM
HC-5	4470	10	0.13	88	0.41	50	3	40	t	1	3	2	0	0	1	0	AM
HC-7	1760	9	0.47	44	0.31	7	17	1	1	t	0	2	71	0	t	0	OS
HC-7A	1450	10	0.11	89	0.45	20	52	9	1	t	0	2	4	0	0	11	OS
HC-9	1200	10	0.24	77	0.64	8	10	0	26	35	2	0	0	14	1	4	OS
HC-10	1090	10	0.33	69	0.57	20	18	0	43	10	1	0	0	7	t	1	OS
M2-4	2360	10	0.09	91*	0.51	6	9	0	48	9	2	0	0	26	t	t	OS
M2-2	1500	9	0.33	68*	0.36	66	1	0	10	3	1	0	0	16	2	1	OS
M2-1	720	11	0.17	84*	0.64	34	1	0	8	10	15	0	0	23	4	5	OS
P1-1	1670	11	0.26	73	0.57	40	5	28	12	9	2	0	4	0	1	t	SM
P1-3	750	8	0.12	89	0.76	22	23	16	17	17	3	0	0	0	1	0	SM
P1-5	1540	8	0.17	84	0.44	17	36	34	9	0	2	2	0	0	1	0	SM
P1-7	3220	8	0.20	82	0.61	26	11	24	37	0	1	1	0	0	1	0	SM
P1-9	1140	9	0.21	81*	0.44	27	12	1	55	2	3	0	t	0	t	0	SM
P1-11	4990	10	0.19	83	0.51	46	7	11	30	4	t	1	0	0	t	0	SM
P1-14	2530	9	0.17	85	0.46	52	7	31	6	2	t	1	0	0	2	0	CS
P1-15	1960	10	0.19	82	0.50	50	12	23	8	3	1	t	1	0	3	0	CS
P1-17	440	8	0.43	1	0.43	11	15	10	3	t	0	0	60	0	t	0	CS
P1-19	1030	8	0.17	85	0.51	32	45	19	1	2	t	0	0	0	1	0	CS
P1-21	410	8	0.07	93	0.46	53	2	18	3	2	3	0	20	0	0	0	CS
P1-23	2510	8	0.07	94	0.59	39	25	24	1	4	0	0	5	0	1	0	CS
P1-25	2240	12	0.10	93	0.41	18	52	19	2	1	t	1	2	0	t	6	CS
P1-27	280	9	0.61	30	0.52	24	30	0	42	2	1	0	0	1	t	t	PL
P1-28	520	9	0.59	21	0.50	26	27	0	44	1	1	0	0	t	t	t	PL

part of the *K. amsdeni* Zone in the ostracode silty marlstone at Haragan Creek and the crinoid sparite at section P1 (table 3). In this case the decrease in *D. obliquicostatus* corresponds to a level of unusually high abundance for a closely related species, *D. praecipuus.*

Even at this level in the arthropod micrite facies, the acme in abundance of *D. praecipuus* occurs, but *D. obliquicostatus* shows only a moderate decrease in relative abundance. These variations in the abundance of *D. obliquicostatus* may reflect interspecific compe-

TABLE 3.—*Continued*

Sample	C/kg	S	SD'	DO%	SDO'	PU%	PS%	WS%	DF%	OX%	K%	DS%	DP%	BS%	PSP%	OT%	F
AQL-21	2500	13	0.33	68	0.60	28	10	29	22	4	2	1	t	0	2	1	SM
AQL-22	3310	8	0.27	76	0.66	26	19	23	28	2	t	0	0	0	1	0	SM
AQL-23	2160	9	0.31	71	0.62	21	35	10	27	6	1	t	t	0	1	0	SM
AQL-24	1970	7	0.20	83	0.64	35	22	29	11	0	1	0	0	0	2	0	SM
AQL-25	2060	8	0.40	62	0.53	21	49	17	12	0	t	0	1	0	t	0	SM
AQL-27	1030	7	0.27	75	0.53	13	52	18	15	0	1	0	0	0	1	0	SM
AQL-28	1300	8	0.28	74	0.46	12	55	24	8	0	t	0	1	0	t	0	SM
AQL-28A	640	7	0.62	34	0.37	15	39	6	38	0	0	0	t	0	2	0	SM
AQL-29	1140	6	0.44	60	0.39	11	22	t	66	0	0	0	1	0	t	0	SM
AQL-30	2040	9	0.35	67	0.56	23	11	11	46	5	0	3	t	0	1	0	SM
AQL-31	1960	10	0.22	79	0.61	37	6	24	16	13	t	4	t	0	2	0	SM
C1-2	7280	8	0.18	84	0.64	21	25	16	34	3	t	0	0	0	t	0	SM
C1-11	2150	9	0.34	68	0.57	11	26	16	45	t	t	t	0	0	t	0	SM
C1-13	3140	10	0.24	77	0.60	21	31	16	29	t	t	2	1	0	1	0	SM
C1-5	3470	9	0.31	71	0.55	40	15	6	34	4	t	1	0	0	1	0	SM
C1-14	3080	10	0.34	84*	0.59	39	10	15	27	4	t	0	t	0	4	t	SM
C1-18	9500	9	0.19	83	0.63	24	19	14	35	1	0	3	1	0	2	0	SM
C1-19	5070	10	0.24	77	0.45	28	52	12	2	3	t	1	t	0	t	0	CS
C1-20	4790	10	0.17	84	0.39	29	59	5	3	t	t	t	1	0	1	1	CS

C/kg - conodont elements per kilogram of sample.

S - number of species.

SD' - evenness of species-abundance distribution of all species (see text).

DO% - relative abundance of *Dapsilodus obliquicostatus* (asterisk * indicates samples for which the abundance of elements was calculated as described in text).

SDO' - evenness of species-abundance distribution without *D. obliquicostatus*.

Relative abundance of following species was calculated after the sum of elements of *D. obliquicostatus* was subtracted from total (t - less than 1 percent):

PU - *Panderodus unicostatus.*

PS - *Pseudooneotodus bicornis.*

WS - *Walliserodus sancticlairi.*

DF - *Decoriconus fragilis.*

OX - *Ozarkodina excavata excavata.*

K - species of *Kockelella.*

DS - *Dapsilodus sparsus.*

DP - *D. praecipuus.*

BS - *Belodella silurica.*

PSP - *Panderodus* sp. nov.

OT - all other species combined.

F - Fitzhugh facies to which the sample belongs. (Abbreviations as in fig. 21.)

Samples are listed in ascending stratigraphic order for each section.

Sampling intervals for all sections but P1 have been published in Barrick and Klapper (1976) or Barrick (1977).

Section P1: (datum is base of Fitzhugh Member):

1: (*Kockelella ranuliformis* Zone) 0.0-0.3 m.   3: 0.9-1.0 m.   5: 1.7-1.9 m.   7: 2.8-2.9 m.
9: (base of *Kockelella amsdeni* Zone) 3.5-3.7 m.   11: 4.5-4.6 m.   14: 5.4-5.5 m.
15: 5.8-5.9 m.   17: 6.8-7.0 m.   19: 7.3-7.5 m.   21: 8.2-8.4 m.   23: 11.0-11.1 m.
25: 11.4-11.6 m.   27: 11.7-11.9 m.   28: 12.0-12.2 m.
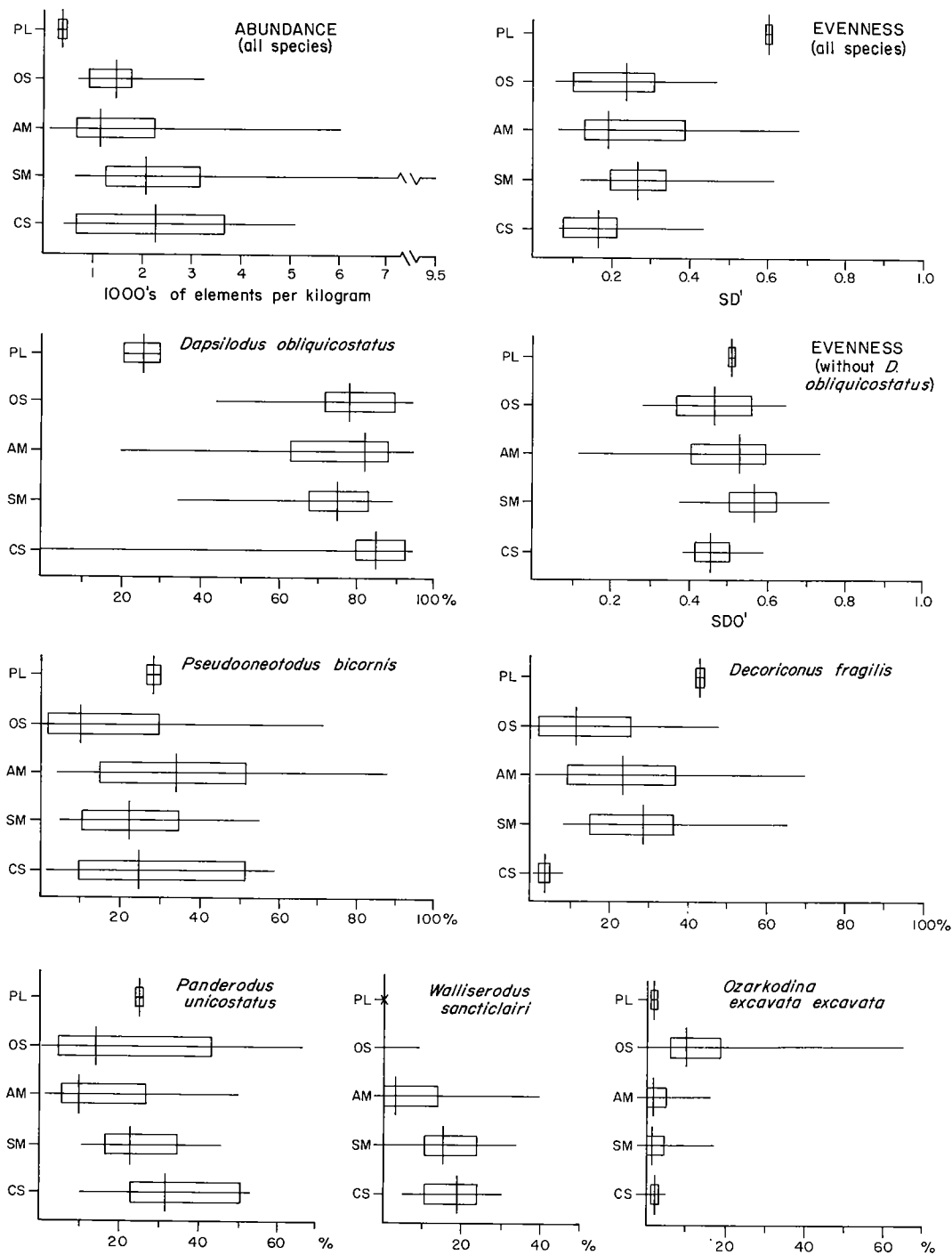
Text-figure 21. Distribution of values of total abundance, evenness of species-abundance distributions, and relative abundance of common conodont species for Fitzhugh facies. Horizontal line indicates range of values, boundaries of rectangle are first and third quartiles, and vertical line is median. Number of samples from each facies as follows: *PL* (*Placotriplesia* Beds), two; *OS* (ostracode silty marlstones), 12; *AM* (arthropod micrites), 21; *SM* (interbedded mic- rites and sparites), 23; *CS* (crinoid sparites), nine. See text for method of calculation of values. Data from which figure was prepared given in table 3.

tition and perhaps the occurrence of geographically widespread variations in some ecologic factor that is otherwise unrecorded in the strata.

Conclusions

Considering the variations in species composition and abundance discussed here, the Fitzhugh conodont microfauna is remarkably uniform over the observed facies spectrum (text-fig. 19). Major changes in lithofacies and benthic macrofossil associations are accompanied by only minor alterations of species composition. Only the relative abundance of species fluctuates to any extent, and then only a few species appear to be significantly affected. Apparently, only one major conodont biofacies occurs within the Fitzhugh, with the possible exception of the *Placotriplesia* beds.

The major ecologic factors that controlled conodont distribution must have been relatively uniform over the area of deposition of the Fitzhugh Member to account for the uniformity of the conodont faunas. The identity of these factors remains uncertain. This is not surprising, for many of the hydrographic features that most strongly affect the distribution of marine organisms, such as temperature, salinity, and even the distribution of food resources, are those that rarely leave any record in the strata, independent of their effects on the organisms whose remains are preserved.

The distribution of species of conodonts in the Fitzhugh Member contributes little to the understanding of their mode of life. Unlike the benthic megafauna, the species apparently exhibited no clear dependence on substrate. The distribution of agglutinated foraminifers, inarticulate brachiopods, and thin-shelled ostracodes was also relatively independent of the megafaunal associations and substrate. The first two groups were dominantly benthic organisms, the latter probably free-swimming. Consequently, the conodont species found in the Fitzhugh may have had either of these modes of life.

SUMMARY

The Fitzhugh Member of the Clarita Formation in the Arbuckle Mountains–Criner Hills region of Oklahoma has been studied with the goal of presenting an integrated lithofacies–biofacies model of the paleoenvironment. Lithostratigraphic, petrologic, and chemical data allow the recognition of three major lithofacies that appear to be closely related to the abundance of different groups of benthic megafauna as determined by counts of skeletal grains in thin sections. In their typical development, each of these facies is reasonably distinct, but they merge vertically and laterally and should be regarded as a continuously intergrading series. The crinoid sparites largely comprise grain-supported pelmatozoan detritus cemented by spar. Some micrite may be associated with the spar, and the insoluble detritus is everywhere low, averaging less than 1 percent. In the intergradational arthropod micrites, the spar matrix is largely eliminated, and the quantity of terrigenous insoluble detritus increases to an average of about 6 percent. The proportion of pelmatozoan plates is reduced, trilobites and ostracodes increase, and the brachiopods are largely replaced by gastropods and cephalopods. A mud-supported fabric bearing scattered fossils characterizes the ostracode silty marlstones, which are intergradational with the arthropod micrites. From the latter facies, the quantity of insoluble detritus has increased sharply to an average of about 18 percent. The sessile and vagrant benthos is largely eliminated, and thin-shelled ostracodes dominate the calcareous shelly fauna.

A clear geographic and stratigraphic pattern in the distribution of the Fitzhugh facies exists within the Arbuckle Mountains–Criner Hills area. The arthropod micrite facies makes up most of the Fitzhugh in the central and southeastern Arbuckle Mountains and in the Criner Hills, while the sparites are confined to the northeastern Arbuckle Mountains. The greatest concentration of terrigenous detritus is in the central and southeastern parts of the Arbuckle Mountains and in the Criner Hills, undoubtedly reflecting proximity to the Ouachita clastic province. The ostracode silty marlstones are best developed in the upper part of the Fitzhugh Member in the central part of the Arbuckle Mountains, where they foreshadow the widespread marlstones of the overlying Henryhouse Formation.

The dramatic variation in the distribution of the megafaunal sessile and vagrant benthos with respect to the change from spar to micrite to marlstone suggests that bottom conditions were a major controlling factor. Whereas the clear water and moderately tur-

bulent conditions responsible for the sparites created firm, clean-washed skeletal sands suitable for an abundant benthos, the increased siltation and bottom turbidity of the micrite environment adversely affected the sessile filter feeders, and, in the increasingly severe conditions represented by the marlstone environment, the benthic megafauna was virtually eliminated.

The bottom-dwelling agglutinated foraminifers and inarticulate brachiopods are an exception to this distribution pattern. The latter are common in all facies, including the silty marlstones. Their presence in the marlstones is not unusual, since inarticulate brachiopods are present in many fine-grained clastics with little or no benthic fauna, indicating that this group of brachiopods has considerable tolerance for a wide range of ecologic conditions. Foraminifers are also present in all facies, reaching their climax in the silty marlstones. This relationship would seem to be reasonably related to the abundance of fine quartz detritus for use in construction of their tests. Perhaps the most surprising element in this biofacies pattern is their relatively strong representation in the sparites, a lithofacies in which terrigenous detritus is at a minimum.

As a group, ostracodes occupied all Fitzhugh depositional environments, although morphologic changes are associated with changes in facies. Thick-shelled types are common in sparites, decrease in number in the micrites, and are rare in the marlstones. In contrast, small, thin-shelled types are present in the sparites, increase in abundance in the micrites, and completely dominate the marlstones. Present-day ostracodes occupy a wide range of habitats, including freeswimming as well as bottom-dwelling forms, and it would seem reasonable to interpret the thick-shelled forms as representatives of the vagrant benthos, and the thin-shelled types as free-swimming.

Conodont elements (largely simple-cone species) are abundant in all environments represented in the Fitzhugh Member and constitute a single major biofacies that is characterized by the strong dominance of the simple-cone species *Dapsilodus obliquicostatus*. Minor fluctuations in the relative abundance of certain species occur in each environment, but the specific ecologic factors responsible cannot be identified. The pattern of distribution of conodonts in the Fitzhugh

does not resolve the uncertainty surrounding the mode of life of conodont animals.

REFERENCES CITED

Amsden, T. W., 1960, Hunton stratigraphy, *pt. 6 of* Stratigraphy and paleontology of the Hunton Group in the Arbuckle Mountain region: Oklahoma Geological Survey Bulletin 84, 311 p., 17 pls.

_____ 1967, Chimneyhill limestone sequence (Silurian), Hunton Group, Oklahoma, revised: American Association of Petroleum Geologists Bulletin, v. 51, p. 942–945.

_____ 1968, Articulate brachiopods of the St. Clair Limestone (Silurian), Arkansas, and the Clarita Formation (Silurian), Oklahoma: Journal of Paleontology Memoir 1 (Journal of Paleontology, v. 42, no. 3, supp.), 117 p., 20 pls.

_____ 1975, Early Late Silurian biofacies in south-central Oklahoma as determined by point counting [abstract]: Geological Society of America Abstracts with Programs, v. 7, p. 974–975.

_____ 1976, Hunton Group (Late Ordovician, Silurian, and Early Devonian) in the Anadarko basin of Oklahoma: Oklahoma Geological Survey Bulletin 121, 214 p., 15 pls., 11 panels.

_____ 1978, Articulate brachiopods of the Quarry Mountain Formation (Silurian), eastern Oklahoma: Oklahoma Geological Survey Bulletin 125, 75 p., 13 pls.

_____ 1980, Hunton Group (Late Ordovician, Silurian, and Early Devonian) in the Arkoma Basin of Oklahoma: Oklahoma Geological Survey Bulletin 129, 136 p., 12 pls., 4 panels.

Amsden, T. W., and Rowland, T. L., 1965, Silurian stratigraphy of northeastern Oklahoma: Oklahoma Geological Survey Bulletin 105, 174 p., 18 pls.

Barrick, J. E., 1977, Multielement simple-cone conodonts from the Clarita Formation (Silurian), Arbuckle Mountains, Oklahoma: Geologica et Palaeontologica, v. 11, p. 47–61, 3 pls.

_____ 1978, Wenlockian (Silurian) depositional environments and conodont biofacies, south-central United States: University of Iowa, unpublished Ph.D. dissertation, 273 p.

Barrick, J. E., and Klapper, Gilbert, 1976, Multielement Silurian (Late Llandoverian–Wenlockian) conodonts of the Clarita Formation, Arbuckle Mountains, Oklahoma, and phylogeny of *Kockelella:* Geologica et Palaeontologica, v. 10, p. 59–100, 4 pls.

Berry, W. B. N., and Boucot, A. J., 1970, Correlation of North American Silurian rocks: Geological Society of America Special Paper 102, 289 p., 2 pls.

Briggs, Garrett, 1974, Carboniferous depositional environments in the Ouachita Mountains–Arkoma basin area of southeastern Oklahoma: Geological Society of America Special Paper 148, p. 225–279.

Briggs, Garrett, and Cline, L. M., 1967, Paleocurrents and source areas of late Paleozoic sediments of the Ouachita Mountains, southeastern Oklahoma: Journal of Sedimentary Petrology, v. 37, p. 985–1000.

Carls, P., 1977, Could conodonts be lost and replaced? Neues Jahrbuch für Geologie und Paläontologie Abhandlungen, v. 155, p. 18–64.

Conkin, J. E., and Conkin, B. M., 1964, Pre-Pennsylvanian arenaceous Foraminifera of North America: 22d International Geological Congress, India, pt. 8, sec. 8, p. 319–335.

———— 1977, Paleozoic smaller Foraminifera of the North American Borderlands, *in* Swain, F. M., editor, Stratigraphic micropaleontology of Atlantic Basin and borderlands: Elsevier, Amsterdam, p. 49–59.

Dunn, P. H., 1942, Silurian Foraminifera of the Mississippi Basin: Journal of Paleontology, v. 16, p. 317–342, 3 pls.

Fager, E. W., 1972, Diversity: a sampling study: American Naturalist, v. 100, p. 293–310.

Flawn, P. T., Goldstein, August, King, P. B., and Weaver, C. E., 1961, The Ouachita system: University of Texas Publication 6120, 401 p.

Ireland, H. A., 1939, Devonian and Silurian Foraminifera from Oklahoma: Journal of Paleontology, v. 13, p. 190–202.

———— 1961, New phosphatic brachiopods from the Silurian of Oklahoma: Journal of Paleontology, v. 35, p. 1137–1142, pl. 137.

———— 1966, Silurian arenaceous Foraminifera from subsurface strata of northeastern Kansas: Micropaleontology, v. 12, p. 215–234, 1 pl.

———— 1967, Zonation and correlation of the subsurface Hunton Group (Silurian–Devonian) in Kansas by Foraminifera and acid-residues, *in* Essays in paleontology and stratigraphy: University of Kansas Special Publication 2, R. C. Moore Commemorative Volume, p. 479–502.

McClellan, W. A., 1966, Arenaceous Foraminifera from the Waldron Shale (Niagaran) of southeast Indiana: Bulletins of American Paleontology, v. 50, no. 230, p. 447–518, pls. 36–42.

———— 1973, Siluro–Devonian microfaunal biostratigraphy in Nevada: Bulletins of American Paleontology, v. 62, no. 274, p. 235–375, pls. 33–44.

Marszalek, D. S., Wright, R. C., and Hay, W. W., 1969, Function of the test in Foraminifera: Gulf Coast Association of Geological Societies Transactions, v. 19, p. 341–352.

Moreman, W. L., 1930, Arenaceous Foraminifera from Ordovician and Silurian limestones of Oklahoma: Journal of Paleontology, v. 4, p. 42–59, pls. 5–7.

Mound, M. C., 1968, Arenaceous Foraminifera and zonation of the Silurian rocks of northern Indiana: Indiana Geological Survey Bulletin 38, 126 p., 7 pls.

Noland, A. V., 1969, Revisions of selected Silurian arenaceous Foraminifera from north-central Kentucky and southeastern Indiana: University of Louisville unpublished Ph.D. dissertation, Department of Biology, 162 p.

PLATES

Plate 1

Figure 1.—Outcrop of Fitzhugh Member, Clarita Formation; crinoid sparite facies. Lawrence Uplift near north end of Arbuckle Mountains. Arrow points to geologic pick. NW¼ sec. 9, T. 2 N., R. 6 E., Pontotoc County, Oklahoma (stratigraphic section P3-C, Amsden, 1960, p. 275).

Figure 2.—Outcrop of Fitzhugh Member, Clarita Formation; arthropod micrite facies with some beds of ostracode silty marlstone. Near White Mound in central part of Arbuckle Mountains. Arrow points to geologic hammer. NW¼ sec. 17, T. 2 S., R. 3 E., Murray County, Oklahoma (stratigraphic section M3, Amsden, 1960, p. 235, 237).

Plate 1   39

Plate 2

Figure 1.—Outcrop of upper Cochrane and lower Clarita Formations; Lawrence Uplift, near north end of Arbuckle Mountains. Arrow points to geologic pick whose head rests on basal bed of Fitzhugh Member, here comprising interbedded crinoid sparites and arthropod micrites; this member is underlain by Prices Falls Member, consisting of a few inches of argillaceous marlstone resting on glauconitic and cherty limestones of Cochrane Formation. NE¼SE¼ sec. 30, T. 3 N., R. 6 E., Pontotoc County, Oklahoma (stratigraphic section AQL, Barrick and Klapper, 1976, p. 84).

Figure 2.—Fitzhugh Member, Clarita Formation; bedding surface, showing effects of burrowing organisms. Near White Mound, central Arbuckle Mountains; SE¼NE¼ sec. 20, T. 2 S., R. 3 E., Murray County, Oklahoma (stratigraphic section M3, Amsden, 1960, p. 235).

Plate 2   41
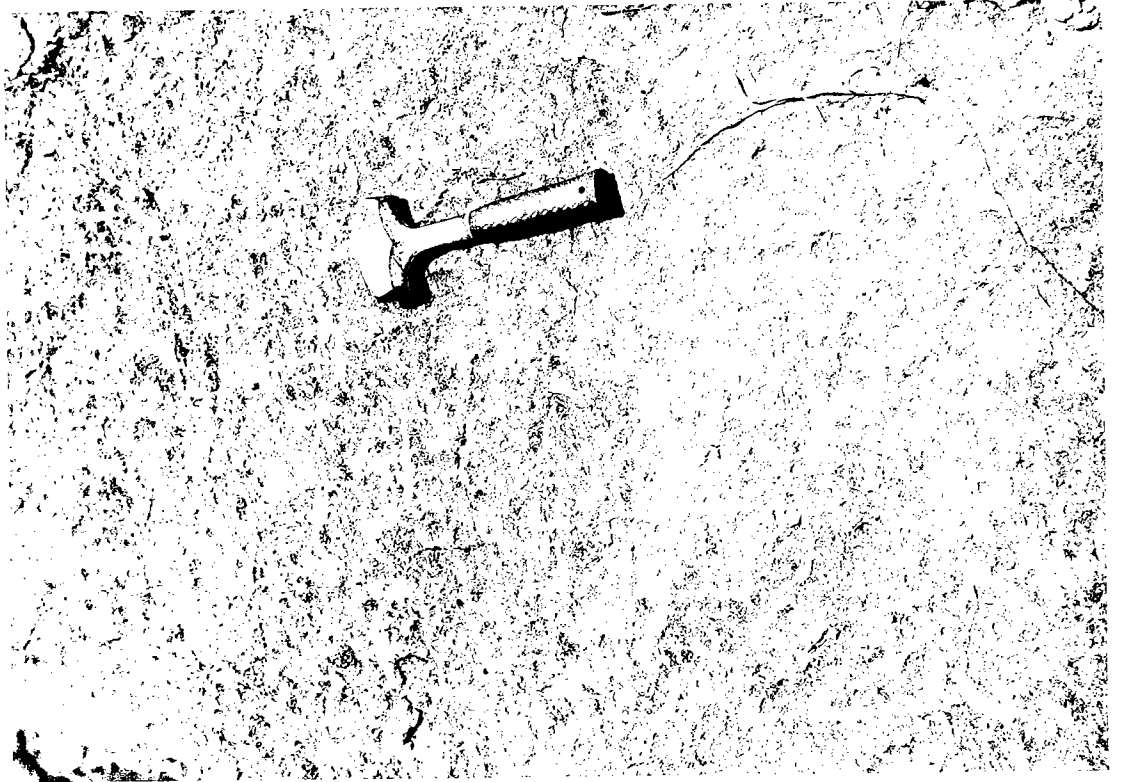
Plate 3

Figure 1.—Bedding plane with three specimens of brachiopod *Eospirifer (Acutilineolus) pentagonus* Amsden (×1); crinoid sparite facies, Fitzhugh Member, Clarita Formation. Following point count of thin section cut from this specimen indicates that concentration of brachiopods is largely confined to this bedding plane (as percentages of total rock volume): micrite, 2.9 percent; spar, 23.5 percent; pelmatozoan plates, 23.5 percent; ostracodes, 5.3 percent; trilobites, 0.6 percent; bryozoans, 5.3 percent; brachiopods 7.6 percent; cephalopods, 1.2 percent; unidentified fossils, 30.1 percent. NW¼ sec 9, T. 2 N., R. 6 E., Pontotoc County, Oklahoma (stratigraphic section P3-C, Amsden, 1960, p. 275; this specimen is from upper part of outcrop shown on pl. 1, fig. 1).

Figures 2, 3.—Two views of bedding plane with cephalopods, and trilobites and cephalopods (×1); arthropod micrite facies, Fitzhugh Member, Clarita Formation. Photomicrograph of thin section cut from this bed illustrated on pl. 6, fig. 1; point count from this thin section (given on plate explanation, pl. 6, fig. 1) shows concentration of shells largely confined to this bedding plane. NW¼NW¼ sec. 22, T. 1 N., R. 7 E., Pontotoc County, Oklahoma (stratigraphic section P9-D, Amsden, 1960, p. 281).

Figure 4.—Bedding plane with trilobites (×2); crinoid sparite facies, Fitzhugh Member, Clarita Formation. SE¼ sec. 5, T. 2 N., R. 6 E., Pontotoc County, Oklahoma (stratigraphic section P1-E, Amsden, 1960, p. 262).

Plate 3

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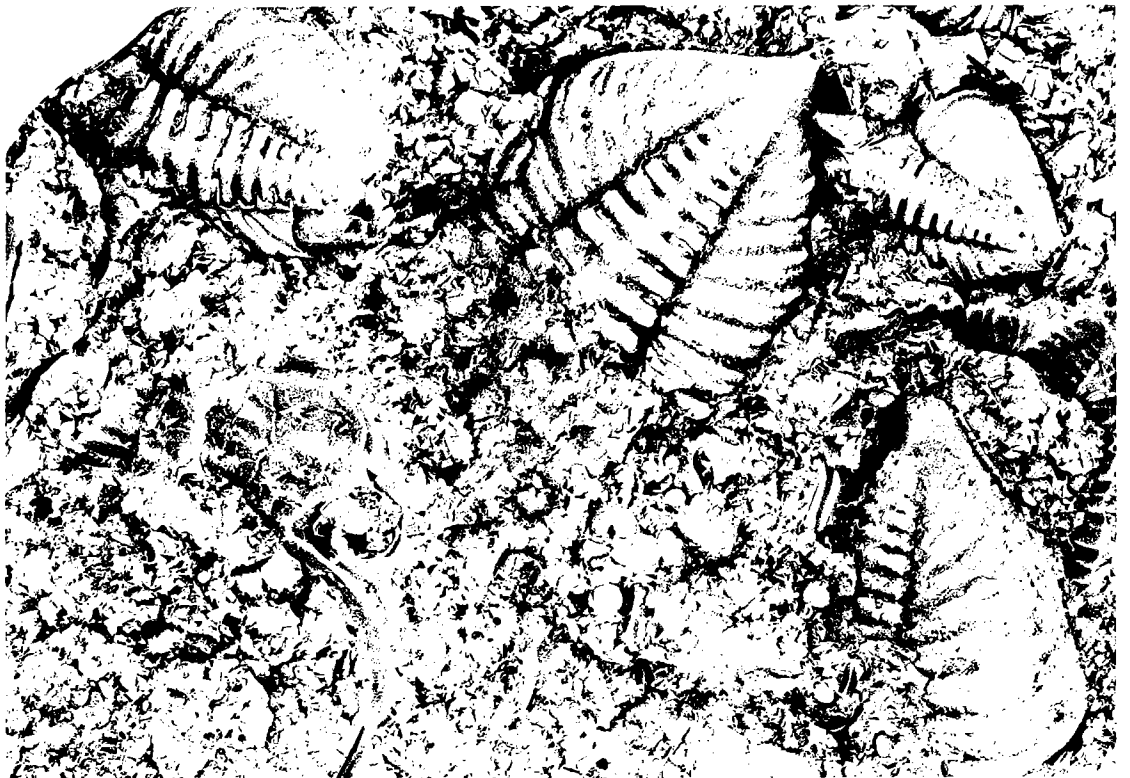
Plate 4

Crinoid Sparite Facies

Figure 1.—Crinoid sparite facies; thin-section photomicrograph. Note microtexture of brachiopod shell in center, also shell thickness and microtexture of ostracodes (cf. to ostracode shell thickness in the arthropod micrite facies shown on pl. 2, fig. 1; pl. 3, figs. 1–4). Fitzhugh Member of Clarita Formation, 2.5 m below top. Chimneyhill Creek, SE¼ sec. 5, T. 2 N., R. 6 E., Pontotoc County, Oklahoma (stratigraphic section P1, Amsden, 1960, p. 268). This shows part of area point counted (as percentages of total rock volume): sparite, 26.2 percent; pelmatozoan plates, 25.7 percent; ostracodes, 20.4 percent; trilobites, 11.1 percent; bryozoans, 2.9 percent; brachiopods, 2.7 percent; unidentified fossils, 11.0 percent. HCl-acid-insoluble analysis not available.

Figure 2.—Crinoid sparite facies; thin-section photomicrograph, Fitzhugh Member, Clarita Formation, upper 6 m, old Hunton townsite, NW¼ sec. 8, T. 1 S., R. 8 E., Coal County, Oklahoma (stratigraphic section C1-F, Amsden, 1960, p. 182). This shows part of area point counted (as percentages of total rock volume): spar 21.5 percent; micrite, 4.9 percent; pelmatozoan plates, 29.3 percent; ostracodes, 12.2 percent; trilobites 7.7 percent; bryozoans, 4.5 percent; brachiopods, 1.6 percent; agglutinated foraminifers, 0.4 percent; unidentified fossils, 17.9 percent; acid insoluble residues, 0.71 percent (weight).

Mixed Sparite-Micrite Facies

Figure 3.—Mixed sparite-micrite facies; thin-section photomicrograph. Note microtexture of articulated brachiopod shell in upper left quadrant. Fitzhugh Member of Clarita Formation, Coal Creek, NW¼NW¼ sec. 22, T. 1 N., R. 7 E., Pontotoc County, Oklahoma (stratigraphic section P9-D, Amsden, 1960, p. 281). This shows part of area point counted (as percentages of total rock volume): micrite, 23.1 percent; spar, 22.0 percent; pelmatozoan plates, 13.9 percent; ostracodes, 8.3 percent; trilobites, 7.3 percent; bryozoans, 2.2 percent; brachiopods, 4.8 percent; unidentified fossils, 18.3 percent; acid-insoluble residues 1.9 percent (weight).

Figure 4.—Mixed sparite-micrite facies; thin-section photomicrograph. Note microtexture of trilobite in upper part of picture. Fitzhugh Member, Clarita Formation, 0.3–0.6 m above base. Abandoned quarry, Lawrence Uplift, NE¼NE¼SE¼ sec. 30, T. 3 N., R. 6 E., Pontotoc County, Oklahoma (stratigraphic section AQL, Barrick and Klapper, 1976, p. 84). This shows part of area point counted (as percentages of total rock volume): micrite, 10.6 percent; sparite, 21.3 percent; pelmatozoan plates, 26.4 percent; ostracodes, 12.5 percent; trilobites, 9.7 percent; bryozoans, 2.4 percent; brachiopods, 1.3 percent; gastropods, 0.4 percent; unidentified fossils, 15.3 percent; acid-insoluble-residue analysis not available.

Plate 4 45

1 mm   I
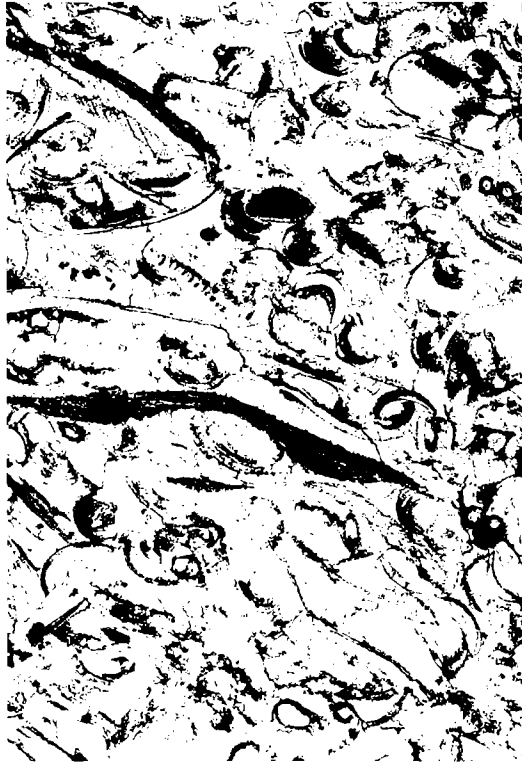
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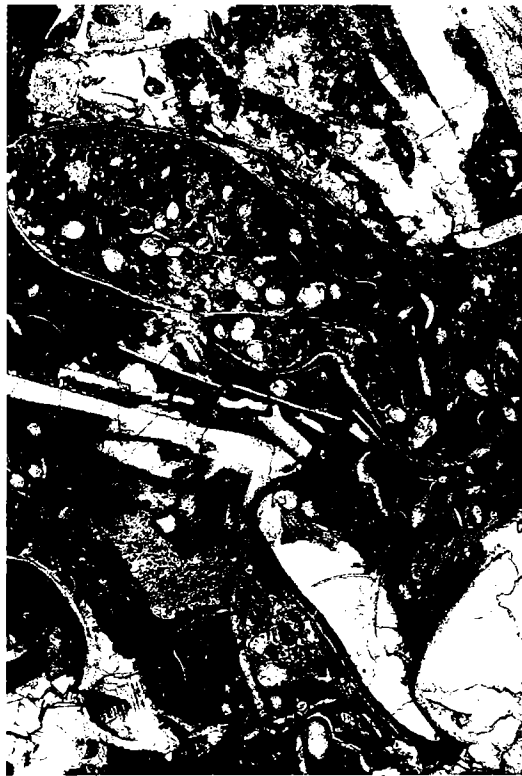
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Plate 5

CRINOID SPARITE FACIES

Figure 1.—Crinoid sparite facies; thin-section photomicrograph. Note thick-shelled ostracodes; cf. to ostracode shells in the arthropod micrite facies in fig. 2, below. Fitzhugh Member, Clarita Formation, 6–10 m above base. Chimneyhill Creek, SE¼ sec. 5, T. 2 N., R. 6 E., Pontotoc County, Oklahoma (stratigraphic section P1-E, Amsden, 1960, p. 268). This shows part of area point counted (as percentages of total rock volume): spar, 23.9 percent; micrite, 3.4 percent; pelmatozoan plates, 24.0 percent; ostracodes, 8.4 percent; trilobites, 14.4 percent; bryozoans, 3.8 percent; brachiopods, 6.1 percent; unidentified fossils, 15.6 percent; HCl-acid-insoluble residues, 0.42 percent.

ARTHROPOD MICRITE FACIES

Figure 2.—Arthropod micrite facies; thin-section photomicrograph. Note articulated brachiopod shell just left of center, microtexture of pelmatozoan plates, and the snail shells preserved in spar; also, thin-shelled ostracodes, some of which are articulated (cf. to thick-shelled ostracodes in crinoid sparite facies shown in fig. 1, above, and on pl. 4, figs. 1, 2). Fitzhugh Member, Clarita Formation, 0.6 m abova base of member. West side of I-35 and U.S. 77, sec. 4, T. 3 S., R. 3 E., Carter County, Oklahoma (this stratigraphic section is a short distance west of stratigraphic section Ca2, Amsden, 1960, p. 198). This shows part of area point counted as percentages of total rock volume: micrite, 42.1 percent; spar, 0.7 percent; pelmatozoan plates, 3.3 percent; ostracodes, 5.6 percent; trilobites, 7.3 percent; bryozoans, 1.5 percent; brachiopods, 3.3 percent; gastropods, 5.6 percent; cephalopods, 6.3 percent; pelecypods, 0.3 percent; unidentified fossils, 23.8 percent.

Plate 5 47

1 mm

I

1 mm

2
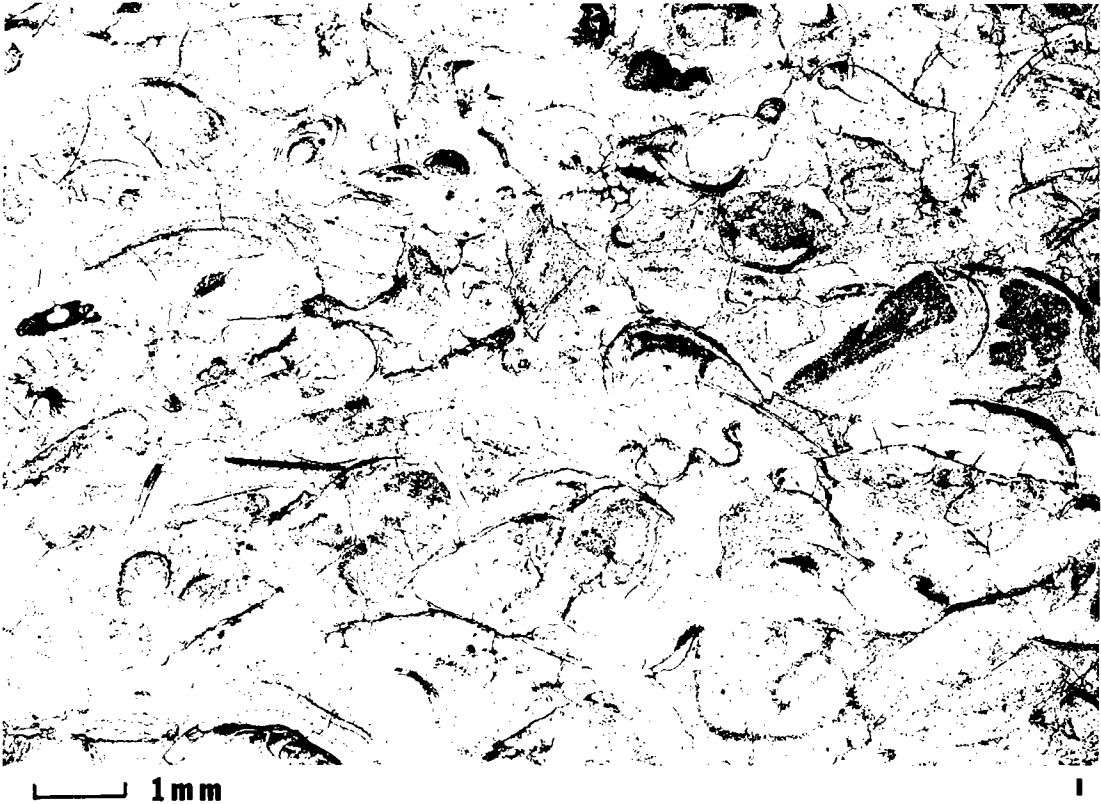
Plate 6

ARTHROPOD MICRITE FACIES

Figure 1.—Arthropod micrite facies; thin-section photomicrograph with cross section of orthocerid cephalopod; note stratification of micrite and fossil debris inside cephalopod conch and sparry calcite wall; also note microtexture of pelmatozoan plate. Fitzhugh Member, Clarita Formation, NW¼NW¼ sec. 22, T. 1 N., R. 7 E., Pontotoc County, Oklahoma (stratigraphic section P9-D, Amsden, 1960, p. 281). This shows small part of area point counted (as percentages of total rock volume): micrite, 29.0 percent; spar, 1.7 percent; pelmatozoan plates, 23.5 percent; ostracodes, 9.2 percent; trilobites, 3.1 percent; bryozoans, 0.6 percent; brachiopods, 1.1 percent; gastropods, 1.3 percent; cephalopods, 5.4 percent; unidentified fossils, 25.1 percent; acid-insoluble residues, 3.0 percent (weight).

Figure 2.—Arthropod micrite facies; thin-section photomicrograph showing gastropod shells preserved as sparry calcite. Note also micro-texture of pelmatozoan plates, and thin-shelled ostracodes (cf. ostracode shells in crinoid sparite facies shown on pl. 4, figs. 1, 2; pl. 5, fig. 1). Fitzhugh Member, Clarita Formation, Price's Falls Road, SE¼NE¼ sec. 30, T. 1 S., R. 2 E., Murray County, Oklahoma (stratigraphic section M5-D, Amsden, 1960, p. 241). This shows a small part of area point counted (as percentages of total rock volume): micrite, 32.9 percent; spar 2.8 percent; pelmatozoan plates, 8.0 percent; ostracodes, 7.6 percent; trilobites, 4.2 percent; bryozoans, 0.7 percent; brachiopods 1.0 percent; gastropods, 9.0 percent; cephalopods, 0.7 percent; unidentified fossils, 33.2 percent; acid-insoluble residues, 3.87 percent (weight).

OSTRACODE SILTY MARLSTONE FACIES

Figure 3.—Ostracode silty marlstone facies: thin-section photomicrograph. Note thin-shelled ostracodes (cf. to ostracodes in crinoid sparite facies, pl. 4, figs. 1, 2; pl 5, fig. 1). Fitzhugh Member, Clarita Formation, 1 m below top of member. Road outcrop north of Buckhorn Ranch, SW¼SE¼ sec. 33, T. 1 S., R. 2 E., Murray County, Oklahoma (stratigraphic section M10-D, Amsden, 1960, p. 250). This shows part of area point counted (as percentages of total rock volume): micrite, 57.9 percent; ostracodes, 23.7 percent; trilobites, 2.7 percent; unidentified fossils, 15.8 percent; acid-insoluble residues, 11.6 percent (weight).

Figure 4.—Ostracode silty marlstone facies; thin-section photomicrograph. Note thin-shelled ostracodes (cf. to ostracodes in crinoid sparite facies, pl. 4, figs. 1, 2; pl. 5, fig. 1). Fitzhugh Member, Clarita Formation, 3 m below Henryhouse Formation. White Mound area, SE¼NE¼ sec. 20, T. 2 S., R. 3 E., Murray County, Oklahoma (stratigraphic section M2, Amsden, 1960, p. 236). This shows part of area point counted (as percentages of total rock volume): micrite, 76.5 percent; ostracodes, 12.6 percent; unidentified fossils, 10.7 percent; HCl-insoluble-residue analysis not available.

Plate 6   49

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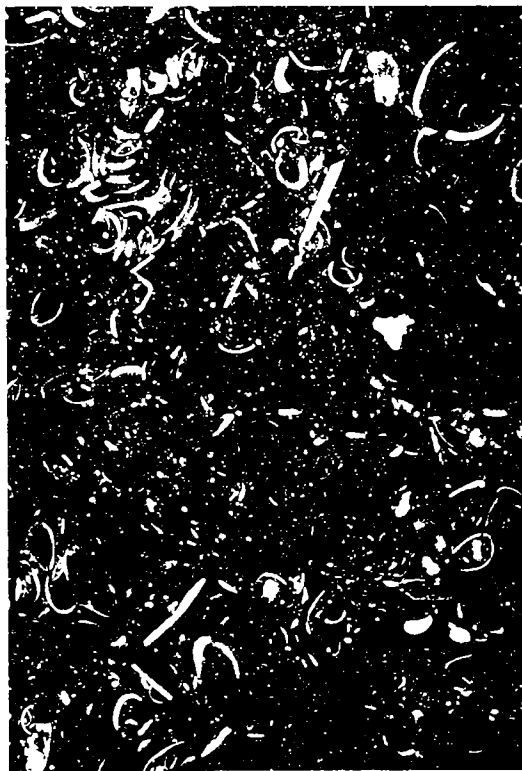
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Plate 7

Thin-section photomicrographs of most abundant Fitzhugh agglutinated foraminifers from Chim-
neyhill Creek section (stratigraphic section P1, Amsden, 1960, p. 262), Pontotoc County, Ok-
lahoma; all ×125.

Figures A–C.—*Ammodiscus exsertus* Cushman.

Figures D–E.—*Ammodiscus siliceus* (Terquem).

Figures F–J.—*Hyperammina harrisi* Ireland.

Figures K–N.—Various random cuts of *Ammodiscus* sp. from petrographic thin sections. Occur-
rence of agglutinated foraminifers in rock thin sections is indeed rare; locality P1 was one of few
places where specimens were observed in any abundance (*Ammodiscus* sp. only).

Plate 7   51
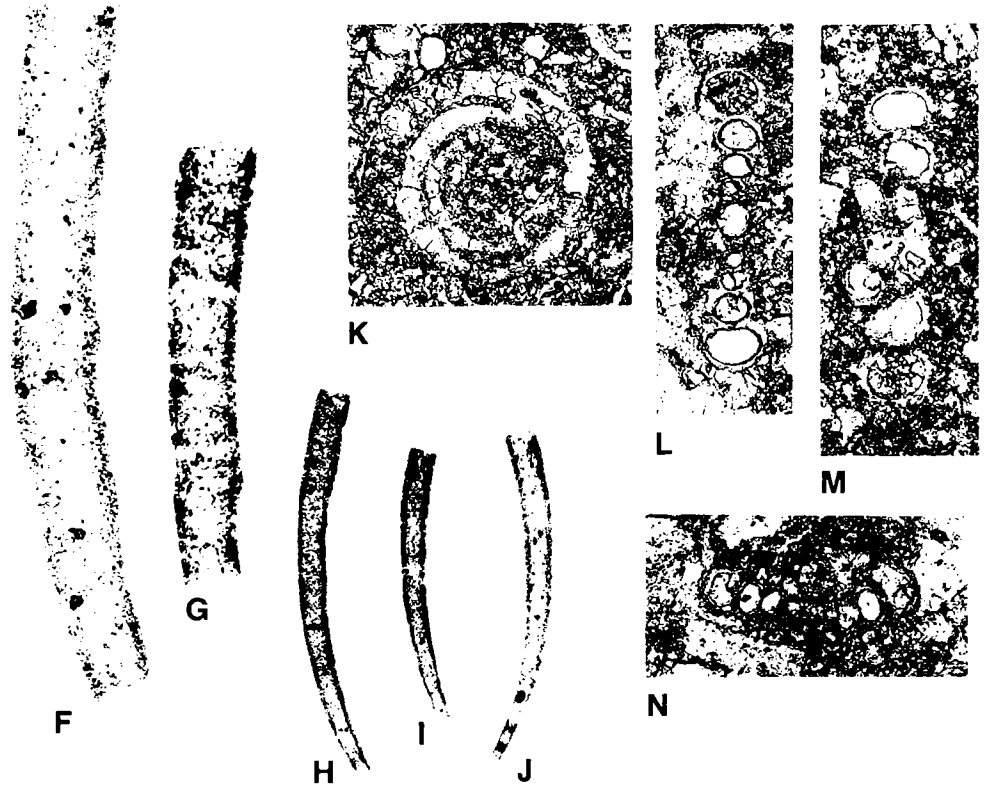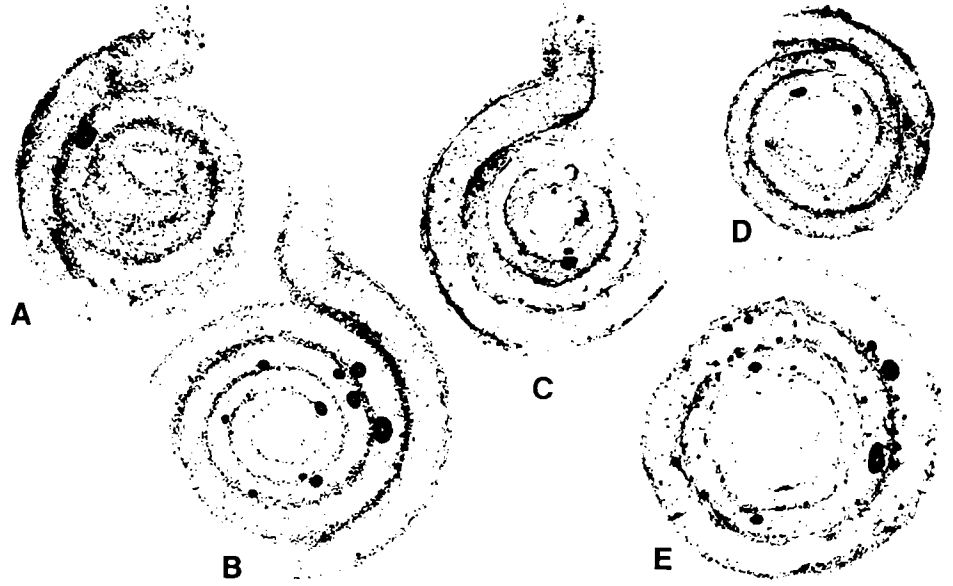
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