Algal-Bank Complex in Wyandotte Limestone (Late Pennsylvanian) In Eastern Kansas

By Donald J. Crowley

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DONALD J. CROWLEY *State University College at Fredonia, New York*

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ABSTRACT

The Wyandotte Limestone is divided into seven lithologically and paleontologically distinct facies: (1) a *terrigenous facies*—mostly unfossiliferous, silty shale, and quartz sandstone; (2) a *stromatolite-sponge facies*—a sponge-bearing stromatolitic biolithite; (3) an *algal-bank facies*—a phylloid algal biomicrite, dismicrite, and intrasparrudite; (4) an *Archaeolithophyllum cap facies*—a phylloid algal biolithite that capped the algal banks; (5) a *calcarenite facies*—biosparite, intrasparite, and *Osagia*-coated biosparrudite; (6) an *oölite* facies—oösparite and oömicrite; and, (7) a *shelly mud facies*—a crinoidal, brachiopodal biomicrite.

The basic factors controlling these facies were geometry and hydrography of the basin of deposition. A platform on the Lane Shale controlled initial carbonate facies development. This was subsequently modified by changes in water circulation and turbulence, the more immediate controlling factors of carbonate facies. Nature of the substrate, salinity variation, water energy, and amount of water circulation were the chief limiting factors in distribution and abundance of the Wyandotte biota.

Calcareous phylloid algae of the genera *Archaeolithophyllum* and *Anchicodium* played an important role in intertidal to shallow subtidal bank development. *Archaeolithophyllum* was abundant in sediments deposited in more turbulent water that was perhaps slightly shallower than the environment where *Anchicodium* thrived. The latter genus served as a baffle, allowing fine carbonate mud to settle out, while in both genera mud was trapped and bound beneath the blades. This produced the banks which provided a well lighted, shallow-water habitat for further prolific algal growth.

INTRODUCTION

A number of recent investigations have shown that phylloid[1] algal carbonate mud banks were common features in the shallow, epicontinental seas that covered the North American continent during the Pennsylvanian and Permian Periods. Banks from the Paradox basin have been described by Choquette and Traut (1963),[2] Elias (1963),[3] and Pray and Wray (1963)[4] and those from Kansas by Wilson (1957), Harbaugh (1959, 1960), and McCrone (1963). The calcareous phylloid algae prominent in the construction of these carbonate mud banks have been identified by Johnson (1946, 1956, 1961), Maslov (1956), Konishi and Wray (1961), Konishi (1961), and Wray (1964).

Previous interpretations of the nature of phylloid algal-carbonate banks were based on lithofacies and biofacies analyses, bank geometry, stratigraphic position, and algal-sediment associations.

The banks probably were initiated by existing water-current patterns within the basin. Regular, vertical lithologic changes in thickened parts of the algal limestones suggest that special environmental conditions, such as shallow water and increased light, led to increased proliferation of phylloid algae. These algae, and possibly bryozoans, served as baffles to the water currents and stabilized sediment, allowing accumulation of lime mud and bioclastic material. Later, more turbulent water conditions resulted in capping the banks with calcarenite. Lateral facies relations in Midcontinent sediments show

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[1] "Phylloid" is a term proposed by Pray and Wray (1963) to describe leaflike algae, including the red coralline genus *Archaeolithophyllum* and the related green codiacean(?) genera *Ivanovia*, *Anchicodium*, and *Eugonophyllum*.

[2] Choquette, P. W., and Traut, J. D., 1963, Pennsylvanian carbonate reservoirs, Ismay Field, Utah and Colorado, *in* Shelf Carbonates of the Paradox Basin: Four Corners Geol. Soc., 4th Field Conf. Symp., p. 157-184. (Guidebook.)

[3] Elias, G. K., 1963, Habitat of Pennsylvanian algal bioherms, Four Corners area, *in* Shelf Carbonates of the Paradox Basin: Four Corners Geol. Soc., 4th Field Conf. Symp., p. 185-203. (Guidebook.)

[4] Pray, L. C., and Wray, J. L., 1963, Porous algal facies (Pennsylvanian), Honaker Trail, San Juan Canyon, Utah, *in* Shelf Carbonates of the Paradox Basin: Four Corners Geol. Soc., 4th Field Conf. Symp., p. 204-234. (Guidebook.)

that banks tend to occur near the shoreward limit of limestone deposition. Contemporaneous terrigenous sands and silts were deposited both on the shoreward side and on the seaward, deeper water side of the carbonate banks.

Previous interpretations point the way toward more definitive investigations. A paleoenvironmental investigation utilizing information and principles gained from Recent organism-sediment studies makes it possible to interpret with greater certainty some of the physical, chemical, and biological factors of the environment, such as bottom topography, water turbulence, depth, salinity, circulation, and floral and faunal assemblages. Such a study also will aid in determining ecologic significance of the different forms of phylloid algae and in evaluating their role in bank building.

This study focuses on a complex of phylloid algal-carbonate mud banks in the late Pennsylvanian Wyandotte Limestone of Johnson County, Kansas, and the surrounding counties of eastern Kansas and western Missouri (Fig. 1). The bank complex (Fig. 2) occurs in an area about 25 by 65 miles in which the formation ranges from 2 to 103 feet in thickness (Fig. 3). Stratigraphy of the Wyandotte formation in this area has been described by Newell (1935), Jewett and Newell (1935), and Searight and Howe (1961), and also is recorded in several unpublished reports on file at the Kansas and Missouri State Geological Surveys.

The Wyandotte consists of a lithologic suite that is common in the late Paleozoic of the Midcontinent but which has received little paleoenvironmental study. A diagnostic biota, oölites, and abundant primary structures, including cross-stratification, mud cracks, intraclasts, and burrow mottling, distinguish this facies complex. Fresh exposures necessary for this study were found readily in quarries and new road cuts in the area.

ACKNOWLEDGMENTS

I wish to thank Professors Léo F. Laporte, Thomas A. Mutch, and R. K. Matthews, all of Brown University, for encouragement and valuable criticisms throughout research and writing of the doctoral dissertation. Gratitude is expressed also to the following for reviews and criticisms and information at various stages in the preparation of this manuscript: Howard G. O'Connor, Philip H. Heckel, and Doris E. Zeller, all of the State Geological Survey of Kansas, William J. Metzger, of the State University College at Fredonia, N.Y., and other persons at the State Geological Surveys of Kansas and Missouri. Special thanks are due Howard G. O'Connor for helpful discussions and permission to use data from maps in preparation at the State Geological Survey of Kansas.

I gratefully acknowledge financial assistance for field, laboratory, and manuscript-preparation expenses from a National Science Foundation Cooperative Summer Fellowship, the Research Fund of the American Association of Petroleum Geologists, and The Society of the Sigma Xi (RESA Research Fund).

STRATIGRAPHY

The Wyandotte Limestone is a predominantly carbonate unit that lies between the Lane Shale below and the Bonner Springs Shale above. These three formations form the Zarah Subgroup at the top of the Kansas City Group in the Missourian Stage of the Pennsylvanian System in the Midcontinent (Table 1).

TABLE 1.—Stratigraphic position of Wyandotte Limestone within Pennsylvanian Midcontinent rock succession.

PENNSYLVANIAN SYSTEM	
UPPER PENNSYLVANIAN SERIES	
MISSOURIAN STAGE	
LANSING GROUP	
KANSAS CITY GROUP	
ZARAH SUBGROUP	
BONNER SPRINGS SHALE	
WYANDOTTE LIMESTONE	INTERVAL STUDIED
FARLEY LIMESTONE MEMBER	
UPPER LIMESTONE UNIT	
MIDDLE SHALE UNIT	
LOWER LIMESTONE UNIT	
ISLAND CREEK SHALE MEMBER	
ARGENTINE LIMESTONE MEMBER	
QUINDARO SHALE MEMBER	
FRISBIE LIMESTONE MEMBER	
LANE SHALE	

The Zarah Subgroup is about 130 feet thick in the Kansas City area where the limestone members of the Wyandotte are prominent. The limestone members thin northward across northwestern Missouri and northeastern Kansas (Burchett, 1959). They pinch out southward in Anderson County, Kansas (Newell, 1935), and westward in the subsurface of Franklin County, Kansas (Parkhurst, 1959).[5] Where the

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[5] Parkhurst, R. W., 1959, Subsurface to subsurface correlation of Lansing-Kansas City rocks (Pennsylvanian) in Kansas: Kansas Geol. Soc., 24th Field Conf., p. 94-100. (Guidebook.)

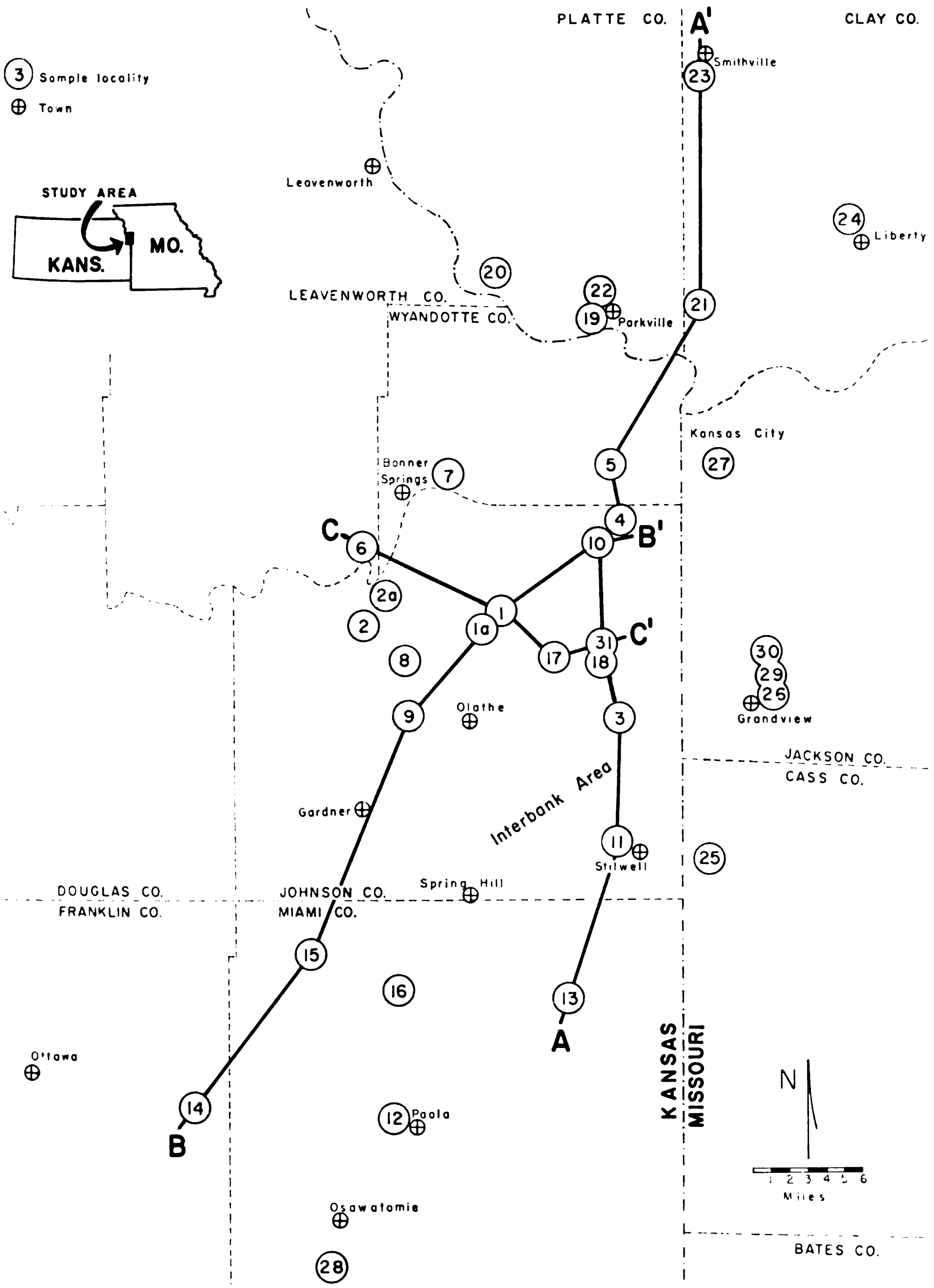

FIGURE 1.—Index map of study area showing sample localities and locations of cross sections (shown on Plate 1).

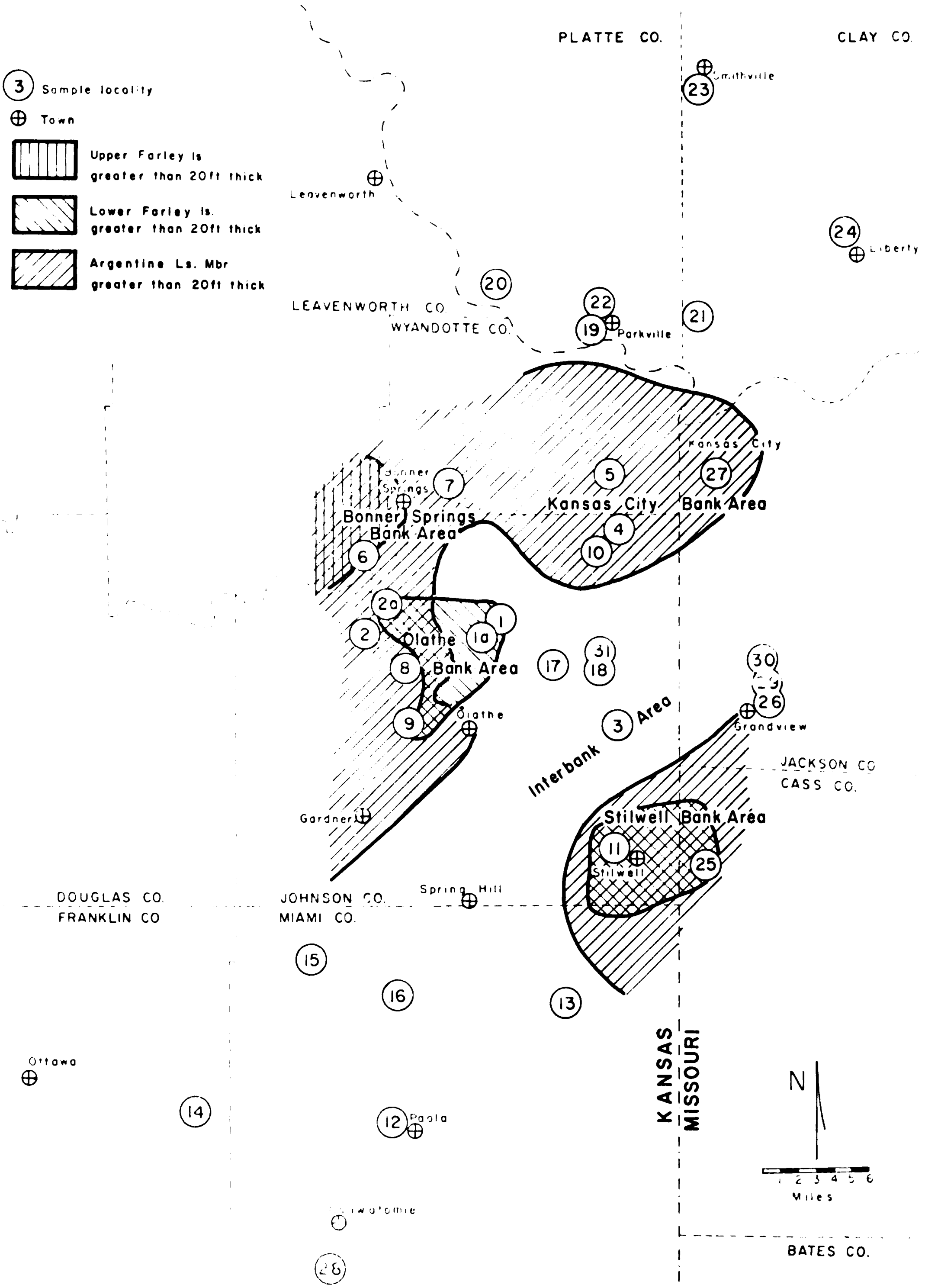

FIGURE 2.—Carbonate bank development in limestone members of the Wyandotte Limestone. Banks tend to form over top of previous banks. Interbank area in southeastern Johnson County was a persistent feature throughout deposition of Wyandotte.

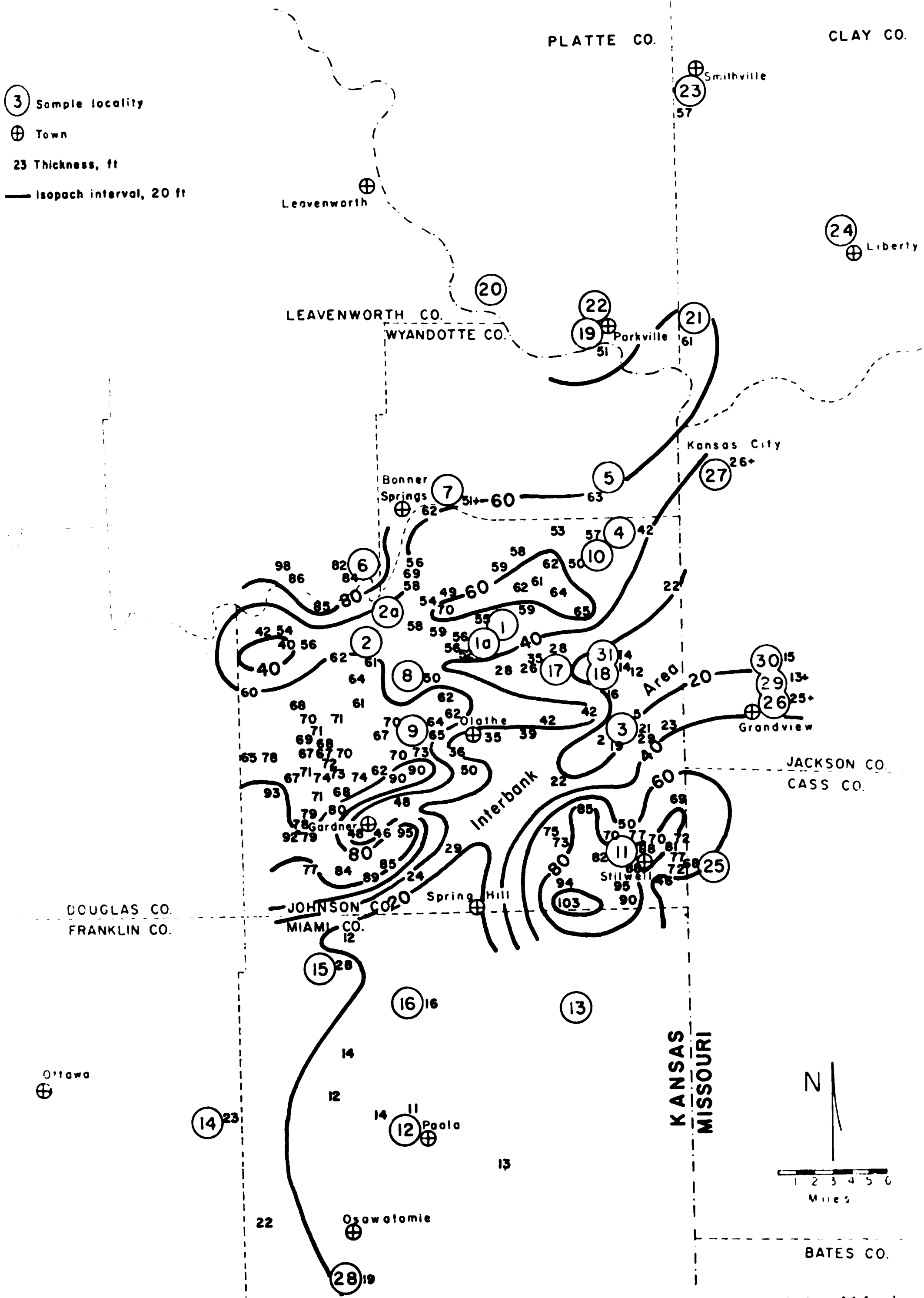

Figure 3.—Isopach map of Wyandotte Limestone. Successive bank development has resulted in thickening of Wyandotte on either side of interbank area. Data for Johnson County from maps prepared for publication by H. G. O'Connor, State Geological Survey of Kansas. Outcrop and subsurface information on file at Kansas Geological Survey; other data from present study, Newell (1935), and Jewett and Newell (1935).

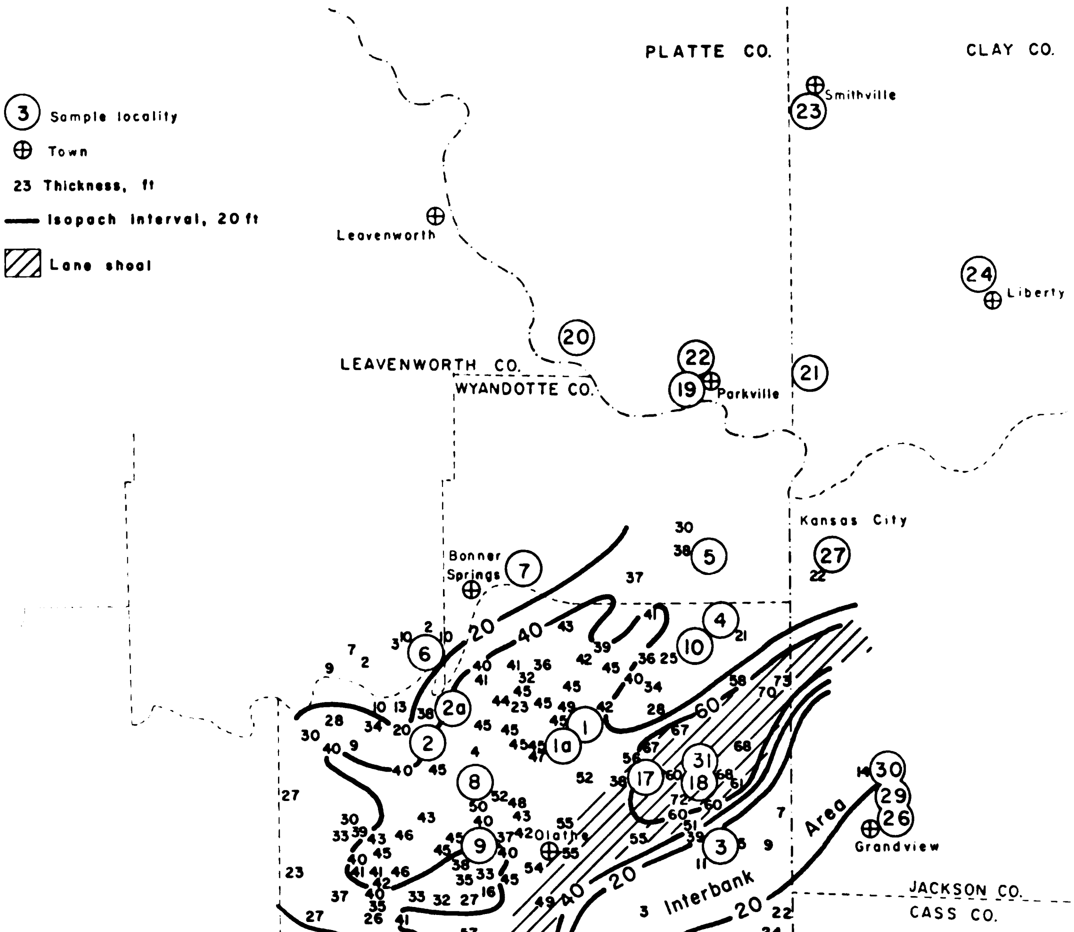

FIGURE 4.—Isopach map of Lane Shale. Thickened part shaded and referred to in text as Lane shoal. Area northwest of shoal is Lane deltaic platform. Note abrupt thinning of shoal southeastward into interbank area. Data sources same as Figure 3.

limestones are thinner the Zarah Subgroup is thinner; where they are absent the Lane Shale and the Bonner Springs Shale cannot be differentiated.

SUBJACENT LANE SHALE

The Lane is an arenaceous to argillaceous gray shale that contains a few thin lenses of quartzose sandstone and coal (Newell, 1935; Jewett and Newell, 1935). It is more sandy to the southwest where it is thickest. Coal occurs only in northwestern Missouri where the formation is thin (Searight and Howe, 1961). A few layers rich in marine fossils, mainly crinoids, occur in the Kansas City area.

The thickest part of the Lane extends from western Miami County northeastward across Johnson County (Fig. 4). This thickened portion of the Lane is paralleled on the southeast by an elongate area of thin Lane that coincides with the interbank area (Fig. 2). Subsequent Wyandotte facies development and distribution are related to these thickness irregularities in the Lane.

SUPERJACENT BONNER SPRINGS SHALE

The Bonner Springs Shale is a gray to buff shale, sandy shale, and sandstone (Newell, 1935; Jewett and Newell, 1935; Searight and Howe, 1961). The sandstone is commonly cross-stratified and occupies channels cut into underlying shale and locally into the top of the Wyandotte. The Bonner Springs is thickest in the interbank area where the Lane Shale and Wyandotte Limestone are thinnest (Fig. 5).

WYANDOTTE LIMESTONE

Frisbie Limestone Member

The Frisbie Limestone (Fig. 6) is the lowest member of the Wyandotte at most localities within the study area. It typically stands out above the Lane Shale as one or two massive beds totaling 5 feet or less in thickness (Fig. 9, *B*). This Member is not present in the interbank area or at the southern margin of the study area.

Quindaro Shale Member

The Quindaro Shale (Fig. 7) is 3.5 feet or less in thickness and has a limited distribution in this area, although it is identified in areas farther north where the lower part is black fissile shale (Burchett, 1959). The Quindaro is absent in parts of Wyandotte County, in the interbank area, and south of Olathe.

Argentine Limestone Member

The Argentine (Fig. 8) is the main limestone of the Wyandotte and shows great variation in thickness within the study area. Bank development in the Argentine attains about 20 feet in the Kansas City and Olathe areas (Fig 9, *B*) and as much as 50 feet at Stilwell, Kansas. In contrast, this Member thins abruptly to 7 feet in the interbank area.

Island Creek Shale Member

A lobe of Island Creek Shale (Fig. 9, *A*) extends southward from northern Wyandotte County between areas of the underlying thickened Argentine (Fig. 10). This shale thickens slightly in the interbank area and thins above all thick parts of the Argentine (Fig. 9, *D*).

Thickness of the Island Creek Shale complements the thickness of the underlying Argentine Limestone, in that the shale is thickest where the limestone is thin except in the interbank area (Fig. 11, *A*). Thus, Argentine topography probably controlled deposition of the Island Creek to some extent. Incomplete thickness compensation may be due to several factors: (1) greater differential compaction of shales, (2) partial subsidence of thick carbonate areas before shale deposition, and (3) incomplete filling of depressions by shale, particularly in the interbank area.

Farley Limestone Member

Lower limestone unit.—Two areas where this limestone unit is thick occur directly above the thickened Argentine at Stilwell and Olathe (Fig. 12). In other areas the lower Farley is thin.

Middle shale unit.—The middle Farley (Fig. 9, *A*) is a less clearly defined shale lobe that extends southward from Missouri (Fig. 13). Like the Island Creek Shale Member, the middle Farley shale also tends to complement the thickness of the underlying limestone unit (Fig. 11, *B*). Although Figure 13 shows 0 thickness for the middle Farley shale in the interbank area, the lower 7 to 8 feet of the Bonner Springs Shale in this area is thought to be the lateral equivalent of the middle Farley shale.

Upper limestone unit.—This uppermost limestone unit of the Wyandotte (Fig. 9, *A*) is relatively thin (Fig. 14), except in the Bonner Springs area, where it is 20 feet thick. Absence of this limestone unit in the interbank area

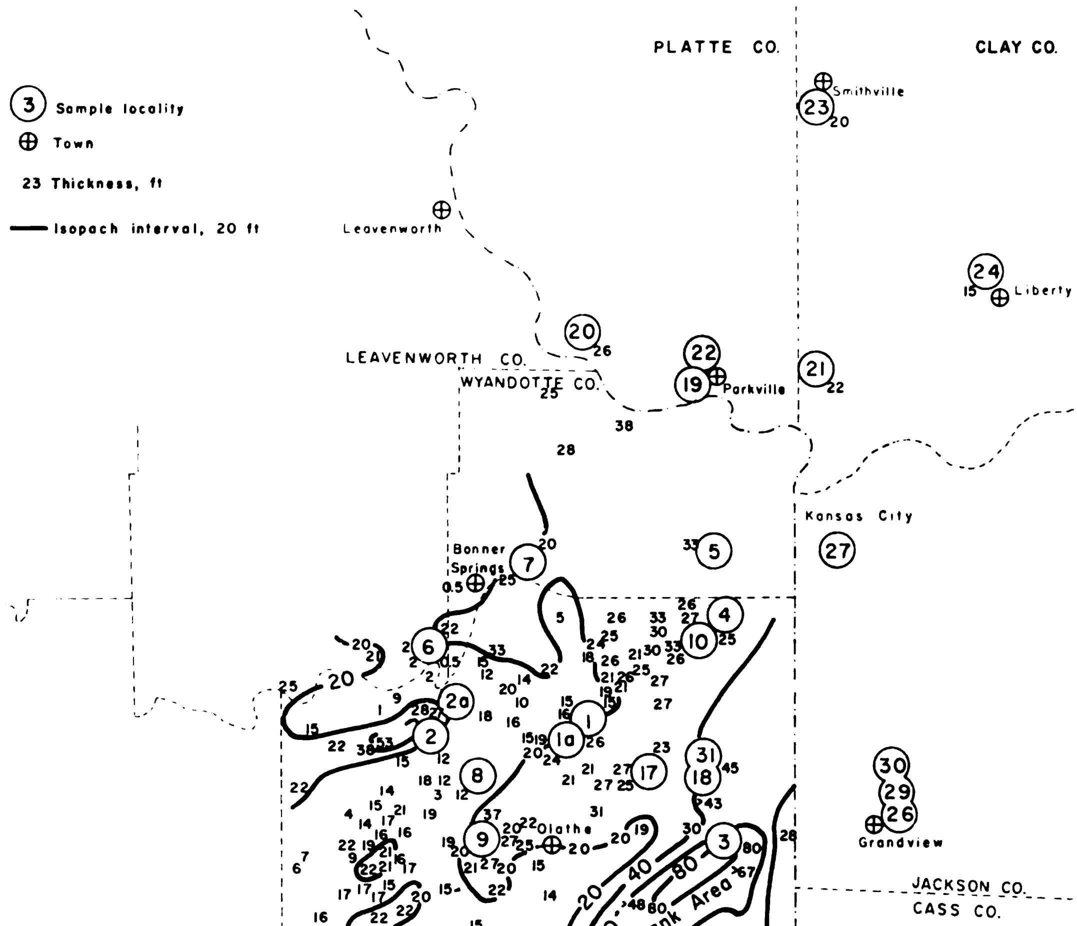

FIGURE 5.—Isopach map of Bonner Springs Shale. Note greater accumulation in interbank area. Data sources same as Figure 3.

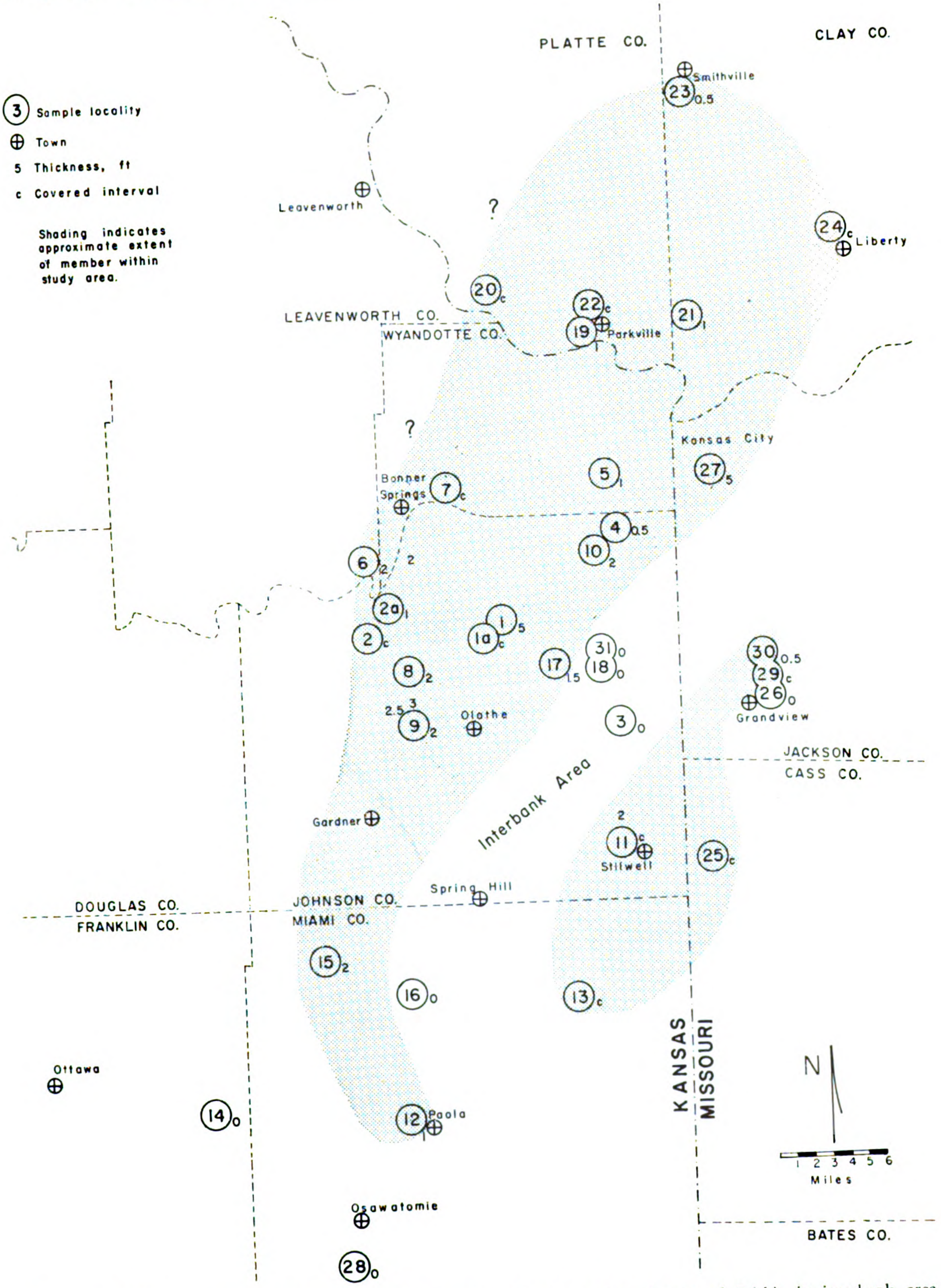

FIGURE 6.—Thickness and distribution of Frisbie Limestone Member. Note absence of Frisbie in interbank area. Data from this study only.

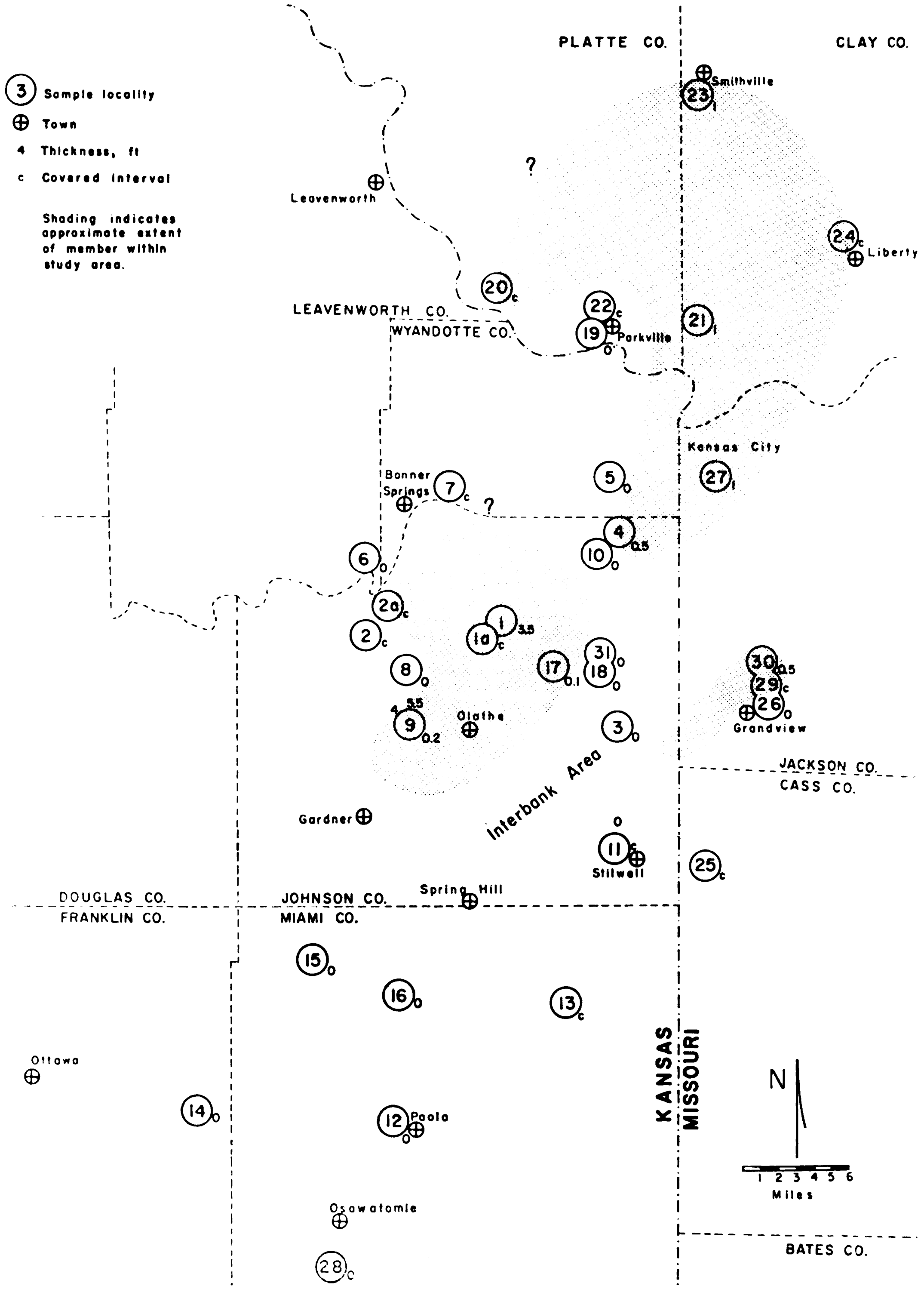

FIGURE 7.—Thickness and distribution of Quindaro Shale Member. In interbank area Quindaro is not distinguished because Frisbie Limestone is absent. Data from this study only.

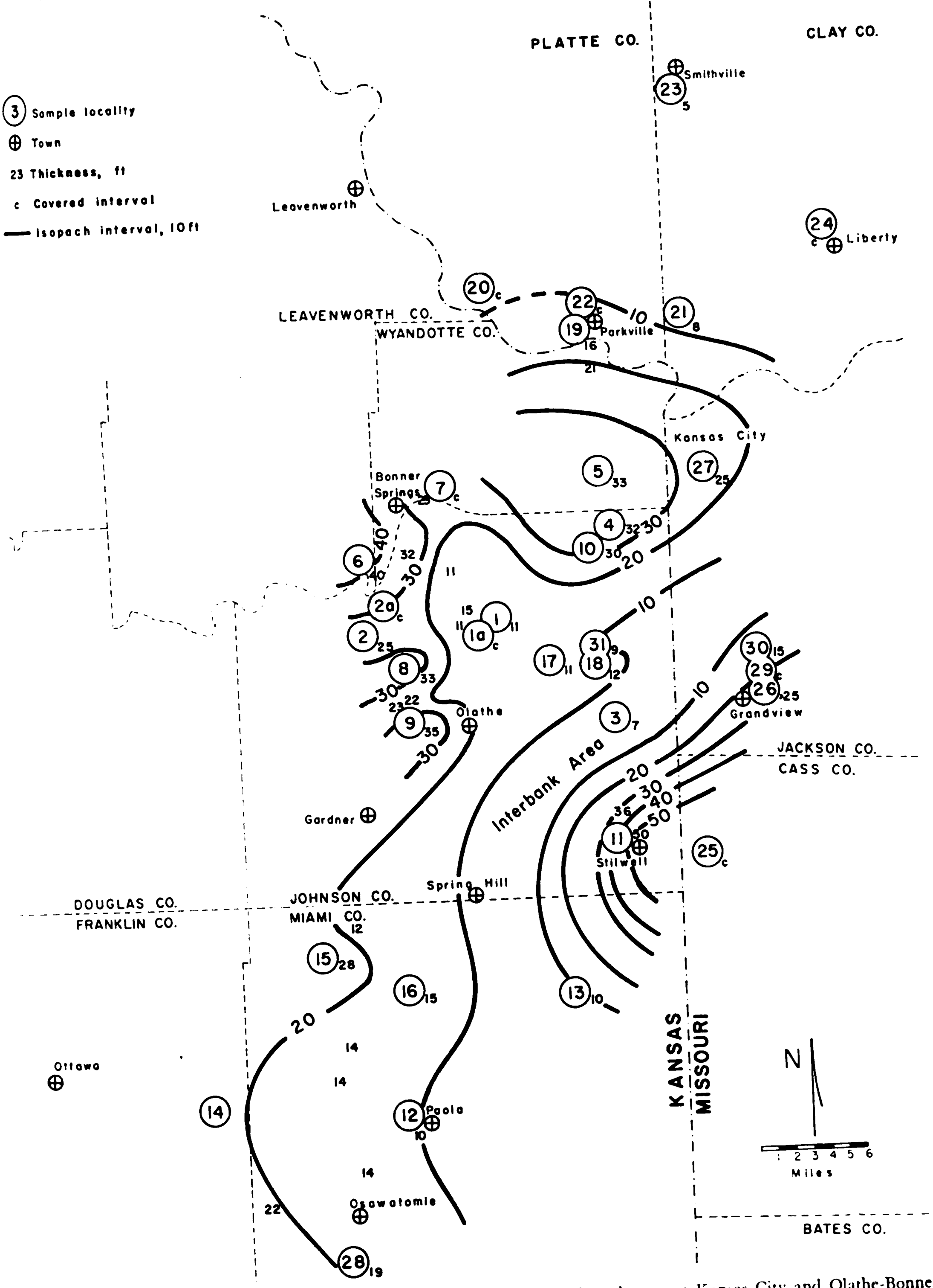

FIGURE 8.—Isopach map of Argentine Limestone Member. Note thickened areas at Kansas City and Olathe-Bonner Springs separated from thickened area at Stilwell by thinner interbank area. Data from present study, Newell (1935), and Jewett and Newell (1935).

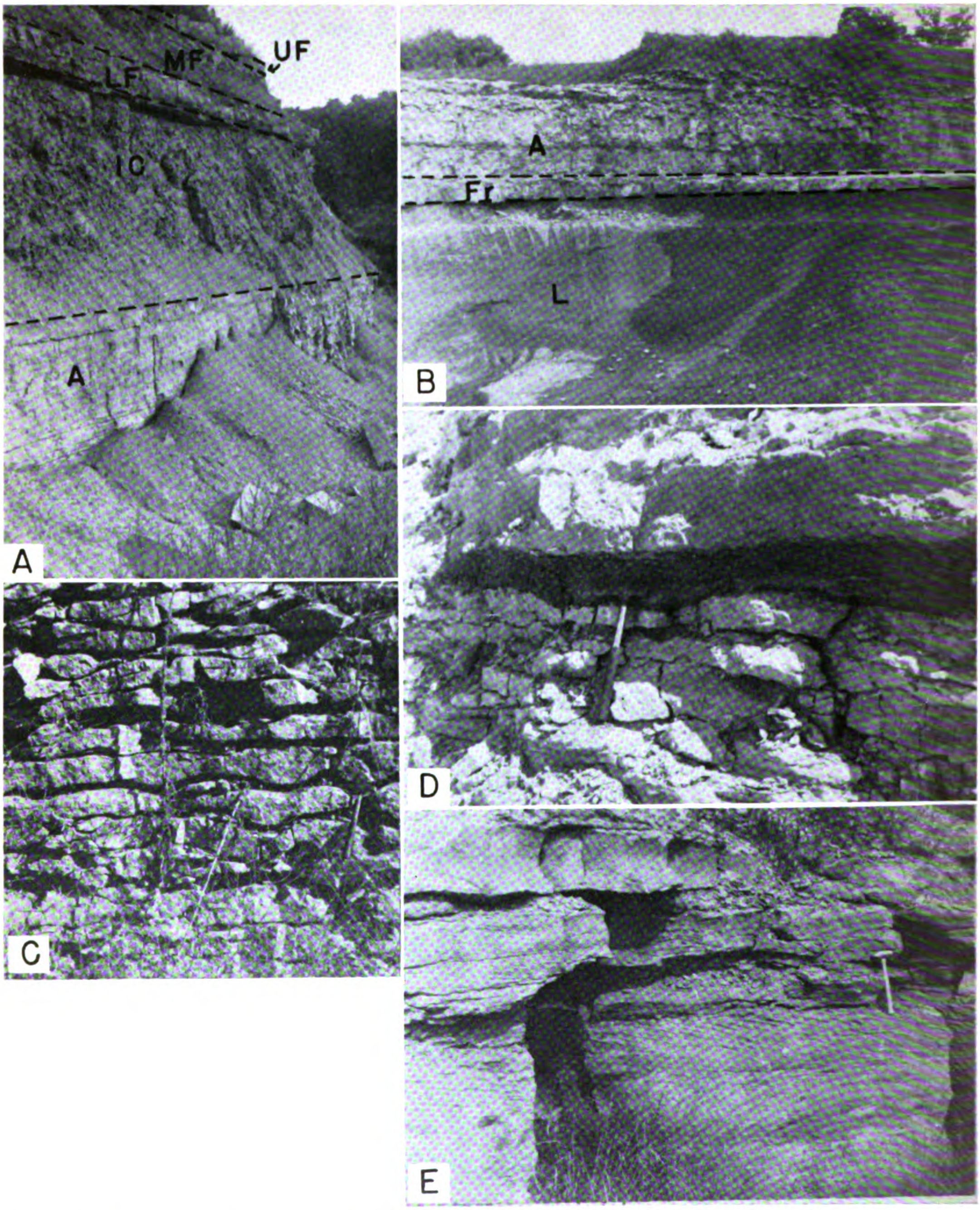

FIGURE 9.—Field views of members of the Wyandotte Limestone. *A,* Argentine Limestone (A); Island Creek Shale (IC), here 18 feet thick; lower Farley limestone (LF); middle Farley shale (MF); and upper Farley limestone (UF) in nonbank area. Locality 19. *B,* Lane Shale (L); massive Frisbie Limestone (Fr), 2 feet thick; Quindaro Shale, 0.2 foot thick and not visible; Argentine Limestone (A), 35 feet exposed in Olathe bank area. Locality 9. *C,* Wavy-bedded Argentine Limestone in which thin, dark shale partings have weathered back from the outcrop. Locality 28. *D,* Thin, fusulinid-rich Island Creek Shale (at hammer head) underlain by Argentine Limestone and overlain by lower Farley limestone in Stilwell bank area. Locality 11. *E,* Cross-stratified oölite facies of lower Farley. Locality 21.

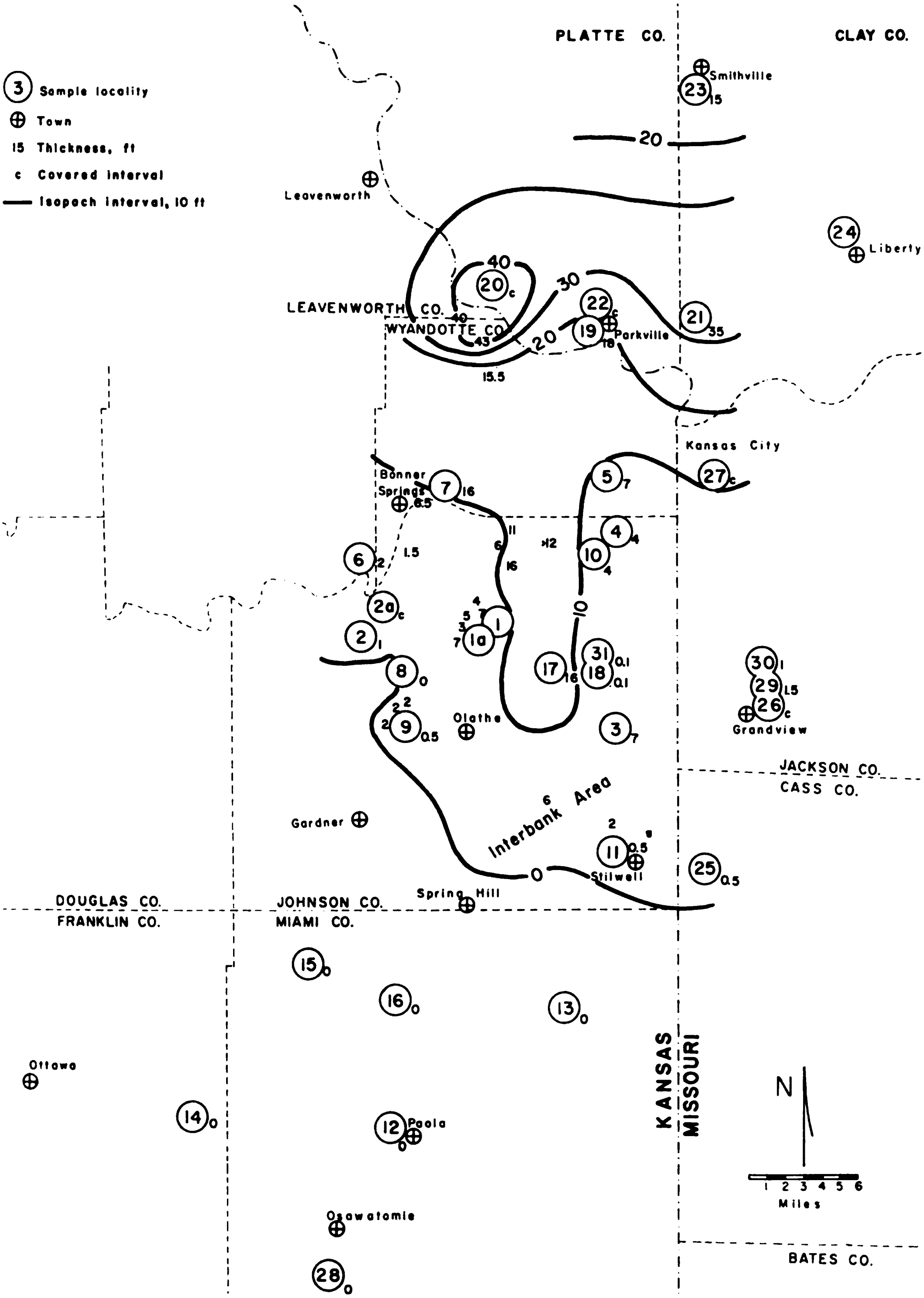

FIGURE 10.—Isopach map of Island Creek Shale Member. Note lobe of underlying Argentine extending southward from Wyandotte County between Kansas City and Olathe-Bonner Springs bank areas. Data source same as Figure 8.

may be due to erosion because channel sandstones in the Bonner Springs Shale have been observed to cut down into the lower Farley limestone at Locality 31 in the interbank area as well as just east of Locality 11 in the Stilwell bank area.

CORRELATION PROBLEMS

Frisbie-Quindaro

North of the interbank area the Frisbie Limestone Member typically is separated from the next higher limestone (Argentine Member)

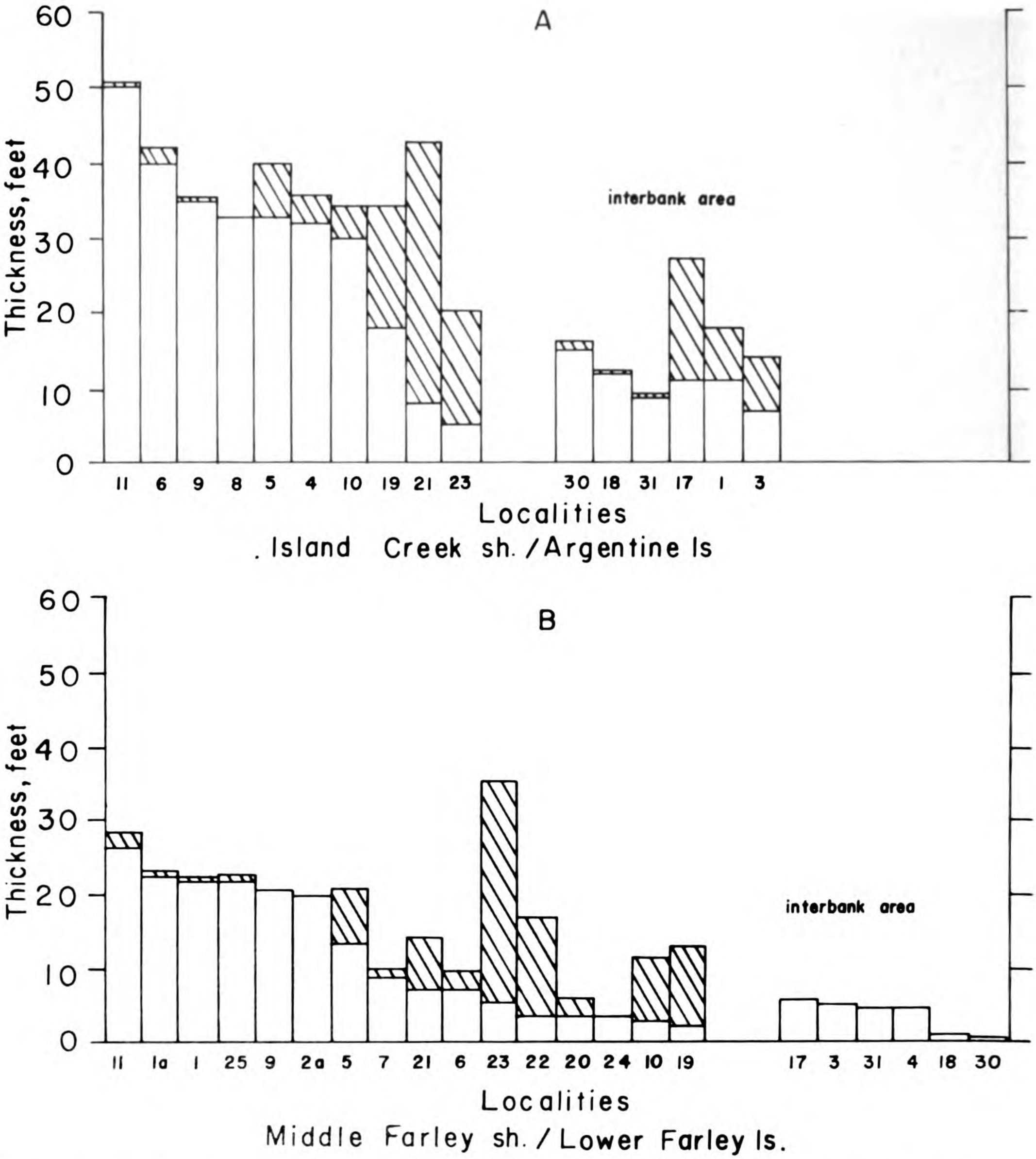

Figure 11.—Thickness of two Wyandotte shales compared with underlying limestones. *A*, Thickness of Island Creek Shale Member (diagonally ruled) tends to complement thickness of underlying Argentine Limestone except in interbank localities. *B*, Thickness of middle Farley shale (diagonally ruled) also tends to complement thickness of underlying lower Farley limestone except in interbank localities. Because upper Farley limestone is absent in interbank localities, shale immediately above lower Farley limestone is mapped as next higher shale (Bonner Springs), although it may be equivalent to middle Farley shale.

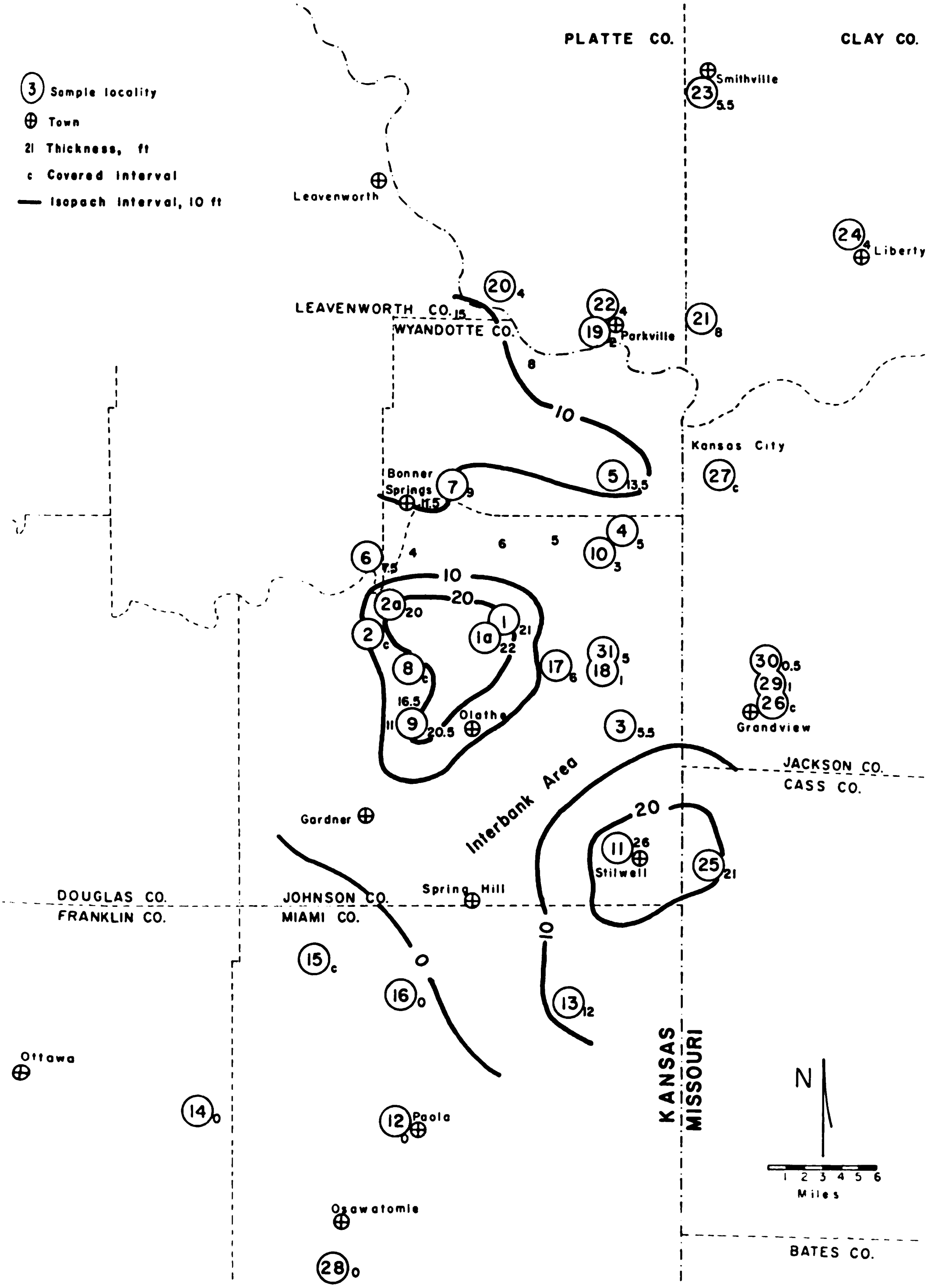

Figure 12.—Isopach map of lower part of Farley Limestone Member. Unit thickens above Argentine bank development in Stilwell and Olathe areas. Data source same as Figure 8.

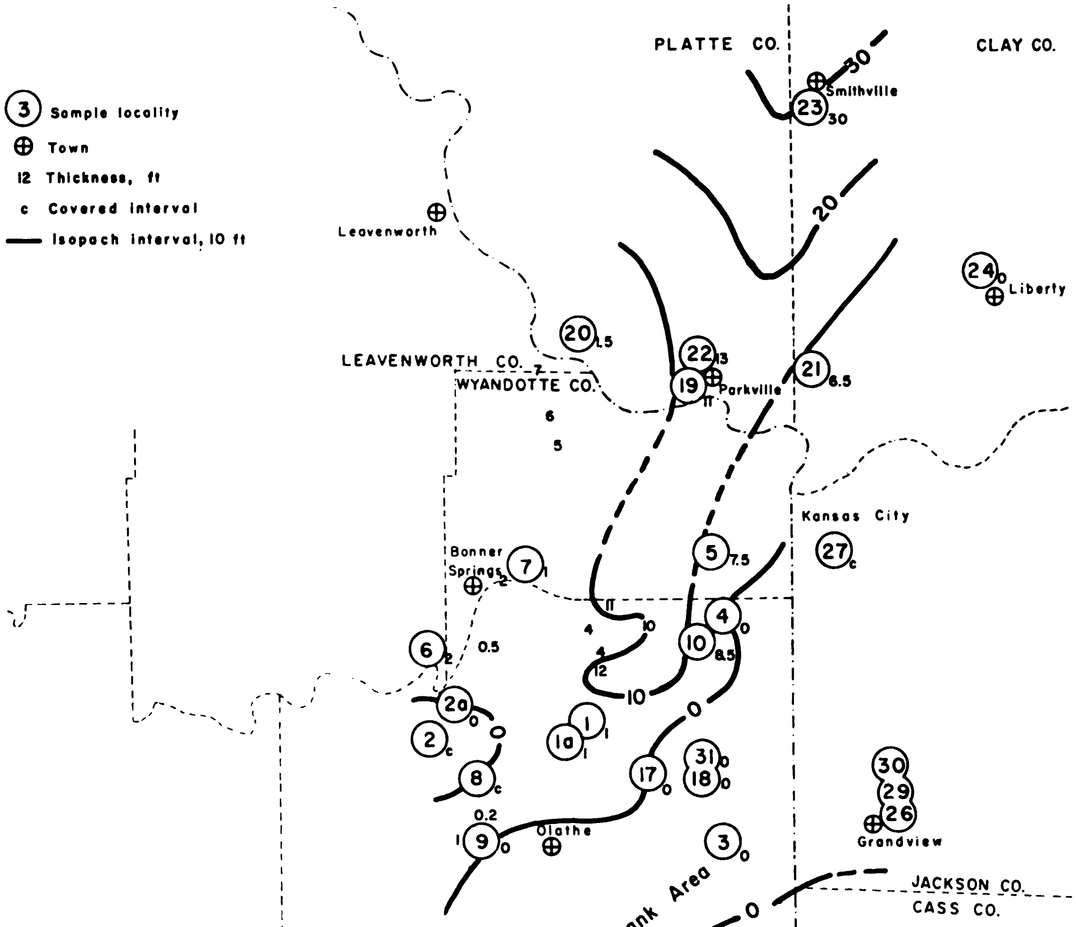

FIGURE 13.—Isopach map of shale in middle of Farley Limestone Member. Lobe extends southward from Platte County on east side of lower Farley bank area at Olathe. Middle Farley shale not differentiated in interbank area, but 7 or 8 feet of basal Bonner Springs formation there may be equivalent. Data source same as Figure 8.

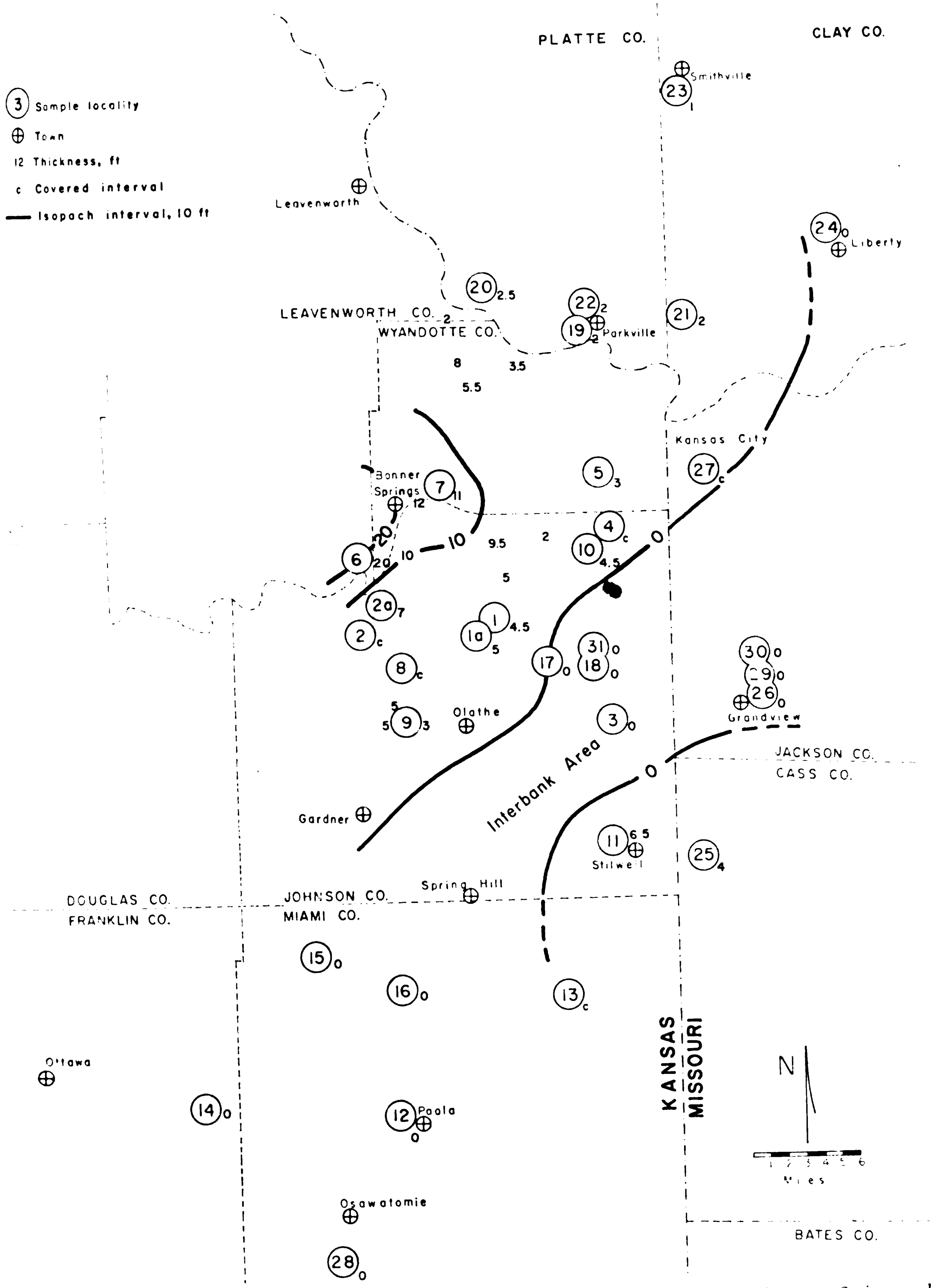

FIGURE 14.—Isopach map of upper part of Farley Limestone Member. Unit thick only around Bonner Springs and may have been eroded in interbank area. Data source same as Figure 8.

by the thin Quindaro Shale Member (Fig. 6 and 7) and is thus relatively easy to map. In this area the Frisbie is lithologically distinct from most of the Argentine Limestone Member. Recognition of the Frisbie becomes difficult to the south where the Quindaro Shale is absent and lithologic distinction from the Argentine is less marked. The Frisbie probably is absent in the interbank area where the Quindaro Shale is not distinguishable, and the basal layers of the Wyandotte resemble the Argentine (see Pl. 1).

Correlation Across the Interbank Area

The sequence of banks at Stilwell is separated from other algal banks to the north and west by the interbank area. Lack of outcrop and subsurface control makes it difficult to trace members across the interbank area, where they undergo rapid thinning and lithologic change. However, vertical succession and facies relationships of the sequence at Stilwell correlate well with the members of the Wyandotte Limestone at Olathe. This suggests that perhaps similar lithologies developed at the same time on both sides of the interbank area in which a different and thinner lithologic sequence was deposited.

Middle Farley Shale in the Interbank Area

The lower 7 or 8 feet of Bonner Springs Shale in the interbank area, where the upper Farley limestone is missing, is thought to correlate with the middle Farley shale to the north (Cross section A-A′, Pl. 1). At Locality 31 a channel sandstone in the Bonner Springs cuts down through about 7 feet of gray shale that overlies the lower Farley limestone. This dark-gray shale closely resembles the middle Farley shale at Locality 10 a few miles to the north and is distinct from the light-gray to buff, sandy shales of the lower Bonner Springs in this area. The dark-gray shale at Locality 31 is overlain by a 6-inch layer of limestone-pebble conglomerate which might represent the erosional product of the upper Farley. This shale, therefore, is considered to be correlative with the middle Farley shale.

LOCATIONS OF EXPOSURES

Approximate locations are shown in Figure 1. Lithologic type of selected samples is given in Table 4, and stratigraphic position of samples is shown on Plate 1.

1. S line of SE SE SW sec. 25, T 12 S, R 23 E, Johnson County, Kansas. Road cut on south side of new county road. Complete Wyandotte section.
1a. E NE sec. 1, T 13 S, R 23 E, Johnson County, Kansas. Railroad cut 1 mile southeast of Craig. Upper part of Island Creek Shale Member and Farley Limestone Member.
2. NW NW NW sec. 1, T 13 S, R 22 E, Johnson County, Kansas. Quarry in northwest bluff of Camp Creek. Argentine Limestone Member, Island Creek Shale Member, and lower Farley limestone.
2a. SW NE sec. 25, T 12 S, R 22 E, Johnson County, Kansas. Both sides of east-west road cut (K-10). Complete Wyandotte section.
3. West end of line between sec. 30 and sec. 31, T 13 S, R 25 E, Johnson County, Kansas. Road cut (K-150) 300 yards west of intersection of old U.S. Highway 69. Complete Wyandotte section.
4. NE NE NW sec. 4, T 12 S, R 25 E, Johnson County, Kansas. Road cut along 18th Street Expressway. Complete Wyandotte except for upper part of Farley Limestone Member.
5. Composite section from SW NW NE and E SE NE sec. 29, T 11 S, R 25 E, Wyandotte County, Kansas. Former is abandoned quarry and latter is road cut on 18th Street Expressway. Complete Wyandotte section.
6. SW NE SW sec. 14, T 12 S, R 22 E, Leavenworth County, Kansas. Loring Quarry. Acetate peels of core furnished by S. M. Ball, State Geological Survey of Kansas. Complete Wyandotte Section.
7. NE SE NE sec. 28, T 11 S, R 23 E, Wyandotte County, Kansas. Road cut along north side of Camp Naish entrance road. Upper part of Argentine Limestone Member, Island Creek Shale Member, and Farley Limestone Member.
8. SE SE sec. 7, T 13 S, R 23 E, Johnson County, Kansas. South side of east-west road up bluff of Cedar Creek. Complete Wyandotte section.
9. NE NE sec. 32, T 13 S, R 23 E, Johnson County, Kansas. Along north side of New Olathe Lake spillway, 2.2 miles west of Olathe. Complete Wyandotte section.
10. SE SW SE sec. 12, T 12 S, R 24 E, Johnson County, Kansas. Road cut and creek bed at intersection of U.S. Highway 50 and Turkey Creek Expressway. Complete Wyandotte section.
11. SW SE sec. 31, T 14 S, R 25 E, Johnson

County, Kansas. Quarry 0.3 mile west of old U.S. Highway 69. Acetate peels of core furnished by S. M. Ball, State Geological Survey of Kansas. Complete Wyandotte section.

12. NE SE SE sec. 18, T 17 S, R 23 E, Miami County, Kansas. West side of road cut. Complete Wyandotte section.
13. NE NW sec. 14, T 16 S, R 24 E, Miami County, Kansas. Abandoned quarry. Complete Wyandotte except for upper Farley limestone.
14. SW SW SW sec. 9, T 17 S, R 21 E, Franklin County, Kansas. Road cut. Complete Wyandotte section.
15. SW sec. 33, T 15 S, R 22 E, Miami County, Kansas. Road cut on south bluff of Rock Creek. Frisbie and Argentine limestones exposed.
16. SE NW SW sec. 8, T 16 S, R 23 E, Miami County, Kansas. Abandoned quarry. Complete Wyandotte section.
17. SW SW SW sec. 10, T 13 S, R 24 E, Johnson County, Kansas. Stream bed. Complete Wyandotte section.
18. NE NE NE sec. 13, T 13 S, R 24 E, Johnson County, Kansas. South side of road cut. Complete Wyandotte section.
19. SE NE sec. 34, T 51 N, R 34 W, Platte County, Missouri. Abandoned quarry 0.5 mile west of Parkville. Complete Wyandotte section.
20. SE NW SE sec. 14, T 51 N, R 35 W, Platte County, Missouri. Road cut 0.3 mile north of Waldron. Farley Limestone Member.
21. Composite section from sec. 33, 34, 27, 22, T 51 N, R 33 W, Platte and Clay counties, Missouri. Road cuts along U.S. Highways 169 and 71. Complete Wyandotte section.
22. NW NE NW sec. 26, T 51 N, R 24 E, Platte County, Missouri. Road cut on south side of route 45. Farley Limestone Member.
23. SE SE SE sec. 22, T 53 N, R 33 W, Clay County, Missouri. Road cut along U.S. Highway 169. Complete Wyandotte section.
24. NW NE sec. 1, T 51 N, R 32 W, Clay County, Missouri. Road cut in northbound lane of U.S. Highway 69 near intersection of U.S. Highway 71. Farley Limestone Member.
25. SW SW SW sec. 28, T 15 S, R 33 W, Cass County, Missouri. Railroad cut under bridge. Upper Argentine Limestone, Island Creek Shale, and Farley Limestone members.
26. W NW NW sec. 13, T 47 N, R 33 W, Jackson County, Missouri. Road cut along U.S. Highway 71. Argentine Limestone Member.
27. SW sec. 8, T 49 N, R 33 W, Jackson County, Missouri. Road cut along Maine Street and intersection of 27th Street. Frisbie Limestone, Quindaro Shale, and Argentine Limestone members.
28. SW sec. 22, T 18 S, R 22 E, Miami County, Kansas. Road cut on U.S. Highway 169, 1 mile southwest of intersection of K-7. Complete Wyandotte section.
29. W sec. 12, T 47 N, R 33 W, Jackson County, Missouri. Road cut along U.S. Highway 71 under Blue Ridge Extension overpass. Upper Argentine and Island Creek Shale members and lower Farley limestone.
30. E sec. 2, T 47 N, R 33 W, Jackson County, Missouri. Road cut along 110th Street exit from northbound lane of U.S. Highway 71. Complete Wyandotte except for upper Farley limestone.
31. SE sec. 7, T 13 S, R 25 E, Johnson County, Kansas. Road cut along Interstate Highway 435. Complete Wyandotte except for upper Farley limestone.

METHODS AND PRINCIPLES OF ANALYSIS

About 40 outcrops of the Wyandotte Limestone were examined and 33 exposures were measured, described in detail, and sampled (Fig. 1; Pl. 1). Where possible, the formations adjacent to the Wyandotte were described and measured. Outcrop correlations were checked in the field and were supplemented by subsurface data on file at the State Geological Survey of Kansas.

Limestones were sampled at various intervals, depending upon frequency of lithologic change. The samples were taken a few inches apart where rock types are thin and at approximately 5-foot intervals in thicker, more homogeneous units, particularly within the algal-bank facies. Numerous large specimens were collected for better definition of fossil-rock relationships and primary structures and were slabbed to about a 4″ x 6″ surface. Shale units in the Wyandotte were sampled at about 5-foot intervals. The top of the underlying Lane Shale and the bottom of the overlying Bonner Springs Shale were sampled for comparison with the Wyandotte shales.

Limestone specimens were slabbed, polished, etched with dilute HCl, and acetate peels were prepared. Selected samples were thin-sectioned. Several vertical and horizontal cuts were made in certain specimens to determine more exactly the orientation of algal blades and primary structures. Thin sections were stained with alizarin red-S for definition of dolomite. Negative peel-prints of all peels and negative prints of thin sections were made for visual comparison of lithology and fossil content. Samples were not point-counted because meaningful lithologic differences were clearly established by visual estimate. Limestones were described using the terminology of Folk (1959) (see Table 4, p. 37). Shale samples were boiled and the clay fraction decanted to obtain the fossil residue.

Generic identification of fossils was made only through use of the paleontologic literature and thus are subject to revision by specialists. General categories such as "productids" and "crinoids" are used because more refined distinction within such groups is not possible in thin section. Relative abundance of the biota in each facies was estimated from polished slabs, thin sections, and photographs, and is summarized in Table 2.

DESCRIPTION OF FACIES

Wyandotte facies are based on a combination of features observed in the rock, potential genetic significance of those features, and dimensions of the facies unit. Several micritic facies were differentiated on the basis of fossil assemblages and primary structures which are environmentally significant. The calcarenite facies was defined as a mixture of different end-member constituents (Fig. 21).

TABLE 2.—Biota of each facies in the Wyandotte Limestone. R=rare; C=common; A=abundant.

	Facies						
Organism	Terrigenous	Stromatolite-sponge	Algal-bank	*Archaeolithophyllum* cap	Calcarenite	Oölite	Shelly mud
Phylloid algae							
Archaeolithophyllum							
missouriense		C	R-C	A	A	R	
lamellosum				A			
Anchicodium		C	A				
Other			R				
Epimastopora					R		
Stromatolitic algae							
crusts		A					
Osagia			R		C-A	R	C
Foraminifers							
Calcitornellid		C	R	R			
Tetrataxid		C	R				
Triticites	R-A				R-C		
Calcisponges		C			R		
Lophophyllid corals	R	R	R				
Bryozoans							
fenestrate	C	C	C		C-A	R	C-A
ramose	C	C	C		C	R	C
encrusting		C	C				
Brachiopods							
Productids	C	C	C-A		C	R	C
Composita	C	C	C-A	C	C	R	C
Punctospirifer	C	C	C		R	R	
Neospirifer	C	R	R				
Hustedia	C	C	C				
Enteletes			R-C				
Ambocoelia		R					
Mollusks							
Gastropods	C	C	C	C	C	R	C
Pelecypods	R				C-A	C	R-C
Cephalopods					R	R	
Arthropods							
Trilobites		R	R		R	R	R
Ostracodes		R	R		R	R	R
Echinoderms							
Crinoid ossicles	A	A	A		A	C	C
Echinoid spines	R	R	R		R	R	
Burrowing organisms		C-A	C	C	C	C	C

Because facies represent sediments formed contemporaneously side by side, they are bound to be intergrading and interfingering, owing to lateral shifting of environments. Boundaries of facies thus are arbitrary and fixed on diagrams only as a matter of convenience for discussion. Facies characteristics are summarized in Table 3.

TERRIGENOUS FACIES

Field description.—The terrigenous facies consists predominantly of shale with a minor amount of sandstone. The chief rock type is gray to dark-gray, silty to sandy shale which exhibits medium to poor bedding. Quartzose sandstone occurs as cross-stratified and ripple-marked lenses as much as 3 feet thick in the middle Farley shale in Platte County, Missouri, and as a light-gray, parallel-bedded lens in the Island Creek Shale at Locality 4. Minor rock types include a thin, limonitic, nodular layer in the middle of the Island Creek Shale at Locality 19 and nodular limestone in the upper part of the Quindaro Shale at Locality 1.

Fossil assemblage.—The terrigenous facies is unfossiliferous except in the top few inches, just below a shale-limestone contact. Where shales are thin, they are commonly fossiliferous throughout, as is the Quindaro at most localities and the Island Creek above algal banks near Stilwell and in the Olathe-Bonner Springs area (Fig. 9, *D*).

The fossil assemblage in the top of the terrigenous facies (Table 2) typically extends into the lower few inches of the overlying carbonate facies. The adjacent basal layer of carbonate is a silty, packed biomicrite in which skeletal grains are locally coated with *Osagia* (Fig. 15, *A*).

Crinoid columnals, fenestrate and ramose bryozoans, and brachiopods dominate the assemblage almost everywhere except in the thin Island Creek above algal banks, where a highly elongate form of *Triticites* occurs in great abundance (Fig. 15, *A*). *Triticites* is only a minor constituent elsewhere and is typically smaller and less elongate.

Stratigraphic relationships.—The shale members of the Wyandotte, whose distribution has been discussed previously, comprise the terrigenous facies. A few shale partings between the thin, wavy limestone beds of the algal-bank facies widen locally to several inches. These lenticular shales show no tendency to become thicker or more numerous toward areas where the shale members are thicker and, therefore, are included within the algal-bank facies.

STROMATOLITE-SPONGE FACIES

Field description.—The stromatolite-sponge facies typically occurs as one or two massive, dark bluish-gray limestone beds overlying a shale. At the base of the limestone in most exposures are a few, thin, slabby layers of shaly biomicrudite representing the downward transition to shale. The underside of these shaly biomicrudite layers exhibits overlapping burrows averaging 1 inch in diameter and extending downward into the topmost layer of shale. Burrow mottling is present throughout the stromatolite-sponge facies.

Characteristic laminated algal stromatolites and calcisponges are readily apparent in the field. The stromatolites are space-linked hemispheroids (Logan, Rezak, and Ginsburg, 1964), and appear as isolated crusts, averaging about 0.5 cm in thickness and 5 to 10 cm in length (Fig. 16, *A*). They may occur in growth position scattered throughout dark, burrow-mottled, intraclastic biolithite or as fragments rolled out of place in biomicrudite or intramicrudite. Domal irregularities in the crusts are small and occur at irregular intervals around intraclasts of carbonate mud and shell fragments, and over microrelief in the substrate. Locally, voids formed by mud-cracking beneath algal crusts were sheltered from infilling by carbonate mud (Fig. 16, *A*). Increase in thickness, length, and density of laminated algal crusts is associated with increase in brecciation and fossil abundance in the micrite.

Petrographic description.—Microscopic examination of the stromatolitic crusts reveals irregular layers of micrite, microspar, (Fig. 17, *E, F*) encrusting cyclostome bryozoans, and calcitornellid and tetrataxid foraminifers. Some stromatolites encrust blades of the phylloid alga *Archaeolithophyllum* (Fig. 16, *B*; 17, *E*). Fragments of *Archaeolithophyllum* and *Anchicodium* may occur in the micrite between stromatolitic crusts. The alga *Anchicodium* locally forms a blade-supported intramicrudite in which micrite and small intraclasts or pellets fill depressions on top of the blades (Fig. 16, *D*). Angular grains that may be calcite pseudomorphs after anhydrite or celestite (Illing, Wells, and Taylor, 1965, p. 97; Beales, 1965, p. 69) occur in a micritic matrix in one specimen (Fig. 16, *D*). Microspar fills some burrows and mud cracks.

The dark color of this facies may be due primarily to presence of sulfides disseminated throughout the micrite. Pyrite and sphalerite crystals are apparent in the field and on polished slabs. These minerals were not detected in the other carbonate facies.

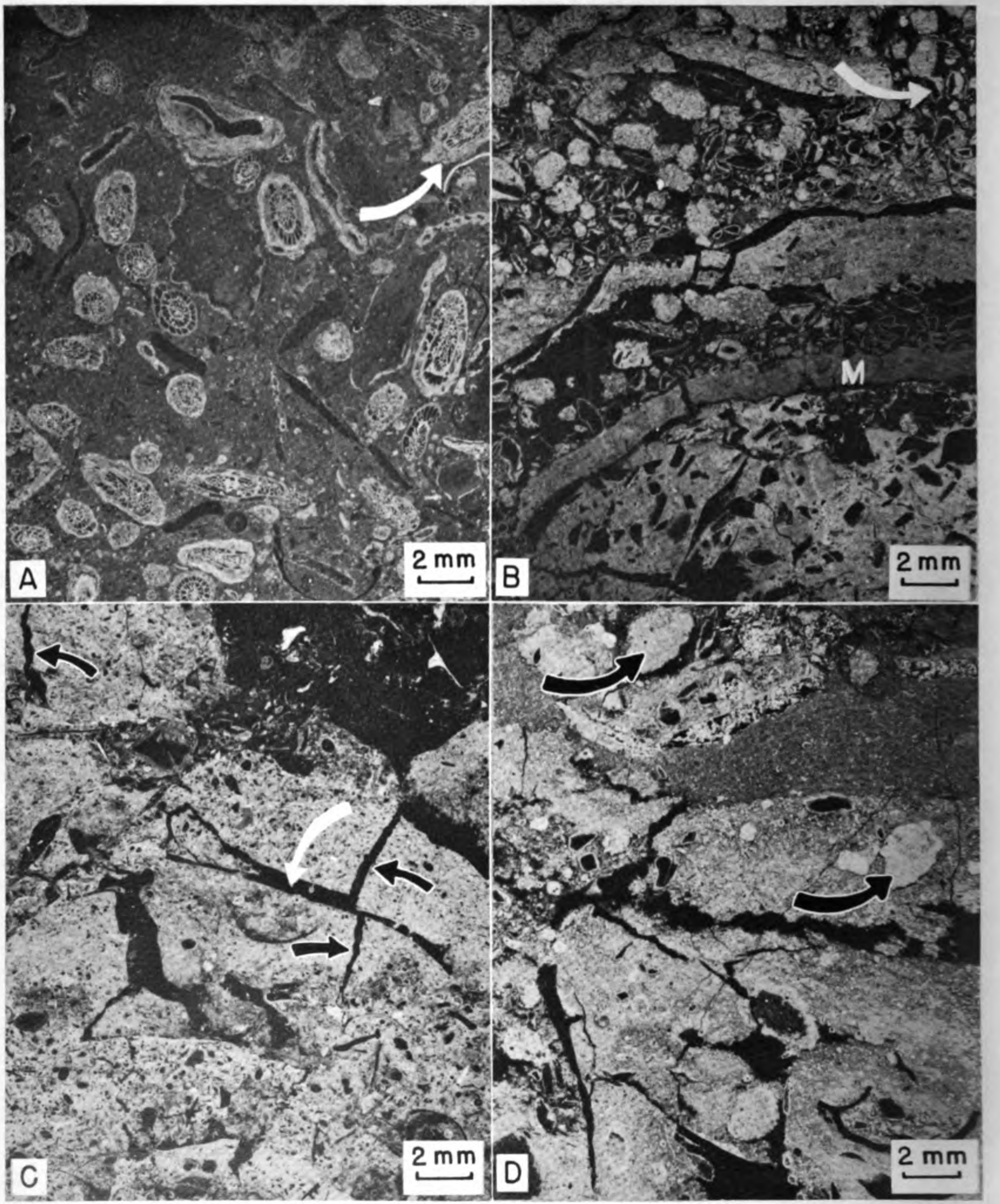

FIGURE 15.—Negative prints of thin sections of algal-bank facies. *A,* Fusulinid-bearing silty biomicrite. Transition zone between terrigenous facies of Island Creek Shale and overlying algal-bank facies. Fusulinids *(Triticites)* have been broken, abraded, and some coated with *Osagia* (arrow). Locality 11(12).* *B,* Phylloid algal intrasparrudite. Thin layers of micrite (M) have been broken into intraclasts. Small, angular, spar-replaced fragments of phylloid algae (arrow) have thin micritic envelopes that set them off from matrix. Micrite is "clotted" or pelleted. Locality 9(5). *C,* Dismicrite. Layers of micrite have spar-filled triangular cracks opening both up and down from bedding surfaces (black arrows). White arrow points to fragment of *Anchicodium.* Locality 1a. *D,* Intramicrudite. Rounded intraclasts (arrow) in micrite matrix. Locality 9(7).

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* Sample number in parenthesis after locality number gives stratigraphic position on Plate 1.

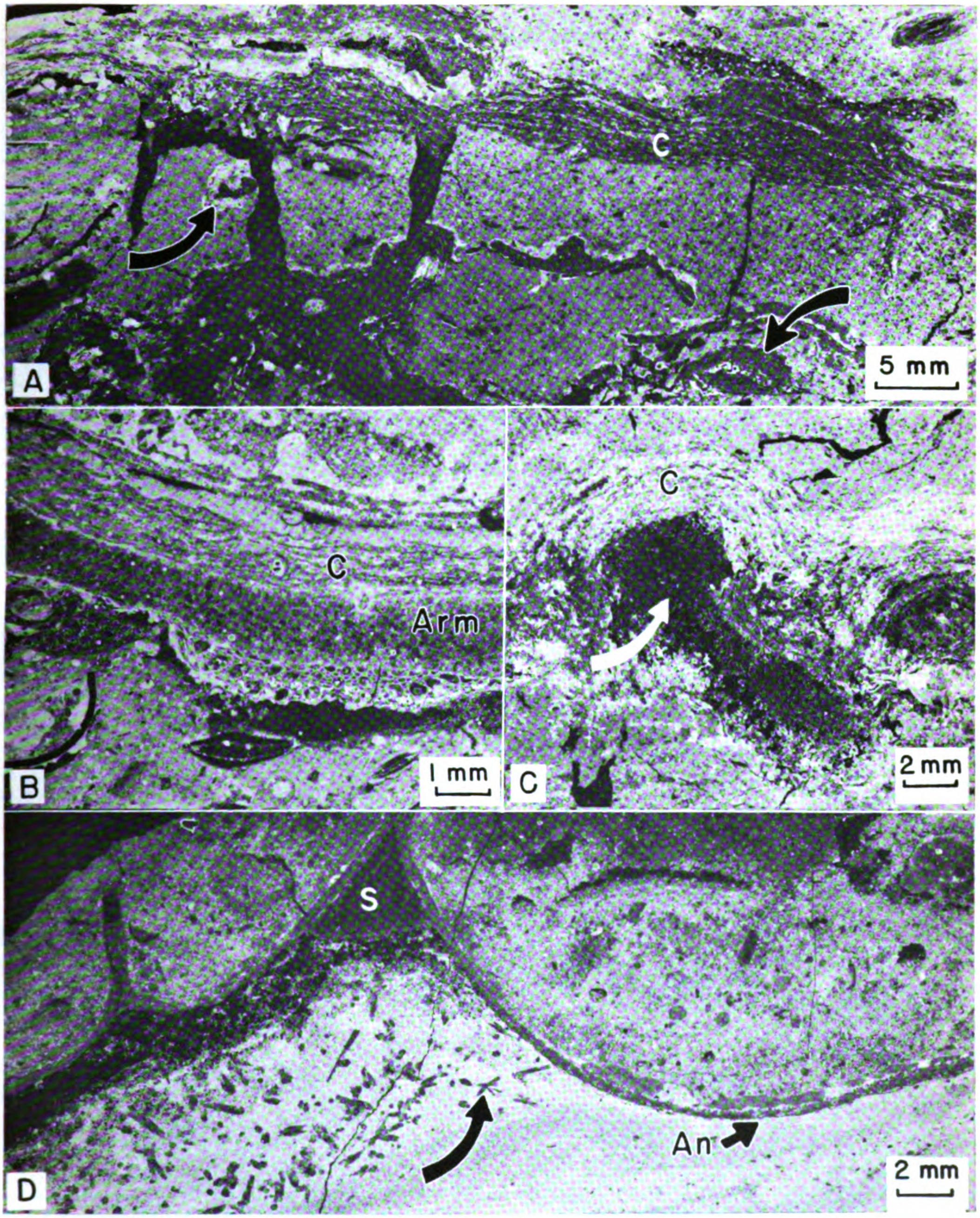

FIGURE 16.—Negative prints of thin sections of stromatolite-sponge facies. *A,* Stromatolitic biolithite. Mud-cracked biomicrite beneath algal-stromatolite crust (C). Algae encrust and are encrusted by calcitornellid foraminifers (arrows). Locality 21(2).* *B,* Stromatolitic pelmicrite. Algal-stromatolite (C) encrusting blade of *Archaeolithophyllum missouriense* (Arm). Encrusting byrozoan beneath algal blade suggests blade was once upright. Locality 21(2). *C,* Stromatolitic biolithite. Calcisponge fragment (arrow) surrounded by dismicrite and covered by algal-stromatolite crust (C). Locality 21(2). *D,* Phylloid algal pelmicrite. Large blades of *Anchicodium* (An) lying concave-upward and filled with pelmicrite. Limonitic, silty micrite beneath blades contains possible calcite pseudomorphs after anhydrite or celestite (arrow), some with hexagonal cross sections. Spar (S) fills primary voids beneath higher parts of blades. Locality 1(3).

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* Sample number in parenthesis after locality number gives stratigraphic position on Plate 1.

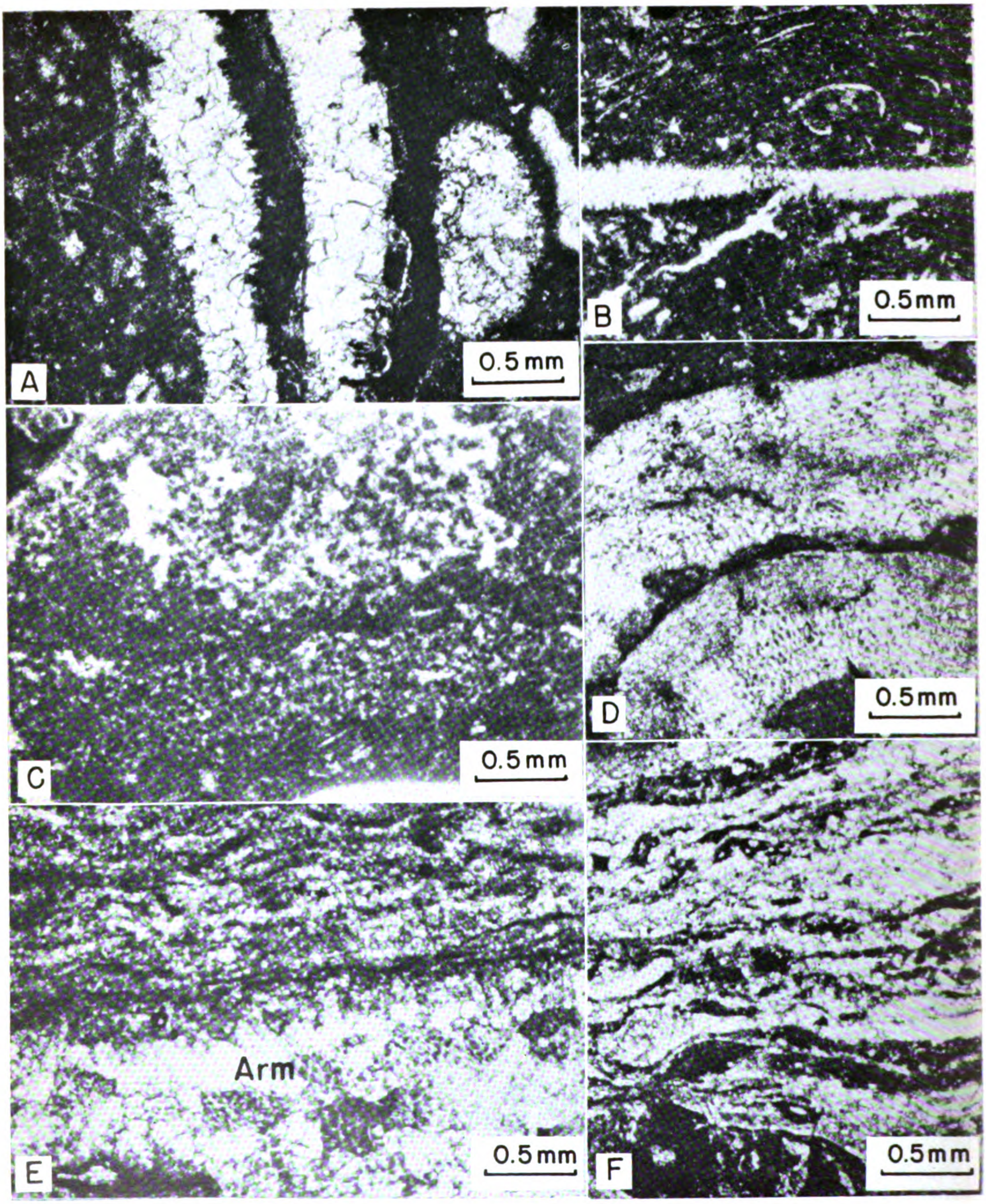

FIGURE 17.—Photomicrographs of thin sections of constituent grains and algal structures. *A*, Two *Anchicodium* blades. Note parallel threadlike utricles perpendicular to outer margin of blades. *B*, *Eugonophyllum?* blade across center. Note cross section of rounded utricles connected by branchlets perpendicular to margin of blade. *C*, Portion of intraclast showing smooth surface (bottom) that is mold of an algal blade; uncompacted micrite is composed of pellets with "fluffy" boundaries and thus appears "clotted." Note increase in packing density downward away from top sheltered by next higher algal blade. *D*, *Archaeolithophyllum missouriense* with typical cellular structure. *E*, Algal-stromatolite crust on top of *Archaeolithophyllum missouriense* blade with cellular structure (Arm). Note lack of skeletal structure in stromatolite. *F*, Algal-stromatolite crust showing interlayered micrite, microsparite, and various encrusting organisms.

Fossil assemblage.—The biota associated with the laminated algal crusts includes forms characteristic of the terrigenous facies; however, the fauna is more diverse, except in the transitional beds at the base (Table 2). Blades of the phylloid algae *Archaeolithophyllum* and *Anchicodium,* calcisponges, encrusting foraminifers, *Ambocoelia,* trilobites, ostracodes, and unidentified burrows, distinguish the biota of this facies from that of the terrigenous facies. Calcisponges occur as unencrusted whole fossils or as fragments associated with and locally encrusted by stromatolites (Fig. 16, *C*). These sponges may belong to the family Wewokellidae King, 1943.

Stratigraphic relationships.—The stromatolite-sponge facies comprises all the Frisbie Limestone Member north of the interbank area and the basal few feet of the Argentine Limestone in Platte County, Missouri, and at Localities 4 and 5 near by in Kansas. This facies overlies the terrigenous facies and is either overlain by a thin wedge of the terrigenous facies or, in the Argentine, is gradational upward into the algal-bank facies.

ALGAL-BANK FACIES

Field description.—The algal-bank facies is a light-gray to buff, relatively soft, thin, wavy-bedded biomicrite. In a fresh exposure the wavy beds are separated by concentrations of paper-thin layers of dark argillaceous material enclosing oriented and typically fragmented fossil debris (Fig. 18, *A*). Weathering tends to widen these dark layers (Fig. 9, *C*), differentially exposing the fossils and coloring the limestone beds with a buff to yellow limonitic stain.

Biomicrite beds average about 6 inches in thickness but range from 1 inch to as much as 1 foot. Internal stratification is evident in parallel to subparallel orientation of the large phylloid algal blades and some productid shells, but most finer bioclastic material appears randomly oriented.

Thin beds of nodular chert and associated dolomite rhombs occur in the middle or lower part of the algal-bank facies in the Argentine Limestone. Large chert nodules are abundant only locally, as at Locality 26 in the Stilwell bank area, and disappear within 2 miles. This chert tends to obliterate primary structures and some fossils and appears to be definitely secondary in origin.

Petrographic description.—The algal-bank facies characterizes thicker parts of limestone members but in several areas persists into the thinner units. In the thick portions of the facies, however, the phylloid algal biomicrite has a disturbed or intraclastic primary texture, which is not found in the thinner units. Throughout the thickened portions of the bank, the lithology ranges from undisturbed biomicrite to unrounded and rounded intrasparrudite. The entire range of disturbed primary texture can be observed within a few feet vertically and laterally at any one locality. No regular vertical variation of primary texture is maintained from one outcrop to another.

Biomicrite characteristic of the algal-bank facies contains from 50 to 95 percent micrite. The amount of bioclastic material required to form a packed biomicrite, in which grains support each other, varies with size and shape of the grains. Perhaps as little as 20 percent bulk abundance of large curved blades of phylloid algae or large fenestrate bryozoans can support each other, as suggested experimentally by Dunham (1962). Smaller fragments of these fossils or such grains as brachiopod shells must form 30 to 50 percent of the rock to be grain-supporting. Spar-filled voids beneath the shelter of organic fragments is good evidence of grain support.

Most of the carbonate mud matrix is less than 5 μ in grain size but in a few cases there is some matrix material in the size range of 10-30 μ. This larger matrix material may be either microsparite, formed by grain enlargement from micrite, or finely comminuted bioclastic debris.

In many specimens micrite is loosely packed and has a "clotted" appearance where it has been sheltered from compaction by supported algal blades. These "clots" somewhat resemble pellets in that they have no internal structure and range in size from 30-50 μ (Folk, 1959). Their poorly defined grain boundaries, however, give them an irregular, indistinct outline, and they appear to be aggregates of micrite set in spar (Fig. 17, *C*). An increase in packing density causes obliteration of the clots or pellets resulting in a more solid micritic matrix. The change from loosely packed, clotted micrite to more densely packed, homogeneous micrite may occur within a few millimeters vertically (Fig. 17, *C*).

Internal stratification in the biomicrite is evident in only a few samples containing horizontal blades of algae (Fig. 19, *D*). Most biomicrite has been stirred and burrowed.

Previous existence of phylloid algal blades within dismicrite[8] or intrasparrudite can be

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[8] "Dismicrite" is Folk's (1959, p. 28) term for disturbed micrite with less than 1 percent allochems. In this study the term is used for micrite containing more than 1 percent allochems, only a slight deviation in terminology.

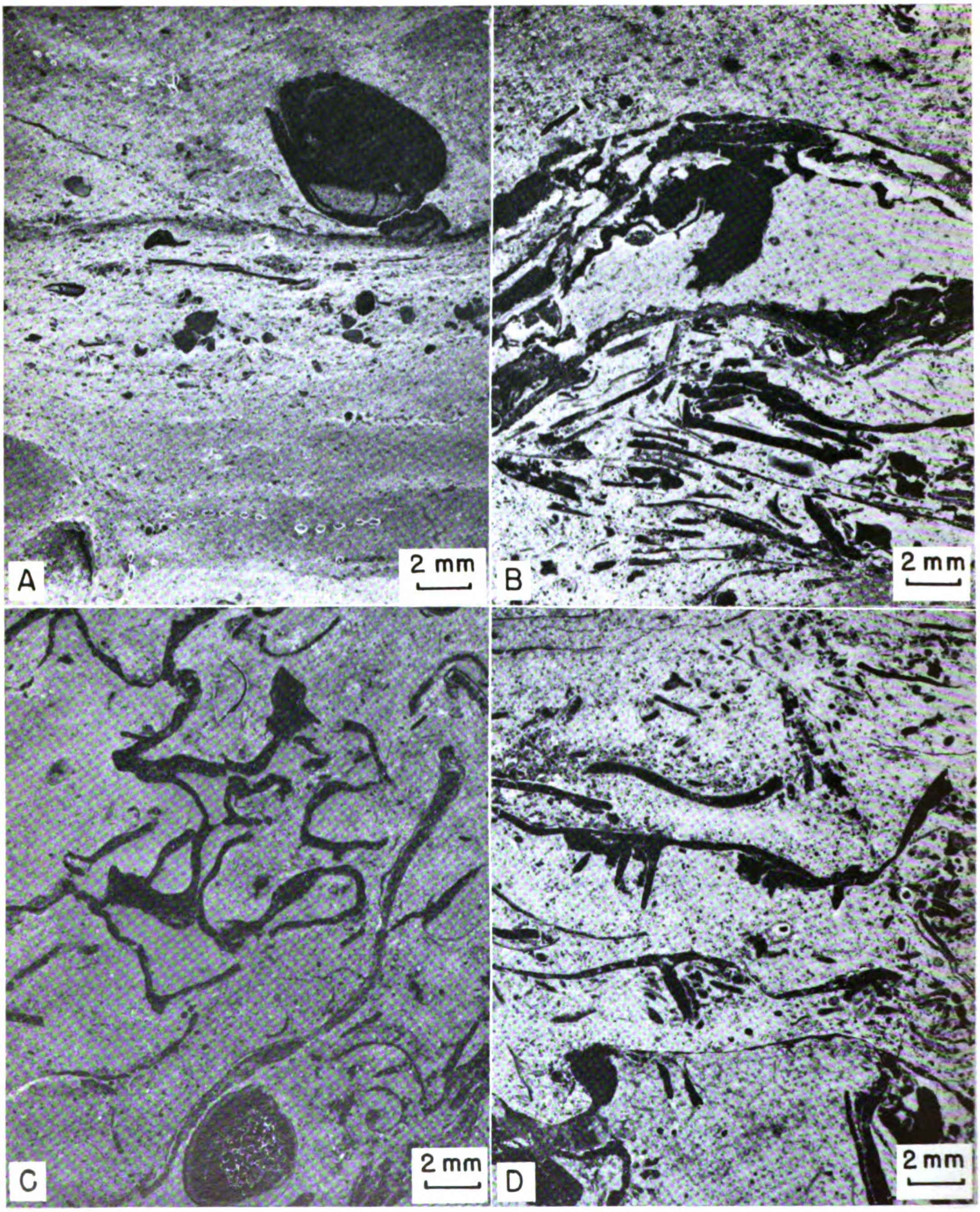

Figure 18.—Negative prints of thin sections of algal-bank facies. *A*, Biomicrite. Horizontal argillaceous laminations that contain brachiopod and crinoid fragments tend to weather back from outcrop and cause surrounding pure biomicrite beds to stand out in relief (Fig. 9, *C*). Locality 11(13).* *B*, Blade-supported *Anchicodium* biomicrite. Algae and calcitornellid foraminifers encrust blades. Locality 1(18). *C*, Phylloid algal biomicrite. Phylloid algae, possibly *Archaeolithophyllum*. Acetate peel. Locality 17(5). *D*, Phylloid algal biomicrite. Phylloid algae, possibly *Eugonophyllum*. Locality 1a.

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* Sample number in parenthesis after locality number gives stratigraphic position on Plate 1.

detected by subtle primary textures. Color mottling and differential compaction of micritic clots within intraclasts, which have a smooth, undulating base, indicate compaction onto an algal blade, which was later recrystallized or dissolved (Fig. 19, *C*). In other examples, only thin micritic envelopes (Bathurst, 1964) around the sparry calcite of algal fragments set them off from void-filling spar (Fig. 15, *B*).

Disturbance and fragmentation of biomicrite ranges from slight cracks to angular intraclasts exhibiting slight movement (Fig. 19, *C*) to intraclasts abraded into rounded lumps (Fig. 15, *D*). This range may be observed in a single specimen. Cracks are often triangular, opening at an obscure bedding plane, and gradually diminishing a short distance into the micrite (Fig. 15, *C*). These triangular cracks occur both up from and down from the margins of a micrite layer or intraclast (Fig. 15, *C*). A few cracks open within a single biomicrite layer and diminish in both directions before reaching a bedding-plane surface (Fig. 15, *C*; 19, *C*).

Cracks and spaces between angular intraclasts are typically not filled with micrite (Fig. 15, *B, C*). Rounded intraclasts, indicating more disturbance of the sediment, are associated with more micrite filling spaces between them (Fig. 15, *D*; 19, *A*).

Sparry calcite fills most voids except for the interiors of some large brachiopods. Skeletal material has either been recrystallized or the original material dissolved out and sparry calcite precipitated in its place. In some cases the enclosing micrite has collapsed into the void before spar was deposited, leaving only a thin outline of the shape of the skeletal fragment (Fig. 19, *B, D*).

Fossil assemblage.—The dominant fossils of the bank facies are phylloid algae represented by the green codiacean *Anchicodium* Johnson (1946) (Fig. 17, *A*; 18, *B*) and the red corallinacean *Archaeolithophyllum missouriense* Johnson (1956, Fig. 17, *D*; 19, *C*). Abundance of phylloid algae generally shows few detectable trends in individual bank development. An exception is the increase in relative abundance of *Archaeolithophyllum* upward in the Argentine. In overlying banks of the lower Farley, the abundance of phylloid algae is greater and the relative percentage of *Archaeolithophyllum* is higher. Diversity of shapes of codiacean blades suggests that more than one species or perhaps other related genera, such as *Ivanovia* Khvorova (1946) or *Eugonophyllum* Konishi and Wray (1961) (Fig. 17, *B*; 18, *D*), may be represented in the Wyandotte. Other unidentified forms of phylloid algae that are unlike published descriptions of any of the above genera were found in some horizons of the algal-bank facies.

Algal blades up to 10 cm in length occur in the micrite matrix. Where these blades were dense enough to support each other they formed sheltered cavities. Sediment with different texture or color collected in a few cavities, and sparry calcite was later precipitated in all remaining cavities (Fig. 19, *D*).

Brachiopods, all growth forms of bryozoans, crinoid columnals, and small horn corals are found throughout the algal-bank facies (Table 2). The brachiopods are *Composita, Dictyoclostus, Juresania, Echinoconchus, Marginifera, Linoproductus,* and *Neospirifer.* No systematic variation in the relative abundance of brachiopods was detected in most of the bank facies. At certain horizons, however, they form layers of shell-supported biomicrudite up to 1 foot thick. These brachiopod concentrations have a limited lateral extent and cannot be traced from one outcrop to another. One systematic variation in brachiopod diversity first noted by Newell (1935) is apparent in the Argentine Limestone. *Enteletes* occurs to the exclusion of almost all other brachiopods in the southwestern part of the study area (Loc. 14, 28) but is rare to the north.

The algal structure *Osagia,* along with cyclostome bryozoans, and calcitornellid and tetrataxid foraminifers encrust algal blades and fenestrate bryozoan fronds in the bank facies (Fig. 18, *B*).

Skeletal debris similar to that in the biomicrite layers is concentrated along shaly bedding planes (Fig. 18, *A*). Phylloid algal fragments are conspicuously absent from these shaly layers, either because they were rapidly dissolved and their molds not preserved, or they never inhabited these local areas.

Stratigraphic relationships.—The algal-bank facies comprises most of the abnormally thick portions of the Argentine and Farley Limestone members in the study area (Fig. 2). Five separate algal banks have been identified in the Wyandotte in and around Johnson County, Kansas. Four of these consist of the algal-bank facies. The exception is the bank in the upper Farley at Bonner Springs, which lithologically belongs to the *Archaeolithophyllum* cap facies. Cross sections of these banks are shown on Plate 1.

The most extensive bank development occurs in the Argentine Limestone, which accumulated to a thickness of about 40 feet in the Kansas City-Olathe-Bonner Springs area,

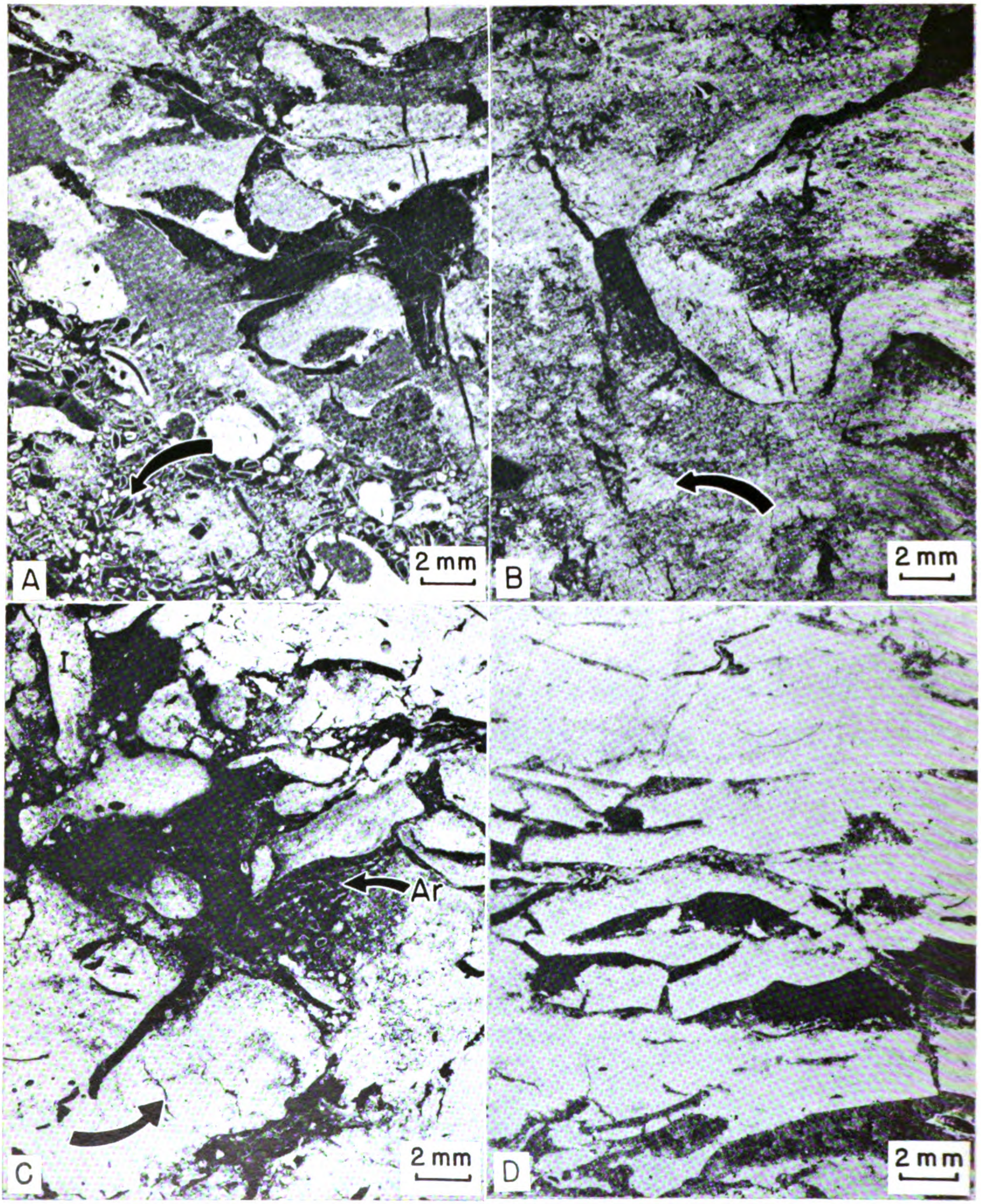

FIGURE 19.—Negative prints of thin sections of algal-bank facies. *A*, Intramicrudite. Intraclasts in darker micrite matrix. Primary voids between some intraclasts filled with spar. Small angular fragments of phylloid algae (arrow) have been replaced with spar but are defined by thin micritic envelopes. Some of "muddy" matrix is relatively coarse-grained and seems to be composed of finely broken skeletal debris or pellets. Locality 9(6).* *B*, Phylloid algal dismicrite. Layers of dismicrite and intramicrudite. Intraclasts (arrow) are very indistinct and seem deformed around other clasts. Locality 5(12). *C*, Phylloid algal intrasparrudite. Much of the spar-filled space in center contains fragments of *Archaeolithophyllum* (Ar) defined by thin micritic envelopes. Spar also fills primary voids between intraclasts. Intraclast (I) shows smooth, wavy surface boundary on left side that is a mold of the surface of a phylloid algal blade, and "clotted" surface on right side that was probably an uncompacted sur-

while an isolated bank attained a similar thickness in the Stilwell area (Fig. 2). Smaller banks developed in the lower Farley limestone over the Argentine banks at Stilwell and Olathe.

A significant lateral facies change from algal bank to shelly mud occurs where the Argentine thins rapidly across the interbank area. In this change, phylloid algae are progressively replaced by fenestrate bryozoans, crinoid columnals, and productid brachiopods. A similar change occurs in the lower part of the Argentine at the north end of the study area where only 2 to 3 feet of algal-bank facies remains at the top of the member.

Preservation of phylloid algae.—In this study, phylloid algae were identified from published descriptions by Johnson (1946, 1956, 1961), Konishi and Wray (1961), and Wray (1964). Internal structure is rarely preserved in *Anchicodium* but is somewhat more common in *Archaeolithophyllum.* Where internal structure has not been preserved, general shape and dimension of the blades was used where possible to distinguish between the groups; however, this is difficult because of the external similarity of the two forms.

Differential preservation of the two groups of phylloid algae can be explained by the stability order of the different forms of $CaCO_3$ (Friedman, 1964). Codiacean algae are composed of aragonite, which is dissolved more easily than high-magnesium calcite, the mineral secreted by corallinacean algae. Apparently aragonite is either recrystallized or dissolved out, leaving a mold which is later filled with sparry calcite. This results in complete obliteration of original cell structure, leaving only external form.

On the other hand, high-magnesium calcite seems to lose magnesium by leaching while the original calcite crystal remains intact. Because low-magnesium calcite is stable, the possibility of preservation of cell structure is increased. Nevertheless, cell structure has been destroyed in many fragments of *Archaeolithophyllum.*

Two different forms of obliteration of the cell structure in *Archaeolithophyllum* are common in the Wyandotte. In one form the original texture has been obliterated by degrading crystallization (Folk, 1965), forming a texture similar to cryptocrystalline calcite described by Purdy (1963) in Recent carbonate grains in sediments off the Bahamas. The other involves solution of original or later recrystallized calcite, leaving a mold, with infilling by sparry calcite. Both forms are observed in a single blade. Cell structure tends to be better preserved in red algae in the spar matrix of the calcarenite facies than in the micrite matrix of the algal-bank facies.

ARCHAEOLITHOPHYLLUM CAP FACIES

Field description.—This facies characteristically occurs as a single bluish-gray mottled limestone bed that is more resistant than the underlying wavy-bedded algal-bank facies. It is typically closely associated with thin layers of calcarenite. In some localities these two facies are interbedded, but elsewhere large intraclasts of typical *Archaeolithophyllum* cap lithology are incorporated into the calcarenite facies.

Petrographic description.—Phylloid algae are closely associated with primary structures in micrite. Fragments of *Archaeolithophyllum missouriense* Johnson (1956) are typically abundant enough in the micrite to be blade-supporting (Fig. 17, *D*; 20, *A*). Burrows and spaces beneath algal blades are filled with micrite that is generally lighter in color than the surrounding matrix. Some spaces between large intraclasts are filled with biosparite similar to the overlying calcarenite facies (Fig. 20, *B*). The encrusting species *Archaeolithophyllum lamellosum* Wray (1964) binds layers and angular intraclasts of biomicrite to form a biolithite (Fig. 20, *C, D*).

Fossil assemblage.—Faunal diversity of the *Archaeolithophyllum* cap facies is much less than in the closely associated algal-bank and calcarenite facies (Table 2). *Composita* and high-spired gastropods are the only common invertebrate fossils in the assemblage. The

face sheltered by other algal blades before clast was moved out of place (enlarged view, Fig. 17, *C*). Note cracks in micrite (curved arrow) that diminish in both directions and do not extend to surface. Locality 29. *D*. Blade-supported phylloid algal dismicrite. Algal blades have been dissolved and micrite matrix has caved into voids beneath blades. Note smooth surface that was against algal blade and irregular "clotted" surface that was protected from compaction beneath original blade. (Compare with intraclast in Fig. 19, *C*). Voids are filled with spar. Acetate peel. Locality 30.

• Sample number in parenthesis after locality number gives stratigraphic position on Plate 1.

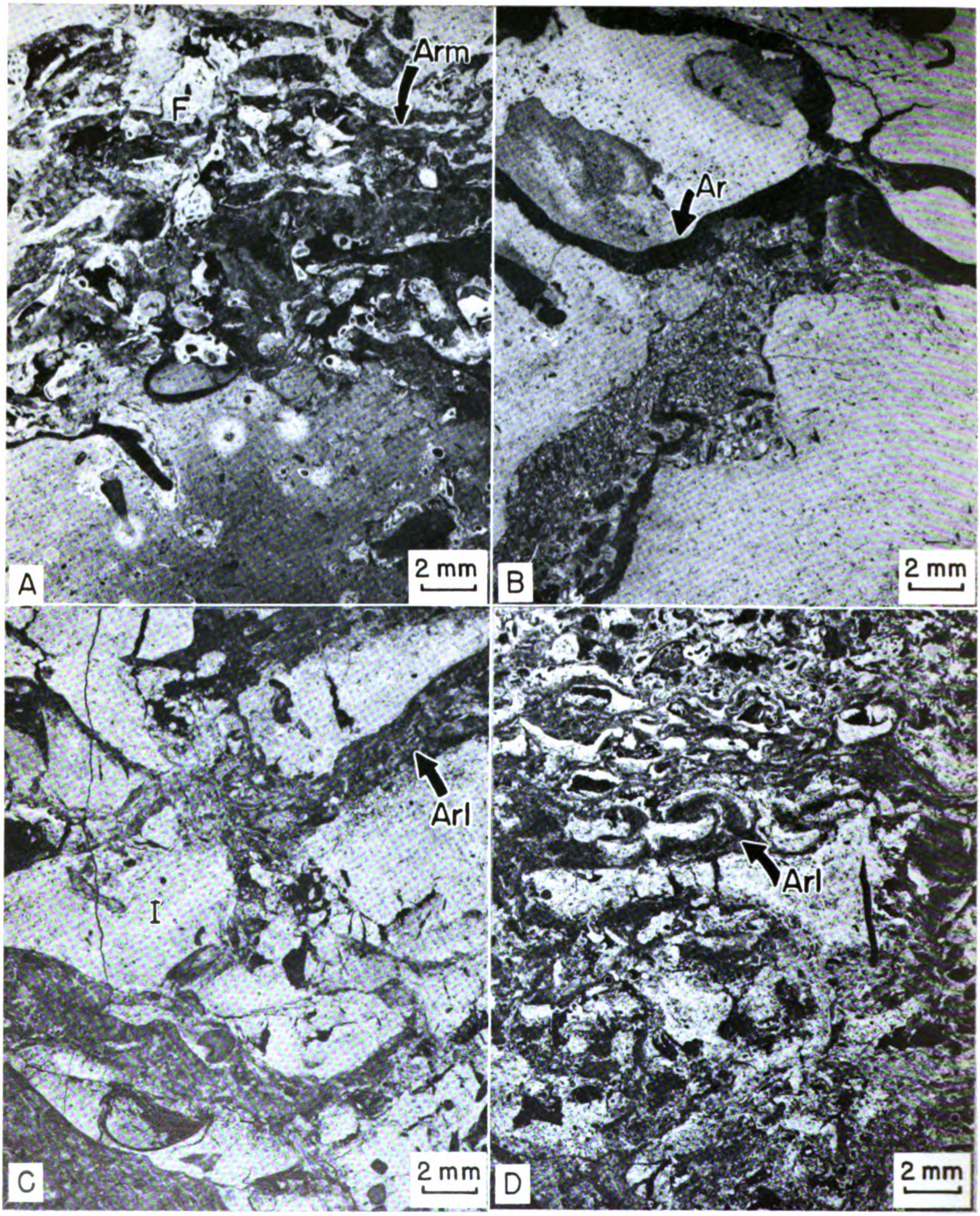

FIGURE 20.—Negative prints of thin sections of *Archaeolithophyllum* cap facies. *A*, Blade-supported phylloid algal biomicrite. Fragments of *Archaeolithophyllum missouriense* (Arm) encrusted by calcitornellid foraminifers (F). Cell structure of algae is well preserved (see Fig. 17, *C*). Locality 11(24).[*] *B*, Phylloid algal biomicrite. Crack beneath *Archaeolithophyllum* blade (Ar) is filled with biosparite from overlying calcarenite facies. Locality 9(12). *C*, Phylloid algal biolithite. Layers of *Achaeolithophyllum lamellosum* (Arl) bind intraclasts (I) of micrite. Clasts have been cracked by differential compaction. Locality 1(25). *D*, Phylloid algal biolithite. Layers of *Archaeolithophyllum lamellosum* (Arl) bind layers and intraclasts of micrite. Cell structure of algae has been obliterated by recrystallization. Locality 9(25).

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[*] Sample number in parenthesis after locality number gives stratigraphic position on Plate 1.

micrite has been intensely burrowed, but burrowing organisms other than gastropods have not been preserved.

Stratigraphic relationships.—This facies occurs as thin layers, typically less than 2 feet thick, capping thicker portions of the algal-bank facies in the Argentine and lower Farley limestones (Pl. 1). It does not cap developments of algal-bank facies less than about 15 feet thick, as at Localities 17, 19, 21, and 23 in off-bank areas.

The upper Farley limestone consists of alternating layers of *Archaeolithophyllum* biomicrudite and biolithite and biosparite of the calcarenite facies. In the Bonner Springs area the calcarenite layers are relatively thin and the whole upper Farley is considered *Archaeolithophyllum* cap facies. Because this unit exceeds 20 feet in thickness and is made up essentially of phylloid algae and micrite, it is termed "a bank" in this area (Fig. 2).

CALCARENITE FACIES

Field description.—The calcarenite facies occurs as one or several horizontal, massive to faintly cross-stratified beds ranging from 6 inches to 2 feet in thickness. It is interbedded with the *Archaeolithophyllum* cap facies on top of the algal-bank facies, and also occurs in places between two shale members. A thin layer of shaly pelecypod biomicrudite is commonly found at the base of the calcarenite facies above the terrigenous facies.

Petrographic description.—The calcarenite facies is mainly biosparite composed of three types of grains: (1) skeletal debris, (2) well-rounded micrite intraclasts containing bioclastic material, and (3) *Osagia*-coated grains. These types may be considered end members of a ternary system (Fig. 21). Complete gradation is found only between intraclasts and skeletal grains. *Osagia*-coated grains may occur with only minor amounts of the other constituents. Rocks composed mainly of *Osagia*-coated grains have not been set off as a separate facies because (1) these grains do occur as a minor constituent in much of the calcarenite facies; (2) nuclei of the coated grains are similar to uncoated grains found elsewhere in the calcarenite facies; and (3) not enough is known about the environmental significance of *Osagia* at this time to warrant distinction as a separate facies.

Algal fragments typically show good preservation of cell structure (Fig. 22, *A*). Fragments of *Archaeolithophyllum* in which cell structure has been obliterated by recrystallization, however, are easily mistaken for intraclasts. Most grains are moderately to well sorted and well rounded (Fig. 22, *B*), but a few large pelecypod and brachiopod shells, as well as fenestrate bryozoan fronds, were buried before being broken. The micrite intraclasts contain gastropods and phylloid algal material, indicating derivation from the *Archaeolithophyllum* cap facies.

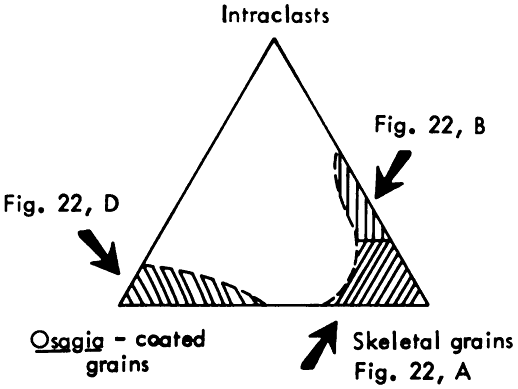

FIGURE 21.—Diagram illustrating end-member components of calcarenite facies. Total grain composition tends to fall within ruled areas. Figures cited show examples of grain types.

Osagia-coated grains locally contain encrusting calcitornellid foraminifers (Fig. 22, *D*), but this algae-foraminifer association seems to be fortuitous (Toomey, 1962), and grains are bound into aggregates also by calcitornellid foraminifers alone (Fig. 22, *C*). *Osagia*-coated grains are most common in the northeastern part of the study area and are found only as a minor constituent in the calcarenite facies elsewhere. These grains occur both in the spar and the micrite matrix.

Fossil assemblage.—Skeletal debris in the calcarenite facies includes fragments of *Archaeolithophyllum missouriense*, the green dasycladacean alga *Epimastopora* (Fig. 22, *F*), pelecypods, gastropods, nautiloid cephalopods, brachiopods, bryozoans, echinoderms, fusulinids and other foraminifers, trilobites, and ostracodes (Table 2). This is the most diverse biota in any of the Wyandotte facies. Especially notable are the abundant pelecypods, which do not occur in most of the micritic facies. These include *Myalina, Septimyalina, Aviculopecten,* and the burrowing pelecypod *Aviculopinna,* which was found in vertical living position at Locality 14.

Stratigraphic relationships.—The calcarenite facies occupies several positions relative to other facies in the Wyandotte. It occurs as massive beds 6 inches to 2 feet in thickness above the

TABLE 3.—Summary of facies characteristics.

	Terrigenous facies	Stromatolite-sponge facies	Algal-bank facies
Field	Silty shale, quartzose sandstone; parallel and cross-stratified, limonitic nodules in shale	Dark, sponge-bearing, stromatolitic biolithite; burrows on underside of lowest limestone bed	Thin, wavy-bedded, phylloid algal biomicrite; shaly layers separate limestone beds; some chert nodules
Geometry	Lenticular, lobate; tends to be thick where underlying limestone is thin and to be thin over limestone "thicks"	One or two persistent beds; little thickness variation	Forms "thicks," or banks separated by thinner areas composed of other facies
Stratigraphy	Same as shale members of Wyandotte	Comprises all of Frisbie Limestone Member north of interbank area; and base of Argentine Limestone Member in Kansas City area	Comprises most of Argentine Limestone and most of lower Farley limestone where they are more than about 10 feet thick
Petrography Allochems		Stromatolite crusts (space-linked hemispheroids), fossil debris, intraclasts	Fossils, intraclasts
Matrix		Mostly micrite; some spar in mud cracks	Mostly micrite; spar fills primary voids
Primary structures		Mud cracks beneath algal crusts; intraclasts; burrows	Mud cracks; intraclasts; burrows; voids beneath algal blades
Diagensis		Possible calcite pseudomorphs after anhydrite or celestite	Spar fills primary voids; secondary chert with dolomite rhombs
Dominant fossils	Crinoid ossicles, brachiopods, bryozoans, snails, fusulinids abundant locally	Stromatolite crusts, clacisponges, brachiopods, crinoid ossicles, snails, burrows, phylloid algae	Phylloid algae, crinoid ossicles, brachiopods, snails, bryozoans

	Archaeolithophyllum cap facies	Calcarenite facies	Oölite facies
Field	Massive-bedded, phylloid algal biolithite	Massive-bedded biosparite and intrasparite; faint cross-stratification	Massive, cross-stratified oösparite and oömicrite
Geometry	Forms thin layer over top of thick parts of algal banks	Forms thin layers at or near top of algal banks and also between shale members; interbedded with *Archaeolithophyllum* cap facies and oölite facies	Forms layers between shale members and on top of part of algal bank
Stratigraphy	At or near top of algal banks in Argentine Limestone Member and lower Farley limestone; forms bank in upper Farley in Bonner Springs area	At top of Argentine and at top of, or forming entire lower Farley limestone; interbedded in or at base of, or forms all of upper Farley limestone	Lower Farley limestone north of interbank area

Petrography Allochems	Fossils, intraclasts	Fossils, well-rounded intraclasts, *Osagia*-coated grains	Oöids, fossils
Matrix	Micrite	Mostly spar; some micrite	Spar, micrite
Primary structures	Phylloid algal-bound micrite and intraclasts, burrows	Cross-stratification	Intraclasts of oösparite, cross-stratification
Diagensis	Spar fills most primary voids	Most grains recrystallized	Many oöids dolomitized
Dominant fossils	Bladelike and encrusting algae, *Composita*, snails, burrows	Brachiopods, crinoid ossicles, snails, clams, bryozoans	Clams, crinoid ossicles, burrows

	Shelly mud facies		
Field	Thin, wavy-bedded biomicrite; very thin shaly layers separate thin limestone beds		
Geometry	Thin off-bank layers; laterally transitional to algal-bank, calcarenite, and oölite facies		
Stratigraphy	Comprises Argentine Limestone Member in interbank area; lower Farley and most of Argentine in north end of study area		
Petrography Allochems	Fossils, *Osagia*-coated grains		
Matrix	Micrite		
Primary structures	Burrows		
Diagensis	Spar fills primary voids		
Dominant fossils	Crinoid ossicles, brachiopods, bryozoans, burrows		

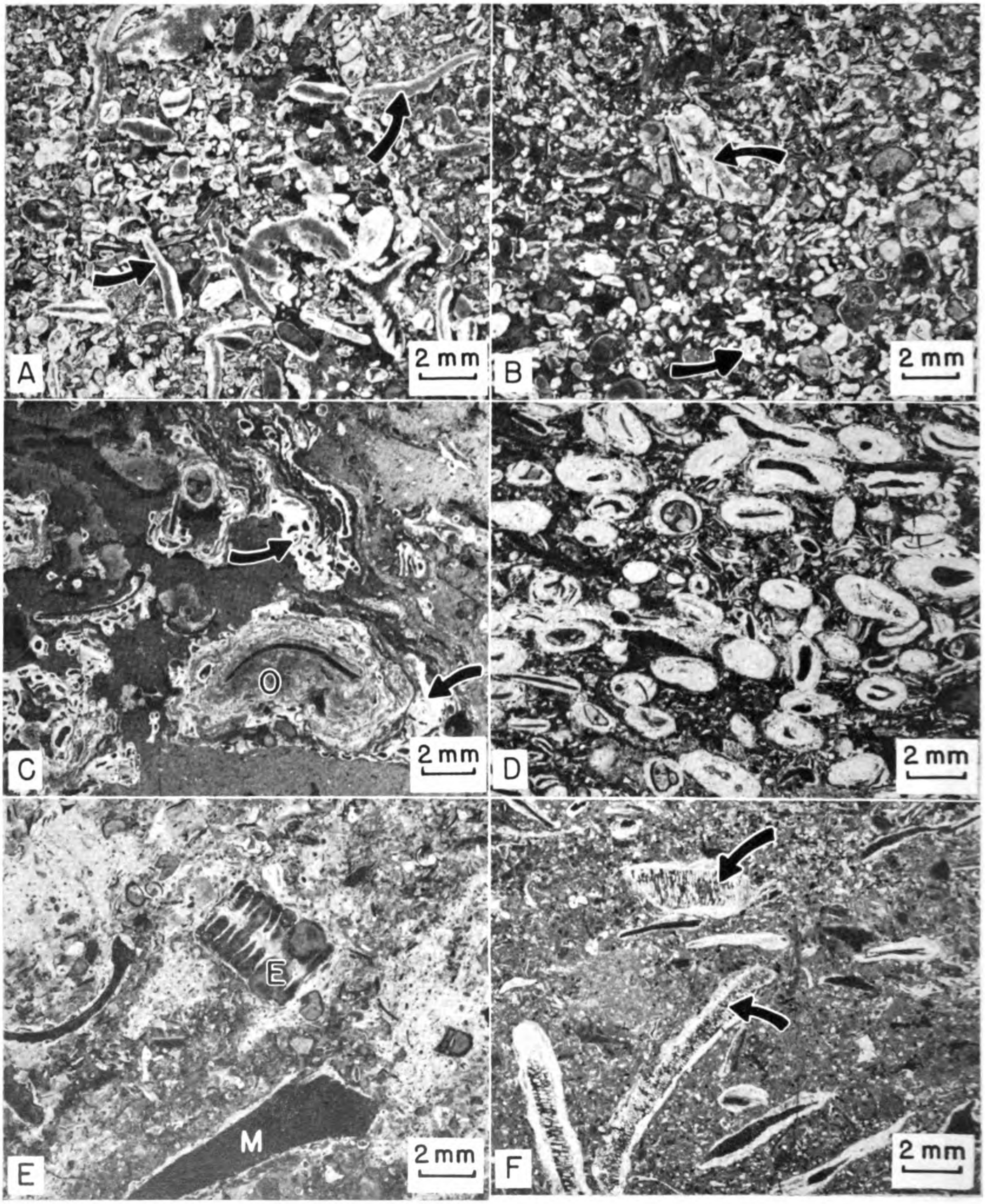

FIGURE 22.—Negative prints of thin sections of calcarenite facies. *A*, Biosparite. ***Archaeolithophyllum*** (arrows) is predominate grain. Locality 1(10).* *B*, Biosparite. Rounded skeletal grains and intraclasts (arrows). Locality 9(13). *C*, *Osagia*-calcitornellid biomicrite. Algal-coated grains (O) are bound into larger aggregates by calcitornellid foraminifers (arrows). Locality 1(24). *D*, *Osagia*-coated biosparite. Calcitornellid foraminifers along with *Osagia*. Locality 21(22). *E*, Mixed biosparite and biomicrite. Large crinoid stem segment (E) and large *Myalina* shell (M). *Osagia* and calcitornellid foraminifers coat many fragments. Locality 3(11). *F*, Biomicrudite. Large fragments of *Epimastopora* (arrows) coated with *Osagia*. Small black specks are quartz grains. Locality 17.

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* Sample number in parenthesis after locality number gives stratigraphic position on Plate 1.

TABLE 4.—Lithology of samples. Numbered samples for each locality (shown on cross sections on Plate 1) are grouped according to lithologic type.

Lithologic type	Sample Localities														
	1	3	4	5	6	9	10	11	13	14	15	17	21	23	31
1. Phylloid algal biomicrite, dismicrite, intrasparrudite, intramicrudite	3-5-6-7 8-14-15 16-18-19 20		5-7-8 12-17-18	5-6-10 11-12	8-9-12 13-14-15 16-17-19 22	5-6-7-8 17-18-19 20-21-22 23-24	1-2-3-4 5-6-9	1-2-8-9 10-14-15 17-18-23	1-2-3 5-6-7	2-3-5 6-7-8	1-4 5-6	2-3-4 5-6-12	6-7-8	4-5	1-2-3 4-5-6 8
2. Crinoidal biomicrite		6	9-10-11	8-9	3-4-5 6-7	4-16		4-5-6-7 13-16		1-4	2-3	10			
3. Skeletal biomicrite		1-2-3-4						3	4			1-11		3-11	
4. Stromatolite-sponge biolithite	1-2		1-3	2-3-4	1-2	2							1-2-4-5	1-2	
5. *Archaeolithophyllum* biolithite	25-26-27		13	13	10-11 20-23	11-25-26 29-30	7	20-24				16	/		
6. *Osagia*-coated biomicrite		10-13		1-14		1-15		12						8-9 10-14	
7. *Osagia*-coated biosparite	24			23-24									22		
8. Biosparite	9-10-21 22						12-13	22		9-10 11-12	7				
9. Biomicrite (grain-supported)		8-9-11	4-19	17	18-19	9-10	8	19				13-14 15	9-21		9
10. Intrasparite						12-13	10-11								
11. Oösparite			20-21	15-19-20 22		27-28							13-14-15 16-17-18		10-11
12. Oömicrite				16-18-21											
13. Clay-shale, siltstone	4-11-12 13-17-23	5-7	2-6-14 15	7		3-14		11-21		8-9			3-10-11 12-20	6-7-13	7
14. Quartzose sandstone			16										19		

algal-bank facies in the Argentine and is interbedded with the *Archaeolithophyllum* cap facies. Thin layers of calcarenite facies are interbedded with the oölite facies in the lower Farley and with the *Archaeolithophyllum* cap facies throughout the upper Farley. *Osagia*-coated biosparrudites dominate the calcarenite facies at the top of the Argentine and in the upper Farley toward the northeast.

OÖLITE FACIES

Field description.—The oölite facies forms typically cross-stratified beds that are generally 1 to 2 feet thick, but which may range up to 13.5 feet locally. Fossils typically stand out on the weathered surface of the oölite. Thin lenses of calcarenite are interbedded with the oölite facies. In places contacts between the oölite facies and other facies are gradational, but locally they are erosional. Slabby layers of shaly biomicrite containing oöid-filled burrows mark the base of the oölite facies where it overlies terrigenous facies.

Petrographic description.—Most of the facies is well sorted oösparite (Fig. 23, *A*), but locally it is poorly sorted oömicrite in which some oöids are not in contact. Intraclasts of oömicrite and burrow mottling are apparent in the micritic portion of this facies (Fig. 23, *B*).

Concentric laminations are preserved in a few oöids, but most have been obliterated by recrystallization or by replacement with dolomite. Many kinds of grains—skeletal fragments of any shape, microcrystalline calcite aggregates, quartz sand—serve as a nucleus for oöids, but the percentage of quartz sand nuclei increases northeastward. This trend parallels the increase in thickness of the terrigenous facies.

Near Olathe (Loc. 9) rounded intraclasts of oösparite have been coated with what may be an algal structure *(Osagia?)* and incorporated into a similar oösparite (Fig. 23, *A*). The upper surface of this oösparite bed is irregular and truncates individual oöids. The *Archaeolithophyllum* cap facies overlies this local erosional surface.

Fossil assemblage.—The fauna of the oölite facies is similar to that of the calcarenite facies but is much less abundant (Table 2). Concentrations of shells, mainly pelecypods, occur at the base of the oölite and along some bedding planes where there are several shale partings. Phylloid algal fragments are found only in shaly, fossiliferous oömicrite layers at the base above the terrigenous facies.

Stratigraphic relationships.—The oölite facies is well developed in the lower Farley limestone in the east-central part of the study area (see cross section A-A′, Pl. 1). This facies is also present on top of the algal-bank facies in the lower Farley at Olathe, Kansas, where it is overlain with erosional contact by the *Archaeolithophyllum* cap facies of the upper Farley.

SHELLY MUD FACIES

Field description.—The shelly mud facies is essentially a biomicrite superficially resembling the algal-bank facies, with thin, wavy beds and sparse fossils.

Petrographic description and fossil assemblage.—This facies contains as many fossils as, or more than, the bank facies, but it carries a somewhat different assemblage (Table 2). Phylloid algae are absent in the shelly mud facies, and faunal diversity depends on relationship to adjacent facies. Where the shelly mud facies is laterally equivalent to the algal-bank facies, the assemblage closely resembles that of the algal-bank facies, except for the lack of phylloid algae (Fig. 23, *C*). In contrast, the fauna of the shelly mud facies is similar to that of the calcarenite facies where these two facies are laterally equivalent (Fig. 23, *D*).

The fauna in the latter case is more abundant than in the former case and contains pelecypod fragments. As in the calcarenite, *Osagia* encrusts many fragments, but tends to develop more strongly on one side, and in some cases is absent on the underside (Fig. 23, *D*). Quartz sand is common in this facies to the north.

Stratigraphic relationships.—Lateral transition from the algal-bank facies to the shelly mud facies in the Argentine (Loc. 29 to 30, 21 to 23) (Kansas City-Olathe-Bonner Springs area) has been described previously. This transition occurs where the limestone thins to less than ten feet around areas of maximum bank development. The shelly mud facies at the north end of the lower Farley (Loc. 23) is laterally transitional into an interbedded oölite and calcarenite facies near Parkville, Missouri (Loc. 19, 21).

ENVIRONMENTAL INTERPRETATIONS OF FACIES

TERRIGENOUS FACIES

The gray, sandy shales and thin quartz sandstones comprising the terrigenous facies of the Wyandotte are typical of many late Paleozoic marine terrigenous units in the Midcontinent. These have been shown by Wanless,

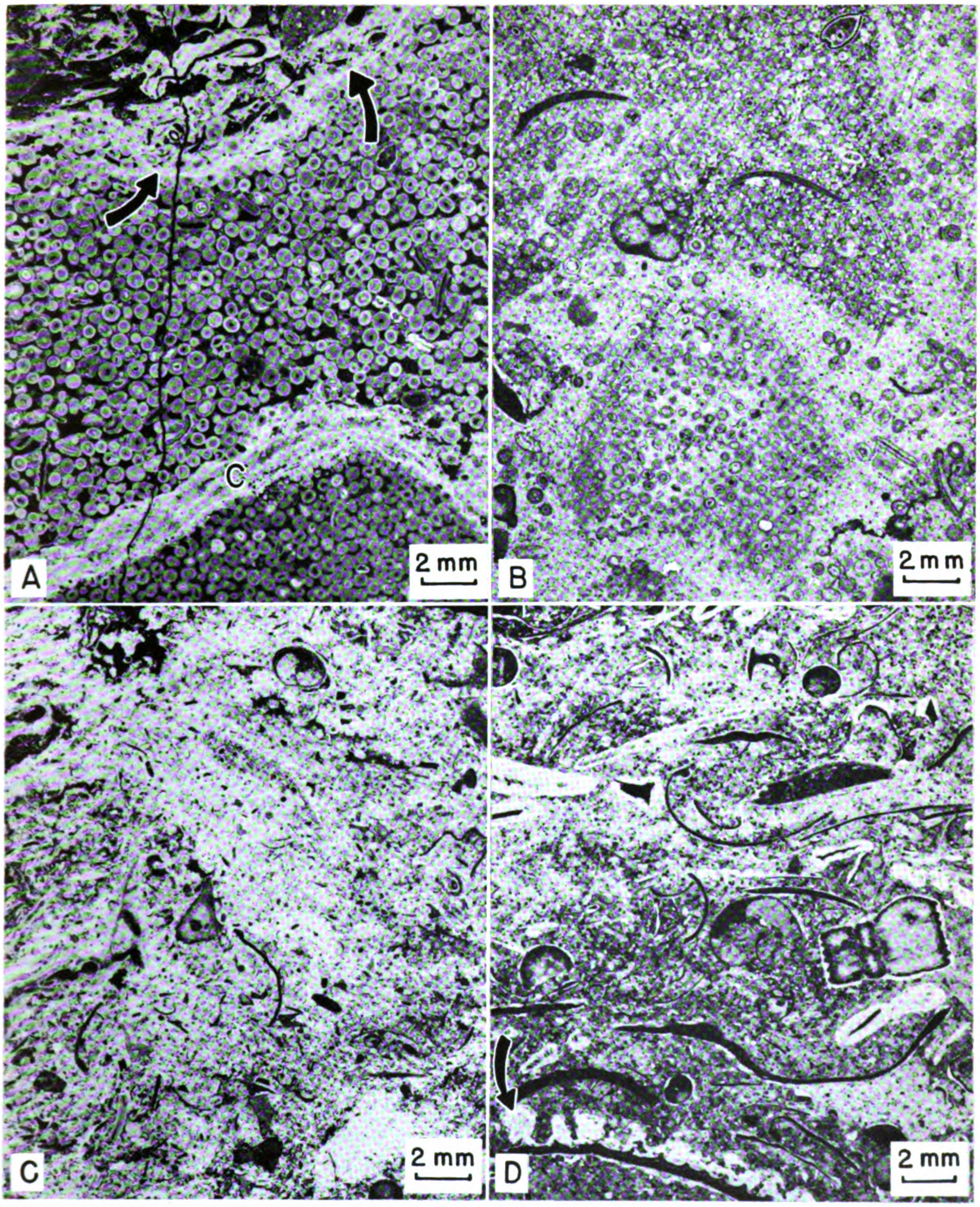

FIGURE 23.—Negative prints of thin sections of oölite and shelly mud facies. *A,* Contact between oölite and ***Archaeolithophyllum*** cap facies, oösparite below. Oöids show well-preserved concentric laminations and some quartz sand nuclei. Lower right is portion of large intraclast of oösparite that has been organically(?) coated (C) then reincorporated into similar oölite. Erosional upper contact (arrows) cuts across oöids. Intrasparrudite overlies erosional contact. Locality 9(27).* *B,* Oölite facies. Oömicrite. Poorly sorted oölites in micrite. Note oömicrite intraclast in lower center. Small black specks are quartz grains. Locality 5(16). *C,* Shelly mud facies near transition to algal-bank facies. Biomicrite. Note poorly sorted skeletal debris and lack of phylloid algae. Locality 3(1). *D,* Shelly mud facies near transition to calcarenite facies. Silty biomicrite. Many grains coated by *Osagia* as in calcarenite facies; some coated only on top. Note algae forming "microhemispheroids" on costae of clam shell (arrow). Many quartz grains present. Locality 23(9).

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* Sample number in parenthesis after locality number gives stratigraphic position on Plate 1.

Tubb, Gednetz, and Weiner (1963) to be prodelta and delta-front deposits associated with periods of increased terrigenous influx into shallow epicontinental seas where calcium carbonate deposition normally takes place. Swann (1964, p. 651) has pointed out that most thin Mississippian limestone units pinch out into a continuous terrigenous sequence at the margins of depositional basins. Marginal pinchout of the Wyandotte into terrigenous units on the south and west has been documented.

A combination of both delta migration (Moore, 1959) and periodic progradation and retrogradation of river systems (Swann, 1964) is probably responsible for the stratigraphically irregular lobate pattern of shales between the marine limestones of the Wyandotte.

Persistent lateral extent north of the study area, close association with limestones interpreted to be intertidal and subtidal, and high density of fossils suggest that the Quindaro Shale was deposited very slowly in a shallow, shelf lagoon that extended over much of the basin during Wyandotte deposition.

The greater thickness and lobate form of the Island Creek and middle Farley shales suggest that they were closer to the source of sediment supply, that is, the distributary mouth. These units are mostly unfossiliferous, except where transition to limestone occurs and along the thinner distal margins. Parker (1956) and Lagaaij and Kopstein (1964) suggest that fossil density is a function of depositional rate. Parker (1956, p. 361) found that density of shells in Recent sediments of the Gulf Coast is inversely proportional to the sedimentation rate and that the prodelta silty clays, which have the highest rate of deposition, have the lowest density of shells. Thus it is probable that slower rates of silt and clay deposition at thin distal margins and at vertical transitions to limestone in the Wyandotte shale lobes allowed noticeable accumulation of bioclastic debris, while more rapid deposition of the thicker parts resulted in low fossil density. This low density may have been accentuated by further loss of fossils in post-depositional leaching in the thicker shales, which are now nearly unfossiliferous. Moreover, the more intense terrigenous influx responsible for the thicker shales may have been accompanied by much lower salinities, unfavorable for survival of a normal marine fauna. Then, as influx of terrigenous material and freshwater decreased, a marine fauna was reestablished on top of the shale lobe just before carbonates began to accumulate.

STROMATOLITE-SPONGE FACIES

Comprising much of the lowest limestone, this is the earliest carbonate facies in the Wyandotte. An intertidal to shallow subtidal environment is strongly indicated by stromatolite-encrusted intraclasts. Where stromatolites are not in place, the large fragments imply that they formed near by. The close association of stromatolites with calcisponges and other marine forms suggests that the intertidal mud flats were interspersed with subtidal areas. Sponges, crinoids, and other organisms probably lived in these slightly deeper areas and then were bound into stromatolites after being thrown up onto the mud flats. Burrowing organisms probably inhabited most of the mud. Mudcracks were sheltered beneath some crusts (Fig. 16, *A*), but some partially consolidated carbonate mud was dislodged to form intraclasts, which also became encrusted.

The possible presence of pseudomorphs after anhydrite or celestite would attest to restricted water circulation and evaporitic conditions (Illing, Wells, and Taylor, 1965). Because the associated crinoid and brachiopod fauna indicates normal salinity, evaporating pools may have formed on the mud flats, perhaps only during periods of aridity. Evaporites may have been more common during deposition, but were subsequently dissolved, leaving only a few crystals in protected places such as underneath blades of algae (Fig. 16, *D*).

ALGAL-BANK FACIES

Although framework-building organisms such as corals are not evident, it is probable that phylloid algae were instrumental in the accumulation of abnormal thicknesses of carbonate mud in banks of the Wyandotte. Sediment-trapping by marine grasses is well documented by Ginsburg and Lowenstam (1958) in Recent carbonate mud banks in Florida Bay, but initiation of the pattern of these banks is thought to be a function of complex current patterns and tidal exchanges (Gorsline, 1963[7]). Once initiated, however, luxuriant growth of *Thallassia* on the banks baffles the currents and allows carbonate mud to settle out, thus perpetuating the bank. As carbonate mud accumulates and is stabilized by the thick growth of grass, interbank areas are maintained and possibly deepened by the greater water flow necessary in con-

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[7] Gorsline, D. S., 1963. Environments of carbonate deposition Florida Bay and the Florida Straits, *in* Shelf Carbonates of the Paradox Basin: Four Corners Geol. Soc. 4th Field Conf. Symp., p. 130-143. (Guidebook.)

stricted areas (Purdy and Imbrie, 1964, p. 35[8]). The potential of phylloid algae as baffles and sediment stabilizers in Pennsylvanian and Permian limestone banks has been pointed out (Harbaugh, 1959, 1960; Konishi and Wray, 1961; Choquette and Traut, 1963[9]; Elias, 1963[10]; Pray and Wray, 1963[11]; and Wray, 1964). Several authors have suggested an analogy in ecologic and sedimentary role between *Thallassia* and the phylloid algae. Uncalcified plants may have assisted in the trapping of carbonate mud but would not be preserved because of lack of hard parts (Beales, 1963).

A feature characteristic of thicker parts of the algal-bank facies is the intraclastic texture of micrite above phylloid algal blades. In horizons where phylloid algal blades are sufficiently abundant to be in contact, there are typically sparry calcite-filled voids under some blades. After partial consolidation of the carbonate mud and decay or solution of supporting algal blades, the structure collapsed and brecciated intraclasts caved into the voids (Fig. 19, *D*). In other cases, layers of biomicrite bounded by encrusting or bladelike forms of phylloid algae appear to have cracked from differential compaction caused by uneven distribution of the layers of algae (Fig. 15, *C*). A few of these layers were sufficiently disturbed so that the clasts were moved. All varieties of intraclastic texture suggest that the carbonate mud was partially consolidated at or near the surface, either beneath a cover of phylloid algae or beneath a thin layer of overlying sediment. Some intraclasts were covered by algal blades before more carbonate mud could filter into the interstices while other intraclasts were incorporated into carbonate mud of a different texture.

The origin of intraclasts, and whether or not they necessarily imply subaerial dessication, is still obscure. Many investigators have pointed out that mud will form cracks while covered by water (Lindstrom, 1963; Van Straaten, 1954; Burst, 1965). These synaeresis cracks supposedly form as a consequence of interparticle ionic attraction, causing rapid squeezing out of interstitial water, the degree of cracking being a function of the amount of clay particle flocculation, which in turn depends on the ionic content of the water (White, 1961). Some of the mud cracks in the algal-bank facies may have formed in this manner, but this would have depended upon the degree of consolidation of the carbonate mud.

Modern carbonate sediments under water remain very soft to considerable depth as indicated by many investigators who have commented on how far one may sink into a mud bank. On the other hand, Purdy and Imbrie (1964, p. 34[12]) state that ". . . clasts of plastic lime mud are eroded from the walls and bottom of the adjacent tidal channel . . ." in Joulters Cays in the Bahamas. This suggests that lime mud in a tidal channel, which is presumably under water, is coherent enough to form intraclasts.

Ginsburg (1957, p. 91) points out that carbonate mud becomes semilithified upon exposure to air and can be rounded into lumps by wave action. Such lumps, or intraclasts, would probably be difficult to differentiate after burial from those formed in a tidal channel. Thus, intraclasts in the algal-bank facies could have formed both subaerially from intertidal mud and subaqueously from subtidal mud. Occurrence of such environments adjacent to one another is supported by recent studies.

The intraclasts in Figure 19, *B* are difficult to distinguish from the surrounding micrite and appear to have been deformed around other clasts. These most probably formed under water and were still soft during burial. On the other hand, intraclasts (Fig. 15, *B*, *D*; 19, *A*) that are angular, that show marked contrast to associated matrix, that are not deformed around other grains, and that were partially unsupported in voids may have formed from subaerially dried mud. The latter are more common in micritic rocks of the Wyandotte. Exclusive occurrence of such intraclasts in thickened portions of the banks suggests that the thickest carbonate mud deposits were formed in areas periodically, but perhaps incompletely, exposed to the air.

Little stratigraphic correlation of highly intraclastic horizons between bank areas or within one bank area seems evident. Slightly different rates of mud accumulation or of subsidence, or shifting depositional sites could cause this apparent random distribution. Perpetuation of carbonate mud accumulation, however, was not random and resulted in areas of especially thick deposits and in two successive phases of bank development, one above the other (Fig. 2).

Differences in thickness of the bank facies reflect not only higher rates of accumulation, but perhaps also differences in initial bottom topography. Intraclast distribution suggests that water covering areas of thinner carbonate ac-

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[8] Purdy, E. G., and Imbrie, John, 1964, Carbonate sediments, Great Bahama Bank: Geol. Soc. America, 1964 Field Trip Guidebook No. 2, p. 1-58, (Guidebook.)

[9] *Loc. cit.*

[10] *Loc. cit.*

[11] *Loc. cit.*

[12] *Loc. cit.*

cumulation within the banks was deeper than over the thicker accumulations. Differences in water depth are thought to be slight, most likely less than 25 feet, and the slopes of the banks so gradual as to be difficult to detect. H. G. O'Connor (personal communication, 1967) has found primary dips in algal-bank facies in the Stilwell area.

Recent carbonate banks in Florida Bay average a height of 6 feet above interbank areas (Ginsburg, 1956), while carbonate banks in the backreef zone east of the Keys are about 10 feet above the surrounding sea floor (Turmel and Swanson, 1964, p. 26[13]). Carbonate mud in slightly deeper water around these Recent banks is similar to that on the banks and the biota is also similar although somewhat less abundant off the banks.

Bank and interbank biotic assemblages are similar in the Wyandotte except for the absence of phylloid algae in the interbank shelly mud facies. Thus carbonate banks in the Wyandotte may not have been elevated much more than 10 feet above the interbank areas. This difference could have been sufficient to bring the tops of the banks into the shallow subtidal and intertidal zones, but a greater difference might have been necessary to keep the interbank area below the optimum depth for growth of phylloid algae, as modern algae live to depths of at least 100 feet (Wray, 1964).

The present study supports Konishi's (1961) paleoecological interpretations for *Anchicodium* by analogy to the ecology of living genera of the subfamily Udodoidae as summarized below:

1. Species were calcified, bladelike, and attached to the substrate by means of a rhizome.
2. Thalli grew on both carbonate sand and mud and probably acted as sediment baffles and stabilizers.
3. These forms were normal saline eurytherms that lived in shoal water below low tide, probably in areas of low turbulence such as lagoons.

The present study also suggests that *Anchicodium* was restricted to areas of low turbulence.

A typical late Paleozoic marine fauna, dominated by *Composita,* productids, crinoids, and fenestrate bryozoans, occurs in the phylloid algal carbonate banks. All these organisms presumably lived under water at all times. They most likely inhabited narrow intra- and interbank areas that were continually under water. Upon death, their shells and disarticulated hard parts were distributed throughout the carbonate mud. Several thin layers of shell concentrations in the banks probably represent lag deposits similar to those described by Ginsburg and Lowenstam (1958) in the carbonate banks of Florida Bay. A few organisms such as snails and burrowing worms were probably able to live in wet mud even if exposed intermittently to air.

At any one time during bank development only a portion of each area was actually undergoing accumulation, while shallow, narrow, intrabank areas drained from bank areas into the larger and more stable interbank area. Periodic shifting of intrabank and active bank areas resulted in apparently random variation of bank-facies lithology within the major areas of development. Subtidal organisms, living in the slightly deeper intrabank areas, were mixed with algae and other organisms that thrived on the shallower parts of the banks. Locally, lag concentrations of these shells were preserved. Widespread interruption of bank development by changes in physical and chemical conditions resulted in formation of other facies, but in some areas similar conditions returned, and more banks were built directly over the older ones.

Thus, pre-existing geometry and hydrography of the area, such as the Lane shoal and interbank channel, determined the *position* of the carbonate banks of both the Argentine and lower Farley limestones. Subsequent *development* of the banks themselves depended upon a complex of other factors.

ARCHAEOLITHOPHYLLUM CAP FACIES

The thin layers of *Archaeolithophyllum* intramicrudite and biolithite of this facies probably formed in a more turbulent environment than that of the algal-bank facies. Supporting evidence is: (1) abundant micrite stabilized and bound by encrustations of *Archaeolithophyllum*; (2) micrite facies interbedded with biosparite of the calcarenite facies; and (3) clasts of the *Archaeolithophyllum* cap facies incorporated into the biosparites.

Intercalation of the *Archaeolithophyllum* cap facies and calcarenite facies suggests that their environments were closely related. Better understanding of this association might be gained from analogy with Recent mud banks.

Rodriguez Key, one of several carbonate mud banks between a living reef and the Florida Keys, is sheltered on the windward side by the *Goniolithon-Porites* sand zone (Fig. 24, *A*).

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[13] Turmel, Reid, and Swanson, Roger, 1964, Rodriguez Bank: Geol. Soc. America, 1964 Field Trip Guidebook No. 1, p. 26-44. (Guidebook.)

Codiacean algae, mainly *Halimeda* and *Penicillus,* produce carbonate mud, and abundant marine grasses and mangroves stabilize the sediment. The muddy area containing the algae is less than two feet below mean low water, whereas the windward skeletal sand zone is intertidal. The mangrove area is 4 inches to 1 foot above mean low water.

Capping the algal banks of the Wyandotte, prolific growth of *Archaeolithophyllum missouriense,* crinoids, brachiopods, pelecypods, gastropods, and bryozoans, produced debris that formed a sand bar complex comprising the calcarenite facies. The muddy area behind the sand bar was stabilized by blades of *A. missouriense* and encrusting *A. lamellosum* to form

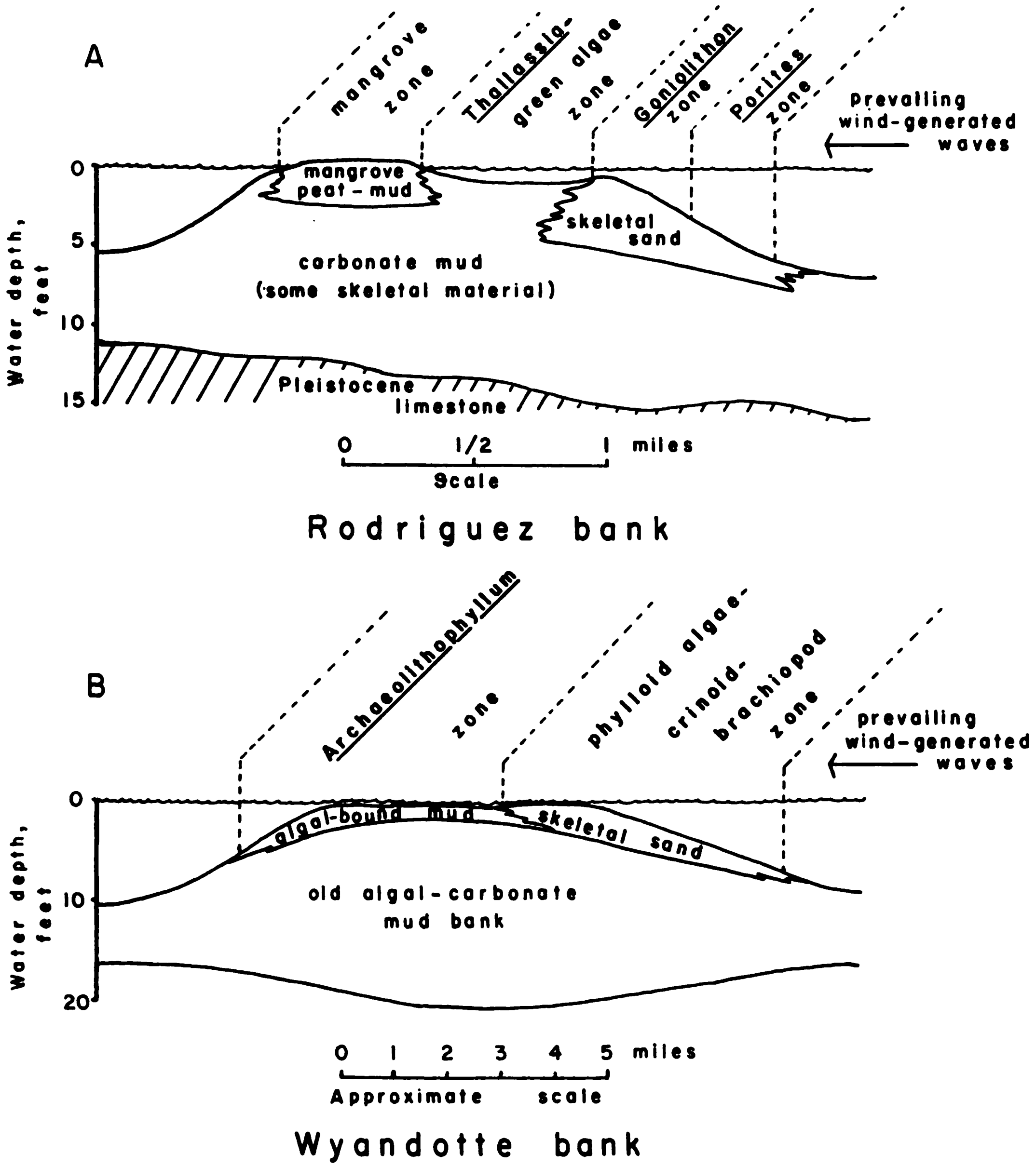


FIGURE 24.—Comparison of calcarenite and *Archaeolithophyllum* cap facies environments in Wyandotte with those of a Recent bank (Rodriguez Key) in Florida Bay. *A,* Cross section of Rodriguez bank (adapted from Turmel and Swanson, 1964). See footnote 13. *B,* Hypothetical cross section of Wyandotte bank. *Archaeolithophyllum*-bound mud zone is analogous to Recent *Thallassia*-green algae mud zone, while phylloid algae-crinoid-brachiopod sand zone is analogous to Recent *Goniolithon-Porites* sand zone.

the *Archaeolithophyllum* cap facies (Fig. 24, *B*). Later shifts in current patterns resulted in interbedding and some mixing of the two different facies capping the algal banks.

This interpretation is compatible with the paleoecological interpretations by Wray (1964, p. 12) for the genus *Archaeolithophyllum:*

> 1. Species developed as either encrusting, locally attached, or free forms.
> 2. Thalli were semi-rigid crusts capable of providing a self-supporting skeletal framework and a sediment-binding function in the depositional environment.
> 3. Thalli are believed to have grown on both carbonate mud and coarser-grained sediment substrata.
> 4. Based on lithologic evidence and on analogy with Recent coralline algae, *Archaeolithophyllum* most probably inhabited the inner sublittoral marine environment, being able to tolerate appreciable wave agitation, but it also extended to depths of about 100 feet.

In the Wyandotte these algae seem to have thrived in shallower water than suggested by Wray. In contrast to Rodriguez Key, limited abundance and diversity of the biota in the muddy capping environment and the intraclastic texture of the micrite suggest intertidal conditions for the Wyandotte bank.

CALCARENITE FACIES

Depositional environment of the calcarenite facies associated with the *Archaeolithophyllum* cap facies has been discussed in the previous section. Similar carbonate sands also occur in thin sheets interbedded with oösparite in the lower Farley. Very thin layers of grain-supported phylloid algal biomicrudite at the base of these calcarenite beds show that some mud accumulated before the sands were spread into thin sheets and lenses.

Constituent grains in the biosparites in the lower Farley in the interbank area are mainly productid shells and crinoid ossicles, whereas intraclasts and phylloid algal fragments are absent. This difference lends further support to a different depositional regimen in this area during lower Farley deposition. Interbank currents were sufficiently strong that carbonate mud did not accumulate and phylloid algae could not find a substrate for attachment.

Ginsburg (1960) states that Recent blue-green algal-encrusted grains, or oncolites, which may be analogous to Pennsylvanian *Osagia*-coated grains, are indicative of low intertidal and shallow subtidal zones. Laporte (personal communication, 1965) has found that oncolites are forming on the Bahama Banks in water 6 feet or less deep, about the same depth at which oöides are forming. This water, however, is less agitated than that in which oöids are forming and oncolites are only occasionally tossed about.

There is some correlation in the Wyandotte between abundance of *Osagia*-coated grains, amount of quartz silt in the calcarenite facies, and thickness ratio of the shale-limestone members of the Wyandotte. These characteristics all increase northeastward and most likely indicate a source direction of terrigenous material and fresh water. The best developed *Osagia* biosparites of the Wyandotte are overlain by the Bonner Springs Shale, which is interpreted as a prograded delta complex. Abundant occurrence of *Osagia*-coated grains probably indicates reworking of previously deposited grains in a nearshore, shallow-water environment developed prior to progradation of a delta. Laporte (1962) also found *Osagia* biosparites in the nearshore facies of the Cottonwood Limestone (Permian) of east-central Kansas.

Faunal diversity in the calcarenite is greater than in all other Wyandotte facies (Table 2). The most noticeable fossils in this facies, compared to the micritic facies, are pelecypods, which were not found in either the algal-bank facies or the *Archaeolithophyllum* cap facies. Pelecypods may have been absent in very muddy areas because of turbidity and poor water circulation. Calcarenites formed in areas where water was sufficiently turbulent to sweep away the mud and sufficiently circulated to supply fresh nutrients and normal salinities, thus allowing establishment of an abundant pelecypod fauna. Ginsburg (1956) reports that clams are very common in the muddy areas of Florida Bay, but these forms may be more tolerant than their ancient relatives.

OÖLITE FACIES

Recent investigations by Newell, Purdy, and Imbrie (1960) show that formation of oöids is related to a sharp physico-chemical gradient along the margin of the Bahama Platform. At the platform edge where water shoals rapidly to a depth of 6 feet or less, turbulence increases greatly and water temperature rises. The water becomes supersaturated with calcium carbonate, resulting in precipitation of concentric laminae of aragonite around any grains that act as nuclei. Oöids then accumulate in cross-stratified lenticular deposits subject to movement by currents. Warmed, supersaturated water and turbulence are postulated, also, for the formation of oöids in Laguna Madre, Texas (Rusnak, 1960), although turbulence seems to be less than in the Bahamas.

These authors point out also that accretion of oöids is not actively taking place in all areas where Recent oölite deposits are found. Shifting conditions have apparently left certain parts of the area inactive while oöids are actively accreting elsewhere. Some oöids in inactive parts of Bahamian shoals are partially, or wholly recrystallized to cryptocrystalline aragonite, resulting in obliteration of the fine concentric laminations. Lithification of oölites has been observed only in areas that have been subaerially exposed (Ginsburg, 1957).

Some of the Wyandotte oölitic deposits were lithified, then broken into intraclasts that have been rounded and coated with a light-colored layer of calcite before being deposited again in more oölite (Fig. 23, *A*). It is not known whether this white coating is organic or inorganic in origin. The rounded intraclasts of oösparite and the erosional upper contact (Fig. 23, *A*) with truncated oöids beneath intramicrudite of the ***Archaeolithophyllum*** cap facies indicates that lithification was probably due to subaerial exposure. Recent oölite deposits that have not been exposed to the air are loose and would not produce eroded surfaces that truncate the grains.

Interbedded biosparites of the calcarenite facies and oösparites and oömicrites of the oölite facies indicate that these sediments formed contemporaneously side by side. Similar biota inhabited both facies (Table 2), but their abundance is much less in the oölite. Apparently, as in the Bahamas, organisms found it difficult to live in an area of active oölite formation but were able to inhabit the same area during periods of nonaccretion. In addition, skeletal debris from the nearby calcarenite facies probably was transported into the oölite.

Recent sediments resembling the oömicrite with algal-coated oöids encountered at Locality 5, are found at Joulters Cays in the Bahamas where an oölite shoal is prograding bankward over an older carbonate mud area, resulting in a mixture of the two sediments.

SHELLY MUD FACIES

The abundance of micrite and the normal-marine but nonalgal biota that characterize the shelly mud facies indicate that (1) current strength and turbulence were sufficiently low to permit accumulation of carbonate mud without the aid of sediment-stabilizing phylloid algae; (2) water was normally saline in order to support the brachiopod-crinoid-bryozoan fauna; and (3) water was not shallow enough for proliferation of algae.

The environment of this facies contrasts markedly with that of surrounding environments. Absence of phylloid algae in the interbank area and thinness of the shelly mud facies suggests slightly deeper water than that over the bordering algal banks. Stronger currents may have prevented accumulation of much available carbonate mud, accounting for thinness of the facies.

Shelly mud facies adjacent to the calcarenite and oölite facies underwent less wave and current action. It may have been that water was slightly deeper, or that the shelly mud facies formed in a sheltered area behind the calcarenitic and oölitic areas that bore the brunt of wave and current action. The latter alternative is less likely, however, as such sheltered areas might support only a restricted biota, like that of the ***Archaeolithophyllum*** cap facies. Some organisms such as pelecypods and ***Osagia,*** which are characteristic of the calcarenite facies, had ecologic ranges that extended into the adjacent shelly mud environment, although the smaller grains could have been transported in by currents.

SEDIMENTARY HISTORY

LANE SHALE DELTAIC PLATFORM

Carbonate sedimentation is sensitively controlled by the topography and geometry of the basin of deposition (Illing, 1959; Ginsburg, Lloyd, Stockman, and McCallum, 1963; Laporte and Imbrie, 1964). This would have been especially true in the shallow epicontinental seas that covered parts of the North American Continent during the late Paleozoic because slight variations in bottom topography, depth of water, water circulation, and patterns of terrigenous sediment influx would effect greatly the distribution of carbonate facies. It is, therefore, important to consider the nature of the Lane Shale and the inferred topography after deposition because of its potential effect on subsequent carbonate deposition of the Wyandotte.

Characteristics of the Lane Shale compare favorably with similar deposits considered by Moore (1959) and Wanless, *et al.* (1963) as deltaic complexes—thin distributary channels, interdistributary bays, and prodelta lobes. What is most important, however, in evaluating deposition of the Wyandotte, is the final topography of the Lane deltaic platform. The Lane is unusually thick on the northwest side of the interbank area in Johnson County, Kansas (Fig. 2, 4). It thins abruptly into the interbank area and thickens to the southeast. Northeastward, the Lane thins to about 30 feet and remains constant to the northern edge of the study area. Newell (1935) and Jewett and Newell (1935) show that there is no consistent relationship between thickness variation in the Lane Shale and the underlying relatively constant Iola Limestone (Linn Subgroup).

The thickest portion of the Lane extending as a narrow belt southwestward across central Johnson County is interpreted as having been a shoal at the edge of a broad deltaic platform to the north and northwest (Fig. 4). Water circulation from the slightly deeper interbank area over the deltaic platform was restricted by this shoal. Several lines of evidence suggest this topography of the Lane:

1. The Lane Shale does not appear to be filling depressions in the underlying Iola Limestone, primarily because the Iola does not undergo much thickness variation in this area.
2. The largely intertidal stromatolite-sponge facies of the Frisbie occurs only northwest of the interbank area.
3. The algal banks to the north of the shoal thin abruptly over the shoal (Pl. 1).
4. The shelly mud facies suggesting deeper water occurs in the interbank area southeast of the shoal.

WYANDOTTE ALGAL-BANK COMPLEX

Cessation of Lane terrigenous clastic influx left a shallow, undulatory platform adjacent to a deeper area. Organisms that had been excluded from the highly turbid and possibly brackish water reestablished themselves across this platform, and skeletal debris began to accumulate with minimum dilution by terrigenous material.

Intertidal carbonate mud flats began to cover the restricted area behind (north of) the Lane shoal (Fig. 25, *A*). Blue-green algal mats formed on the exposed flats and trapped carbonate mud, forming laminar structures preserved as stromatolites. Skeletal debris derived from biota living on the flats, as well as in shallow areas that drained the flats, was incorporated into the carbonate mud and encrusted by the algal mats. Organisms such as encrusting bryozoans and tetrataxid and calcitornellid foraminifers lived within or on the algal mats themselves. Calcisponges, crinoids, brachiopods, and ***Anchicodium*** probably lived in the slightly deeper areas and after death were thrown up onto the mud flats by waves.

General restriction of water circulation prevented complete oxidation of organic matter, resulting eventually in formation of disseminated sulfides, which give the micrite a dark color. Evaporite minerals, such as anhydrite or celestite, may have formed in isolated supersaturated pools on the shallow mud flats. Most of the crystals of the evaporite minerals probably were dissolved later by a less saline water influx, but a few were preserved as pseudomorphs beneath algal blades. Constant shifting of mud flats resulted in the formation of a unit of mixed intertidal, algal-stromatolite, and subtidal skeletal carbonate comprising the Frisbie Limestone on the platform.

Tidal-flat carbonate deposition was interrupted by a brief influx of terrigenous material forming the Quindaro Shale which covered the stromatolite-sponge facies behind the Lane shoal. On the Lane shoal, the Frisbie was not deposited, and so the top of the Lane Shale is indistinguishable from the Quindaro Shale (Fig. 25, *B*).

Immediately following the influx of the Quindaro Shale, restricted intertidal conditions returned briefly to a few small areas toward the north, but in other areas, perhaps deeper water with less restricted circulation prevailed. Carbonate mud containing abundant phylloid algae began to accumulate as elevated banks in the Stilwell, Kansas City, and Olathe-Bonner Springs areas. A single bank may have covered only a portion of these areas at any one time (Fig. 25, *B*), but major circulation patterns controlled by the Lane shoal and the deeper area to the south, confined bank formation to the areas named above. Banks shifted laterally within these areas, resulting in thick carbonate mud accumulation during deposition of most of the Argentine (Fig. 25, *B*, *C*).

Blades of phylloid algae, mainly *Anchicodium*, acted as baffles to slow water velocity and to trap carbonate mud that settled out. The more shallow bank areas were favorable for maximum algal growth and probably also for higher rates of carbonate mud production. This interaction tended to be self-perpetuating until major changes in water circulation forced a shift in deposition.

The shallow water over the banks was perhaps even intertidal at times. The relief of individual banks was more than likely only a few feet above the surrounding sea floor, and there was little difference between sediments on the bank and in the intrabank areas. Moreover, active bank areas and intrabank channels probably shifted around to such an extent that the deposits have become more or less homogeneous and difficult to differentiate on outcrops of the Argentine.

Less sediment, with essentially no phylloid algal fragments, accumulated in the deeper interbank area, resulting in the formation of the thin shelly mud facies (Pl. 1; Fig. 25, *B, C*).

The Argentine phase of algal-bank formation was culminated by increases in wave and current energy. Skeletal sands were washed up along the margins of the algal banks while bladelike and encrusting forms of the red alga *Archaeolithophyllum* stabilized carbonate mud on top of the banks behind the carbonate sand bars (Fig. 24, *B*; 25, *C*). Before final burial these skeletal sands were spread into lenses and sheets and mixed with large intraclasts of *Archaeolithophyllum* biomicrite.

As the interbank area received none of this facies mixture, it was apparently swept clear at this time. Northeast of the Kansas City bank area, *Osagia*-coated grains in otherwise similar carbonate sand were deposited on top of much thinner algal carbonate mud. The carbonate sediments were then covered by an influx of terrigenous clastics, apparently from the north or northeast. These muds and sands of the Island Creek Shale Member formed a thick lobe southward between carbonate banks in central Johnson County, accumulating to 7 or 8 feet in the interbank area, and lapping up onto and thinning over the surrounding algal banks (Fig. 25, *D*). The thick shale lobe in Johnson County controlled water circulation at the start of the second phase of algal-bank formation.

In the second, or lower Farley bank phase, thick accumulation of phylloid algal carbonate mud occurred directly above the Argentine banks in the Stilwell and Olathe areas (Fig. 2). Although banks of the second phase were considerably more limited geographically, they attained thicknesses similar to those below and contained consistently more abundant phylloid algae.

The second phase was terminated, like the first, with development of *Archaeolithophyllum* mud, skeletal sands, and oölite. Oölite bars formed in certain limited areas on top of the second Olathe bank near Locality 9 and also around Kansas City. From the latter area oölites were carried northward from the shoals and mixed with carbonate mud at Locality 5, and remained to form cross-stratified oösparites farther northward at Localities 19 and 21. The result of this period of turbulent sedimentation was nearly complete capping of the second phase of algal banks with oölite and/or calcarenite facies, as well as covering portions of the Island Creek Shale where no algal banks had formed (Fig. 25, *E*). Once again terrigenous influx flooded most of the carbonate area and accumulated to greatest thicknesses between the lower Farley banks.

A recurrence of the *Archaeolithophyllum* cap facies, locally interbedded with biosparites of the calcarenite facies, covered the middle Farley shale in the Stilwell and Olathe-Bonner Springs areas. This accumulation is considered to be the third and final phase of Wyandotte bank development, where it attains 20 feet at Bonner Springs (Fig. 25, *F*). *Osagia*-coated, well-washed skeletal sands covered the middle Farley shale north of Kansas City. This final carbonate phase was covered by the prograding Bonner Springs deltaic complex. Bonner Springs clastics filled the interbank area to a great thickness, and cut into the top of the Wyandotte in several places, perhaps as distributary channels.

CONCLUSIONS

1. Detailed biofacies and lithofacies analysis of the Wyandotte Limestone has resulted in the definition of seven environmentally significant facies: (1) terrigenous, (2) stromatolite-sponge, (3) algal-bank, (4) *Archaeolithophyllum* cap, (5) calcarenite, (6) oölite, and (7) shelly mud. The carbonate facies were all deposited in a well-lighted, very shallow epicontinental sea ranging from intertidal to probably less than 25 feet in depth.

2. Initial position of the algal carbonate mud banks of the Wyandotte was determined by preexisting geometry and hydrography of the basin, manifested by the irregular surface of the underlying Lane Shale deltaic platform and shoal. These shallow banks provided suitable conditions for growth of the calcareous phylloid algae *Anchicodium* and *Archaeolithophyllum*, which in turn produced baffles for the water currents and stabilized the mud, thus perpetuating bank development. Bank upbuilding altered the basic geometry and hydrography of the area and was terminated by subsequent changes in water turbulence and circulation, which resulted in the deposition of associated carbonate facies (Table 5). Carbonate deposition was periodically interrupted by terrigenous influx but sub-

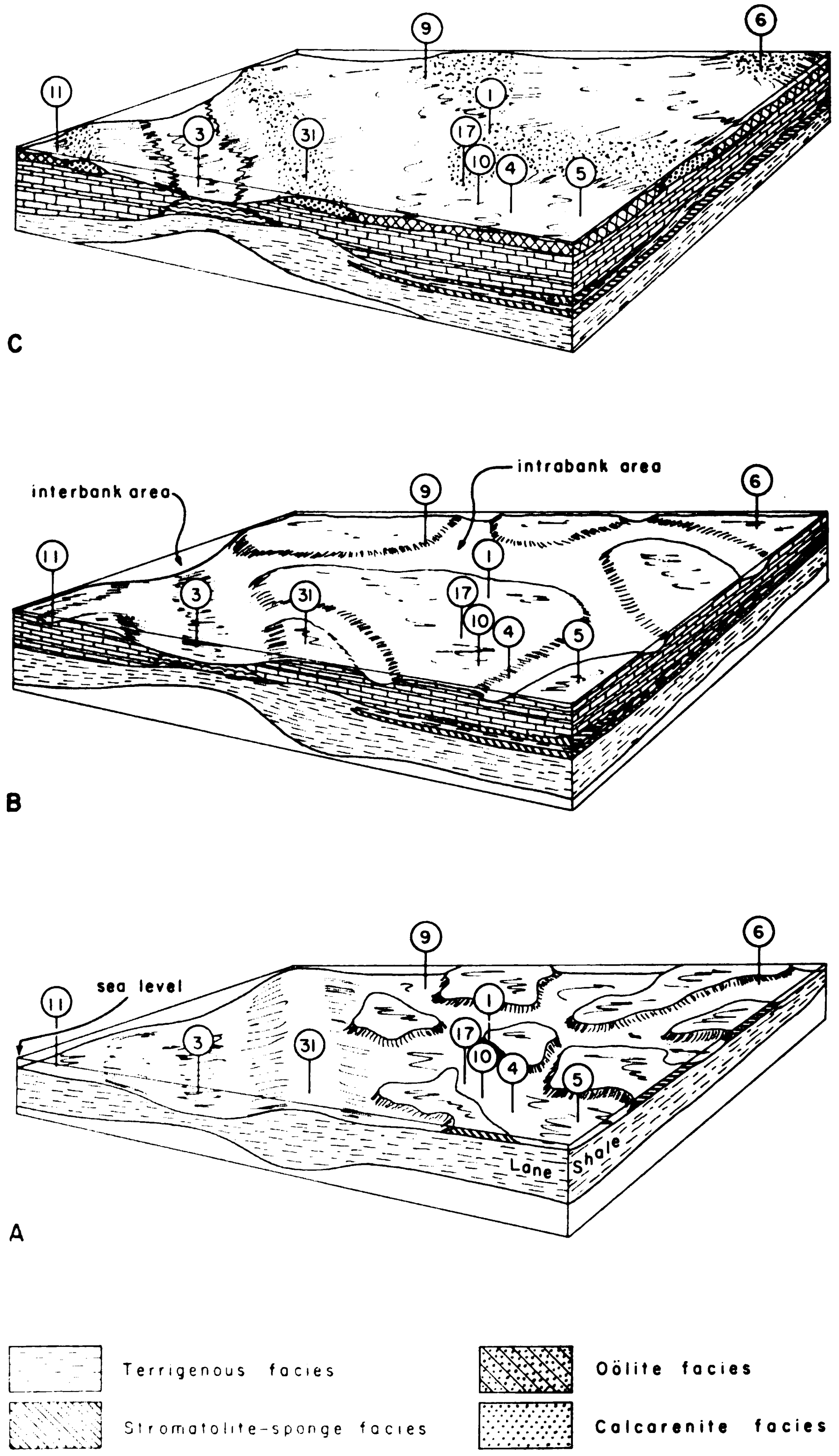
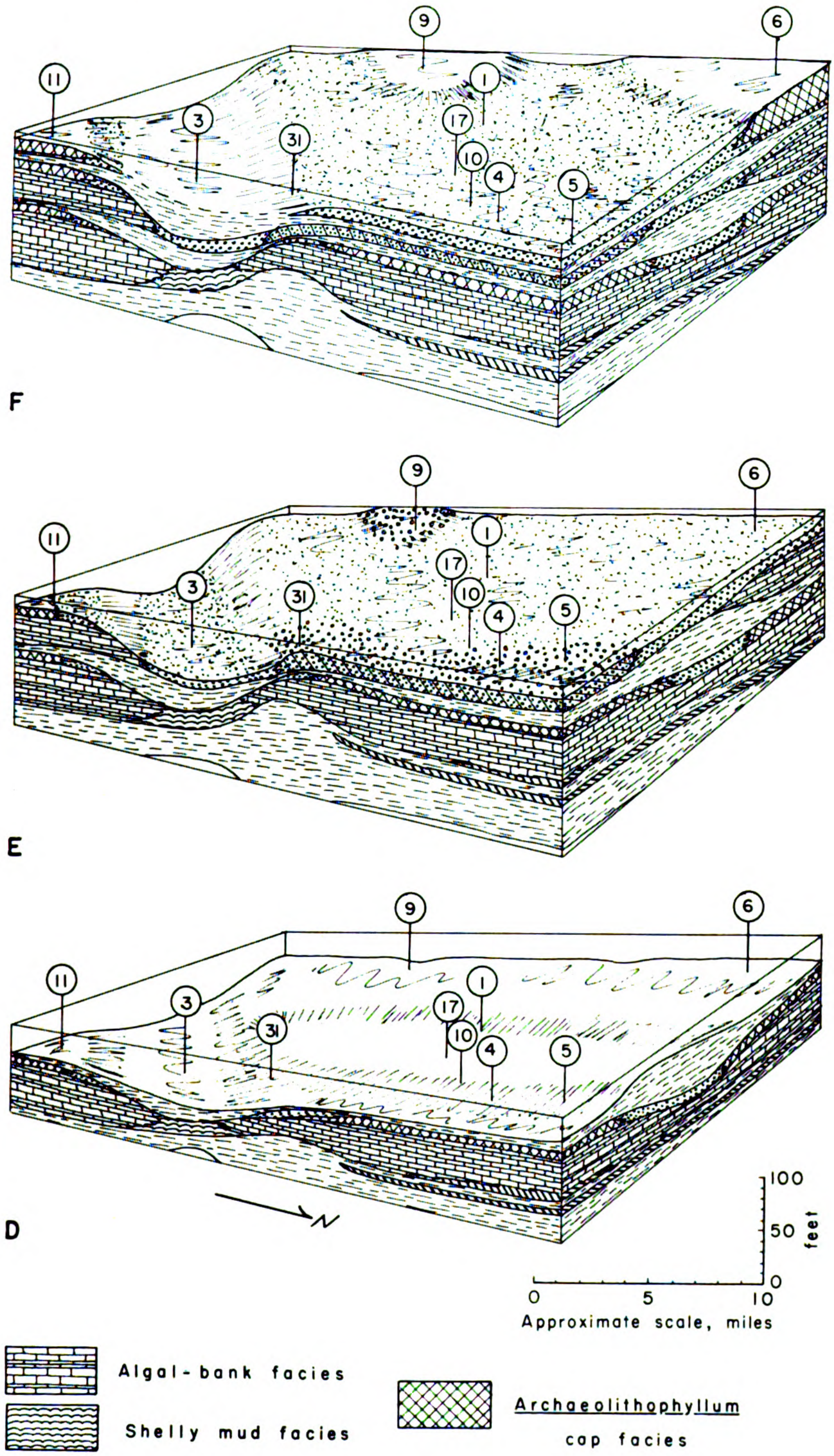


FIGURE 25.—Series of block diagrams illustrating successive development of facies in the Wyandotte. Area shown is marked by numbered localities (Fig. 1, 2) and covers Johnson and southern Wyandotte and Leavenworth counties, Kansas, where algal banks are best developed. *A*, During Frisbie Limestone deposition. *B*, At end of



algal-bank deposition in Argentine. *C*, At end of Argentine Limestone deposition. *D*, At end of Island Creek Shale deposition. *E*, At end of lower Farley deposition. *F*, At end of upper Farley deposition.

TABLE 5.—Relationship of carbonate facies to variations of two controlling factors.

	MOSTLY SUBTIDAL			MOSTLY INTERTIDAL
TURBULENCE Increasing ↑	Oölite facies Calcarenite facies (excluding *Osagia*-coated biosparite)			
		Archaeolithophyllum cap facies	*Osagia*-coated grain biosparite (calcarenite facies)	Stromatolite-sponge facies
	Shelly mud facies	Algal-bank facies		

Increasing restriction →

CIRCULATION

sequently resumed in much the same pattern, resulting in bank development in some of the same areas.

3. Environmental interpretation of the Wyandotte facies is compatible with recent detailed environmental analyses of terrigenous phases of Midcontinent late Paleozoic cyclic deposits (Swann, 1964; Wanless, *et al.*, 1963; Moore, 1959). Many details of vertical and lateral facies changes in the Wyandotte are understandable in terms of shallow-marine environments related to shifting or prograding deltaic complexes. In shallow environments, rapid but consistent changes in water turbulence and circulation patterns occurred following changes in amount and direction of terrigenous and fresh water influx, producing a vertical sedimentary sequence that is repeated several times.

4. Nature of the substrate, variation in salinity, water turbulence, and amount of water circulation were the main limiting factors in distribution and abundance of the Wyandotte biota. Distinctive fossil assemblages characterize each of the facies, although there is a great deal of overlap in the occurrence of several ubiquitous organisms (*Composita*, crinoids, and bryozoans). Some mixing of skeletal debris from adjacent environments is also apparent.

5. The algal-bank complex in the Wyandotte is similar to those in the Lansing Group, which overlies the Zarah Subgroup in the Midcontinent area (Harbaugh, 1959, 1960). These banks also compare favorably with those described from the Paradox Basin (Choquette and Traut, 1963[14]; Elias, 1963[15]; and Pray and Wray, 1963[16]). Phylloid algae are much more abundant in the Paradox banks and there is also a related evaporite sequence with no known analogy in the Midcontinent banks.

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[14] *Loc. cit.*
[15] *Loc. cit.*
[16] *Loc. cit.*

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Restored Cross sections of the Wyandotte Limestone

Lines of cross-sections shown on Figure 1.

Samples taken for each locality are numbered upward from base.

DATUM: top Bonner Springs Sh.

▨	Terrigenous facies
▨	Calcarenite facies
▨	Algal - bank facies
▨	Oölite facies
▨	*Archaeolithophyllum* cap facies
▨	Stromatolite - sponge facies
▨	Shelly mud facies