Carbonate Facies of the SWOPE LIMESTONE FORMATION (Upper Pennsylvanian)

Southeast Kansas

John H. Mossler

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STATE GEOLOGICAL SURVEY of KANSAS

BULLETIN 206, PART 1

Carbonate Facies of the Swope Limestone Formation (Upper Pennsylvanian), Southeast Kansas

By

John H. Mossler

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JOHN H. MOSSLER[1]

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ABSTRACT

The Swope Limestone Formation is composed of three members. The basal member, the Middle Creek Limestone, is a thin uniform biomicrite that is known to be present only in the northern part of the Kansas outcrop. The overlying Hushpuckney Shale, composed of black, fissile shale overlain by gray, blocky shale also is known to be present only in the northern part of the outcrop. The Bethany Falls Limestone Member, uppermost member of the Swope, is composed of three facies in the northern part of its Kansas outcrop belt. Here the lower part of this member is composed of (1) biomicrite containing a diverse marine biota, including abundant phylloid algae fragments. This unit interfingers southward with (2) less fossiliferous, color-mottled biomicrite. An oolite-pelletoid facies (3) composed of oosparite, oomicrite, pelsparite, and pelmicrite overlies the biomicrite and mottled biomicrite facies. An algal mound complex composed of phylloid algal biomicrite is present in the southern part of the outcrop belt. South of the mound complex in the extreme southern part of the outcrop belt, a thin dolomitic subfacies of the biomicrite facies, laterally equivalent to the mound complex, wedges out into the detrital sedimentary rocks of overlying and underlying formations.

Ubiquitous distribution of phylloid algae indicates all limestones of the Swope formed in shallow water. The presence of oolitic limestone in the upper part of the Bethany Falls Member overlying biomicrites with a normal marine fauna suggests that shallowing of marine waters took place during deposition of the member. The distribution of subfacies in the oolite-pelletoid facies is analogous to the distribution of facies belts in modern oolitic carbonate sediments on the Bahama Platform west of Andros Island. Oosparites at the southern end of the outcrop belt of the facies resemble tidal bars and marine sand belts along the edge of the Bahama Platform. Oomicrites, pelsparites and pelmicrites in the northern part of the outcrop belt resemble the platform interior sediments of the Bahama Platform. Dolomitic micrites found in Iowa at the extreme northern edge of the Bethany Falls outcrop belt resemble shallow intertidal to supratidal sediments found on the west side of Andros Island.

INTRODUCTION

In eastern Kansas, Pennsylvanian rocks crop out in a belt that extends south-southwesterly through the state from the northeastern corner. The stratigraphic units are thin, laterally persistent, alternating layers of shale and limestone, with local sandstones, all dipping gently toward the northwest at 15 to 30 feet per mile.

The subject of this study, the Swope Formation, is one of the persistent limestone units in the Upper Pennsylvanian sequence. It is composed of three members which are, in ascending order, the Middle Creek Limestone, the Hushpuckney Shale, and the Bethany Falls Limestone (Fig. 1).

The objectives of this paper are to present a detailed description of the petrography of the carbonate rocks in the Swope Formation in the southeastern Kansas part of the outcrop belt, identify facies of the unit along this part of the outcrop, and interpret the depositional significance and interrelationships of these facies. Diagenesis and dolomitization in the limestone of the formation have already been described (Mossler, 1971).

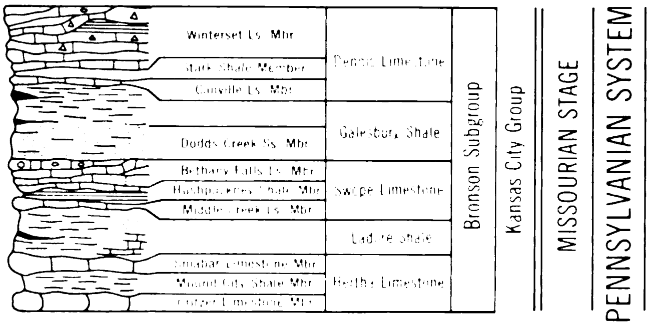

FIG. 1.—Generalized columnar section for Bronson Subgroup. Adapted from Moore (1948) and Zeller (1968).

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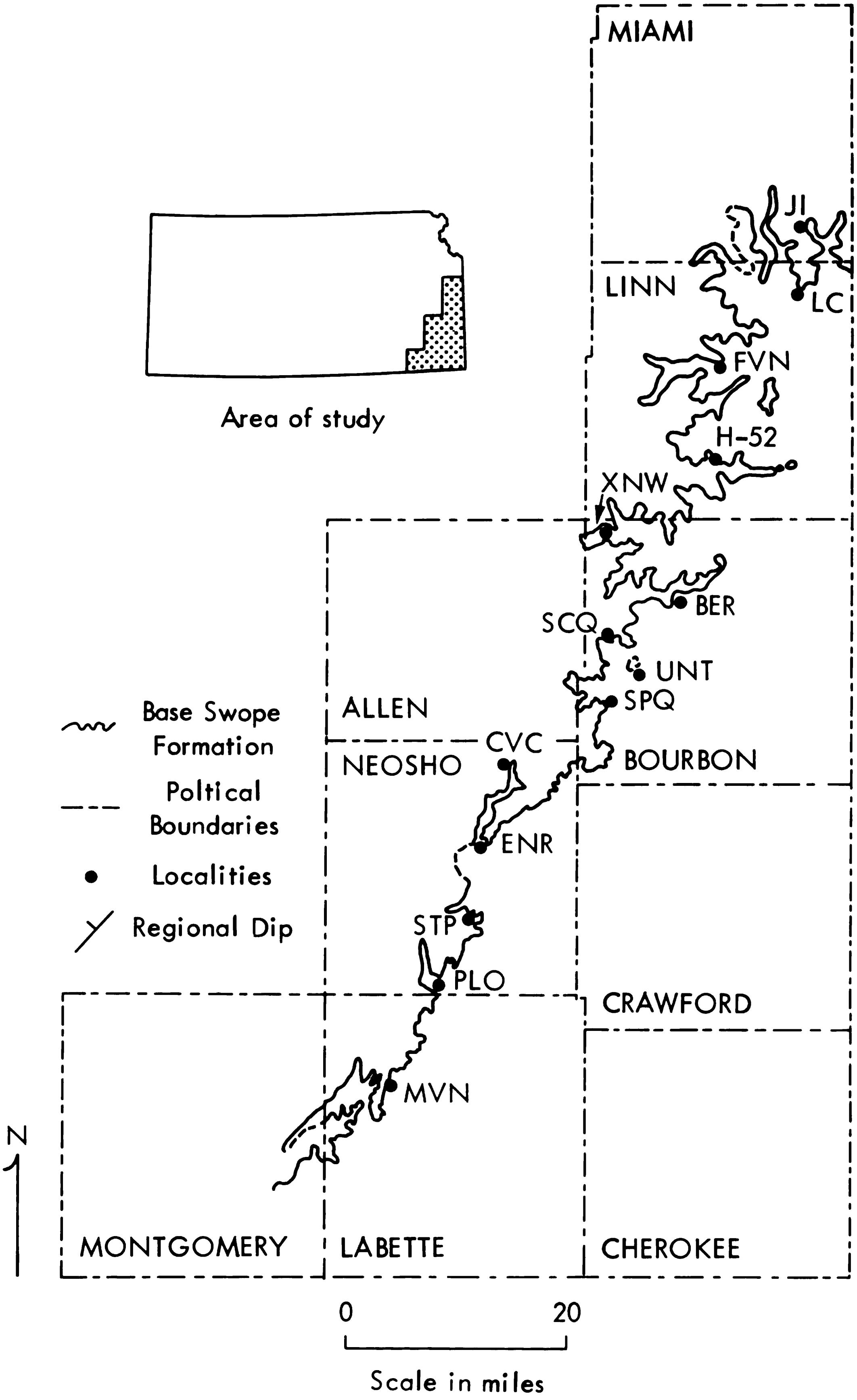

FIG. 2.—Outcrop trace of Swope Formation showing localities incorporated in schematic cross section (Fig. 3).

Several previous investigations provide a general framework for this study. Payton (1966) made a detailed study of the Missouri and Iowa outcrop of the Swope Formation in which he subdivided the formation into ten lithologic facies and interpreted environmental conditions under which they formed. Other investigators have made important contributions toward petrologic and environmental interpretation of the Swope Formation as part of the more general studies of several units in the Missourian Series. Heckel and Cocke (1969) discuss algal mound complexes observed in outcrops of Upper Pennsylvanian limestones of the Midcontinent region. Their publication is a continuation of work begun by Harbaugh (1959, 1960) who was the first to realize the important role of phylloid algae as a biotic constituent and rock builder in Upper Pennsylvanian limestones of southeastern Kansas. Hamblin (1969) studied marine paleocurrent directions in oosparites of the Bethany Falls and other limestones of the Upper Pennsylvanian Kansas City Group of southeastern Kansas, and related these directions to the paleogeography of the region. More recently, Scott (1970) presented a generalized model for Bethany Falls deposition based on a study of the member throughout its outcrop belt in Kansas, Missouri, and Iowa.

The stratigraphic nomenclature used in this report is that proposed by Moore (1948, p. 2028-2031). Folk's nomenclature (1959) is used for classifying limestone facies. Modifying adjectives are used with these names in order to describe the various rock types more thoroughly and to help delineate different facies in certain limestones.

Thirteen complete or nearly complete exposures of the Swope Formation in southeastern Kansas were intensively studied in 1968. These exposures were selected at relatively evenly spaced intervals along the outcrop belt (Fig. 2) and were chosen so that all significant variations in facies occurring along the Kansas outcrop were represented. In addition, many intermediate exposures were visited to delineate areal extent of the facies and to detect any lithological variations that might lead to more accurate interpretations of relationships between different facies. Exact locations for all measured sections are given in Mossler (1970).

Petrographic investigations involved use of 220 thin sections, stained to facilitate distinction of calcite and dolomite using the procedure of Dickson (1966) and 40 polished, stained rock slabs which were sprayed with clear acrylic. Several samples were serially sectioned to determine gross morphology of algae in the algal mound facies to decipher fabric relationships in color-mottled carbonates. Etched thin sections (Lees, 1958) and insoluble residues helped reveal distribution of detrital material within certain limestones.

ACKNOWLEDGMENTS

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GENERAL STRATIGRAPHIC AND ENVIRONMENTAL SETTING

The Swope Formation on outcrop represents part of a shallow marine shelf that extended northward from northeastern Oklahoma into Iowa. The regional slope of the sea bottom was generally toward the southwest (Payton, 1966; Hamblin, 1969). Unfossiliferous, laminated, dolomitic micrites, interpreted to have formed in very shallow marine to supratidal environments (Heckel, 1968) and *Osagia* biomicrites that formed in shallow-water environments (Payton, 1966) are found in Iowa, north of the open marine biomicrite facies of Kansas. They indicate that southwestern Iowa was near the northern landward end of the shallow marine shelf.

During the same time interval, the southern end of the shelf was the depocenter for thick wedges of terrigenous sediment which have been interpreted to be of deltaic origin (Wanless, *et al.*, 1971). The terrigenous formations directly beneath and above the Swope Formation both thicken southward in Kansas. The underlying Ladore Shale averages 10 feet in thickness in the north and thickens southward to 40 feet in Neosho County (Fig. 2). The overlying Galesburg Shale thickens southward from 10 feet or less of shale in Linn and Miami counties to more than 75 feet of shale and sandstone in southern Neosho County (Jungmann, 1966).

The Swope and other Upper Pennsylvanian limestone units of southeastern Kansas reflect the proximity of deltaic sedimentation in northeastern Oklahoma which influenced nearby calcareous shelf sediments in Kansas (Heckel and Cocke, 1969). Shallow marine shelf carbonates throughout most of Kansas thicken into algal mound complexes near their southern limits. Southward the mounds grade abruptly into thin biomicrites that interfinger with thick terrigenous clastic strata. Thick deltaic aprons of terrigenous sediment

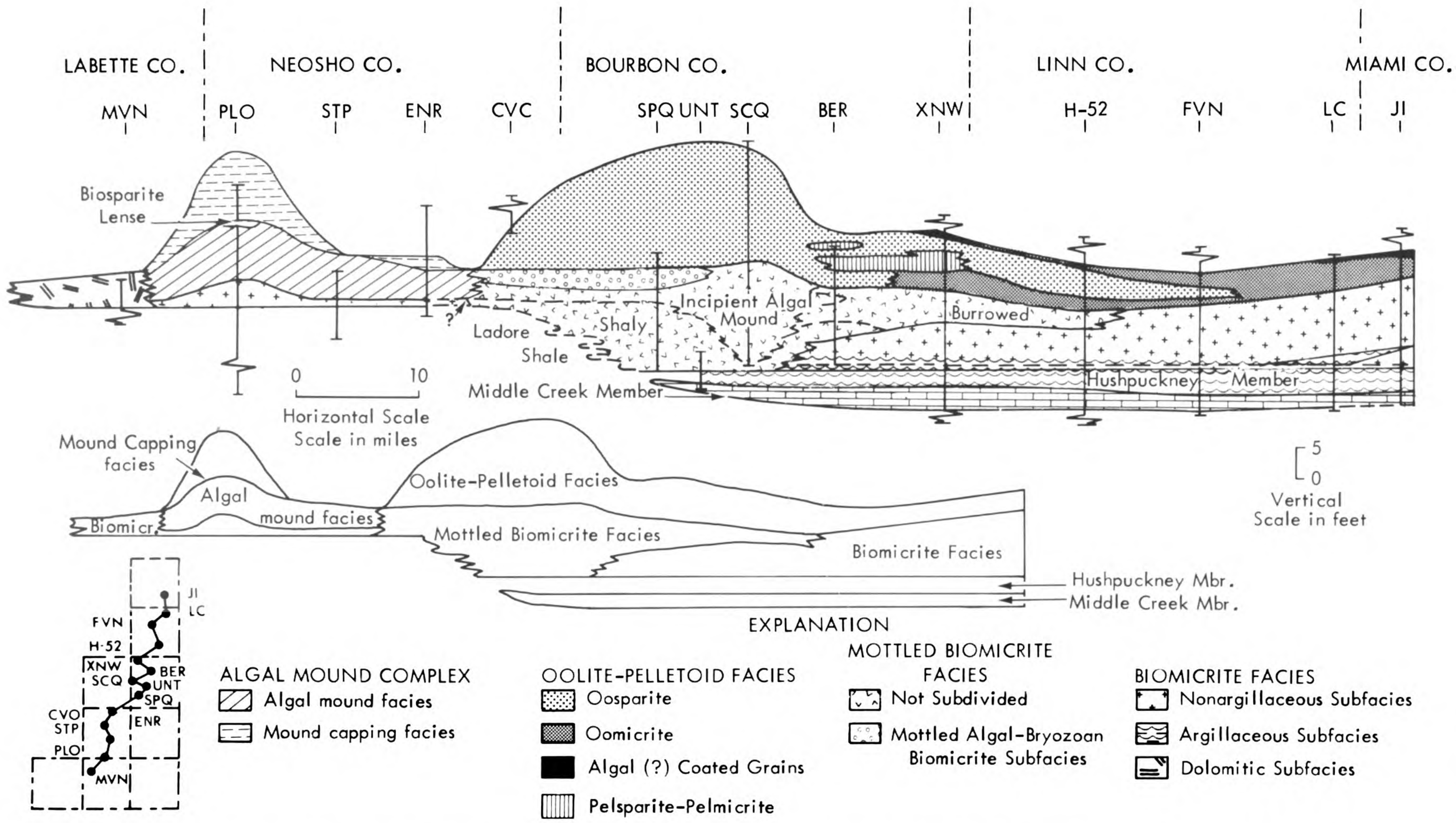

FIG. 3.—Schematic cross section through Swope Formation, southeastern Kansas. Solid vertical lines indicate portion of Swope Formation exposed at each outcrop. Zig zag lines at ends of vertical lines indicate deletion of part of outcrop from cross section. Legend refers to facies and subfacies in Bethany Falls Member of Swope Formation. Locations of outcrops used in construction of section shown in figure 2. Inset diagram shows distribution of five major facies of Bethany Falls. Biomicr. = biomicrite facies. North is to right.

at the southern end of the shallow marine shelf, as well as slight and subtle structural control, are interpreted to have provided localized topographic highs favorably situated for proliferation of algae (Cocke, 1968; Heckel and Cocke, 1969).

The Bethany Falls Member of the Swope Formation exhibits marked lateral lithological variations along its outcrop belt (Fig. 3) and comprises four major facies groups: 1) algal mound facies complex including mound capping facies, 2) oolite-pelletoid facies, 3) biomicrite facies, and 4) mottled biomicrite facies. In the northern part of southeastern Kansas the member is composed of biomicrite up to 14 feet thick overlain by 5 to 10 feet of oomicrite. Southward, in the central part of the outcrop belt, the biomicrite is replaced by a distinctively mottled biomicrite, and the overlying oomicrite grades into oosparite that attains nearly 20 feet in thickness. Near the southern end of the outcrop belt, the mottled biomicrites and oosparites disappear and are apparently equivalent to phylloid-algal biomicrites and biolithites 5 to 25 feet thick, grouped together into an algal mound complex. In the extreme southern part of the outcrop belt, where the Swope Formation wedges out and disappears between thickened overlying and underlying detrital units, it is a 5- to 6-foot-thick dolomitic biomicrite with abundant brachiopod and echinoderm fragments and silicified sponges.

The lower two members of the Swope Formation (Figs. 1 and 3) are known only from the region north of the algal mound complex and do not exhibit such marked lithological changes along the strike of the outcrop. The Hushpuckney Shale, directly beneath the Bethany Falls Limestone, is typically 5 to 6 feet thick; the basal half is black, fissile shale, and the upper part is a gray, blocky shale. The basal Middle Creek Limestone Member typically is a 3- or 4-foot-thick biomicrite but has been reported to thicken locally to 8 feet (Zeller, 1968, p. 28). Neither the Middle Creek nor the Hushpuckney are positively known to be present south of the most southerly outcrops of the mottled biomicrite facies of the Bethany Falls Member. The upper part of the Ladore Shale may be their southward equivalent. However, because of poor exposure of the base of the formation in this part of the outcrop belt, the identity of the member of the Swope occurring as the algal mound complex and biomicrite at the southern end of the outcrop belt is not conclusively proven; thus, the correlations shown in Figure 3 are indicated to be questionable. It is possible that the southern algal mound complex may be a mound at the southern terminus of the Middle Creek Member.

PETROGRAPHIC DESCRIPTION AND INTERPRETATION OF FACIES

Biomicrite Facies

The biomicrite facies (Fig. 3) is the most extensive carbonate facies of the Swope Formation. It is present throughout most of the Kansas outcrop belt, usually constituting the basal part of the Bethany Falls Member as well as the entire Middle Creek Member. Because of lithologic variations within the facies, it is divided into three subfacies that are discussed separately.

Nonargillaceous subfacies. This subfacies extends from the northeastern extremity of the outcrop belt in Kansas to locality BER in central Bourbon County (Figs. 2 and 3). It ranges in thickness from 14 feet in the north to a feather edge in the south where it interfingers with the mottled biomicrite facies. The basal part of the unit is the most persistent and extends the farthest south.

This subfacies is considered to be equivalent to the brachechinobiomicrite facies which Payton (1966) describes in Missouri. However, because of the preponderance of unidentifiable, subrectilinear, wavy fragments of skeletal material which has been recrystallized to sparry calcite, no modifying adjective describing fossil content is utilized. Whereas some of this sparry material can be identified as phylloid algae because it contains relict pores or utricles (Fig. 4), the identity of a large proportion of it cannot definitely be established.

Other fossils which are numerically important as fragments include echinoderms; bryozoans; brachiopods, particularly productid spines; and calcitized

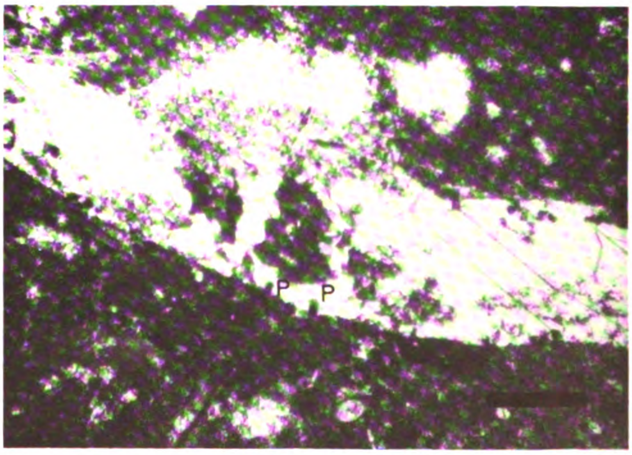

FIG. 4.—Fragment of phylloid algae as indicated by pores or utricles along bottom margin (P). Collapse of micrite into fragment indicates void-filling nature of sparry calcite now composing algal fragment. Nonargillaceous subfacies, biomicrite facies (locality JI). Bar = 1 mm.

monoaxonic sponge spicules. Ostracodes, fusulinids and pelecypods are minor constituents. Fossil fragments commonly are distributed in swirled patterns in the matrix and are finely comminuted, suggestive of reworking by burrowing organisms. The matrix is composed of microspar with the characteristic loaf-shaped crystals of calcite described by Folk (1965). Some areas of the microspar possess pelletoid texture interpreted to be the fecal pellets of scavenging organisms; in some instances these pellets fill portions of burrows.

Dolomite occurs in two forms: 1) silt-sized euhedra that replace micrite matrix; and 2) coarser ferroan spar crystals that replace fossil fragments and sometimes fill fractures and primary void spaces preserved within fossils. Commonly the silt-sized dolomite selectively replaces calcium carbonate matrix that is interpreted to have filled burrows, like similar dolomite in the basal argillaceous subfacies (see below). Silicification is widespread in this facies of the Bethany Falls, and occurs along bedding planes in the form of microcrystalline chert nodules that replace micrite and skeletal material.

Argillaceous subfacies. The basal foot of limestone in the northern part of the biomicrite facies is an argillaceous, dark colored, massive bed which is slightly different from the overlying nonargillaceous subfacies (Fig. 3). It carries disarticulated and broken fragments of a diverse fossil assemblage that includes gastropods, phylloid algae with recognizable microstructure, echinoderms, trilobites, ostracodes, bryozoans, pelecypods, brachiopods and some unidentified fossil fragments of collophane. The skeletal fragments do not exhibit any evidence of abrasion but they are arranged in swirled patterns suggestive of burrowing by organisms.

The unit is characteristically widely dolomitized by silt-sized (0.025-0.03 mm), subhedral to euhedral crystals selectively replacing the matrix, especially along burrowed zones. Minor amounts of dolomite partially replace fossil fragments composed of sparry calcite.

Payton (1966) observed this same zone at the base of the Bethany Falls Member in Missouri where he described it as a separate facies, the argillaceous pyritic biomicrite facies. He interprets it to be transitional between overlying limestone of the Bethany Falls and underlying Hushpuckney shale. Thin limestone lenses within the Hushpuckney Shale in Kansas (loc. LC), which are lithologically similar to the basal argillaceous zones, support this interpretation.

The basal Middle Creek Member of the Swope Formation is similar to the basal argillaceous subfacies in both its lithology and pattern of dolomitization. It is an argillaceous, medium- to dark-gray biomicrite with an abundant, diverse fauna which resembles that in the argillaceous subfacies. Dolomite usually occurs as silt-sized crystals replacing micrite along burrowed zones.

Dolomitic subfacies. South of the algal mound complex, the Swope Formation thins to 5 to 6 feet of biomicrite that extends from northern Labette County into Montgomery County (Figs. 2 and 3). In Montgomery County, thin biomicrites considered part of this southern facies may actually be lenses of limestone occupying stratigraphic positions in the thick Ladore-Galesburg clastic wedge that are equivalent or nearly equivalent to Swope limestones to the north (P. H. Heckel, pers. comm., 1968). Poor, discontinuous exposures preclude certainty about exact stratigraphic relationships between the limestone in Montgomery County and that to the north. South of southern Montgomery County, the thin biomicrites disappear and terrigenous clastics are stratigraphically equivalent to the Swope.

This subfacies is classified as a dolomitic biomicrite. The unit contains varied fossil constituents including echinoderms, bryozoans, pelecypods, phylloid algae, and foraminifers. The top foot of the limestone commonly contains large chert masses which contain sponges.

Most of the coarse calcite spar in the biomicrite replaces phylloid algae blades, but some appears to fill voids created by burrowing organisms or decay of soft-bodied organisms. Dolomite occurs in the form of silt-sized euhedra replacing micritic groundmass. The selective replacement of the fine-grained groundmass by dolomite is similar to dolomite replacement in argillaceous biomicrites beneath the algal mound and in the northern basal argillaceous subfacies. Most dolomite in outcrop has been intensively weathered and leached so that only molds of former dolomite crystals remain. The rock has also invariably been stained by hydrated iron oxides. The intensive alteration may be due to overlying porous sandstones that would give percolating ground waters easy subsurface access to the unit. Elsewhere the Bethany Falls usually is overlain by shales which provide the unit with a cap less permeable to ground water and would help protect it from intensive alteration.

Paleoenvironmental interpretation. Lack of criteria for grain support listed by Dunham (1962) indicates that the limestones in the biomicrite facies are mud-supported rocks. The large proportion of fine-grained sediments and the absence of conclusive evidence for grain support suggest the environment was relatively quiet, below wave base or sheltered from current activity.

The limestone typically does not possess well-developed stratification. The limestone is burrow mottled indicating reworking by burrowing organisms. Much of the comminution of skeletal material may have been done by scavenging organisms.

Most of the skeletal material probably is the remains of organisms that lived in the area. Abundant calcareous algae suggest that the biomicrite facies formed in shallow waters that were relatively clear. Absence of phylloid algal mounds in the northern non-argillaceous subfacies of the biomicrite may be due to the absence of appreciable sea-floor relief and rapid subsidence, features favoring localized proliferation of the algae as mounds (Heckel and Cocke, 1969). The diverse fauna in the northern biomicrites indicates open marine waters with unrestricted circulation which provided sufficient nutrients to support such a fauna (Heckel and Cocke, 1969).

Mottled Biomicrite Facies

The mottled biomicrite facies is present along the outcrop belt of the Bethany Falls Member from southern Linn County to northern Neosho County (Fig. 3). Thickness of this facies ranges from a feather edge at its northern end to about 12 feet close to its southern end.

The most distinctive attribute of this facies is color mottling. Darker, moderate brown to grayish-brown zones that may be in discrete patches (Fig. 5) or in anastomosing networks are set in a lighter pale-yellowish-brown groundmass.

Mottling in the mottled biomicrites can be grouped into three categories: 1) Mottling associated with diagenetic alterations along shale partings similar to that described by McCrossan (1958) and Leavitt (1968) (Fig. 6); 2) mottling associated with animal burrows now filled by carbonate spar (Fig. 7); and 3) mottling associated with subrectilinear to irregular zones of calcite and dolomite spar interpreted by Heckel and Cocke (1969) as filling or replacement of remains of phylloid algal blades and sheltered voids formerly present beneath the blades (Fig. 8). Burrows, algal blades, and shale partings may be intimately associated in the rock; thus, mottling within a small area of the facies may be related to more than one of the factors. However, each category is most prominent in a part of the mottled biomicrite facies. Mottling relating to shaly partings is most prominent in the southern part of the facies, mottling due to burrows is most prominent in the north, and mottling due to the sheltering effects of algal blades is most prominent in the central part (Fig. 3).

Fig. 5.—Field appearance of mottled biomicrite facies, locality XNW, northern Bourbon County.

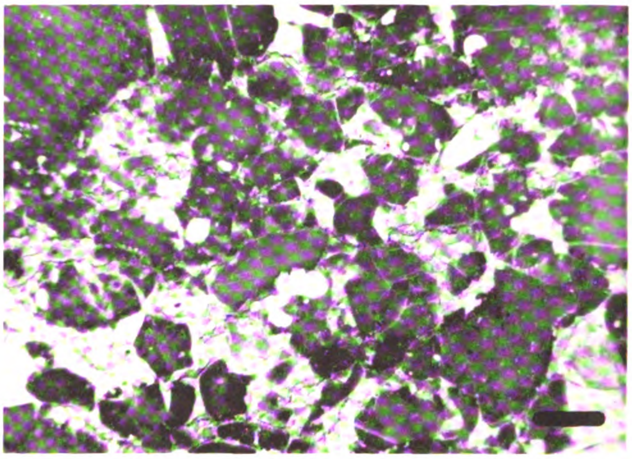

Fig. 6.—Polished surface showing appearance of shaly type of mottled biomicrite (locality SPQ). Argillaceous, micritic, lighter colored groundmass surrounds the discrete, darker colored zones of microspar. Bar = 1 cm.

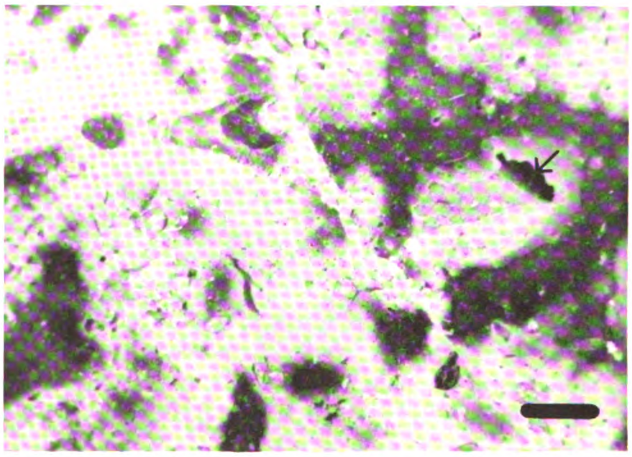

Fig. 7.—Polished surface showing burrowed type of mottled biomicrite facies (locality H-52). Note burrow (right side of photo) filled with two generations of internal sediment overlain by sparry calcite filling (arrow). Bar = 1 cm.

In all cases mottling appears to have been controlled by variations in the amount of permeability

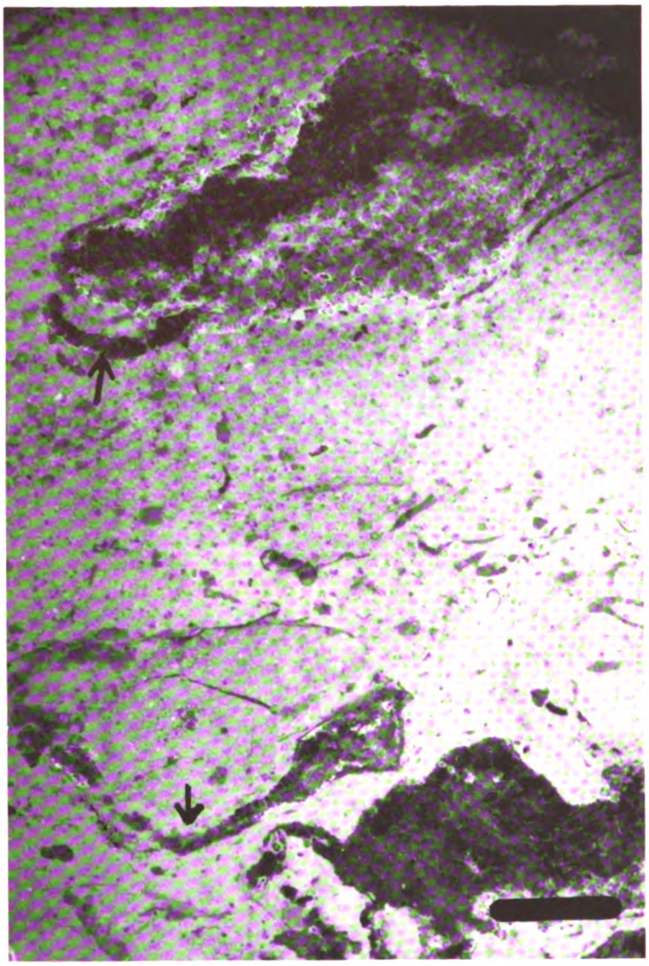

FIG. 8.—Negative print of thin section from locality SCQ showing appearance of spar-filled zones inferred to fill voids beneath phylloid algal blades that have either dissolved or disintegrated to micritic calcite. Elongate tracts of spar (arrows) resemble algal blades found elsewhere in Bethany Falls Member. Bar = .5 cm.

within fine-grained carbonate muds that originally constituted the mottled biomicrite facies (see also Scott, 1970). More permeable zones were selectively leached and bleached to lighter color by ground waters during early diagenesis, whereas less permeable zones retained original organic matter and remained darker.

The mottled biomicrite facies is usually micritic, but sometimes the micrite is recrystallized to microspar. Pelletoid texture is generally absent in this facies. Fossils constitute a smaller proportion (8-10%) of the rock in this facies than they do in the biomicrite facies (20-40%). The most prominent skeletal grains are those from fenestrate bryozoans and brachiopods; echinoderm and phylloid algae fragments are locally prominent. Monaxon sponge spicules are locally abundant in the rock, but volumetrically are of minor importance as a rock builder. Ostracodes, trilobite fragments, solitary horn corals, pelecypods, and foraminifers, including some fusulinids, are present in minor amounts.

At localities BER and XNW (Fig. 2) lenticular zones of mottled biomicrite 2 to 10 inches thick are interbedded in the biomicrite facies. The presence of these beds in the biomicrite and the similar stratigraphic position of these two facies in the lower half of the Bethany Falls Member directly beneath the oolite-pelletoid facies demonstrate that they are lateral equivalents. To the south, stratigraphic equivalence of the algal mound complex and the mottled biomicrite facies is difficult to establish because there are few outcrops in the area where the inferred facies change takes place.

Some features suggest that the algal mound complex and mottled biomicrite are at least partly equivalent. Zones containing calcite and dolomite-spar-filled vugs interpreted to be remnants of calcareous algae and sheltered voids that developed beneath them are prominent in the upper part of the mottled biomicrite facies near its southern end (localities SPQ and SCQ, Fig. 2). At locality SPQ this zone grades upward into a thin mottled algal-bryozoan biomicrite subfacies which may be the northern extremity of the algal mound complex.

The basal part of the mottled biomicrite facies possesses prominent shale partings near its southern end at locality SPQ indicating that it may be partly equivalent to the upper part of the Ladore Shale, if the Hushpuckney and Middle Creek are absent to the south.

Paleoenvironmental interpretation. The environment of formation of the mottled biomicrite facies is interpreted to have been the same as that of the biomicrite facies, a shallow open marine environment below wave base. The prominent lithological differences between the two facies are diagenetic.

The mottled biomicrites with relict algal structures at locality SCQ and near the top of locality SPQ may record incipient mound development by phylloid algae which failed to produce an algal mound on the scale of the thick mound farther south. The reasons a mound failed to develop are unknown, but may be related to unfavorable water depths, or absence of local topographic prominence on which mound-building algae could flourish, or lack of enough subsidence to delineate a buildup (Heckel and Cocke, 1969).

Oolite-Pelletoid Facies

The oolite-pelletoid facies of the Bethany Falls Limestone (Fig. 3) extends from locality CVC (Fig. 2) in northern Neosho County northward into Missouri where its distribution has been described by

Payton (1966). Where present, it is the uppermost facies of the Bethany Falls and directly underlies the Galesburg Shale. This facies exhibits pronounced lithologic variation in Kansas as it ranges from oosparite in the southern end of the outcrop to a preponderance of oomicrite and oomicrosparite with some interbedded pelmicrite and pelsparite at the northern end of the Kansas outcrop.

Ooids in this facies range from less than 0.05 to 1.5 mm in diameter. Ooids larger than 1.0 mm are rare. Nuclei are usually micritic pellets and less commonly bioclastic grains, usually from echinoderms, brachiopods, bryozoans, or molluscus. Other fossil fragments such as foraminifers rarely serve as nuclei. Terrigenous grains such as quartz were not observed to form nuclei in the ooids. The micritic pellets exhibit homogenous texture and are generally less than 0.15 mm in diameter, consistent with criteria of Folk (1959) for identifying fecal pellets. Some micritic nuclei may, however, have formed by the agglutination process described by Illing (1954). The ooids are generally recrystallized to sparry calcite that typically preserves the relict concentric structure of the orginal accretionary lamellae.

In Kansas, the oolite-pelletoid facies increases in thickness southwards along the outcrop. The thickest measured section of this facies is near its southern extremity at locality SCQ (Fig. 2), where it is 19 feet thick. Accompanying this increase in thickness is an increase in amount of sorting of the grains, decrease in amount of interstitial micrite, and increase in the proportion of grains that are true ooids with several concentric lamellae.

In the northern half of the outcrop belt (localities JI, LC, FVN, and H-52), where micrite is the predominant interstitial material, the oolite-pelletoid facies is 5 to 7 feet thick. Pellets and coated grains are common in this subfacies and some zones are primarily composed of pellets. This regional trend is reflected also in Missouri where Payton (1966) classifies most of the upper part of the Bethany Falls Limestone as micrite and reports only subordinate amounts of oolite limestone.

Petrographic and field observations indicate that outcrops of the oolite-pelletoid facies can be placed in two subfacies that reflect variation in environmental conditions at the time the sediments were being deposited. These subfacies are analogous to facies described by Ball (1967) from Holocene oolitic sediments on the Bahama Platform.

The southern outcrops of the facies (localities SCQ, SPQ, and CVC) (Figs. 2 and 3) represent the first subfacies. These outcrops are composed of oosparite and pelletoidal oosparite. Micrite is absent. Oomoldic porosity is well developed and cross-bedding is conspicuous. Although fossil material is scarce, a thin biosparite is present at the base of the units at locality SCQ and whole or nearly whole pelecypods and nautiloids are present along bedding planes at locality CVC. Scarcity of burrows and of micrite in this subfacies and the prominence of cross-bedding and oolitic sand grains with well-developed concentric lamellae indicate strong current activity during deposition of the subfacies. Oosparites in this part of the oolite-pelletoid facies resemble oolitic sands along the crests of bars in the tidal bar belts and in the marine sand belts described by Ball (1967) in the Bahamas.

The second subfacies is represented by outcrops in the northern part of the outcrop belt (localities BER, XNW, H-52, FVN, LC, and JI) (Fig. 2). It consists primarily of pelsparite (Fig. 9) and pelmicrite along with oomicrite. Oosparite with common pellets also is present in this subfacies. In addition to local cross-bedding in the oosparite in this subfacies, burrowing is indicated also by patches of pelletoidal oomicrite and micrite which transect bedding planes within oosparite zones. Pelmicrites and pelsparites commonly are arranged in regular, alternating, horizontal laminae that reflect original depositional control; some of these laminae are distorted, probably by activities of burrowing organisms.

Fossil material is as volumetrically unimportant in this subfacies as in the oosparite subfacies. Ooids with several concentric envelopes are still volumetrically important, and coated grains and sand-sized grains of micrite are usually present in accessory amounts.

Water agitation in the depositional environment of this subfacies was less than in the oosparite in the south. Occasionally, however, more turbulence must have been present in the area as indicated by local, thin, cross-bedded oosparites. Some poorly exposed

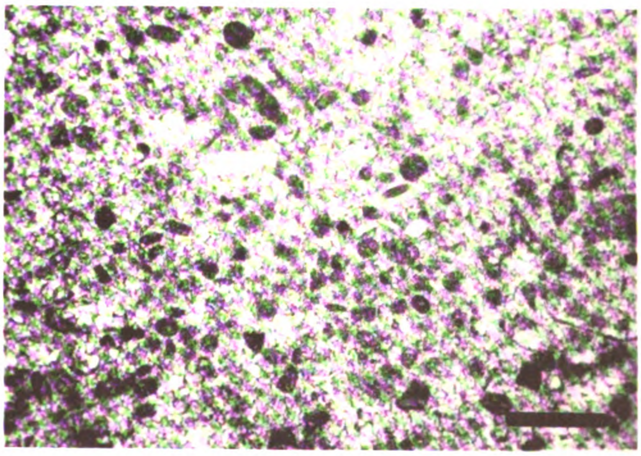

FIG. 9.—Pelsparite from oolite-pelletoid facies, locality XNW. Bar = 1 mm.

localities in Linn and Miami counties contain cross-bedded oosparites and demonstrate the pronounced lithological changes that occur in short distances in this facies. Modern oolitic sand belts may be very narrow, sometimes only a mile wide (Ball, 1967); therefore, only general interpretations can be made about the regional distribution of oolitic sand bars from the limited number of exposures of this facies.

Pelsparite (Fig. 9) may indicate environmental conditions similar to those reported by Kornicker and Purdy (1957) in Bimini. There, delicate fecal pellets are preserved because of low agitation, scarcity of scavengers, and induration by bacteriological precipitation of interstitial aragonite between the pellets. Recent pelletoid carbonate sediments described in the literature (Illing, 1954; Kornicker and Purdy, 1957; Cloud *et al.*, 1962) occur in low energy environments on platforms or in lagoons between oolitic sand belts and the strandline. There is no evidence to suggest that the water in which the pelletal limestones were deposited was sufficiently hypersaline for formation of contemporaneous gypsum or dolomite. Dolomite is present only in minor amounts in the pelletal limestones, and is in the form of void-filling ferroan dolomite spar that apparently precipitated later than most of the drusy calcite cement.

Nearly vertical burrows are present at localities H-52, FVN, LC, and JI. Some of these burrows extend for 3 or 4 feet (personal observation; Newell, 1935; Miller, 1966) and are about 0.75 inch in diameter. In some places they penetrate 1.2 feet into underlying biomicrite facies. Back filling can be observed in some of these burrows, and in some cases it is indicated by aligned parallel arcs of ooids which transect the burrow. In places the burrows were not filled with sediment and are analogous to modern burrows that are reported to remain open under as much as eight feet of sediment (Shinn, 1968a). These open burrows were later partially filled by calcite and ferroan dolomite spar.

The abundance of deep, vertical burrows in this zone of the oolite-pelletoid facies suggests an extremely shallow, nearshore environment. Rhodes (1967) found that in contrast to shallow horizontal offshore burrows, deep vertical burrows characterize nearshore, particularly intertidal, environments apparently because the organism needs greater protection from fluctuations in temperature, salinity, and dessication at the sediment-water interface in extremely shallow water.

The characteristics of the second subfacies of the oolite-pelletoid facies are similar to those of shallow water platform interior sand bodies in the Bahamas that have been described by Ball (1967), Newell, Purdy and Imbrie (1960), and Illing (1954). The variable proportions of micrite in different beds at a single exposure of this subfacies of the oolite-pelletoid facies may reflect local variations in water agitation on the shelf. By analogy to modern platform sands, micritic rocks probably formed on the lee sides of barriers (such as oolitic sand bars) that restricted currents. The presence of larger amounts of well-washed oosparites and of pelsparite in some exposures and of vertical burrows in others suggests minor variations in depth and in proximity of the platform deposits to the strandline. Possibly the sediments of the most northern exposures were closer to the shoreline and subject to more restrictive current conditions. Supporting this conclusion that the more northerly exposures may have been closer to the strandline are possible blue-green algal structures coating grains in the top feet of the subfacies at the two most northerly localities.

Crude ovoid intraclasts up to about 6 mm in length are present in the top foot of the oolite-pelletoid facies at locality LC. The intraclasts are composed of micrite that appears pelletoid; they are laminar only on the outside and resemble algal-coated grains described elsewhere (Tyrrell, 1969). Sparry calcite ooids and fossil fragments associated with the coated intraclasts also have thick laminated micritic coating that may result from algae (Fig. 10). The matrix of the rock is dense micrite with laminated fenestral or birdseye texture that indicates trapping of gas bubbles by algal mats (Shinn, 1968b). Calcite spar fills the birdseye structures; no dolomite was observed in the unit. Similar algal coatings were observed elsewhere only at localities XNW and JI where some ooids in the top foot of this facies had laminated micritic algal coatings. Tyrrell (1969) considered similar rocks representative of the unwinnowed shelf carbonate-sand en-

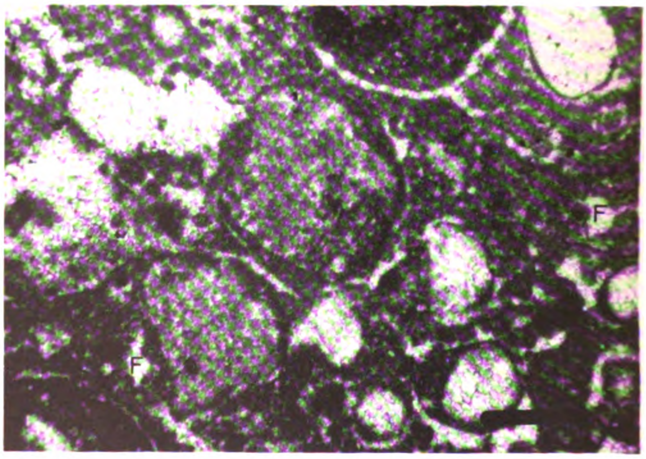

FIG. 10.—Intraclasts and sparry calcite grains coated by micrite of possible algal origin; matrix of rock contains fenestral or birdseye structures (F) (locality LC). Bar = 1 mm.

vironment whose modern analogue is the inner Florida reef tract. Birdseye structure and fenestral-laminated algal lime sediments indicate supratidal and intertidal environments (Illing, Wells, and Taylor, 1965; Shinn, Ginsburg, and Lloyd, 1965). The presence of these structures at the top of the oolite-pelletoid facies may indicate further shallowing of water in this northern area prior to deposition of overlying Galesburg terrigenous sediments.

In summary, the regional variation in this facies resembles that of a section through modern platform sediments in the Bahamas (Fig. 11). The southern oosparites are equivalent to cross-bedded sands of modern tidal-bar and marine-bar belts, and the northern oomicrites and pelletoidal rocks are equivalent to the modern muddy platform-interior sediments. Unfossiliferous laminated dolomitic micrites found in Iowa (Heckel, 1968) are equivalent to modern intertidal to supratidal sediments. This apparent trend toward more restricted conditions toward the north is consistent with marine paleocurrent data collected by Hamblin (1969) which indicates that the paleoslope in southeastern Kansas during Kansas City time descended toward the southwest.

Phylloid Algal Mound Complex

A phylloid algal mound complex is present along the outcrop belt from central to southern Neosho County. The mound complex attains a maximum thickness of 22 to 27 feet near the south end at locality PLO and thins northward to 7 feet at locality ENR. The complex consists of two facies, the algal mound and the mound-capping facies, and it overlies a subfacies of the biomicrite facies.

Argillaceous biomicrite subfacies beneath mound complex. Rocks assigned to the argillaceous biomicrite subfacies of the biomicrite facies are present beneath the algal mound facies (Fig. 3). Like the argillaceous biomicrite at the base of the biomicrite facies, this rock is transitional between the underlying dominantly terrigenous Ladore Shale and the purer carbonate of the overlying algal mound facies. This subfacies is 1 to 4 feet thick.

The fine-grained groundmass of this facies is intensely dolomitized everywhere it was observed except at locality PLO where only the basal foot is so altered. The skeletal grains, which have remained calcitic, are floating in the matrix of subhedral to euhedral silt-sized dolomite crystals. Ferroan calcite is interstitial to dolomite rhombs in the groundmass. The skeletal material is dominated by fragments of bryozoans, brachiopods (including some large, whole individuals), and pelecypods. Algae are not abundant in the unit except where it is more than a foot thick at locality PLO. Even in the thicker development, bryozoans, brachiopods, crinoids, and pelecypods are prominent biotic constituents.

Algal mound facies. The algal mound facies is composed of algal biolithite and biomicrite that differs from that in Lansing Group mounds (Harbaugh, 1959) by having smaller amounts of calcite and dolomite void-filling spar. The algal mound facies attains a maximum measured thickness of about 12 feet at locality PLO; northward it thins to 5 feet at locality ENR. The algal mound facies is characterized by abundant phylloid algal blades which appear to be preserved in original growth position in certain zones, and are interpreted to form algal biolithite (Fig. 12). Identifiable algae in the mound are probably codiaceans. J. L. Wray (pers. comm., 1969) identified material from localities PLO and ENR as *Ivanovia* (Khvorova, 1946), but states that the identification should be considered tentative. Bryozoans and other fossil forms are scarce in the algal biolithite but are important constituents in algal biomicrites overlying and interbedded with the biolithite zones.

Unlike other Upper Pennsylvanian algal mound limestone described by Heckel and Cocke (1969), the Bethany Falls mound does not possess more than localized zones containing conspicuous amounts of void-filling calcite and ferroan dolomite spar. Ferroan dolomite in the algal mound facies is mostly confined to fractures transecting the rock and to central portions of the algal blades. The growth form of *Ivanovia* may not have been as amenable to preservation of void space by the umbrella effect as the growth forms *Archaeolithophyllum,* which commonly grew as crusts and blades subparallel to the substrate (Wray, 1965). Wray (pers. comm., 1969) states that the growth form of *Ivanovia,* like that of related *Eugonophyllum* (Konishi and Wray, 1961), is one of upright blades. Serial sectioning of algal biolithite indicates many of the *Ivanovia* (?) blades in the Bethany Falls are concave-convex in cross-section, with the concave side upward (Fig. 12). This configuration would have allowed the blades to act as natural traps for sediment while preserving little void space beneath them. The abundance of micritic carbonate in the groundmass of the rock indicates that the algae grew in a quiet environment where silts and clays were not winnowed out.

Micrite in some portions of this facies is characterized by clotted texture. This texture may be due to fecal pellets that were protected from compaction by algal blades or may be pellets of algal origin similar to those reported by Wolf (1965).

At locality PLO, a small lens of biosparite occurs at the top of the algal mound. It is 8 to 10 inches thick and about 3 feet in width and has a biconvex

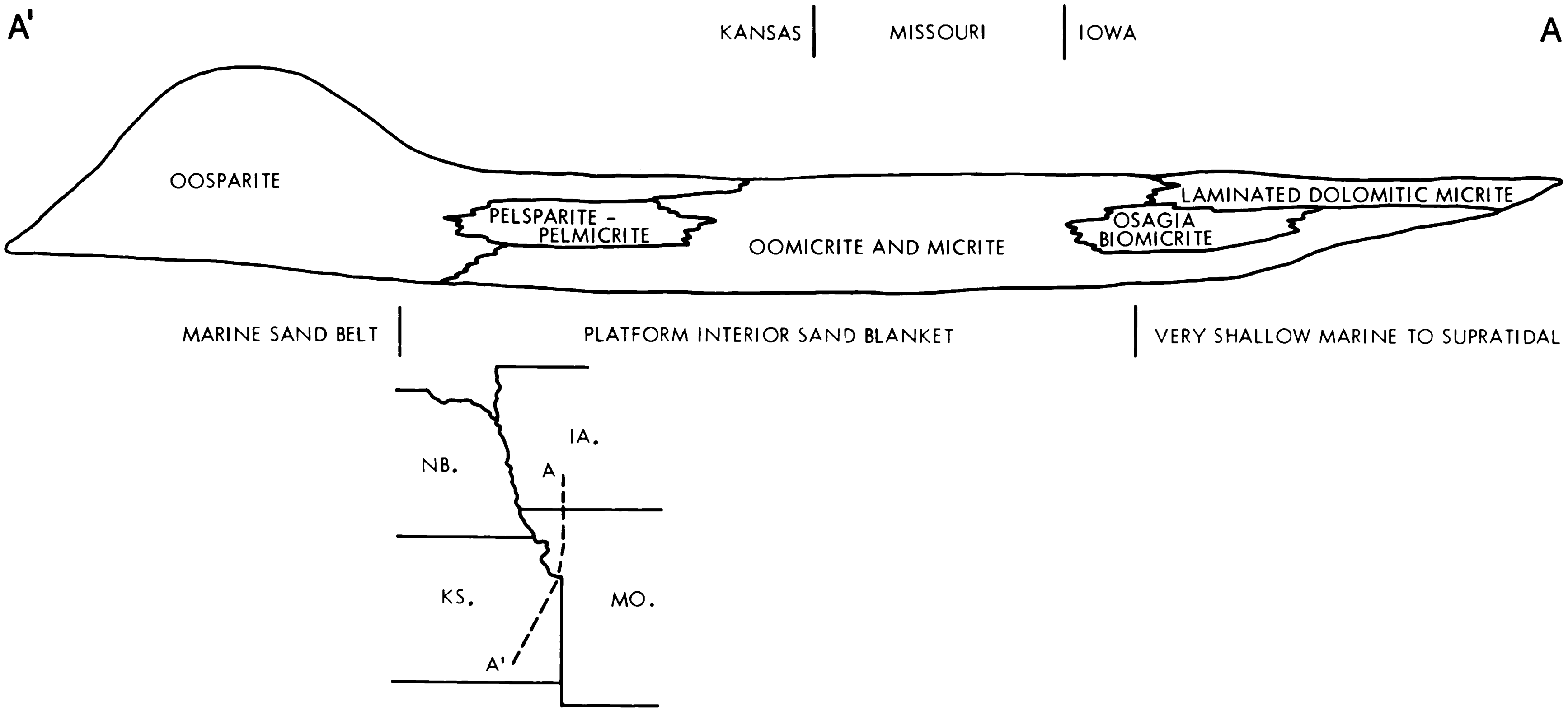

FIG 11.—Schematic cross section from southeastern Kansas to southwestern Iowa illustrating inferred relationships between subdivisions of the oolite-pelletoid facies at the top of the Bethany Falls Member. Southward regional dip is indicated both by facies belts and paleocurrent data of Hamblin (1969). Distribution of lithologic types in the oolite-pelletoid facies is analogous to distribution of modern sedimentary facies in Bahamas (Ball, 1967) shown beneath the diagram. Adapted in part from Payton (1966) and Heckel (1968). Not to scale.

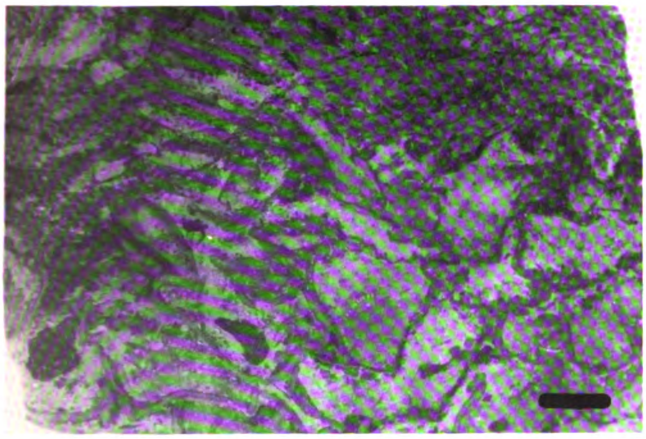

FIG. 12.—Polished surface of algal biolithite (lower part of photograph) from locality ENR showing concave upward configuration of many algal blades. Bar = 1 cm.

shape. It is composed chiefly of bryozoan and echinoderm fragments with subordinate amounts of pelletal material. There are also some transported grains of drusy calcite that may be fragmented algae blades. This lens may be a small intramound channel similar to those mentioned by Heckel and Cocke (1969) and analogous to those Ball (1967) ascribes to tidal currents in muddy algal banks in Florida Bay. Or alternatively, it may be a small lime sand bar that formed on the mound.

Mound-capping facies. The mound-capping facies, rocks which were influenced sedimentologically by proximity to the mound, overlie and are interbedded with the algal mound facies in Neosho County, and are possibly present in southern Bourbon County. They are generally relatively thin biomicrites. They differ in this respect from those of other algal mounds (Pray and Wray, 1963; Heckel and Cocke, 1969) which typically are thick biosparites and oosparites that commonly are cross-bedded.

Approximately 11 feet of rubbly to poorly bedded biomicrite overlies the algal mound facies at locality PLO. Algal fragments are the most abundant grain type, and bryozoan fragments rank second in importance. All algal material seems fragmented and displaced, and none apparently is in growth position. Some whole or nearly whole brachiopods are present in the rock. Foraminifers, echinoderm fragments, and brachiopod spines are numerically less important constituents in the facies, but commonly are observed in thin section.

The interstitial micrite possesses a clotted texture, similar to that previously attributed to fecal pellets. Some of the algal fragments have rounded to biconvex shapes that may be due to grain diminution or dissolution effects similar to those found on algal grains in color-mottled biomicrites in Bourbon County or may be due to abrasion. Aside from minor amounts of possible pseudospar, derived probably from recrystallization of matrix, the chief diagenetic alteration is minor silicification along bedding planes. This zone may have formed in slightly deeper water flanking nearby algal mounds.

Another type of capping facies is present at locality ENR. This cap rock is a thin, sparsely fossiliferous biomicrite. At the base is about 1 foot of pelletoidal biomicrite. Overlying this unit is about 1 foot of intramicrudite. The intramicrudite is overlain by a thin-bedded 4-inch unit that ranges in composition from calcareous, very fine-grained orthoquartzite to fossiliferous intrasparite. Except for its higher carbonate content this unit resembles the overlying Dodds Creek Sandstone. The sandy unit contains intraclasts of carbonate up to 2 to 3 millimeters in diameter that are lithologically similar to the limestone in the two underlying units. In addition, large fossil fragments including brachiopods, pelecypods, bryozoans, echinoderms, and foraminifers are present. These three units document the change in sedimentation from carbonate deposition in the algal mound to terrigenous deposition of the overlying Dodds Creek Sandstone. The contact is not a marked unconformity, but the intraclasts indicate some reworking of carbonate sediment prior to and during initial deposition of the Dodds Creek.

The mottled algal-bryozoan biomicrite subfacies (locality SPQ) may also be a lateral equivalent of the algal mound facies. Here, as at the mound-capping facies at locality PLO, the algae may not have proliferated as rapidly as they did in the mound because of unfavorable environmental conditions.

Paleoenvironmental interpretation. By analogy to closely related *Eugonophyllum* discussed by Konishi and Wray (1961), abundance of Swope algae in a moundlike accumulation probably reflects prolific growth in very shallow water. Konishi and Wray state that the large algal blades may have trapped and bound sediment just as do modern marine grasses in shallow subtidal banks. The occurrence of a small channel or bar of biosparite on the algal mound at locality PLO indicates impingement of wave base on the mound. Micritic mound-associated rocks capping the algal mound at locality PLO and laterally extensive with the mound at locality SPQ in southern Bourbon County may have formed in slightly deeper waters between adjacent mounds or flanking an algal mound. Baars (1963) reports that deeper waters surrounding algal banks in Florida Bay are carpeted with the same green algal flora as the banks but that the flora is not as profuse. The intramicrudite at locality ENR may result from reworking of underlying mound rock just before deposition of the Dodds Creek Sandstone or it may record formation of a nonalgal tidal flat environment prior to deposition of the sandstone.

CONCLUSIONS

Both of the lower units of the Slope, the uniform biomicritic Middle Creek and overlying Hushpuckney, are present only in the north and may be equivalent to the uppermost part of the underlying Ladore Shale in the southern part of the Kansas outcrop.

The Bethany Falls member is composed of four major facies groups (Fig. 3); 1) the biomicrite facies, 2) the mottled biomicrite facies, 3) the algal mound complex, including the mound capping facies, and 4) the oolite-pelletoid facies. The main part of the biomicrite facies (1) crops out at the north end of the Kansas outcrop belt and is characterized by an abundant varied fauna and conspicuous sparry calcite algal fragments. This facies passes southward into the mottled biomicrite facies (2) which has a shaly southern subfacies and a burrow-mottled northern subfacies separated by a zone that apparently represents localized incipient algal mound formation. Overlying the mottled and non-mottled biomicrites is the oolite-pelletoid facies (3) composed of thick cross-bedded oolites in the south and thin interbedded oosparites, oomicrites and pelsparites-pelmicrites in the north. South of the mottled biomicrite facies is the algal mound facies complex (4) consisting of the mound composed of algal biomicrites and biolithites, underlain by a thin argillaceous, dolomitic to completely dolomitized subfacies of the biomicrite facies and overlain and flanked by mound associated facies composed of algal-bryozoan biomicrite, crinoidal biosparite and intramicrudite. South of the algal mound complex there is a thin ironstained dolomitic subfacies of the biomicrite facies (1) which thins southward to a feather edge between thickened over and underlying detrital units.

Correlation between the algal mound in the southern part of the Kansas outcrop belt and the biomicrites and oolitic limestones in the northern part is equivocal. The algal-mound facies is interpreted to be partly correlative with both the mottled and non-mottled biomicrites in the lower part of the Bethany Falls Limestone in the northern part of the outcrop belt and the oolite-pelletoid facies in the upper part of the northern outcrop, but stratal continuity is not proved at this point. The shaly subfacies at the southern end of the mottled biomicrite facies may be equivalent to the uppermost part of the Ladore Shale southward.

The oolite-pelletoid facies of the Bethany Falls fits a sedimentological framework similar to that presently prevailing on the Bahama Platform west of Andros Island. It is primarily oosparite at the southern end, oomicrite, pelsparite, and pelmicrite in the central part, and barren, laminated, dolomitic micrites at its northern end in Iowa (Heckel, 1968). This broad pattern of subfacies indicates a regional slope of the sea floor towards the south during deposition of the facies and is consistent with the regional slope indicated by marine plaeocurrent directions (Hamblin, 1969).

The presence of fine-grained carbonates with a normal marine fauna in the color-mottled biomicrite facies and the biomicrite facies of the lower part of the Bethany Falls indicates that this part of the Bethany Falls formed in slightly deeper water than the overlying oolite-pelletoid facies. However, phylloid algae are a prominent biotic constituent in the northern biomicrites of Kansas, and stromatolites are important in Missouri (Payton, 1966) indicating that depth of sedimentation nevertheless was not below the photic zone. The abundance of cross-bedded oolites in the upper part of the Bethany Falls indicates that water must have shallowed during deposition of the unit until some of the carbonate sediments were forming above wave base. The interpretation that water progressively shallowed during deposition of the Bethany Falls in Kansas is consistent with Payton's (1966) similar conclusion concerning the member in Missouri and Iowa.

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