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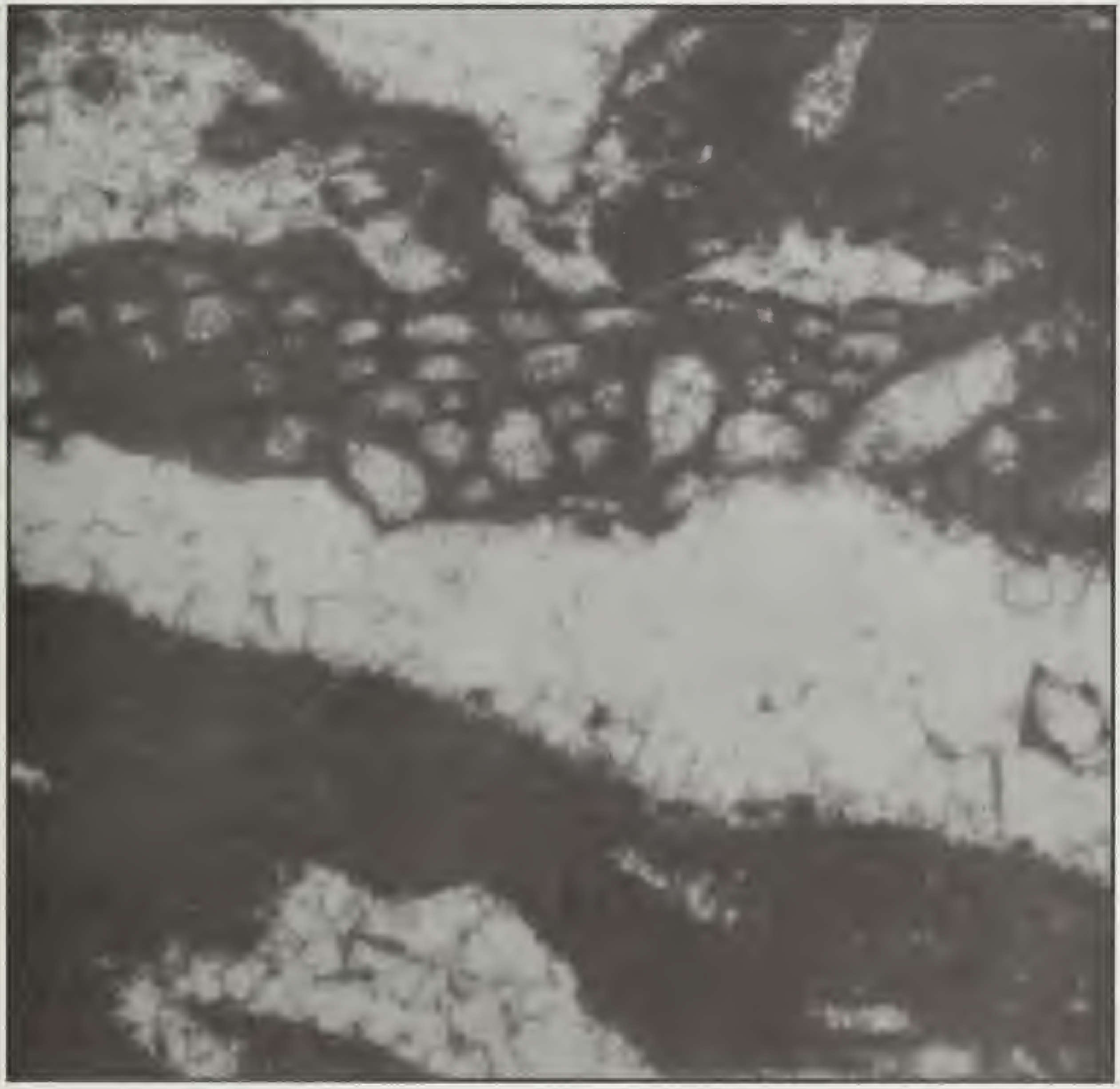
Upper Pennsylvanian Algal Bank Limestones on the Northern Margin of the Illinois Basin, Livingston County, Illinois

Gordon S. Fraser



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Cover photo Photomicrograph of the platy algal facies of the La Salle Limestone showing encrusting bryozoa on margin of recrystallized algal plate (90x mag.)

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ABSTRACT

The exposed limestones in Livingston County, Illinois, were studied in outcrop and thin section to define their stratigraphic relationships and establish their environments of deposition. The limestones belong to the Cramer Limestone Member, exposed along the Vermilion River in the central part of the county, and to the La Salle Limestone Member, exposed in quarries in the southern part of the county.

Six microfacies occur in the two units. The Cramer Limestone is an intraclastic conglomerate consisting of bioclastic wackestone fragments in an argillaceous fossiliferous matrix. The lower part of the La Salle Limestone is a bioclastic calcareous mudstone consisting of scattered fossil fragments in an argillaceous micrite matrix. It is overlain by a phylloid algal wackestone/packstone consisting of phylloid algal plates in a matrix of pelletal micrite and fine-grained shell debris. At intervals within this facies are thin beds of bioclastic packstone consisting of large fossil fragments and intraclasts, and these may be laterally associated with lenses of fossiliferous shale containing abundant complete specimens of a variety of echinoderms. An upper unit to the north is a brecciated algal wackestone/packstone consisting of angular fragments of the phylloidal algal facies and broken and abraded fossil fragments.

The facies of the La Salle Limestone probably developed in an algal bank complex that occurred during Missourian time. A key to interpreting the relationships among the various facies in the limestones of Livingston County, and to reconstructing the environment in which they were deposited, is the recognition that algae were the principal biotic constituent of the rocks. The algal bank complex began to develop after a transgression reduced the yield of terrigenous clastics to the area. It developed initially below storm-wave base, but as it accreted, its surface eventually was exposed to storm-generated currents. Patches of echinoderms were established on the bank where they produced a local baffling effect that slowed currents and trapped muds. They were periodically disrupted by storms that spread echinoderm debris over the bank as thin beds of bioclastic packstone.

Intraclastic conglomerates of the Cramer Limestone could have formed when algal bank sediments slumped off an adjacent bank into low-energy, protected areas. However, this facies may not be related to any algal mound complex because the Cramer is stratigraphically lower than the other facies, and no algal mounds have yet been identified in it.

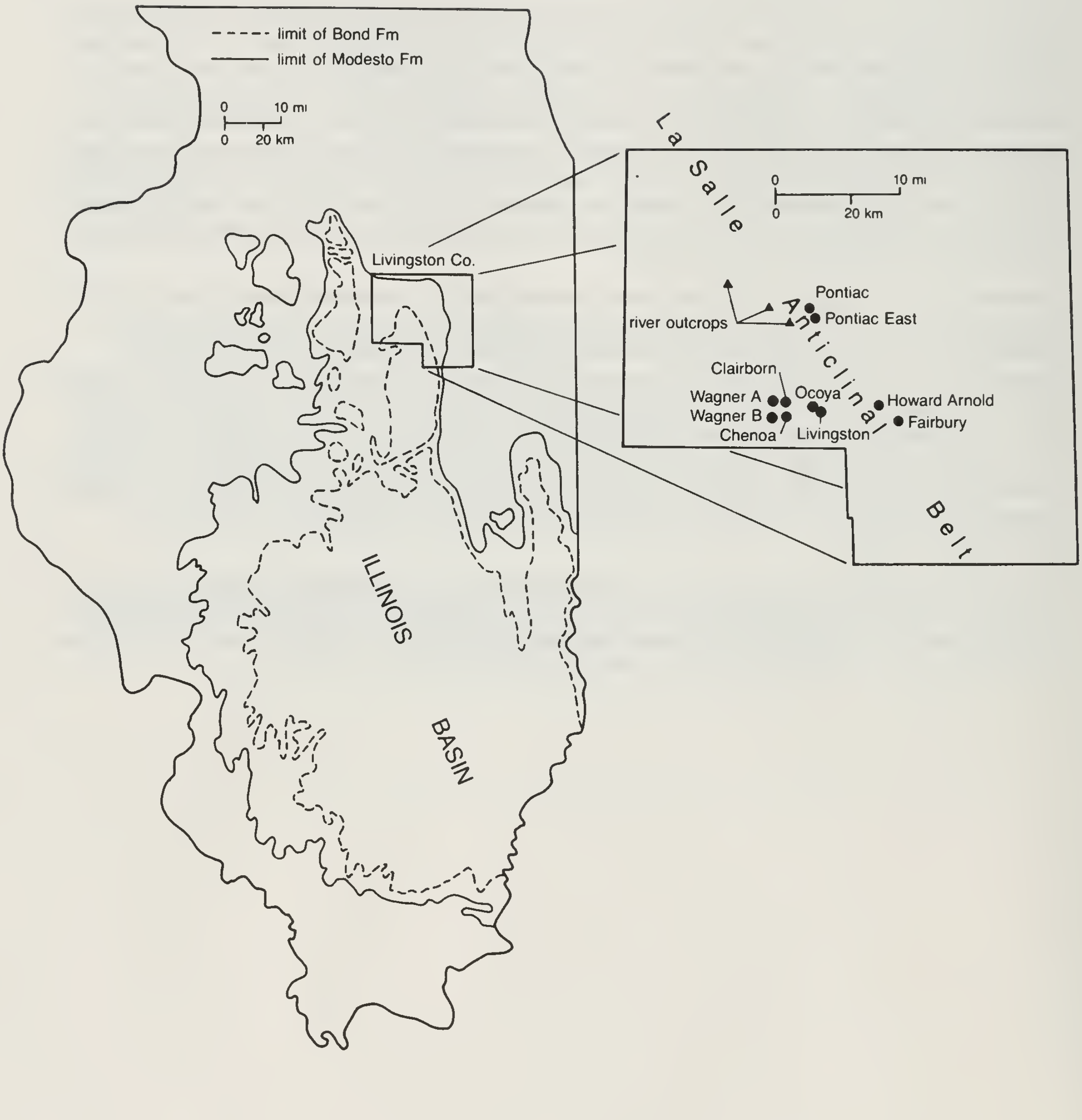

Figure 1 Location of Livingston County with respect to the Illinois Basin, the La Salle Anticlinal Belt, the extent of the Modesto and Bond Formations in Illinois, and the location of surface exposures of the Cramer and La Salle Limestone Members.

INTRODUCTION

Background

Phylloid algal limestones are uncommon in the Illinois Basin. Occurrences in the Missourian Series (Pennsylvanian), however, have been reported on the northern margin of the basin (Fraser 1970, 1971, Hughes and Morris 1972) and in the Bond Formation of the west-central part of the basin (Welch 1977).

This paper reports the results of a petrologic analysis of limestone bodies in the upper Modesto and upper Bond Formations in Livingston County, Illinois. The results are derived from examination of 200 thin sections, mineral analysis of more than 50 samples, and examination of the quarry and outcrop exposures shown in figure 1.

The units and area were selected because such work had not been done on the platform bordering the northern side of the Illinois Basin. I also wanted to compare the sediments of this area with algal bank limestones elsewhere. The Livingston County area was chosen because it offered several excellent exposures (fig. 1), and because the limestone in the area is of significant economic interest.

These limestones in the Illinois Basin and those of the central and southwestern United States are strikingly similar, but there are substantial differences as well. Phylloid algal mounds commonly occur in late Paleozoic carbonates of western Texas and southern New Mexico (Choquette and Traut 1964, Pray and Wray 1963, Elias 1964, Wray 1968, Wermund 1975, Wilson 1975, 1977, Toomey 1976, Toomey et al. 1977; Toomey and Babcock 1983, Choquette 1983, Pol 1985) and in the midcontinent, especially Kansas and Missouri (Harbaugh 1959, 1960, Laporte 1962, Payton 1966, Crowley 1969, Neal 1969, Heckel and Cocke 1969, Frost 1975).

Geologic Setting

Livingston County straddles the La Salle Anticlinal Belt on the northern edge of the Illinois Basin in north-central Illinois (fig. 1). Rocks of the Bond and Modesto Formations outcrop in the county in quarries or along stream valleys, or subcrop beneath the Pleistocene cover (Fraser 1970). They primarily consist of mudstones and minor sandstones that probably were deposited in a variety of fluviodeltaic and marginal marine environments (Horne 1968) (fig. 2).

The Missourian Series in Livingston County is poorly understood. Structure in the area considerably complicates correlation, and no complete section of the unit is either exposed in outcrop or available in core. In addition, megascopic examination of the limestone beds in the upper part of the section indicates that they closely resemble the algal marine bank limestones found in the midcontinent and southwestern United States. Abrupt lateral facies changes associated with such marine banks make physical correlation difficult.

The Cramer Limestone Member of the Modesto Formation (fig. 2) outcrops along the Vermilion River northwest of the city of Pontiac. Fraser (1970) had earlier identified these rocks as belonging to the Hall Limestone Member on the basis of their structural setting and compositional characteristics, but Jacobson (1989, written communication, ISGS) has indicated that they belong to the Cramer (formerly Macoupin) Limestone Member.

The La Salle Limestone Member of the Bond Formation is quarried extensively within a triangular area bounded by the cities of Pontiac and Fairbury and the town of Ocoya (fig.1). Thickest exposures of the La Salle occur in the southwest part of the county where as much as 20 feet of the limestone, as well as underlying gray fossiliferous shale and black fissile shale, are exposed. The limestone is mottled gray and interbedded with thin gray shale stringers in the southwest, but it is white to buff, thinner bedded, and less argillaceous to the east and north. The general sequence of limestone/gray shale/black fissile shale downward in the section is found in every exposure despite the variability of the limestone.

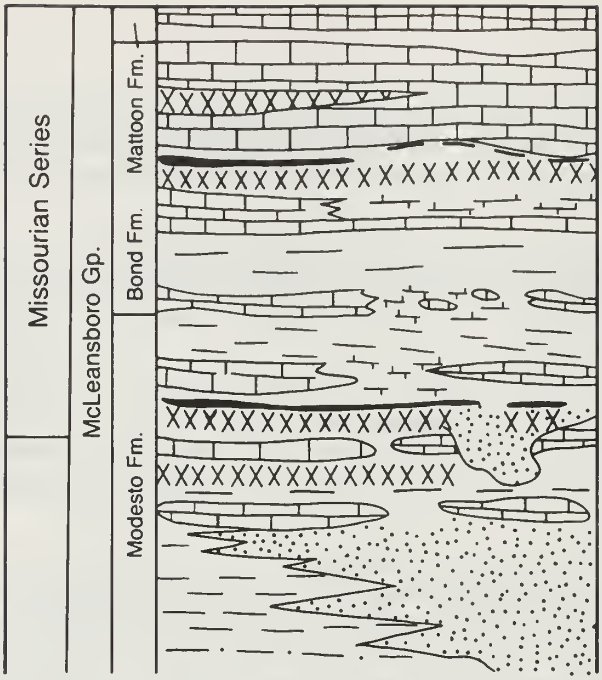

Figure 2 Stratigraphic column showing the positions of the limestones in the upper Modesto and lower Bond Formations on the northern margin of the Illinois Basin (from Jacobson 1985)

The exposed limestones in Livingston County formerly were grouped together into a single unit, informally termed the Pontiac Limestone by Lamar (1929). Ostrom (1956) correlated the exposed limestones of the county with the La Salle Limestone Member of the Bond Formation. Later (1957) he renamed them the Pontiac Limestone and correlated them with the Shoal Creek Limestone Member of the lower Bond Formation. At that time the La Salle Limestone was thought to be equivalent to the Livingston and Millersville Limestone Members of the upper Bond Formation (Wanless and Siever 1956; Kosanke et al. 1960). Later, Clegg (1969, personal communication, ISGS) physically correlated the Pontiac Limestone to the Shoal Creek Limestone Member of the lower Bond Formation. The La Salle Limestone, by its relationship to the Pontiac Limestone, also was correlated with the Shoal Creek Limestone. Willman et al., (1967) placed the La Salle in the lower Bond Formation in the same position occupied by the Shoal Creek Limestone in the southern part of the state.

Most geologists previously included all the limestones exposed in the county in a single unit because the downward sequence of limestone/gray shale/black shale was present in all exposures. Fraser (1970), however, suggested that because of structural complications imposed by minor features of the La Salle Anticlinal Belt, not all the limestones belonged to the same stratigraphic unit, and that limestones exposed along the Vermilion River belonged to the Hall Limestone Member.

Jacobson (1983) used detailed subsurface correlations to establish that the La Salle Limestone (Pontiac Limestone) in Livingston County is not the correlative of the Shoal Creek (presently termed the Carthage Limestone). Instead, it is likely the correlative of the Millersville and Livingston Limestones as suggested by Wanless and Siever (1956) and Kosanke et al. (1960). Additional unpublished work by Jacobson (1980, written communication, ISGS) also has shown that the limestones along the Vermilion River do not belong to the Hall Limestone as postulated by Fraser (1970), but instead are the Cramer Limestone of the Modesto Formation.

CARBONATE PETROGRAPHY

Platy Algal Wackestone/Packstone

The dominant feature of this facies is the abundant plates of phylloidal algae in a partially recrystallized, pelletoidal micrite matrix (fig. 3a). Very little of the original plates is left because they have been dissolved and replaced by void-filling sparry calcite, but their external morphology is like that of phylloidal algae that have been identified in Pennsylvanian and Permian rocks of the mid-continent and southwestern parts of the United States. The former position of the plates is marked, in some instances, by remnants of lamellar structures or by a thin layer of micrite at the boundary between the sparry calcite and the matrix. In other places the former position of plates is indicated by encrusting bryozoa or foraminifera (fig. 3b). Algal plates are normally unbroken and unabraded, and are mud-supported by the matrix. Locally, however, the plates are in contact, forming a loose framework structure.

The matrix consists primarily of pelletal micrite (fig. 3c), but it also contains abundant fine-grained bioclastic debris, consisting chiefly of ostracodes along with some brachiopod and crinoid fragments less than .2 mm in grain size. A few nearly intact brachiopod shells are present and some have been fractured in place. Complete gastropods also are abundant. These two fossils commonly display geopetal structures in which the lower interior of the shell is filled with matrix and the upper part is filled with primary void-filling sparry calcite. In addition, many larger brachiopod shells accumulated with the convex side upward and acted as "umbrellas," forming a void filled with sparry calcite.

Three kinds of sparry calcite occur in this facies. Primary void-filling calcite fills original voids inside fossil shells, under shells, or under accumulations of algal flakes. Crystal sizes decrease gradually toward the void margins, and the crystals adjoin one another along smooth, straight faces. Where the void filling abuts matrix material, such as at the lower boundary of an umbrella structure, recrystallization of the micrite generally has occurred.

Secondary void filling occurs where algal chips have been dissolved and the voids have filled with sparry calcite. Again, the crystal boundaries are smooth and straight and in many cases a suture line forms where crystals growing from the sides of the voids meet in the center. Crystals nearest the matrix generally are much smaller than the next layer of crystals in the void so that there is no gradation in size toward the boundaries of the voids.

Recrystallization of the matrix produces pseudospar. Recrystallization is indicated by nongradation in size toward the margins of the affected areas, embayed crystal boundaries, and the presence of many inclusions in the crystals. Recrystallization is evident especially at the margins of affected areas. Patchy recrystallization may extend as far as 2 mm into the matrix where this occurs. In other cases, recrystallization has occurred in randomly scattered patches throughout the matrix.

The limestones have been partly dolomitized in places. Dolomite occurs in voids, as much as 1 cm wide, that are incompletely filled with sparry calcite, and also along fractures and argillaceous stringers in the rock. Sparry calcite in the voids and fractures has been selectively dolomitized and the dolomite has partially replaced the matrix as well. These same areas also tend to localize pyritization.

Fossiliferous Shale

The top of the platy algal limestone sequence is marked by shale-filled depressions up to 4 feet (1.2 m) deep (fig. 4a). Limestone nodules in the lower portion of these mudstone lenses are composed of echinoderm spines in reciprocal contact and set in a matrix of argillaceous micrite (fig. 3d). The spines appear unabraded, and apparently accumulated parallel to bedding. Relative scarcity of other echinoderm fragments is probably because most of the echinoderms are preserved as complete specimens. Christina Cleburn (1969, personal communication) has collected numerous such specimens from these localities, and a diverse fauna from these shale lenses has been described by Strimple and Moore (1971).

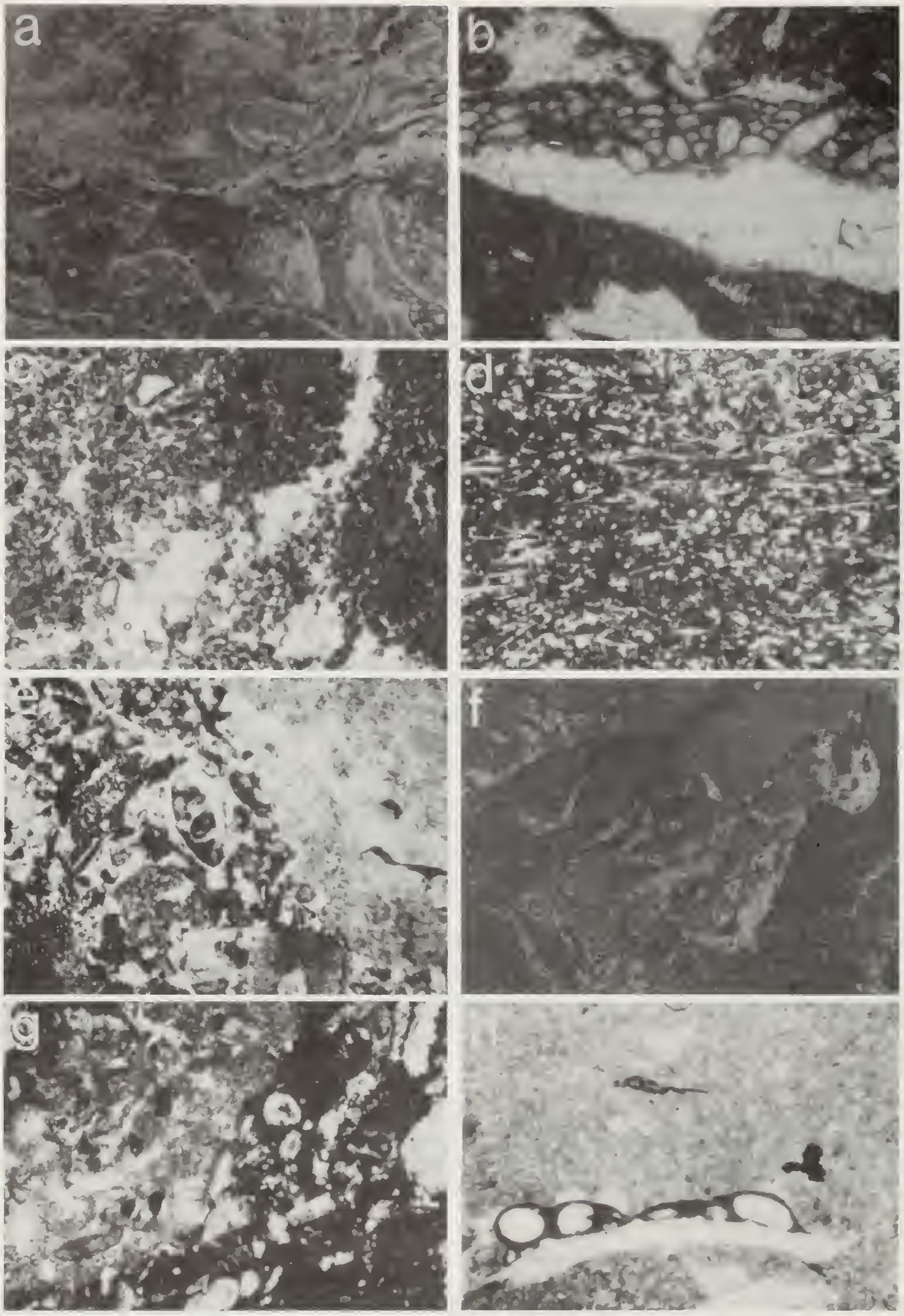

Figure 3 Photomicrographs and prints from acetate peels of various facies of the limestones in Livingston County: a) print from acetate peel of the algal wackestone facies (2x mag.); b) photomicrograph of encrusting bryozoa on margin of recrystallized algal plate (30x mag.); c) photomicrograph of pelletal micrite matrix in the algal wackestone facies (30x mag.); d) photomicrograph of echinoderm spines in argillaceous matrix in the fossiliferous shale facies (30x mag.); e) photomicrograph of the bioclastic packstone facies where it overlies the fossiliferous shale facies (30x mag.); f) print from acetate peel of brecciated algal wackestone (2x mag.); g) photomicrograph of contact between intraclast and matrix in the intraclastic conglomerate facies (30x mag.); h) photomicrograph of fossiliferous micritic mudstone facies (30x mag.)

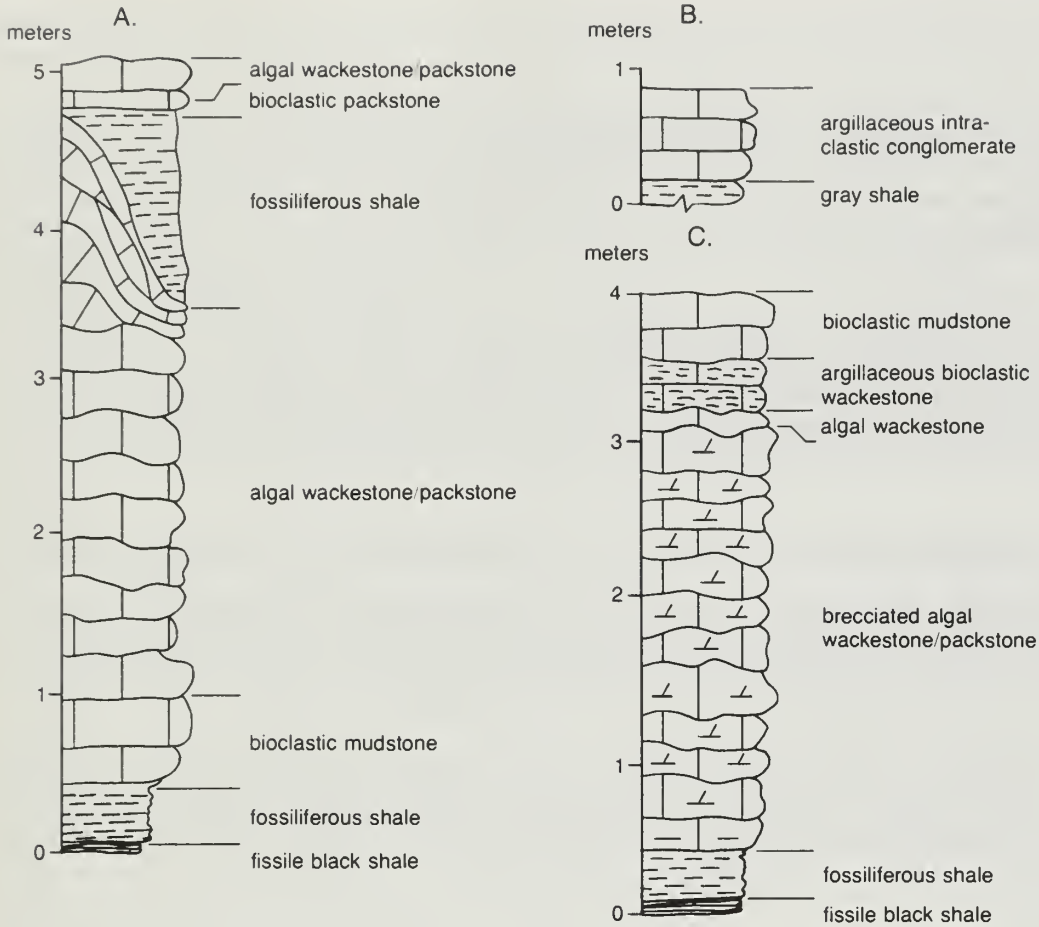

Figure 4 Idealized lithologic columns showing vertical facies distributions where(a) algal wackestones predominate, (b) intraclastic conglomerate is the dominant facies, and (c) brecciated algal wackestone is the predominant facies.

The abundance of spines decreases upward in the mudstone sequence, and the fauna diversifies. Bryozoa, crinoid stem fragments, and stringers of argillaceous micrite containing abundant ostracode fragments are present. The matrix outside of the argillaceous stringers has been partially recrystallized to pseudospar.

Abundant large fragments of crinoid stems, fragments of bryozoa and brachiopods, and smaller ostracode shells occur in reciprocal contact at the top of the sequence. The larger fragments generally bear encrusting foraminifera, which also occur on the margins of linear patches of void-filling sparry calcite that probably mark the former positions of algal plates.

Platy algal limestone adjacent to the shale lenses resembles that occurring elsewhere, except that primary voids are absent and the matrix is coarser grained. In addition, intraclasts of the normal algal facies occur, as well as an abundant, diverse faunal assemblage. Fossil debris includes gastropods, ostracodes, crinoid stems, echinoderm spines, foraminifera, and isolated bryozoa zooecia, often in reciprocal contact.

Bioclastic Packstone

Beds of coarse-grained bioclastic packstone cap fossiliferous shale lenses and also extend beyond the margins of the lenses into the adjacent limestone facies (fig. 5). Fossil debris is visibly rounded and includes very large crinoid stems, brachiopod shells, and bryozoa colonies in an

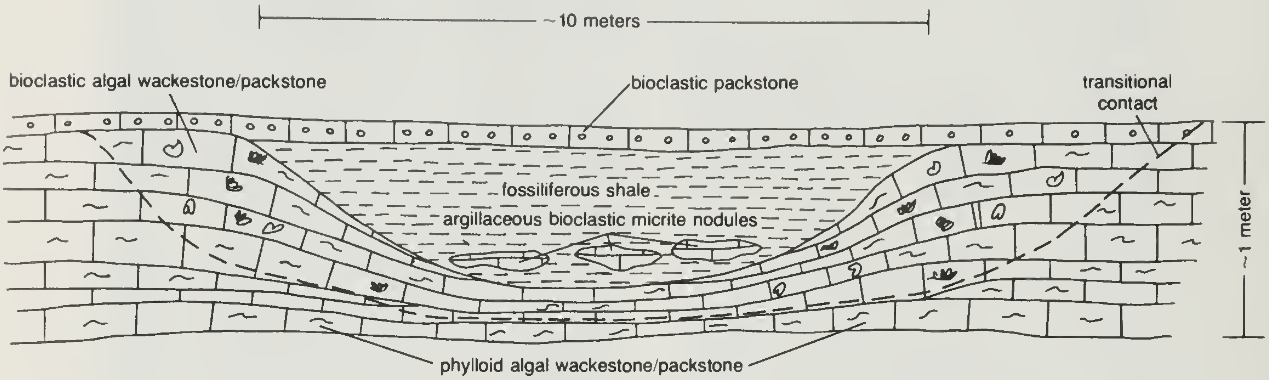

Figure 5 Diagrammatic cross section showing the facies distribution around a lens of fossiliferous shale.

argillaceous micrite matrix (fig. 3e). The uppermost bed of this sequence contains fewer fossils and these, as well as portions of the recrystallized matrix, have been replaced by chalcedony. A small amount of primary void-filling sparry calcite is present, but it only occurs beneath shell fragments rather than beneath algal plates, as in the platy algal facies.

Similiar thin beds of bioclastic packstone are found at intervals elsewhere in the upper part of the platy algal facies, but these were not found in association with other mudstone lenses. Because the shale lenses are small, however, it may be that these beds of bioclastic packstone are associated with lenses that have not yet been exposed by quarrying operations.

Algal Breccia

This facies consists of angular to semi-angular fragments of the algal wackestone/packstone facies (fig. 3f). Most of the clasts are bounded on one side by recrystallized algal flakes. Some of the fragments are angular, indicating only slight movement, and many of these can be placed in the cavities from which they came. Most of the clasts are partially rounded, suggesting that some movement occurred after the clasts were produced.

The micrite matrix generally is coarser grained than that of the platy algal facies and contains more abundant fossil shell fragments. Fossils include brachiopods, ostracodes, gastropods, but very few crinoid fragments. Other faunal elements are encrusting foraminifera and bryozoa. The matrix is vaguely pelletoidal, but where recrystallization has taken place the pellets stand out more clearly.

Through most of the rock, fragmentation has been incomplete and the only evidence of disturbance is the occurrence of V-shaped cracks in the micrite. These cracks generally contain primary void-filling calcite, although they also may be filled by a pelletoidal micrite or recrystallized micrite. The downward-extending fractures filled with uncompacted micrite probably formed syndepositionally by desiccation of the sediment. In other cases, fossil shells have fractured in place and the overlying matrix material contains upward-extending fractures filled with void-filling sparry calcite. This fracturing was probably the result of postdepositional compaction.

All three types of sparry calcite noted in the platy algal facies also occur in the algal breccia facies. Where clasts of matrix material appear suspended in the cement and form a loose network of fragments and sparry calcite, these three types of calcite are associated intimately.

The algal breccia facies is developed best in quarries of the Pontiac Stone Company north of Pontiac, and the Livingston and Ocoya Stone Companies near Ocoya (fig. 1). However, a bed of algal wackestone, 6 inches (10 cm) thick, occurs in the upper part of the sequence exposed in these latter two quarries.

The algal wackestone is overlain by a bed of bioclastic wackestone, 1 foot (35 cm) thick, in a laminated argillaceous micrite matrix. Bioclasts consist of small brachiopod and ostracode shells, single bryozoa zooecia, foraminifera, and siliceous sponge spicules. Grains of silt-sized angular quartz are concentrated in clay-rich laminae within the micrite. This bed, in turn, is overlain by nonlaminated micritic mudstone containing scattered large fragments of crinoid stems (fig. 4c).

Intraclastic Conglomerate Facies

This facies occurs only in the parts of the Cramer Limestone Member exposed in the valley of the Vermilion River near Pontiac. Clasts are dominantly of the bioclastic packstone facies consisting dominantly of crinoid and bryozoa fragments, and minor amounts of algal plates and brachiopod shell fragments in a partially recrystallized micrite matrix (fig. 3g). Nearly all the fossil debris is covered by encrusting foraminifera. Clasts are roughly equidimensional, but they have irregular margins.

The intraclasts occur in an argillaceous bioclastic packstone matrix. The fossil fragments in the matrix are in reciprocal contact and consist almost entirely of corroded and recrystallized crinoid stem fragments as well as minor amounts of brachiopod and bryozoa fragments. These bioclasts are almost entirely free of encrusting foraminifera and are set in an argillaceous, partially recrystallized micrite matrix. Elongate fragments are arranged parallel to the sides of the intraclasts.

Bioclastic Micritic Mudstone

This facies occurs only at the base of the La Salle Limestone exposed in the quarry operated by Howard Arnold Stone Company northwest of Fairbury (fig. 1). It consists of micrite with a few mud-supported fossil fragments (fig. 3h) chiefly composed of brachiopods, ostracodes, and a few crinoid stems and algal flakes. The elongate fragments lie parallel or subparrallel to bedding, and nearly all fragments are encrusted with foraminifera. Unlike the other microfacies studied, this one has almost no small fossil fragments forming part of the matrix.

DEPOSITIONAL MODEL

Classification of Algal Constituents

A key to interpreting the relationships among the various facies present in the limestones of Livingston County, and to reconstructing the environment in which they were deposited, is the recognition that algae were the principal biotic constituent of the rocks. The specific identification of these algae is impossible for the most part, however, because of the degree of recrystallization they have undergone. Parks (1962), for example, has pointed out that specific identification of many late Pennsylvanian algae is impossible when internal structures are not preserved because they share a common external form.

Although all the algal fragments have been at least partially dissolved and replaced by sparry calcite, tentative identification has been made on the basis of indistinct structures that are preserved in a few specimens. As in Kansas and Missouri, *Archeolithophyllum* is the genus most frequently identified on the basis of general external form. One fairly well-preserved specimen, however, most closely resembles the genus *Cuneiphycus* (Johnson 1961). In addition, some faintly preserved lamellar structures approximate the arrangement of cell threads in the genus *Ungdarella* (Johnson 1961). *Eugonophyllum*, a common constituent of Pennsylvanian algal mounds in the central and southwestern United States, has not been identified, although Welch (1977) made a tentative identification of this genus from the Millersville Member of the Illinois Basin (upper Bond Formation).

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Ecology of Algae

Ecological conditions favorable for the growth of algae include strong light for photosynthesis. Light, in turn, is dependent on water depth and the amount of suspended material in the water. At least fair water circulation is necessary, and the degree of water turbulence influences the morphology of the algae. Articulated forms, such as *Halimeda*, preferentially occupy deeper water in the sublittoral zone, but crustose forms tend to occupy littoral or intertidal zones (Johnson 1961). Coralline algae may tolerate a fairly wide range of water levels and degree of turbulence. Some species can even occupy positions exposed to a large degree of turbulence.

Water temperature has some bearing in restricting certain genera. Algae in general, however, have adapted to a wide range of temperatures. *Lithophyllum*, for instance, includes species with a wide latitudinal distribution. *Halimeda*, however, is not widely distributed with reference to temperature; most species are found only in warm waters.

Harbaugh (1960) states that the green algae *Halimeda* may be a Recent analog of the Pennsylvanian phylloidal algae. *Halimeda* grows as small bushy plants attached to the bottom. The leaves or segments gradually become encrusted with lime mud and break off the plant. They can collect in place or they may be transported and concentrated elsewhere by current action (Cloud et al. 1956).

Wray (1964) argues for a correlation of *Archeolithophyllum* with *Lithophyllum*, a Recent coralline algae, on the basis of size, shape, internal structure, and reproductive organs. *Lithophyllum* exhibits two growth forms: as crustose masses attached to the substrate, or as an erect form with branches and blades growing from an encrusting base. Most species tend to prefer a hard substrate, but others have been described as growing on muddy bottoms.

Crowley (1969) points to the relationship of *Anchicodium* to the living genera of the subfamily *Udoidea*. This subfamily is characterized by blade-like forms attached to the substrate by a rhizome, and living in areas of low water turbulence such as lagoons.

Toomey (1976, 1981) speculates that phylloidal algae grew as erect plants consisting of relatively broad leaves that accumulated on the sea floor when the plants died. Because they were probably efficient baffling agents, they tended to build mounds once they colonized part of the sea floor. Wray (1977) and Toomey (1981) also point out that recent counterparts of phylloidal algae are able to produce new crops of plants every few weeks. Such rapid growth rates contributed to their mound-building ability, and also enabled them to dominate the sea floor by excluding most other organisms from the environment. The only organisms that could successfully coexist in these algal "meadows" would be those that encrusted the leaves, burrowed in the substrate, or lived under the protection of the plants. As upright plants with broad leaves, phylloid algal communities could not have withstood a high degree of wave turbulence (Toomey and Babcock 1983). The size of the Pennsylvanian algal mound complexes and the faunal assemblages with which they are associated suggest that the initial colonization phase of bank growth may have occurred in depths as great as 100 feet (30 m) (Wilson 1975, Pol 1985).

The mounds, however, were able to grow above fairweather wave base, but this was accompanied by a distinct facies change. Phylloid algae were no longer dominant as a more normal marine community was established. Encrusting foraminifera and stromatolitic blue-green algae formed a true boundstone that was able to resist wave-generated currents.

Facies Interpretation

The algal wackestone facies appears to have developed in relatively quiet water. Insoluble residues, consisting mainly of terrigenous clastic debris, average about 10 percent of the rock. In addition, the algal plates do not seem to be broken nor are they particularly abraded. The abundance of primary void-filling sparry calcite under loose collections of algal flakes, and the presence of complete fossil shells, especially fragile ostracode shells, both indicate fairly low energy levels as well. The formation of the algal wackestone, therefore, seems to be analogous to the conditions under which debris from *Halimeda* and the branching forms of *Lithophyllum* accumulates in modern seas.

The algal packstone within the platy algal facies formed under conditions of greater turbulence, but not necessarily in shallower water. Such conditions of turbulence may have occurred during storms. The amounts of insoluble residues are greater in this facies and indicate either less sustained winnowing or greater influx of clay and silt. The occurrence of abundant, coarse, fossil debris in the facies indicates that an increased flux of terrigenous clastic debris to the area is more probable.

The presence of many complete echinoderm fossils indicates that the lenses of fossiliferous mudstone near the top of the algal facies in the Wagner Stone quarry just west of Ocoya (fig. 1) formed under conditions of very low turbulence. Apparently the echinoderms acted as baffles, reducing turbulence and causing deposition of clay and silt that might otherwise have been more evenly distributed over the remainder of the algal mound.

Shale bodies may have begun accumulating in low areas in the algal mound surface. The rather sharp contact between shale and limestone suggests this might have been the case. On the other hand, lenses of fossiliferous shale may have begun simply as patches of echinoderms which, by the baffling action of the organisms, caused clay and silt to accumulate. This in turn reduced the amount of light penetrating the surrounding water. Because algae are dependent on light for photosynthesis, their growth would be inhibited and they might eventually die out in areas where argillaceous sediment was accumulating. The gradation in the surrounding limestones toward thinner beds, less algal debris, and a greater abundance of hard-shelled fossils, especially gastropods, supports the view that initial deposition of mudstone lenses occurred in minor low areas on the bank surface and continued development was controlled by the presence of echinoderm colonies.

Shinn, et al. (1969), describe the development of ponds in a carbonate mud flat near Andros Island in the Bahamas that show a similar morphology to the shale bodies in Livingston County. Ponded sediments accumulated in a subtidal zone and consisted of the softest and muddiest sediments in the tidal flat. Their occurrence, however, was dependent on surrounding levees to provide the quiet water environment. No organisms were needed to provide a baffling action.

Welch (1977) reports the occurrence of identical mudstone lenses in the Millersville limestone on the eastern flank of the Illinois Basin. He believes, however, that the lenses formed in pools created by local subsidence of parts of the bank, caused by differential compaction of the underlying shale. Occurrence of depressions in the surface of the shale directly below the depressions in the limestone supports his hypothesis. Such a mechanism, however, should have caused deformation of the intervening limestone beds beneath the shale-filled depressions, but no such deformation was noted beneath the mudstone lenses in the La Salle Limestone.

The bioclastic mudstone lenses more likely formed as a result of a combination of events including (1) accretion of the bank into a water depth favorable for colonization by echinoderms; (2) presence of minor irregularities in the bank surface; and (3) establishment of an echinoderm colony that trapped sediment, increased turbidity, and inhibited the growth of algae. These colonies were periodically destroyed or disrupted by storms that spread fossil debris and terrigenous clastics across the surface of the bank, thus forming the thin beds of bioclastic packstone that occur in the upper part of the algal wackestone facies.

The algal breccia facies apparently developed in shallower and more turbulent waters. Coarser textures in the matrix, lower amounts of insoluble residues, and abundant desiccation cracks and brecciated textures indicate that this facies developed in shallower water on a substrate subjected to periods of subaerial exposure. Subaqueous shrinkage also may have acted as a mechanism in the formation of the breccia through the production of synaeresis cracks. Synaeresis cracks have been described by White (1961), who states that ionic attraction between clay particles during flocculation may act to expel water and form cracks in the clay because of the volume reduction. Clasts formed by synaeresis, however, would be relatively soft and probably deformed. Clasts formed by desiccation would be semilithified after exposure to air and less liable to deformation.

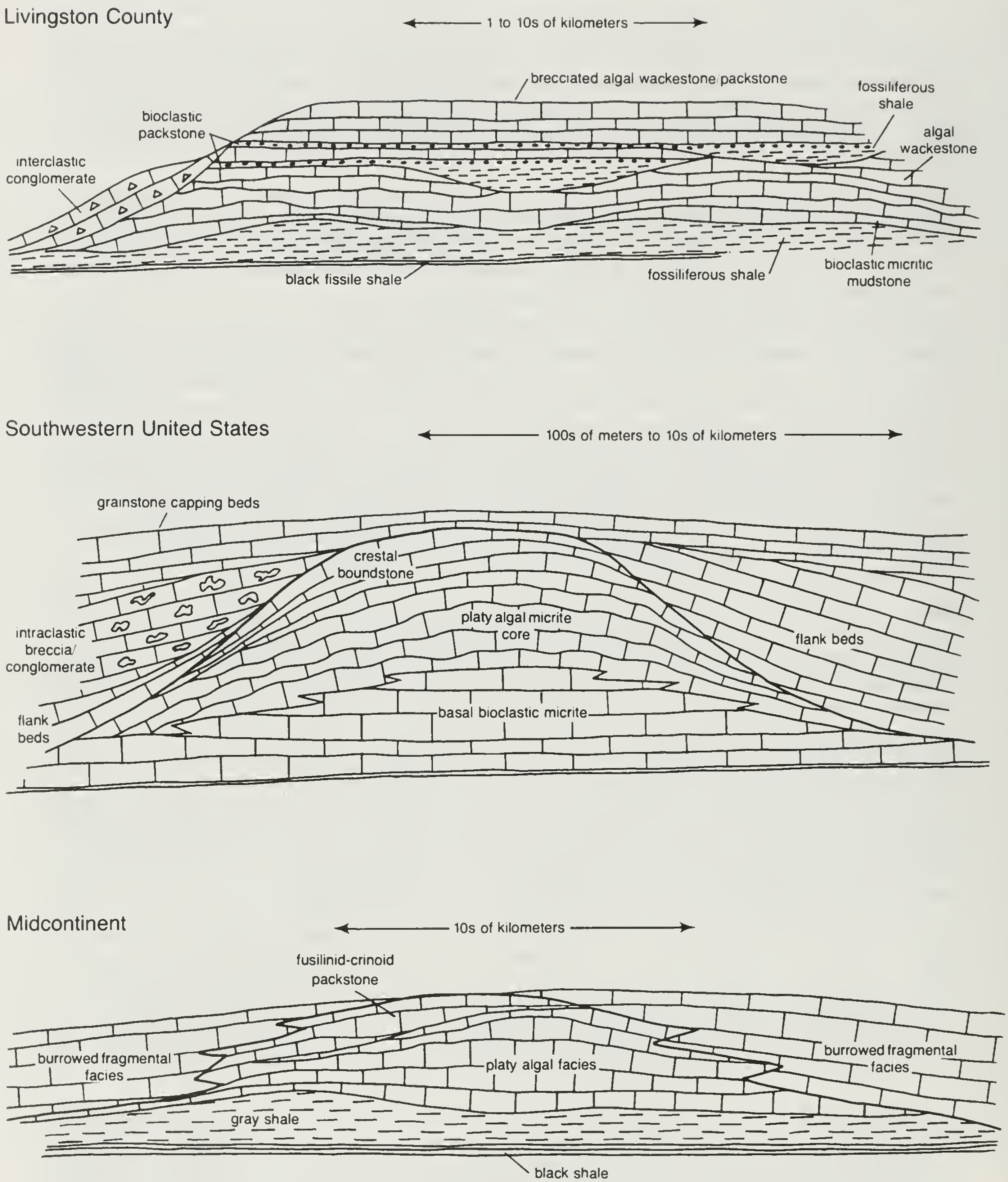

Figure 6 Diagrammatic cross sections comparing algal mound and algal bank limestones in Livingston County, southwestern United States (after Wilson 1975), and the midcontinent (after Neal 1969). Measurements represent the range of sizes the mounds may attain.

Most of the clasts of the algal breccia facies in Livingston County are undeformed and intermittent subaerial exposure is assumed to be the more important mechanism in the formation of this facies. The algae represented in the facies were probably crustose or mat forms of phylloidal algae like *Archeolythophullum lammelosa*.

The high iron-dolomite percentages in the quarries north of Pontiac might also be evidence of supratidal or intertidal deposition. These environments are favorable to dolomitization during early diagenesis (Friedman and Sanders 1967). Textures, however, showing replacement of void-filling sparry calcite with dolomite rhombs and localization of dolomite along fractures and argillaceous stringers, indicate that dolomitization took place some time after lithification. High dolomite percentages in the Pontiac quarries may be explained by the high porosity of the rocks. This porosity may have produced a more favorable site for dolomitization than the less porous rocks of the other quarries. This is substantiated by the fact that, except for the brecciation, the algal wackestone facies at the Ocoya and Livingston Stone quarries is similar to that at the Pontiac quarries, but it is less porous and relatively dolomite free. The dolomite, therefore, probably did not form syndepositionally in the sediments at the Pontiac quarries, but was the result of a phase of late-stage diagenesis of the sediments unrelated to their probable origin in a supratidal environment.

The laminated bioclastic wackestone in the algal breccia facies seems to indicate deeper or less turbulent water. Its association with algal wackestone immediately below and nonlaminated, crinoidal mudstone above indicates that a minor transgression may have occurred and the bank was no longer subjected to subaerial exposure and brecciation. The facies closely resembles the sponge-bearing calcisiltite described by Choquette and Traut (1963) and Elias (1964) in the Paradox Basin. They believe this rock to have formed in low areas between individual algal mounds.

The intraclastic conglomerate facies also seems to have developed in generally quiet waters that were subjected, however, to periodic disturbances. Quiet water conditions would be the normal environment for the deposition of what now forms the matrix. Disturbances on an adjacent bank, either through storms or slumping off the flanks of the bank, would provide the relatively unlithified material that now forms the clasts. Such high-energy conditions persisting for short periods of time would account for the chaotic textures noted in the facies.

Intraclastic conglomerates are common in the flanking beds of algal mounds in the central and southwestern United States, where they are attributed to slumping or storm transport of eroded material from the mound into intermound areas (Wilson 1975, Toomey and Babcock 1983, Schatszinger 1983, Choquette 1983, Pol 1985). However, the intraclastic conglomerate in Illinois occurs in the Cramer Limestone, which is not known to contain algal mounds. The intraclastic conglomerate may have come from unexposed mounds in the Cramer, or it may be the result of storm wave destruction of an incipient mound.

Algal Bank Evolution

The Hall and Cramer Limestones exposed in Livingston County probably both formed in association with algal banks that developed on the north and east flanks of the Illinois Basin during the late Pennsylvanian. It is possible to combine the two limestones into a depositional model that can explain their distribution and characteristics using modern and ancient counterparts of these mounds (fig. 6).

The black, pyritic shale at the base of all the limestones probably represents a post-transgressional period when the terrigenous clastic yield to the area was greatly reduced and anoxic conditions existed at the sea floor. A similar interpretation is given to black shales occurring at the bases of algal mound complexes in the southwestern United States (e.g. Choquette 1983), the midcontinent (Neal 1969), as well as at the base of the Millersville Limestone on the east side of the Illinois Basin (Welch 1977).

The reestablishment of an oxygenated sea floor is marked by the deposition of fossiliferous gray shales and bioclastic micritic mudstones. Carbonate deposition may have been initiated on low shoals that occurred over an area with only a few meters of local relief. This initial depositional phase also is recorded in the "transitional facies" of the Millersville Limestone (Welch 1977) and the "shelly calcilutite" (Choquette and Traut 1964) or "shelly wackestone" (Toomey and Babcock 1983) in the southwestern United States, and the lime mudstone facies of Neal (1969) in the mid-continent.

Colonization of the substrate by algae is represented by deposition of the algal wackestone facies. This stage also has equivalents in the southwestern United States where rapid algal growth resulted in the construction of mounds with steep flanks and substantial local relief (Toomey and Babcock 1983). In Livingston County, however, the algal wackestones are flat-lying or only slightly dipping as are the beds of the Millersville Limestone (Welch 1977). The lack of a well-defined mound shape and associated flank facies may be a product of basin shape and resulting hydrodynamics. The algal mounds in the southwestern United States formed at the margins of relatively deep basins (Wilson 1975) that could generate and sustain significant currents that could force the algae to grow in mounds separated by channels where coarse fossil debris was deposited as bioclastic grainstones (Pol 1985). By the late Pennsylvanian, however, the Illinois Basin had been largely filled (Horne 1978), forming a broad, shallow basin in which strong currents could be generated only by storms. These currents affected the algal banks by forming algal bioclastic packstones, but they were not sustained long enough to affect bank morphology. Similar broad shapes and horizontal bedding characterize some of the algal bank limestones in the mid-continent (Neal 1969), although minor mounds apparently existed on bank surfaces (Heckel and Cocke 1969).

As the bank accreted it became increasingly subject to reworking by normal marine currents, and it may have become subaerially exposed. At this time the algal breccia facies and associated bioclastic packstone facies were deposited. Their counterparts are found in the upper algal bank facies of the Millersville Limestone (Welch 1977). The counterpart facies in the southwestern United States, however, consist of foraminiferal boundstones and grainstone capping beds that apparently formed under higher energy conditions (Wilson 1975, Toomey and Babcock 1983, Pol 1985). Again, the difference between the algal breccia and bioclastic packstone facies of the Illinois Basin, and the higher energy facies of the southwestern United States may be related to differences in basin hydrodynamics.

SUMMARY

Six microfacies are present in the carbonate rocks exposed in Livingston County. Five of these facies, including bioclastic calcareous mudstone, algal wackestone/packstone, bioclastic packstone, fossiliferous shale, and brecciated algal wackestone/packstone, are found in the La Salle Limestone Member. These facies probably developed in an algal bank complex that occurred along the northern margin of the Illinois Basin during Missourian time. The sixth microfacies, occurring in the Cramer Limestone Member, is an intraclastic conglomerate that probably also developed in association with algal mounds, although no mounds have yet been found at this lower stratigraphic level.

Algal mound complexes were common features on the margins of late Paleozoic basins in the southwestern United States. These were relatively deep basins that could generate and sustain significant currents resulting in the growth of steep-sided mounds separated by channels where coarse fossil debris accumulated. By the late Pennsylvanian, on the other hand, the Illinois basin was broad and shallow, and probably incapable of sustaining strong currents except during storms. As a result, the algal mound complexes of the Illinois basin were apparently broad features characterized by horizontal bedding. In addition, the capping beds in the algal mounds of the southwestern United States consist of foraminiferal boundstones and grainstones in response to the higher energy conditions that prevailed in those basins. The absence of sustained strong currents in the Illinois Basin during the late Pennsylvanian age, on the other hand, is reflected in the capping beds of the algal mound complex in Livingston County, which consist of algal breccia and bioclastic packstone.

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