

Construction versus accumulation in phylloid algal mounds: an example of a small constructed mound in the Pennsylvanian of Kansas, USA

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Abstract

Most phylloid algal mounds are currently interpreted as no more than accumulations of leaf-like thalli supported by mud. We report here phylloid algae from the Upper Pennsylvanian (Late Carboniferous) Frisbie Limestone Member in Kansas, USA, which built small mounds with recognizable primary topographic relief. Cup-shaped algal thalli, growing closely packed and juxtaposed near and above one another, produced a framework in the shapes of topographically conspicuous mounds from smaller, centimeter-scale to meter-scale features. Meter-scale mounds are composites of smaller, juxtaposed, centimeter-scale mounds and intramound areas contain crinoid debris, sponges, bryozoans, brachiopods, and skeletal grains. The intercup voids enclosed in the framework fabrics of individual thalli are filled with a variety of matrix and cements: (1) peloidal grains, both in clotted wackestone and grainstone; (2) early marine cement; (3) microbial encrustations, often oriented against gravity; and (4) mudstone. Bedded limestones equivalent to and overlying the mounds are bioclastic wackestone and differ fundamentally from the mound limestone in facies, biotic components, absence of both frameworks and of peloidal clotted grains. Topographic relief above the sea floor, the growth fabrics with a framework including primary intramound and intercup voids and their complex infillings, and the lithic and biotic differences between mound and off-mound intervals fulfil the stratigraphic and biological criteria characterizing reefs. The model proposed here interprets these mounds as the result of active constructional algal growth, in contrast to published hypotheses that most phylloid algal mounds were passive accumulations of algal thalli within a mud matrix and/or early diagenetic marine cements.

Keywords: reefs; algal mounds; phylloid algae; Midcontinent; Kansas; Mississippian; Pennsylvanian; Carboniferous

1. Introduction

Algal mounds are among the most dominant

type of buildups in the Late Paleozoic. Phylloid algae are a major contributor to their construction (Wray, 1968; Heckel, 1974; Wilson, 1975, 1977; Toomey, 1980) during the Pennsylvanian, when phylloid algal mounds had worldwide distribution: Canadian Arctic Archipelago (Davies et al., 1989; Beauchamp et al., 1989), Arctic of

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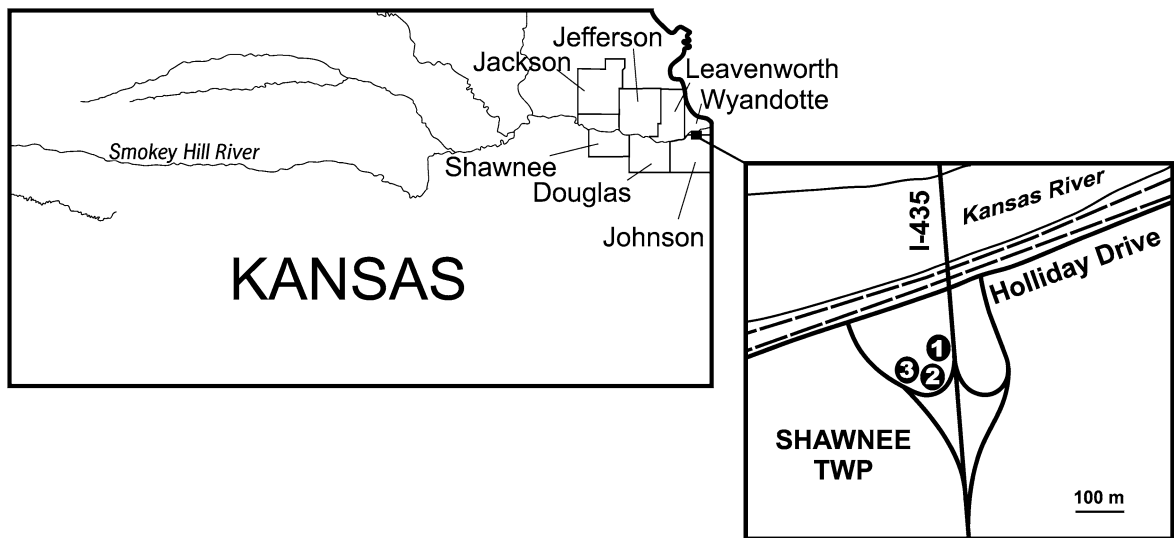


Fig. 1. Setting of study area and measured sections. Numbers 1–3 show location of algal mounds (with #3 pictured in Fig. 3) within, which dominate the continuous exposures around this cut.

Norway (Bruce and Toomey, 1992), Russian Platform (Chuvashov, 1983), Northern Africa (Vachard et al., 1989; Toomey, 1991), and China (Fan and Rigby, 1994). Most Pennsylvanian mounds are reported from the central and western United States (see Heckel and Cocke, 1969; Heckel, 1974; Fagerstrom, 1987; West, 1988; among others, for reviews).

Construction of phylloid algal mounds (except for the crustose red alga *Archaeolithophyllum* that is not treated in the present paper) is currently generally considered to be simple, principally as accumulations of leaf-like ('phylloid') algae supported by a micritic matrix (cf. discussion in Fagerstrom, 1987 and West, 1988). This model implies a passive role of algae in the construction of buildups, and a structure free of a framework as opposed to metazoan reefs that exhibit a rigid framework. Ball et al. (1977, p. 239) stated: 'The least equivocal example of phylloid algae preserved in a probably upright growth position shows no evidence of resultant depositional topography. The principal conclusion of this report is that the organisms grouped as phylloid algae were not builders of depositional topography, but rather were a source of building material'. Some recent investigations have re-evaluated the morphology of the conspicuous phylloid algae

(Torres, 1995, 1997; and references cited therein). Considering the revealed growth forms, the fabrics of mounds constructed by these enigmatic plants need to be reconsidered. The structure of these mounds needs attention, in particular to determine the diversity of mounds assigned to this simple and generalized model. Although Antoshkina (1998) and Chidsey and Eby (1999) recently reported topographic relief associated with phylloid algal mound facies, no original preserved framework has been described.

Detailed sampling and analysis of polished slabs and thin sections of three well-exposed mounds in northeastern Kansas, USA, reveals enough of the internal structure and the growth mode of these mounds to challenge this general model.

2. Setting and stratigraphy¹

The mounds studied are located in the Frisbie limestone in a roadcut of the southbound exit

¹ The stratigraphic nomenclature used in this paper is based on Heckel (1999) and at this writing is still informal.

from I-435 to Holliday Drive, at the Johnson-Wyandotte County line, on the southwestern outskirts of Kansas City, Kansas, USA (Fig. 1).

The Frisbie Limestone Member is the lowest member of the Wyandotte limestone, Zarah Sub-

group, Kansas City Group (Fig. 2). The Frisbie limestone typically consists of one or two massive beds totaling 1.5 m or less in thickness and is the transgressive member of the Wyandotte cyclothem. It overlies the nearshore Liberty Memorial

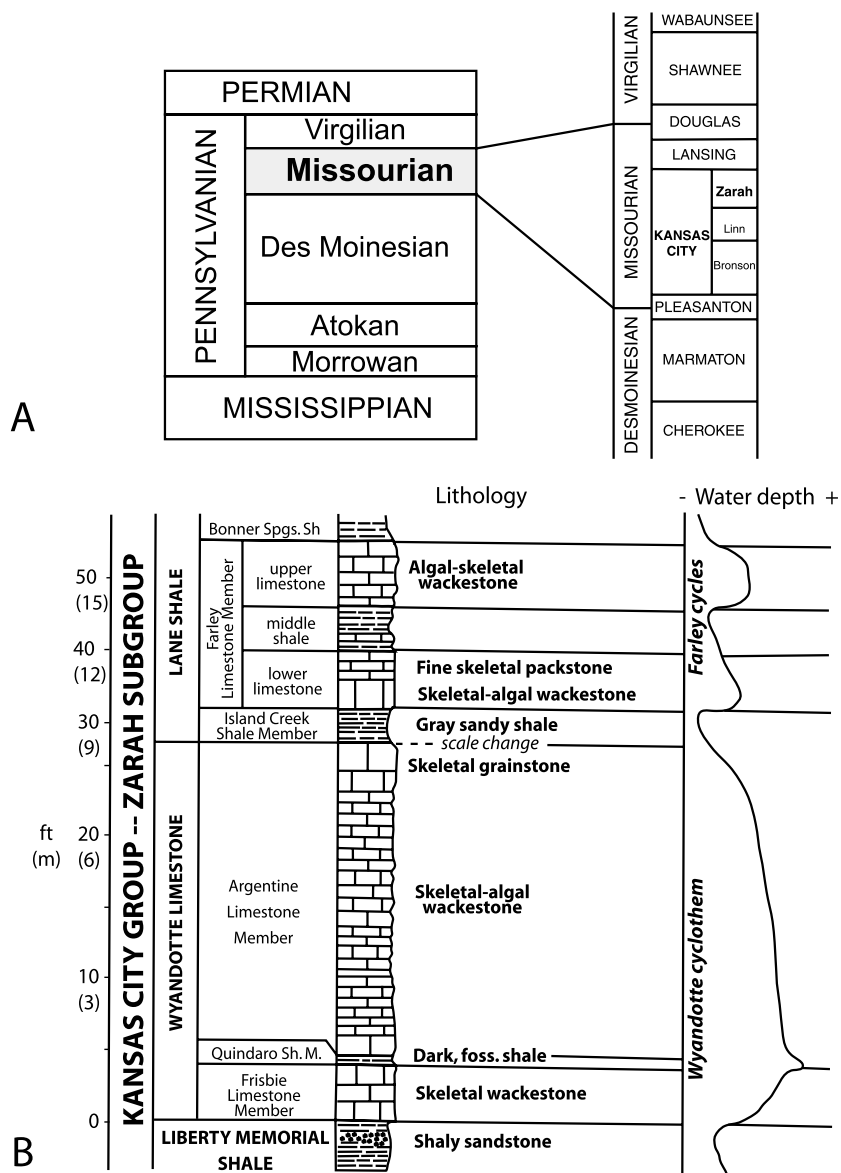


Fig. 2. Stratigraphic position of Frisbie limestone within Pennsylvanian succession (A) in Midcontinent, based on Heckel (1999). (B) Frisbie Limestone Member is the lowest member of Wyandotte limestone (Zarah Subgroup, Kansas City Group). Liberty Memorial Shale was formerly 'Lane Shale' of Crowley (1969). Wyandotte limestone is a typical cyclothem with transgressive Frisbie limestone, offshore (core) Quindaro shale, and regressive Argentine limestone; both underlying Liberty Memorial (formerly 'Lane Shale') and overlying Island Creek are nearshore shales (Heckel, 1999). No change has been made to Heckel's generalized lithologic pattern of the Frisbie Limestone Member to acknowledge the mounded facies.

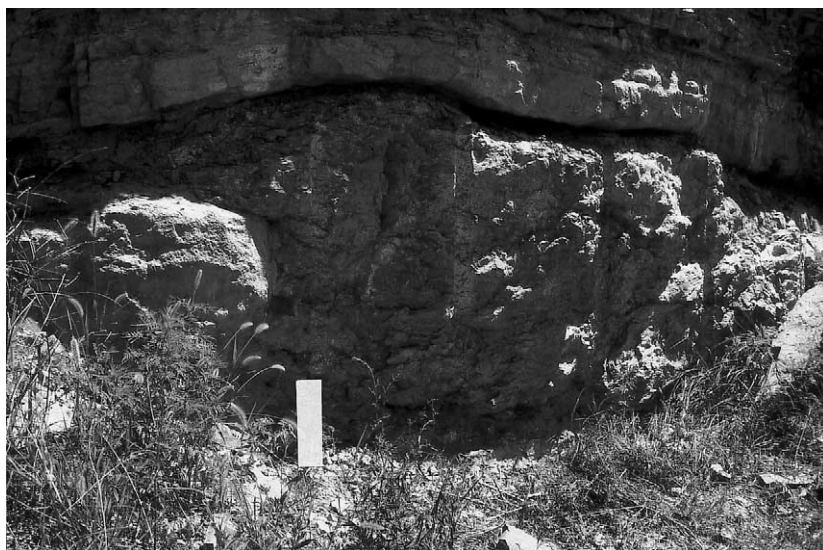


Fig. 3. Detail of large mound (3 on Fig. 1) 1.40 m thick, and 4.20 m across. Deposition of beds overlying mound obviously followed mound morphology, indicating primary relief above sea floor. White bar (covering hammer in photo) is 30 cm.

Shale (formerly 'Lane Shale') and is overlain by the offshore Quindaro Shale Member, hence is a transgressive member of a typical cyclothem (Fig. 2; see Heckel, 1999 for details on cyclothem patterns and stratigraphy).

3. Dimensions and morphology of mounds

Two small mounds at #1 and #2, and one large mound at #3 have been measured (Fig. 1). The latter is 1.40 m high and 4.20 m across. A topography with flanks dipping approx. 30° (Figs. 3 and 4) is obvious. The well-bedded capping facies in the overlying members obviously follows the primary relief of the mounds above the sea floor (Fig. 3). The third dimension is unknown because of inadequate exposure.

Five to 20 cm of fossiliferous marine Quindaro shale onlaps the mound, and is in turn overlain by well-bedded limestones at the base of the Argentine Limestone Member, all of which thin above the mounds. The mound on-lapping beds, thicker in the intermound area and thinner toward the mound demonstrate the primary relief above the sea floor (Fig. 4).

4. Internal mound fabrics

The lowermost part of the Frisbie Limestone Member below the mound (and the entire Frisbie in non-mound facies) consists of bioclastic wackestone and packstone. Brachiopods, bryozoans, gastropods, ostracodes, crinoids, *Shamovella*, smaller foraminifers, such as *Tuberitina*, and fragments of phylloid algal thalli are the recognizable

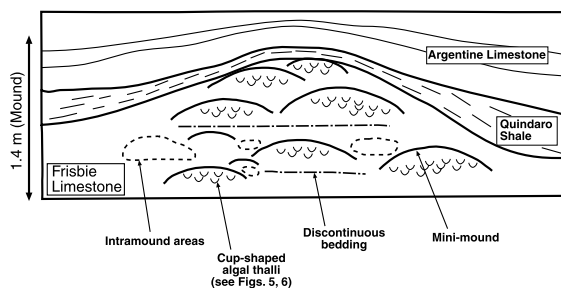


Fig. 4. Sketch of mound #3 on Fig. 1 showing internal structure composed of nine smaller mounds (mini-mounds). Juxtaposed mini-mounds enclose intermound areas, which can be distinguished from the mini-mounds by their concentrations of invertebrate fossils (see Fig. 8C). Two discontinuous horizontal surfaces have been noted, which cannot be traced into the flanks.

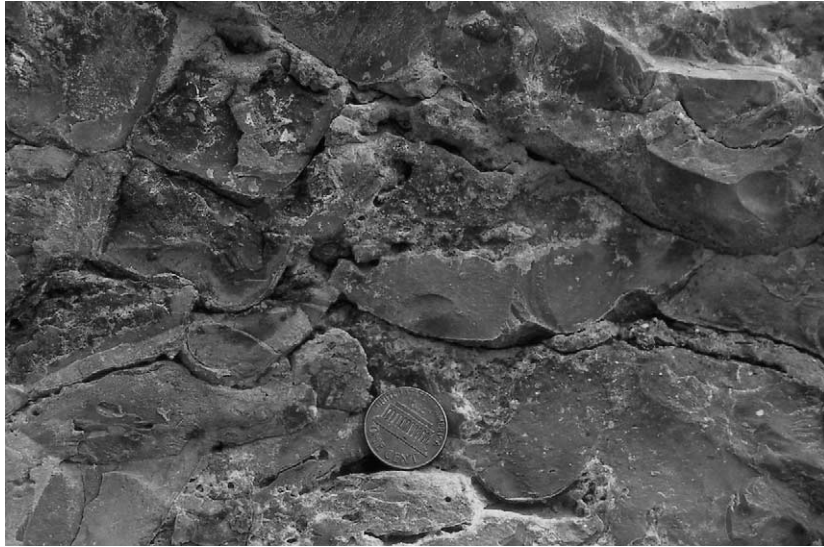


Fig. 5. Close-up view of mini-mound showing cup-shaped, closely packed algal thalli. Note smoother mud infillings of algal cups in contrast to darker, rougher intercup voids, the latter partly filled with early marine cements (see Fig. 6).

biota. Grain coating and encrustation are frequent, with *Archaeolithoporella* and bryozoans as the main encrusters. Some areas (<5%) contain peloids.

The large mound (#3) consists of a composite of nine smaller mounds, each <0.5 m high and 0.5–1 m long, and labelled mini-mounds (Fig. 4). Intramound areas (space between mini-mounds)

were occupied by macroscopically recognizable sponges and crinoid debris, and thus differ from the algal-dominated facies of the mini-mounds. Mini-mounds are composed of cup-shaped, closely juxtaposed algal thalli (Figs. 5 and 6). All of these algal cups are similar in size, form, and infillings. The thallus form corresponds to the recent reconstruction of bowl-shaped, cyathiform algae (Torres et al., 1992; Torres, 1995). Algal thalli are 20–60 mm in diameter and 0.5–3 mm thick. They are almost always replaced by blocky calcite cement and their systematic position is therefore indeterminable. Similar growth forms have been identified as *Ivanovia* and *Eugonophylum* (Torres, 1995, 1997). The delicate framework and abundance of micrite indicate a position below wave base, as suggested in previous studies of algal mound facies (Toomey, 1976).

Intracup voids are filled with two different types of peloidal matrix containing marine spar and uniform matrix. Peloidal matrix consists of clotted structures and clumps of peloids lacking clear contours sometimes oriented against gravity. In some cases, peloids built domal forms (Figs. 6 and 7A). This matrix can occur in the bottoms of the algal cups (Fig. 7A). It is nearly free of fossils, with only rare foraminifers and ostracodes. Peloid

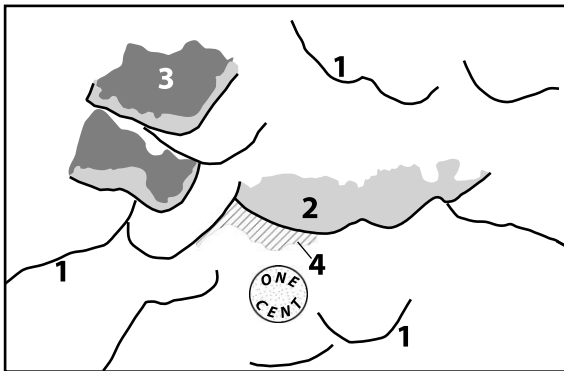
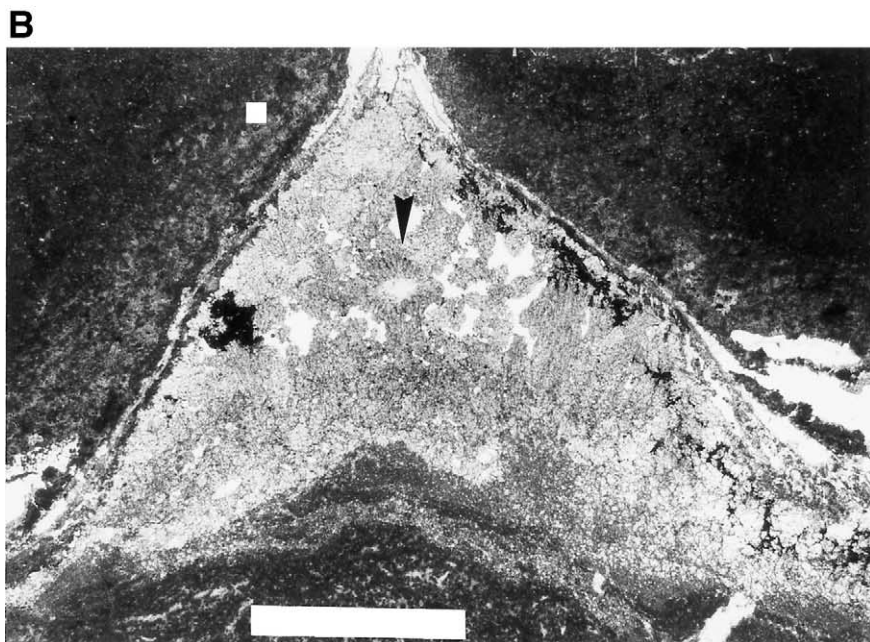
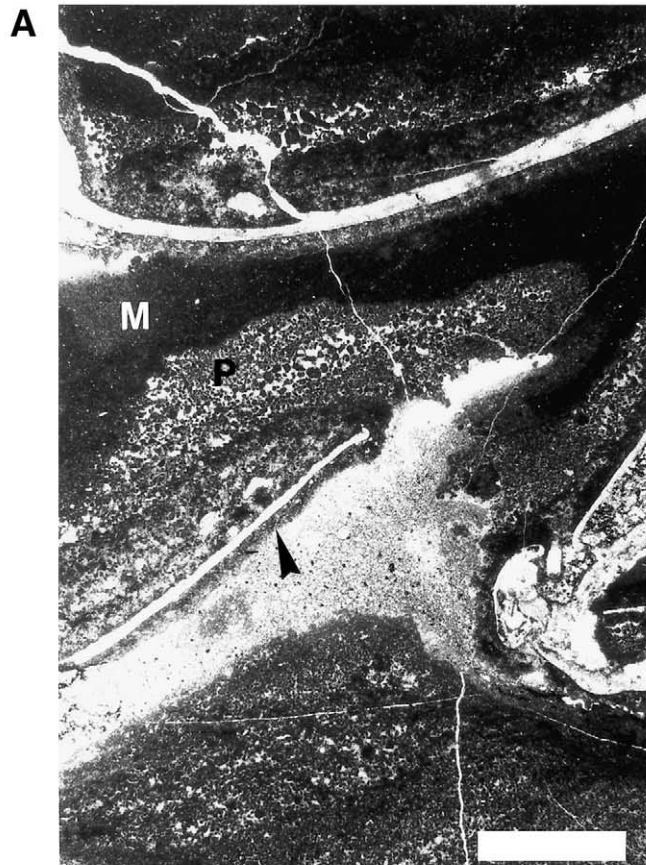


Fig. 6. Sketch of algal thalli and intercup voids including cements, derived from exposure photographed in Fig. 5. (1) Cup-shaped algal thalli in growth position; (2) micritic infilling, predating spar; (3) peloidal clotted grainstone with irregular surfaces; (4) intercup void, filled with spar and including marine fossils (e.g. ostracode in Fig. 7). One cent (2 cm) for scale. See photomicrographs in Fig. 7A,B.



grainstone consists of subspherical peloids floating in spar with a somewhat graded fabric, becoming coarser and/or finer upward (Fig. 7A). Bioclasts are rare herein but include gastropods, bryozoans, ostracodes, and brachiopods. Cements occur predominantly below the cups, in some cases below micritic crusts (Figs. 6 and 7A). In one thin section, an ostracode is enclosed within the spar (Fig. 7B). The undifferentiated homogeneous matrix (M in Fig. 7A) is yellowish mudstone and wackestone similar to that of inter-mound facies and is partly dolomitized.

Intramound areas are up to 30 cm in thickness (Fig. 4), and are composed of bioclastic wackestone and packstone. These areas lack algal thalli. Disarticulated and larger segments of crinoids, sponges, and bryozoans (Fig. 8) are the most frequent biota, representing volumetrically more than 70% of the total biota in these areas. Other fossils include brachiopods, and rare *Shamovella*, trilobite remains, and calcitornellid foraminifers. Bryozoans acted principally as encrusters on crinoid stems and calcisponges; some of the latter encrusted other calcisponges, and, rarely, crinoid stems.

5. Off-mound facies

The off-mound facies is a bioclastic wackestone. The matrix is uniform, and peloidal clotted areas are absent as are cements described from the mound areas. Some beds contain numerous phylloid algal thalli, but these are only straight or slightly bent fragments rather than the cup shapes found in the mounds. They do not show the framework fabrics typical of the mound facies. Recognizable fossils include crinoid debris, sponges, bryozoans, gastropods, *Archaeolithoporella*, and ostracodes, the same as in the intra-

mound areas. Because thalli are completely recrystallized in both mound and off-mound facies, the taxonomical position of both and the origin of the off-mound algal thalli (autochthonous or allochthonous) are unknown.

6. Genetic model

Various models have been proposed to explain internal mound fabrics of Pennsylvanian phylloid algal mounds. We discuss those most pertinent to the fabrics we studied in detail in the Frisbie limestone.

(1) 'Meadow' model. This model is inferred from modern shallow-water meadows of sea grass and *Halimeda* mounds, which are able to produce sediment by the breakdown of thalli, to trap and bind fine sediments, and to build large banks (Wray, 1968). Such examples are known from south Florida, USA (e.g. Ginsburg and Lowenstam, 1958; Enos and Perkins, 1979; Bosence, 1995; Wanless et al., 1995), Shark Bay, Australia (e.g. Davies, 1970; Read, 1974), and from many other sites (see Roberts and Macintyre, 1988). Another type of the meadow model are the *Halimeda* segment reefs described by Braga et al. (1996). The latter contain a large amount of cement, which is relatively less abundant in the Frisbie mounds. Furthermore, the depositional environment of the Frisbie algal mounds is below wave base. Thus, modern parameters of the meadow model do not fit the data.

(2) 'Corn flakes' or 'potato chip' model. The corn flakes model (Wray, 1964), by far the most common in past studies, explains the genesis of algal mounds as an accumulation of leaf-like or 'potato-chip-like' thalli (Toomey and Babcock, 1983) supported by mud, with a few enclosed voids filled with cements (often botryoidal ce-

Fig. 7. (A) Cup-shaped algal (thin clear blade) coated by thin clotted microbial encrustation on base and by thicker encrustation on top, is overlain by peloidal clotted grainstone (P) and uniform mudstone (M). Intercup voids are filled with cements. Note irregular tops of peloidal clotted areas, which partly rise over algal cups (center), and micritic crusts (arrow) below algal cups and above cement-filled voids. (B) Detail of an intercup void filled with early marine spar (arrow point is on the marine cement rim around the ostracode) enclosing an ostracode. Such voids occur predominantly below the lower surfaces of raised edges of algal thalli and show that the cup-shaped thalli form a framework type of structure at this small scale (unlike that of most previously described phylloid algal accumulations). Scale bar is 5 mm long.

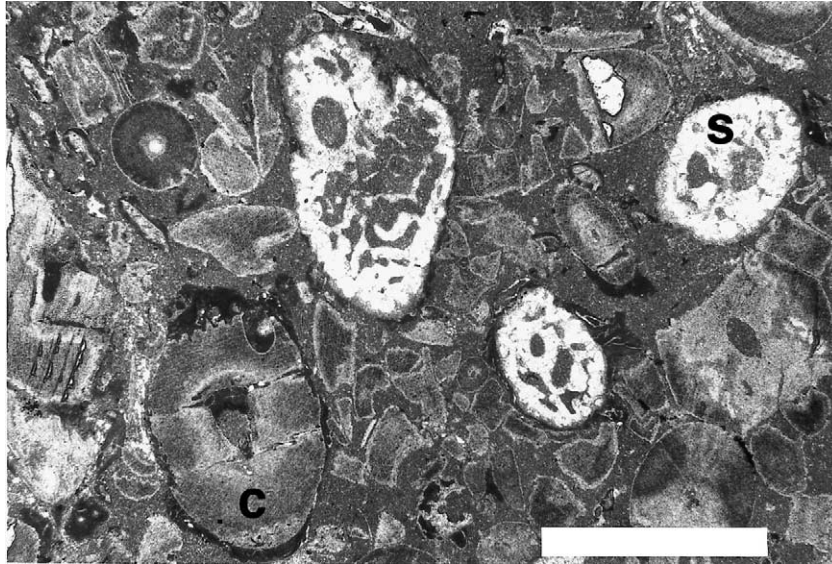


Fig. 8. Photomicrographs of crinoid ossicles (C), calcisponges (S), along with bryozoans and brachiopods (not pictured), which are typical fossils of intramound areas shown in Fig. 2. These fossils, absent in intercup voids, may represent remains of cryptic biota living in actual intramound areas away from mini-mounds. Scale bar is 5 mm long.

ments). Originally suggested by Konishi and Wray (1961), this model has been used by many subsequent authors (Pray and Wray, 1963; Toomey and Winland, 1973; among others). The original authors assumed that the blades could not have provided a substantial ‘reef’ framework (Ball et al., 1977; Toomey and Babcock, 1983, p. 131). The growth fabrics shown by our data clearly differ from this model (see below).

(3) The ‘Card house’ model was proposed by Roylance (1990) for bioherms from the Paradox basin, Utah and Colorado, USA. According to this model, broken algal fragments are arranged card-like on a mud substrate, forming a stable framework upon which botryoidal aragonite grew. Some of the enclosed pores are filled with botryoidal cement and sediments. The resulting boundstone is brecciated through subsequent compaction. As cements are only a minor component of the Frisbie mounds, no botryoids were observed, and brecciation is nearly absent, this model does not appear suitable.

(4) ‘Cup’ model. Here we propose a model in which algae with a cup-like growth form grew near enough to each other to form a framework (Figs. 5 and 6). The framework protected intra-

mound areas and intercup voids, which show different filling features. The algal blades appear to have served as a host to microbial encrustations that produced micritic cements and stabilized peloidal masses. More uniform peloidal sediment (Fig. 7A), which may also be biogenic in origin, contributed to the stabilization of the whole fabric. Early marine cements, volumetrically of minor importance, filled pores predominantly on the lower surface of the algal thalli. The remaining space was filled with homogeneous sediments, probably settling of suspended mud from the water column. This model acknowledges the results of trophic analysis by Toomey (1976) and the recently described morphological structures of these algae (Torres, 1995, 1997). The frequency and extension of similar mounds need further investigation.

7. Conclusion

Frisbie mounds of this study are characterized by a framework of cup-shaped algal thalli, which grew closely packed and juxtaposed next to and above one another. The largest mound, 1.4 m

thick and 4.2 m across, is a composite mound composed of smaller mounds (mini-mounds). Thus, we recognize two mound types: small, centimeter-scale mounds, and large, meter-scale composite mounds. Intramound areas, up to several decimeters in size, are filled with crinoid debris, sponges, bryozoans, brachiopods, and non-peloidal grains. Fossils in intramound voids may represent remains of a cryptic biota, similar to sponges, crinoids, and bryozoans as reported from many extant and fossil reef crypts (see Wood, 1999 and references therein). The framework fabric of individual thalli includes intercup voids which are filled with: (1) peloidal grains, both peloidal clotted wackestone and peloid grainstone; these grains seem to represent microbial encrustation on the top of the blade and are continuous with the micritic cement on the underside of the blade; (2) early marine cement; (3) micritic cements, often oriented against gravity; and (4) mudstone. Although invertebrate fossils have been found only within intramound areas, these areas do not contain any fragments of algal thalli. The bedded limestone in the Argentine limestone above the mounds is a bioclastic wackestone that differs fundamentally from the mound limestone in biotic components, absence of a framework and of peloidal grains.

Topographic relief above the sea floor produced by a growth framework including primary intramound areas and intercup voids with complex infillings, and the lithologic and biotic differences between mound and off-mound intervals fulfil the stratigraphic and biological criteria for characterizing reefs. The model proposed here interprets these mounds as the result of active constructional algal growth, in contrast to the previous hypotheses that they were always passive accumulations of algal thalli within a mud matrix and/or early diagenetic marine cements. Our model is in agreement with growth forms of phylloid algae proposed by Toomey (1976) and Torres (1995, 1997). Their position at the top of a transgressive limestone in deepening water probably helped to preserve these mounds from currents and storms that would tend to destroy algal growth forms in shallower water – as might have occurred in the overlying regressive Argen-

tine limestone which contains numerous small algal blades but no mound features like those in Frisbie. Testing of this model continues with examination of other algal mounds in Kansas, as well as some in New Mexico and Texas.

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