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Title: Contribution of Red Algae to Algal Bioherms of the Shawnee Group (Upper Virgilian, Pennsylvanian) of Eastern Kansas

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ABSTRACT

Algal stromatolites that contributed to the formation of bioherms of the Shawnee Group (Virgilian Stage, Upper Pennsylvanian) have historically been attributed to the Chlorophyta (green algae) and Cyanobacteria ("blue-green algae"). *Archaeolithophyllum,* a genus of the Rhodophyta (red algae) had previously been identified in the Toronto Limestone, a regressive limestone of the Shawnee, but in no other member of the group. Therefore, field and laboratory work was conducted to: (1) confirm the published report of the presence of red algae in the Toronto Limestone; (2) search for red algae in other regressive limestones of the Shawnee Group; and (3) make preliminary interpretations of the bioherm environment based on the stromatolitic morphology of the algae.

Archaeolithophyllum was identified in the Toronto, Ervine Creek, and Hartford limestones, but not in the Beil and Plattsmouth limestones. The Toronto, Plattsmouth, and Hartford limestones display only spheroidal stromatolites; the Beil Limestone contains only laterally linked hemispheroidal stromatolites; and the Ervine Creek Limestone has only vertically stacked hemispheroidal stromatolites.

Results of this study: (1) confirmed the presence of red algae in spheroidal stromatolites in the Toronto Limestone; (2) documented for the first time the presence of red algae in spheroidal stromatolites in the Hartford Limestone; and (3) discovered vertically stacked hemispheroidal stromatolites of red algae in the Ervine Creek Limestone. Because all previous reports in the literature of red algal stromatolites are of spheroidal structures, this is the first documentation of red algae forming vertically stacked hemispheroidal stromatolites.

CONTRIBUTION OF RED ALGAE TO ALGAL BIOHERMS OF THE SHAWNEE GROUP (VIRGILIAN, UPPER PENNSYLVANIAN) OF EASTERN KANSAS

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by

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CHAPTER 1: INTRODUCTION

PURPOSE

During the Pennsylvanian Period Kansas was covered by seas that responded to eustatic sea-level changes resulting in a series of marine transgressions (onlap of water onto the continent) and regressions (offlap of water to the previous sea level) (Figure 1.1). Fluctuating water levels led to the deposition of marine and non-marine sedimentary rocks. These sedimentary rocks often preserved the marine fossils that existed in these environments. One fossil type that is common in these sedimentary rocks is an algal bioherm, a sedimentary structure of calcareous composition, resulting from the secretion, precipitation, and trapping of calcium carbonate by colonial algae and other microorganisms.

Algal bioherms appear throughout rocks of the Permian and Pennsylvanian age in Kansas, but are concentrated in rocks of the Wabaunsee (Virgilian Stage, Upper Pennsylvanian), Shawnee (Virgilian Stage, Upper Pennsylvanian), and Kansas City (Missourian Stage, Upper Pennsylvanian) groups. The organisms that formed algal bioherms in Kansas during Pennsylvanian-Permian time have been interpreted as Cyanobacteria ("blue-green algae") and Chlorophyta (green algae) (Johnson, 1946). The Rhodophyta (red algae) occur in Mississippian and Permian strata of Kansas, but are not well documented in Pennsylvanian rocks of the region (Johnson, 1946). This study focuses on algal bioherms that occur in limestone members of the formations that make up the Shawnee Group (Virgilian Stage, Upper Pennsylvanian) exposed in eastern Kansas. The purposes of this study are to (1) confirm or refute the published report of the presence

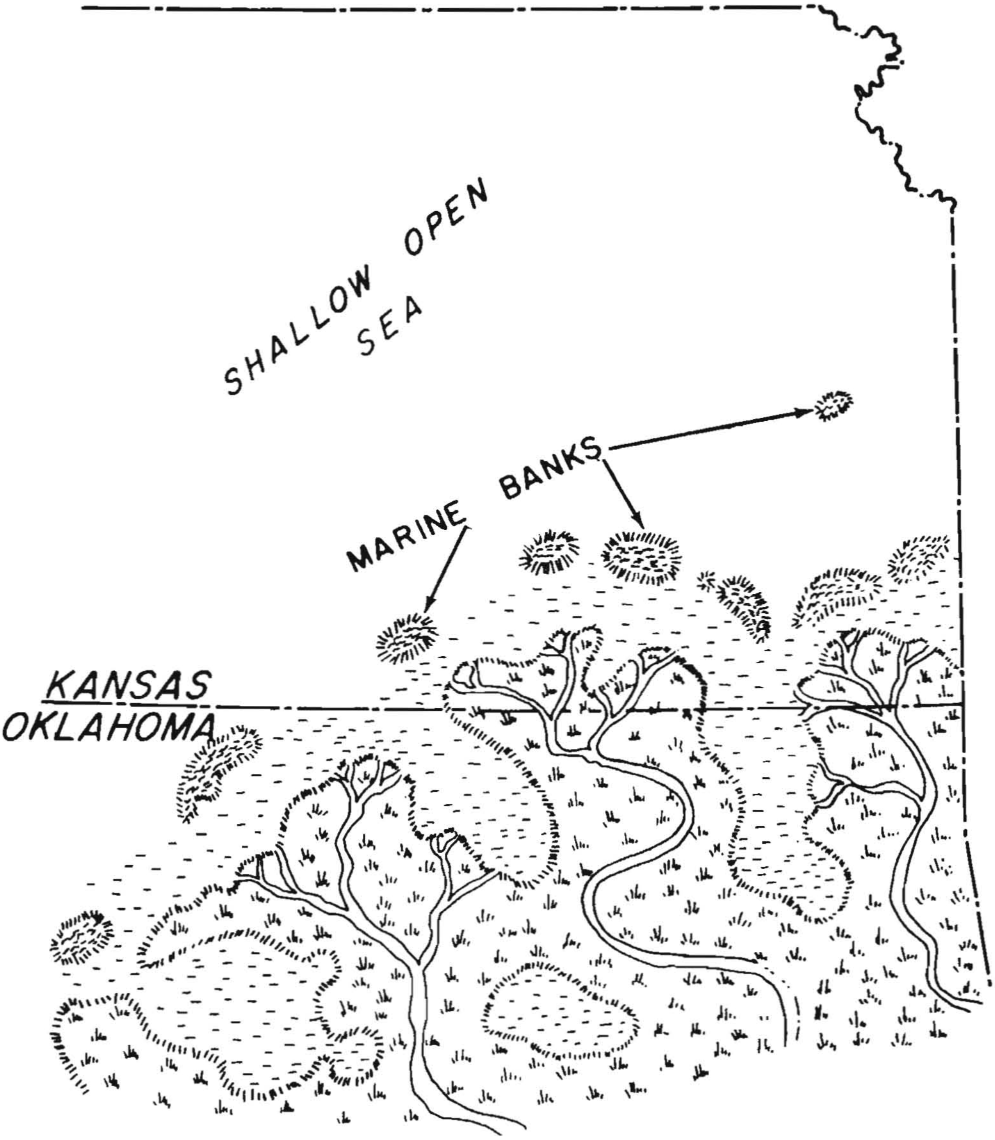


Figure 1.1 Map of Paleosea in Kansas (from Harbaugh, 1964).

of red algae in the Toronto Limestone member; (2) search for red algae in other regressive limestones of the Shawnee Group of eastern Kansas; (3) and, from the stromatolite morphology, interpret the depositional environments in which the bioherms were found.

Rhodophytes are generally found within fore-reef to back-reef environments; cyanobacteria and chlorophytes are usually found in the back-reef to tidal-flat environments (Figure 1.2) (Brasier, 1980). Therefore, taxonomic identification is an important parameter to determine the general environment present during bioherm formation. The stromatolitic morphology is related to the type of substrate upon which the bioherm was built and the energy of the depositional environment (Johnson, 1946).

PREVIOUS WORK

STRATIGRAPHY

The early studies of the Shawnee Group, through the last decade of the 19th century, centered in northeastern Kansas and was done by Haworth (1894), Beede (1898), Bennett (1896), and Kirk (1896). These individuals developed the initial interpretations of the stratigraphy and described the first geologic sections of Kansas rocks. Algal fossils (from Pennsylvanian and Lower Permian rocks) were first described in eastern Kansas by Twenhofel (1919).

Moore (1949, 1951), Newell (1935), Jewett (1935), and Condra (1927) refined the stratigraphy and geology of the earlier workers by extending the studies to older rock units and into Nebraska. They published data on the surficial geology of counties not previously

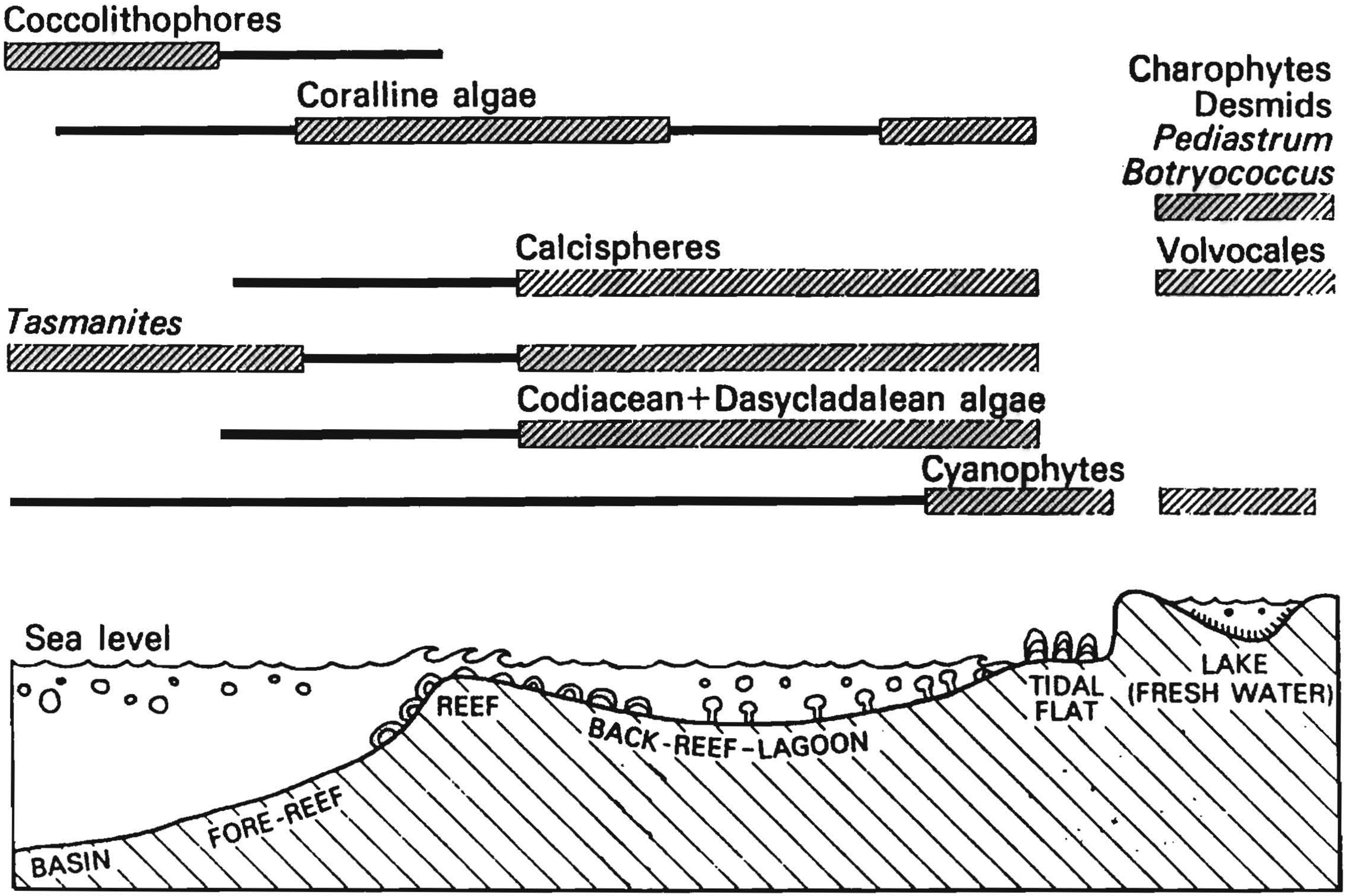


Figure 1.2 General Environmental Distribution of Living and Fossil Algae (from Brasier, 1980).

covered. Their work was used as the basis for construction of geologic maps of Kansas by Moore and Landes (1937).

As the stratigraphic work in Nebraska and Kansas was completed, it led to the recognition of the cyclic nature of these units, particularly within the Shawnee Group. Wanless and Weller (1932) proposed a cyclothem model, a series of beds deposited during a single sedimentary cycle that represent a marine transgression and regression for the cyclic sedimentation in Illinois. Consistent with the cyclothem model, algal fossils were found within limestone members deposited during the regressions.

ALGAL FOSSILS

Johnson (1946) collected algal fossils (belonging to the green and "blue-green" (actually cyanobacteria) groups) from 74 formations in eastern Kansas, spanning the Lower Pennsylvanian to the Lower Permian. He found no evidence of red algae, but suggested that well-preserved samples may be found because the red algae are well known in both Mississippian and Permian strata of eastern Kansas (Johnson 1946).

Heckel and Cocke (1969) identified about 25 algal bioherms exposed in surficial rocks in eastern Kansas and northeastern Oklahoma. His study focused on the Lansing Group (Missourian Stage, Upper Pennsylvanian), Kansas City Group (Missourian Stage, Upper Pennsylvanian), and older units. Merriam and Wolf (1983) expanded the studies of bioherms by focusing on the Shawnee Group (Virgilian Stage, Upper Pennsylvanian) in Greenwood, Elk, and Chautauqua counties, Kansas. He did a comparative study of the size, thickness, and site of development of the algal bioherms of the Shawnee and Lansing through Kansas City groups. In general, the Shawnee algal bioherms differ from all the others in that they are smaller, thinner, and appear to have developed on topographic irregularities.

RHODOLITHS

Toomey (1975) studied rhodoliths, algae-coated nuclei of either organic or inorganic composition, from the Toronto Limestone, a member of the Shawnee Group. He interpreted the algal coatings as red algae, specifically *Archaeolithophyllum*, based on preserved cellular structure; thus he established the presence of red algae in the Shawnee Group.

Modern studies of rhodoliths include works by Reid and MacIntyre (1988) and Bosellini and Ginsburg (1971). These studies show that rhodoliths are found at depths less than 200 meters (m), and form in an environment with slow deposition and intermittent agitation by waves or currents. Rhodoliths in low-energy environments develop a bumpy surface, whereas rhodoliths in high-energy environments become smoother. The appearance of rhodoliths is similar to that of another rolled structure called an oncolite. Oncolites are formed by cyanobacteria instead of red algae. Oncolites may be distinguished from rhodoliths because they have layers of sediment trapped between each layer of cyanobacteria, whereas rhodoliths lack the sediment.

STROMATOLITES

Kalkowsky (1908) coined the terms stromatolite and stromatoids. Originally stromatolites were defined as whole algal mounds, whereas stromatoids were the individual elements. The term stromatoid has since been superseded by stromatolite for the individual structures, whereas the whole mound is now referred to as an algal bioherm (Harbaugh, 1959). Kalkowsky (1908) described the morphology of stromatolites as ranging from flat-lying to discrete columns and other various laminated shapes, but he made no attempt to correlate morphology with depositional environment. Bates and Jackson (1987) define stromatolites as organosedimentary structures produced by sediment trapping, binding, and/or precipitation as a result of the growth and metabolic activity of microorganisms.

Logan *et al.* (1964) published a classification of stromatolites based on geometric arrangement of their structure. They described three main geometries: laterally linked hemispheroid (LLH), discrete vertically stacked hemispheroid (SH), and discrete spheroid (SS). These authors expanded the definition of stromatolites to include discrete spheroids (oncolites and rhodoliths) as stromatolites.

Excellent examples of recent stromatolites, produced by cyanobacteria, occur in Shark's Bay Australia, a shallow water body connected to the sea. Due to evaporation the salinity of the bay is much higher than the open sea. Because it is hypersaline, the water inhibits the number of grazing metazoans who consume the cyanobacteria, thus allowing the cyanobacteria to flourish in the shallow waters. Stromatolites exist today only in areas protected from predation (Boher, 1998).

THROMBOLITES

Aitken (1967) introduced the term thrombolite as algal-like structures that are related to stromatolites, but which lack laminations and are characterized by a macroscopic clotted fabric. Clotted fabric is a distinct internal mesoscopic structure, large enough so a microscope is not needed for viewing but small enough to be seen entirely; it consists of millimeter (mm)- and centimeter (cm)-size clots of microbial communities separated either by patches of mud and sand-sized sediments or by sparry carbonate (Aiken, 1967). Kennard and James (1986) compared thrombolites and stromatolites and determined that both are formed by calcified cyanobacteria communities and have similar external forms. Thrombolites have not been reported from the Shawnee Group.

METHODS

FIELD WORK

The Toronto, Hartford, and Ervine Creek limestone members were chosen for this study based on preliminary, unpublished work by Dr. William Lanier (of Emporia State University) and the author. Literature research verified that the Toronto Limestone contains the red algae *Archaeolithophyllum* and has been interpreted as a regressive limestone (Toomey, 1975). In this present study the search for outcrop exposures that were accessible began in Emporia, KS, and extended south to the Kansas-Oklahoma border and east toward the Kansas-Missouri border. During the investigation of the Toronto, Hartford, and Ervine Creek limestones, accessible outcrops of the Beil and Plattsmouth limestones were found. The Beil and the Plattsmouth limestone members contained preserved algal bioherms on the exposed surfaces, so were collected to sample other regressive limestones.

The five limestones were chosen because they were deposited during the regressive stage of the seaward cycle of the cyclothem. Samples were chosen based on the visible presence of preserved stromatolitic structures and were collected using rock hammers or an airless jackhammer. Each sample was marked with a field identification number (ie: EC-98-1-1 = limestone-year-sample location-sample number) and a stratigraphic "up" indicator mark.

SITE LOCATION

Stromatolites were collected in eastern Kansas in the counties of Lyon, Greenwood, Woodson, and Coffey (Figures 1.3 – 1.9). See Table 1.1

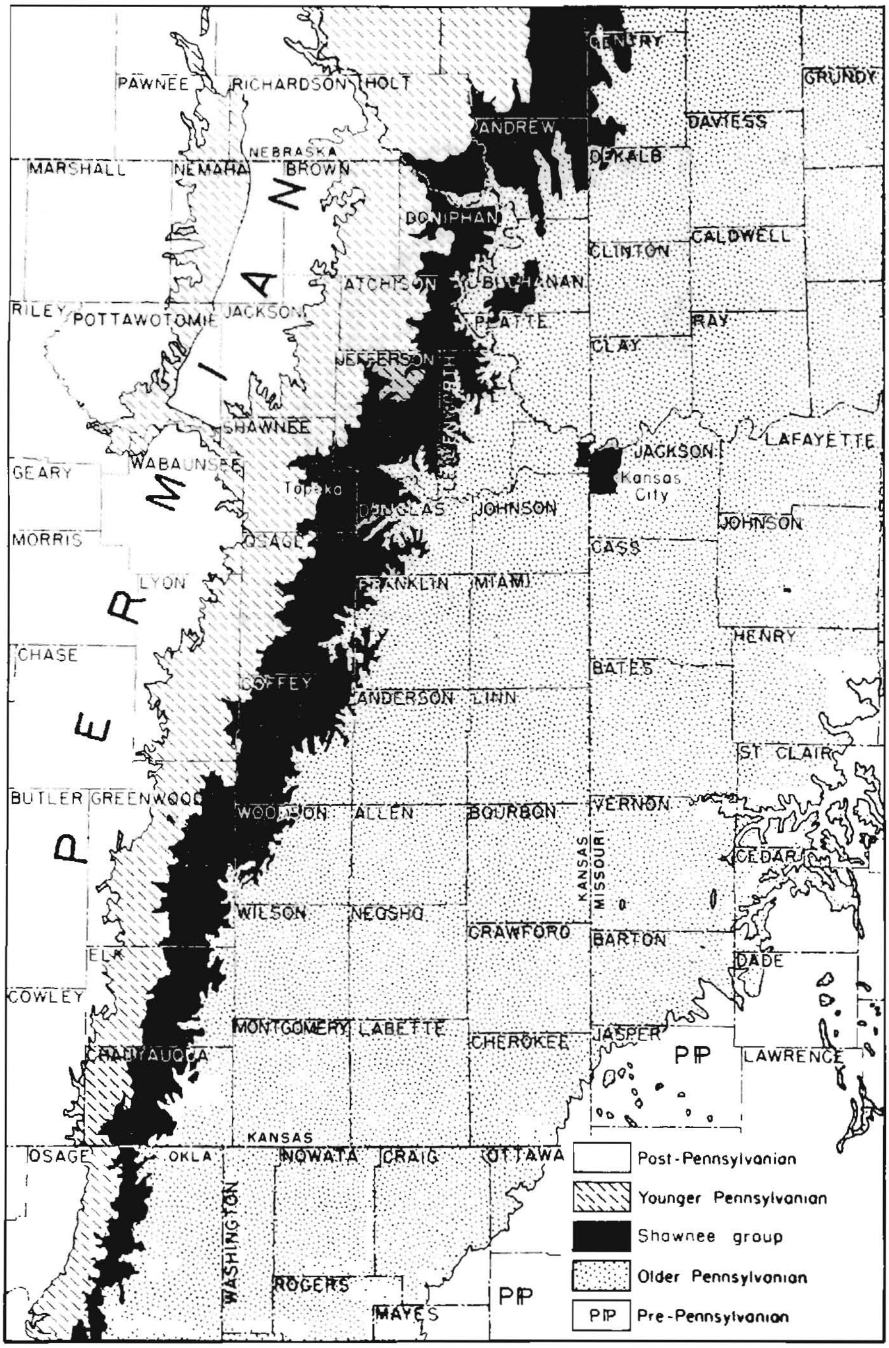


Figure 1.3 Distribution of the Shawnee Group in Eastern Kansas (from Moore, 1949).

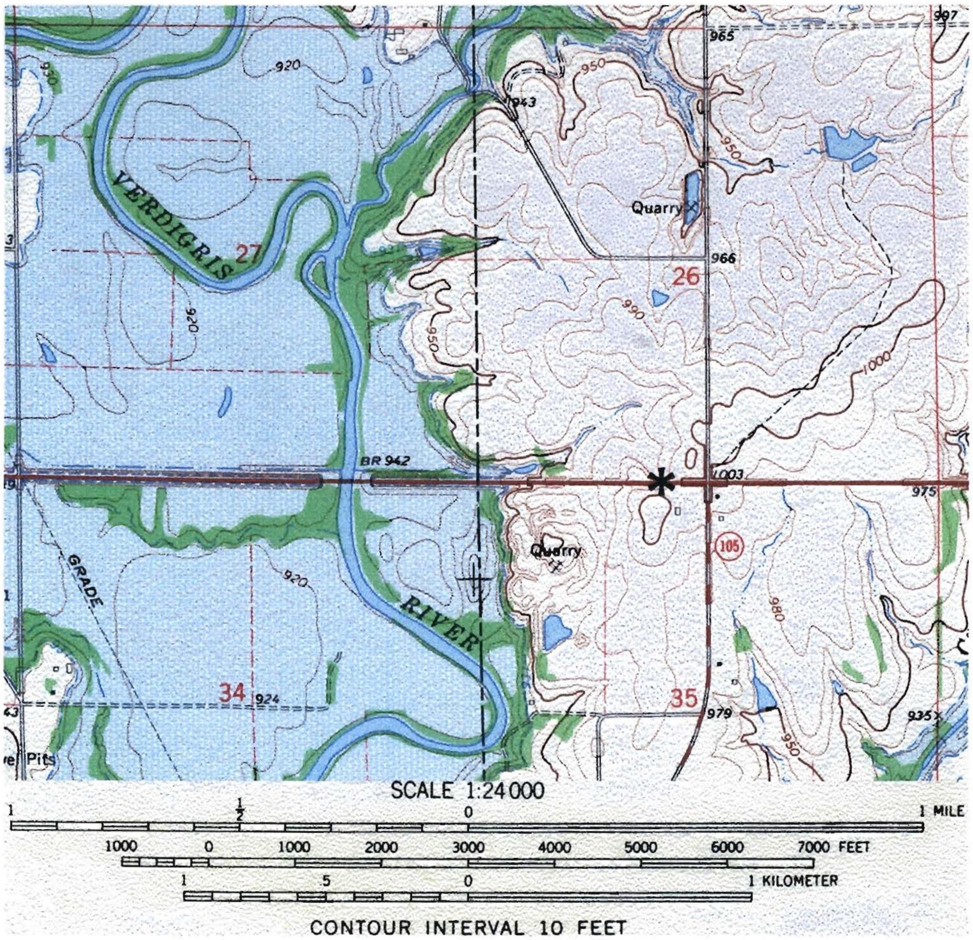


Figure 1.4 Toronto Limestone Sample Site: Toronto Quadrangle; Township 25S; Range 13E; Sections 26, 27, 34, 35. (* = Site)

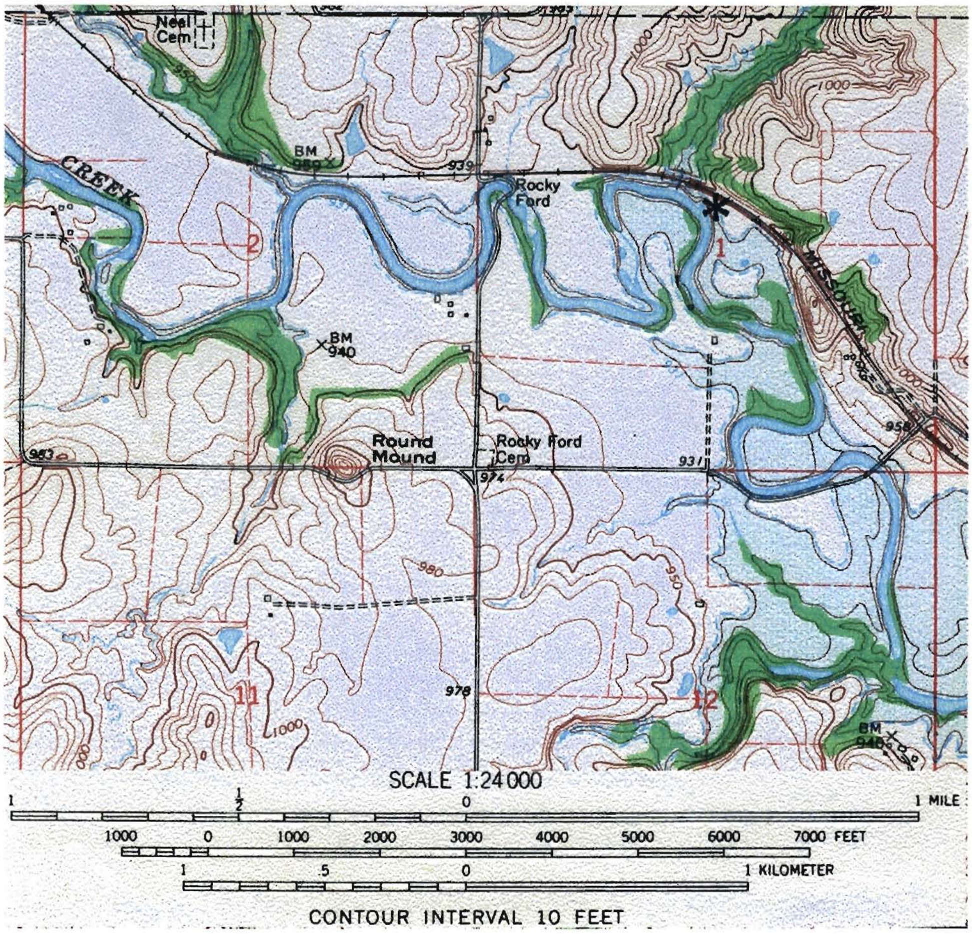


Figure 1.5 Plattsmouth Limestone Sample Site: Neal Quadrangle; Township 26S; Range 12E; Sections 1, 2, 11, 12.

(* = Site)

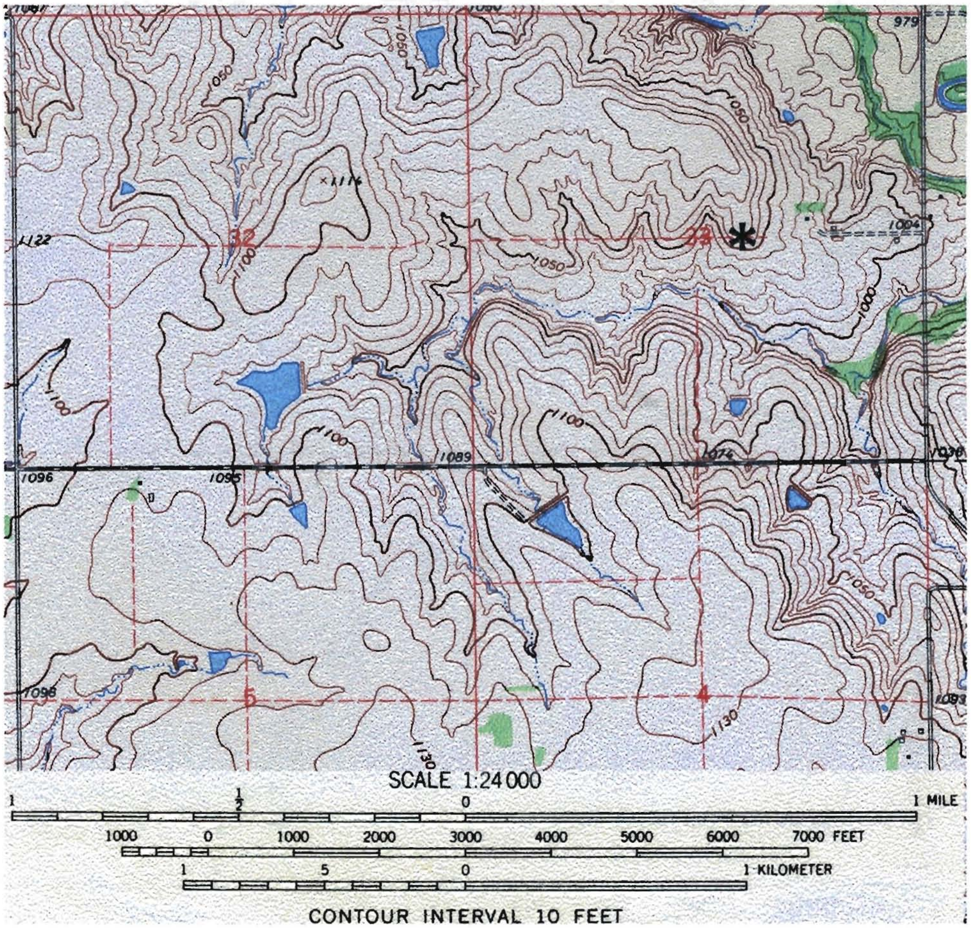


Figure 1.6 Beil Limestone Sample Site: Virgil Quadrangle; Township 24S; Range 12E; Sections 32, 33, 5, 4. (* = Site)

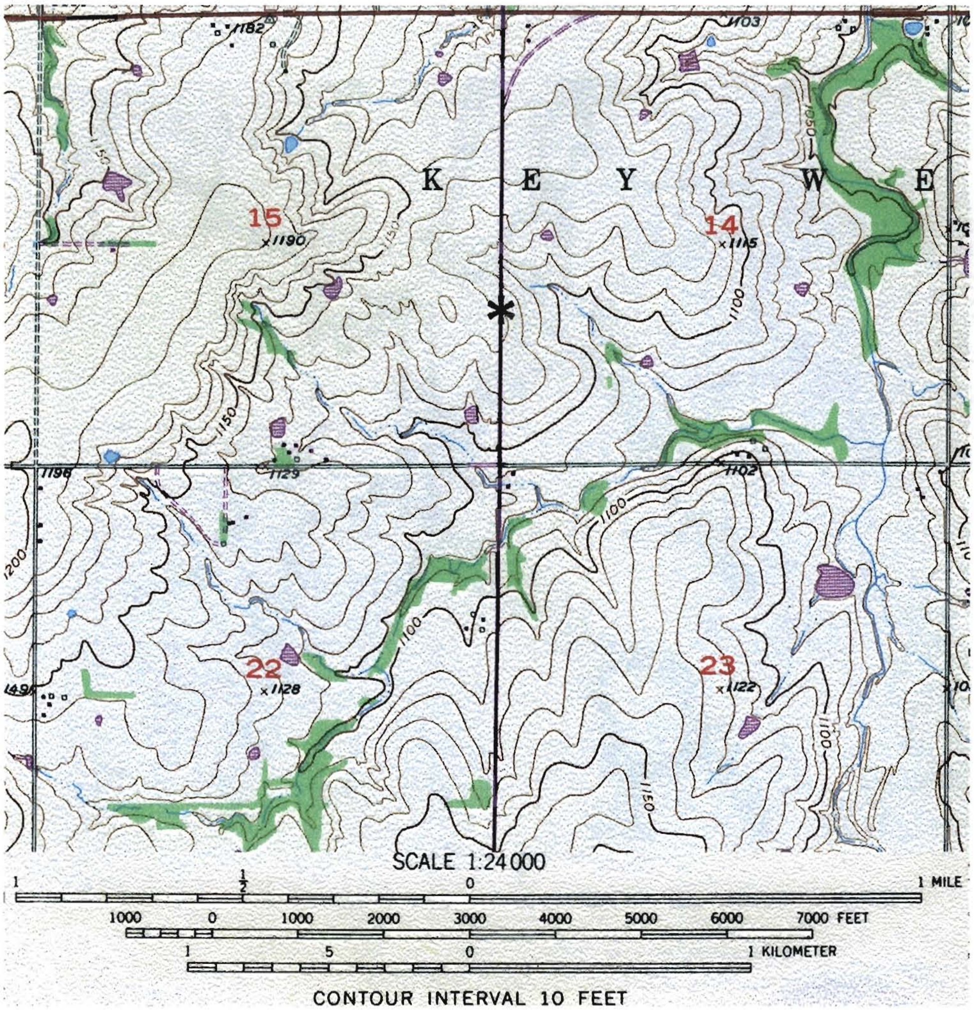


Figure 1.7 Ervine Creek Limestone Sample Site: Waverly Quadrangle; Township 19S; Range 15E; Sections 14, 15, 22, 23.
(* = Site)

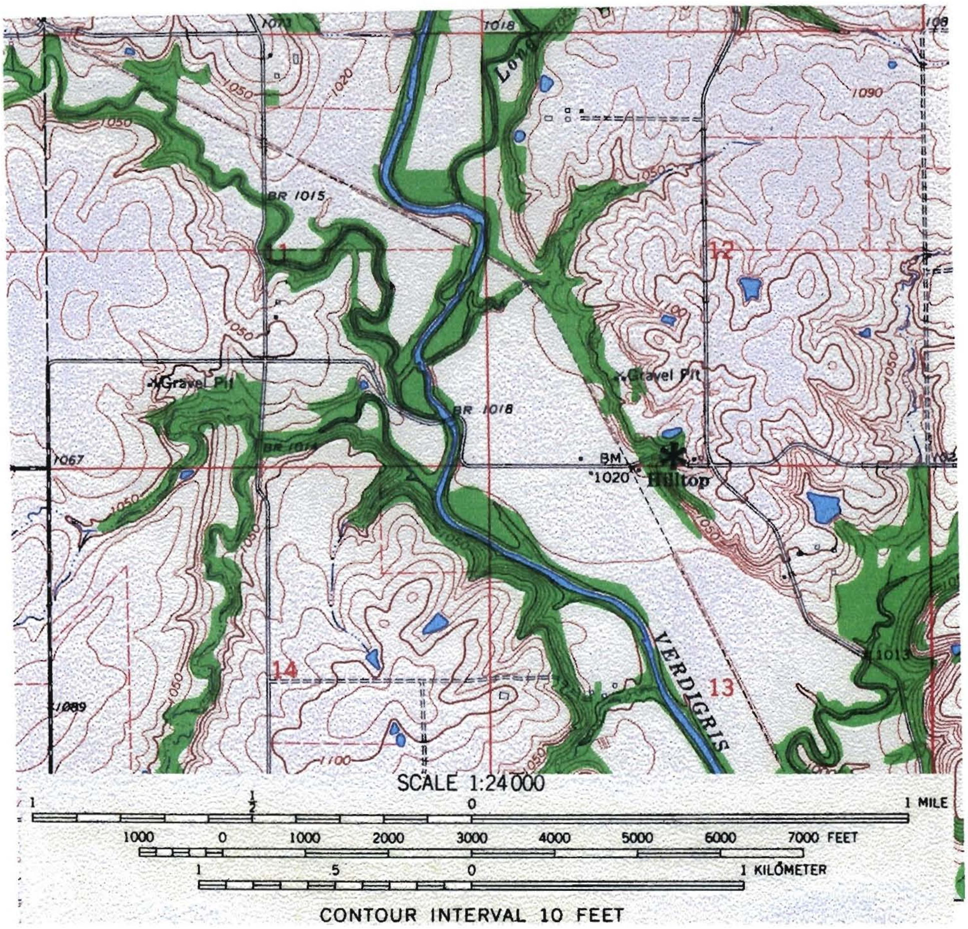


Figure 1.8 Hartford Limestone Sample Site: Lamont Quadrangle; Township 23S; Range 12E; Sections 12, 11, 14, 13.
(* = Site)

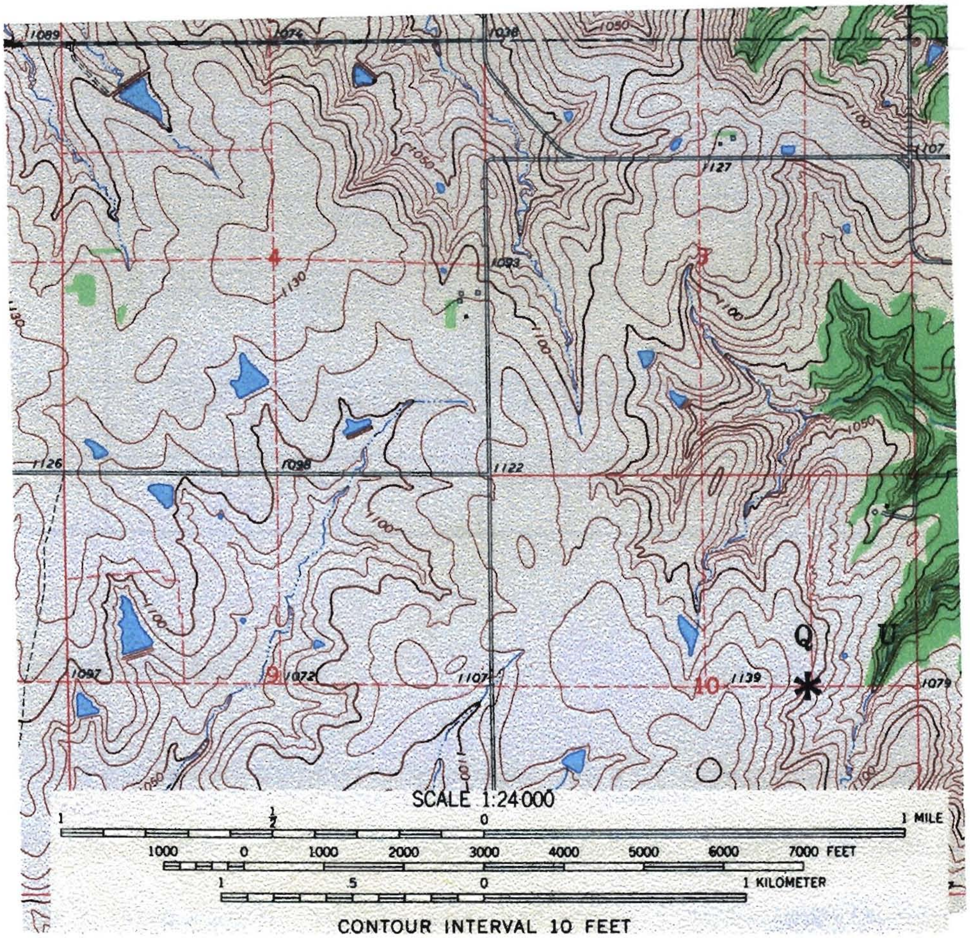


Figure 1.9 Hartford Limestone Sample Site: Virgil Quadrangle; Township 25S; Range 12E; Sections 3, 4, 9, 10.
(* = Site)

Table 1.1 Map Locations of Sample Areas

MEMBER	SITE	LOCATION	1/4	1/4	SEC.	R	T	QUAD.
Toronto	Roadcut	N.54 Highway	SE	SW	26	13E	25S	Toronto
Plattsmouth	Rivercut	Walnut Creek	SW	NE	1	12E	26S	Neal
Beil	Roadcut	Country road	SW	NE	33	12E	24S	Virgil
Ervine Creek	Roadcut	Highway 75	NW	SW	14	15E	19S	Waverly
Hartford 1	E. Wall	Hilltop Quarry	SE	SW	12	12E	23S	Lamont
Hartford 2	Roadcut	Country road	SW	NE	10	12E	25S	Virgil

LABORATORY WORK

Field samples were trimmed to small slabs with a 24" Covington rock saw and a 16" Great Western Lapidary saw. The slabs were used to examine stromatolite gross morphology in cross section. Samples were then sent to P.M. Organist (Newark, DE), a commercial vendor, for further preparation into thin sections.

ANALYSIS

The thin sections were examined using a Nikon Optiphoto 2 petrographic microscope. The type of optical microscopy used in this study involves transmitted visible light passing through a sample for viewing. The microscope was fitted with photography equipment to take pictures of thin sections. The Nikon Optiphoto 2, with a magnification of 25X to 1000X power, was used to study the preserved organisms at the 50X and 100X magnification powers. Microphotographs were made of the preserved organisms for subsequent analyses.

STRATIGRAPHY

All limestones sampled for this study belong to the Shawnee Group (Virgilian Stage, Upper Pennsylvanian Series, Pennsylvanian System), which includes the following seven formations, in stratigraphic order from oldest to youngest: Oread Limestone (includes the Toronto and Plattsmouth limestone members), Kanwaka Shale, Lecompton Limestone (includes the Beil Limestone member), Tecumseh Shale, Deer Creek Limestone (includes the Ervine Creek Limestone member), Calhoun Shale and Topeka Limestone (includes the Hartford Limestone member). Four of the seven are predominantly limestones that alternate with siliciclastic formations of shale with sandstone (Figure 1.10). These alternating calcareous and siliciclastic formations reflect major sedimentary responses to eustatic oscillations of sea level. They were deposited during a single eustatic oscillation or cycle.

CYCLOTHEMS

A cyclothem is a series of beds deposited during a single sedimentary cycle that represents a single marine transgression and associated regression (Bates and Jackson, 1987). An ideal cyclothem is a theoretical construct that represents the optimum succession of deposits during one complete onlap-offlap. The ideal cyclothem (Table 1.2) contains ten members labeled one to ten from bottom to top; members one to five and

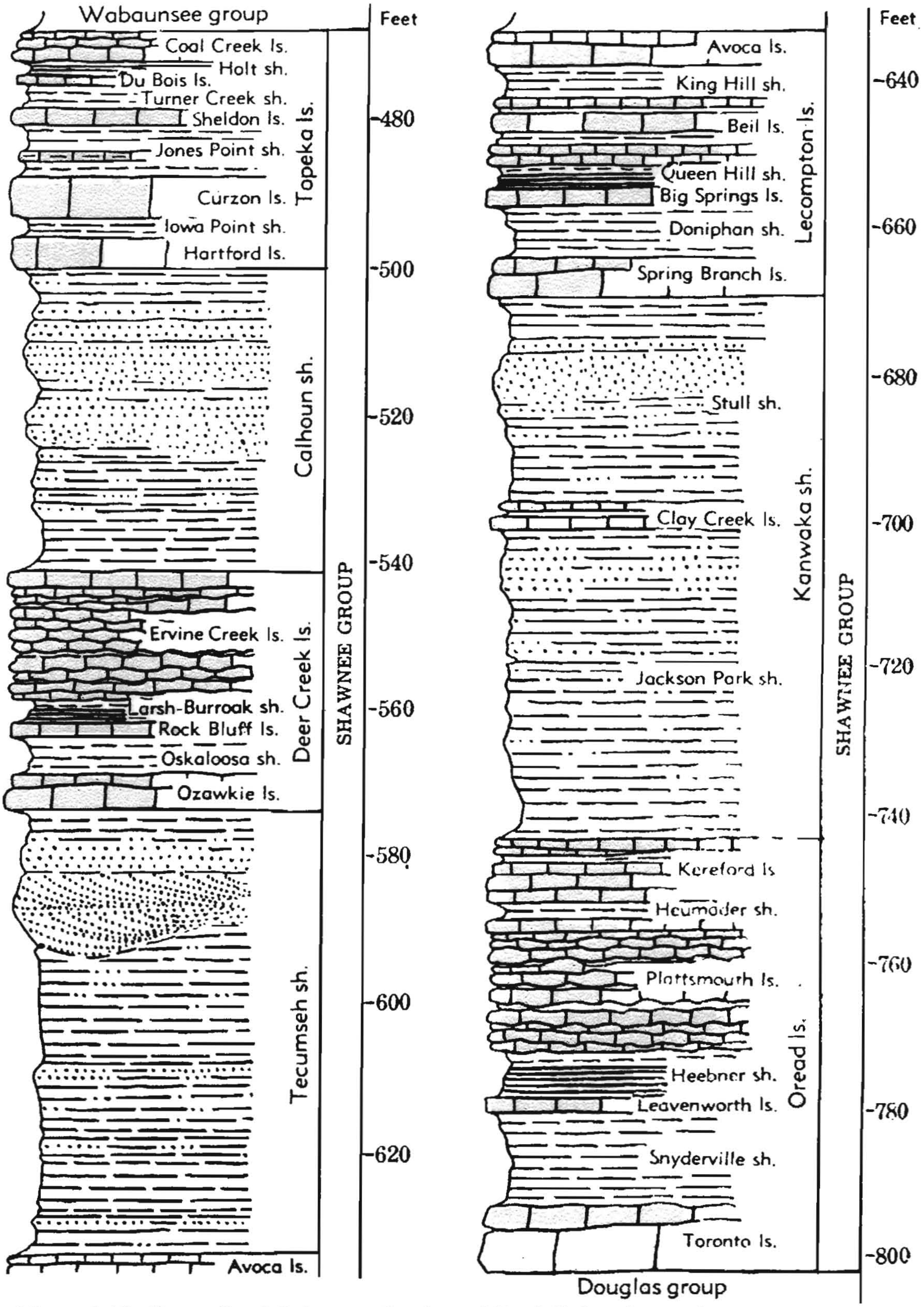


Figure 1.10 Generalized Columnar Section of Rock Belonging to the Shawnee Group in Kansas (from Moore, 1949).

part of six are non-marine (regressive), and the remaining units are marine (transgressive) (Wanless and Weller, 1932).

Table 1.2 Model of Ideal Cyclothem (from Wanless and Weller, 1932)

10.Shale, marine with ironstone concretions	Transgressive
9. Limestone, marine	Transgressive
8. Shale, black, laminated with limestone concretions or layers	Transgressive
7. Limestone, marine, impure, lenticular, fine-grained	Transgressive
6. Shale, marine, gray with pyritic nodules	Transgressive/ Regressive
5. Coal	Regressive
4. Underclay	Regressive
3. Limestone, freshwater usually non-fossiliferous,	Regressive
2. Shale, sandy	Regressive
1. Sandstone, fine-grained micaceous, locally unconformable on underlying beds	Regressive

Few of the stratigraphic sequences in the mid-continent contain all of the members described in the ideal cyclothem model. The freshwater limestone that occurs below the underclay in an ideal cyclothem is often missing in the mid-continent cyclothem. In addition, a typical well-developed cyclothem of the mid-continent (Table 1.3) contains different members than the ideal cyclothem. The mid-continent cyclothem typically contains three marine limestone members instead of the two marine limestones of the ideal cyclothem. These differences are not unexpected because the mid-continent was more seaward than the region (Illinois) upon which the ideal cyclothem model was based (Moore and Merriam, 1959).

Table 1.3 Mid-Continent Cyclothem (from Moore and Merriam, 1959)

Disconformity	Erosion
10. Shale, brackish and nonmarine	Regressive
9. Shale, marine	Regressive
8. Limestone, algal, contains near-shore and brackish water invertebrates	Regressive
7. Limestone, contains off-shore invertebrates especially fusulinids	Transgressive
6. Limestone, shaly, contains intermediate off-shore invertebrates	Transgressive
5. Shale, marine, contains near-shore invertebrates	Transgressive
4. Coal	Transgressive
3. Underclay	Transgressive
2. Shale, nonmarine, commonly sandy	Transgressive
1. Sandstone, nonmarine	Transgressive
Disconformity	Erosion

Virgilian-age rocks of Kansas contain few coals, no freshwater limestones, and few sandstones, all of which are indicators of nonmarine environments. The Kansas sequence is principally of marine origin, consisting of alternating limestone and shale members (Moore and Merriam, 1959). Coal beds are the obvious markers of nonmarine phases in a predominantly marine sequence. In areas where no coal is present, the underclay may indicate the coal horizon. The cap rock over the coal is commonly impure limestone or clay-ironstone (Moore and Merriam, 1959).

The transgressive limestones are dense, dark, and contain diverse and abundant marine fossils. These fossils indicate the limestones formed farther off shore and in water below effective wave base, but within the photic zone (Brandy and Armal, 1973). Regressive limestone members generally contain a greater variety of facies compared to the transgressive limestones (Heckel, 1979). The variety of faces may be caused by the advancing shoreline continuing to furnish clastic material into a carbonate-producing environment (Johnson, 1964). This would permit an increase in the amount of shale or shaley members within a limestone formation.

Five regressive limestone within the Shawnee Group were examined for this study: Toronto and Plattsmouth members (of the Oread Limestone formation), Beil member (of the Lecompton Limestone formation), Ervine Creek member (of the Deer Creek Limestone formation), and Hartford member (of the Topeka Limestone formation). Each of these limestones contains algal bioherms. Published data by Toomey (1975) indicates that the Toronto Limestone contains the red algal *Archaeolithophyllum*. Preliminary unpublished data collected by Lanier indicates that the Ervine Creek and Hartford limestones may contain possible fossils of red algae. The Plattsmouth and Beil limestones were added to this study because they were regressive limestones containing stromatolites.

CHAPTER 2: CLASSIFICATION

ALGAE

Algae is a generic name given to several divisions of single-celled or simple multicellular eukaryotic plants capable of photosynthesis, but in which there is little or no differentiation into tissue systems. Cyanobacteria (blue-green algae) are no longer included with algae since they are prokaryotic and not eukaryotic (see Cyanobacteria section). Algae are thallophytic plants lacking roots, stems, and leaves, and are the most ancient form of life capable of photosynthesis (Bold and Wynne, 1985).

Algae are most common in aquatic environments, while some survive on land, and others exist in moist soils. They are widely distributed, both geographically and ecologically, and can survive in extreme environments. Their habitats range from the near boiling waters of hot springs, to the freezing temperatures of Antarctic waters. Algae vary in size from unicellular forms less than 10 micrometers in diameter to multicellular kelp, which may grow 60 m in a year (Bold and Wynne, 1985). The divisions of living algae are based on the photosynthetic pigments the plants contain (Smith, 1951), as indicated in Table 2.1. However, the taxonomic identification of algal fossils is based primarily on body parts, because photosynthetic pigments are not preserved.

Fossil organisms belonging to the groups Chlorophyta, Rhodophyta, and Cyanobacteria have been identified in the rock record, and all three form stromatolites (Johnson, 1946). Stromatolitic structures formed by members of these fossil groups are classified on the basis of features such as microstructure and growth habit (Johnson, 1946).

Table 2.1 Divisions of Algae and Characteristics

DIVISION	PIGMENTS	STROMATOLITE FORMING
Chlorophyta	Chlorophyll A & B, Xanthophylls, Alpha & Beta Carotene	Yes
Chrysophyta	Xanthophylls and Carotene	No
Euglenophyta	Chlorophyll A & B, Xanthophylls, Alpha & Beta Carotene	No
Phaeophyta	Chlorophyll A & C, Beta Carotene, Xanthophylls	No
Pyrrhophyta	Xanthophylls and Carotene	No
Rhodophyta	Chlorophyll A, two Carotenes, Xanthophylls, Phycocyanin, two Phycoerythrin	Yes

RHODOPHYTA

Kingdom: Plantae

Subkingdom: Algae

Division: Rhodophyta

Rhodophytes, or red algae, are one of the oldest groups of eukaryotic algae. They vary greatly in shape, including plate-like, crust-like, coralline, and feather-like forms. Fossils of red algae have been found in rocks as old as 500 million years. They are unique among algae in that they have no flagellated cells during their life cycle (Bold and Wynne, 1985). The red algae can occur at all latitudes, but are especially abundant in the temperate and tropical regions. They occur from intertidal environments to the lower limits of the photic zone, about 200 m, a greater depth than any other algae (Adey and MacIntyre, 1973). Fossil red algae belonging to *Archaeolithophyllum* have been identified in southeastern Kansas in the Lansing Group (Missourian Stage, Upper Pennsylvanian), which is lower in the section than the Shawnee Group (Wray, 1964).

Archaeolithophyllum has a thallus, a relatively undifferentiated plant body lacking true leaves, stems, and roots, which consists of calcified, undulating, irregularly shaped crusts of variable thickness. Thalli occur as solitary crusts or as foliated and multilayered masses. The internal tissue is differentiated into a thick central portion (hypothallus) and a thin outer layer (perithallus). The hypothallus is composed of rows of polygonal cells, and the perithallus is made up of smaller, rectangular cells arranged in rows parallel to the surface of the thallus. Subconical conceptacles, cavities which contain the reproductive organs, with single apical apertures, are distributed irregularly over the upper surface of the thallus (Wray, 1964).

CHLOROPHYTA

Kingdom: Plantae
Subkingdom: Algae
Division: Chlorophyta

The Chlorophyta, or green algae, is the largest division of the algae, with 6000 to 7000 species. Chlorophytes may occur as single cells, in colonies, and as multicellular filaments. The unicellular forms may be any shape, and may be motile or nonmotile. Colonies occur as loose aggregates of single cells, or they may have cells arranged in a characteristic pattern. Most colonies are nonmotile. Some filamentous types are nonmotile and may resemble higher plants (Bold and Wynne, 1985).

Chlorophytes are found in numerous environments and are especially abundant in freshwater, marine, or terrestrial environments (Bold and Wynne, 1985). They are most numerous in the upper part of the intertidal zone. Two families of the Chlorophyta have been described in the Shawnee Group, the Codiaceae, and Dasycladaceae (Merriam, 1986).

The Codiaceae have been identified in the Plattsmouth, Beil, Ervine Creek, and Hartford limestones (Merriam, 1986). The Dasycladaceae have been identified in the Plattsmouth and Beil limestones (Merriam, 1986).

Codiaceae. "These colonial algae occur as crustose masses from which straight or nearly straight cylindrical thalli develop. The thallus may branch or develop rounded protubances. Some are irregularly constricted, but others are very regular. Each thallus is composed of a sponge-like mass of rounded threads or branches. The center of the thallus tends to be poorly organized or pithlike; but toward outer margins of thalli, branches tend to become parallel. In some species, branches end in tufts of fine branches that usually are perpendicular to the outer surface of thallus. The outer part of the thallus is calcified, but the amount of calcification varies. Calcified areas usually preserve microstructure, whereas uncalcified portions are filled with clear calcite. There are no sporangia observed in the fossil green algae. The preserved thallus thickness ranges from .001 mm to 1 mm. In Kansas rocks, they are found in the Pennsylvanian and Permian" (Johnson, 1946: 1098).

Dasycladaceae. "These are nonpartitioned, multinucleate algae. The thallus is composed of a central stem from which whorls of primary branches develop that may bear tufts of secondary and even tertiary branches. Sporangia, spore-producing structures, may develop: (1) within the stem, (2) attached to the stem, (3) on primary branches, and (4) on secondary branches. Calcium carbonate is precipitated on stem and primary branches, generally covering them, and may also cover secondary and tertiary branches" (Johnson, 1946: 1095).

"Fossil Dasycladaceae usually consist of a hollow calcareous body of spherical, cylindrical, or club-shaped form open at one end and perforated by numerous openings. It forms a calcareous mold of the stem, or stem and branches. In Paleozoic and most Mesozoic fossils, openings have been filled with calcite of a texture and tint different from original wall deposits. Thus, stem and branches appear as pores in the walls. Fossil Dasycladaceae are known from the Ordovician through the Permian deposits in Kansas" (Johnson, 1946: 1095).

CYANOBACTERIA

Kingdom: Monera

Subkingdom: Eubacteria

Division: Cyanobacteria

"Cyanobacteria, the so called 'blue-green algae', are not true algae. Modern cyanobacteria are sometimes mistakenly grouped with true algae because they share similar pigments (Chlorophyll A) and they liberate free oxygen during photosynthesis. Cyanobacteria lack a membrane bounded nucleus and other specialized cell structures, thus they are in fact bacteria" (Bold and Wynne, 1985: 34).

Cyanobacteria occur as single cells, colonies, or filaments. Cyanobacteria inhabit numerous environments including: marine water, freshwater, soils, or moist rocks (Bold and Wynne, 1985). In marine environments they are usually found from supratidal to subtidal zones. They can endure extreme dryness and high light intensity for a limited time. The oldest fossil cyanobacteria are at least 3.5 billion years old (Schopf, 1983).

"The cyanobacteria genus, *Cryptozoon*, has been found in Pennsylvanian and Permian rocks, in particular the Toronto and Ervine Creek members, of eastern Kansas

(Johnson, 1946: 1105). They occur as small flattened round colonies that have thin concentric growth laminae. They are composed of branching filaments with an average diameter of .008 mm. Colonies may occur separately or in crowded masses. The average size of a colony is 7 x 2.5 x 4 cm." (Johnson, 1946: 1106). Cyanobacteria range from the Archean to Recent (Schopf, 1983).

STROMATOLITIC MORPHOLOGY

Morphology refers to the macrostructure of the fossil stromatolites and reflects many variables within the environment such as current strength, substrate conditions and rates of sedimentation. Sedimentary structures formed by algae and cyanobacteria include stromatolites, oncolites, and thrombolites, depending on the paleoenvironmental conditions that existed during their formation.

STROMATOLITES

Stromatolites are organosedimentary structures produced by the sediment trapping, binding, and/or precipitation as a result of the growth and metabolic activity of microorganisms (Bates and Jackson, 1987). These structures have been found in rocks from Archean to present (Schopf, 1983). Stromatolites have been divided into several morphotypes by Logan *et al.* (1964). Work of the latter authors was the basis for the identification of stromatolite morphology in this study as summarized below.

Stromatolite morphotypes are divided into laterally linked hemispheroids (LLH), discrete, vertically stacked hemispheroids (SH), and spheroidal structures (SS). Laterally linked hemispheroids (LLH) occur as algal mats which are wrinkled into a series of small domes or hemispheroids. The hemispheroids are linked laterally to other hemispheroids within the mat terrain. There are two types of lateral linkage: close-linked hemispheroids

(LLH-C) and space-linked hemispheroids (LLH-S). The distance between the structures of close-linked hemispheroids is less than the diameter of the structure (Figure 2.1). The distance between the structures of the space-linked hemispheroids is greater than the diameter of the structure. Doming of the mat may be due to four factors working separately or in combination: (1) lateral growth expansion of the continuous mat, (2) doming over pre-existing irregularities, (3) dome differentiation by greater sediment accretion on crests of domes, and (4) evolution of gases beneath mats.

Discrete, vertically stacked hemispheroids (SH) are algal domes formed by the vertical stacking of discrete hemispheroidical structures that are not laterally linked. Two types have been described: those with a constant base radius (SH-C), and those with a variable basal radius (SH-V). Constant basal radiuses are discrete structures formed of vertically stacked hemispheroids in which the upper hemispheroidal laminae overlap the base of the preceding ones without increasing the basal radius (Figure 2.2). Variable basal radii are discrete structures composed of vertically stacked hemispheroids in which the upper hemispheroidal laminae do not reach the base of the preceding ones (Figure 2.2). Discrete, vertically stacked hemispheroids are formed by successive algal laminae over pre-existing irregularities such as mud cracks, pre-existing algal domes, or erosional irregularities on intertidal surfaces. Vertical height is determined in Recent forms by the distance between the base of the structure and high-water level.

Spheroidal structures (SS) form by algal coating of an organism or lithic fragment instead of on a substrate. Three types of this spheroidal structure are recognized: (1) inverted stacked hemispheroid (SS-I), (2) concentrically stacked hemispheroids (SS-C),

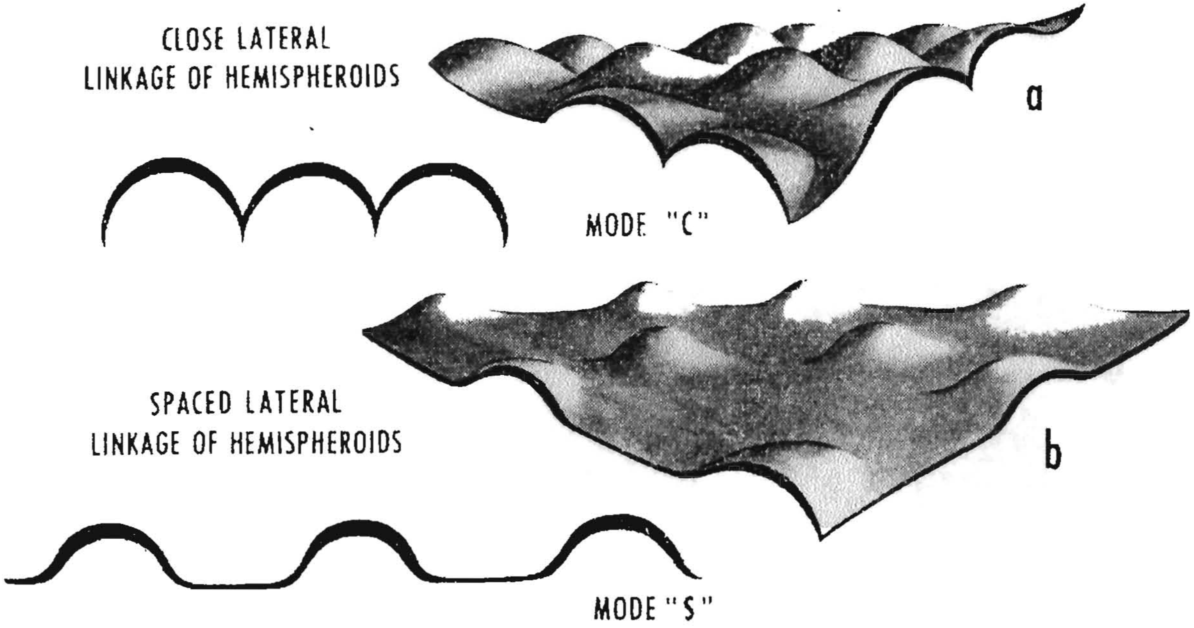


Figure 2.1 Laterally Linked Hemispheroid Stromatolites (from Logan et al., 1964).

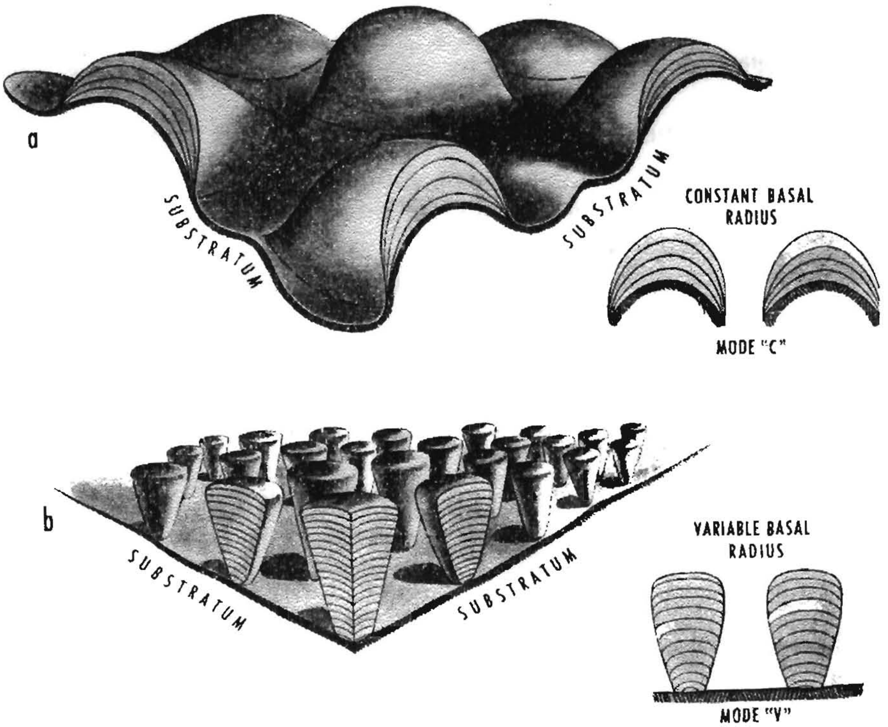


Figure 2.2 Discrete, Vertically Stacked Hemispheroid Stromatolites (from Logan et al, 1964).

and (3) randomly stacked hemispheroids (SS-R) (Figure 2.3). Structures of this type vary in size from a fraction of millimeters to centimeters in diameter.

The majority of algal stromatolites are composed of LLH and SH arrangements on both a macroscale and microscale. In describing structures that have both a macrostructure and a microstructure, the macrostructure is designated above the microstructure, e.g., SH/LLH. If a structure is both LLH and SH on a macroscale, the passage of one arrangement into another should be designated LLH-SH. If structural arrangement alternates, then the stromatolites may be designated as LLH-SH-LLH (Figure 2.4).

LLH structures mainly develop in protected intertidal mud flats such as re-entrant bays, and behind barrier island sand ridges where wave action is usually slight. SH structures develop within exposed intertidal headlands consisting of tidal waters or semipermanent tide pools. These environments have a number of different physical processes operating such as prolonged wetting, runoff, heavy sedimentation, and desiccation which prevents algal mats of the domes to transverse the intervening area between the domes.

SS structures are generally indicative of agitated, lower intertidal conditions. The prime requisite for the growth of SS structures is movement of the laminated bodies by waves and currents. SS-I structures are found today low in the intertidal zone and in shallow waters that are not greatly agitated. SS-R structures form in response to frequent agitation either low in the intertidal zone or in shallow water. The periods of agitation are separated by rather long intervals during which the structure is not moved. SS-C structures indicate more or less continual motion which results in the concentric growth.

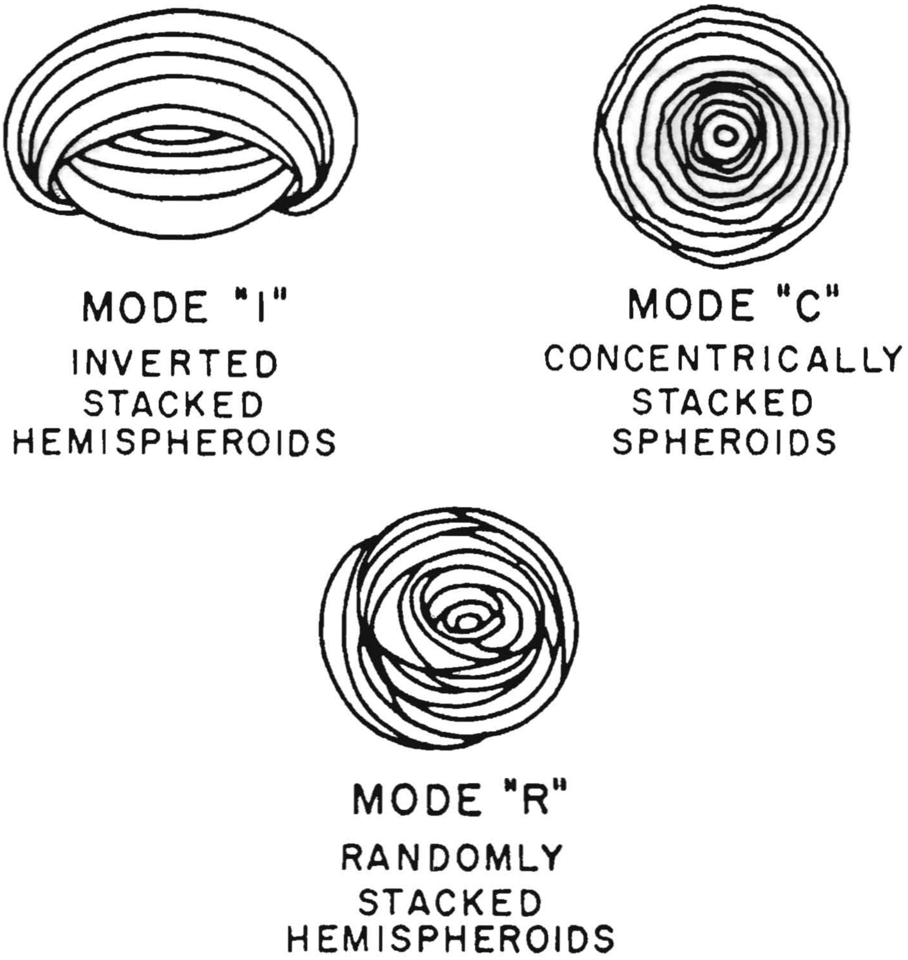
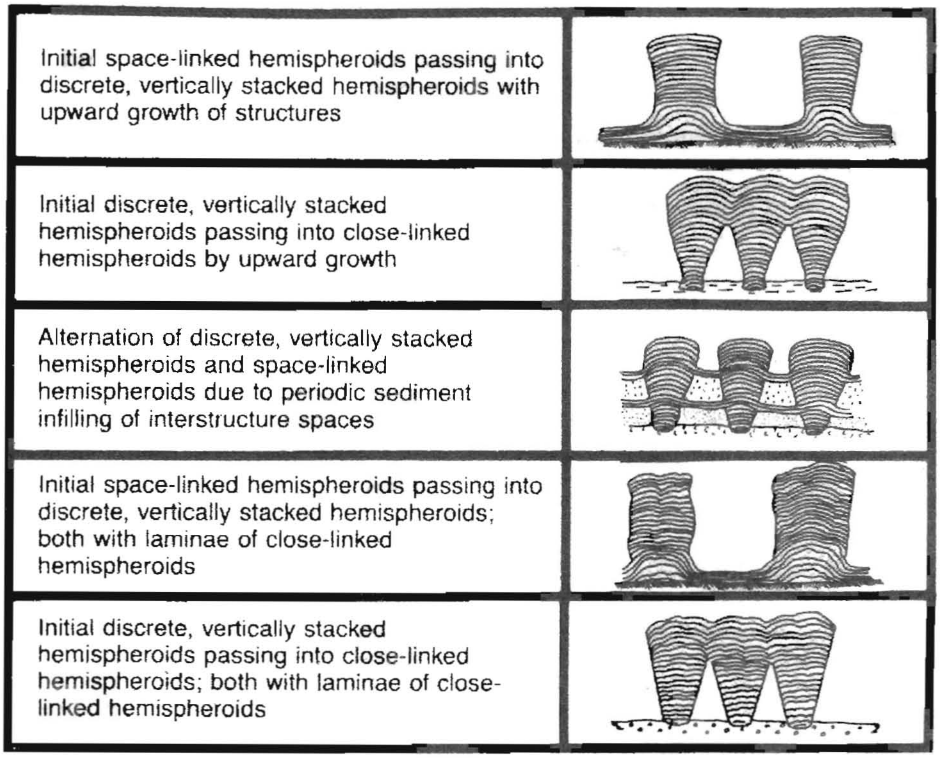


Figure 2.3 Spheroidal Structure Stromatolites in Cross-Section (from Logan et al, 1964).



Initial space-linked hemispheroids passing into discrete, vertically stacked hemispheroids with upward growth of structures

Initial discrete, vertically stacked hemispheroids passing into close-linked hemispheroids by upward growth

Alternation of discrete, vertically stacked hemispheroids and space-linked hemispheroids due to periodic sediment infilling of interstructure spaces

Initial space-linked hemispheroids passing into discrete, vertically stacked hemispheroids; both with laminae of close-linked hemispheroids

Initial discrete, vertically stacked hemispheroids passing into close-linked hemispheroids; both with laminae of close-linked hemispheroids

Figure 2.4 Composite Structure Stromatolites in Cross-Section (from Logan et al, 1964).

This type is probably restricted to areas continually under water and sufficiently agitated to permit almost continual motion of the structure. Compound structures represent either transitions in the environment, or environmental factors that control the growth of each type.

THROMBOLITES

Thrombolites are algal-like structures with mesoclots instead of laminations. Thrombolites were originally thought to be bioturbated stromatolites in which the laminae were disrupted to form the mesoclots, but are now interpreted as discrete colonies or growth forms of calcified, internally poorly differentiated, and coccoid dominated cyanobacteria communities by Kennard and James (1986). Their work was used for the description of thrombolite morphology used in this study.

Mesoclots range from millimeters to centimeters in diameter, and are separated by mud-to-sand-sized sediment. They display a variety of geometric shapes, from round to digitate. Mesoclots generally make up in excess of 40% of the volume of a thrombolite. Thrombolite external form is similar to that of stromatolites.

Thrombolites first appeared in the Early Cambrian, and were most abundant in Late Cambrian. After the Late Cambrian, thrombolites occur infrequently in the fossil record until they became extinct in the Late Jurassic. Their distribution appears to first have been controlled by the appearance of calcareous microbes, and the later radiation of grazing and bioturbating metazoans. They may have also declined due to niche competition from newly evolved reef builders, skeletal metazoans, and algae. Thrombolites do not occur in any carbonate environments today.

CHAPTER 3: RESULTS

ORGANISM IDENTIFICATION

Due to the recrystalization by calcite or aragonite that obliterates internal cellular structures, the identification of fossil algae is based on features associated with the outer walls of the thallus (Toomey, 1975). The primary feature for the identification of the red algae *Archaeolithophyllum* is the presence of the conceptacles, which are externally located on the thallus, thus allowing its preservation. Other genera of red algae also possess conceptacles, but the conceptacles are internally located within the thallus and are less likely to be preserved. Chlorophytes and cyanobacteria both lack conceptacles.

The presence of red algae, specifically *Archaeolithophyllum*, was documented in the Toronto Limestone by Toomey (1975). Of the seven samples prepared for this study, three showed external conceptacles, which are a diagnostic characteristic of *Archaeolithophyllum*. Samples TR-1, TR-5, and TR-7 all contain such conceptacles (Figure 3.1-3.2). The Hartford Limestone did display evidence of *Archaeolithophyllum*. Of the seven prepared samples, four (thin sections HT-1, 2, 3, and 7) showed external conceptacles (Figures 3.1-3.2). The Ervine Creek Limestone contains algal bioherms which have been attributed to green algae by Wray (1977). Examination of the samples (EC-2, 5, and 6) showed the presence of external conceptacles (Figures 3.1 and 3.2) which would signify *Archaeolithophyllum*. Measurements of conceptacle size were made along the greatest width and height of the conceptacles.

Figure 3.1 Preserved Conceptacle at 100X Magnification in Cross-Section.

Figure 3.2 Pair of Preserved Conceptacles at 100X Magnification in Cross-Section.

Table 3.1 Size Range of Toronto Limestone Conceptacles (in micrometers)

SAMPLE NUMBER	WIDTH X HEIGHT	SLIDE NUMBER
1	16 X 7	TR-1
2	16 X 8	TR-7
3	17 X 8	TR-7
4	35 X 15	TR-5
Mean	21 X 10	-------

Table 3.2 Size Range of Hartford Limestone Conceptacles (in micrometers)

SAMPLE NUMBER	WIDTH X HEIGHT	SLIDE NUMBER
1	22 X 9	HT-7
2	23 X 9	HT-2
3	35 X 17	HT-1
4	36 X 14	HT-3
5	36 X 17	HT-1
Mean	30 X 13	-------

Table 3.3 Size Range of Ervine Creek Limestone Conceptacles (in micrometers)

SAMPLE NUMBER	WIDTH X HEIGHT	SLIDE NUMBER
1	9 X 6	EC-2
2	21 X 12	EC-6
3	30 X 8	EC-5
4	35 X 12	EC-6
5	35 X 18	EC-2
Mean	26 X 11	--------

STROMATOLITIC MORPHOLOGY

Analysis of stromatolite morphology was conducted on slab faces in cross-sectional view. Descriptions of morphology follow the systematics of Logan *et al.* (1964). Measurements of spheroidal-structure stromatolites were done along the longest axis of the stromatolite, and then the short axis was measured perpendicular to the longest. Measurements of the laterally linked and the discrete hemispheroid stromatolites were accomplished by measuring the greatest width and height of individual hemisperoids, and the minimum distance to the next closest hemispheroid.

The stromatolitic morphology in the Toronto Limestone is only of spheroidal structures (SS) (Table 3.4) (Figures 3.3 and 3.4). The stromatolites are oval-to-round in shape and range in size from four by two mm to 50 by 48 mm (Table 3.7). The laminae are mostly continuous around the nucleus. The laminar beds which cover the nucleus range

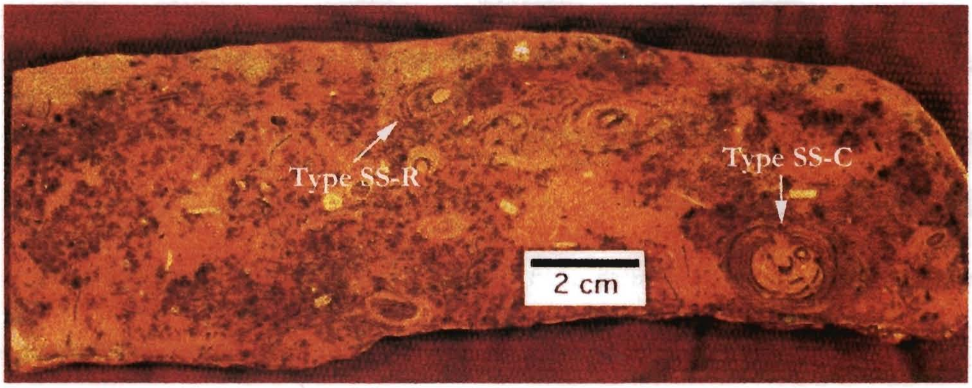


Figure 3.3 Spheroidal Structure Stromatolites of the Toronto Limestone in Cross-Section.

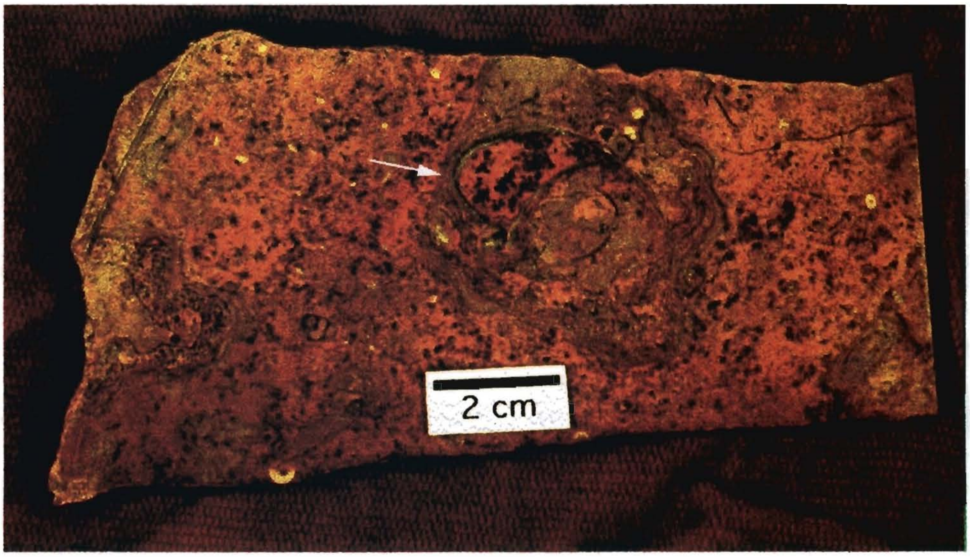


Figure 3.4 Spheroidal Structure Stromatolite of the Toronto Limestone in Cross-Section.

from one to eight mm in total thickness. The nuclei of the stromatolites consist of shell fragments and silt grains.

The stromatolitic morphology of the Plattsmouth Limestone is only of spheroidal structures (SS), (Table 3.4), (Figures 3.5 and 3.6). The stromatolites are oval to irregular in shape. They vary in size from eight by eight mm to 31 by 18 mm (Table 3.6). The lamina bed which covers the nucleus ranges from five to nine mm in thickness, and are mostly continuous around the nuclei. The nuclei are composed of fragmented shells.

The stromatolitic morphology in the Beil Limestone is only of the laterally linked hemispheroid structural form (Table 3.4). The hemispheroids are spaced approximately one to 19 mm apart, so they are classified as spaced lateral linked hemispheroids (LLH) (Figures 3.7 and 3.8). The stromatolite hemispheroids range from three to 14 mm in width and one to six mm in height (Table 3.9). They appear very wavey and disrupted.

The stromatolitic morphology in the Ervine Creek Limestone is only of the vertically stacked hemispheroids with space-linked hemispheroids (SH), (Table 3.4), (Figures 3.9 and 3.10). The hemisperoids height is from five to 61 mm and the width is from 11 to 39 mm (Table 3.8). The distance between hemispheroids ranges from two to 25 mm. These stromatolites are linear in their arrangement.

The stromatolitic morphology preserved in the Hartford Limestone is only of spheroidal structures (SS), (Table 3.4), (Figures 3.11 and 3.12). These stromatolites range from five by four mm to 43 by 22 mm (Table 3.5). The lamina layers range from one to 22 mm in thickness. The layers often appear disrupted. The nuclei are shell fragments

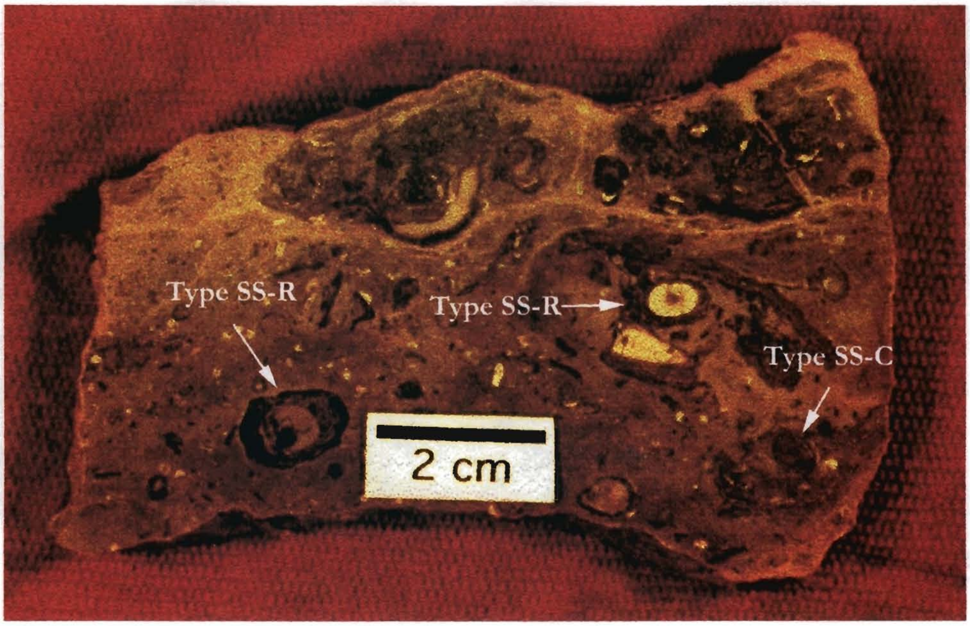


Figure 3.5 Spheroidal Structure Stromatolites of the Plattsmouth Limestone in Cross-Section.

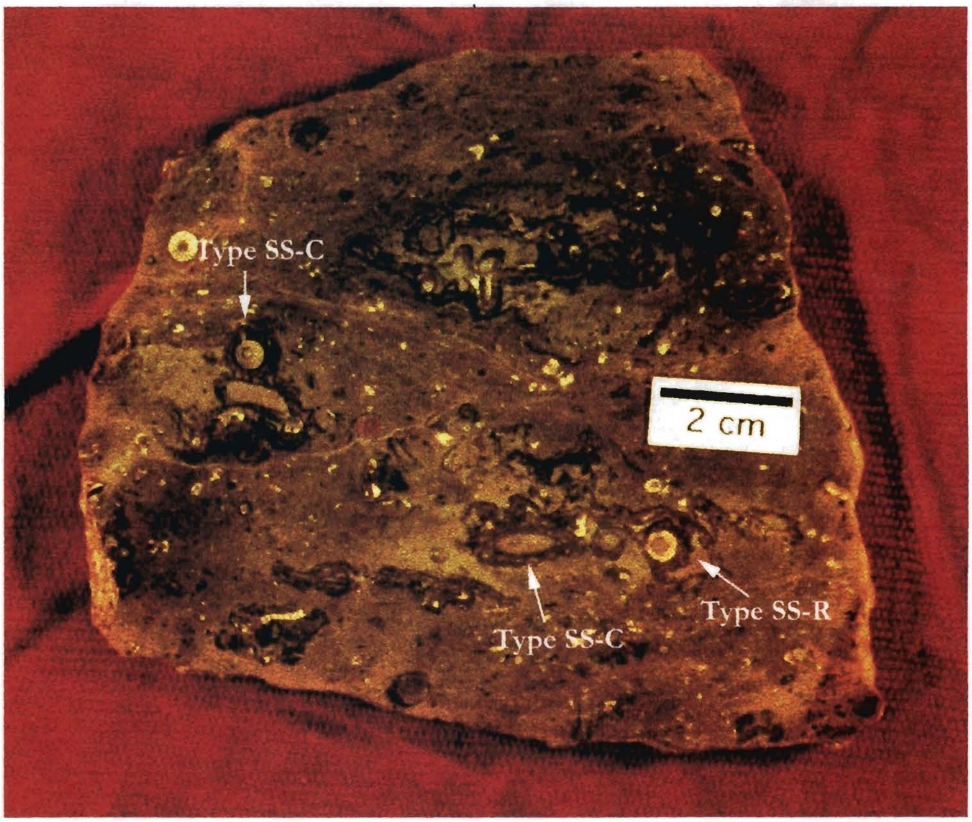


Figure 3.6 Spheroidal Structure Stromatolites of the Plattsmouth Limestone in Cross-Section.

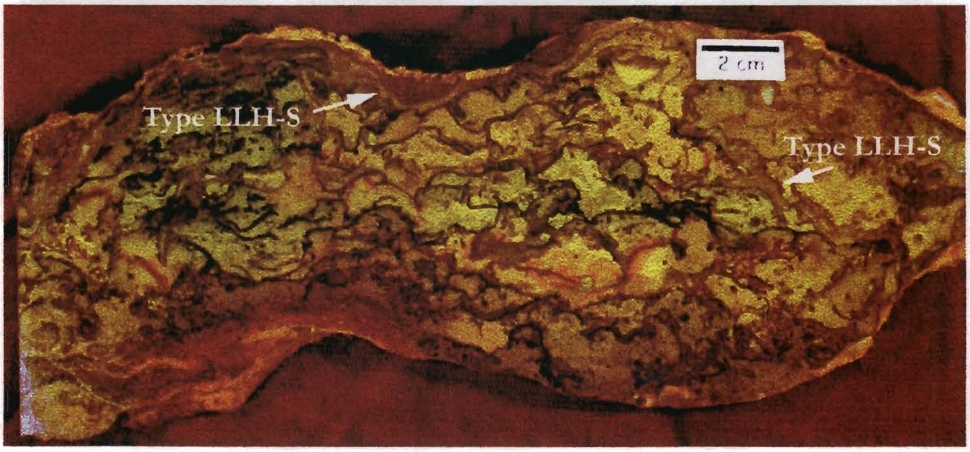


Figure 3.7 Laterally Linked Hemispheroid Stromatolites of the Beil Limestone in Cross-Section.

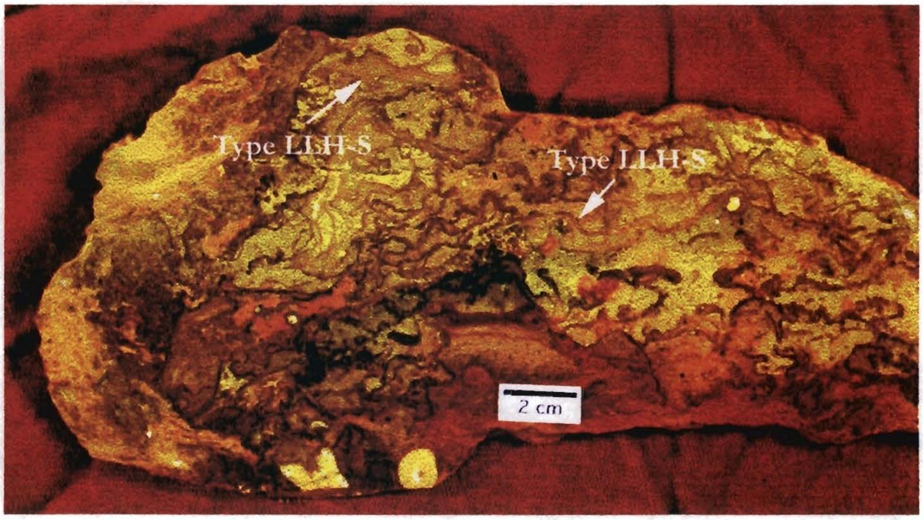


Figure 3.8 Laterally Linked Hemispheroid Stromatolites of the Beil Limestone in Cross-Section.

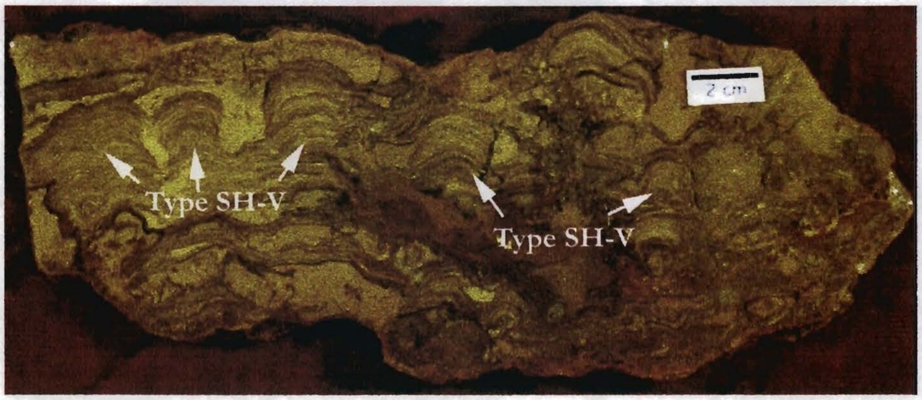


Figure 3.9 Vertically Stacked Hemispheroid Stromatolites of the Ervine Creek Limestone in Cross-Section.

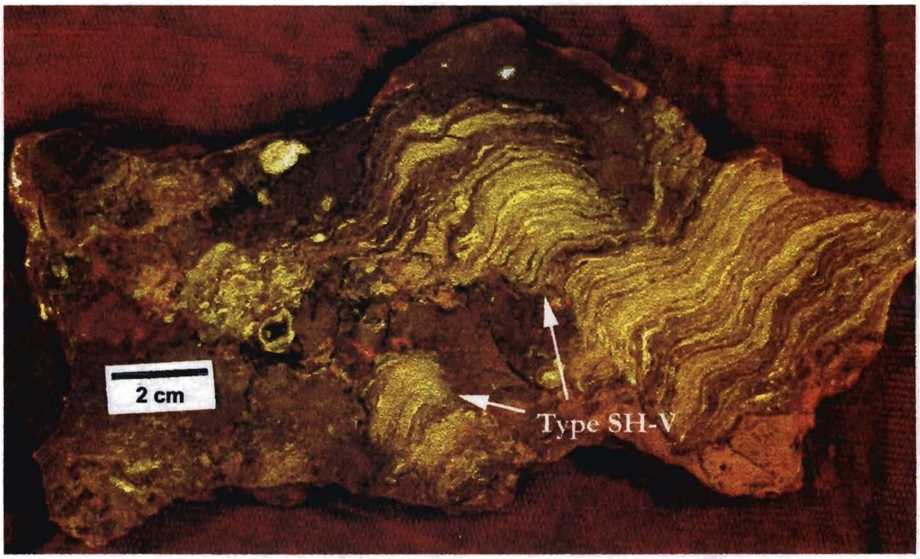


Figure 3.10 Vertically Stacked Hemispheroid Stromatolites of the Ervine Creek Limestone in Cross-Section.

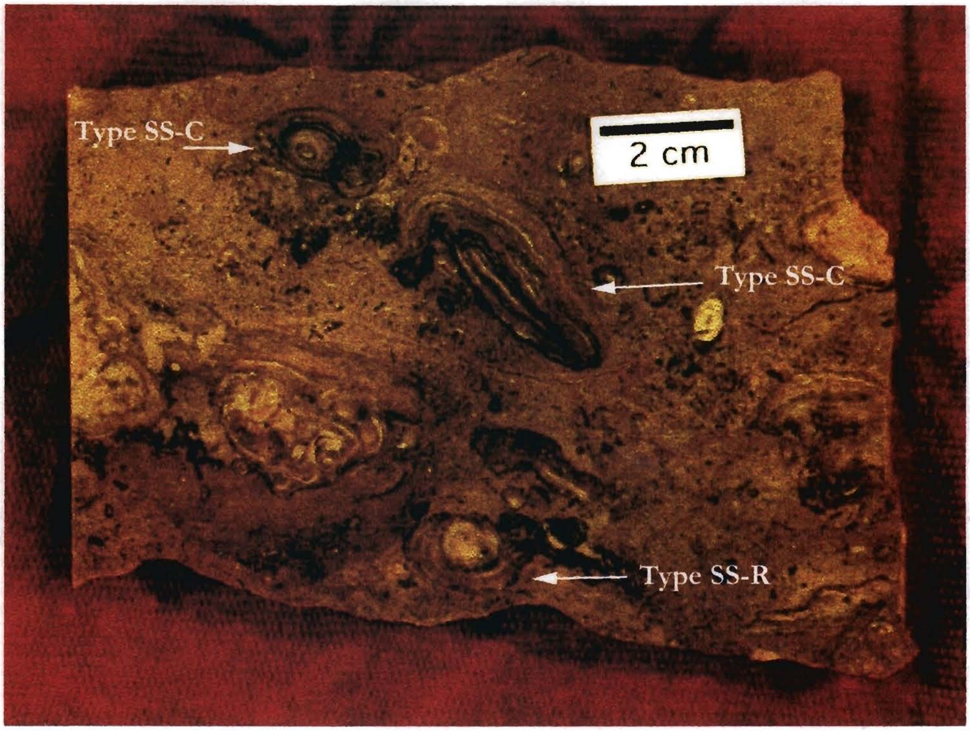


Figure 3.11 Spheroidal Structure Stromatolite of the Hartford Limestone in Cross-Section.

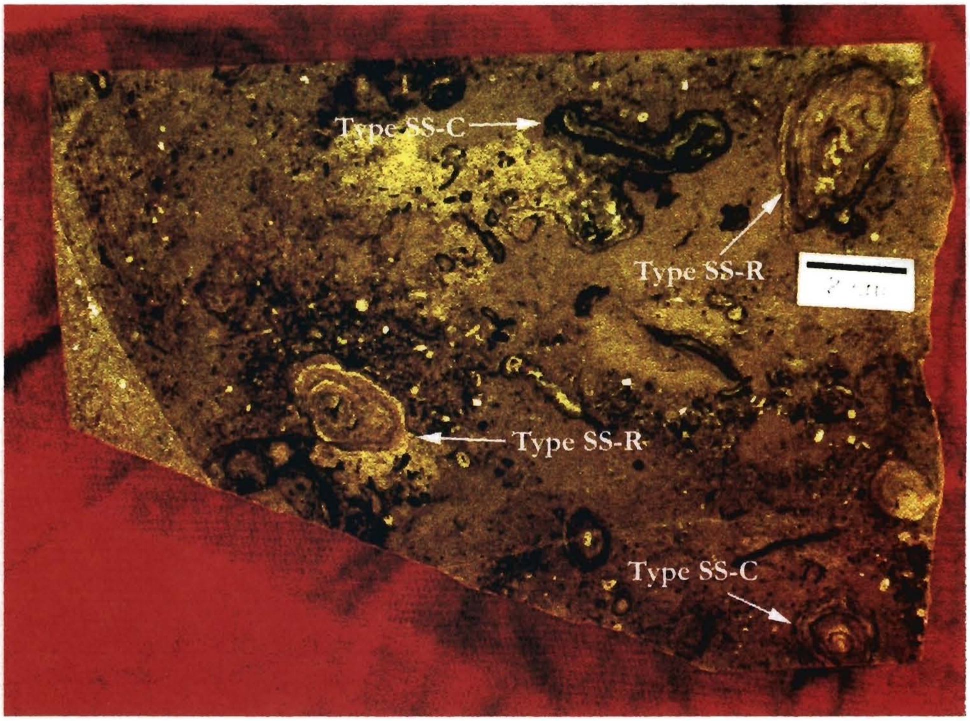


Figure 3.12 Spheroidal Structure Stromatolite of the Hartford Limestone in Cross-Section.

Table 3.4 Numerical Count of Stromatolitic Morphologies from Slabs

	HARTFORD	ERVINE CREEK	BEIL	PLATTSMOUTH	TORONTO
LLH-C	0	0	0	0	0
LLH-S	0	0	11	0	0
SH-C	0	6	0	0	0
SH-V	0	9	0	0	0
SS-I	0	0	0	0	0
SS-C	8	0	0	6	11
SS-R	16	0	0	14	10
Total	24	15	11	20	21

Table 3.5 Size Range of Hartford Limestone Spheroidal Stromatolites from Slabs (in mm)

SAMPLE NUMBER	LENGTH X WIDTH	STROM. NUMBER	SAMPLE NUMBER	LENGTH X WIDTH	STROM. NUMBER
1	5 X 4	HT-97-1-1.6	14	22 X 12	HT-97-1-3.1
2	6 X 4	HT-97-1-5.1	15	22 X 12	HT-97-2-2.2
3	9 X 6	HT-97-1-1.4	16	22 X 18	HT-97-2-2.1
4	12 X 8	HT-97-1-1.1	17	23 X 9	HT-97-1-4.2
5	13 X 4	HT-97-1-3.3	18	23 X 14	HT-97-1-2.5
6	13 X 12	HT-97-1-3.2	19	24 X 8	HT-97-1-2.2
7	15 X 4	HT-97-1-5.2	20	30 X 12	HT-97-2-1.2
8	18 X 16	HT-97-1-1.2	21	35 X 34	HT-97-2-1.1
9	19 X 7	HT-97-1-4.1	22	40 X 15	HT-97-1-2.1
10	19 X 12	HT-97-1-2.4	23	42 X 26	HT-97-1-6.1
11	20 X 13	HT-97-1-2.3	24	43 X 22	HT-97-1-1.3
12	21 X 16	HT-97-1-1.5	Mean 22 X 12		
13	22 X 3	HT-97-1-1.7			

Table 3.6 Size Range of Plattsmouth Limestone
Spheroidal Stromatolites from Slabs (in mm)

SAMPLE NUMBER	LENGTH X WIDTH	STROM. NUMBER	SAMPLE NUMBER	LENGTH X WIDTH	STROM. NUMBER
1	8 X 8	PL-97-1-3.5	12	19 X 6	PL-97-1-4.4
2	9 X 8	PL-97-1-4.3	13	19 X 8	PL-97-1-5.1
3	9 X 9	PL-97-1-3.1	14	19 X 9	PL-97-1-3.3
4	12 X 6	PL-97-1-1.2	15	19 X 12	PL-97-1-2.3
5	12 X 10	PL-97-1-2.2	16	19 X 14	PL-97-1-5.4
6	13 X 7	PL-97-1-5.3	17	20 X 9	PL-97-1-2.4
7	14 X 5	PL-97-1-2.1	18	20 X 19	PL-97-1-4.2
8	14 X 11	PL-97-1-1.1	19	22 X 4	PL-97-1-3.4
9	15 X 6	PL-97-1-3.2	20	31 X 18	PL-97-1-5.2
10	16 X 4	PL-97-1-4.1	Mean		
11	16 X 11	PL-97-1-1.3	16 X 9		

Table 3.7 Size Range of Toronto Limestone Spheroidal Stromatolites from Slabs (in mm)

SAMPLE NUMBER	LENGTH X WIDTH	STROM. NUMBER	SAMPLE NUMBER	LENGTH X WIDTH	STROM. NUMBER
1	4 X 2	TR-97-1-2.7	12	16 X 6	TR-97-1-7.1
2	4 X 3	TR-97-1-6.2	13	17 X 14	TR-97-1-3.2
3	6 X 3	TR-97-1-5.4	14	18 X 9	TR-97-1-2.5
4	6 X 5	TR-97-1-2.4	15	22 X 13	TR-97-1-5.1
5	6 X 6	TR-97-1-2.3	16	25 X 21	TR-97-1-2.6
6	9 X 6	TR-97-1-7.2	17	31 X 12	TR-97-1-2.2
7	10 X 6	TR-97-1-5.2	18	35 X 22	TR-97-1-4.1
8	13 X 9	TR-97-1-2.1	19	38 X 12	TR-97-1-3.1
9	14 X 3	TR-97-1-1.2	20	41 X 25	TR-97-1-1.1
10	15 X 6	TR-97-1-6.1	21	50 X 48	TR-97-1-6.3
11	16 X 5	TR-97-1-5.3	Mean 19 X 11		

Table 3.8 Size Range of Ervine Creek Limestone Discrete Columnar Stromatolites from Slabs (in mm)

SAMPLE NUMBER	WIDTH	HEIGHT	BETWEEN HEMISPHEROIDS	STROMATOLITE NUMBER
1	11	9	11	EC-97-1-1.6
2	12	5	9	EC-97-1-5.1
3	13	6	11	EC-97-1-1.5
4	14	6	3	EC-97-1-4.2
5	15	5	3	EC-97-1-4.1
6	16	15	21	EC-97-1-3.1
7	21	23	21	EC-97-1-3.2
8	22	6	9	EC-97-1-5.2
9	22	19	2	EC-97-1-1.2
10	23	15	15	EC-97-1-1.4
11	23	32	21	EC-97-1-2.1
12	25	21	11	EC-97-1-1.3
13	34	23	25	EC-97-1-3.3
14	35	24	2	EC-97-1-1.1
15	39	61	21	EC-97-1-2.2
Mean	22	18	12	--------------

Table 3.9 Size Range of Beil Limestone Laterally Linked Stromatolites from Slabs (in mm)

SAMPLE NUMBER	WIDTH	HEIGHT	BETWEEN HEMISPHEROIDS	STROMATOLITE NUMBER
1	3	1	1	BE-97-1-1.4
2	4	2	2	BE-97-1-1.2
3	5	2	2	BE-97-1-1.1
4	6	3	1	BE-97-1-1.3
5	6	3	2	BE-97-1-2.2
6	6	4	4	BE-97-1-3.3
7	8	3	4	BE-97-1-3.2
8	9	4	2	BE-97-1-2.1
9	9	4	11	BE-97-1-2.4
10	11	6	19	BE-97-1-3.1
11	14	5	11	BE-97-1-2.3
Mean	7	3	5	----------------

CHAPTER 4: DISCUSSION AND CONCLUSIONS

DISCUSSION

Some of the stromatolites from the Shawnee Group that were examined in this study contain the red algae *Archaeolithophyllum*. The criterion used for the identification of *Archaeolithophyllum* is the presence of externally located conceptacles. The subconical chambers representing conceptacles are present in stromatolites from the Hartford, Ervine Creek, and Toronto limestones. None of the stromatolites examined in the Beil and Plattsmouth limestones showed diagnostic features to distinguish which algal or bacterial groups formed the stromatolites. Unfortunately, the absence of such diagnostic features means that the presence of red algae in the latter two members cannot be confirmed.

Recent studies by Reid and MacIntyre (1988), Toomey (1975), and Bosellini and Ginsburg (1971) have shown that spheroidal algal structures typically become smaller in diameter and more irregular in shape as the water depth of formation increases. Reid and MacIntyre state that the spheroidal algal structures collected from a shelf environment (less than 60 m depth) have diameters ranging from 20 to 150 mm. Spheroidal algal structures collected from the slope environment (60 to 200 m depth) typically have diameters ranging from 20 to 40 mm. Studies by Logan *et al.* (1964) have shown that discrete, vertically stacked hemispheroid stromatolites will attain a height equal to the distance between the substrate and the high-water level.

Brasier (1980) showed that red algae are typically found in the fore-reef, reef, and back-reef environments. The Codiaceae and Dasycladaceae (families of the green algae) exist from the back-reef environment to the tidal-flat environment. Cyanobacteria occur predominantly from shallow lagoon to tidal-flat environments.

TORONTO LIMESTONE

Samples from the Toronto Limestone contain only spherical stromatolites. The spheroidal structures are about equally divided between the randomly stacked spheroids (48%) and the concentrically stacked spheroids (52%) (Table 3.4). The average size of these stromatolites is 19 mm by 11 mm (Table 3.7). The red algae *Archaeolithophyllum* was identified in three out of the seven samples (Table 3.1). Modern, randomly stacked spheroids form in response to agitation within the water. The randomly stacked spheroids indicate periods of agitation which are separated by intervals when the structure is not moved (Logan *et al.*, 1964). The concentrically stacked spheroids indicate more or less continual motion while being completely submerged (Logan *et al.*, 1964). The relative small size of the stromatolites possibly indicates a deeper environment of formation or short time span for the existence of the environment. The elliptical shape of the stromatolite also indicates periods of non-movement. The combination of the two types of rolled structures in the Toronto Limestone shows a transition from continual agitation to sporadic agitation. These stromatolites probably existed on the back of a reef complex in a lagoonal environment. Continuous agitation by currents would occur when the water level exceeded the reef complex. As the water level decreased as the sea receded, currents producing agitation would become dependant on periods of high water. Periods of low water would account for the elliptical nature of the stromatolites. Lower water levels would not receive tide or storm waves to overturn the stromatolites so frequently, thus leading to preferential growth on one side to form an elliptical shape. The small size of the stromatolites is probably due to the short amount of time the lagoon contained sufficient water for the stromatolite formation. The stromatolites need to be submerged in water for their continual growth. If the water level becomes too shallow with the outflow of water (evaporation) exceeding the inflow (storm surges, high tide) of water into the lagoonal environment, the stromatolites will not achieve a large size.

PLATTSMOUTH LIMESTONE

The Plattsmouth Limestone stromatolites are also only of spheroidal structures. The randomly stacked spheroids are in greatest number (70%) while the concentrically stacked hemispheroids make up the rest (30%) (Table 3.4). The Plattsmouth stromatolites average 16 mm by 9 mm (Table 3.6). The red algae *Archaeolithophyllum* was not positively identified in the samples collected. The rolled structures of the Plattsmouth Limestone possibly represent a shallow, subtidal environment (Logan *et al.*, 1964). These stromatolites, like the Toronto stromatolites, show evidence of periods with little or no agitation in their environment of formation. The location of Plattsmouth stromatolite formation in the lagoonal environment is not so certain without the identification of *Archaeolithophyllum*.

BEIL LIMESTONE

All of the stromatolites of the Beil Limestone are spaced laterally linked hemispheroids with a large amount of mud matrix (Table 3.4). Red algae were not confirmed in the samples collected from the Beil Limestone. The Beil stromatolites are broken into smaller mat structures and distorted greatly. The mats probably formed on mud-flats protected by a reef complex. The greater turbulence needed to disrupt the mats may have been caused by abnormally high run-off currents from the terrestrial environment. This would account for the high quantity of mud matrix. These mats may have also experienced periods of desiccation and cracking during low tides, thus forming the smaller fragments that were identified (Logan *et al.*, 1964). This inferred desiccation could have occurred in a mud-flat environment.

ERVINE CREEK LIMESTONE

Stromatolites of the Ervine Creek Limestone are only of the discrete, vertically stacked hemispheroidal type. These hemispheroids show both variable basal radii (60%) and constant basal radii (40%) (Table 3.4). *Archaeolithophyllum* was present in three of the seven samples taken from the Ervine Creek member (Table 3.3). The presence of the red algae *Archaeolithophyllum* may indicate a reef environment (Brasier, 1980). Discrete, vertically stacked hemispheroid stromatolites act as an efficient baffling system of water currents (Merriam, 1986). This baffling of water allows sediments to settle out quickly. The algae use the trapped sediments as new substrates on which to build (Merriam, 1986). The vertical height of the Ervine Creek stromatolites is on the average of 22 mm (Table 3.8). Because the height of these stromatolites is restricted to the maximum level of high water, they probably formed in a shallow water environment with high water energy, such as a pre-existing reef complex. Their formation on a pre-existing reef complex would permit them to stay within the photic zone, and they would receive ample sediments as seawater flowed over the reef.

HARTFORD LIMESTONE

All of the Hartford Limestone stromatolites are spheroidal structures, with the majority being randomly stacked spheroids (67%) and the rest being concentrically stacked spheroids (33%) (Table 3.4). *Archaeolithophyllum* was found in four of the seven samples taken from the Hartford Limestone (Table 3.2). The randomly stacked spheroids form in response to frequent periods of agitation separated by rather long intervals during which time the structure is not moved (Logan *et al.*, 1964). The average size of these stromatolites is 21 mm by 12 mm (Table 3.5), and they are elliptical in shape. The Hartford stromatolites formed in a similar fashion to those of the Toronto Limestone.

CONCLUSIONS

SIGNIFICANCE OF RESULTS

The spheroidal stromatolites (including oncolites and rhodoliths) are known to be formed by cyanobacteria and red algae. The laterally linked hemispheroid stromatolites (mat like) are formed by cyanobacteria and green algae. Discrete, vertically stacked hemispheroid stromatolites are only known to be formed by cyanobacteria.

The identification of the red algal rhodoliths (spheroidal structures) in the Toronto Limestone confirmed the published work of Toomey (1975). Red algal rhodoliths are documented for the first time in the Hartford Limestone, thus confirming Lanier's hypothesis. Biogenic structures of trapped sediment layers and red algae filaments arranged in vertically stacked hemispheroid structures were discovered. These stromatolitic structures were primarily unknown for red algae. Therefore, this study is the first documentation of discrete columnar stromatolites formed by red algae.

FUTURE RESEARCH

In this study transmitted polarized light was used for the examination of thin sections of limestone from the Shawnee Group. Another type of microscopy is cathodoluminescence. Cathodoluminescence directs the focused beam of a scanning electron microscope over a sample (plan view or cross-section), and excites luminescence from the sample, which is subsequently detected with a variety of monochromator/detector combinations. Cathodoluminescence readily reveals the nonluminescent skeleton of the algae, which contrasts sharply with the bright luminescent calcite cements that fill the skeletal cells (Moshier and Kirkland, 1993). The skeletal structures are rarely apparent when viewed in transmitted polarized light, so cathodoluminescence could be used in future studies of algal bioherms from the Shawnee Group.

The Ervine Creek member of the Deer Creek Limestone in the Shawnee Group is unique because it is shown to contain red algae, green algae, and cyanobacteria. The Ervine Creek member should be considered for additional bioherm studies. Biomass studies of the three organisms would show how much each microorganism is responsible for the formation of the bioherm. The study may include if the organisms co-exist, or is there a succession from one microorganism to another. It could indicate whether one microorganism survives better at a given depth or light level than another.

The primary sedimentary data of the studied limestones should be collected to continue the study of the environment of deposition. The sedimentological data may be correlated with the algal data to construct models of the environment.

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Bioherms of the Shawnee Group
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of Eastern Kansas

Title of Thesis

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