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Fossil algae in the St. Louis limestone, near St. Louis, Missouri

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FOSSIL ALGAE IN THE ST. LOUIS LIMESTONE,

NEAR ST. LOUIS, MISSOURI

BY

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ABSTRACT

Although Mississippian algae research is fairly extensive, little has been published on algae from the Mississippian type locality, the Upper Mississippi River Valley. For this study, portions of sixteen St. Louis Limestone stratigraphic sections containing units with oncolites, domal stromatolites, laminations, or mottled (possibly algal) textures, were measured, described, and sampled to determine: (1) to what extent algae are preserved in the St. Louis Limestone, (2) if enough of the delicate structure was fossilized to determine morphology, (3) depositional environment of the algae, and (4) if the algae are related to a lithologic pattern. Thin sections of the sampled units were described and studied for calcareous algae types and environments of deposition of both units and algae.

The author found fragments of calcareous algae belonging to four genera, *Koninckopora, Crtonella, Girvanella,* and *Pseudohedstroemia,* as well as several unidentifiable types. Green algae fragments were more abundant in beds of intertidal and subtidal origin than in beds of supratidal origin. Beds with blue-green algae fragments were of high energy, intertidal to upper subtidal origin, while cryptalgal beds in which the presence of blue-green algae is inferred, were of supratidal to subtidal origin. The algal and oncolitic beds were not deposited in a particular

lithologic sequence, but they are related to environmental conditions at the time of deposition. Several algal and oncolitic beds were associated with dolomite, which suggests the beds provided a porous pathway for dolomitizing waters.

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INTRODUCTION

Algae are predominantly a group of chlorophyll-producing, aquatic plants with a unicellular or a multicellular structure. Most live in the ocean, but many algae species are brackish and fresh water types. Requiring strong sunlight for optimum growth, algae flourish in clear, shallow, warm water with fair circulation, but without strong currents.

Algae may be either calcareous or noncalcareous. Calcareous algae secrete calcium carbonate skeletons, and thus are more easily preserved than noncalcareous nonskeletal algae. Generally, fossilized skeletal algae correspond to living algae and accordingly are given a binomial name. Classification of the older forms is more difficult, however, due to morphological differences between fossilized and Recent genera (Johnson, 1961). To geologists, blue-green algae are the only important noncalcareous fossil algae. The sediment-binding and trapping action of nonskeletal blue-green algae forms laminated calcareous sedimentary structures, algal stromatolites. Stromatolites have been classified on a biological basis, but classifications based on their geometry are now being used. Logan et al. (1964) assign letter abbreviations to three main forms: (1) laterally linked hemispheroids (LLH), (2) vertically stacked hemispheroids (SH), and (3) spheroidal structures (SS). Generally, oncolites, algal balls, are considered to be a type of unattached, spheroidal stromatolite, while planar laminated structures are called algal-laminated sediments (Wray, 1977), or cryptalgalaminate carbonates (Aitken, 1967).

Classification of Algae

Algae are grouped into divisions (considered to be phyla by some botanists and classes by others) according to their color: red, green, blue-green, or brown. Although the systems of classification vary, most major divisions are similar. The classification shown in Table I is from J. Harlan Johnson's Mississippian algae study (1956). The red and green algae are classified similarly to their Recent counterparts, while the simpler forms not comparable to living algae are classified on the basis of preserved structures. Because delicate structures are easily destroyed, algae are often erroneously grouped.

Importance of Algae

To geologists, algae are an important fossil group. They are among the oldest known fossils and occur in rocks from Precambrian to Recent in age. They are also important as limestone builders, especially of carbonate reefs. Because of the high porosity and permeability of carbonate reefs and algal buildups, they may serve as host rocks for oil and mineral deposits. Furthermore, taxa with a narrow stratigraphic range are good for dating and correlating units, and taxa with limited tolerances are good

TABLE I

CLASSIFICATION OF MISSISSIPPIAN ALGAE
(FROM J.H. JOHNSON, 1956)

Division	Family	Characteristic Structures
Rhodophyta (red algae)	Solenoporaceae	Rows of closely packed cells with polygonal cross section. Cross partitions present though frequently very thin.
Phaeophyta (brown algae)	Laminariales and others?	Corded strands of parallel threads. Fronded types.
Chlorophyta (green algae)	Codiaceae	Small tubes loosely arranged so as to form segmented stems. Tubes round in cross section and branching.
	Dasycladaceae	A central stalk, preserved as a tube or bulb, surrounded by tufts of leaves or leaf bases, preserved as knobs or brush like protuberances.
Charophyta (green algae)	Trochiliscaceae	Oogonia show 7 to 10 dextrally spiralled enveloping cells.
	Sycidiaceae	Oogonia show 16-20 vertical units.
Chlorophyta or possibly Cyanophyta	Porostromata	Small tubes so loosely arranged as not to compress each other. No cross partitions visible.
Cyanophyta (blue-green algae)	Spongiostromata	Cellular structure seldom preserved. The $CaCO_3$ is deposited as crusts on the outside of the colony or cell, or between the tissues, not in the cell wall. Classified on the basis of growth habit and form of the colony.

environmental indicators.

Previous Works

Geologists have studied and written much more about calcareous algae than noncalcareous algae since they are more easily preserved. Papers on this fossil group number in the thousands, and most of these are in languages other than English. A bibliography only of Carboniferous calcareous algae, compiled by the author, contains over 600 references. Yet, with all the studies that have been made, fossil algae is not well understood.

Three papers, one by J.H. Johnson (1946), the second by C.L. Bieber (1966), and the third by B.L. Mamet and A. Roux (1978), relate directly to fossil algae in the St. Louis Limestone. J.H. Johnson studied algal limestones in the St. Louis, Missouri area from what he believed to be the base of the Ste. Genevieve Formation, but which is probably the top of the St. Louis Limestone. He divided the algal limestones into two types: (1) pellet limestones (oncolitic), and (2) massive, mottled limestones. Type 1 is composed of "rounded, irregular, algal colonies embedded in a fine ground mass", while Type 2 contains "dark, irregularly rounded, finger-shaped or stag horn-like algal colonies closely packed together in a light, sandy-textured ground-mass." Johnson recognized eight algae varieties in the St. Louis Limestone. Two were taxonomically designated, *Girvanella maplewoodensis* and *Ortonella kershopensis*. The others were listed and described as varieties one through six. Finally, he characterized algal limestone depositional environments. Bieber described algal nodules from the lower and middle St. Louis Limestone of the Putnam County area in western Indiana. Fossilized tube-like structures were attributed to three calcareous algae genera: *Ortonella, Garwoodia,* and *Solenopora*. He mentioned other algal-like fossils, and outlined nine environmental conditions requisite for the growth of algae. Mamet and Roux taxonomically described algal types from a Tennessee borehole. The core was middle Mississippian in age, equivalent to the Namurian and Visean stages in Europe, and included the St. Louis Limestone section. Five new algae genera and 13 new algae species were erected with 27 taxa illustrated. The authors concluded the algae were abundant but not diversified.

Statement of the Problem

Although Mississippian algae research is fairly extensive, most studies were conducted outside the United States. Of United States investigations, the brief report by J.H. Johnson on algae in the St. Louis Limestone is at this time the only published paper on algae from the Mississippian System type locality, the Upper Mississippi River Valley.

The St. Louis Limestone sediments were deposited in a warm, shallow sea suitable for algal growth. Therefore, the purpose of this study is to determine: (1) to what extent algae are preserved in the St. Louis Limestone, (2) if enough of the delicate structure was fossilized to determine morphology, (3) depositional environment of the algae, and (4) if the algae are related to a lithologic pattern.

Procedure

Dr. A.C. Spreng has studied the St. Louis Limestone for several years. Certain portions of several of his stratigraphic sections were chosen for this algae study. The selected sections contain units with (1) oncolites, (2) domal stromatolites, (3) laminations (possibly planar stromatolites), or (4) mottled (possibly algal) limestones. The algal units, as well as the beds which lie immediately above and below, were studied. Sixteen stratigraphic sections, in quarries and roadcuts, were measured, described, and sampled in the St. Louis area in Missouri and Illinois. An index map of the study area showing locations of the measured stratigraphic sections appears in Figure 1. The measured stratigraphic sections next to their assigned thesis letter (A, B, C, etc.) and their locations either by street, or by section, township, range, county, and quadrangle, are listed in Table II. Many of the land-plat sections in the St. Louis area are odd sizes and shapes, so for ease in indicating stratigraphic section localities, some of the more regular section lines were extended into the confused area to form one mile squares

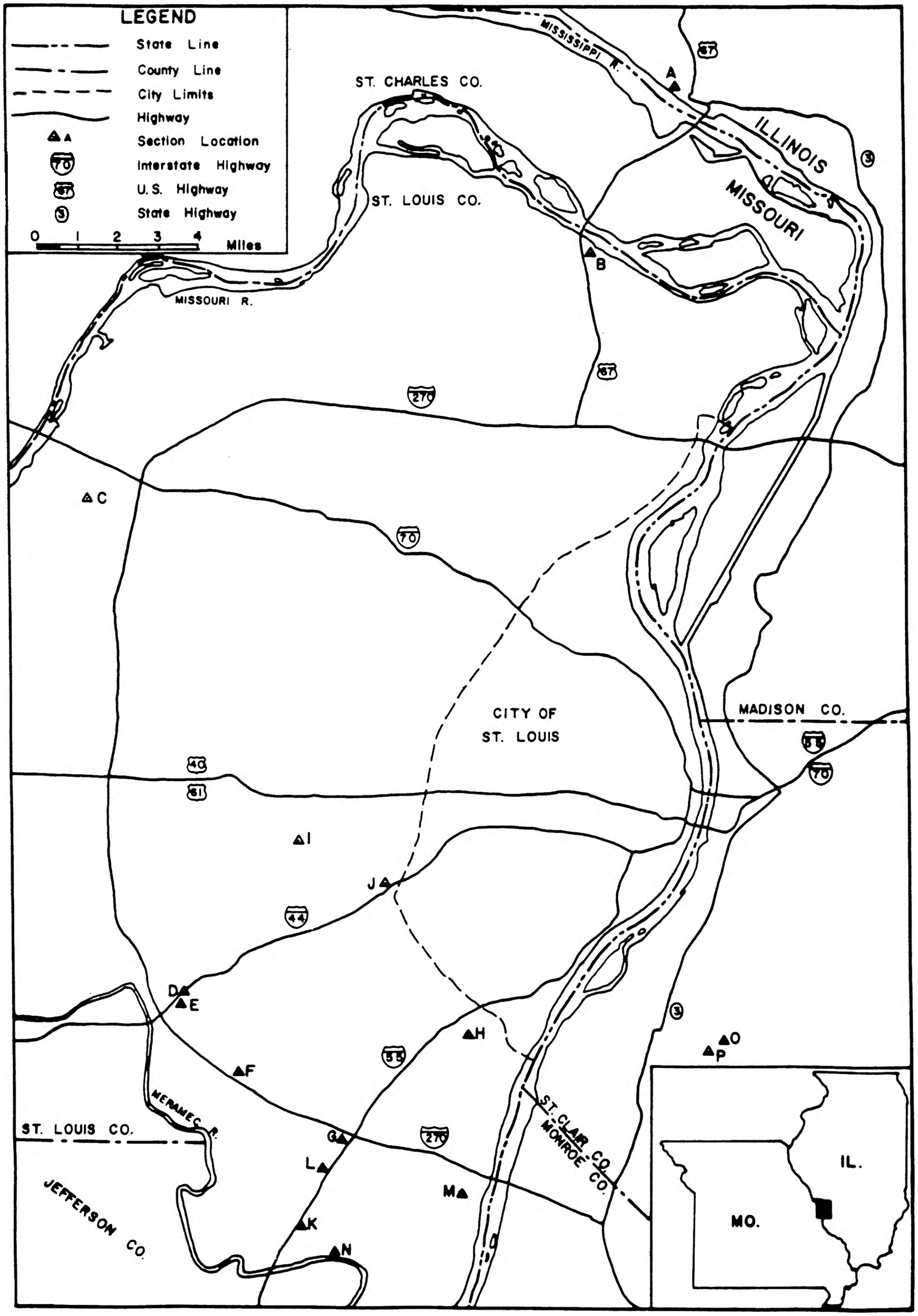

Figure 1. Index map of study area.

TABLE II

MEASURED STRATIGRAPHIC SECTIONS AND LOCALITIES

	section	street locality	section locality	county	7½' quadrangle
A.	Miss. River bluff	McAdams Parkway - Alton, Ill.	SW¼, SW¼, SW¼, sec. 11, T5N, R10W	Madison, Ill.	Alton
B.	Ft. Belle-fontaine Quarry	east of HW 67 just south of Mo. River	S½, SW¼, sec. 4, T47N, R7E (ex.)	St. Louis, Mo.	Columbia Bottom
C.	Vigus North Quarry	north of Creve Coeur Road	SW¼, sec. 9, T46N, R5E, (ex.)	St. Louis, Mo.	Creve Coeur
D.	Watson Road	between Watson Rd. exit ramp and I-44	SW¼, SE¼, NE¼, sec. 14, T44N, R5E	St. Louis, Mo.	Kirkwood
E.	I-270 & I-44	I-44 & I-270 inter-section, southeast quarter	NE¼, NW¼, SE¼, sec. 14, T44N, R5E	St. Louis, Mo.	Kirkwood
F.	Gravois Rd.	I-270 & Gravois Rd. intersection, east quarter	SW¼, NW¼, sec. 30, T44N, R6E (ex.)	St. Louis, Mo.	Kirkwood
G.	I-270 & I-55	I-270 & I-55 inter-section, southwest quarter	SW¼, SW¼, SW¼, sec. 34, T44N, R6E	St. Louis, Mo.	Webster Groves
H.	Ruprecht Quarry	northeast of LeMay Ferry Rd. on Mt. Olive St.	S½, SE¼, NE¼, sec. 24, T44N, R6E (ex.)	St. Louis, Mo.	Webster Groves

TABLE II (cont.)

	section	street locality	section locality	county	7½' quadrangle
I.	Rock Hill Quarry	north of Manchester Rd. on McKnight Rd.	NE¼, NW¼, sec. 29, T45N, R6E (ex.)	St. Louis, Mo.	Webster Groves
J.	Shrewsbury	I-44 west & Shrewsbury exit, north side of I-44	SE¼, SW¼, NE¼, sec. 34, T45N, R6E (ex.)	St. Louis, Mo.	Webster Groves
K.	Butler Hill Rd.	0.85 mi. south of Butler Hill Rd. exit	E½, NE¼, SE¼, sec. 8, T43N, R6E	St. Louis, Mo.	Oakville
L.	Mattis Rd.	I-55 south & Mattis Rd. bridge, north of Butler Hill interchange	C, S½, NE¼, sec. 4 T43N, R6E	St. Louis, Mo.	Oakville
M.	Bussen Quarry	south of Pottle Rd. off Telegraph Rd. west of Miss. R.	NE¼, NW¼, SW¼, sec. 7, T43N, R7E (ex.)	St. Louis, Mo.	Oakville
N.	Vigus South Quarry	on Baumgartner Rd., north of Meramec River	C, S½, SE¼, sec. 15, T43N, R6E	St. Louis, Mo.	Oakville
O.	Stolle Quarry	northeast of Dupo, Ill., south of Harding Ditch, east of HW 157	SE¼, NW¼, NW¼, sec. 14, T1N, R10W (ex.)	St. Clair, Ill.	Cahokia
P.	East St. Louis Stone Co. Quarry	same as O	NE¼, NE¼, SW¼, sec. 13, T1N, R10W (ex.)	St. Clair, Ill.	Cahokia

where a regular section would have been. The abbreviation, ex., in the section locality indicates this extension (e.g., S½, SW¼, sec. 4, T47N, R7E, ex.). Petrographic thin sections of the sampled units were then prepared. An analysis of constituents was made in order to determine the extent of algae preservation, algae morphology, environment of deposition of both the units and the algae, and if lithologic patterns relate to the algae.

STRATIGRAPHY

George Engelmann (1847) first described the St. Louis Limestone naming the unit for the area he studied, St. Louis, Missouri, but not designating a type section. Engelmann included the Salem Formation, the St. Louis Limestone, and the Ste. Genevieve Formation in his original description as did G.C. Swallow (1855). B.F. Shumard (1860) defined the Ste. Genevieve Limestone as a formation separate from the St. Louis Limestone. Finally, E.O. Ulrich (1904) distinguished the St. Louis Limestone from the Spergen Hill Formation, now accepted by the United States Geological Survey (U.S.G.S.) as the Salem Formation. (A complete synonymy of St. Louis Limestone terminology is found in Thompson and Anderson, 1976, pages 47-48.)

In Missouri and Illinois, the majority of the St. Louis Limestone outcrops occur in quarries near the Mississippi River and in bluffs in Lincoln, St. Charles, St. Louis, and Jefferson Counties in Missouri, and Calhoun, Jersey, Madison, and St. Clair Counties in Illinois. The thickness ranges from 50 to 175 feet. The unit is about 50 feet thick in northeastern Missouri and southwestern Missouri, but it ranges from zero to 75 feet in the subsurface of northwestern Missouri due to post-depositional erosion. In Illinois, the St. Louis Limestone thins from 500 feet thick in the southeast, to as little as 40 feet thick in the northwest. Although this study pertained only to outcrops of the St. Louis Limestone in Missouri and Illinois, the formation is also present in Alabama, Georgia, Indiana, Iowa, Kentucky, Tennessee, and Virginia.

The study area is located in portions of St. Louis County, Missouri, Madison County, Illinois, and St. Clair County, Illinois between the Ozark Dome and the Illinois Basin. Due to the proximity of the Ozark Uplift, the strata in these counties dip slightly to the northeast toward the Illinois Basin. Most of the sections studied lie between the northwest-southeast trending House Springs-Eureka and Dupo Anticlines. Figure 2 demonstrates the relationship of the study area to the surrounding structural features. For detailed descriptions of these and other minor structures in the St. Louis area, see McCracken (1966).

Stratigraphic Position

E.O. Ulrich (1904) delineated the St. Louis Limestone from the underlying Salem Formation and the overlying Ste. Genevieve Formation, and he proposed combining the lower two formations (Salem and St. Louis) with the Warsaw Formation to comprise the Meramec group, named for its type locality, the Meramec River Valley. Weller et al. (1948) used the terms Meramec Series and Osage Series (instead of group) for Missouri in the current correlation chart. The Meramec Series now includes the Warsaw Formation, Salem Formation, St. Louis Limestone, and the Ste. Genevieve Formation.

In Missouri, the Kinderhookian Series, Osagean Series,

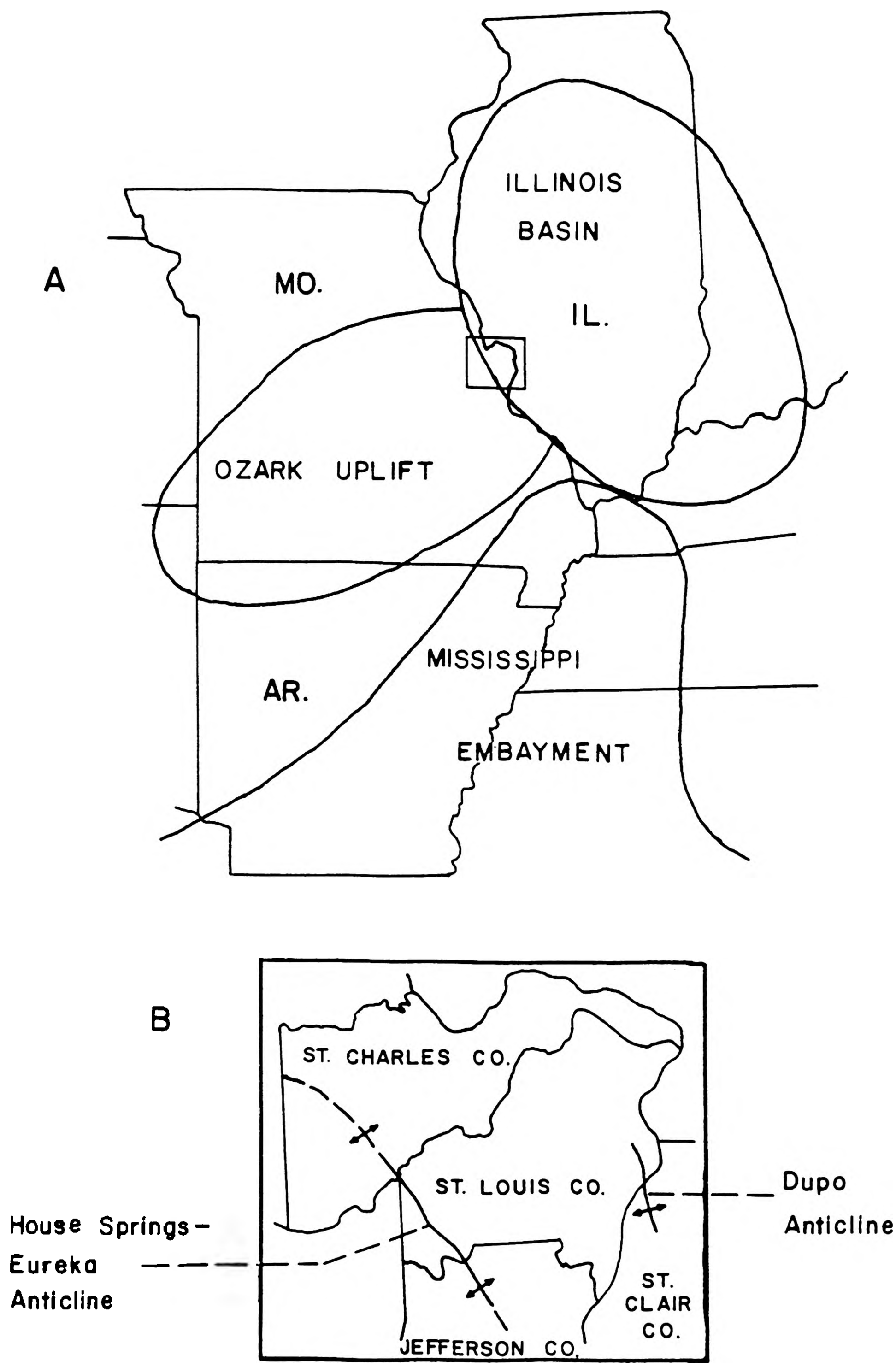

Figure 2. Structural features in study area. A. Regional structures (adapted after Thacker et al., 1977). B. Inset from A, showing structural features in the vicinity of St. Charles and St. Louis Counties (adapted after McCracken, 1966).

Meramecian Series, and Chesterian Series are the time-stratigraphic units of the Mississippian Period. In Illinois, however, the Osagean and Meramecian Series are combined as the Valmeyeran Series, making three Mississippian divisions, Kinderhookian Series, Valmeyeran Series, and Chesterian Series, compared to Missouri's four divisions (Fig. 3).

Previous Works

General studies on the St. Louis Limestone are numerous. Buckley and Buehler (1904), Weller and St. Clair (1928), and Spreng (1961), describe general characteristics of the formation in Missouri. Observations of the unit in the St. Louis quadrangle of Missouri and Illinois are recorded by N.M. Fenneman (1911). Additional works in Illinois include those of Weller (1920), Rubey (1952), and Willman et al. (1975). Stratigraphic studies in other states were made by Van Tuyl (1922) in Iowa, Ulrich (1905) in Kentucky, and Weller and Sutton (1940) in Indiana, Kentucky, and Iowa, as well as in Illinois and Missouri.

The stratigraphy of the Mississippian St. Louis Limestone in Missouri and Illinois has been considerably discussed. Stratigraphic descriptions were prepared by Martin and Wells (1966), Borahay (1970), Lane and Brenckle (1977), and Thacker and Satterfield (1977). J.A. Lineback (1970 and 1972) discusses the lower boundary of the St. Louis Limestone in southern Illinois, while Fielding (1971) and

MISSISSIPPIAN SYSTEM

Series (Mo.)	formations present	Series (Ill.)
Chesterian	none	Chesterian
Meramecian	Ste. Genevieve Fm. St. Louis Ls. Salem Fm. Warsaw Fm.	Valmeyeran
Osagean	Keokuk Ls. Burlington Ls. Fern Glen Fm.	
Kinderhookian	Chouteau Fm.	Kinderhookian

Figure 3. General stratigraphic column of the Mississippian formations in study area.

Collinson et al. (1958) consider the upper boundary in Missouri and Illinois respectively.

Papers on fossils in the St. Louis Limestone are not as abundant, although several of the works listed above mention some paleontology. Fossil algae is described from sections in Indiana by C.L. Bieber (1966), while Thompson (1966), and Rexroad and Collinson (1963) studied conodonts for establishing zones in the Meramec Series.

The limestone is quarried extensively for cement manufacture, road building and agricultural use, but other economic production is unimportant. Hinchey et al. (1947), analyzed St. Louis Limestone samples to determine uses for this limestone. Oil production in Missouri is very scarce in the unit, but Bristol and Howard (1966) report on production in Illinois.

Description of Stratigraphic Sections

Graphic representations of the 16 stratigraphic sections which were measured, described, and sampled, appear in the Appendix. The measured sections include algal layers and the beds which lie immediately above and below. Unit measurements, taken with a Jacob staff and hand level to the nearest tenth of a foot, were later converted to centimeters. Angle of dip was not measured as the St. Louis Limestone beds are essentially flat-lying. The following characteristics were considered in the unit descriptions: major and minor lithologies, fresh color, weathered color, stratification, sedimentary structures, jointing, weathering, fossils present, accessory minerals, thickness, and contact with overlying unit.

Most lithologies were limestones. Of these, several were lithographic limestones, homogeneous, very fine-grained limestones with conchoidal to subconchoidal fracture. There were also many dolomites. By means of alizarin red S staining, several dolomites, which had been mistaken for limestones in the field, were identified in thin section. Argillaceous limestones were next in abundance. These units were shaley, with a green hue, and with indistinct or fissile bedding. Five sections (H, I, K, L, N) contained quartzose limestones, defined as limestones with megacrystalline quartz as a principal constituent. The quartz was present in bluish gray masses, not in grains. The bedding was generally wavy, and the quartzose beds were associated with dolomite. Other minor lithologies included light colored shales, very thin calcareous shales, argillaceous dolomites, dolomitic limestones, sandy limestones, one oolitic limestone, one calcareous dolomite, brecciated limestones, and brecciated dolomites. The photograph in Figure 4 illustrates a brecciated bed from Section E, located at the junction of I-44 and I-270. At least two of the brecciated beds in the described stratigraphic sections (Section H, Ruprecht Quarry, Unit 7, and Section I, Rock Hill Quarry, Unit 8) are what Norton (1917) termed crackle breccias. He defines crackle breccia as "one whose fragments

Figure 4. Brecciated limestone from Section E, I-44 and I-270, Unit 3.

are parted by planes of fission and have suffered little or no relative displacement."

The origin of brecciated limestone and dolomite beds in the St. Louis Limestone has long been a problem to geologists. Van Tuyl (1922) believed the brecciation formed as a result of three processes: (1) wave action at the time of deposition of the limestone, (2) deforming fractures within the limestone, and (3) shearing on a large scale. Collinson and Swann (1958), on the other hand, attribute brecciation to solution of evaporite beds associated with certain limestone beds. Smith et al. (1961) cite submarine rock slumping as the cause for brecciated beds. Four pre-1926 references pertaining to the breccia origin problem are listed in Rubey's study of the Hardin and Brussels quadrangles in Illinois (1952).

The rock colors were determined by comparison with the Geological Society of America (GSA) Rock Color Chart. The colors present in the stratigraphic sections are listed next to their GSA numerical designation in the Appendix.

Stratification was recorded as very thick, thick, thin, or very thin, based on the following divisions:

greater than 4'	very thick bedding
2'-4'	thick bedding
2"-2'	thin bedding
less than 2"	very thin bedding.

Most of the bedding was either thin or thick. The shaley layers generally had very thin to thin bedding and none of the units had very thick bedding. Many units had indistinct bedding, meaning bedding that was discontinuous or not readily visible. Independent of thickness, the term massive described bedding that was homogeneous, without internal structure (joints, fissility). Other terms used to describe bedding were wavy and discontinuous, while streaks and lenses referred to lens-shaped beds.

Many sedimentary structures were observed. The presence of laminations, sparry patches and veins, stylolites, intraclasts, brecciation, sinkholes, and coarse or microcrystalline texture was recorded. Stromatolites, oncolites, and any other beds of a possible algal origin were particularly noted. Jointing was minor, found in a few units, and thus, was of little importance in this study.

Weathering terms characterize the weathered surface of a unit. The terms utilized in the stratigraphic sections descriptions were: smooth, rough, soft, dense, fractured conchoidally, fractured linearly (implies planar fractures), crumbled, pitted, iron-stained, and/or partly covered by plants or trees.

One common invertebrate fossil noted during field work was the tabulate coral, *Syringopora* sp.. Other fossils present (roughly in order of abundance) were: crinoids, brachiopods, bryozoans, horn corals, worm burrows, ostracodes, and echinoid plates.

Accessory minerals included pyrite, chalcopyrite, illite, and chert. Illite was identified by x-ray analysis (Spreng, pers. comm.). Chert nodules were fairly common in the units. They ranged from small (3-5 cm. or .1'-.2'), oval nodules and tabular lenses, to thin, irregular, chert beds. Some nodules contained well-preserved, whole fossils.

Additional lithologies within the units were measured and described in the same manner as each unit was described.

The contact referred to is a unit's upper boundary unless otherwise stated. The contact terms were: wavy, sharp, covered, stylolitic, and gradational. The tops of some units formed a bench, a relatively level strip or platform of rock produced by differential erosion, or, in the quarries, produced by selective blasting.

Nearly all the units measured and described were also sampled. The shale beds, and some of the calcareous shales, argillaceous dolomites, and argillaceous limestones were not sampled because their fissility and clay content made them difficult to thin section. Most units were sampled once, but those with minor lithologies, or algal zones, were sampled two or more times, with the samples labeled a, b, c, etc. in order from base to top. The positions of the samples are shown by arrows on the stratigraphic sections in the Appendix. Any sample's source is easily identified by letters and numbers. Each section has an assigned capital letter (see Table II), each unit within the section is numbered in order from base to top, and each sample within the unit is labeled with lowercase letters. Thus, A2a, refers to the basal sample in unit two of Section A, the Mississippi River Bluff section.

Description of Thin Sections

Folk Terminology

The thin sections were studied and named according to Robert L. Folk's petrographic classification of limestones (1959) shown in Table III. His classification is based on the relative volume of allochems, the transported, coarse, framework grains, and orthochems, the precipitated cement. Allochems are of four major types: (1) intraclasts, (2) oolites, (3) fossils, and (4) pellets. Orthochems include: (1) sparry calcite cement (crystals with a diameter of 15 microns or more), (2) microcrystalline calcite (micrite) ooze matrix (crystals with a diameter of one to four microns), (3) microsparite, recrystallized micrite (crystals with a diameter of four to 15 microns), (4) pseudosparite, a limestone recrystallized to sparry calcite with no vestige of previous constituents, (5) primary or secondary dolomite, and (6) other post-depositional replacement minerals.

Folk defines three major limestone families based on proportions of constituents. Family I, requiring vigorous currents, consists of "abundant allochems cemented by sparry calcite." Family II includes limestones with a micrite matrix and variable amounts of allochems deposited in ineffective currents, while the third family contains micritic limestones, deposited in low energy environments. Next, Folk divides these three basic groups into eleven groups according to type of allochem and matrix:

TABLE III

CLASSIFICATION OF CARBONATE ROCKS (FROM FOLK, 1959, TABLE I)

Volumetric Allochem Composition	Limestones, Partly Dolomitized Limestones, and Primary Dolomites (see Notes 1 to 6): >10% Allochems, Allochemical Rocks (I and II): Sparry Calcite Cement > Microcrystalline Ooze Matrix — Sparry Allochemical Rocks (I)	>10% Allochems, Allochemical Rocks (I and II): Microcrystalline Ooze Matrix > Sparry Calcite Cement — Microcrystalline Allochemical Rocks (II)	<10% Allochems, Microcrystalline Rocks (III): 1-10% Allochems (Most Abundant Allochem)	<10% Allochems, Microcrystalline Rocks (III): <1% Allochems	Undisturbed Bioherm Rocks (IV)	Replacement Dolomites[7] (V): Allochem Ghosts (Evident Allochem)	Replacement Dolomites[7] (V): No Allochem Ghosts
>25% Intraclasts (i)	Intrasparrudite (Ii:Lr) Intrasparite (Ii:La)	Intramicrudite* (IIi:Lr) Intramicrite* (IIi:La)	Intraclasts: Intraclast-bearing Micrite* (IIIi:Lr or La)	Micrite (IIIm:L); if disturbed, Dismicrite (IIImX:L); if primary dolomite, Dolomicrite (IIIm:D)	Biolithite (IV:L)	Finely Crystalline Intraclastic Dolomite (Vi:D3) etc.	Medium Crystalline Dolomite (V:D4)
<25% Intraclasts; >25% Oolites (o)	Oösparrudite (Io:Lr) Oösparite (Io:La)	Oömicrudite* (IIo:Lr) Oömicrite* (IIo:La)	Oolites: Oolite-bearing Micrite* (IIIo:Lr or La)			Coarsely Crystalline Oolitic Dolomite (Vo:D5) etc.	Finely Crystalline Dolomite (V:D3)
<25% Intraclasts; <25% Oolites; Volume Ratio of Fossils to Pellets >3:1 (b)	Biosparrudite (Ib:Lr) Biosparite (Ib:La)	Biomicrudite (IIb:Lr) Biomicrite (IIb:La)	Fossils: Fossiliferous Micrite (IIIb: Lr, La, or Ll)			Aphanocrystalline Biogenic Dolomite (Vb:D1) etc.	
<25% Intraclasts; <25% Oolites; Volume Ratio of Fossils to Pellets 3:1-1:3 (bp)	Biopelsparite (Ibp:La)	Biopelmicrite (IIbp:La)	Pellets: Pelletiferous Micrite (IIIp:La)			Very Finely Crystalline Pellet Dolomite (Vp:D2) etc.	etc.
<25% Intraclasts; <25% Oolites; Volume Ratio of Fossils to Pellets <1:3 (p)	Pelsparite (Ip:La)	Pelmicrite (IIp:La)					

NOTES TO TABLE I

* Designates rare rock types.

[1] Names and symbols in the body of the table refer to limestones. If the rock contains more than 10 per cent replacement dolomite, prefix the term "dolomitized" to the rock name, and use DLr or DLa for the symbol (e.g., dolomitized intrasparite, Li:DLa). If the rock contains more than 10 per cent dolomite of uncertain origin, prefix the term "dolomitic" to the rock name, and use dLr or dLa for the symbol (e.g., dolomitic pelsparite, Ip:dLa). If the rock consists of primary (directly deposited) dolomite, prefix the term "primary dolomite" to the rock name, and use Dr or Da for the symbol (e.g., primary dolomite intramicrite, IIi:Da). Instead of "primary dolomite micrite" (IIIm:D) the term "dolomicrite" may be used.

[2] Upper name in each box refers to calcirudites (median allochem size larger than 1.0 mm.); and lower name refers to all rocks with median allochem size smaller than 1.0 mm. Grain size and quantity of ooze matrix, cements or terrigenous grains are ignored.

[3] If the rock contains more than 10 per cent terrigenous material, prefix "sandy," "silty," or "clayey" to the rock name, and "Ts," "Tz," or "Tc" to the symbol depending on which is dominant (e.g., sandy biosparite, TsIb:La, or silty dolomitized pelmicrite, TzIIp:DLa). Glauconite, collophane, chert, pyrite, or other modifiers may also be prefixed.

[4] If the rock contains other allochems in significant quantities that are not mentioned in the main rock name, these should be prefixed as qualifiers preceding the main rock name (e.g., fossiliferous intrasparite, oölitic pelmicrite, pelletiferous oösparite, or intraclastic biomicrudite). This can be shown symbolically as Ii(b), Io(p), IIb(i), respectively.

[5] If the fossils are of rather uniform type or one type is dominant, this fact should be shown in the rock name (e.g., pelecypod biosparrudite, crinoid biomicrite).

[6] If the rock was originally microcrystalline and can be shown to have recrystallized to microspar (5-15 micron, clear calcite) the terms "microsparite," "biomicrosparite," etc. can be used instead of "micrite" or "biomicrite."

[7] Specify crystal size as shown in the examples.

(1) intrasparites, (2) oosparites, (3) biosparites, (4) biopelsparites, (5) pelsparites, (6) intramicrites, (7) oomicrites, (8) biomicrites, (9) biopelmicrites, (10) pelmicrites, and (11) micrites or dismicrites (if irregular spar patches are present indicating a disturbance).

Limestones with fossils in growth position, biolithites, and replacement dolomites are listed separately from Families I, II, and III. The name of the undisturbed fossil modifies biolithite (e.g., algal biolithite). Replacement dolomites are classified by allochem content and by grain size (aphanocrystalline to extremely coarsely crystalline) according to the following Wentworth scale (1922):

aphanocrystalline	under 0.0039 mm.
very finely crystalline	0.0039-0.0156 mm.
finely crystalline	0.0156-0.0625 mm.
medium crystalline	0.0625-0.25 mm.
coarsely crystalline	0.25-1.00 mm.
very coarsely crystalline	1.00-4.00 mm.
extremely coarsely crystalline	over 4.00 mm.

A limestone with more than ten percent replacement dolomite is modified by dolomitized, while those with dolomite of uncertain origin are called dolomitic.

Prefixes before the limestone types explain other important constituents present. For instance, if more than ten percent and less than fifty percent terrigenous material is present, sandy, silty, or clayey modifies the limestone type depending on grain size. Other significant allochems present may be included in the limestone name at the individual's discretion.

Petrology of the St. Louis Limestone

In order to determine preservation, morphology, environment of deposition, and lithologic relationships of algae in the St. Louis Limestone, 210 thin sections from 135 selected beds, including minor lithologies, were described. Thin section descriptions of each collected unit were recorded on description sheets (Fig. 5). Several thin sections from one unit were described on the same sheet. Percentages of allochems, orthochems, terrigenous material, and pore space were visually estimated. Other features were noted, and a Folk name and environment of deposition were assigned to the unit's thin section(s). The Folk names are listed in parentheses next to each lithology in the Appendix.

Major allochems noted were fossils, intraclasts, pellets, and oolites. The total number of fossils observed in thin section was larger than the number observed in the field, but the relative abundances were in approximately the same order. Fossils present in thin section, but not observed in the field were: (1) foraminifers, (2) ostracodes, (3) calcareous algae fragments, (4) calcispheres (possible algal spores), (5) gastropods, (6) trilobites, and (7) pelecypods. In order of abundance, the fossil types observed in thin section were: echinoderm debris, foraminifers, brachiopods, bryozoans, ostracodes, corals, calcispheres, algae, gastropods, worm burrows, trilobites, and pelecypods.

MICROSCOPIC DESCRIPTION OF CARBONATES

Field Number ________________ Thin Section Number __________

Collector ________________ Date of Description __________

I. Field Notes Petrographer ______________

Locality ____

Formation ____

Stratigraphic Position of Sample ______________________________

II. Hand Specimen Description

III. Thin Section Analysis

a. Thin section orientation b. Staining

c. Percentage distribution of constituents

ALLOCHEMS Max. size ______ Min. size ______	ORTHOCHEMS	TERRIGENOUS	PORE SPACE
Fossils	Spar (10M & larger)	Quartz	
		Clays	
	Micrite (1-4M)	Carbonates	
	Other (qtz. & other filling minerals)	Others	
Intraclasts ______ Recal. % ______	Secondary Carbonates Microspar (5-30M)		
Oolites ______			
Pellets ______ f p = ______	Pseudospar		
Lumps ______	Dolomite	Method of determination of percentages	

d. Dolomitization

e. Recrystallization Replacement

f. Geopetals

g Abrasion

h Packing

IV Comments

V. Rock Name

VI Environment of Deposition

Figure 5. Microscopic description of carbonates sheet (devised by A.C. Spreng).

Most intraclasts were rounded micritic fragments, and thus, were easily confused with pellets, especially when the limestone was poorly washed. Other micritic fragments cemented with spar, were distinctly intraclastic in origin. Pellets and oolites were not as common as fossils and intraclasts.

Orthochems observed in thin section were micrite, spar, and the secondary carbonates microspar, pseudospar, and dolomite. Some limestones, micrites and dismicrites (carbonate muds that are disturbed, lithified, then spar-filled), contained less than one percent allochems. Of these, about three-fourths were dolomitized. Sparry calcite cement was easy to identify because of the large, equant crystals. Microspar and pseudospar were relatively rare, present in only five beds. Microspar develops by recrystallization of micrite, while pseudospar may form by indiscriminate recrystallization. Nearly one-third of all the beds were dolomitized at least ten percent. Frequently, the dolomite replaced only the matrix, not the fossils, with anhedral, subhedral, and euhedral crystals. Many beds, especially micrites, were dolomitized in round dots, suggesting either preferential dolomitization was based on original depositional fabric, or the alizarin red S staining was not thorough.

Particles of sand- and silt-sized quartz were the only terrigenous materials observed. The well-sorted, rounded, and clean nature of the sands and silts indicate that they are mature sediments. Wentworth's grain size boundary between sand and silt, 0.0625 millimeters was used. Only eight beds were silty and four beds were sandy. Since the argillaceous units were not sampled, clay-sized terrigenous material was not observed in thin section.

The Folk names of the St. Louis Limestone thin sections basically describe their contents. Some modifiers were used, however, to reveal the presence of other important constituents. Besides the previously explained prefixes (dolomitized, sandy, and silty), common modifiers were fossiliferous, disturbed, algal, oncolitic, and calcispheric. The term fossiliferous is self explanatory. Disturbed lithologies were those in which irregular spar patches indicated a disturbance of the original matrix. Some dismicrites (disturbed micrites) might have been mistaken for pelletal limestones, except the micrite patches were irregular in shape and not of uniform size. If any algae were present in thin section, then algal modified the rock name even if the percentage of algae was small (one to two percent). Oncolitic was used when the unit contained abundant megascopic or microscopic oncolites. If more than five percent of the limestone consisted of calcispheres, then calcispheric prefixed the limestone type unless algae were present, in which case algal was preferential. One exception, however, sample N1, had a significant amount of both calcispheres (30 percent) and algae, so both terms were used as modifiers.

The most abundant Folk-type lithology was biomicrite, comprising nearly one-third of all lithologies. Dolomitized beds were nearly as large in number. Fourteen carbonates with over 50 percent dolomite were named dolomites, while 36 carbonates, containing 10 to 50 percent replacement dolomite were prefixed with dolomitized. Of the dolomites, 86 percent were very finely crystalline and 14 percent were finely crystalline. Forty-three percent of the dolomites were biogenic, while seven percent contained spar and seven percent contained algal fragments. The rest of the dolomites (43 percent) contained no allochems.

Beds with algal origins were prefixed with algal, oncolitic, or calcispheric, or they were designated algal biolithites if the algae were in growth position. About 17 percent of all the sampled beds contained calcareous algae fragments (algal beds), while less than six percent were calcispheric, and only two percent were algal biolithites. Some algal biolithites were possibly misnamed dismicrites since little or no skeletal structure was preserved verifying an algal origin.

Folk terminology was not applicable to four units, A2, B3, B4, and J6. These units were not assigned a Folk name, but were designated as "N.A." in the Appendix, and are described in a later section.

The thin section study was vital to this research. Through thin section analysis, the preservation, morphology, environment of deposition, and lithologic pattern of St.

Louis Limestone algae were determined.

Environments of Deposition

One objective of this study was to determine the environments of deposition of the algae in the St. Louis Limestone. This was solved through thin section analysis of each sampled bed. The constituents and sedimentary structures revealed the environmental conditions of each unit, then a general pattern for algae deposition was established.

Environments of the Carbonate Units

Every sampled unit in the stratigraphic sections (Appendix) was assigned at least one of three shallow marine environments: (1) supratidal, (2) intertidal to upper subtidal, and (3) open marine or lower subtidal (Fig. 6). Two environments were assigned to those units with overlapping environments. The cross-sectional distance across each depositional environment is dependent upon slope of the substrate and upon tidal amplitude. According to Irwin (1965), the distances may be hundreds of miles across the low energy supratidal and subtidal environments, and tens of miles across the high energy intertidal environment in clear-water epeiric (inland or continental shelf) seas.

The supratidal environment is inland from the shoreline. Being above mean high tide, this area is a low energy environment receiving only occasional inflow of seawater. This area may include marsh lands, tidal or mud flats, or

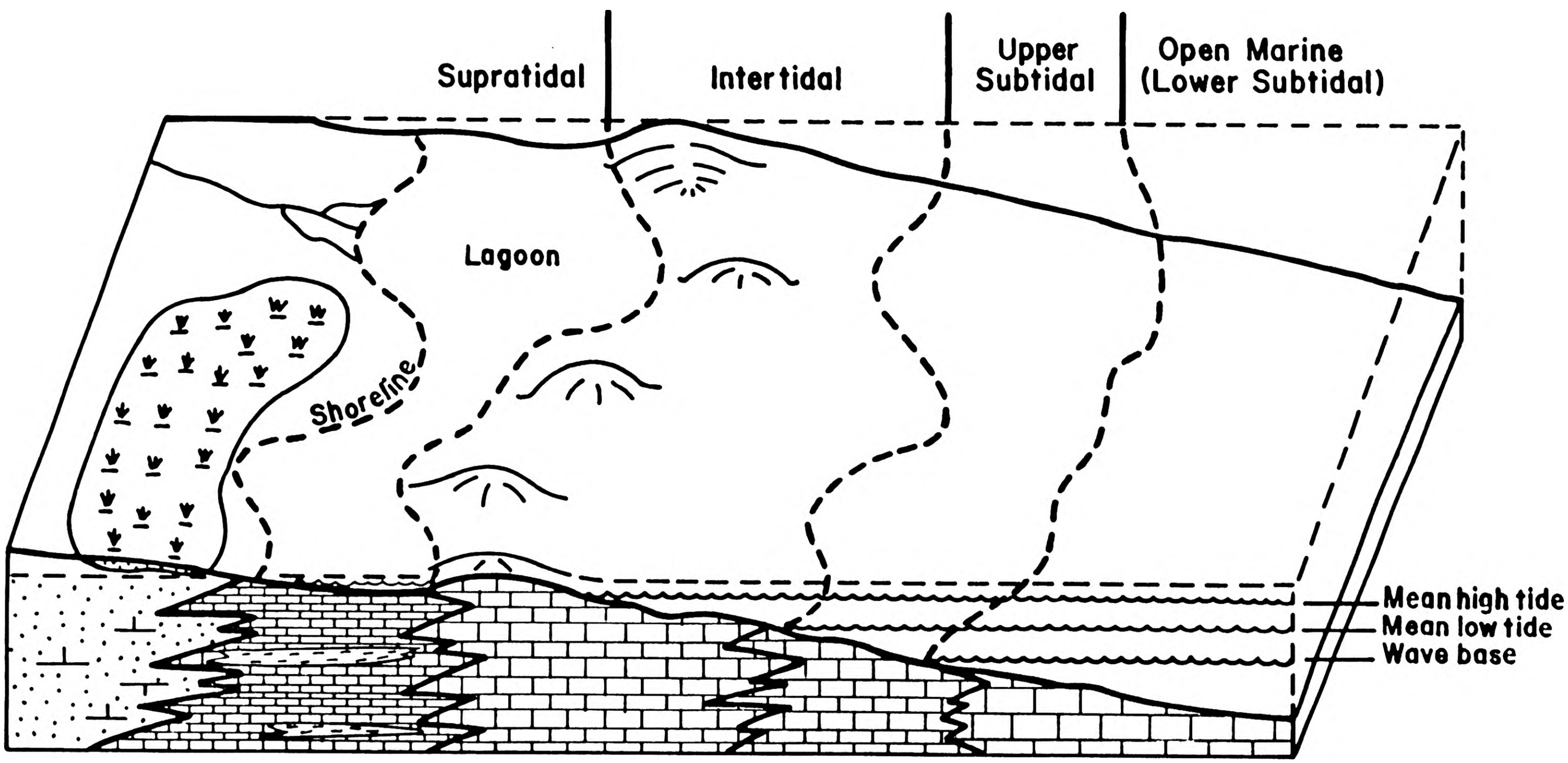

Figure 6. Model of shallow marine environments of deposition (not to scale).

restricted lagoons. Seaward is the intertidal area, between mean high tide and mean low tide, and thus, is a higher energy environment receiving wave action whose energy is dependent on slope of the substrate. This area may include organic buildups with vertical relief, such as oolite bars or domal stromatolites. Farthest from shore, but still nearshore is the subtidal environment which is below mean low tide, but not necessarily below wave base (the area at which waves no longer disturb the bottom sediments) and thus, is an area of both high and low energy. Therefore, to delineate the high energy areas from the low energy areas, the intertidal area (high energy) was combined with the upper subtidal area (high energy, above wave base) and the lower subtidal area (low energy, below wave base) was designated as the open marine environment. In all, the three environments are: (1) supratidal (low energy), (2) intertidal to upper subtidal (higher energy), and (3) open marine or lower subtidal (low energy).

The environment of deposition was determined for each sampled unit through study of the unit's allochems, orthochems, sedimentary structures, and other factors. Most of these features were observed in thin section and all factors were considered in environmental determination. Table IV lists the important criteria for environmental interpretation.

Of the allochems (fossils, intraclasts, oolites, and pellets), the fossils were most important in determining

TABLE IV

MAJOR CRITERIA FOR DETERMINING ENVIRONMENTS OF DEPOSITION

Supratidal	Intertidal - Upper Subtidal		Open Marine (Lower Subtidal)
		corals	corals
	brachiopods	brachiopods	brachiopods
		echinoderms	echinoderms
		bryozoans	bryozoans
calcispheres			
	oncolites		
	domal stromatolites		
micrite			micrite
	spar		
	intraclasts		
	oolites		
laminations			laminations

depositional environment of the carbonates. Several factors affect organisms in an environment. Some of them are temperature, salinity (dependent on influx of fresh water from rivers, streams, or rain, and on rate of evaporation), clearness of the water (dependent on terrigenous influx and turbidity), firmness of the substrate, and water depth. Figure 7 from Heckel (1972) shows the distribution of modern organisms in different water depths. Since these organisms currently live in certain water depths, it is probable that during the Mississippian Period they lived in the same water depths.

Strictly marine organisms found in St. Louis Limestone thin sections are corals, brachiopods, bryozoans, and echinoderms. These four animal groups require at least some water movement for feeding, but few can withstand intense water turbulence (Heckel, 1972). Of these four organisms, the three indicative of the subtidal environment (both upper subtidal, high energy, and lower subtidal, low energy, open marine) are corals, bryozoans, and echinoderms. Because some brachiopods can tolerate moderate water turbulence, they may be found both in the subtidal and intertidal environments. Unlike corals and brachiopods, bryozoans and echinoderms can tolerate salinities lower than normal sea water, and thus, they may be found both in the subtidal region and in brackish water where fresh water influxes occur.

Ostracodes, foraminifers, gastropods, pelecypods, and

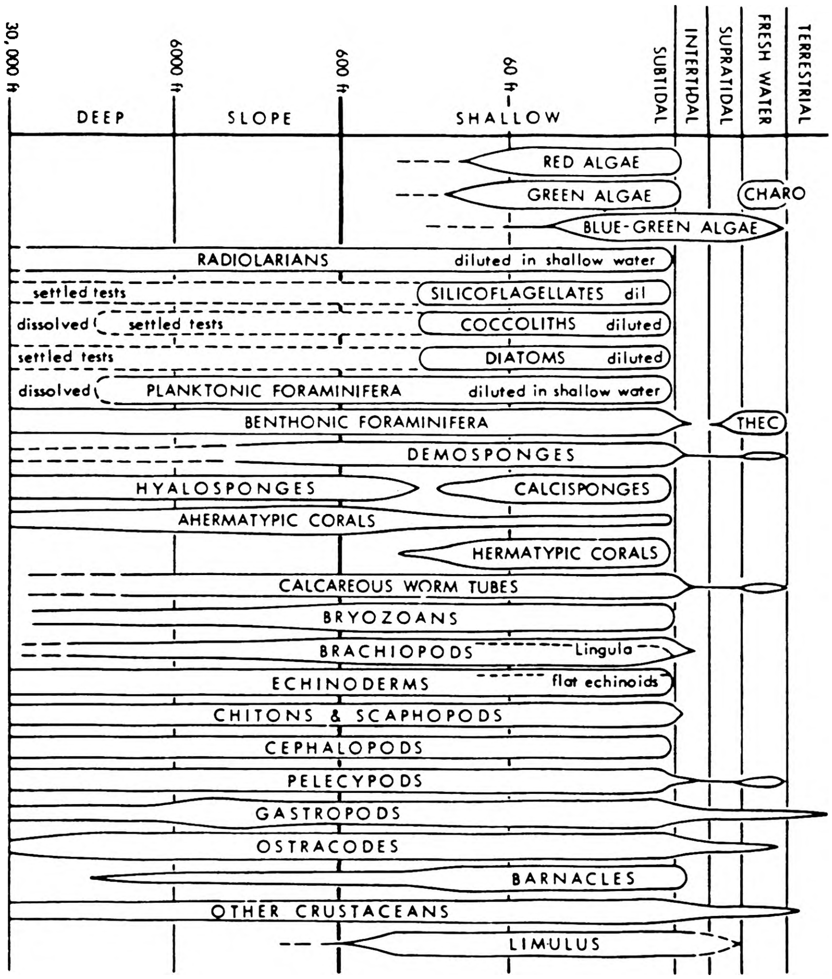

Figure 7. Modern distribution of major fossilizable nonvertebrate groups relative to water depth (from Heckel, 1972, Figure 4).

blue-green algae inhabit fresh, brackish, and marine waters. Their presence in thin section was not indicative of a particular environment. Instead of these, organisms with limited tolerances were considered in determining environment of the carbonate units.

Calcispheres are microscopic calcite spheres believed to be blue-green algal spore cases. Blue-green algae mats flourish in supratidal and intertidal environments. Rupp (1966) and Kazmierczak (1967) found calcispheres to be a good environmental indicator as they are found only in rocks having a very shallow water environment with restricted circulation. In this study, units containing abundant calcispheres were placed in the supratidal environment which has a restricted circulation in addition to being a quiet water environment which is required for calcispheres to settle out. Unit N1 was one bed containing abundant calcispheres (nearly 30 percent) which was assigned to a questionably supratidal environment because of the presence of sparse brachiopod pieces. Having a microcrystalline texture, the unit was composed of very small fossil fragments observed in thin section. Possibly the unit was deposited in an open marine area where brachiopods thrive and calcispheres settle after being washed from the supratidal area. Since the brachiopod fragments are scarce and no other open marine fauna are present, the environment is probably not open marine, but supratidal where calcispheres are found in abundance. Storm waves might have invaded the supratidal region carrying brachiopod debris into it and breaking other fossils into very small fragments.

Algal stromatolites are laminated structures formed by the trapping of fine detritus by green and blue-green algae. They may be either spheroidal, domal, planar, columnar, or undulose in form, or a combination of these forms. Oncolites are spheroidal stromatolites formed by accretion of algae to shell and mud fragment nuclei, thus requiring wave and current action for their formation. They are indicative of the lower intertidal area where wave action is constant. However, oncolites may be deposited downslope into the open marine area as was found in three biomicrite units with both open marine fauna and oncolites. A fourth oncolitic biomicrite, Unit P2, was assigned a supratidal environment because of the presence of numerous calcispheres and lack of open marine fauna. The oncolites in this unit were not completely spherical in form, but appear to be curved fragments from a dried supratidal algal mat.

Domal stromatolites, referred to as algal biolithites in the Appendix, were observed in two sections and are also restricted to the intertidal area. Logan, Rezak, and Ginsburg (1964, p. 79) list several factors affecting the formation of Recent domal stromatolites, or what they term laterally linked hemispheroids (LLH), in a protected intertidal area and in continental lakes. These factors are:

1. Periodic wetting and drying by the fluctuation of tidal waters.
2. Aperiodic flooding by abnormal, high storm

tides and storm waves in the marine littoral and by aperiodic runoff influx in lakes and salinas.
3. Wetting by wave splash.
4. Prolonged periods of desiccation during low tides in the marine environment and by evaporation of water in shallow lakes and salinas.
5. Scouring and mechanical fragmentation by storm waves.
6. Scouring and channeling by tidal water run-off.
7. Burial by sediment influx into the mat terrain.
8. Biotic activity such as browsing and boring by animals.

Since type-LLH stromatolites are presently forming in protected intertidal areas, then ancient stromatolites of the same type probably formed in the same environment and under the same conditions.

Planar stromatolites are referred to as cryptalgalaminate carbonates by J.D. Aitken (1967). The flat laminae of these algal mats are characteristic of supratidal or upper intertidal areas (Heckel, 1972). Several St. Louis Limestone laminated beds were cryptalgalaminate carbonates and all were supratidal in origin.

Intraclasts, oolites, and pellets are other allochems considered in environmental interpretation. The term intraclast was introduced by Folk (1959) to describe "fragments of penecontemporaneous, usually weakly consolidated carbonate sediment that have been eroded from adjoining parts of the sea bottom and redeposited to form a new sediment . . . ." If they are smaller than 0.2 millimeters, intraclasts may be confused with pellets. Most often, the intraclasts were formed by wave and current movement and were present in beds with a spar cement. These units were placed in the intertidal to upper subtidal zone where formation of intraclasts and winnowing of mud occur. Intraclasts may also originate in a supratidal mud flat where periodic desiccation causes the mud to crack and break apart into small concave pieces. Inundation of the area by storm waves or rain water leads to reworking and redeposition of the clasts. Oolites are small (diameter of 0.25 to two millimeters), round particles showing radial and/or concentric structure. Presently, oolites form in agitated water supersaturated with $CaCO_3$ (Heckel, 1972). For the purposes of this study, oolites were placed in the intertidal to upper subtidal environment since they require currents and wave action for their formation. Pellets, round to oval, structureless, micrite aggregates, are believed to be invertebrate fecal pellets (Folk, 1959). They may be found wherever invertebrate animals lived, from supratidal to open marine areas. Therefore, pellets alone are not good environmental indicators.

Micrite, spar, microsparite, pseudosparite, and dolomite are orthochems precipitated under certain conditions. Micrite, microcrystalline calcite mud, settles in low energy, supratidal or open marine zones, while sparry calcite is a void-filling cement precipitated after vigorous currents winnow mud from the sediments in the intertidal area. Most of the sparite units were partly muddy indicating currents were not very strong possibly because of a very low substrate slope. Microsparite and pseudosparite are secondary carbonates which obliterate all or part of the original fossils and sedimentary structures. Therefore, the environments of deposition of the units containing these secondary carbonates were difficult to determine and questionable.

The origin of dolomite is a problem not yet solved. Generally, it is considered to have a replacement origin. Evidence for this lies in the fact that dolomite presently is not forming on a large scale, but in semi-arid to arid climates, in Florida Bay (Shinn, 1964), in the Netherlands Antilles (Deffeyes, Lucia, and Weyl, 1965), in the Persian Gulf (Illing, Wells, and Taylor, 1965), and in the Bahamas (Shinn, Ginsburg, and Lloyd, 1965), it is forming in supratidal lagoons or mudflats by replacement. In these areas, the dry, warm climate stimulates evaporation of the supratidal waters to the stage of gypsum precipitation which in turn increases the salinity and magnesium content of the water favoring calcium carbonate replacement by dolomite. Evaporation also enhances replacement by increasing water density causing the heavier water to displace the lighter interstitial water of the underlying sediments.

Because of the Recent examples (Florida Bay, Netherlands Antilles, Persian Gulf, and Bahamas) of supratidal dolomite replacement, for this study, most of the dolomites (eight out of 14), and most of the dolomitized limestones

(30 out of 36) were placed in the supratidal environment. Additional evidence supporting supratidal dolomites is the presence of layered gypsum associated with dolomite in a St. Louis Limestone exposure north of St. Louis (Spreng, pers. comm.), gypsum in the subsurface just east of St. Louis (Illinois Geological Survey well record library), and the presence of halite crystal casts in Section H associated with a dolomite bed. Eleven dolomites and dolomitized limestones, however, were probably deposited in an open marine area evidenced by the open marine fauna present, and eight dolomite-related beds were deposited in a high energy intertidal to upper subtidal area evidenced by sparry cement or intraclasts. One dolomite bed containing both laminations, indicative of a supratidal area with few organisms, and burrows, indicative of a prolific, possibly intertidal area, was placed in both environments. (Refer to Table V for the number of dolomites and dolomitized limestones placed in the three environments.) Either a regression after deposition of these open marine to intertidal beds transformed the areas to a dolomitizing supratidal flat, or the beds were dolomitized by some other means.

Laminations, burrows, and breccias are sedimentary structures which may be useful in environment determination. Laminations reflect intermittent deposition or changes in the sediment type (Heckel, 1972). Preservation of laminae depends on the absence of burrowing organisms, or deposition in a regime without burrowers. So, the presence of

TABLE V

ENVIRONMENT OF DEPOSITION OF DOLOMITE-RELATED BEDS IN THE ST. LOUIS LIMESTONE

environment	dolomites	dolomitized limestones
supratidal	8	22
intertidal to upper subtidal	1	7
open marine	4	7
supratidal & intertidal to upper subtidal	1	
	14	36

laminations in St. Louis Limestone carbonates indicated a supratidal environment or a subtidal environment where unusually few burrowing animals lived. The basal portion of Unit C13 (intertidal and supratidal), however, exhibited laminae cut by burrows. The upper portion of the unit contained neither burrows nor laminae. The limited bioturbation of the lower part of this unit suggests the area was transitional between the intertidal and supratidal zones. Organisms intolerant of supratidal conditions rarely ventured into the area, and thus, supratidal laminations were not destroyed. Other exceptions, Unit L5, and Unit J7, were intrasparites, indicative of an intertidal area. Laminations in these units were preserved due to absence of burrowers possibly because of unfavorable environmental conditions.

Burrowing organisms require a soft substrate through which to filter food. Since both organisms and appropriate substrate are present in open marine, intertidal, and supratidal as well as alluvial environments, bioturbations by themselves are not indicative of a certain environment. However, specific traces left by organisms, ichnofossils, may be useful as environmental indicators. Since only a few units contained burrows, they were not studied in detail.

The formation of breccias may be interpreted many ways due to the large number of processes by which rocks are broken and cemented into breccia (Norton, 1917). Because of the numerous environmental interpretations of breccia formation, other features, especially fossil assemblage, were utilized in determining environment of deposition of brecciated units. Unfortunately, no single environment represented the brecciated beds because breccias were present in units with supratidal to open marine characteristics. So, the brecciated beds in the St. Louis Limestone sections probably formed by means of more than one process, including submarine slumping, wave action, deforming fractures, and solution of evaporite beds.

Other factors found in St. Louis Limestone beds and possibly related to environment of deposition are cherts, terrigenous clastics, and abraded allochems. The formation of chert is still a subject of controversy, so the environment of units with chert beds, nodules, and lenses was determined through study of other features. Shales and sandy or silty limestones, also, were not good environmental indicators as terrigenous material may be deposited from deep-sea to alluvial environments. The amount of abrasion of allochems, however, was helpful in distinguishing a high energy environment from a low energy environment. The intertidal region would have reworked sand- to silt-sized fossil debris in it while the supratidal and open marine regions would be more likely to have whole fossils in them along with very fine mud-sized debris winnowed from the intertidal zone.

The environments of deposition of the carbonate units were determined mainly through thin section study of the constituents and secondarily through field descriptions. The major determining factors, in order of importance, were micrite, indicating quiet, supratidal or lower subtidal deposition, and spar cement, indicating high energy, intertidal to upper subtidal deposition. Second in importance was the fossil assemblage. Echinoderms, corals, and bryozoans are open marine (upper and lower subtidal) fauna, while brachiopods may be found in the open marine zone as well as in the intertidal zone. Domal stromatolites and oncolites form in the intertidal area, while abundant calcispheres indicate a restricted circulation, supratidal environment. The presence of other constituents, dolomite, sedimentary structures, and other factors were considered in environmental interpretation, but only secondarily to fossil assemblage and micrite or spar cement content.

Problems in environment of deposition interpretation include the transportation of allochems. Organisms may be carried from their living area and deposited in another environment by turbidity currents, storm waves, or migration of animals carrying encrusters (Heckel, 1972). A rapid sea level rise or fall, also, would put organisms in an environment deeper or shallower than where they normally thrive. Oncolites and intraclasts, too, may be carried from their environment of formation. Another problem with the environments is the skipping from a supratidal to an open marine environment or vice versa. This is because the sampling was not detailed enough for multiple environments to be observed in one unit, or because intermediate environments were not preserved in rock records due to a rapid transgression or regression.

The environment of deposition of the studied portions of the St. Louis Limestone was a very near-shore, normal marine, epeiric sea with shallow, clear, warm water and with occasional influx of fine-grained quartz and clays from wind-blown beach sands or mature river/stream sediments. Tides were low causing gradational facies changes. Occasional oolite bars and algal buildups (stromatolites) formed barriers behind which lagoons formed. The shoreline fluctuated frequently in response to minor tectonic activities.

Environments of St. Louis Limestone Algae

Algae growth is dependent upon a combination of environmental factors. The most important factors are light, water depth, water clarity, substrate character, water salinity, water temperature, and water circulation. Algae depend primarily on sufficient light to perform their metabolic functions. Since sunlight penetrates to certain depths depending on water clarity, these three conditions, light, water depth, and water clarity are interdependent. In turn, suspended silt and other matter affects the substrate character. Different algae types prefer rocky, sandy, or muddy substrates and will grow only where the preferred substrates are. Some types of algae will grow only in waters with a normal marine salinity while others have adapted to a wide range of salinities and flourish in hypersaline water to fresh water. Temperature of the water influences geographic distribution of algae greatly. Most modern species live in warm water, while some live in temperate water and only a few are restricted to cold water (Johnson, 1961). Since temperature varies with depth of water, algae growth depends on a combination of both factors. Some circulation is required for abundant algae (Johnson, 1961), but according to Heckel (1972), ". . . luxuriance of algal growth is inversely proportional to turbidity of the water." That is to say, slightly agitated water without strong currents are preferred for prolific algal growth. Light, water depth, water clarity, substrate character, water salinity, water temperature, and water circulation are interrelated factors affecting algae distribution. The combined effects of these environmental conditions determine the type and amount of algal growth.

Evidence of algae growing at the time of deposition of calcareous sediments which now comprise the St. Louis Limestone is found in preserved calcareous green and blue-green algae fragments, algal spore cases (calcispheres), and blue-green algal structures (cryptalgalaminate carbonates, oncolites, and domal stromatolites).

Most green algae species inhabit marine waters while some species inhabit fresh water and a few species inhabit brackish water. Green algae prefer a stable, sandy or muddy substrate, as well as shallow, warm, slightly agitated waters. This algae group is most abundant just below low tide level, but may grow in waters up to 180 feet deep (Heckel, 1972). St. Louis Limestone green algae fragments were from exclusively marine Codiaceae and Dasycladaceae families. Both families tolerate salinity changes and are most abundant in shallow protected lagoons (Wray, 1971b). The units containing fragments of green algae were deposited in supratidal, intertidal to upper subtidal, and open marine environments. Two-thirds of these units were intertidal to open marine, and one-third were supratidal. Although marine green algae are placed only in intertidal and subtidal regimes by Heckel as seen in Figure 7, a supratidal origin is also possible since several types of green algae have been found in brackish bays and lagoons along the Texas coast (Taylor, 1954). Since most of the St. Louis Limestone units containing calcareous green algae fragments were deposited in intertidal to subtidal areas, green algae most likely were more abundant here than in supratidal areas.

Blue-green algae inhabit much more diverse environments than green algae. They are found in fresh water, hot and cold springs as well as in normal marine to hypersaline water. Calcareous cellular framework of blue-green algae may be preserved, but generally blue-green algae form mucilagenous mats in supratidal and intertidal flats withstanding extreme salinity variations in addition to periodic long-term desiccation (Heckel, 1972). In algal mats, the algae are preserved only in the structures they created by sediment-trapping (oncolites and stromatolites). Thus, blue-green algae in these structures are not taxonomically identifiable since their calcareous "skeletons" were destroyed.

Fragmented calcareous "skeletons" of blue-green algae were found in a few St. Louis Limestone units of intertidal to upper subtidal origin. Calcispheric units and cryptalgalaminate carbonates (planar stromatolites) were supratidal in origin, while most oncolitic units and all domal stromatolites (algal biolithites) were intertidal to upper subtidal in origin. A few oncolitic beds were of open marine origin because of transport of the oncolites into an open marine area by currents. In the St. Louis Limestone units that were studied, blue-green algae grew in supratidal and intertidal to upper subtidal environments.

ALGAE IN THE ST. LOUIS LIMESTONE

Aitken's Classification of Algal Carbonates

J.D. Aitken (1967) set up a classification of algal carbonates appropriate for use in this study (Fig. 8). Aitken divided algal carbonates into two major categories: those composed of skeletal calcareous algae and those composed of noncalcareous blue-green and green algae, defined as cryptalgal carbonates. The term cryptalgal was chosen by Aitken ". . . in reference to the fact that in these rocks the influence of algae in the rock-forming process is more commonly inferred than observed." Aitken did not further classify calcareous algae carbonates, but he concentrated on defining and classifying carbonates with probable algal origin. According to Aitken, cryptalgal carbonates are either cryptalgal biolithites or cryptalgal fragmental carbonates.

Cryptalgal biolithites comprise most cryptalgal carbonates and include oncolites, stromatolites, thrombolites, and cryptalgalaminate carbonates. Oncolites are algal-related, generally spheroidal structures with somewhat concentric laminations. Although Logan et al. (1964) consider oncolites as a type of stromatolite, Aitken classifies the two separately. Stromatolites are defined by Aitken as ". . . bodies of cryptalgal origin, characterized by non-planar lamination and possessing definable boundaries or contacts with other stromatolites." The term thrombolite

ALGAL CARBONATES

- Carbonates composed wholly or partly of skeletal calcareous algae (not further classified)
- CRYPTALGAL CARBONATES (Noncalcareous, blue-green and green algae)
  - Cryptalgal biolithites
    - Oncolites (Oncolitic carbonates)
    - Stromatolites (Stromatolitic carbonates)
    - Thrombolites (Thrombolitic carbonates)
    - Cryptalgalaminate carbonates
  - Cryptalgal fragmental carbonates
    - Cryptalgal biocalcirudite *
    - Cryptalgal biocalcarenite *
    - Cryptalgal biocalcisiltite *
    - Cryptalgalaminate breccia *

* (or derived dolomite)

Figure 8. Classification of algal carbonates (from J.D. Aitken, 1967).

is proposed for stromatolite-related structures which are ". . . lacking lamination and characterized by a macroscopic clotted fabric." By their definition of stromatolites, Logan et al. (1964) include planar laminated carbonates in the stromatolite group, but they do not include planar laminated carbonates in their classification. Thus, Aitken introduced the term cryptalgalaminate in reference to carbonates with planar laminations probably resulting from sediment-trapping green and blue-green algae mats.

The second division of cryptalgal carbonates is cryptalgal fragmental carbonates. These are carbonates containing fragments with a filamentous fabric. According to size of the fragments, from coarse to fine, the cryptalgal fragmental carbonates are cryptalgal breccias, cryptalgal biocalcirudites, cryptalgal biocalcarenites, or cryptalgal biocalcisiltites.

Algae in the St. Louis Limestone

Calcareous Algae Fragments

Identified Types

Fragments of calcareous algae observed in several St. Louis Limestone units were identified as belonging to four genera, *Koninckopora*, *Ortonella*, *Girvanella*, and *Pseudohedstroemia*. A simplified classification of the identified calcareous algae genera appears in Table VI. By volume, the algae fragments always comprised less than ten percent and generally comprised less than five percent of the total

TABLE VI

CLASSIFICATION OF IDENTIFIED CALCAREOUS ALGAE GENERA FROM THE ST. LOUIS LIMESTONE

Green algae

Codiaceae

Ortonella

Pseudohedstroemia

Dasycladaceae

Koninckopora

Green or blue-green algae

Porostromata

Girvanella

thin section. The algae fragments were observed mainly in biosparites and biomicrites, but were also observed in two intrasparites, one oosparite, and one biolithite. Most of the algae were associated with several fauna, but especially echinoderms and foraminifers. Ostracodes, bryozoans, calcispheres, and brachiopods occurred next in abundance in algal beds, while gastropods and corals were sparse in algal beds. Other allochems occurring in algal beds in order of abundance were intraclasts, oolites, and pellets. Secondary carbonates, microspar, pseudospar, and dolomite, were not associated with the algae fragments and only one algal bed contained a small amount (about five percent) of silt-sized terrigenous quartz. Preservation of the algal fragments ranged from poor to good, with most fragments in the poor category. Those bits of algae that were too poorly preserved for identification are discussed in the next section.

All but three of the St. Louis Limestone carbonates prefixed with "algal" in the Appendix contained calcareous algae fragments. Two of the exceptions were algal biolithites while the third was an algal dolomite. In thin section, calcareous algae fragments were not preserved in all three beds, but algal-like structures and filaments indicated their algal origin. In all, eighteen algal-prefixed carbonates contained greater than one percent calcareous algae fragments, and four beds not applicable to Folk's classification (labeled N.A. in the Appendix) contained calcareous algae fragments. All identified algae were from four genera. Table VII lists all 29 St. Louis Limestone beds under the genus (genera) of the algae found in those beds.

The following morphological characteristics of the genera, *Koninckopora, Ortonella, Girvanella,* and *Pseudohedstroemia* were taken from J.H. Johnson (1961), J.H. Johnson and K. Konishi (1956), J.L. Wray (1977), and B.L. Mamet and A. Roux (1978). The growth forms of these genera are illustrated in Figure 9.

Koninckopora has an elongate, cylindrical thallus with closely spaced, cylindrical or subpolygonal branches. Species are determined on the basis of cell and cell wall diameters (of the branches). According to Johnson and Konishi (1956), some plants may have been over 50 centimeters long and ranged from less than one centimeter to over four centimeters in diameter. Fragments over ten centimeters long have been found.

Ortonella is distinguished by uniform tube diameters with y-shaped branching, usually at a 40 degree angle. The straight to slightly undulating tubes are separated from each other. Species are determined on the basis of tube diameter and angle of branching. Individual filaments are 25 to 50 microns in diameter, while growth forms range from one to ten millimeters (Wray, 1977).

Girvanella consists of sinuous, simple, unsegmented, rarely branching tubes of uniform diameter and thick walls. Species are determined on the basis of tube diameter. The

TABLE VII

ST. LOUIS LIMESTONE BEDS CONTAINING CALCAREOUS
ALGAE FRAGMENTS FROM FOUR GENERA

Koninckopora	*Ortonella*	*Girvanella*	*Pseudohedstroemia*
algal-prefixed beds	algal-prefixed beds	beds not applicable to Folk's classification	algal-prefixed bed
A1	D4	A2	P3
C7	D5	B3	
D2	K2b	B4	less than one percent algae fragments
D4	O4b	J6	P5
F1a	P1		
F5	P4		
G5b	P6a		
H1	P6b		
N1			
less than one percent algae fragments			
D1			
D6			
I1b			
L2a			
M10			
M11			

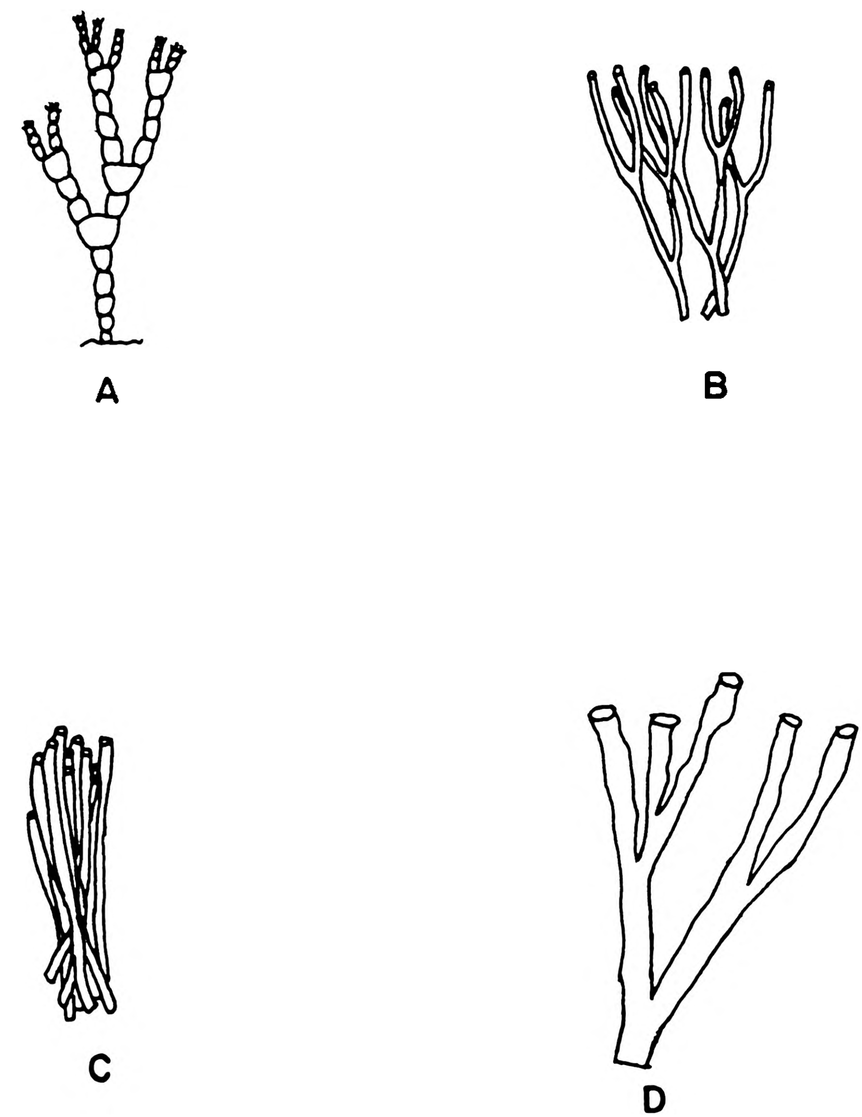

Figure 9. Growth forms of four identified calcareous algae genera from the St. Louis Limestone. A. *Koninckopora* (after Wray, 1971a, dasycladacean growth form). B. *Ortonella* (after Mamet and Roux, 1975). C. *Girvanella* (after Mamet and Roux, 1975). D. *Pseudohedstroemia* (after Mamet and Roux, 1978).

external diameter averages ten to thirty microns, but tubes with diameters of less than ten microns and up to 100 microns have been found (Wray, 1977).

Pseudohedstroemia was first described by B.L. Mamet and A. Roux (1978). The thallus forms a radial arrangement of undulating, branching tubes with variable diameters. The tubes may range from a minimum of 15 to 20 microns to a maximum of 95 microns, although tubes sometimes reach a diameter of 110 microns.

For synonymies of *Koninckopora* and *Girvanella* which are fairly complete to 1970, refer to Petryk and Mamet (1972) and Armstrong and Mamet, 1977 (*Girvanella* synonymy is late Devonian and Carboniferous only). The synonymy for *Ortonella* is given by Mamet and Roux (1975) and by Perret and Vachard (1977). *Pseudohedstroemia* was named and described by Mamet and Roux (1978) for forms from the St. Louis Limestone in Tennessee. To the author's knowledge, the specimens found in the St. Louis Limestone in Missouri and Illinois represent the only other recorded specimens.

Fragments of calcareous algae belonging to the genus, *Koninckopora,* were more abundant than those belonging to the other three genera. The observed fragments ranged from less than 0.1 millimeter in diameter in oblique sections (Fig. 10) to as large as 4.5 millimeters by 0.34 millimeter in transverse sections (Fig. 11). Although the fragments preserved in the beds are quite small in comparison to the plant's original size, most *Koninckopora* fragments were well

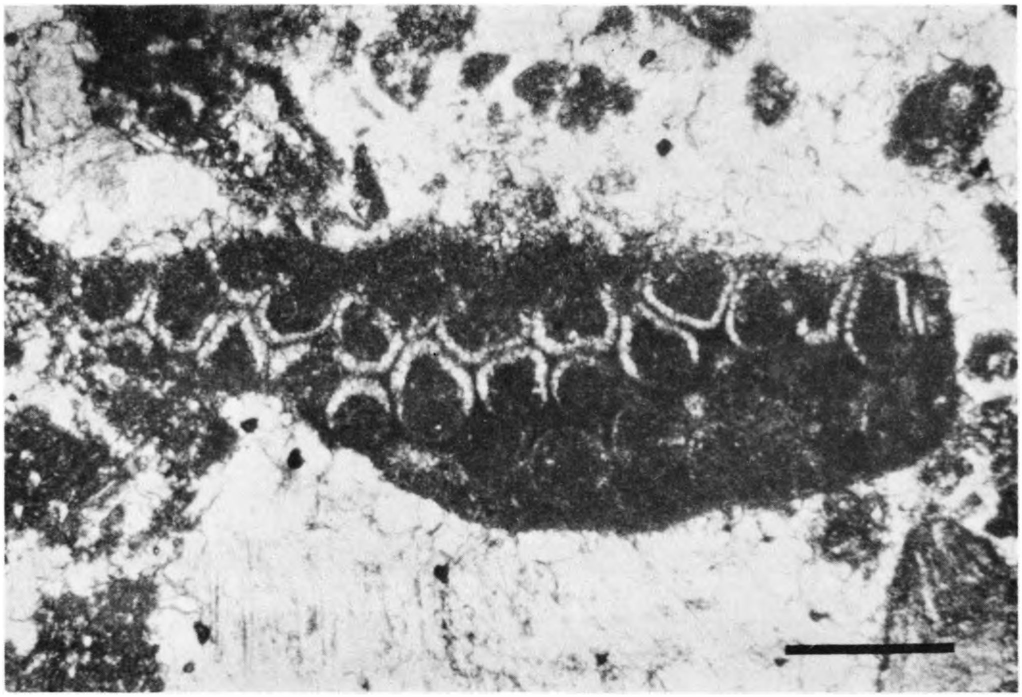

Figure 10. Photomicrograph of oblique cross-section of *Koninckopora*, Unit A1. Scale bar is 0.25 millimeter. Upward is toward the right of the photograph.

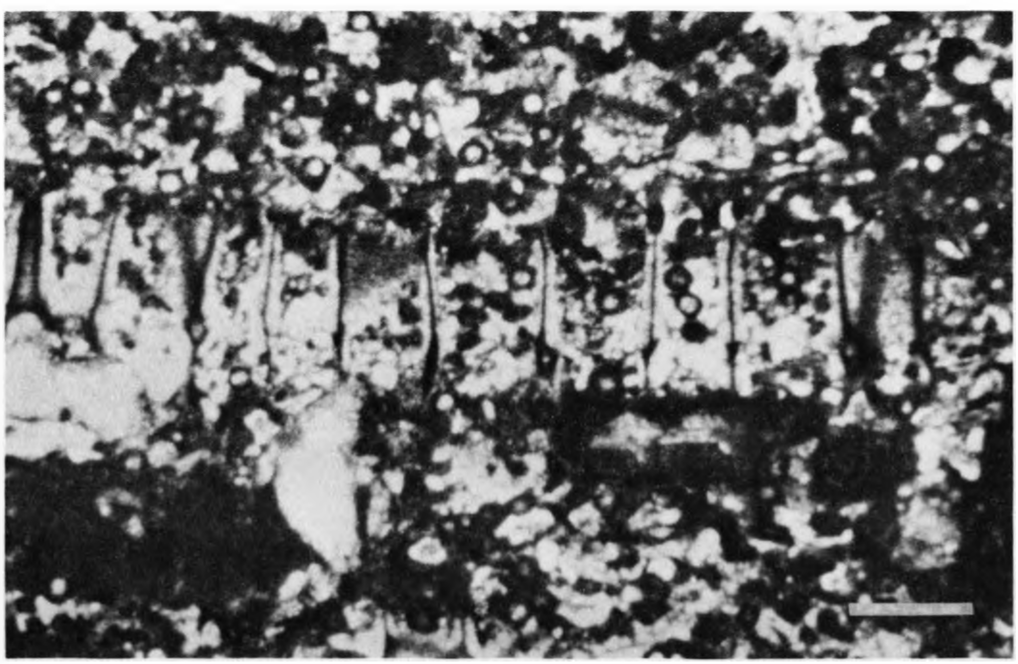

Figure 11. Photomicrograph of transverse cross-section of *Koninckopora*, Unit N1. Scale bar is 0.25 millimeter. Upward is toward the right of the photograph.

preserved.

Next in abundance were *Ortonella* fragments which ranged in size from about 0.75 millimeter long by 0.2 millimeter wide to about 4.5 millimeters in diameter. *Ortonella* filaments were present inside distinct intraclasts in beds D4 (Fig. 12), P6a, and P6b. The photomicrograph in Figure 13 illustrates *Ortonella* encrusting the top side of an unidentified fossil fragment. In this bed, as in most *Ortonella* beds, a dark, micritic matrix makes *Ortonella* fragments almost indistinguishable from the background.

Girvanella filaments were observed in four units, A2, B3, B4, and J6, as well as in oncolites of bed J4a (which will be discussed in the section on oncolites). Some of the *Girvanella* tubes might be encrusting foraminifers as the two are very similar in form (Brenckle, pers. comm.). L.G. Henbest (1963) discusses the *Girvanella*/Foraminifera relationships of *Ottonosia* and *Osagia* which are growth forms of algal-foraminiferal colonies named by Twenhofel (1919). *Ottonosia* colonies encrust the top side of fragments while *Osagia* colonies surround the nuclei in concretionary growths. According to Henbest, both growth forms are composed of girvanellids alone, of both girvanellids and cornuspirinids (family of foraminifers), but not composed solely of foraminifers. Therefore, *Girvanella* is present in part or in whole in *Ottonosia* and *Osagia* colonies.

Measurements of all good *Girvanella*/Foraminifera tube cross-sections in Unit J6 averaged 19.9 microns internal

Figure 12. Photomicrograph of *Ortonella* filaments within an intraclast, Unit D4. Scale bar is 0.5 millimeter. Upward is toward the top of the photograph.

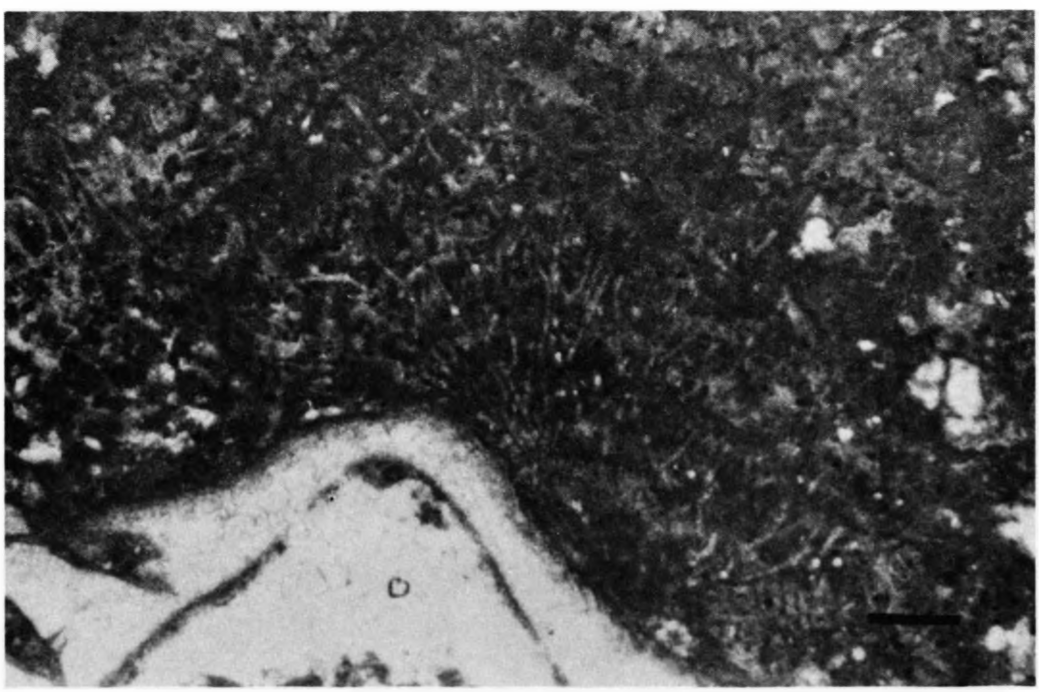

Figure 13. Photomicrograph of encrusting *Ortonella* filaments on the top side of an unidentified fossil fragment, Unit O4b. Scale bar is 0.25 millimeter.

diameter and 31.3 microns external diameter which fits John L. Wray's (1977) range of ten to thirty microns for *Girvanella*. The distinguishing characteristics of encrusting foraminifera is not size, however, but hemispherical cross-section with one side slightly flattened (Brenckle, pers. comm.). The author and T.L. Thompson (Missouri Geological Survey) were unable to differentiate girvanellids from foraminifers in the St. Louis Limestone units.

The photomicrograph in Figure 14 illustrates encrusters on a spar-filled gastropod (?) fragment. This is an example of the form genus *Osagia* described by Twenhofel (1919). For the purposes of this study, the encrusting tubes in this and in other St. Louis Limestone thin sections are designated *Girvanella*, even though some foraminifers may be present. The photomicrograph in Figure 15 illustrates more encrusting individuals of *Girvanella*.

Pseudohedstroemia intraclasts were observed in only two units, P3, and P5, both of which were intrasparites. In specimens from these beds, the algae intraclasts have been rotated from their original upward oriented position indicated by the radially-arranged filaments pointing away from the upward direction. Abundant algae intraclasts are associated with both fibrous and sparry calcite in Unit P3, an algal intrasparite (Fig. 16), while only one algae intraclast is preserved in the dolomitic matrix of Unit P5, a dolomitized silty intrasparite (Fig. 17). Although more intraclasts were present in Unit P3, they were not as well

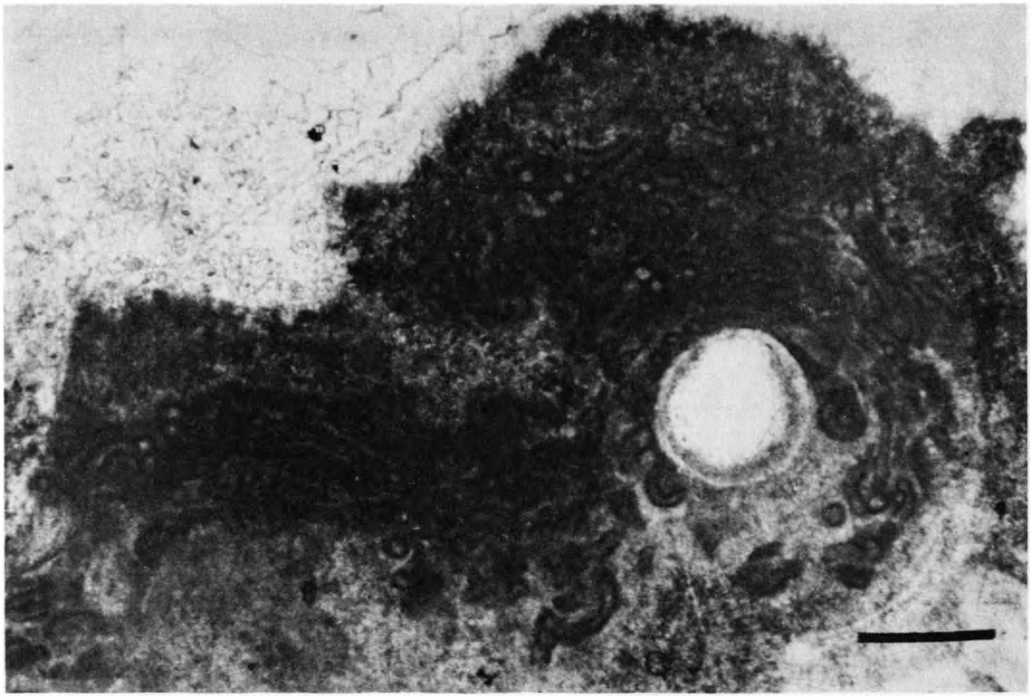

Figure 14. Photomicrograph of encrusting *Girvanella* tubes, Unit A2. Scale bar is 0.5 millimeter. Upward is toward the top of the photograph.

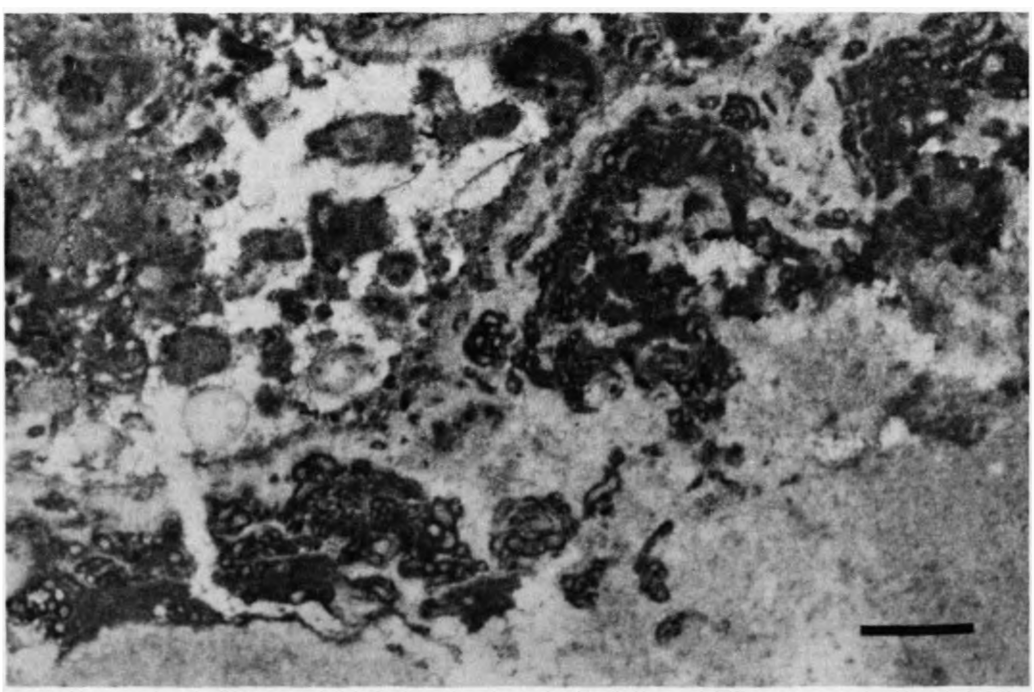

Figure 15. Photomicrograph of encrusting *Girvanella* tubes, Unit B3. Scale bar is 0.5 millimeter. Upward is toward the top of the photograph.

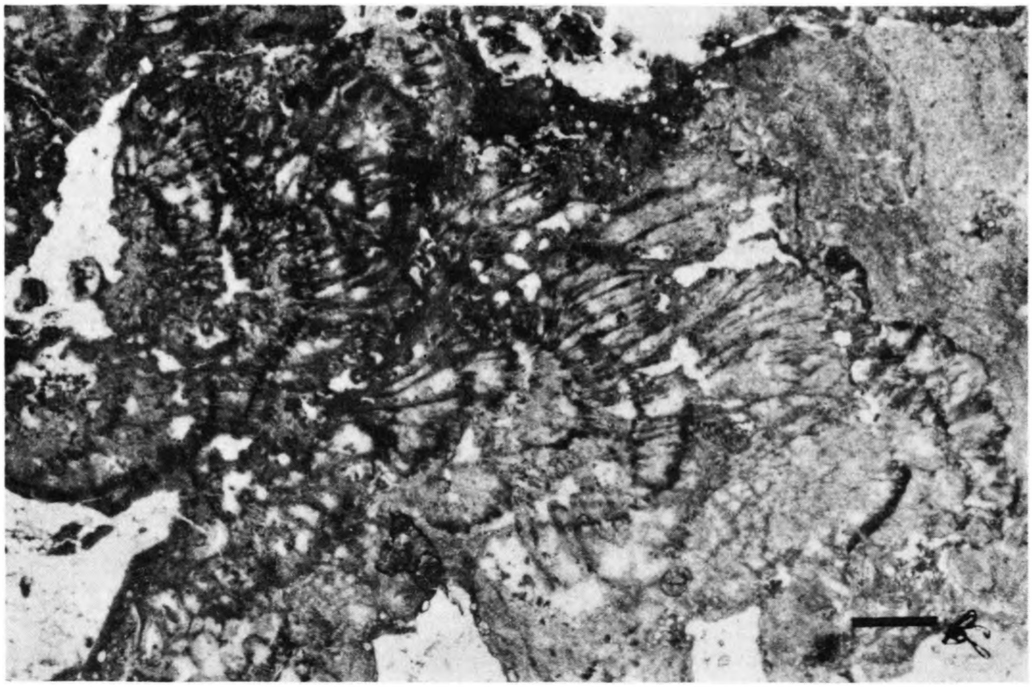

Figure 16. Photomicrograph of poorly preserved intraclasts containing *Pseudohedstroemia*, Unit P3. Scale bar is 1.0 millimeter. Upward is toward the top of the photograph.

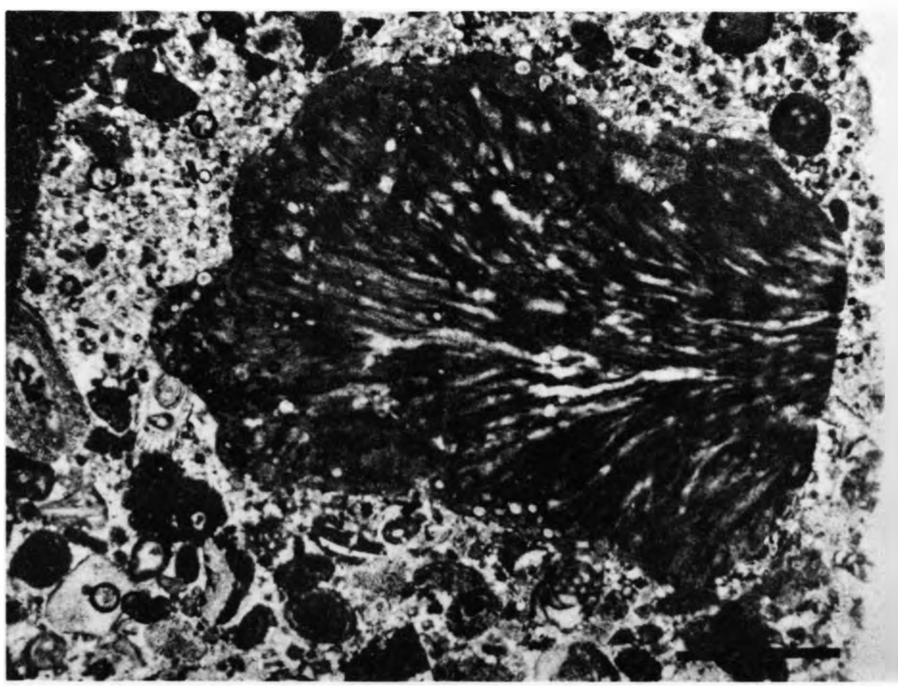

Figure 17. Photomicrograph of intraclast of *Pseudohedstroemia*, Unit P5. (Note the multiple branching.) Scale bar is 1.0 millimeter. Upward is toward the top of the photograph.

preserved as the only intraclast in Unit P5.

Unidentified Types

Several fragments of probable algal origin were unidentifiable either due to poor preservation and/or due to the fragments' small size. The algal fragments probably belong to the green algae families, Dasycladaceae and Codiaceae, and to a group of algae which is ancestral to the Corallinaceae, a Recent red algae family.

Micritized fragments the same size and shape as dasycladacean genera were noted in several thin sections, but particularly in bed G5b (Fig. 18), Unit D4, and Unit C7. *Kamaena,* a genus belonging to the Dasycladaceae, are typified by straight, cylindrical thalli which are divided by horizontal partitions. Often, spar fills the inner cells. The figured specimen resembles *Kamaena* in size, shape, and thick wall, but it lacks the inner cell partitions. Thus, it is not possible to determine if the fragments were originally *Kamaena* or *Koninckopora* (dasycladacean genera), or some other micritized organic fragment.

Several thin sections contained small fragments of poorly preserved algae which resembled the codiacean *Ortonella,* but with tubes too large in diameter. The algae fragments show definite branching and are the right size for codiaceans. Small chunks of algae were preserved in Units P1 (Fig. 19) and F3, while only scattered filaments were preserved in Unit P2 and bed H7b. The algae probably belongs to the Codiaceae family and is possibly

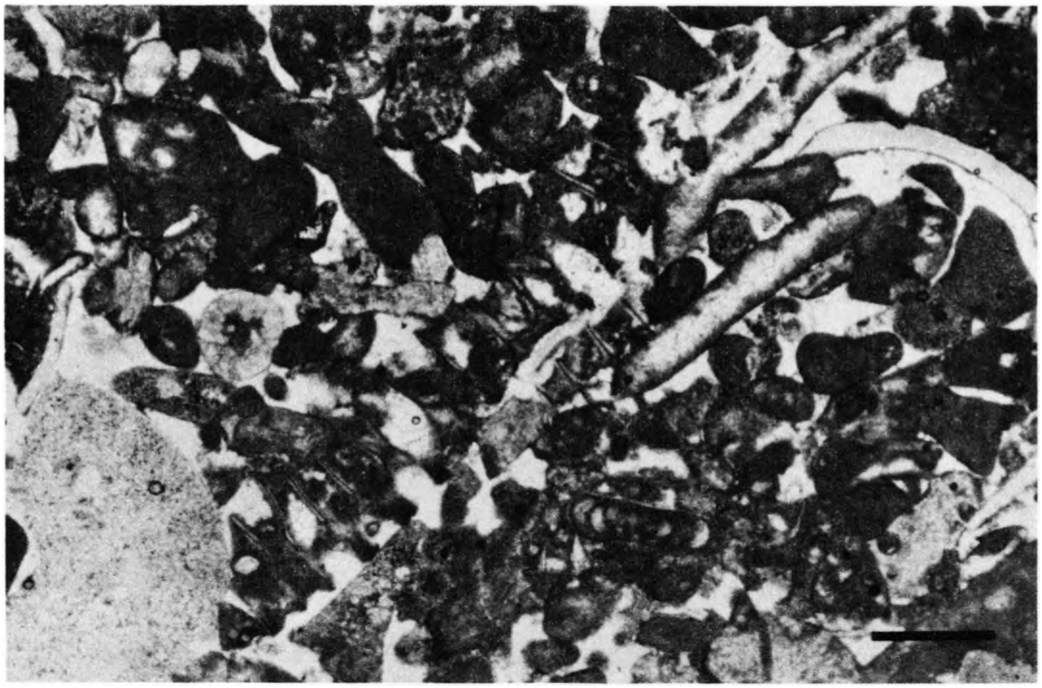

Figure 18. Photomicrograph of possible dasycladacean, *Kamaena?*, bed G5b. (Note *Koninckopora* fragments.) Scale bar is 0.5 millimeter. Upward is toward the right of the photograph.

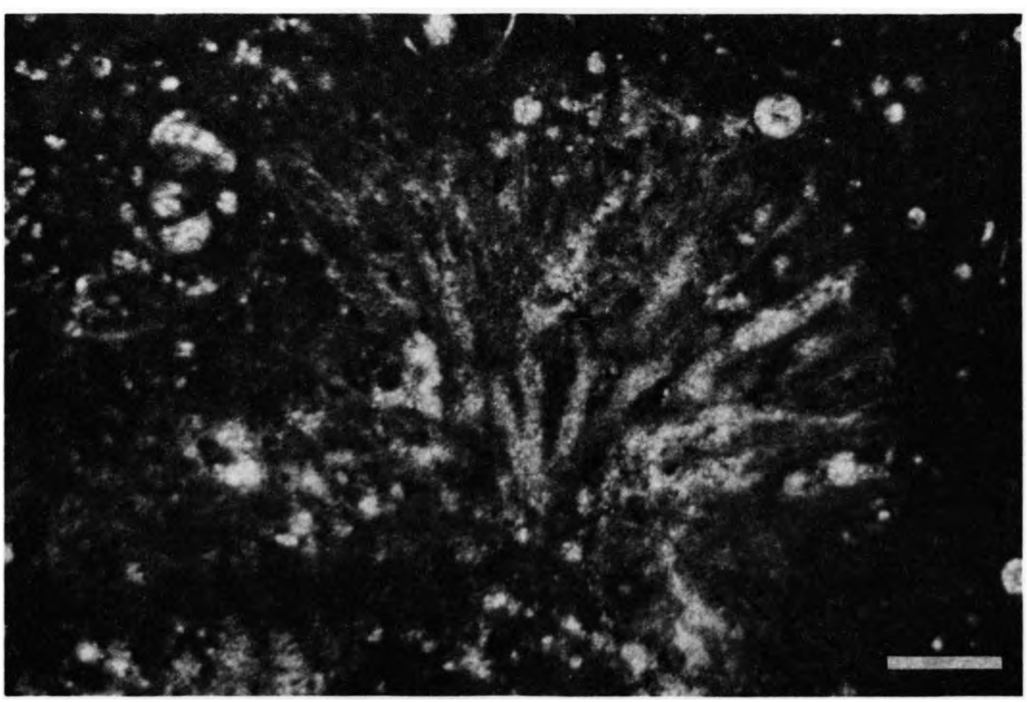

Figure 19. Photomicrograph of possible codiacean, *Pseudohedstroemia?*, Unit P1. Scale bar is 0.25 millimeter. Upward is toward the top of the photograph.

Pseudohedstroemia, *Garwoodia*, or some other branching codiacean. Similar unidentifiable algae fragments were observed in Unit D4. The largest fragment was about 3.5 millimeters across, hemispherical in shape, and consisted of radially-arranged tubes 0.19 millimeter in diameter. The type of branching was undeterminable. One of the better preserved fragments appears in the photomicrograph in Figure 20. Shaped like a fan, the algae fragment is 2.5 millimeters across with tubes similar to those of the codiacean genera.

An unusual and unique fossil fragment of possible red algal origin is pictured in Figure 21. The fragment is 0.86 millimeter to 0.9 millimeter across with large cells lined lengthwise down the center and with progressively smaller cells parallel to and located on either side of the large cells. The largest cell is about 0.16 by 0.28 millimeter, while the next size cell is about 0.09 by 0.09 millimeter, and the smallest cells are 0.09 by 0.04 millimeter. The cell shapes range from subpolygonal to rectangular. An ancestral coralline genus, *Archaeolithophyllum*, ranging from early Carboniferous to late Permian, has a similar closely packed cell arrangement. The thallus of this alga is several centimeters in length and 0.2 by 0.8 millimeter thick (Wray, 1977). The cellular tissue is differentiated into an inner, thick hypothallium consisting of polygonal cells up to 0.15 millimeter in length and an outer perithallium consisting of smaller rectangular cells parallel to the surface of the thallus. Although the cells

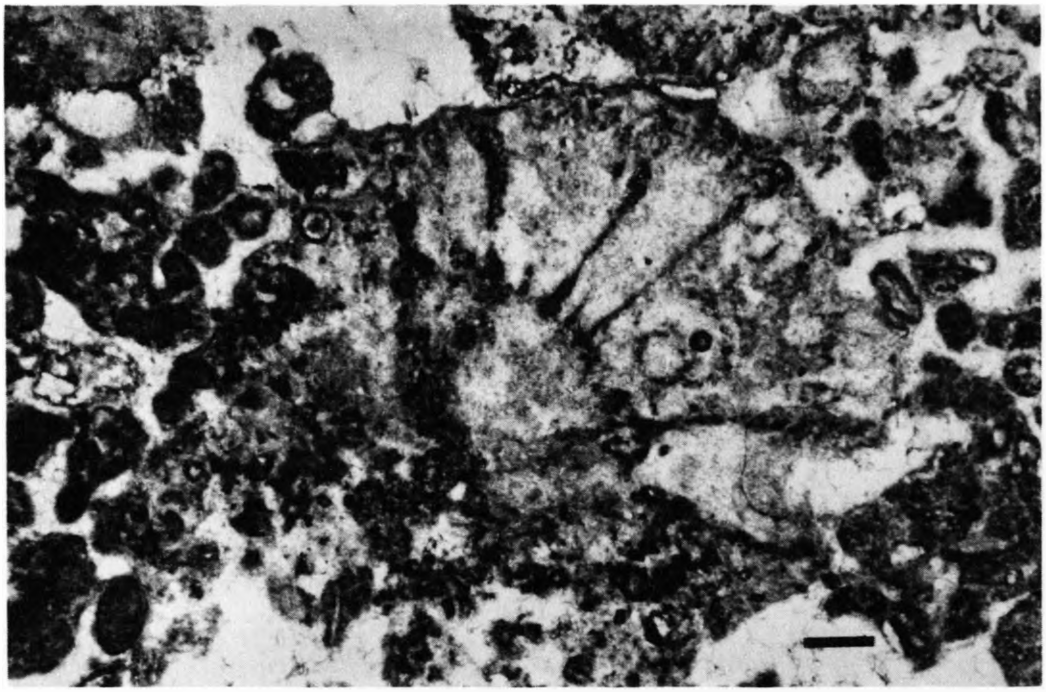

Figure 20. Photomicrograph of possible codiacean, Unit D4. Scale bar is 0.25 millimeter. Upward is toward the top of the photograph.

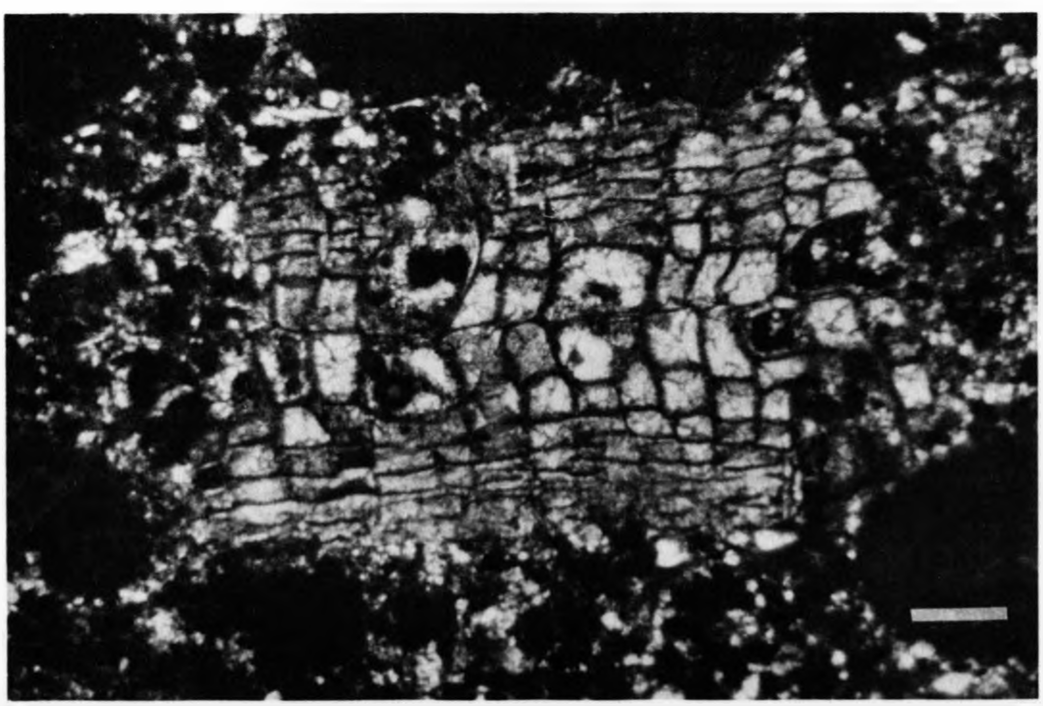

Figure 21. Photomicrograph of possible ancestral member of the Corallinaceae, Unit H11. Scale bar is 0.2 millimeter. Upward is toward the top of the photograph.

of the algae fragment from Unit H11 are slightly larger than those of *Archaeolithophyllum,* their cell shapes and arrangement are very similar. The algae fragment from Unit H11 is probably an ancestral member of the Corallinaceae.

Cryptalgal Carbonates

Cryptalgal Biolithites

The cryptalgal biolithites of Aitken's classification (1967) include oncolites, stromatolites, thrombolites, and cryptalgalaminate carbonates. Folk defines biolithites as undisturbed biohermal rocks in his classification which was utilized in thin section study. Since oncolites require movement for algal accretion, they are not biolithites by Folk's definition. So, St. Louis Limestone beds containing abundant oncolites were termed oncolitic carbonates. Stromatolites and algal-laminated sediments, on the other hand, were considered biolithites since the sediment-binding algae, when living, was growing in mats now represented by laminae. Thrombolites as described by Aitken were not observed in St. Louis Limestone thin sections or in the field, but some units displayed thrombolite characteristics.

Seventeen St. Louis Limestone beds contained oncolites (Table VIII), but only eight beds contained a sufficient amount to be termed oncolitic. The oncolites ranged in size from about three millimeters to about nine centimeters, with an average of two to three centimeters in diameter. Their shape was oval to round and many were flattened. Cross-sections in three perpendicular planes revealed

TABLE VIII

ST. LOUIS LIMESTONE BEDS CONTAINING ONCOLITES

beds containing abundant oncolites	beds containing sparse oncolites
A4	A7
A5	B2
A6	E1
I7	E3
J4a	H10
J5	J6
O4b	J7
P2	P4
	P6

concentric laminations which suggests the algal balls were rolled around in many different directions and did not form in long rolled sheets which later disintegrated into small fragments. Although concentric, the laminae were generally crinkly and uneven. Most of the oncolites formed individual balls, but some oncolites were incorporated in new algal ball growths which resulted in a mass of connected balls (Fig. 22). The photograph in Figure 23 illustrates an undeveloped form of oncolite without visible laminae. Desiccation of algal mud resulted in curled fragments. A later inundation rolled the algal fragments into oncolites. Many oncolites associated with fine silt generally weathered out on the outcrop (Fig. 22, upper specimen). Other oncolites, in a fine carbonate matrix, were not as easily weathered out (Fig. 24). In thin section, the oncolites were associated with fine fossil debris, usually of girvanellids, ortonellids, ostracodes, gastropods, echinoderms, and encrusting foraminifers, and sometimes of sponge spicules, bryozoans, and calcispheres (Fig. 25A). Although the oncolite thin section illustrated in Figure 25A shows a micrite matrix, more often than not, the oncolitic carbonate matrix was spar cement, probably due to winnowing currents which also form oncolites. Both the oncolite in Figure 25A and the hand specimen oncolites in Figure 25B are from Unit I7.

Only two units, D5, and C14, could be considered domal stromatolites, both of which were algal biolithites. Unit

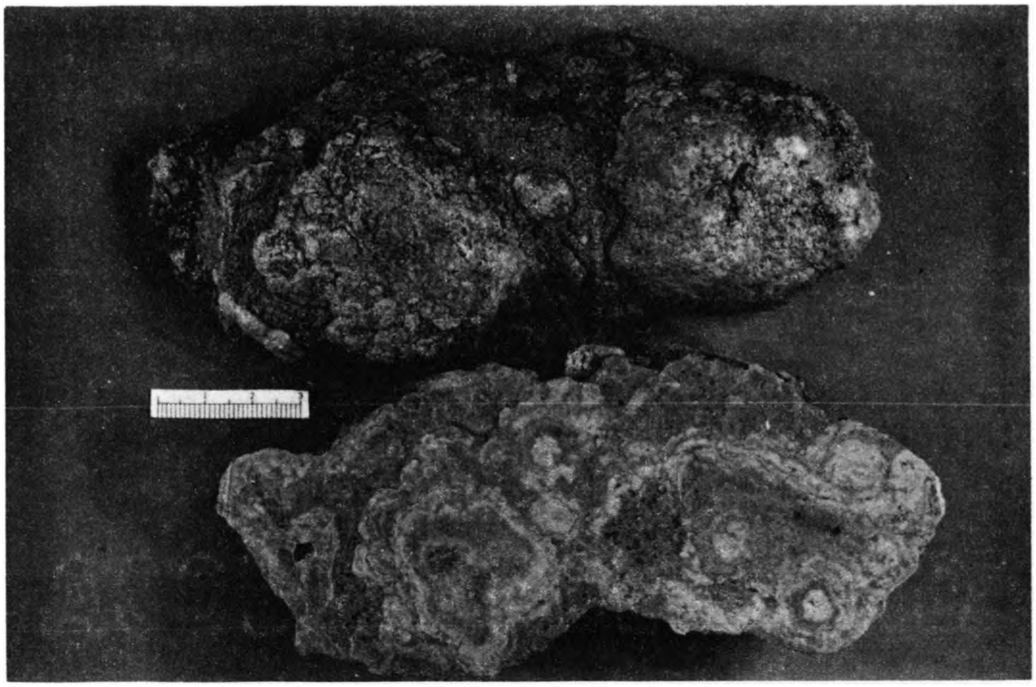

Figure 22. Weathered surface (above) and cut surface (below) of intergrown oncolites, bed J4a. Scale is in centimeters. Upward is toward the top of the photograph.

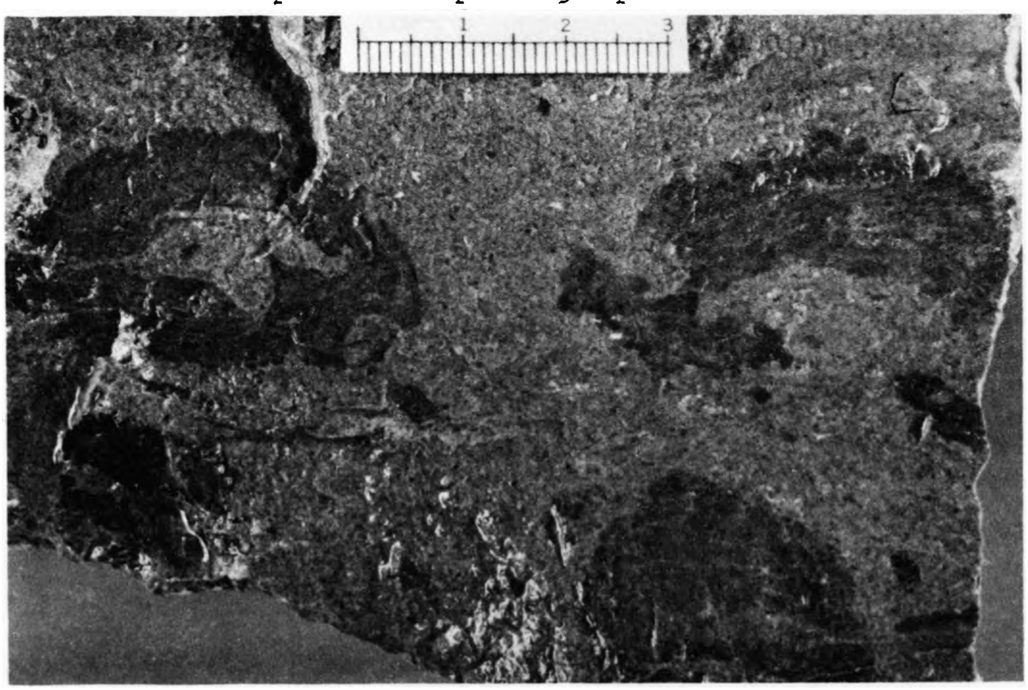

Figure 23. Partially developed oncolites, hand specimen, Unit P2. Stages of development from primitive to mature are demonstrated in the oncolites from upper right, to upper left, to lower right. Scale is in centimeters. Upward is toward the top of the photograph.

Figure 24. Oncolites in outcrop, Stolle Quarry, Unit O4. Scale bar is approximately 12.5 centimeters.

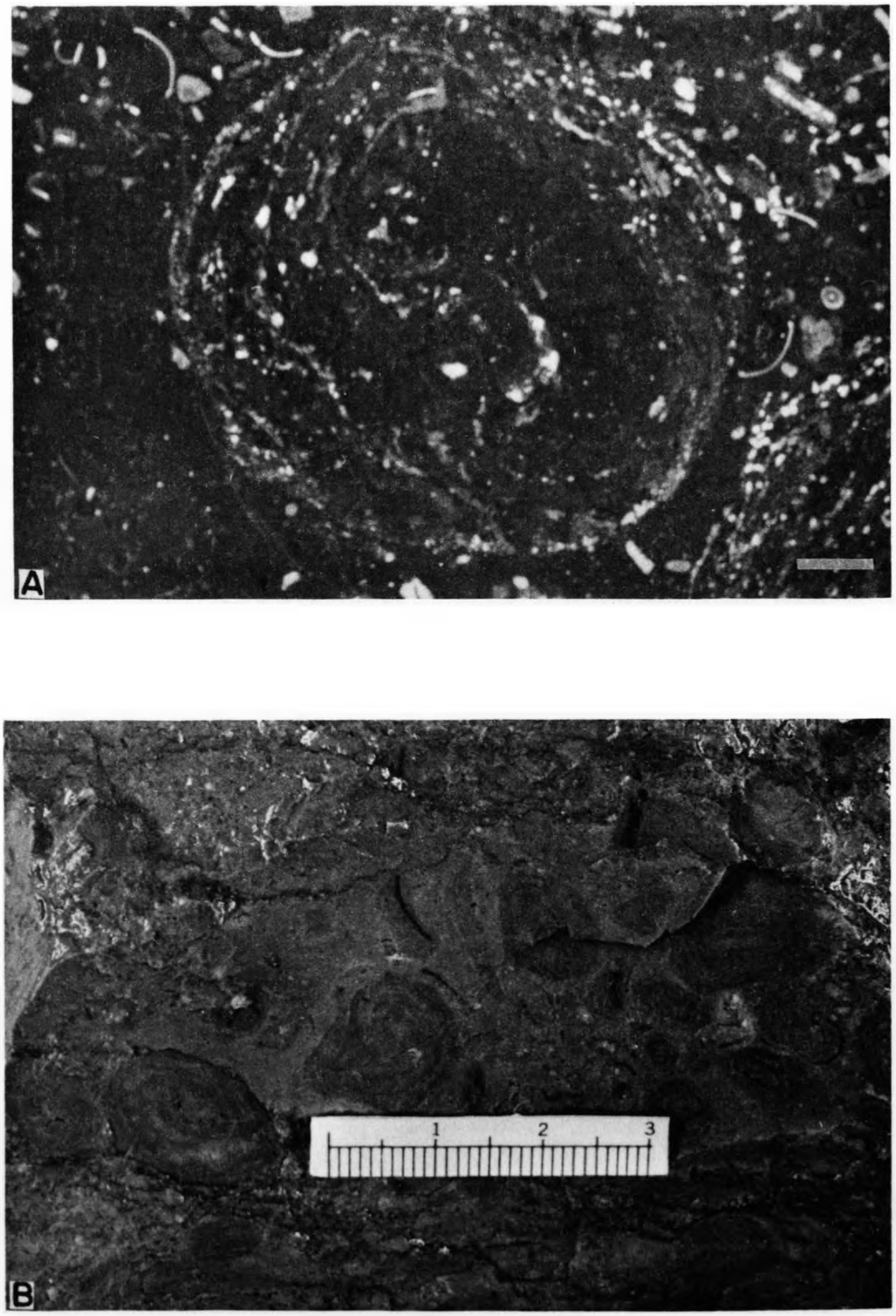

Figure 25. Oncolites from Rock Hill Quarry, Unit I7.
A. Thin section photomicrograph. Scale bar is 1.0 millimeter. Upward is toward the right of the photograph. B. Hand specimen photograph. Scale is in centimeters. Upward is toward the top of the photograph.

D5 consisted of broad domal buildups 30 to 305 centimeters in diameter with up to 30 centimeters vertical relief. The mounds were very weathered and pitted at the top of the unit with dolomitic channels running between them (Fig. 26). The mound buildups were attributed to the alga, *Ortonella,* through thin section study (Fig. 27). The *Ortonella* fragments were recrystallized and thus, are not very well preserved. Sparse ostracode and gastropod fragments were present as well as unidentifiable encrusting foraminifers or another alga. Unit C14, on the other hand, consisted of small-scale stromatolites in the upper 15 centimeters with laminae displaying relief from only four to five centimeters. In thin section, the unit appeared to be an algal laminate with scarce fossil debris and associated with a little dolomite. Because of both thin section and field characteristics, the unit was considered a domal stromatolite.

Several St. Louis Limestone beds were laminated on both macro- and micro- scales. Some laminae were formed by sediment changes and others were formed by layering of fossil fragments. Many laminae, however, were probably formed by sediment-trapping blue-green and green algae in which case the units should be classified as cryptalgalaminate carbonates. Aitken (1967) lists several factors for identifying cryptalgalaminate carbonates, a combination of which may be expressed by cryptalgalaminate carbonates. These identifying criteria are:

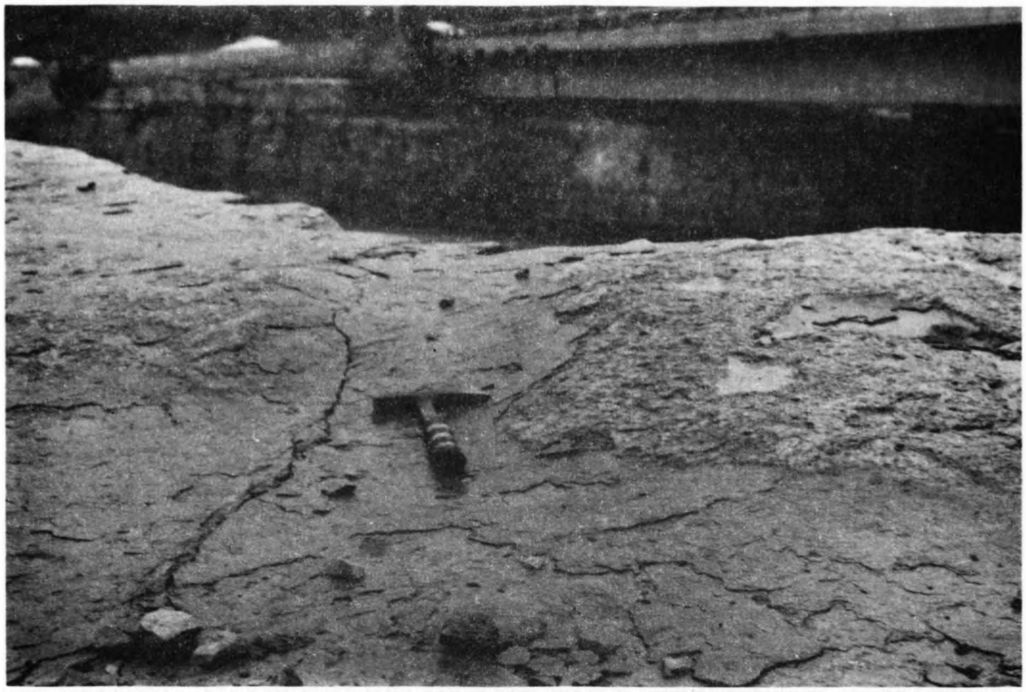

Figure 26. Outcrop view of domal stromatolites (algal mounds) from Watson Road roadcut, Unit D5. Hammer is scale lying in a dolomitic channel between mounds.

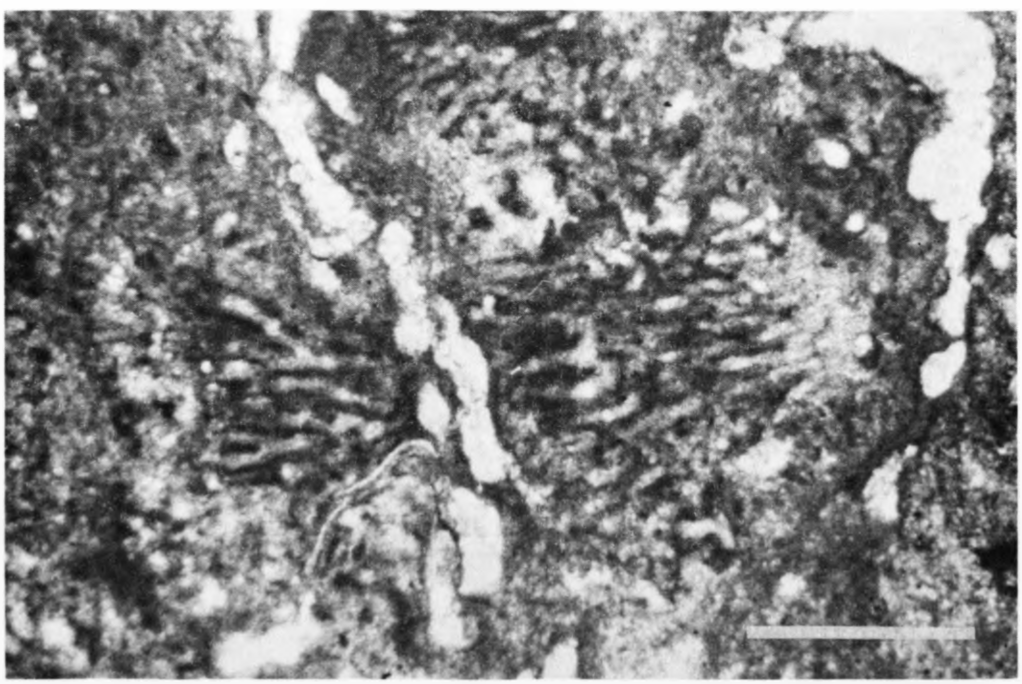

Figure 27. Photomicrograph of recrystallized *Ortonella* fragments from domal stromatolites, Unit D5. Scale bar is 0.125 millimeter. Upward is toward the right of the photograph.

a. The lamination is not explainable as due to settling of sediment in still water, deposition from currents of variable velocity, or periodic chemical precipitation.
b. The laminae do not pinch and swell to compensate for relief on the underlying surface, but rather bear an encrusting relationship.
c. Small-scale "disconformities" are common.
d. Domes and bubbles on the scale of a few millimeters are common.
e. "Birdseyes" (Ham, 1952) of sparry calcite or dolomite are common.
f. Domal or polygonal stromatolites may be associated.
g. Desiccation cracks may be present.
h. Thin breccias of chips of carbonate rock identical with the associated laminated carbonates and of lamina thickness are commonly associated.
i. The carbonates are characteristically dense and light-colored, and are more commonly dolomite than limestone.
j. Pellets similar to those found in stromatolites are common and may be abundant.
k. Particles such as intraclasts and pellets are generally not in contact with one another, but are 'supported' by dense matrix or sparry carbonate.
l. Traces of poorly preserved filaments may be present.
m. Tubules (burrows?) of sub-millimeter diameter may be abundant.

Aitken stresses the fact that not all the above characteristics need be present in order for the bed to be a cryptalgalaminate carbonate.

Two St. Louis Limestone units, H4 (Fig. 28) and L6, displayed several cryptalgalaminate characteristics. Because the now-replaced algae mats are still in their original growth position, the units should be considered biolithites. Unit L6 was named a biolithite, but because Unit H4 was a dolomite, and biolithites are classified under limestones by Folk, the unit was named an algal dolomite

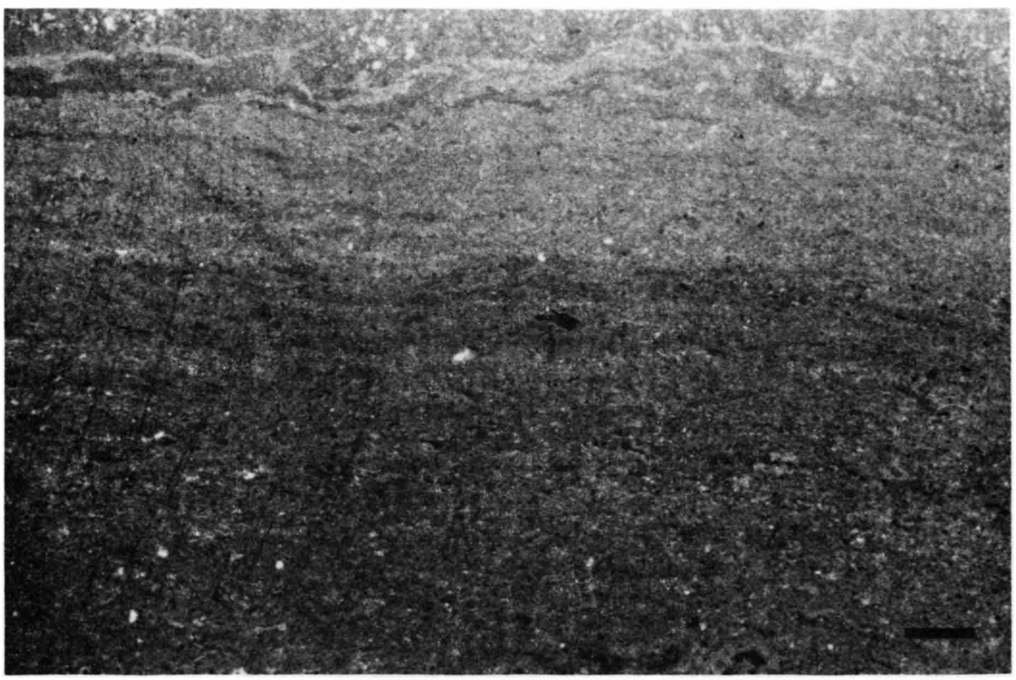

Figure 28. Photomicrograph of a cryptalgalaminate carbonate, Unit H4. Scale is 1.0 millimeter. Upward is toward the top of the photograph.

in the Appendix.

Nine other laminated beds displaying subtler cryptalgalaminate characteristics were: C6, C7, E2, F2, I4, L2b, L4, N2, and N3. The laminae in these units were due to dolomite/micrite, micrite/spar, or microspar/spar microinterlayering. According to Gebelein and Hoffman (1971), dolomite/calcite interlaminations on a micro-scale may be stromatolitic or cryptalgal in origin with the dolomite derived from algal-rich laminae and the limestone derived from sediment-rich laminae. Their laboratory experiments with living blue-green algae revealed algal mat material contains three to four times the amount of magnesium as calcium. Because Recent stromatolites with algal mat laminations alternating with sediment laminations do not contain dolomite, the authors conclude the dolomitization is secondary, controlled by the primary constituents, algae and sediment layers. The interlayering of different sizes of carbonate grains in St. Louis Limestone beds is difficult to explain, but is probably controlled by primary layers, also. The process of carbonate grains recrystallizing to a larger crystal size of the same composition is termed aggrading neomorphism by Folk (1965). This type of recrystallization may have taken place in St. Louis Limestone laminated carbonates with final crystal size proportional to original crystal size. Another explanation for the presence of alternating layers of large and small crystals might be dedolomitization, that is, replacement of dolomite by calcite. In this case, primary or secondary layers of dolomite and calcite control the final layered crystal sizes. Because the cryptalgal characteristics in these laminated beds were subtle, the beds were not considered biolithites, but they might be cryptalgalaminate carbonates.

Four St. Louis Limestone units, A2, B3, B4, and J6, displayed the clotted fabric characteristic of Aitken's (1967) thrombolites, but the units were bedded and not variously shaped lenses as were those of Aitken. Because the four units contained two carbonate rock types each in thin section, they were not applicable to Folk's classification and thus, were designated "N.A." in the Appendix.

Among common elements, the four units contained two carbonate types each and fibrous spar which is not categorized in Folk's classification. In thin section, all four units displayed fibrous spar (mostly intraclasts), micritic intraclasts, and coarse sparry calcite (Fig. 29). Ostracodes, fibrous spar-filled gastropods, and girvanellids (Fig. 30) were fossils common to all four units. In hand specimen, the four samples were very similar, mottled dark and light gray. Figures 31 and 32 illustrate hand sample photographs of three of the units. Since Units B3 and B4 are very similar, photographs of only Unit B4 are included.

The main difference between the units was the amount and preservation of the fibrous spar. Unit A2 contained the least amount and poorest preserved fibrous spar in only a few intraclasts, while J6 contained about 40 percent

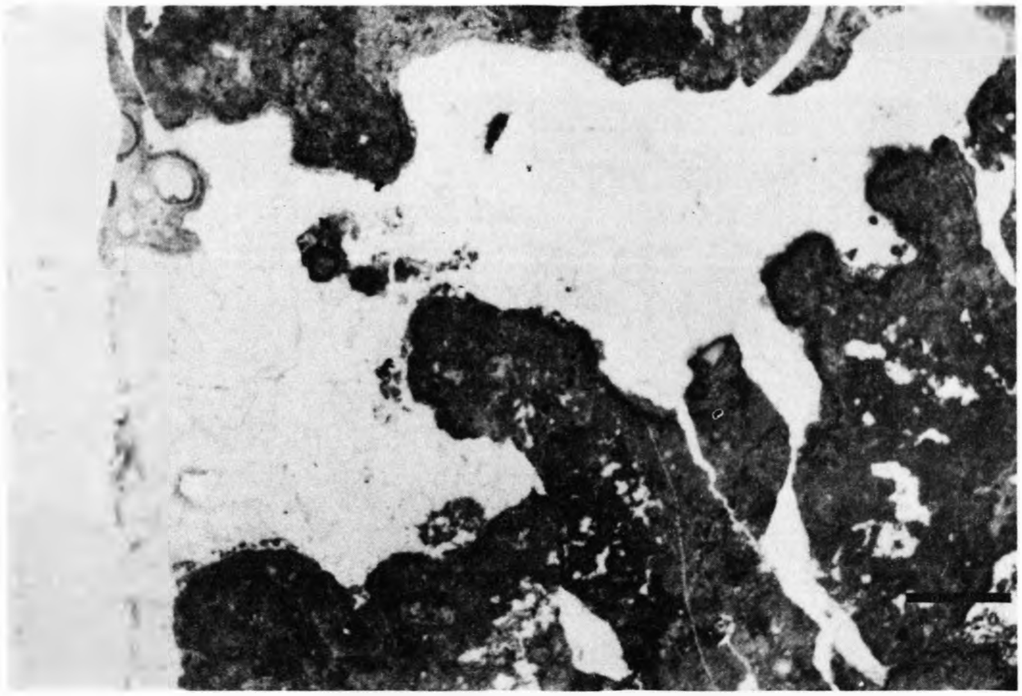

Figure 29. Photomicrograph of biomicrite intraclasts in a coarse spar matrix, Unit B4. (Fibrous spar not visible at this scale.) Scale is 1.5 millimeters. Upward is toward the top of the photograph.

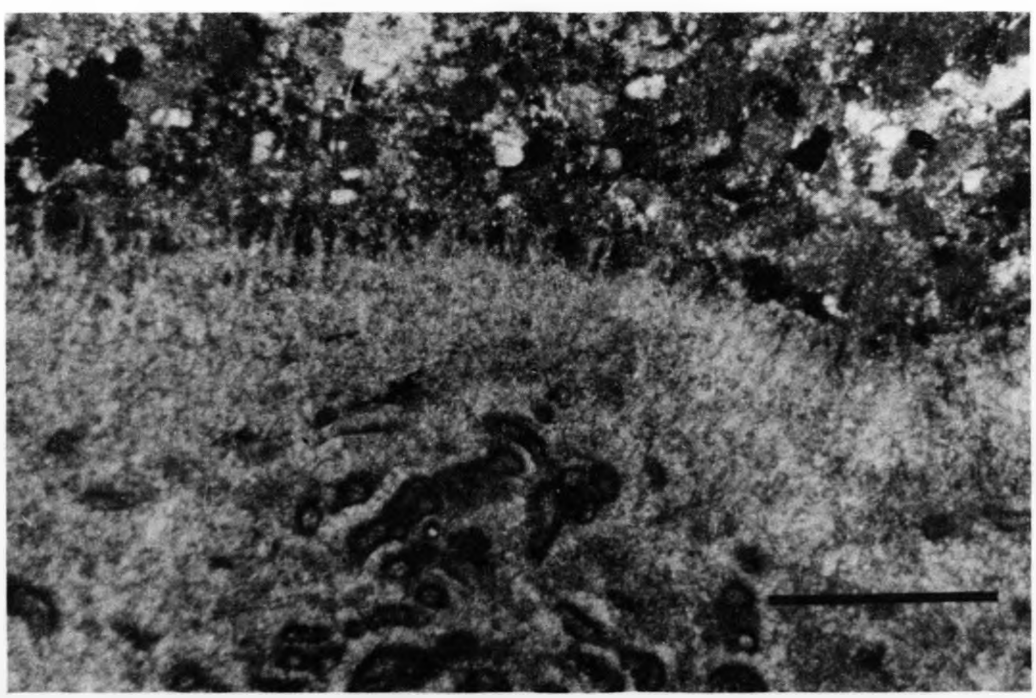

Figure 30. Photomicrograph of encrusting girvanellids in fibrous spar, Unit J6 (crossed nicols). Scale bar is 0.125 millimeter.

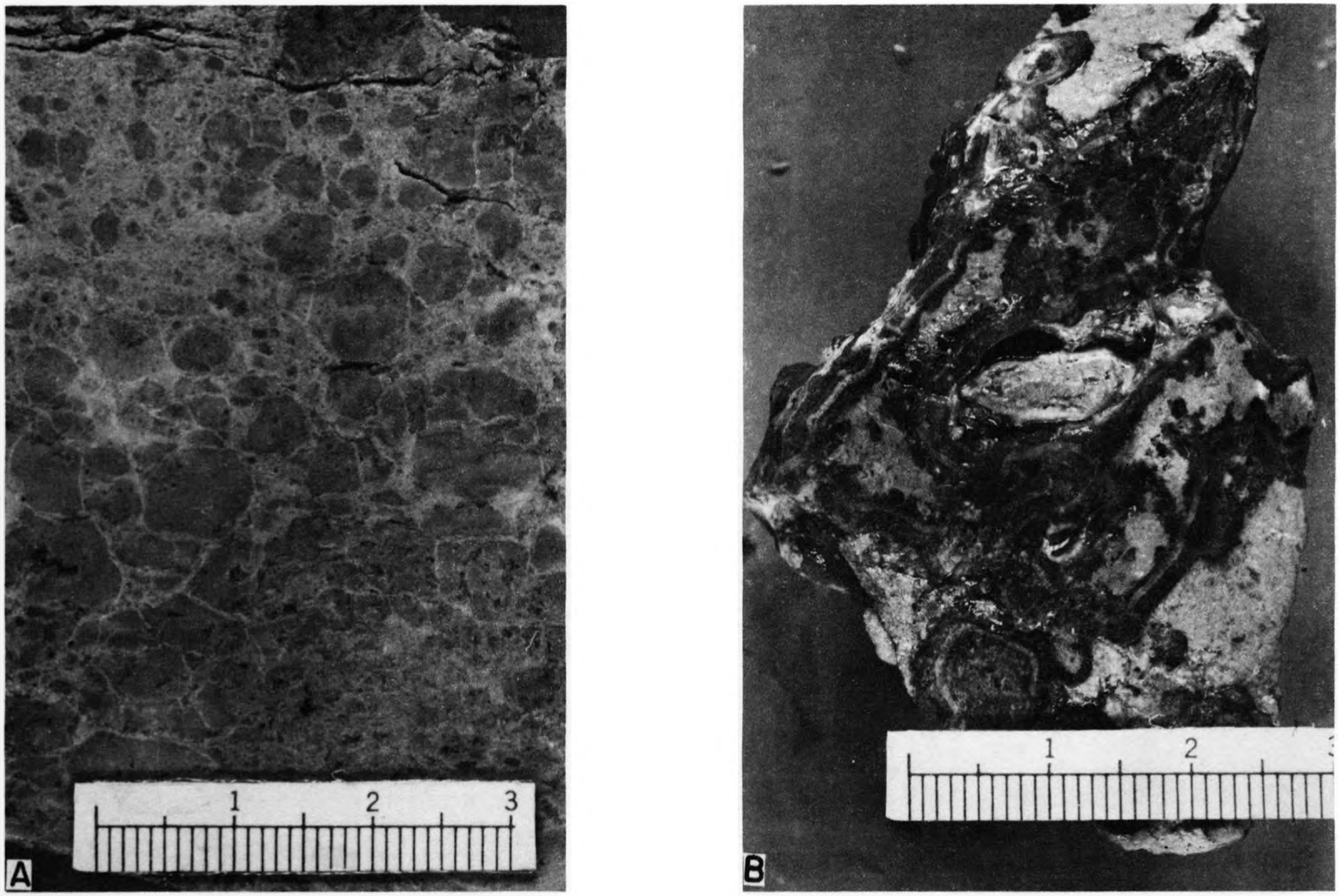

Figure 31. Hand specimen photographs of three similar units. A. Cut surface of Unit A2. Upward is toward the top of the photograph. B. Uncut surface, Unit J6. Scale is in centimeters.

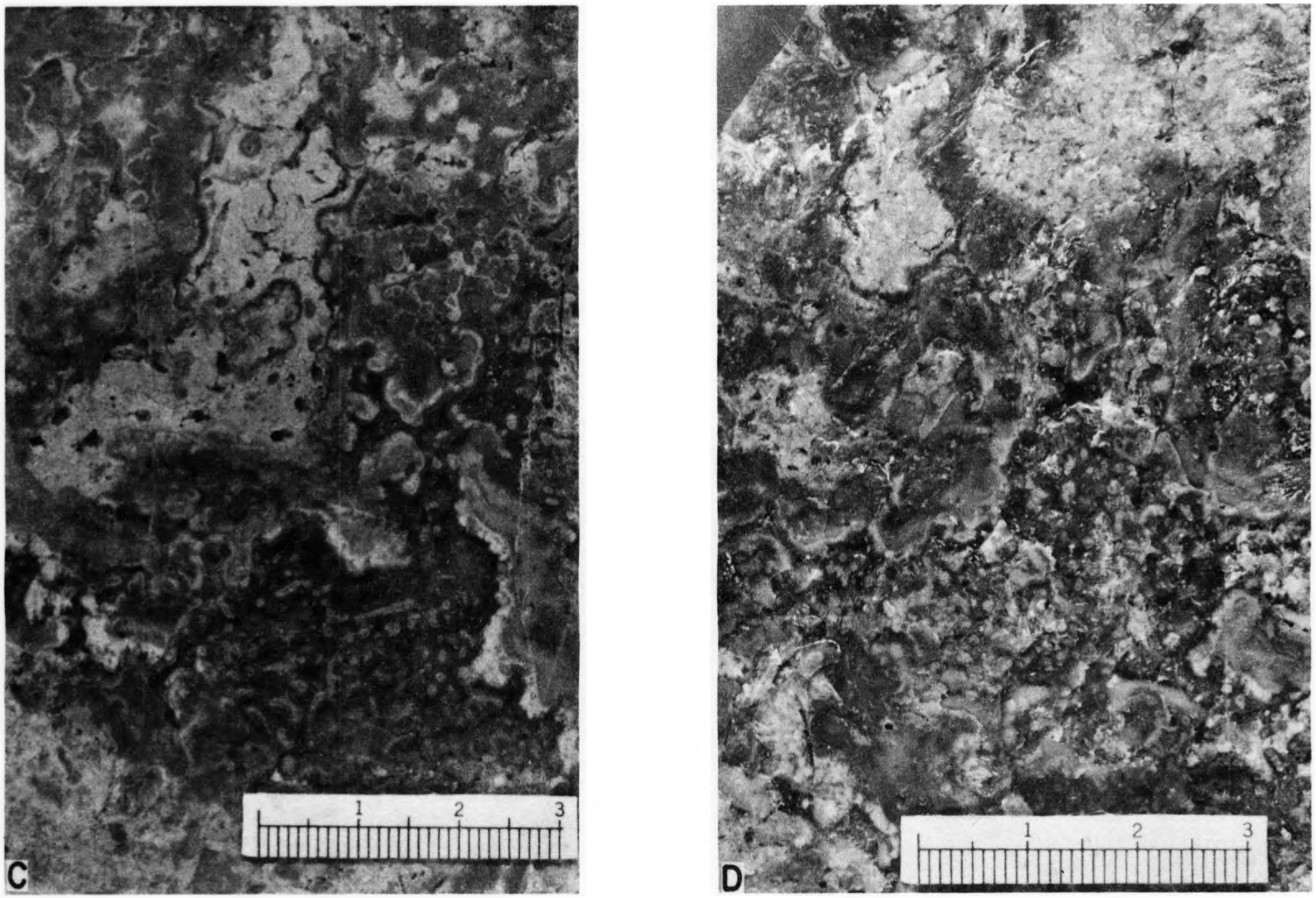

Figure 32. Hand specimen photographs of three similar units (continued). C. Cut and polished surface of Unit B4. D. Uncut surface of Unit B4. Scale is in centimeters. Upward is toward the top of both photographs.

well-preserved fibrous spar. The amounts of fibrous spar in Units B3 and B4 were intermediate. Other differences between the units included the presence or absence of clastic material, and additional fossils present. Unit A2 had a silty matrix, and Unit J6 had a sandy matrix, while Units B3 and B4 had no clastic material. In addition to ostracodes, gastropods, and girvanellids, Unit J6 had a very small amount of brachiopod and bryozoan pieces.

Two units similar both in hand sample and thin section to the four units just described were Units O5 and P3 (Fig. 33). Unit O5, an intrasparite, contains similar fibrous spar (not well-preserved) with coarse spar and micritic intraclasts. Unit P3, an algal intrasparite, also is similar, except the bulk of the material is comprised of algal remnants instead of fibrous calcite. The algae in Unit P3 clearly were torn up, then filled in with sparry calcite cement. These two units differ from the other four units (A2, B3, B4, J6) in fossil content. Unit O5 contains ostracodes, but no girvanellids or gastropods. Some characteristics of the six units are listed in Table IX.

The origin of fibrous spar is attributed to several factors in a book on carbonate cements edited by Owen P. Bricker. Two authors, James Marlowe (1971) and V. Schmidt (1971), discussed the formation of fibrous spar cement in a subtidal environment with exact origin unknown. Klaus Germann (1971), on the other hand, believed fibrous calcite was a primary precipitate from solutions percolating after

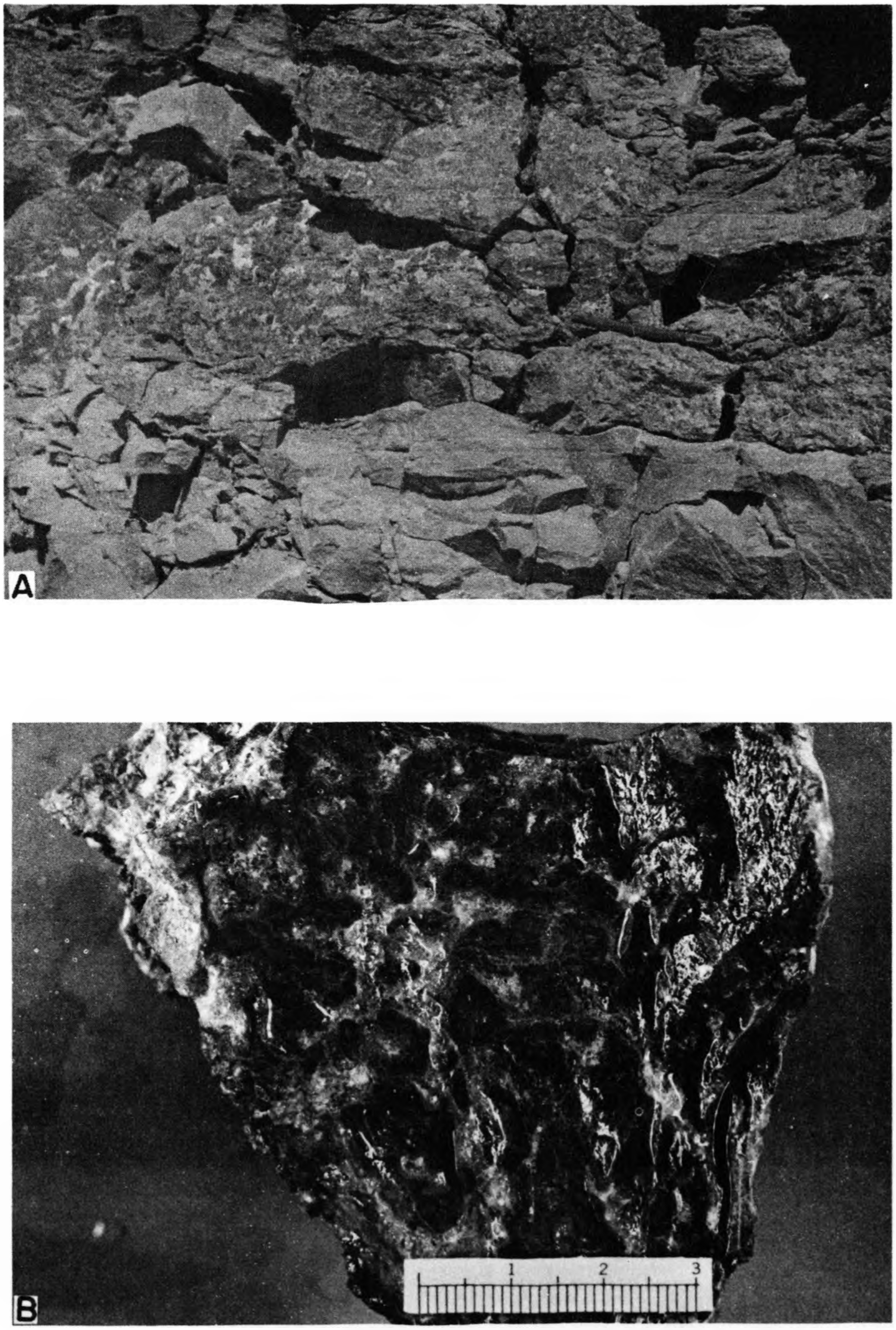

Figure 33. Photographs of two units similar to four thrombolite-like units (A2, B3, B4, and J6). A. Outcrop photograph of Unit O5. Mechanical pencil for scale (at arrow). B. Hand specimen photograph of Unit P3. Scale is in centimeters. Upward is toward the top of the photograph.

TABLE IX

CHARACTERISTICS OF SIX SIMILAR UNITS

	A2	B3	B4	J6	O5	P3
ostracodes	X	X	X	X	X	-
intertidal to upper subtidal environment	X	X	X	X	X	X
girvanellids	X	X	X	X	-	-
gastropods	X	X	X	X	-	X
fibrous spar	X	X	X	X	X	-
intraclasts	X	X	X	X	X	X
mottled light and dark gray color	X	X	X	X	X	X
Pseudohedstroemia fragments	-	-	-	-	-	X

rock burial, while Taylor and Illing (1971) attributed the fibrous calcite cement to either primary precipitation or secondary replacement of aragonite. Two other authors, Frank Beales (1971) and H. Zankl (1971), concluded fibrous spar was an aragonite replacement.

H. Zankl (1971) described a Triassic reef limestone with characteristics similar to the St. Louis Limestone units containing fibrous spar, especially Unit J6. The deposition of the unit began with calcispongea skeletons forming a framework on which bryozoans, foraminifers, and possible algal material encrusted. Next, mud and pelletal mud filled the skeletal interstices providing the inter-framework sediment. Foraminifers and algal material encrusted the outside of post-depositional cavities, while fibrous calcite lined the inside of the cavities. A second inflow of mud and skeletal sand filled the remaining voids along with space-filling, sparry calcite.

The major difference between Zankl's limestones and Unit J6 was the skeletal framework forming the cavities. Calcispongea skeletons, recrystallized, but still preserved, served as a framework in Zankl's limestones, but no skeletal framework was preserved in Unit J6. Possibly, the framework was originally calcareous algae which was recrystallized to fibrous spar, or which formed the cavities in which the spar later precipitated.

Unit P3, similar to Unit J6, consists largely of pieces of the codiacean, *Pseudohedstroemia,* instead of fibrous calcite found in Unit J6. According to Wray (1977), living members of the Codiaceae Family are aragonitic in composition. Thus, it is most likely that *Pseudohedstroemia* was originally aragonitic. If the calcareous fibrous spar is a secondary replacement of aragonite, then it is possible the original framework in Unit P3 was aragonitic algae. Evidence against this possibility is the encrusting girvanellids/foraminifers within the fibrous spar. These encrusting forms are in distinct layers suggesting their colonization took place during episodes of submarine cementation (Brenckle, pers. comm.). Or, perhaps the encrusters colonized between episodes of algal growth. Thus, the origin of the fibrous spar in Unit J6 as well as the poorly preserved fibrous spar in Units A2, B3, and B4 may be due to secondary replacement of aragonitic algae, precipitation during episodes of submarine cementation, or some other process.

Cryptalgal Fragmental Carbonates

Carbonates composed largely of filamentous algae clasts are defined as cryptalgal fragmental carbonates by Aitken (1967). Although several St. Louis Limestone units were composed of some unidentifiable algae fragments, not enough clasts were preserved to consider the units cryptalgal fragmental carbonates.

Calcispheres

W.C. Williamson (1880) proposed the generic name, *Calcisphaera* for microscopic, hollow, spherical organisms with darker spherical walls. Calcispheres may be divided into two types: (1) radiosphaerid calcispheres with external, radially-arranged spines and (2) nonradiosphaerid calcispheres with smooth external walls. Species names are assigned according to wall structure. Williamson attributed the origin of calcispheres to tests of some extinct protozoa or ". . . reproductive capsules of some marine form of vegetation." Other geologists and biologists have assigned calcispheres to a variety of taxa including Foraminifera and algae. However, many geologists agree that at least some calcispheres have an algal origin as a spore case (Kaisin, 1926; Cayeux, 1929; Derville, 1942; Baxter, 1960; Rupp, 1966; Petryk and Mamet, 1972; Kazmierczak, 1976). For synonymies of *Calcisphaera,* refer to Armstrong and Mamet (1977) and Kazmierczak (1976).

Eight St. Louis Limestone beds contained more than five percent calcispheres (usually five to ten percent) and thus, they were considered calcispheric carbonates in the Appendix. Nineteen more beds contained at least a few calcispheres, generally one to two percent. Typically, within each unit, the calcispheres were of uniform size (Fig. 34A). Only Unit Pl had calcispheres of varying sizes (Fig. 34B). All of the calcispheres were nonradiosphaerid, that is, without external spines. A detailed study of the calcispheres should be made to determine the number and type of *Calcisphaera* species in St. Louis Limestone beds.

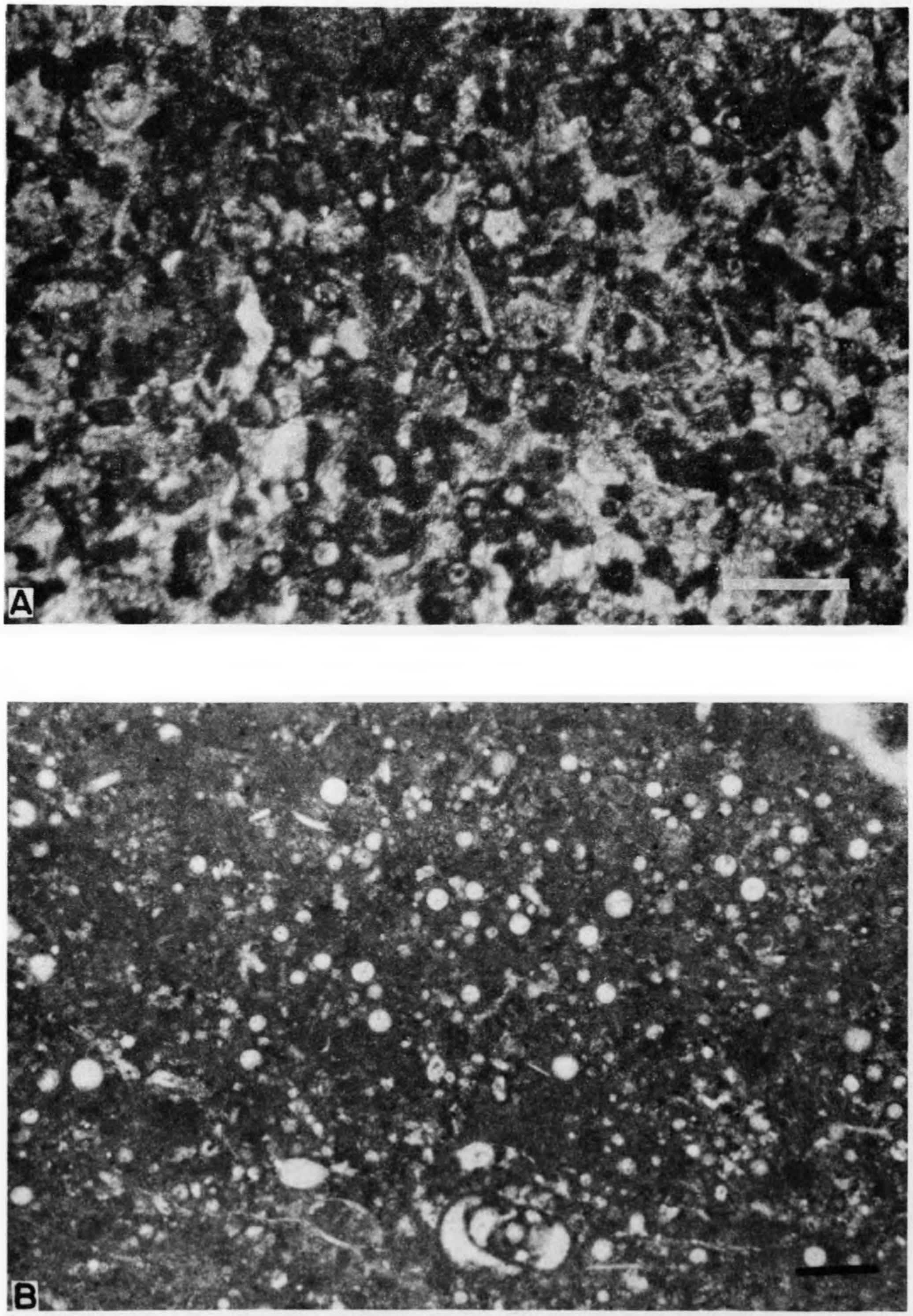

Figure 34. Photomicrographs of calcispheres. A. Uniform sized calcispheres, Unit N1 (crossed nicols). Scale bar is 0.25 millimeter. Upward is toward the top of the photograph. B. Various sized calcispheres, Unit P1. Scale bar is 0.25 millimeter. Upward is toward the top of the photograph.

Johnson's Algal Limestones From St. Louis, Missouri

Dr. A.C. Spreng collected samples from two algal zones in a section under the Laclede Station Road bridge and along the St. Louis-San Francisco (Frisco) Railroad tracks (SE¼, NW¼, SW¼, sec. 34, T45N, R6E, ex.), close to the same section J.H. Johnson described in 1946. Overall, the Frisco section was similar to Section J, Shrewsbury, described and sampled for this thesis. The algae from this section were present in oncolites in both samples, and thus, the units would have been considered Type I limestones (pelletal limestones) by Johnson.

In thin section, the lower algal zone was similar to sample J4a, both units being silty disturbed oncolitic biomicrites according to Folk's classification. The lower algal zone contained ostracodes, gastropods, and girvan-ellids. The upper algal zone was intraclastic with poorly preserved, algal (?) structures.

This brief comparison revealed only a few similarities to Johnson's descriptions. Fossils common to Johnson's section and the lower algal zone were ostracodes, gastro-pods, and *Girvanella,* one of two taxonomically designated algal types in Johnson's units. The oncolites in the lower and upper algal zones were comparable to those in Johnson's Type I limestones.

Bieber's Algae From Indiana

C.L. Bieber described algal nodules, or oncolites, from the lower and middle St. Louis Limestone observed in several outcrops in Putnam County, Indiana. He compared the fossilized tube-like structures within the nodules to the algae genera, *Ortonella, Garwoodia,* and *Solenopora*. Other described algae and algal-like fossils were:

1. chain-like tracks somewhat like small crinoid stems, but probably algae, like *Bevocastria*.
2. scattered tubes about one millimeter in diameter, filled with calcite, resembling corallites from *Syringopora,* but probably algae, like *Palaeoporella*.
3. thin, thread-like structures, like *Girvanella*.
4. laminated, undulating, wavy beds much like stromatolitic limestone, which may include fossil algae, like '*Stromatolites*'.

The Indiana limestones containing algal nodules were generally not fossiliferous, although a few other microfossil fragments resembling foraminifers were associated with the algae.

Bieber's hand specimen description of algal nodules matches the author's observations of oncolites from the St. Louis area. The fragments of calcareous algae within the Indiana oncolites, however, are more diverse and probably are better preserved, since Bieber was able to identify several genera. Oncolites from Missouri and Illinois contain a variety of fossil debris, while those from Indiana contain only a few microfossils other than algae.

Mamet and Roux's Algae from Tennessee

Bernard Mamet and Alain Roux described Mississippian algal microflora from a Tennessee borehole, including many species from the St. Louis Limestone. In all, thirteen taxa were erected: five new genera and eight new species. Eight algae species illustrated and described from the St. Louis Limestone are: *Rectangulina geniculosa, Pseudohedstroemia polyfurcata, Issinella devonica, Koninckopora tenuiramosa, Palaeoberesella cf. lahuseni, Asphaltinella? bangorensis, Mametella skimoensis*, and *Aoujgalia richi*. Table X is an abbreviated classification of the St. Louis Limestone algae species from Tennessee.

Only two out of eight genera described by Mamet and Roux, *Koninckopora* and *Pseudohedstroemia,* were discovered in St. Louis Limestone sections from Missouri and Illinois. On the other hand, *Ortonella* and *Girvanella,* studied from Missouri and Illinois sections, were not described from Tennessee sections. The limestones in Tennessee contained more diverse and/or better preserved fragments of calcareous algae than the limestones in Missouri and Illinois, judging from the more numerous Tennessee genera.

Lithologic Patterns Relating to Algae

The Folk limestone names and field descriptions in each stratigraphic section were compared, in groups of three or more, to groups of Folk limestone names and field

TABLE X

CLASSIFICATION OF EIGHT ALGAE SPECIES FROM THE ST. LOUIS LIMESTONE IN TENNESSEE

Chlorophycophyta?

Porostromata - section

Rectangulina geniculosa

Chlorophycophyta?

Asphaltinella? bangorensis

Chlorophycophyta

Codiaceae

Pseudohedstroemia polyfurcata

Dasycladaceae

Issinella devonica
Koninckopora tenuiramosa
Palaeoberesella cf. lahuseni

Rhodophycophyta

Ungdarellaceae

Mametella skimoensis
Aoujgalia richi

descriptions of the same number from all the other stratigraphic sections to determine if a lithology pattern existed for the algal beds. The comparisons were not time correlations, but stratigraphic sequence correlations from one section to another. One hundred nineteen comparisons between sections were made. Many matches were found between lithology name groups from the stratigraphic sections. Of the matching groups, only those with algal and oncolitic beds were further considered. Lithology groups of three or more from five sections containing algal beds, Sections C,F, G,K, and P, matched lithologies from Section D, which had three algal beds (Table XI). The algal beds in all six sections are associated with dolomite. Two other beds with fragments of calcareous algae, five other cryptalgalaminate carbonates, and one oncolitic bed are also associated with dolomite. Twelve beds in all are related to dolomite: eight are underlain by dolomite, two are underlain by dolomitized limestones, two are dolomite beds, and two are dolomitized limestones.

There are several problems when attempting to correlate algal beds and their overlying and underlying units. First, not many algal beds were observed as little algae was preserved in St. Louis Limestone beds. Second, the sampling was not detailed enough to find all preserved algae, so there are possibly more than 21 algal beds. Third, the preserved algae may not be in their original growth environment since they are present in transported

TABLE XI

CORRELATION OF LITHOLOGY GROUPS CONTAINING ALGAL BEDS FROM SIX ST. LOUIS LIMESTONE SECTIONS

Section	D	C	F	G	K	P
	6 Fossiliferous Intrasparite				2a Fossiliferous Intrasparite	5 Dolomitized Silty Intrasparite
	5 Algal Biolithite	14 Algal Biolithite	5 Algal Biomicrite		2b Dolomitized Algal Biomicrite	4 Disturbed Algal Biomicrite
	4 (upper) Algal Intrasparite			5 Algal Oosparite		3 Algal Intrasparite
	4 (basal) Dolomite	13 Very Finely Xln. Biogenic Dolomite	4 Very Finely Xln. Biogenic Dolomite	4 Very Finely Xln. Biogenic Dolomite	1 Very Finely Xln. Biogenic Dolomite	2 Dolomitized Oncolitic Calcispheric Biomicrite
	3 Finely Xln. Biogenic Dolomite	12 Very Finely Xln. Dolomite	4 Very Finely Xln. Biogenic Dolomite	3 Dolomitized Biomicrite		
	2 Algal Biomicrite		3 Dolomitized Algal Biomicrite			
	1 Fossiliferous Intrasparite					

intraclasts and fragments. Fourth, lithology is a function of environment, so the algal and oncolitic beds are directly a function of environmental conditions.

Out of 21 algal beds, 11 possible cryptalgalaminate carbonates, and 17 beds containing oncolites, 12 were associated with dolomite. Since many of the dolomite beds are secondary, the algae probably provided a more porous pathway for dolomitizing waters. Algal beds not associated with dolomite either originally contained little pore-forming algae, or other conditions requisite for dolomitization were not present.

Lithologies most often associated with algal and oncolitic beds are biomicrites, biosparites, and intrasparites. Algae would logically be found in biomicrites and biosparites with other biota since they grow in areas conducive to plant/animal productivity. The presence of algae and oncolites in intrasparites is expected also, since algae grow in both high energy areas and supratidal areas where intraclasts form by wave action or desiccation. The final product, algal intraclasts, or oncolites, depends on the amount of energy at the time of deposition.

The St. Louis Limestone algal and oncolitic beds were not deposited in a certain lithologic sequence, but they are related to environmental conditions at the time of deposition. Many algal beds are associated with dolomite or dolomitized limestones, suggesting porous algal beds provided a pathway for dolomitizing waters. The algae and oncolites most often occur in biomicrites, biosparites, and intrasparites, lithologies whose formation are a function of environment.

CONCLUSIONS

1. Twenty-nine out of 135 beds from 16 incomplete stratigraphic sections of the St. Louis Limestone contain fragments of calcareous algae; twenty-two beds contain more than one percent fragments of calcareous algae and seven beds contain less than one percent fragments of calcareous algae.
2. The algae which could be identified belong to the genera, *Koninckopora*, *Ortonella*, *Girvanella*, and *Pseudohedstroemia*.
3. The preservation of the calcareous algae was such that many fragments could not be identified.
4. Seventeen beds contain oncolites; eight have abundant oncolites and nine have sparse oncolites.
5. Two beds contain domal stromatolites.
6. Two beds are cryptalgalaminate carbonates and nine others are possible cryptalgalaminate carbonates.
7. Four beds have a mottled texture possibly due to recrystallized codiacean (green) algae.
8. Eight beds contain more than five percent calcispheres.
9. Nineteen beds contain less than five percent calcispheres.
10. All calcispheres are nonradiosphaerid. Most calcispheres are of uniform size.
11. The alga, *Girvanella*, was found in St. Louis Limestone sections described by J.H. Johnson and by the author.
12. Oncolites and the alga, *Ortonella*, were observed in St.

Louis Limestone sections described by both C.L. Bieber (in Indiana) and by the author (in Missouri and Illinois). The fragments of calcareous algae within Indiana oncolites were more diverse than the fragments within Missouri and Illinois oncolites, while associated microfossils were less diverse.

13. Eight algae genera from the St. Louis Limestone in Tennessee were described by B. Mamet and A. Roux, two of which were found in the author's sections. The St. Louis Limestone in Tennessee contains more diverse and/or better preserved fragments of calcareous algae than the limestones in Missouri and Illinois, judging from the more numerous Tennessee genera.

14. The environment of deposition of the studied portions of the St. Louis Limestone was a very near-shore, normal marine, epeiric sea with shallow, clear, warm water, and with occasional influx of fine-grained quartz and clays from wind-blown beach sands or mature river/stream sediments. Tides were low causing very gradational facies changes. Occasional oolite bars and algal buildups (stromatolites) formed barriers behind which lagoons formed. The shoreline fluctuated frequently in response to minor tectonic activites.

15. Green algae fragments are more abundant in intertidal and subtidal beds than in supratidal beds.

16. Blue-green algae fragments occur in beds of intertidal to upper subtidal origin.

17. Calcispheres occur in beds of supratidal origin.

18. Cryptalgalaminate carbonates occur in beds of supratidal origin.

19. Oncolites occur in beds of intertidal to upper subtidal origin. A few oncolites accumulated in open marine beds because of their transport by currents.

20. Domal stromatolites occur in beds of intertidal to upper subtidal origin.

21. Algal and oncolitic beds are most often biomicrites, biosparites, and intrasparites.

22. Algal and oncolitic beds were not deposited in a particular lithologic sequence, but they are related to environmental conditions at the time of deposition.

23. Seven beds with fragments of calcareous algae, six cryptalgalaminate carbonates, and one bed with oncolites were associated with dolomite, suggesting algal beds provide a porous pathway for dolomitizing waters.

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In August, 1977, she enrolled in the Graduate School of the University of Missouri-Rolla. For two years she held a teaching assistantship in the Geology Department. She is now employed by Amoco Production Company in Houston, Texas.

APPENDIX

DESCRIPTIONS OF MEASURED STRATIGRAPHIC SECTIONS

Following are figures of measured stratigraphic sections of the St. Louis Limestone from east-central Missouri and western Illinois. The locations of the sections by street and by township, range, and section are listed in Table II. Each figure includes: (1) a graphic section of the weathered, exposed rocks, (2) sample locations, (3) unit numbers, (4) depositional environment, and (5) field descriptions with Folk name (in the case of the carbonates) in parentheses. Depositional environment and Folk names were determined for each unit by thin section analysis.

Description abbreviations are as follows:

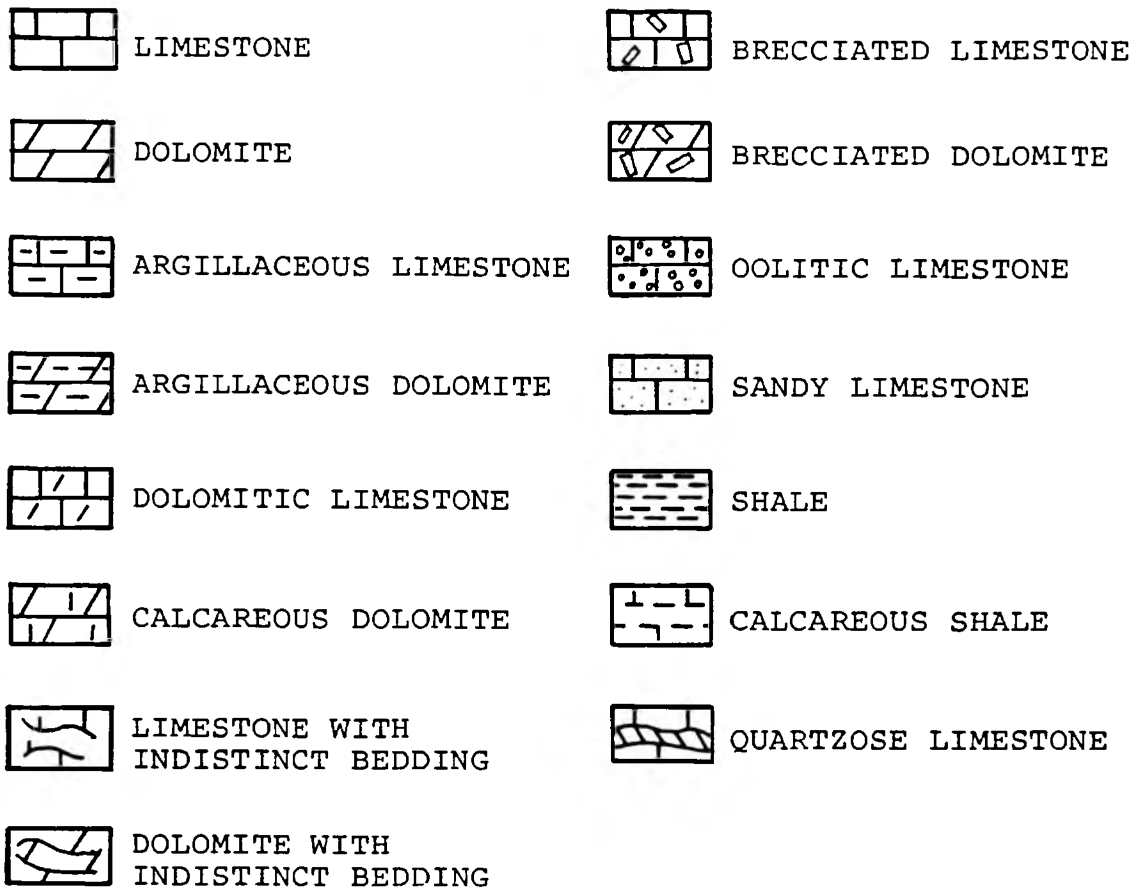
approx. - approximately
av. - average
bdg. - bedding
brachs. - brachiopods
brn. - brown
bryz. - bryozoans
cm. - centimeters
dk. - dark
fossilif. - fossiliferous
fr. - fresh
frac. - fracture
fracd. - fractured
frags. - fragments
grn. - green
lam. - laminated
lams. - laminations
lg. - large
lt. - light
m. - medium
mod. - moderate
(N.A.) - Folk name not applicable
org. - orange
sm. - small
v. - very
wd. weathered

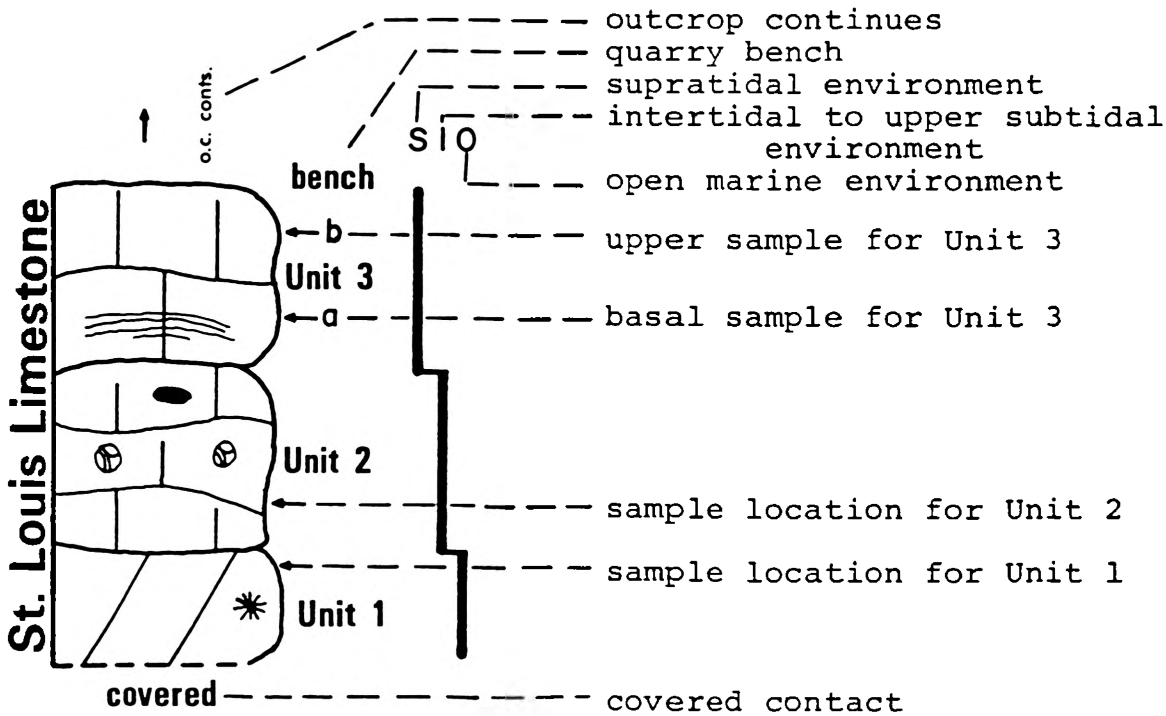
Rock colors determined by comparison with the Geological Society of America (GSA) Rock Color Chart are listed next to their GSA numerical designation on the following page.

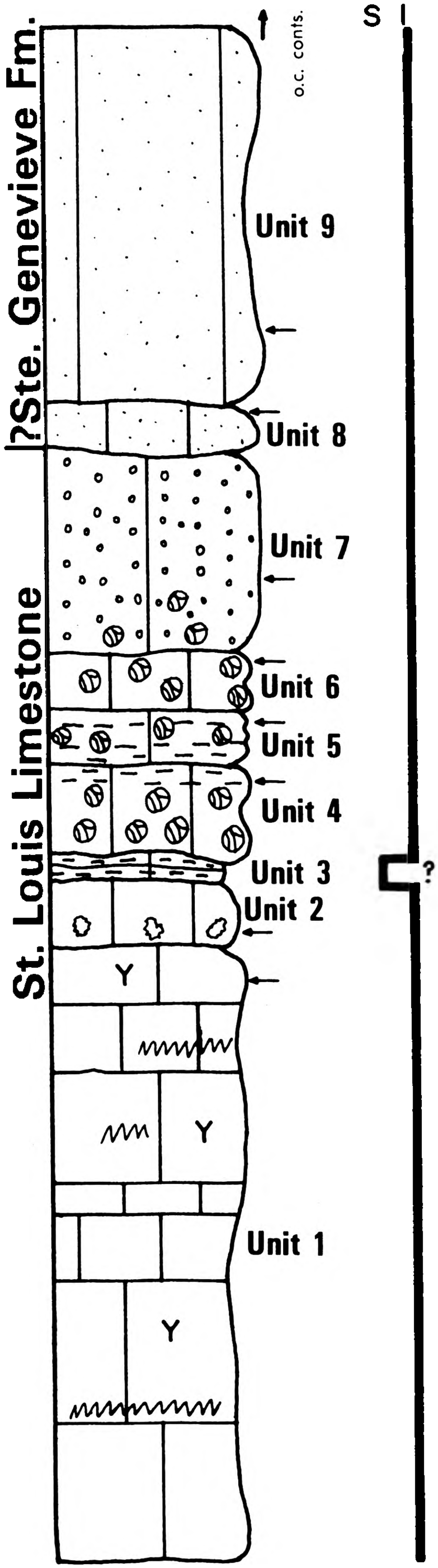
light red	5 R 6/6
very dark red	5 R 2/6
grayish red	10 R 4/2
pale reddish brown	10 R 5/4
moderate reddish orange	10 R 6/6
moderate reddish brown	10 R 4/6
light brown	5 YR 5/6
pale yellowish brown	10 YR 6/2
dark yellowish brown	10 YR 4/2
grayish orange	10 YR 7/4
moderate yellowish brown	10 YR 5/4
pale yellowish orange	10 YR 8/6
dark yellowish orange	10 YR 6/6
grayish yellow green	5 GY 7/2
moderate yellow green	5 GY 7/4
pale green	5 G 7/2
light green	5 G 7/4
grayish green	5 G 5/2
white	N 9
very light gray	N 8
light gray	N 7
medium light gray	N 6
medium gray	N 5
medium dark gray	N 4
brownish gray	5 YR 4/1
brownish black	5 YR 4/1
yellowish gray	5 Y 8/1
light olive gray	5 Y 6/1
olive gray	5 Y 4/1
light greenish gray	5 GY 8/1
light bluish gray	5 B 7/1
medium bluish gray	5 B 5/1

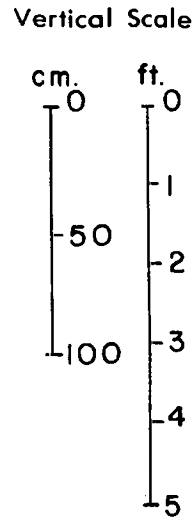
The symbols on the stratigraphic sections are:

brachiopods	fossil debris	laminations
bryozoans	ostracodes	intraclasts
corals	worm burrows	stylolites
crinoids	oncolites	pyrite
echinoid plates	stromatolites	chert nodules


LIMESTONE
DOLOMITE
ARGILLACEOUS LIMESTONE
ARGILLACEOUS DOLOMITE
DOLOMITIC LIMESTONE
CALCAREOUS DOLOMITE
LIMESTONE WITH INDISTINCT BEDDING
DOLOMITE WITH INDISTINCT BEDDING
BRECCIATED LIMESTONE
BRECCIATED DOLOMITE
OOLITIC LIMESTONE
SANDY LIMESTONE
SHALE
CALCAREOUS SHALE
QUARTZOSE LIMESTONE


St. Louis Limestone
o.c. conts.
bench
S I O
b
Unit 3
a
Unit 2
Unit 1
covered
outcrop continues
quarry bench
supratidal environment
intertidal to upper subtidal environment
open marine environment
upper sample for Unit 3
basal sample for Unit 3
sample location for Unit 2
sample location for Unit 1
covered contact





Unit 9: Limestone (Sandy Intrasparite) - m. gray fr., v. lt. gray wd.; one thick, massive bed; 164 cm. (5.4') thick; sharp contact.

Unit 8: Limestone (Sandy Intrasparite) - m. gray to lt. brn. fr., lt. brn. wd.; somewhat fissile to massive bdg.; smooth wd. surface; 19 cm. (.7') thick; sharp contact.

Unit 7: Oolitic Limestone (Oosparite) - lt. gray fr., v. lt. gray wd.; one thick, massive bed; rough surface with small fracs.; oncolitic at base of unit; v. oolitic; 89 cm. (2.9') thick; sharp contact.

Unit 6: Limestone (Fossiliferous Oncolitic Intrasparite) - m. gray fr., lt. gray to v. lt. gray wd.; one thin, massive bed; bumpy wd. surface due to numerous oncolites; 25-28 cm. (.8'-.9') thick; gradational contact.

Unit 5: Argillaceous Limestone (Silty Oncolitic Fossiliferous Intrasparite) - m. gray fr., lt. gray to v. lt. gray wd.; fissile to massive bdg.; bumpy, partially crumbled surface due to numerous wd. oncolites; 23 cm. (.8') thick; sharp contact.

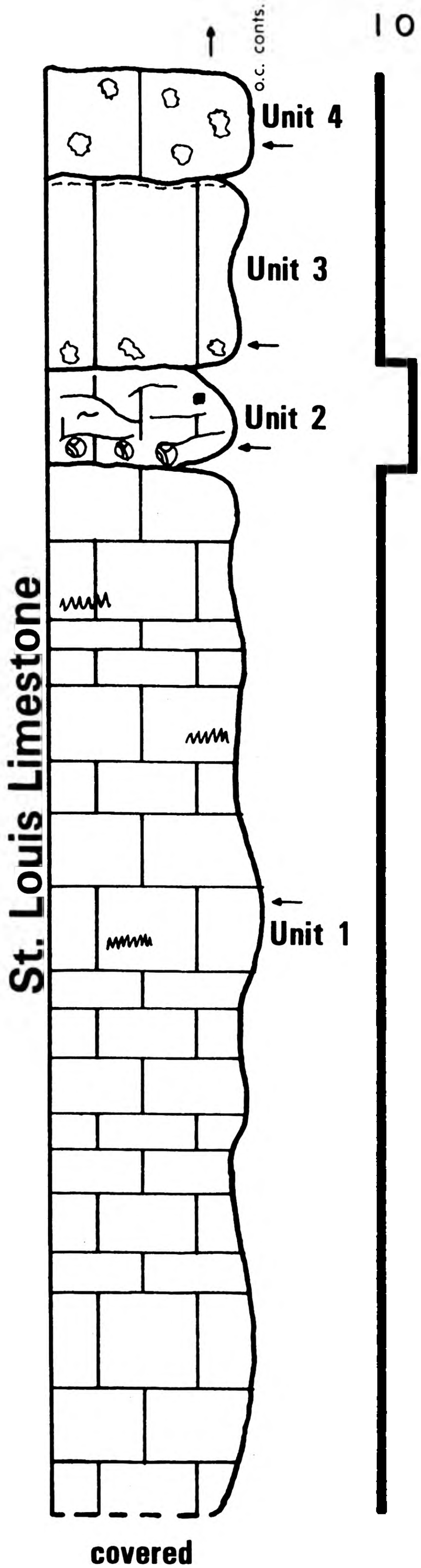
Unit 4: Limestone (Fossiliferous Oncolitic Intrasparite) - like Unit 6; 37 cm. (1.3') thick; gradational contact.

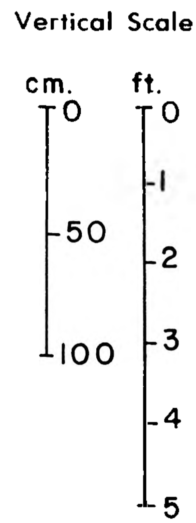
Unit 3: Argillaceous Limestone - lt. olive gray fr., m. gray wd.; v. thin, fissile bdg.; 10-13 cm. (.3'-.4') thick; sharp contact.

Unit 2: Limestone (N.A.) - lt. gray fr., v. lt. gray to dk. gray wd.; one thin, massive bed; smooth wd. surface; bumpy at base due to dk. gray algal? intraclasts with spar between; approx. 30 cm. (1.0') thick; sharp contact.

Unit 1: Limestone (Algal Biosparite) - lt. gray fr., v. lt. gray & dk. gray wd.; thin bdg.; distinct bdg. planes; rough wd. surface; fossilif.: bryz.; stylolitic; at least 305 cm. (10.0') thick; sharp contact.

Figure 35. Mississippi River Bluff section (A).





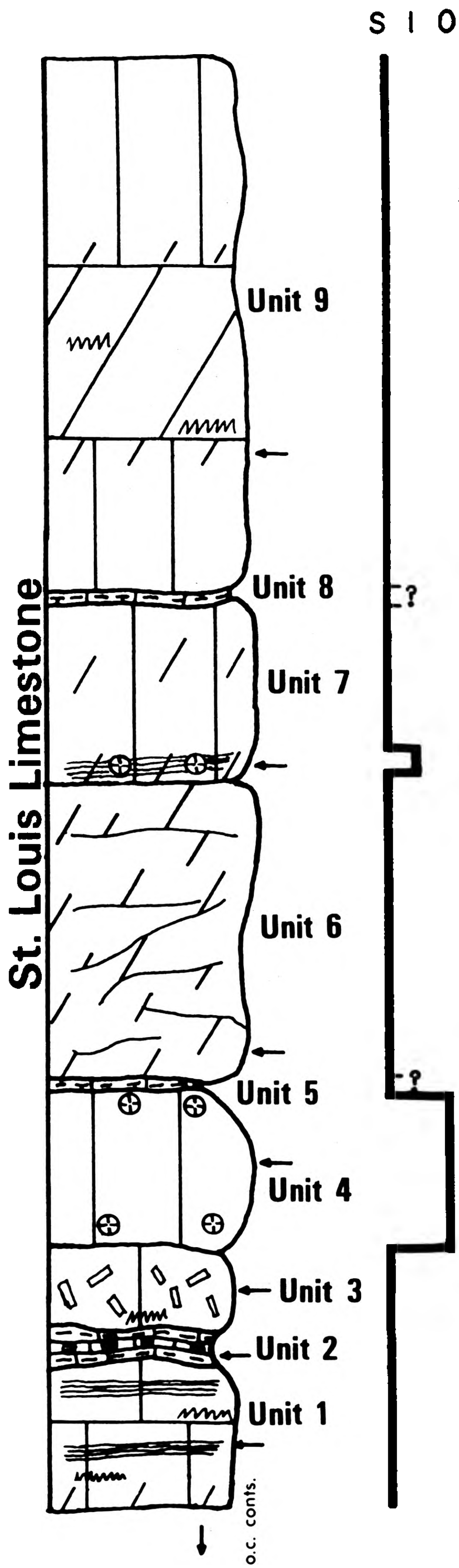
Unit 4: Limestone (N.A.) - m. gray and lt. gray mottled fr. & wd.; one thin, massive bed; intraclasts throughout; 51 cm. (1.7') thick; sharp contact.

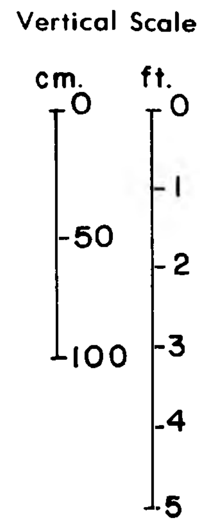
Unit 3: Limestone (N.A.) - lt. gray fr., lt. gray to v. lt. gray wd.; one thick, massive bed; numerous grayish grn. illite patches about 13 cm. (.4') in diameter; basal 15 cm. (.5') contains consistent layer of dk. gray algal intraclasts; 86 cm. (2.8') thick; sharp contact at shaley layer.

Unit 2: Limestone (Biomicrite) - m. lt. gray fr. & wd.; thin to indistinct bdg.; fossilif.; base of unit contains soft, wd. oncolites in fissile, fracd., and crumbled beds; pyritic; 43 cm. (1.4') thick; sharp contact.

Unit 1: Limestone (Biosparite) - lt. gray fr. & wd.; v. thin to thin, massive bdg.; stylolitic; at least 457 cm. (15.0') thick; sharp contact above, covered contact below.

Figure 36. Fort Bellefontaine Quarry section (B).





Unit 9: Limestone (Dolomitized Micrite) - lt. olive gray fr. & wd.; massive, thick bdg., three distinct beds; smooth wd. surface; contains dolomite bed 64 cm. (2.1') from base - yellowish gray fr. & wd., one thick bed, smooth wd. surface, stylolitic, 79 cm. (2.6') thick, gradational contacts with limestone; 237 cm. (7.8') total thickness; sharp contact.

Unit 8: Calcareous Shale - same as Unit 10; 3 cm. (.1') thick; sharp contact.

Unit 7: Dolomitic Limestone (Algal Biosparite below Dolomitized Fossiliferous Micrite) - olive gray fr. & wd.; one massive, thick bed; lam. basal 18 cm. (.6'); fossilif. at v. base: corals; 82 cm. (2.7') thick; sharp contact.

Unit 6: Dolomite (Finely Crystalline Dolomite) - yellowish gray fr. & wd.; indistinct bdg., somewhat fracd.; dk. streaks parallel to bdg.; sparry; 131 cm. (4.3') thick; sharp contact.

Unit 5: Calcareous Shale - same as Unit 10; 3 cm. (.1') thick; sharp to covered contact.

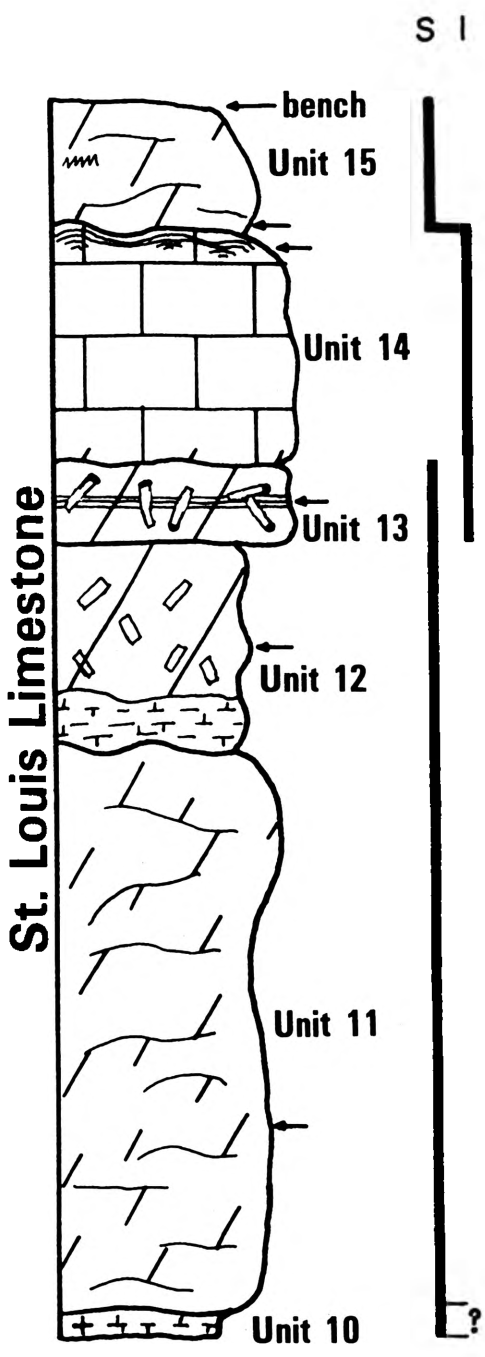
Unit 4: Limestone (Dolomitized Fossiliferous Micrite) - lt. gray fr. & wd.; one massive, thick bed; spar patches; fossilif.: corals, *Syringopora sp.*; 67 cm. (2.2') thick; sharp contact.

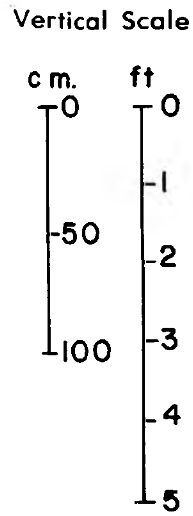
Unit 3: Limestone (Dolomitized Disturbed Biomicrite) - m. lt. gray fr. & wd.; one thin, somewhat brecciated bed; abundant calcite blebs & veins; stylolitic at base; 40 cm. (1.3') thick; sharp contact.

Unit 2: Argillaceous Limestone (Pelmicrite) - grayish grn. to lt. gray fr. & wd.; v. thin, indistinct bdg.; v. wd.; carbonaceous; interbedded with Limestone - like Unit 3, but 5 cm. (.2') thick; 15 cm. (.5') total thickness; wavy contact.

Unit 1: Limestone (Dolomitized Micrite) - lt. olive gray fr. & wd.; massive, thick bdg.; fracd.; v. lam.; stylolitic; 64 cm. (2.1') thick; wavy contact above, gradational contact with dolomite below.

Figure 37. Vigus North Quarry section (C).





Unit 15: Dolomite (Very Finely Crystalline Sparry Dolomite) - lt. gray fr., pale yellowish brn. wd.; indistinct bdg.; sparry layer 15 cm. (.5') from top and at base; smooth wd. surface; slightly stylolitic; 52 cm. (1.7') thick; sharp contact at bench.

Unit 14: Limestone (Algal Biolithite) - lt. gray fr. & wd.; thin, massive bdg.; conchoidal frac.; stromatolitic top 15 cm. (.5'); 91 cm. (3.0') thick; wavy contact.

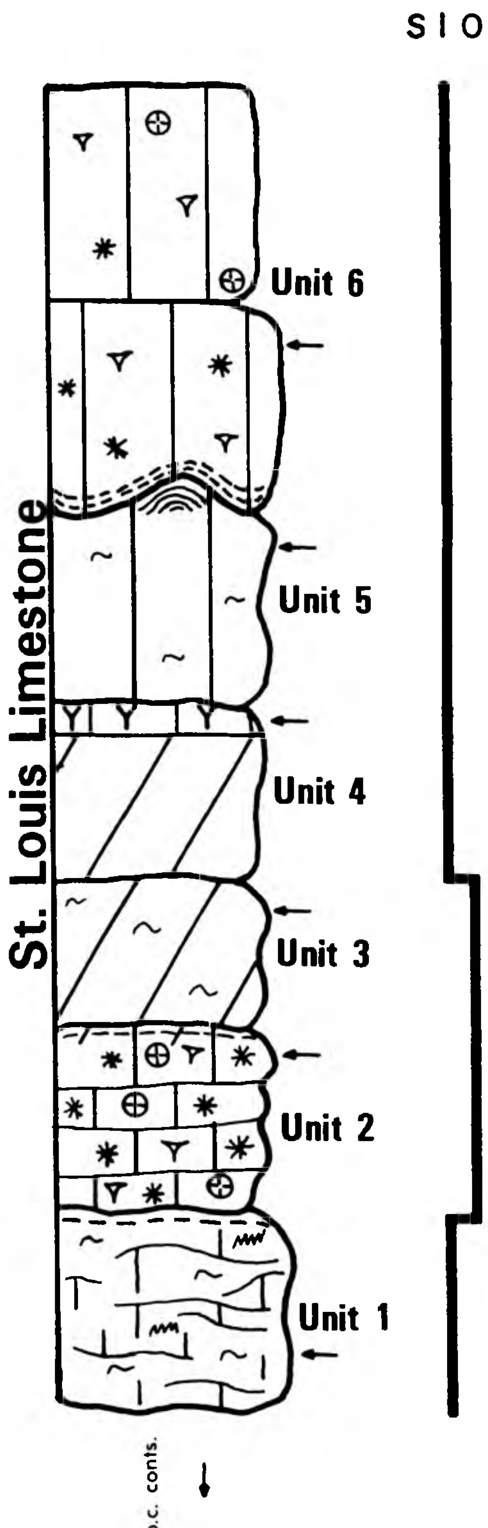
Unit 13: Dolomite (Very Finely Crystalline Biogenic Dolomite) - lt. olive gray fr., yellowish gray wd.; one thin bed; fracd.; lam.; abundant worm burrows; 30 cm. (1.0') av. thickness; gradational contact.

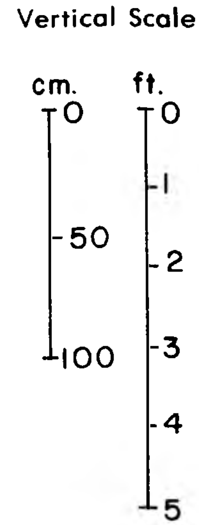
Unit 12: Brecciated Dolomite (Very Finely Crystalline Dolomite) - lt. gray fr. & wd.; one thick bed; conchoidal frac.; contains shale at base - m. gray fr., lt. gray wd., calcareous, somewhat fissile, wd. & crumbled, 21 cm. (.7') thick, wavy contact with brecciated dolomite; 82 cm. (2.7') av. total thickness; sharp contact.

Unit 11: Dolomite (Very Finely Crystalline Dolomite) - m. gray fr., m. lt. gray wd.; indistinct bdg.; dk. carbonaceous streaks; 213 cm. (7.0') thick; wavy contact.

Unit 10: Calcareous Shale - brownish black fr., olive gray wd.; somewhat fissile bdg.; soft; 5-8 cm. (.2'-.3') thick; sharp contact.

Figure 38. Vigus North Quarry section (C) continued.





Unit 6: Limestone (Fossiliferous Intrasparite) - lt. gray fr., lt. olive gray wd.; two massive, thick beds; jointed, conchoidal frac., pitted, rough; fossilif.: corals, crinoids, brachs.; contains an 8 cm. (.3') thick shale at base; 130-165 cm. (4.3'-5.4') total thickness; topmost unit of outcrop.

Unit 5: Limestone (Disturbed Algal Biolithite) - m. gray to lt. gray fr., lt. gray to white with m. gray patches wd.; one massive, thick bed; v. small spar spots; conchoidal frac.; fossilif.; algal mounds - mottled m. dk. gray to lt. gray, v. wd. & pitted, 30-305 cm. (1.0'-10.0') in diameter and up to 30 cm. (1.0') vertical relief, wd. dolomitic channels between and through some mounds; 71 cm. (2.3') thick; v. wavy contact.

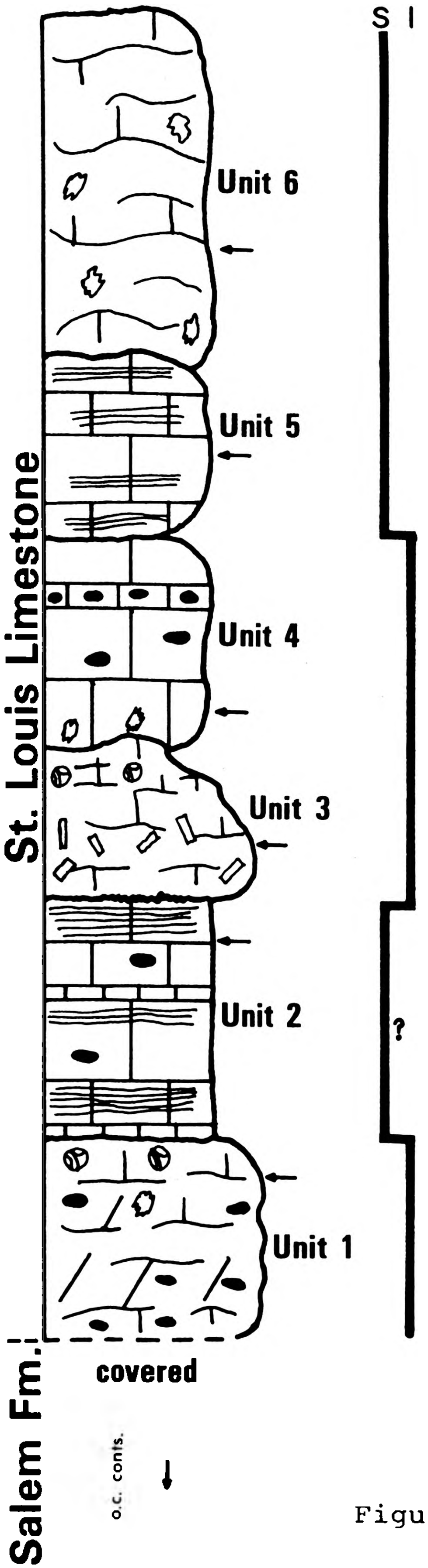
Unit 4: Dolomite - grayish org. to mod. yellowish brn. fr. & wd.; one thick bed; grades upward to Limestone (Algal Intrasparite) - lt. gray to v. lt. gray fr. & wd., v. fossilif. - bryz., bdg. plane v. rough, pitted, 13 cm. (.4') thick; 69 cm. (2.3') total thickness; sharp contact at bench.

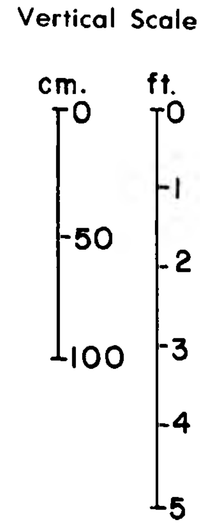
Unit 3: Dolomite (Finely Crystalline Biogenic Dolomite) - grayish org. to mod. yellowish brn. fr. & wd.; one thick, massive bed; microcrystalline; smooth, fracd. surface; relicts of fossils; 56 cm. (1.8') thick; sharp contact.

Unit 2: Limestone (Algal Biomicrite) - lt. gray fr. & wd.; smooth, massive, thin to thick bdg.; fracs. parallel to bdg.; v. fossilif.: crinoids, corals, brachs.; contains fissile shale at top; 71 cm. (2.3') total thickness; gradational contact.

Unit 1: Limestone (Fossiliferous Intrasparite) - lt. gray fr. & wd.; indistinct bdg.; sparry patches; fracd.; jointed; rough surface; fossilif.: v. small frags.; stylolitic; fissile shale on top of unit; 74 cm. (2.4') thick; sharp contact above and below.

Figure 39. Watson Road section (D).





Unit 6: Limestone (Intraclastic Biomicrite) - pale yellowish org. to dk. yellowish org. fr. & wd.; wavy, somewhat fissile bdg.; v. wd., pitted, iron stained, calcite crystals on wd. surface; lt. gray intraclasts; 134-155 cm. (4.4'-5.1') thick; topmost unit of outcrop.

Unit 5: Limestone (Dolomitized Ostracode Biomicrite) - lt. gray to v. lt. gray fr. & wd.; thin bdg.; lam.; 67-76 cm. (2.2'-2.5') thick; v. wavy contact.

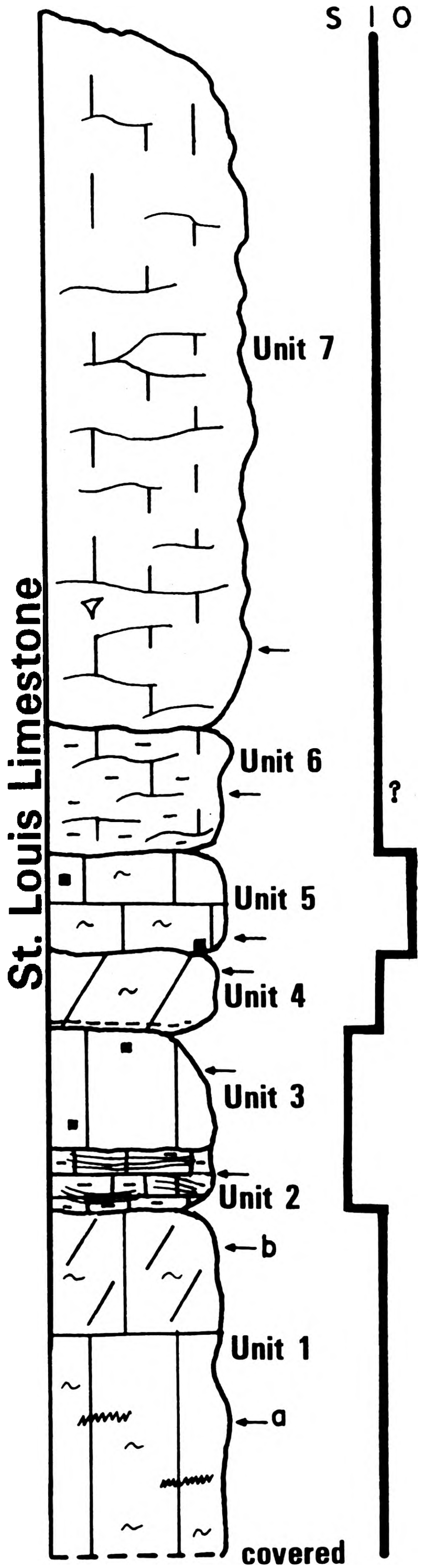
Unit 4: Limestone (Fossiliferous Intrasparite) - lt. olive gray fr. & wd.; thin, massive bdg.; rough texture; conchoidal frac.; layer of chert nodules 13 cm. (.4') from top, other nodules scattered; intraclasts bottom 8 cm. (.3'); 76-91 cm. (2.5'-3.0') thick; sharp contact.

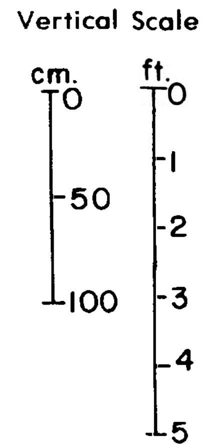
Unit 3: Limestone (Intraclastic Biosparite) - lt. gray to v. lt. gray fr. & wd.; irregular bdg.; uniform texture at base grading upward into breccia; v. fracd.; sparse oncolites, one is 9 cm. (.3') in diameter; 67 cm. (2.2') thick; wavy contact.

Unit 2: Limestone (Micritic Pseudosparite) - lt. gray to v. lt. gray fr., lt. gray to pale yellowish org. wd.; v. thin to thin, somewhat fissile bdg.; lam.; sparse chert nodules; 107 cm. (3.5') thick; irregular contact.

Unit 1: Calcareous Dolomite - m. lt. gray & grayish org. mottled fr. & wd.; indistinct bdg.; v. broken, disoriented pieces (breccia?); abundant chert nodules; grading upward into Limestone (Intrasparite) - m. lt. gray fr. & wd., containing calcite veins & intraclasts, oncolitic at top of bed; 85 cm. (2.8') thick; sharp contact above, covered contact below.

Figure 40. I-270 and I-44 section (E).





Unit 7: Limestone (Intrasparite) - lt. gray fr., yellowish gray to white wd.; brecciated; pitted, v. crumbled, rough wd. surface; fossilif.: brachs.; 366-457 cm. (12.0'-15.0') thick; topmost unit of outcrop.

Unit 6: Argillaceous Limestone (Pseudosparite) - mod. yellow grn. & lt. red to v. dk. red mottled fr. & wd.; crumbled, wavy bdg.; brecciated; v. wd., pitted; 61-91 cm. (2.0'-3.0') thick; covered contact.

Unit 5: Limestone (Algal Biomicrite) - m. lt. gray to lt. gray fr. & wd.; thin, massive bdg.; v. coarse spar patches; smooth wd. surface; fossilif.; pyritic; 51 cm. (1.7') thick; sharp contact.

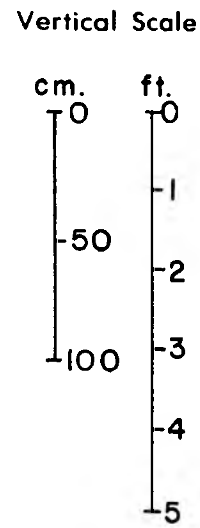
Unit 4: Dolomite (Very Finely Crystalline Biogenic Dolomite) - mod. yellowish brn. to grayish org. fr. & wd.; one thin bed; fracd.; v. wd., argillaceous; org. dots (relicts of fossils?); bottom 8 cm. (.3') v. argillaceous and pale grn.; 51 cm. (1.7') thick; sharp contact.

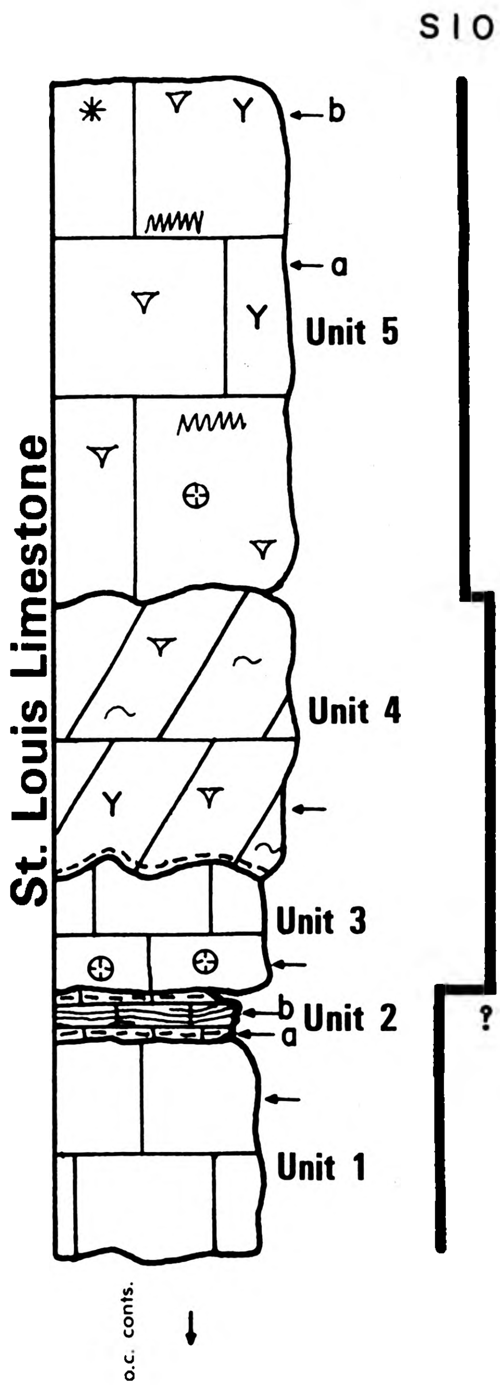
Unit 3: Limestone (Dolomitized Algal Biomicrite) - lt. gray fr., lt. gray to grayish org. wd.; one thin, massive bed; smooth wd. face; pyritic; m. lt. gray blebs (algal patches); 61-82 cm. (2.0'-2.7') thick; sharp contact.

Unit 2: Argillaceous Limestone (Dolomitized Micrite) - lt. gray fr., lt. gray to grayish org. wd.; lam.; grayish grn. illite patches; interbedded in places with overlying limestone; 30-46 cm. (1.0'-1.5') thick; gradational contact.

Unit 1: Limestone (a-Algal Biosparite, b-Dolomitized Intraclastic Biomicrite) - m. gray fr., lt. gray to v. lt. gray wd.; massive, thick bdg.; conchoidal & linear fracs.; fossilif.; stylolitic; top 30-61 cm. (1.0'-2.0') mottled m. gray & grayish org.; at least 177 cm. (5.8') thick; distinct contact above, covered contact below.

Figure 41. Gravois Road section (F).





Unit 5: Limestone (Algal Oosparite) - lt. gray fr., lt. gray to v. lt. gray and dk. gray wd., dk. yellowish org. in places due to iron staining; massive, thick bdg.; rough wd. surface; fossilif.: brachs., corals, bryz., crinoids; stylolitic; 198 cm. (6.5') thick; topmost unit of outcrop.

Unit 4: Dolomite (Very Finely Crystalline Biogenic Dolomite) - grayish org. to dk. yellowish org. fr. & wd.; massive, thick bdg.; coarse spar patches and veins; fossilif.: brachs., bryz.; underlain in places by argillaceous layer - pale grn. fr. & wd., v. altered, indistinct bdg.; 102 cm. (3.4') total thickness; wavy contact.

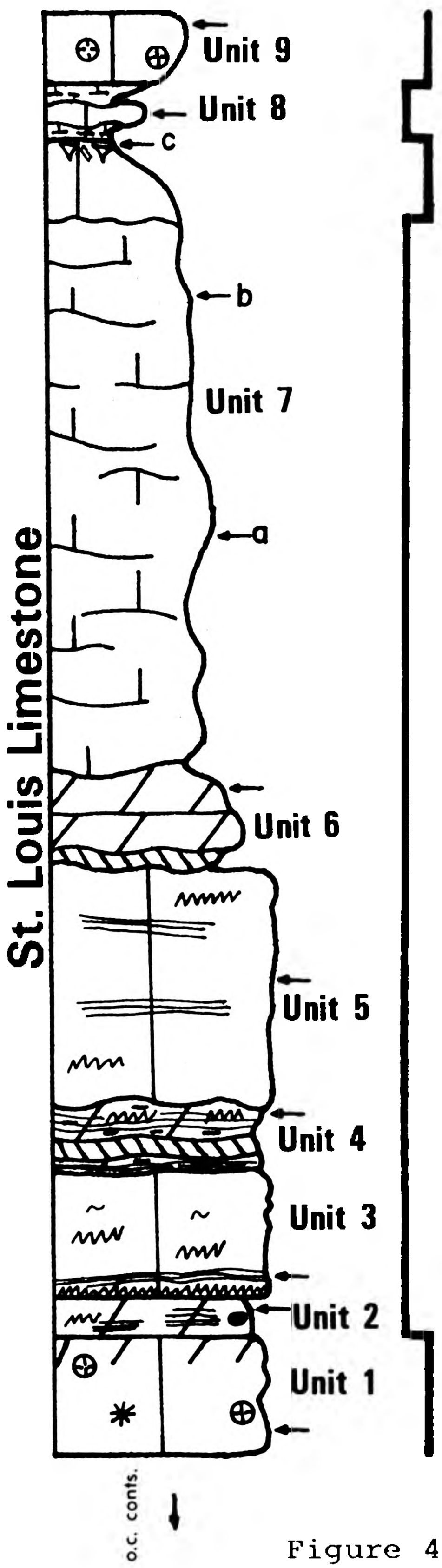
Unit 3: Limestone (Dolomitized Biomicrite) - lt. gray to white fr. & wd.; massive, thin bdg.; v. fossilif. at base: abundant *Lithostrotion* sp.; 41-61 cm. (1.3'-2.0') thick; wavy contact.

Unit 2: Argillaceous Limestone (Pseudosparite) - pale grn. to grayish org. fr. & wd.; v. thin, fissile bdg.; v. broken and wd.; contains one thin limestone bed (Dolomitized Microsparite) 5 cm. (.2') from base - m. lt. gray fr., m. lt. gray and dk. yellowish org. wd., lam., 10 cm. (.3') thick; 20 cm. (.7') total thickness; sharp contact.

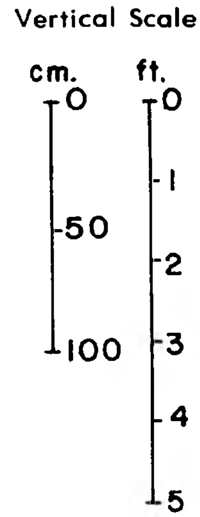
Unit 1: Lithographic Limestone (Dolomitized Micrite) - lt. olive gray fr., lt. gray to white wd.; thin bdg.; smooth wd. faces; linear and conchoidal fracs.; 84 cm. (2.8') thick; wavy contacts above and below.

Figure 42. I-270 and I-55 section (G).

S10



Unit 9: Limestone (Biosparite) - m. lt. gray to v. lt. gray fr. & wd.; one thin, massive bed; clay on wd. surface; fossilif.: abundant *Lithostrotion* sp.; 30 cm. (1.0') thick; sharp contact.



Unit 8: Calcareous Shale - lt. greenish gray fr. & wd.; v. thin, fissile bdg.; v. wd., argillaceous; contains one thin bed of limestone 8 cm. (.3') from base (Disturbed Pelmicrite) - lt. olive gray fr., m. lt. gray wd., one thin bed, dense, fracd., wd., clay on surface, 13 cm. (.4') av. thickness, wavy contact with shale above and below; 10-23 cm. (.3'-.8') total thickness; sharp contact.

Unit 7: Limestone (Calcispheric Biopelmicrite) - lt. olive gray fr., v. lt. gray to lt. olive gray wd.; indistinct bdg.; dense; fracd.; argillaceous wd. surface; fossilif. top 30 cm. (1.0') of bed: numerous *Composita* sp.; sparry top 30 cm. (1.0') of bed; top 8 cm. (.3') is a crackle breccia - hairline fracs., rough, flakey wd. surface, fossilif.; 259 cm. (8.5') total thickness; gradational contact.

Unit 6: Dolomite (Very Finely Crystalline Dolomite) - lt. gray fr., olive gray wd.; thin bdg.; fracd.; v. argillaceous, crumbled; trees, moss growing on exposure; grayish grn. illite; contains quartzose layer bottom 5-8 cm. (.2'-.3') - lt. bluish gray & m. bluish gray mottled fr. & wd., wavy bdg., porous, sparry patches, wavy contact with dolomite; 20-41 cm. (.7'-1.3') total thickness; wavy contact.

Unit 5: Lithographic Limestone (Dolomitized Micrite) - yellowish gray fr. & wd.; one thick, massive bed; dense; slightly lam.; linear and conchoidal fracs.; stylolitic; 99 cm. (3.3') thick; wavy contact.

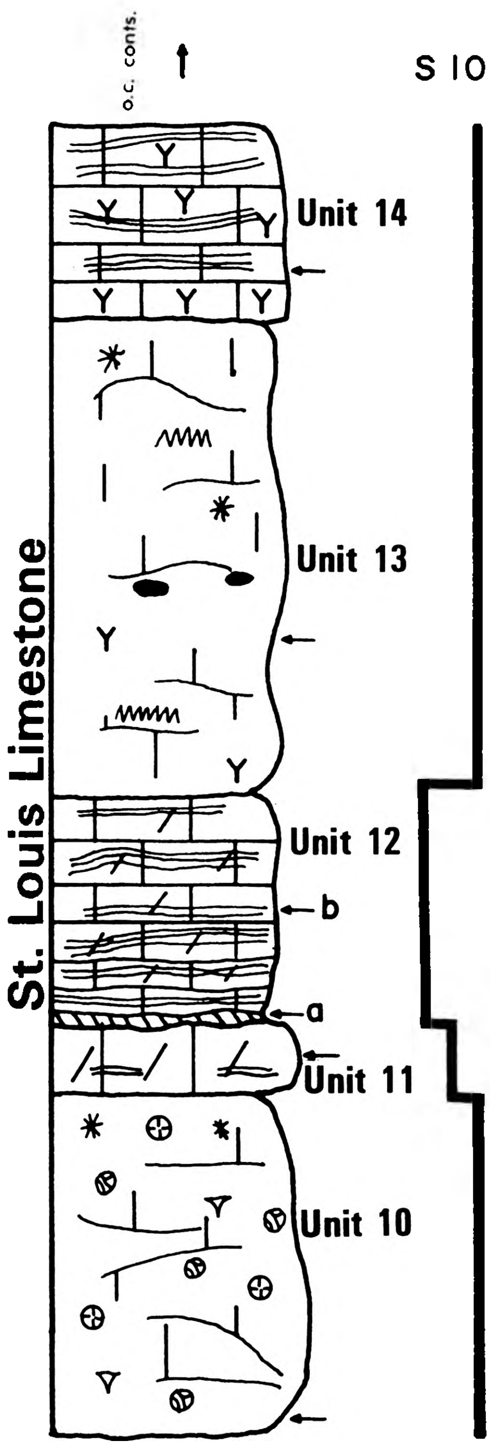
Unit 4: Argillaceous Dolomite (Very Finely Crystalline Algal Dolomite) - yellowish gray & m. bluish gray banded fr. & wd.; one thin, wavy bed; lam.; v. wd., broken; v. stylolitic; contains quartzose layer 5-8 cm. (.2'-.3') from base - same as in Unit 6; 25 cm. (.8') total thickness; sharp, wavy contact.

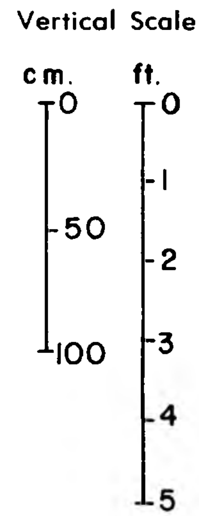
Unit 3: Limestone (Calcispheric Biopelmicrite) - pale yellowish brn. fr. & wd.; one thin, massive bed; basal 8 cm. (.3') is lam.; conchoidal frac.; rough, pitted, argillaceous wd. surface; fossilif.; stylolitic; 53 cm. (1.8') thick; sharp contact.

Unit 2: Dolomite (Very Finely Crystalline Dolomite) - pale yellowish brn. fr. & wd.; one thin bed; slightly lam.; fracd.; argillaceous wd. surface; v. thin stylolites; cherty; grayish grn. illite spots; 15 cm. (.5') thick; sharp contact at a stylolite horizon.

Unit 1: Dolomitic Limestone (Dolomitized Algal Biosparite) - pale yellowish brn. fr. & wd.; like Unit 3, but more fossilif.: crinoids, corals; 56 cm. (1.8') thick; gradational contact above, sharp contact below.

Figure 43. Ruprecht Quarry section (H).





Unit 14: Limestone (Dolomitized Biomicrite) - lt. olive gray fr. & wd.; thin bdg.; v. lam.; rough wd. surface; fossilif.: abundant bryz. in positive relief; 74 cm. (2.4') thick; sharp contact.

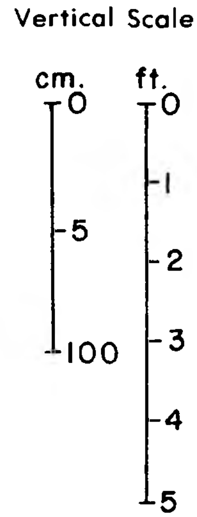
Unit 13: Limestone (Dolomitized Biomicrite) - lt. olive gray fr. & wd.; indistinct bdg.; fracd.; rough wd. surface; v. fossilif.: bryz., crinoids; stylolitic; numerous lg. patches of m. gray quartz associated with white to m. gray spar; sparse chert nodules mid-unit; 183 cm. (6.0') thick; sharp contact.

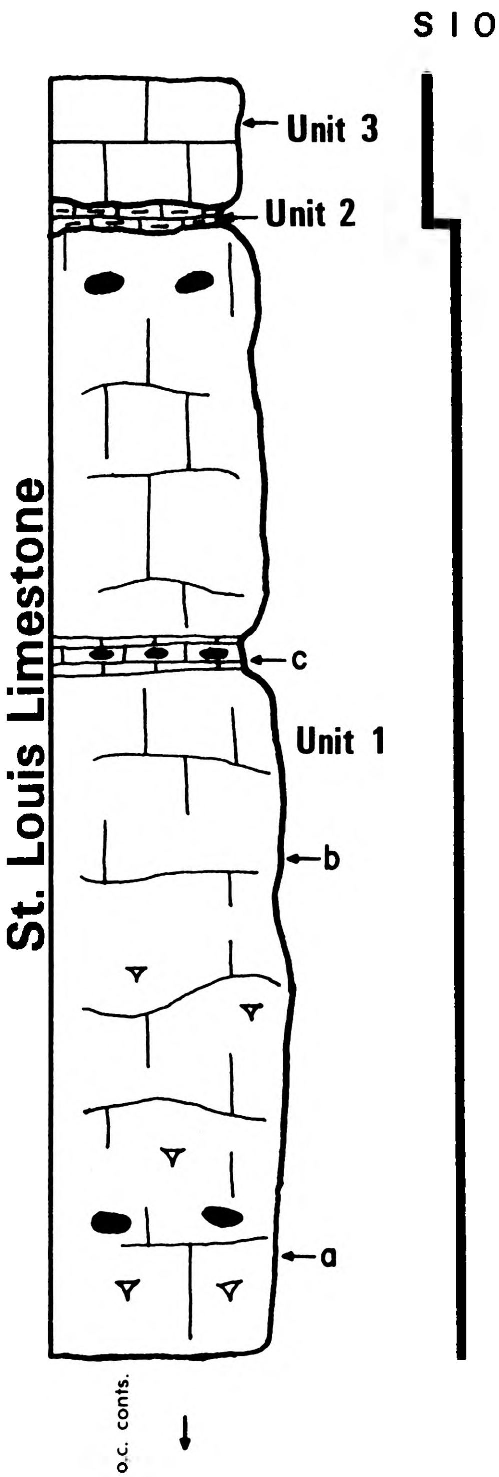
Unit 12: Dolomitic Limestone (Dolomitized Micrite) - lt. olive gray fr., v. lt. gray wd.; thin bdg.; v. lam.; fracd.; basal 4 cm. (.1') is a quartzose layer (Brecciated Quartzose Dolomite) - lt. bluish gray and m. bluish gray mottled, one v. thin bed, sharp contact with limestone; 89 cm. (2.9') total thickness; sharp contact.

Unit 11: Dolomitic Limestone (Silty Dolomitized Fossiliferous Intrasparite) - lt. olive gray fr. & wd.; one thin, massive bed; slightly lam.; rough wd. surface; 23 cm. (.8') thick; sharp contact.

Unit 10: Limestone (Disturbed Biomicrite) - lt. olive gray fr., v. lt. gray wd.; indistinct bdg.; v. fracd.; v. fossilif.: *Lithostrotion* sp.; crinoids, brachs.; numerous oncolites, not wd. out; 130 cm. (4.3') thick; sharp contact where exposed, covered in places by vines.

Figure 44. Ruprecht Quarry section (H) continued.



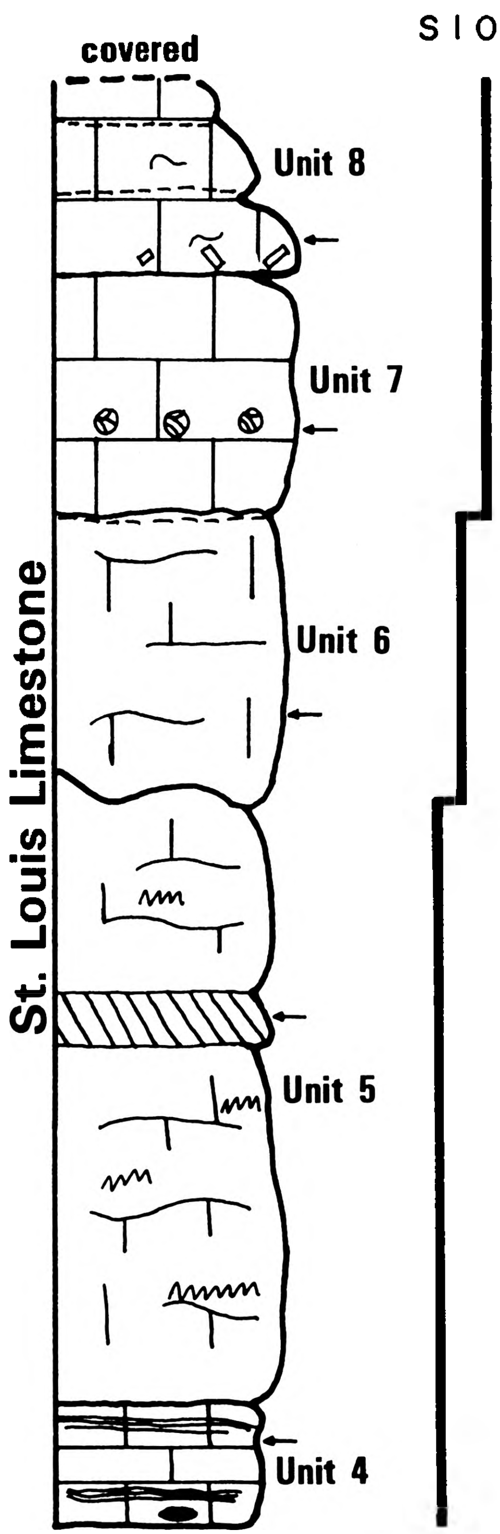


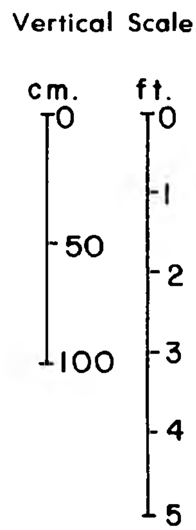
Unit 3: Limestone (Calcispheric Biomicrite) - lt. olive gray fr. & wd.; thin, massive bdg.; smooth wd. surface; 49 cm. (1.6') thick; gradational contact.

Unit 2: Argillaceous Limestone (Dolomitized Dismicrite) - lt. olive gray fr. & wd.; somewhat fissile, v. thin to thin bdg.; smooth wd. surface; grayish grn. illite spots; 5-13 cm. (.2'-.4') thick; sharp contact.

Unit 1: Limestone (Biosparite) - lt. olive gray fr., yellowish gray wd.; thick, irregular bdg.; somewhat fracd.; rough wd. surface; fossilif. basal 152 cm. (5.0'): brachs.; several layers of disseminated chert; contains v. cherty limestone bed (Sparry Calcispheric Pelmicrite) 152 cm. (5.0') from top - v. thin to thin, fissile bdg., 13 cm. (.4') thick, sharp contacts with limestone; 427 cm. (14.0') total thickness; gradational contact above, sharp contact below.

Figure 45. Rock Hill Quarry section (I).





Unit 8: Limestone (Biomicrite) - m. lt. gray fr., lt. gray wd.; thin bdg. with v. thin shale partings; sparry; v. wd.; fossilif.; crackle breccia basal 15 cm. (.5'); at least 73 cm. (2.4') thick; covered contact.

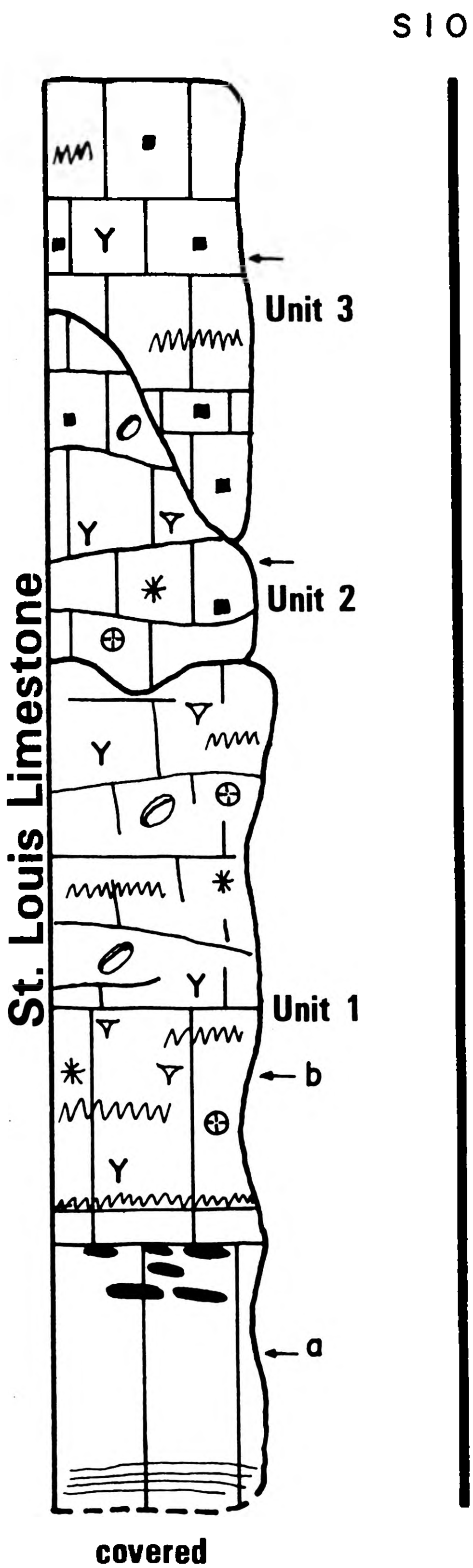
Unit 7: Limestone (Oncolitic Biomicrite) - lt. gray fr., lt. olive gray wd.; thin, massive bdg.; sparry; oncolitic 30 cm. (1.0') from base; 91 cm. (3.0') thick; sharp to covered contact.

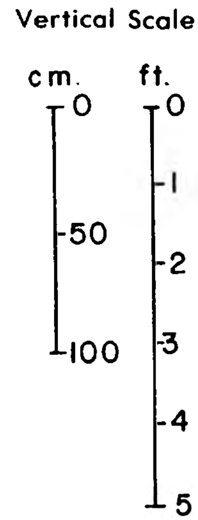
Unit 6: Limestone (Intrasparite) - v. lt. gray fr., yellowish gray wd.; dense, indistinct bdg.; conchoidal frac.; 98-110 cm. (3.2'-3.6') thick; sharp contact at thin shale layer.

Unit 5: Lithographic Limestone (Dolomitized Micrite) - v. lt. gray fr. & wd.; indistinct bdg.; conchoidal frac.; much of outcrop covered by grasses; stylolitic; contains quartzose bed (Quartzose Dolomitized Micrite) 137 cm. (4.5') from base - m. gray & lt. gray mottled fr. & wd., one thin bed, 21 cm. (.7') thick, sharp contacts with limestone; 229 cm. (7.5') total thickness; wavy contact.

Unit 4: Limestone (Dolomitized Micrite) - lt. gray fr., lt. olive gray wd.; thin bdg., fissile in places; lam.; scarce chert nodules at v. base; 46 cm. (1.5') thick; sharp contact.

Figure 46. Rock Hill Quarry section (I) continued.



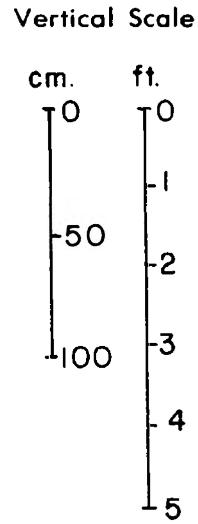


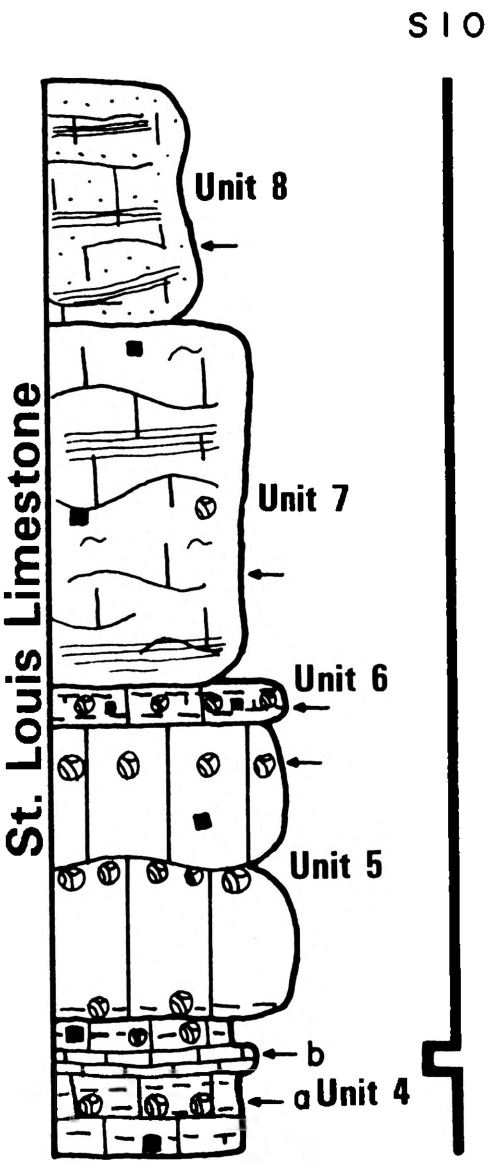
Unit 3: Limestone (Biomicrite) - lt. gray to v. lt. gray fr., lt. brn. & mod. reddish org. wd.; massive, thin bdg.; fossilif.: bryz.; stylolitic; v. pyritic; 67-178 cm. (2.2'-5.8') thick; sharp contact.

Unit 2: Limestone (Biomicrite) - lt. gray to v. lt. gray fr., lt. gray to yellowish gray wd.; thin, uneven bdg.; v. wd., crumbled; fossilif.: corals, bryz., brachs., ostracodes, crinoids; pyritic; 46-137 cm. (1.5'-4.5') thick; wavy to covered contact.

Unit 1: Limestone (Biomicrite) - lt. gray to v. lt. gray fr., lt. gray to yellowish gray wd.; thick, massive bdg. basal half, thin, uneven bdg. top half; lam. at base, small-scale solution sinks at top; becomes fossilif. above 116 cm. (3.8'): same as in Unit 2; v. stylolitic; chert zone approx. 76 cm. (2.5') from base - nodules lt. brn. with m. gray border, zone is 5-30 cm. (.2'-1.0') thick; 274-335 cm. (9.0'-11.0') total thickness; sharp contact at bench above, covered contact below.

Figure 47. Shrewsbury section (J).





Unit 8: Sandy Limestone (Sandy Intrasparite) - lt. gray to v. lt. gray fr., m. gray wd.; indistinct bdg.; lam.; smooth wd. surface; 91 cm. (3.0') thick; topmost unit of outcrop.

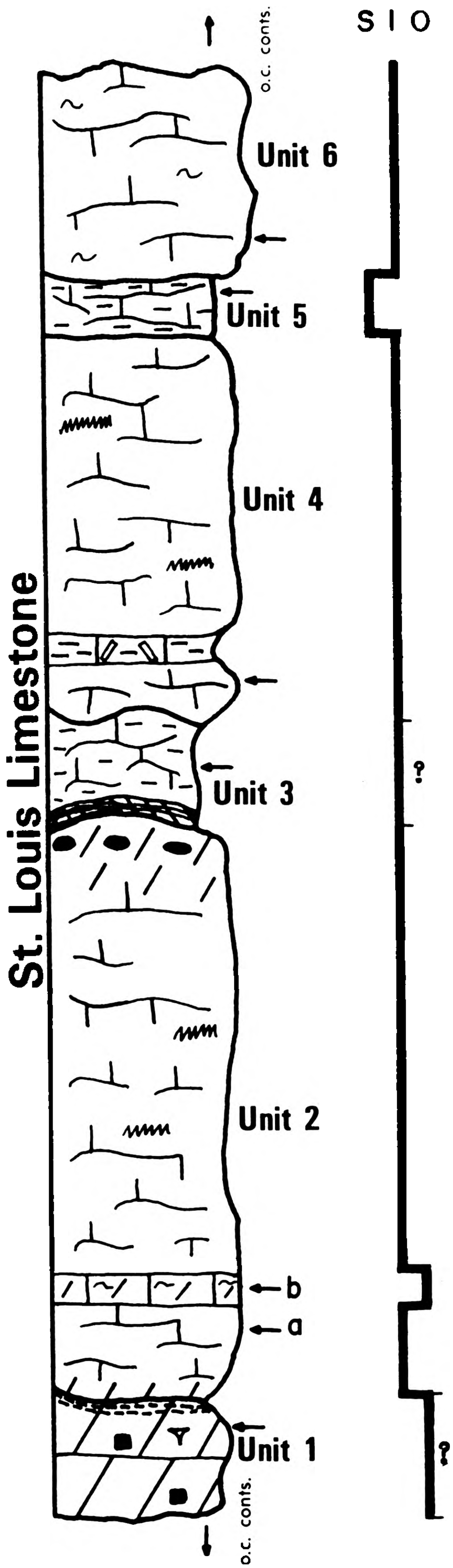
Unit 7: Limestone (Fossiliferous Intrasparite) - lt. gray fr., lt. gray to yellowish gray wd.; wavy, indistinct to massive bdg.; lam.; rough wd. surface; fossilif.; scarce oncolites; pyritic; 137 cm. (4.5') thick; sharp contact at bench.

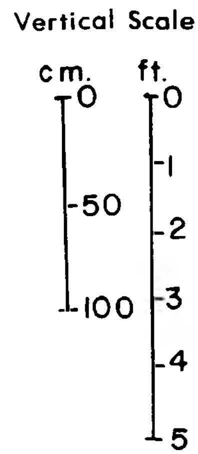
Unit 6: Argillaceous Limestone (N.A.) - pale grn. fr., m. gray wd.; thin, fissile bdg.; v. wd., crumbled; abundant oncolites; pyritic; 15 cm. (.5') thick; sharp contact at bench.

Unit 5: Limestone (Oncolitic Intrasparite) - lt. gray to v. lt. gray fr., m. gray wd.; two thin, massive, wavy beds; calcite blebs; pitted; oncolitic in layers; pyritic; 113 cm. (3.7') thick; sharp contact.

Unit 4: Argillaceous Limestone (Silty Disturbed Oncolitic Biosparite) - like Unit 6, but interbedded with Limestone (Dolomitized Dismicrite) 30 cm. (1.0') from base - two v. thin beds, 10 cm. (.3') thick; 52 cm. (1.7') total thickness; gradational contact.

Figure 48. Shrewsbury section (J) continued.





Unit 6: Limestone (Intrasparite) - lt. gray to v. lt. gray fr. & wd., dk. yellowish org. in places; massive to indistinct bdg.; fracd.; rough wd. surface; fossilif.; 91-106 cm. (3.0'-3.5') thick; wavy contact.

Unit 5: Argillaceous Limestone (Silty Dolomitized Ostracode Micrite) - grayish yellow grn. to dk. yellowish org. fr. & wd.; indistinct bdg.; fracd.; crumbled, pitted; 30 cm. (1.0') thick; sharp contact.

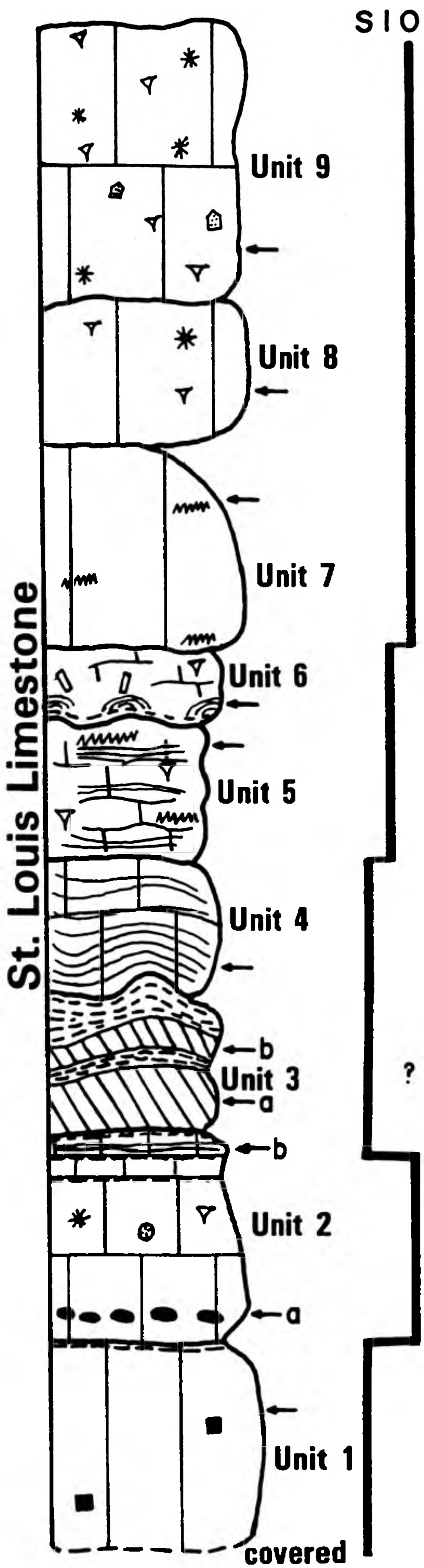
Unit 4: Limestone (Fossiliferous Intrasparite) - m. gray fr., lt. gray to v. lt. gray wd.; conchoidal frac.; smooth wd. surface; stylolitic; contains one thin bed of argillaceous limestone about 30 cm. (1.0') from base of unit - lt. gray fr., yellowish gray to lt. gray wd., wavy bdg., brecciated in places, v. wd., 8-13 cm. (.3'-.4') thick, sharp contacts with limestone; 197 cm. (6.5') total thickness; sharp contact.

Unit 3: Argillaceous Limestone (Pseudosparite) - lt. greenish gray fr., pale grn. to lt. gray wd.; thin, wavy to indistinct bdg.; wd.; contains one thin quartzose bed at base of unit - white to m. gray fr. & wd., lam., wavy bdg., 10 cm. (.3') av. thickness; 48 cm. (1.6') total thickness; wavy contact.

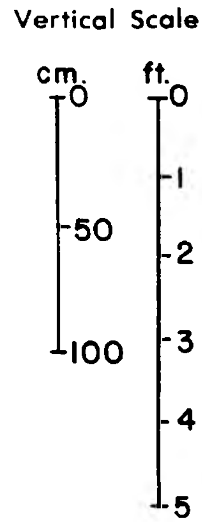
Unit 2: Limestone (Fossiliferous Intrasparite) - lt. gray to v. lt. gray fr. & wd.; thin, massive to indistinct bdg.; fracd.; pitted; stylolitic; chert nodules & spar patches at top of unit, dolomitic streaks top few feet of unit; contains one thin dolomitic limestone bed 56 cm. (1.8') from base (Dolomitized Algal Biomicrite) - pale yellowish brn. fr. & wd., fairly continuous bdg., v. pitted & wd. in exposure about 152 cm. (5.0') long, fossilif. at top, 10-20 cm. (.3'-.7') thick, sharp contact with limestone; 289-304 cm. (9.5'-10.0') total thickness; wavy contact.

Unit 1: Dolomite (Very Finely Crystalline Biogenic Dolomite) - pale yellowish brn. fr. & wd.; thin, massive bdg.; slightly fossilif.: brachs.; pyritic; topped with one v. thin layer of argillaceous dolomite - dk. gray to pale grn. fr., lt. gray to pale grn. wd., v. thin, fissile, wavy bdg.; 66 cm. (2.2') total thickness; gradational contact.

Figure 49. Butler Hill Road section (K).



Unit 9: Limestone (Biomicrite) - pale yellowish brn. fr., pale yellowish brn. to mod. yellowish brn. wd.; thick, massive bdg.; dense; calcite veins throughout; v. fossilif.: brachs., crinoids, echinoids; at least 122 cm. (4.0') thick; topmost unit of outcrop.



Unit 8: Limestone (Biomicrite) - m. lt. gray fr., lt. gray to white wd.; one thin, massive bed; rough to smooth wd. surface; fossilif.: brachs., crinoids; transitional bed from Unit 7 to Unit 9; 61 cm. (2.0') thick; sharp contact.

Unit 7: Limestone (Fossiliferous Micrite) - m. lt. gray fr., lt. gray to white wd.; thick, massive bdg.; dense; sparry patches, dk. patches (algae?); stylolitic; 86 cm. (2.8') thick; sharp contact.

Unit 6: Limestone (Dolomitized Algal Biolithite) - lt. gray fr., lt. gray to v. lt. gray wd.; indistinct bdg.; lam. bottom 8 cm. (.3'), partly brecciated; fracd.; argillaceous wd. surface; fossilif.: brachs.; contains thin shale layer at base - pale grn. fr. & wd., calcareous, wavy bdg., crumbly; 38 cm. (1.3') total thickness; sharp contact.

Unit 5: Limestone (Intrasparite) - lt. gray fr., lt. gray to white wd.; wavy, discontinuous bdg.; dense; lam., conchoidal frac., v. sm. calcite veins; fossilif.: brachs.; stylolitic; 61-76 cm. (2.0'-2.5') thick; wavy contact.

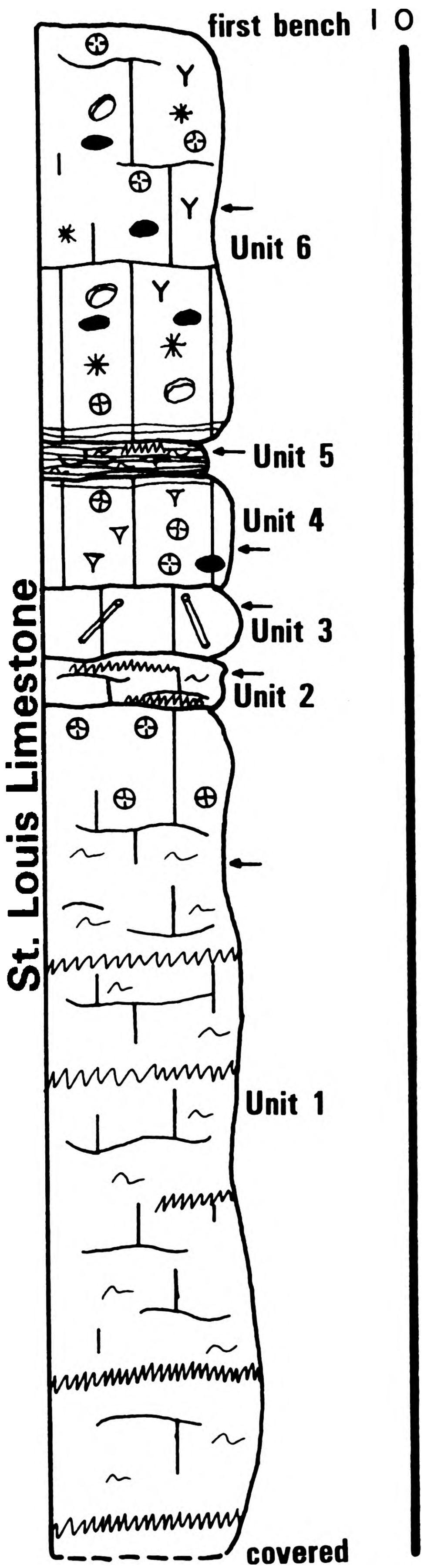
Unit 4: Limestone (Microsparite) - pale grn. to lt. gray fr. & wd.; thin, massive bdg.; v. lam.; 61-81 cm. (2.0'-2.7') thick; v. wavy contact.

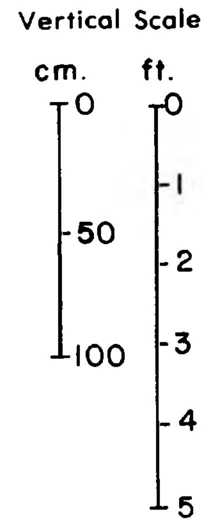
Unit 3: Quartzose Limestone (a-Quartzose Pseudosparite, b-Brecciated Quartzose Microsparite) - lt. bluish gray & m. bluish gray mottled fr. & wd.; indistinct, wavy bdg.; iron stained; interbedded with shale - pale grn. to lt. gray fr. & wd., bdg. not visible, v. wd., crumbled, 5-13 cm. (.2'-.4') thick; 61 cm. (2.0') av. total thickness; wavy contact.

Unit 2: Limestone (a-Biomicrite, b-Calcispheric Biomicrite) - lt. gray to grayish red fr., lt. olive gray wd.; four thin beds; dense; lam. top 8 cm. (.3'); fossilif.: *Lithostrotion* sp., crinoids, brachs.; numerous chert nodules at base; v. thin shale layers between top three beds; 91 cm. (3.0') thick; sharp contact at shale layer.

Unit 1: Limestone (Dolomitized Silty Intramicrite) - lt. gray fr., lt. bluish gray & lt. olive gray wd.; one thick bed; clay coated surface; pyritic; 91 cm. (3.0') thick; sharp contact at shale layer, covered contact below.

Figure 50. Mattis Road section (L).





Unit 6: Limestone (Dolomitized Biomicrite) - pale yellowish brn. fr. & wd.; thin to thick, discontinuous bdg.; v. fossilif.: crinoids, ostracodes, bryz., & silicic, overturned coralla of *Lithostrotion* sp.; chalcopyritic; sparry; abundant chert nodules; 183 cm. (6.0') thick; top forms first bench.

Unit 5: Limestone (Biomicrite) - pale yellowish brn. fr. & wd.; somewhat fissile, indistinct bdg.; v. lam.; fracd.; crumbly; v. fossilif.; stylolitic; 3-15 cm. (.1'-.5') thick; gradational contact.

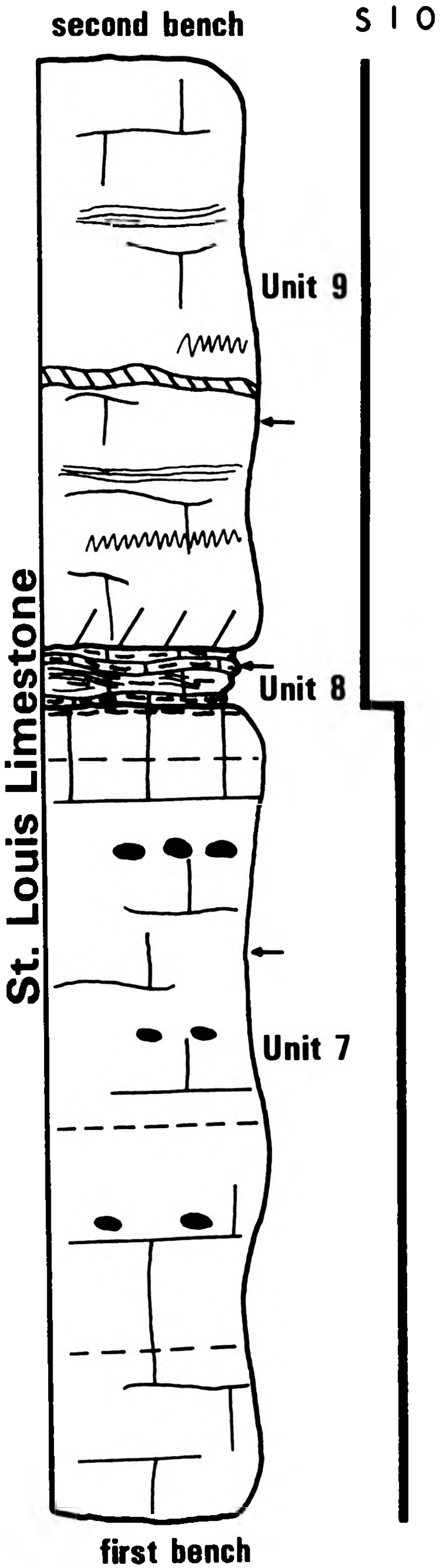
Unit 4: Limestone (Biomicrite) - pale yellowish brn. fr. & wd.; one thin, massive bed; linear & conchoidal fracs.; spar on wd. surface; v. fossilif.: corals, brachs.; grayish grn. illite; a few scattered fossilif. chert nodules; 47 cm. (1.6') thick; gradational contact.

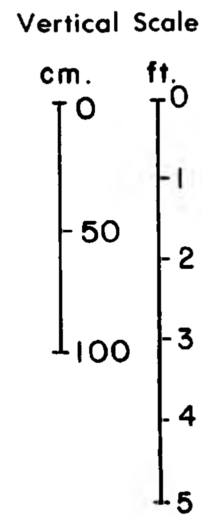
Unit 3: Limestone (Dolomitized Biomicrite) - pale yellowish brn. fr. & wd.; one thin, massive bed; v. smooth wd. surface; linear & conchoidal fracs.; fossilif.: worm burrows; chalcopyritic; scattered grayish grn. illite; small spar patches; 20-30 cm. (.7'-1.0') thick; gradational contact.

Unit 2: Limestone (Dolomitized Fossiliferous Micrite) - pale yellowish brn. fr. & wd.; indistinct, discontinuous bdg.; fracd.; somewhat fissile, crumbled; slightly fossilif.; v. stylolitic; sparse grayish grn. illite balls; 20-23 cm. (.7'-.8') thick; gradational contact.

Unit 1: Limestone (Biomicrite) - pale yellowish brn. fr. & wd.; thin to thick, discontinuous bdg.; fracd.; rough, sparry wd. surface; v. fossilif.: horn corals in upper portion; v. stylolitic; grayish grn. illite balls; approx. 371 cm. (12.2') thick; gradational contact above, covered contact below.

Figure 51. Bussen Quarry section (M).



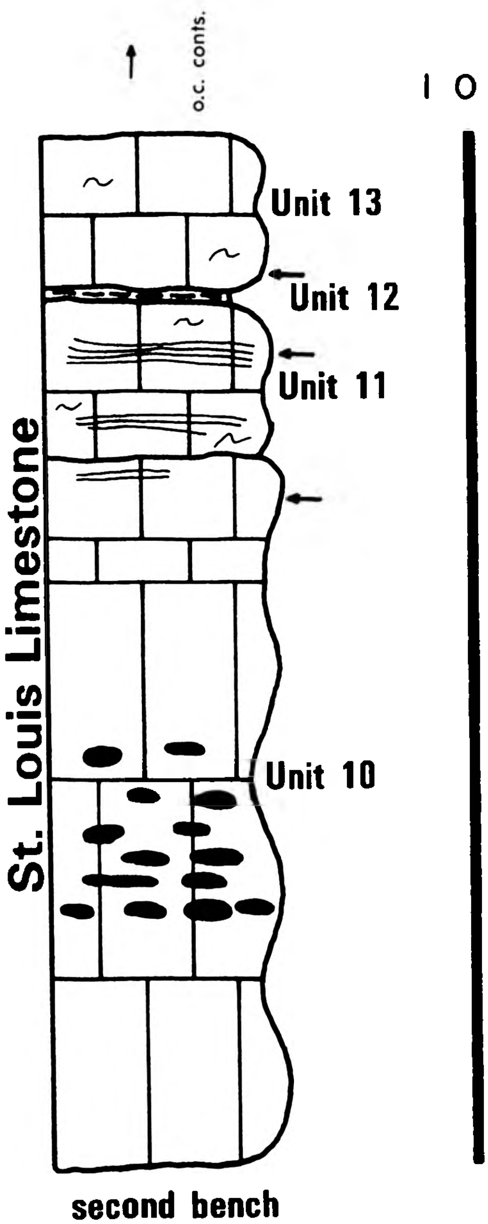


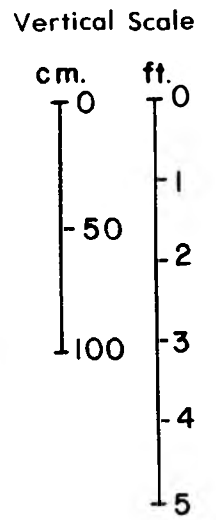
Unit 9: Lithographic Limestone (Micrite) - lt. gray fr., lt. gray to v. lt. gray wd.; indistinct bdg.; dense; v. fracd.; wd. part is lam., broken; stylolitic; basal 18 cm. (.6') is a dolomite streak - pale yellowish org. fr. & wd., discontinuous bed grading laterally into limestone; contains quartzose layer approx. 106 cm. (3.5') from base - white to m. gray mottled fr. & wd., wavy bdg., 5-13 cm. (.2'-.4') thick, wavy contact; 244 cm. (8.0') total thickness; top forms second bench.

Unit 8: Argillaceous Limestone (Silty Calcispheric Micrite) - pale grn. to lt. gray fr. & wd.; fissile, v. thin to thin, wavy bdg.; lam.; 20-23 cm. (.7'-.8') thick; sharp contact.

Unit 7: Limestone (Intrasparite) - pale yellowish brn. fr. & wd.; massive, thin to thick discontinuous bdg.; dense; conchoidal frac.; rough wd. surface; abundant chert nodules in layers; contains a few v. thin, scattered shale layers; 335 cm. (11.0') thick; sharp contact at shale layer.

Figure 52. Bussen Quarry section (M) continued.





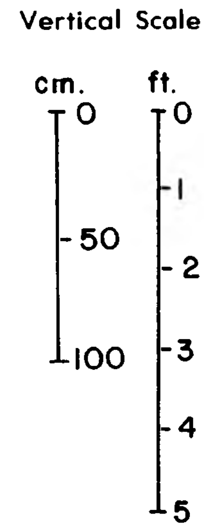
Unit 13: Limestone (Biomicrite) - m. gray fr., lt. gray wd.; one to two thin, massive beds; smooth wd. surface; fossilif.; 58 cm. (1.9') thick; sharp contact.

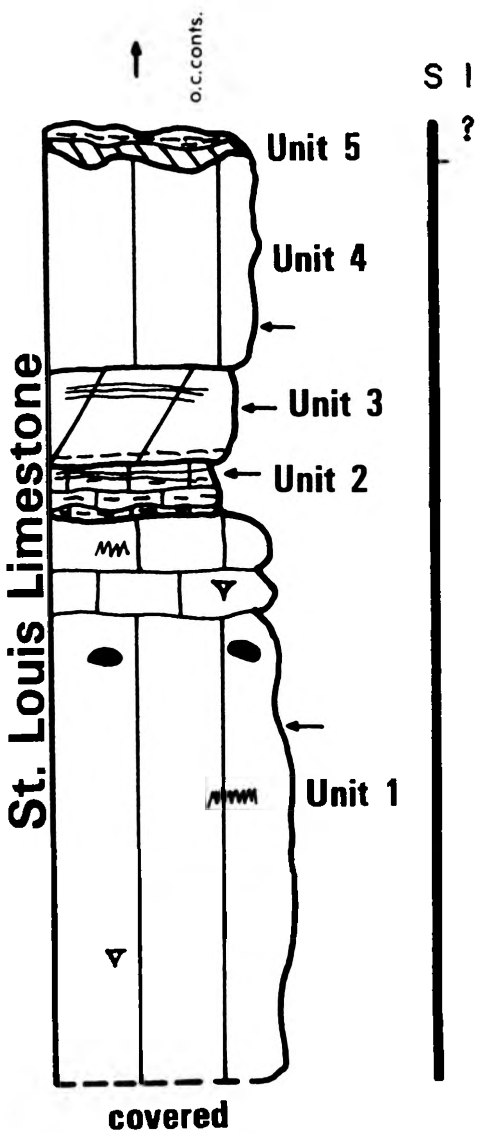
Unit 12: Shale - lt. gray to pale grn. fr. & wd.; v. fissile, wavy bdg.; crumbled; 5 cm. (.2') thick; wavy contact.

Unit 11: Limestone (Fossiliferous Micrite) - m. gray fr., lt. gray to v. lt. gray wd.; two thin, slightly fissile beds; lam.; fossilif.; 58 cm. (1.9') thick; sharp contact.

Unit 10: Limestone (Biomicrite) - m. gray fr., lt. gray to v. lt. gray wd.; thin to thick, massive bdg.; somewhat fracd.; abundant chert nodules and lenses concentrated in a 61 cm. (2.0') thick zone approx. 90 cm. (3.0') from base of unit; 268 cm. (8.8') thick; sharp to gradational contact.

Figure 53. Bussen Quarry section (M) continued.





Unit 5: Shale - pale grn. fr. & wd.; v. thin, fissile bdg.; v. crumbled, soft; underlain by quartzose layer - white to m. gray mottled, thin, wavy bdg., pinches out in places, 5-10 cm. (.2'-.3') av. thickness; 8-15 cm. (.3'-.5') total thickness; wavy, irregular contact.

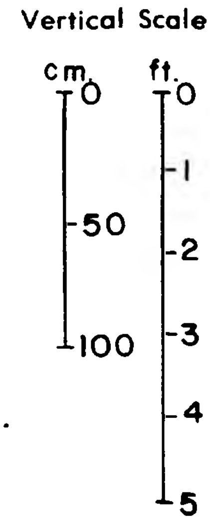
Unit 4: Lithographic Limestone (Dolomitized Micrite) - lt. olive gray fr. & wd.; one thick bed; dense; conchoidal frac.; 71-81 cm. (2.3'-2.7') thick; wavy contact.

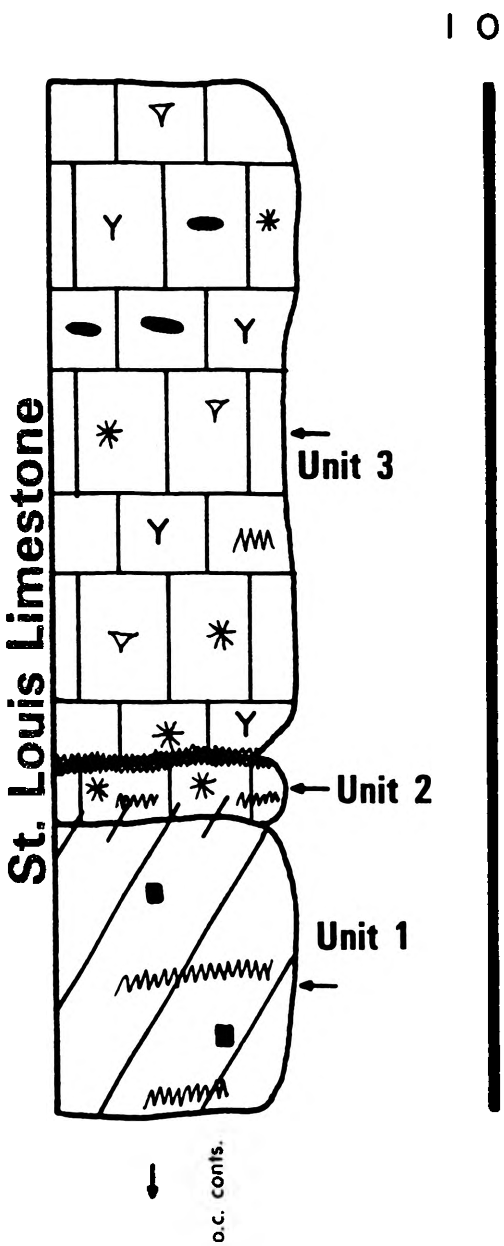
Unit 3: Dolomite (Very Finely Crystalline Biogenic? Dolomite) - lt. gray to white fr., white to yellowish gray wd.; one thin bed, v. soft in most places; lam.; white clay-like coating, v. soft, crumbled; 35 cm. (1.2') thick; sharp contact.

Unit 2: Argillaceous Limestone (Dolomitized Micrite) - lt. gray to pale grn. with m. gray lams. fr. & wd.; v. thin to thin, fissile bdg., wavy in places; coarse spar layers with wavy bdg.; argillaceous portions are v. wd., crumbled, pure limestone is smooth on wd. surface; 15-20 cm. (.5'-.7') thick; gradational contact.

Unit 1: Limestone (Calcispheric Algal Biomicrite) - m. lt. gray fr., lt. gray wd.; thin to thick, massive, bdg.; microcrystalline; linear and conchoidal fracs.; iron stained; slightly fossilif.: brachs.; slightly stylolitic; sparse chert nodules, sparse, v. coarse spar patches in top 30 cm. (1.0') of unit; at least 213 cm. (7.0') thick; sharp contact above, covered contact below.

Figure 54. Vigus South Quarry section (N).



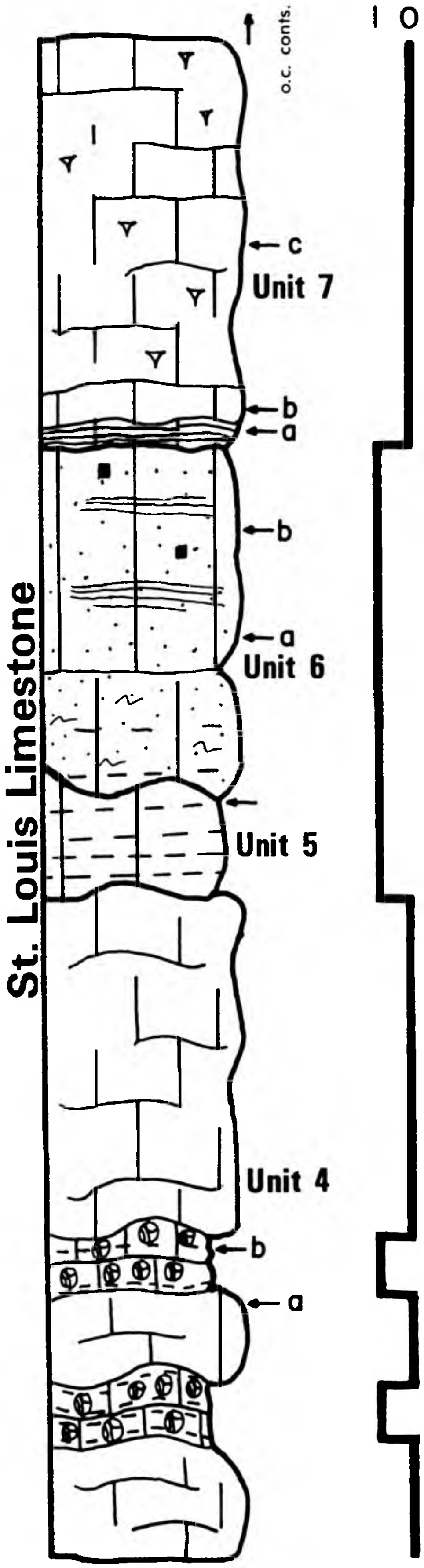


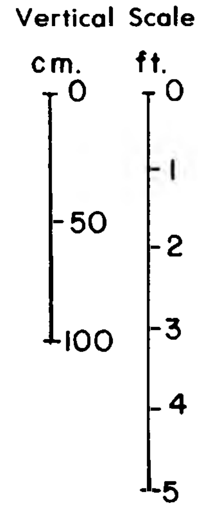
Unit 3: Limestone (Biomicrite) - lt. olive gray fr. & wd.; thin, massive bdg.; conchoidal frac.; fossilif.: brachs., crinoids, bryz.; slightly stylolitic; m. dk. gray and pale reddish brn. chert nodules; numerous spar patches; 254 cm. (8.3') thick; sharp contact.

Unit 2: Limestone (Dolomitized Fossiliferous Micrite) - yellowish gray fr. & wd.; one thin, massive bed; smooth wd. surface; fossilif.: crinoids; stylolitic; sparry in top half of bed; 22 cm. (.8') thick; sharp, stylolitic contact.

Unit 1: Dolomite (Very Finely Crystalline Dolomite) - brownish gray fr., m. gray to brownish gray wd.; one massive, thick bed; v. thin calcite veins; white to lt. brn. caliche on wd. surface; stylolitic; pyritic; 109 cm. (3.6') thick; gradational contact.

Figure 55. Stolle Quarry section (O).





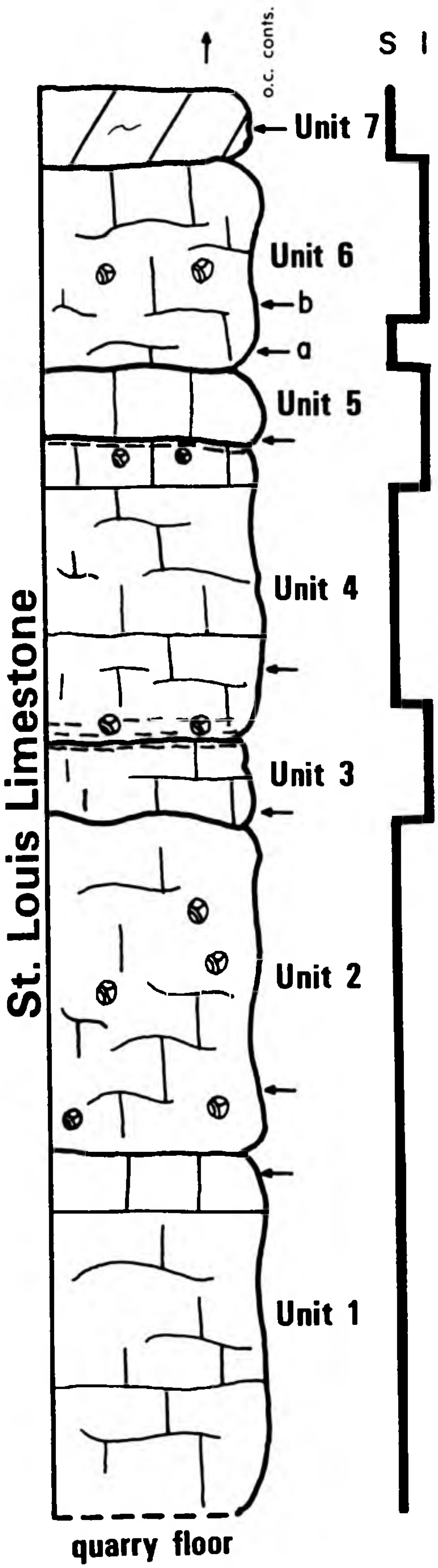
Unit 7: Limestone (Biomicrite) - lt. olive gray fr., lt. olive gray to white wd.; discontinuous, thin bdg., argillaceous on bdg. planes; conchoidal frac.; fossilif.: *Composita* sp.; contains one thin lam. lens at base, 10-13 cm. (.3'-.4') thick; 178 cm. (5.8') total thickness; sharp contact.

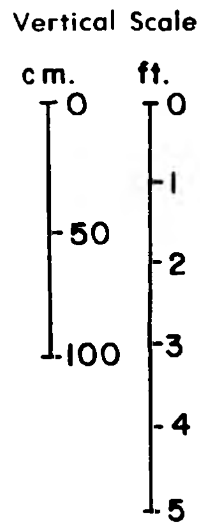
Unit 6: Sandy Limestone (Sandy Intrasparite) - lt. gray fr. & wd.; one thin bed below one thick, massive bed; bdg. lams. barely visible; smooth, uniform texture; argillaceous at base; fossilif. at base; pyritic; 142 cm. (4.7') thick; sharp contact.

Unit 5: Argillaceous Limestone (Intrasparite) - m. gray fr., lt. grn., yellowish gray, and m. gray mottled wd.; one thin, wavy bed; argillaceous on wd. surface; fairly wd., crumbled; numerous dk. gray algal patches with spar between; grayish grn. illite spots; 30-50 cm. (1.0'-1.7') thick; v. wavy contact.

Unit 4: Limestone (Dismicrite) - m. lt. gray fr., lt. gray to m. lt. gray wd., massive, thin to indistinct bdg., sparry in places; alternating with Argillaceous Limestone (Silty Oncolitic Algal Biosparite) - lt. gray to pale grn. fr., pale grn. & grayish org. wd.; v. thin, fissile bdg.; v. wd., broken, crumbled; v. oncolitic; 287 cm. (9.4') total thickness; wavy contacts.

Figure 56. Stolle Quarry section (O) continued.





Unit 7: Dolomite (Dolomitized Micrite) - lt. gray to lt. brn. fr., lt. gray wd.; one thin bed; fracd.; relicts of fossils; scattered grayish grn. illite; 33 cm. (1.1') thick; gradational contact.

Unit 6: Limestone (a-Disturbed Algal Biomicrite, b-Intraclastic Algal Biosparite) - m. gray fr., lt. gray wd.; indistinct bdg.; fracd.; oncolitic; basal 23 cm. (.8') is a lithographic limestone - dk. gray fr. & wd., conchoidal frac.; 84 cm. (2.8') total thickness; gradational contact.

Unit 5: Limestone (Dolomitized Silty Intrasparite) - m. gray fr., lt. gray wd.; one thin, massive bed; coarse texture; smooth wd. surface; 28 cm. (.9') thick; wavy contact.

Unit 4: Limestone (Disturbed Algal Biomicrite) - m. gray fr., lt. gray wd.; thin to indistinct bdg.; fracd.; uniform texture with small, scattered, dk. gray blebs and oncolites in basal 14 cm. (.5') and top 14 cm. (.5') of unit; basal 8 cm. (.3') and top 4 cm. (.2') are argillaceous - m. gray fr., lt. grn. wd., v. crumbly, thin bdg.; 127 cm. (4.2') total thickness; sharp contact at argillaceous layer.

Unit 3: Limestone (Algal Intrasparite) - lt. gray & dk. gray mottled fr., m. gray & dk. gray mottled wd.; thin, discontinuous bdg.; dk. gray algal patches with spar between; thins and thickens 25-40 cm. (.8'-1.3'); sharp contact at argillaceous layer.

Unit 2: Limestone (Dolomitized Oncolitic Calcispheric Biomicrite) - m. gray fr. & wd.; indistinct bdg.; rough, pitted surface; lg. dk. gray oncolites without visible banding, some not completely spherical; 135 cm. (4.4') av. thickness; sharp to wavy contact.

Unit 1: Limestone (Algal Biomicrite) - m. gray fr., lt. gray wd.; thin to indistinct bdg. with v. thin carbonaceous layers; irregular, fracd. surface; small dk. patches (intraclasts/algae); approx. 151 cm. (5.0') thick; sharp contact above, base covered by rubble.

Figure 57. East St. Louis Stone Co. Quarry section (P).