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SEDIMENTARY FACIES OF THE TORONTO LIMESTONE, LOWER
LIMESTONE MEMBER OF THE OREAD MEGACYCLOTHEM
(VIRGILIAN) OF KANSAS

by

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SEDIMENTARY FACIES OF THE TORONTO LIMESTONE,
LOWER LIMESTONE MEMBER OF THE OREAD MEGACYCLOTHEM
(VIRGILIAN) OF KANSAS

by

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ABSTRACT

The Toronto Limestone is the lower limestone member of the Oread Megacyclothem. It averages about 10 feet in thickness and is exposed from northern Oklahoma, where it undergoes facies change to shale, across Kansas to northwestern Missouri and is present at the surface in the Platte River Valley of Nebraska.

The purpose of the study was to determine the sedimentary facies and interpret environments of deposition by a quantitative approach with special emphasis on the constituent composition of the limestone.

Field stratigraphic studies were undertaken at 54 localities and detailed laboratory studies were performed on samples collected from them. The volumetric abundances of 19 skeletal and 4 non-skeletal grain types were determined quantitatively by point-count analyses. Factor analysis of the accumulated data, supplemented with observations on the megafauna and field study, were used in delineating 6 facies. From southern Kansas to northwestern Missouri, the lower half of the Toronto is a skeletal mud facies - characterized by the presence of diverse skeletal grain types. This facies grades northward (in Nebraska) and southward (in southern Kansas) into a brachiopod facies - typified by an abundance of brachiopods, many of them complete specimens. In southern Kansas, the Toronto Limestone interfingers with and is replaced by a fossiliferous terrigenous mud (shale) facies - characterized by myalinid-rich, brachiopod-rich, and fusulinid-rich zones. In northern and central Kansas, a facies charac-

terized by the presence of fenestrate bryozoans and crinoid segments, the fenestrate bryozoan-echinoderm grain facies, is developed near the top of the limestone. A lime mud facies, characterized by the presence of a molluscan fauna and containing intraclasts, is developed at the top of the Toronto Limestone in Nebraska, northwestern Missouri, and in northern Kansas. In southern Kansas, a molluscan-"Cryptozoon" subfacies of the skeletal mud facies is developed in the upper part of the limestone. An Osagia grain facies, an accumulation of algal-coated skeletal grains, is locally developed at the top of the Toronto in south central Kansas.

The Toronto Limestone was deposited during a single advance and retreat of the sea with deltaic deposition taking place along shore in northern Oklahoma and possibly in Nebraska while lime was being deposited offshore in Kansas. The factors of primary importance in facies differentiation are interpreted to have been (1) rate of terrigenous sediment influx; (2) nutrient element supply; (3) salinity; and (4) turbulence. From the delta fringe area to the farthest offshore and most marine conditions the respective facies tracts were (1) fossiliferous terrigenous mud, (2) brachiopod facies, (3) skeletal mud facies, and (4) echinoderm-fenestrate bryozoan grain facies. The lime mud facies was a product of mud flat deposition mainly during the regressive phase.

At several places along the outcrop between northern Oklahoma and northwestern Missouri, the Toronto Limestone was channeled by streams prior to deposition of the Leavenworth Limestone which is continuous across the region. The Leavenworth and the black Heebner Shale which overlies it show greater continuity of facies than the Toronto Limestone. The lower part of the Oread Megacyclothem (Wathena Shale, Toronto Limestone, Snyderville Shale, Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone) are explained by two eustatic sea-level cycles. The Wathena and Toronto were deposited during an intermediate rise of sea-level, the Snyderville accumulated during the regression, and the Leavenworth, Heebner and Plattsmouth were products of a greater rise of sea-level.

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INTRODUCTION

Opening Statement

Even a casual observation of the Pennsylvanian column of Kansas leaves one with a lasting impression of the remarkable number of relatively thin sedimentary deposits of heterogeneous lithology. Limestone and shale, together with lesser sandstone and coal, are present throughout the succession. These lithologies have been described as occurring in cyclical sequences that are repeated in the same arrangement many times in the overall succession (Moore, 1931, 1936, 1950). Certain parts of the Kansas Pennsylvanian section are described as consisting of simple sedimentary cycles; each of which is interpreted to be the record of a single marine advance and retreat (Moore, 1950, p. 7). In parts of the column, however, cycles of cyclothems, termed megacyclothems, have been described (Moore, 1936, 1949, 1950). If the generalizations regarding megacyclothems are true (Moore, 1950, pp. 10, 11), then the depositional environments recorded in each cyclothem should be duplicated or nearly duplicated in corresponding units of other megacyclothems. Only through detailed studies of the individual cyclothems within the different megacyclothems can these hypotheses be tested.

Objectives of the Study

Relatively thin, sheetlike deposits of Pennsylvanian limestone of Kansas, some of which can be traced for distances up to 300 miles on the outcrop and can be identified over comparable distances down dip into basinal areas, have for many years attracted the attention of students of sedimentation and stratigraphy (Moore, 1931, 1936, 1949, 1950, 1959, 1962). However, most of the studies of individual units to date have been concerned primarily with vertical variations. It was the expressed purpose of this investigation to trace and to study at selected outcrops a Pennsylvanian limestone body throughout its area of outcrop and to formulate an hypothesis concerning the depositional history of the unit. Immediate objectives were (1) to determine the general stratigraphic relationships of the limestone internally and externally; (2) to examine in detail the lithological and paleontological aspects within the unit at a number of selected localities along the outcrop belt; (3) to set forth generalities concerning lateral and vertical variations in lithology and paleontology observed; and (4) to reconstruct the general depositional history of the unit. The ultimate objective of this study was to contribute to the development of paleoenvironmental principles and practices that will have application in the study of other carbonate units in the geological record.

Premise and Approach

The approach used in this investigation is based on the presumption that principles gained from studies of Recent carbonate sediments and their sedimentary relatives can be applied to an interpretation of ancient sediments. Assuming that studies of Recent sedimentation are adequate, the fundamental requirement for drawing analogies between Recent and ancient beds is a detailed stratigraphic analysis of ancient sediments involving geometry, sedimentary structures, texture, lithology, paleontology, and related features that provide data to which principles gained from studies of Recent sediments can be applied and inferences made.

Unit Selected for Study

The Toronto Limestone Member of the Oread Limestone Formation was selected for study for the following reasons: (1) it is a member of the Oread Limestone which is included in the Shawnee Group (Virgilian in age) said to contain the most complete record of megacyclothems in the Upper Pennsylvanian of Kansas (Moore, 1950, p. 11); (2) it is a limestone in the basal cyclothem of the Oread megacyclothem; (3) its outcrop has been traced throughout Kansas and into parts of adjacent states so that the stratigraphy is fairly well known; and (4) some data are available on the extent of the Oread members in the subsurface.

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Thanks are due Dr. Carey Croneis who served as chairman of my dissertation committee and Dr. Edward G. Purdy who was my thesis advisor. Dr. Purdy developed many of the methods of petrographic study employed in the investigation.

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photomicrographs. Dr. Robert R. Lankford, Rice University, and Dr. Thomas E. Pulley, Rice University and the Houston Museum of Natural Science, served on the dissertation committee, read and criticized the manuscript, and offered helpful suggestions.

METHODS OF INVESTIGATION

Field Studies

Initial field reconnaissance was begun on the Toronto Limestone in Kansas during the last week of March in 1962. For two weeks in September of the same year, outcrop studies and sample collections were made from localities ranging from northern Oklahoma across Kansas to St. Joseph, Missouri. For a week in January and for the last week of February 1963, some Kansas and Oklahoma localities were revisited and an exposure was studied in southeastern Nebraska. Three weeks of July 1963 were used in making field studies of outcrops in Iowa, Nebraska, Missouri, and Oklahoma. A total of 42 outcrop localities were studied on these excursions.

At most of the localities, the stratigraphic section was measured and described, primary structures were noted, fossils were identified in the field and collected for laboratory study whenever possible, and oriented lithologic samples were collected. In addition, photographs were taken of the outcrop, individual beds, fossils, textures and structures.

In areas where correlations were not certain, intermediate sections were studied and the beds were traced laterally where possible.

Laboratory Studies

In the laboratory, lithologic samples were sawed into slabs normal to bedding surfaces and examined with a binocular microscope. Fossils were freed from these samples wherever possible and were identified and placed in a mega-faunal collection. Several hundred thin-sections (most of them 2 x 3 inches) were prepared and studied.

Megafossil specimens were identified and catalogued almost solely with the aid of available literature as reference specimens were limited.

Quantitative insoluble residues were made from small 10-50 gm. samples of each bed from the various localities by dissolving the sample in dilute acetic or formic acid. The residues were examined and described, using binocular microscope.

Samples of shale from the Toronto as well as from enclosing beds were prepared and studied for microfossil content. Varsol was used in breaking down 100 gram samples for these studies.

X-ray diffraction patterns were run on many of the samples in order to determine the various minerals present in the Toronto Limestone.

REGIONAL GEOLOGICAL SETTING

Rocks of ^{(conodont)?} Upper Pennsylvanian (Virgilian) ^{Virgilian and Missourian} age are exposed from the northern flanks of the Arbuckle Mountains in southern Oklahoma (Pontotoc County) northward to Osage County on the Kansas border (Fig. 1). In Kansas, they outcrop in a north-northeasterly trend from Chautauqua County on the Oklahoma line to Doniphan County on the Missouri River. Virgilian strata are exposed from Platte to Harrison counties in northeastern Missouri, and in southwestern Iowa from Ringold County northward to Madison County and from there westward to Pottawattamie County on the Missouri River (Hershey et al, 1960). They crop out in southeastern Nebraska, especially in Cass and Otoe counties. These rocks dip gently westward in Oklahoma and Kansas (average dip about 15 to 25 feet per mile in Kansas), northwestward in Missouri, southwestward in Iowa, and southeastward in Nebraska.

The northern Oklahoma-southern Kansas area is a region of transition between strata of the southern part of the Mid-Continent area where terrigenous clastics predominate and a more northerly region where thalassigenous* carbonate sediments are dominant.

*The writer proposes usage of the term thalassigenous as a companion to terrigenous. All sediments formed in the sea are thalassigenous (examples are lime sands, lime silts and muds, organic reefs, and evaporites). Those sediments derived outside the depositional basin and transported to the basin in solid form are terrigenous (examples are quartz sand and silt, and clay minerals).

In the subsurface, Virgilian strata have been identified from the outcrop belt westward throughout central and western Kansas, westward from the outcrop and north of the Arbuckle and Wichita mountains in Oklahoma, and north of the buried Amarillo Mountains in the Texas Panhandle. Over most of Kansas carbonate rocks predominate, but in the Anadarko Basin terrigenous clastics are characteristic; the latter increase in thickness and become coarser textured toward the land masses to the south, southwest, and southeast (Apishapa-Sierra grande, Amarillo-Wichita, Arbuckle, and Ouachita positive areas).

Virgilian beds are present in outcrop along the Front Range of Colorado (part of the Fountain Formation) where they are mainly terrigenous clastics (Wilson, 1962, p. 140). Beds of the same age are present in the subsurface of eastern Colorado, eastern Wyoming, much of Nebraska, and part of South Dakota. Virgilian beds are present at the surface in the Hartville Uplift of southeastern Wyoming where evaporites are conspicuous in the section although carbonates and terrigenous clastics are present also.

The major positive and negative Pennsylvanian tectonic features of the northern Mid-Continent area are shown in Figure 1. These include: major and minor source areas, prominent basins, and the more positive features that separated them.

Early Pennsylvanian (Springeran) deposition was confined to the Ardmore-Anadarko foredeep where black shales and sandstones were deposited (Rascoe, 1962, p. 1369) and to the Ouachita geosyncline where a thick sequence of "flysch" sediments accumulated with Wapanucka Limestone deposition being

marginal to the geosyncline (Goldstein and Hendricks, 1962, p. 426). Concurrently, the remainder of the Mid-Continent area was undergoing epirogenic uplift and erosion (Rascoe, 1962, p. 1369). After Springeran sedimentation, a general episode of marine transgression onto the northern Mid-Continent region began. It involved subsidence of the Anadarko Basin and related features. Morrowan beds are present in southwestern Kansas, southeastern Colorado, and across the Oklahoma-Texas Panhandle and into southeastern Oklahoma parallel to the Amarillo-Arbuckle chain which was low or non-existent at this time (Rascoe, 1962, p. 1352).

Deformation of the Ouachita geosyncline began in late Atokan with the axis of the geosyncline migrating northwestward over the foreland into the McAlester Basin (Goldstein and Hendricks, 1962, p. 427). Structural movement in the Ouachitas definitely continued as late as middle Des Moinesian (ibid. p. 427). Continued subsidence, shelfward expansion of the Anadarko Basin, and progressive regional transgression continued from Morrowan through Atokan, Des Moinesian, and into the Missourian which marked the acme of marine transgression over the Mid-Continent area during the Pennsylvanian (Rascoe, 1962, p. 1369).

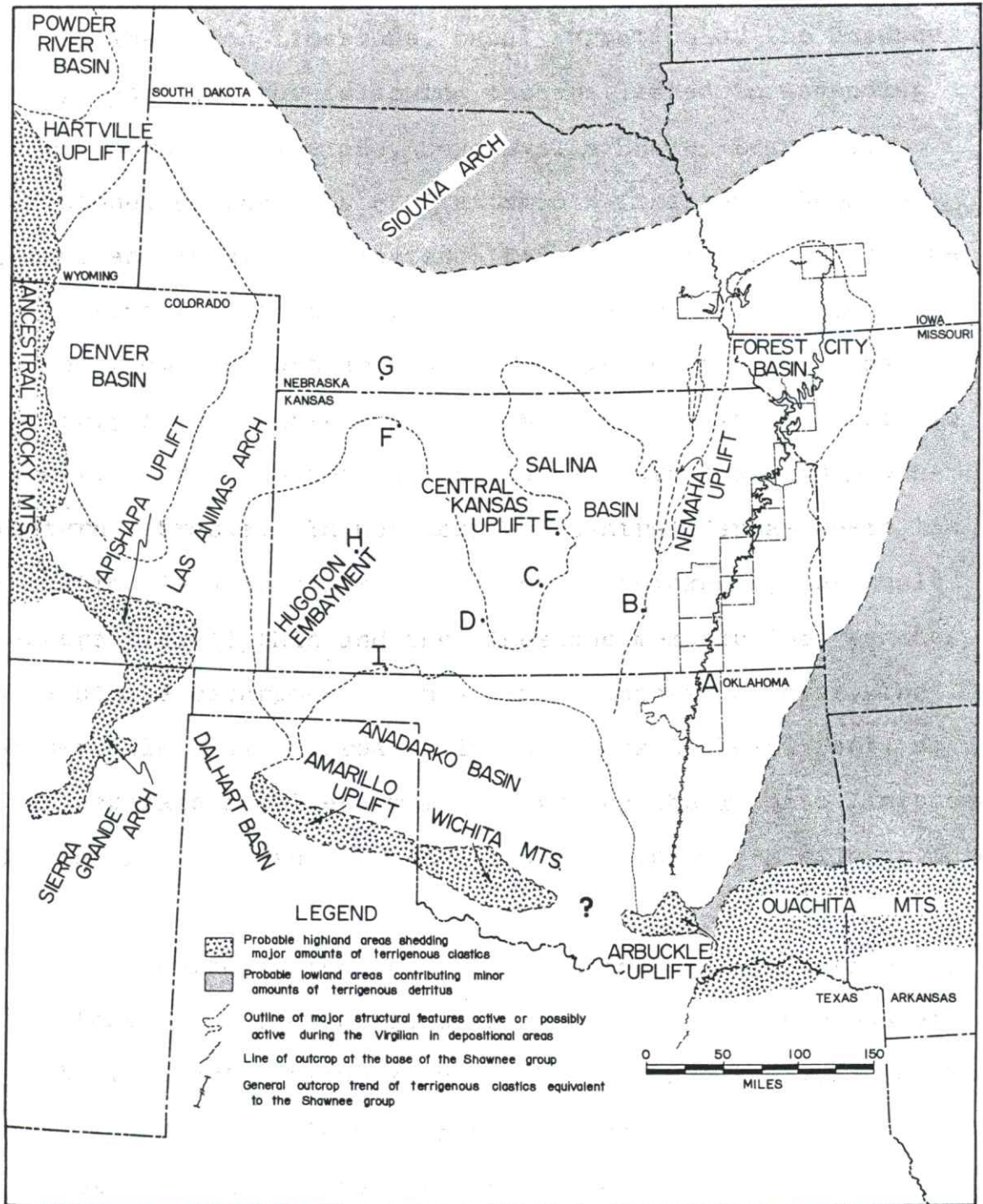
The progressive increase with time in the importance of carbonate rocks from shaly Morrowan beds to thin limestones of the Atokan (Cherokee Group), to the well developed limestones of the upper Des Moinesian (Marmaton Group) and succeeding Missourian and Virgilian beds is significant (Rascoe, 1962, p. 1362). The major source areas for Missourian and Virgilian

sediments of the Kansas-Oklahoma region were the Arbuckles, Wichitas, Amarillcs, and the Apishapa-Sierra Grande Uplift (Rascoe, 1962, figs. 14 and 15; Ball, 1964).

Regional regression which began in Virgilian time involved a lessening in the rate of subsidence and areal extent of the Anadarko Basin, decrease in the importance of the Arbuckles, Wichitas, and Amarillo mountains as sources of terrigenous detritus for the Anadarko Basin, and progressive increase in limestone deposition over the site of the old Anadarko Basin (Rascoe, 1962, p. 1369). Alternating carbonate and noncarbonate deposition continued through the Wolfcampian when evaporitic sedimentation came into prominence. It constitutes the end member or regressive phase of the depositional cycle of the region during the Pennsylvanian and Permian.

EXPLANATION OF FIGURE 1

Major paleotectonic features of Kansas and surrounding states during Virgilian time.



REGIONAL STRATIGRAPHY

Introduction

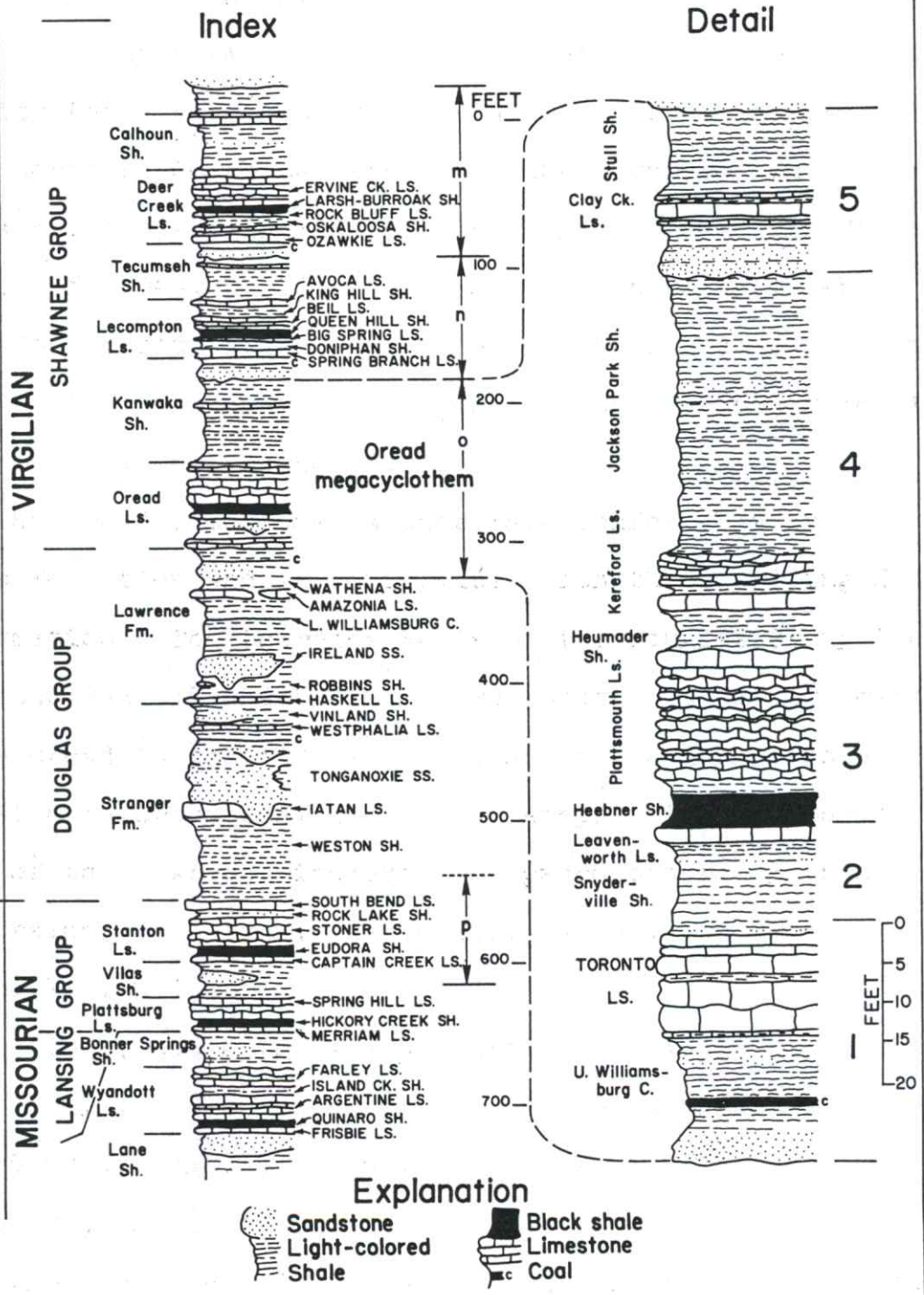
The Oread Limestone, basal formation of the Shawnee Group, contains the following members listed in ascending order: Toronto Limestone, Snyderville Shale, Leavenworth Limestone, Heebner Shale, Plattsmouth Limestone, ^{Huemader} Shale, and Kereford Limestone (Fig. 2). The outcrop of the Oread Limestone forms a prominent escarpment that can be traced from the northern part of Osage County, Oklahoma entirely across Kansas and into Missouri. Exposures of the formation are also present in ^{western} southeastern Iowa and ^{eastern} western Nebraska. In northern and central Kansas where the formation is approximately 50 feet in thickness, the shale members are all thin and the limestone members form benches of a single escarpment. In southern Kansas, however, the Snyderville Shale increases in thickness to 50-80 feet, so that separate small escarpments made by the Toronto Limestone and the Leavenworth-Plattsmouth are as much as a mile or more apart.

In spite of the seemingly monotonous alternations of limestone and shale units, each member of the Oread has distinct lithologic features that allow its recognition; and in areas where a certain member has undergone marked facies changes, that member can be recognized by a knowledge of lithologic characteristics of the other units in the sequence.

EXPLANATION OF FIGURE 2

Stratigraphic position of the Oread Limestone. Columnar section at the left shows the generalized vertical relationships of the Oread Limestone to other rock units. The letters (m, n, o, and p) and arrows between the sections depict four megacyclothems recognized by Moore (1950). The Oread megacyclothem is shown at the right; the arabic numerals on the far right refer to the cyclothems as recognized by Moore (1950) within the Oread megacyclothem.

PENNSYLVANIAN



This is particularly true in northern Osage County, Oklahoma where the Toronto, Leavenworth, and Plattsmouth limestones are thin and disappear by facies change to terrigenous clastics.

The Oread Formation, then, is characterized by regional continuity for a very considerable distance from southwestern Iowa to northern Oklahoma, excepting the Kereford Limestone which is not present in many places along the outcrop (Moore, 1936, p. 168; 1949, p. 150; 1951, p. 67). In Oklahoma where it undergoes rapid facies change to terrigenous clastics, the Oread formation is equivalent to part of the Vamoosa Formation (Miser, 1954; Tanner, 1956, p. 12).

The Oread Limestone is underlain conformably by the Lawrence Formation and is conformable with the overlying Kanwaka Formation. The Lawrence Shale of the Douglas Group lies between the Haskell and Toronto limestones. It differs markedly from the Oread in that it is mainly a shale and sandstone sequence with numerous coal beds and a single limestone unit. Members of the Lawrence include, in upward order: Robbins Shale, Ireland Sandstone, Amazonia Limestone, and Wathena Shale (Ball, 1964).

In 1936, Moore (p. 26-34) defined a megacyclothem as a cycle of cyclothem and described the subdivisions of a typical Shawnee megacyclothem (see Fig. 2). He described (ibid. p. 32) the Oread megacyclothem to include the upper part of the Lawrence Shale, the Oread Limestone, and a large portion of the Kanwaka Shale. The lower three of the five limestones in the megacyclothem are characterized by distinctive lithologic and faunal attributes (Moore, 1950, p. 11)

which are diagnostic of individual cyclothem. Each cyclothem is partly to completely developed and differs in character from associated cycles. The limestones are said to be characterized by yellow-brown, ferruginous, massive beds of the first (Toronto); the thin, blue, dense vertically-jointed nature of the second limestone (Leavenworth); and the light gray, wavy-bedded, comparatively thick nature of the third limestone (Plattsmouth). The fourth and fifth limestones are described as being less distinctive in character (Moore, 1950, p. 11). A diagnostic attribute of the megacyclothem is the presence of black fissile shale (Heebner) in - and only in - the third cyclothem (Moore, 1936, p. 31).

Almost identical sequences of cycles occur at least three times at higher levels in the Shawnee Group; megacyclothems that include cycles analogous to the second, third, and fourth cycles of the Shawnee type are frequent in the Marmaton Group (upper Des Moinesian) and the Kansas City and Lansing groups (Missourian) (Moore, 1950, p. 11).

Toronto Member of the Oread Limestone

The Toronto Limestone was first named by Haworth and Platt, although a type section was not designated, from the town of Toronto in southwestern Woodson County, Kansas (Moore, 1936, p. 162). Ball (1964) has designated a type section in a quarry at NE corner NWNW S.35, T.25S, R.13E. (Locality 1, see Appendix.) This limestone has been traced from Toronto southward to Oklahoma and northward to Nebraska where it has been called the Weeping Water Limestone (Condra, 1927).

Moore (1936, pp. 162-163; 1949, p. 147; 1951, p.69) has described the Toronto as a brownish-gray massive limestone containing fusulines, corals, bryozoans, small brachiopods, crinoid remains, and mollusks in places. Moore (1936, p. 163) characterized the upper few inches to several feet as ". . . distinctly algal in some places and lacks fusulinids." He noted (1951, p. 69) that the Toronto ". . . is typically developed from Woodson County northward . . ." (except for its absence) ". . . in part of southern Douglas County where a limestone conglomerate occupies its approximate stratigraphic position . . .," ". . . but (is) thinner and sandy or locally absent in southern Kansas." Moore (1951, p. 69) described the thickness of the unit as ranging from 8 to 12 feet in northern Kansas but less than 4 feet in the southern part of the state.

In his definitive work on the concept of the megacyclothem, Moore (1936) listed the subdivisions of a typical Shawnee megacyclothem utilizing a Dewey system in designating stratigraphic units for each cyclothem. His cyclothem A (ibid., p. 31), to which the Toronto cyclothem including the Toronto Limestone (A.3 to A.7) and part of the Lawrence Shale (A.0 to A.2) conform, is shown below:

Cyclothem A

*A.9-A.8 Shale, generally fossiliferous

•A.7 Limestone, "oolitic" or granular, molluscan fauna, locally 3 or 4 feet thick

*Most prominent, persistent, and definitely recognized stratigraphic units.

•Recognized in the Toronto Cyclothem by Moore.

- A.6 Shale, generally not differentiated
- *A.5 Limestone, blue-gray weathers brown, ferruginous, impure, massive or uneven thick beds, contains fusulinids and mollus-coids ("lower" limestone)
- A.4 Generally absent or not recognized (shale)
- A.3 May be represented at base of "lower" lime-stone by zone of molluskan fossils (shaly limestone)
- *A.2 Shale, marine, generally molluscan fossils
- A.1 c. Coal, thin, or absent
- A.1 b. Underclay, generally recognized where coal is present
- *A.1 a. Shale, sand, plant fossils
- *A.0 Sandstone, nonmarine, locally contains plant fragments, may be conglomeratic at base

Although most of Moore's generalizations concerning the Toronto cyclothem are correct, many of the features cannot be recognized in any one given section. The stratigraphic units designated have been observed at different exposures and from these observations, an ideal cyclothem has been erected. For example, the sandstone (A.0), shale (A.1a), coal (A.1c), and limestone units (A.7) are generally restricted to different parts of the outcrop belt. It was the writer's objective to examine the Toronto Limestone throughout its outcrop belt and to study lateral, as well as vertical, variations for purposes of environmental reconstruction.

*Recognized in the Toronto Cyclothem by Moore.

*Most prominent, persistent, and definitely recognized stratigraphic units.

The Toronto Limestone is 13 feet thick at its type locality in Woodson County but thins rapidly by facies change with the Lawrence and Snyderville shales to northern Osage County, Oklahoma, where it thins and disappears. Its maximum thickness on outcrop is about 18 feet at Localities 20 and 25 in southern Coffey County, Kansas. Elsewhere in northern Kansas it is commonly 6 to 12 feet in thickness. In Nebraska outcrops it is 7 to 10 feet thick, although the lower 5 feet is very argillaceous and in places contains thin shale beds interbedded with shaley limestone. The Toronto is locally absent in the southern part of Douglas and northern Franklin counties, and although a limestone conglomerate is present in some places, in many exposures the section is undifferentiated Snyderville-Lawrence Shale. Exposures of sandy limestone about 2 feet thick in Madison and Adair counties, Iowa may possibly be correlative with the Toronto Limestone, but proof of lateral continuity will have to be attempted through subsurface studies because the closest known outcrops of Toronto are about 85 miles to the west at Plattsmouth, Nebraska. Even if contiguity of the sandy limestone of Iowa and the Toronto Limestone can be demonstrated, they are different facies.

A thin shaly zone or a shaly parting in places about 5 feet above the base of the member at the type locality is interpreted by the writer to be nearly continuous northward to Tonganoxie in Leavenworth County and may possibly be present as far as St. Joseph, Missouri and Cass County, Nebraska. The same unit can be traced from the type locality

southward as far as Longton in southern Elk County. This shaly zone or parting is used as a datum for purposes of constructing a restored section as well as for determining stratigraphic equivalence of parts of the unit in environmental reconstruction. Local key beds and certain faunal horizons and zones have been found that substantiate the interpretation of the widespread continuity of the thin shaly horizon in the Toronto Limestone.

Snyderville, Leavenworth, Heebner, and Plattsmouth
Members of the Oread Limestone

Overlying the Toronto Limestone is the Snyderville Shale which is commonly 12 to 15 feet thick in northern Kansas and Nebraska, but is 40 to 80 feet or more in thickness from Woodson County southward in Kansas and Oklahoma. Moore (1936, p. 164; 1950, p. 10; 1951, p. 69) has described northern Kansas and Nebraska occurrences, except for the upper foot or so, as a structureless gray to bluish-gray clay that (ibid. 1936, p. 164) ". . . has the character of an underclay . . ." (That) ". . . this part of the Snyderville is, in fact, an underclay . . . is indicated by the character of the upper 1 to 2 feet of the Snyderville which is well laminated, bearing a marine fauna of brachiopods, bryozoans, and some pelecypods. . ." In addition to gray clay, red clay shale is also present in places in the northern areas. In southern Kansas, the Snyderville contains much red, maroon, green, and brown shale, brown siltstones and sandstones, and beds of limestone conglomerate. The upper few inches of the Snyderville, as seen from Chautauqua County northward, contains a marine fauna.

The Leavenworth is a dark bluish-gray, dense, massive limestone, generally a single bed, that can be traced from northern Osage County, Oklahoma to southeastern Nebraska and southwestern Iowa. It is known to be absent from the Oread column at only one exposure in southern Douglas County, Kansas (Locality 13c), but is present approximately 100 yards away. It is a lime mudstone containing scattered fusulinids, crinoid parts, "Osagia" and "Cryptozoon" stromatolites, brachiopods, and mollusks in most of its exposures. In northern Oklahoma, the Leavenworth contains a thin fusulinid-rich zone at the top and, like the Toronto, grades into shales of the Vamoosa Formation; it is last seen approximately 7 miles south of the last known exposure of Toronto Limestone. Its thinness, ^{common} ever-presence, and lithologic distinctiveness make it an ideal stratigraphic datum.

The Heebner Shale is generally about 5 to 7 feet thick along the outcrop from southwest Kansas to Nebraska, but it thickens abruptly at the Oklahoma border to 50 feet or more. Black, platy, hard, carbonaceous shale containing phosphate laminae and nodules is typically the thickest component of the member at most localities although thin, light brown to green or gray shale zones are commonly developed both above and below the black fissile zone at many places. Abundant conodonts and a few pectenoid clams are typical faunal components of the black shale. Small brachiopods and mollusks are characteristic of the light-colored zone subjacent to the overlying Plattsmouth Limestone. Contact between the Heebner Shale and underlying Leavenworth is sharp,

as seen on the outcrop, except for 2 known localities (one on the Nishnabotna River, Cass County, Iowa, and Locality 15A where the Heebner and Leavenworth are intertongued.

The Plattsmouth Limestone is the thickest member of the Oread but shows perhaps the most abrupt changes in thickness, as well as lithology, of any of the Oread limestones. It extends from northern Osage County, Oklahoma completely across Kansas to Nebraska and Iowa, except for an area in Woodson County, Kansas where a section of green calcareous shale occupies its stratigraphic position (Ball, 1964, p. 235). The Plattsmouth is commonly a light bluish gray, thin, wavy-bedded limestone. It contains dark blue-gray chert at places in Iowa, and interbedded limestone and shale is conspicuous in Cass County, Iowa (T. 7 R. 37 S. 16) which suggests that the member is intertongued with shale in that region. At Localith 19 in Chautauqua County, Kansas, the Plattsmouth contains abundant solitary corals and a diverse brachiopod fauna that includes large Neospirifer. Elsewhere it contains stromatolites ("Cryptozoon"), fusulinids, and molluscs. It apparently undergoes a rapid change from its normal thin-wavy-bedded character to a fusulinid coquina in Osage County, Oklahoma. The Plattsmouth averages 15 to 20 feet in thickness in southern Kansas, 17 to 23 in northern Kansas, and approaches 30 feet in thickness in southeastern Nebraska.

Upper Part of Lawrence Shale

The Wathena Shale is the interval between the top of the Amazonia Limestone below and the bottom of the Toronto Limestone above (Ball, 1964, p. 158). At its type locality,

near Wathena in northeastern Kansas, the unit is about 23 feet thick consisting of gray to green and red shale and mudstone. A grayish-red mudstone facies in the Wathena has been reported in all Missouri and Doniphan County, Kansas exposures and is locally developed as far south as the Toronto Limestone has been traced. Reddish mudstone is present in the upper part of the Lawrence Shale in Nebraska exposures although the term Wathena is not applicable in that state. Red shale of the same stratigraphic position is widespread in the subsurface, and except for the limestones, it is said to be the best stratigraphic marker within the Douglas Group. (S. M. Ball, written communication, 1964.)

The Upper Williamsburg Coal, developed within the Amazonia-Toronto interval, extends from southern Elk County to north-central Douglas County although it is not perfectly continuous across this area. Because no outcrops with more than one coal are known, and because variations in stratigraphic position of the coal are uniform, the coal is interpreted as a single lithosome. At the type locality of the Toronto Limestone, the Upper Williamsburg coal is immediately below the Toronto; however, to the north and south of this locality, the coal is separated from the limestone by a shale interval. According to Ball (1964, personal communication), the Upper Williamsburg is the most widespread coal of the Douglas Group. It invariably occurs above the grayish-red mudstone of the Wathena Shale, and does not extend more than 35 miles downdip in the Kansas subsurface (ibid., 1964).

Lateral Continuity of the Oread Limestone

Certain members of the Oread Formation have been identified in the subsurface of Kansas for distances of up to 300 miles west of the outcrop belt (Moore, 1950, p. 12, 13). These include the Plattsmouth Limestone, Heebner Shale, Leavenworth Limestone, Snyderville Shale, and Toronto Limestone. The Heebner Shale is, at least in part, black and strongly radioactive. It is a key bed that can be traced widely because it produces large gamma-ray deflections (Moore, 1950, p. 13; Morgan, 1951, p. 3).

A regional map showing the areal extent of Oread rocks is shown in Figure 1. This shows that the individual members of the Oread, named above, can be recognized as far northwest as F and as far west as H (Moore, 1950, fig. 6, p. 14; Morgan, 1951, exhibit 3, p. 9). Moore notes (p. 13) that a single black shale is present in each of his illustrated sections in the position of the Heebner, except in a southwestern Kansas well where another highly radioactive shale occurs, presumably a few feet higher in the section (I).

Morgan (1951, exhibit 3) shows two cross sections; one is along the approximate axis of the Central Kansas Uplift (from F to a point 100 miles to the northwest). It shows that the Heebner-Lansing interval converges to the northwest on the uplift until the Toronto Limestone is immediately superjacent to the Lansing. The second cross section begins near D on the western flank of the central Kansas uplift and extends across the uplift to a point near E. Both the Heebner and Toronto are continuous across the uplift and the Douglas Group thickens

slightly into the Salina Basin.

At G, in the Ackman Oil Field in southwestern Nebraska, Larson (1962, p. 2084) has recognized the Oread Limestone. He refers to a thin radioactive shale at the base of the Oread as Heebner. He reports that the upper 5-6 feet of Oread in high structural positions in the Ackman Field are an apparent coquinoid accumulation of fossil detritus (ibid., p. 2085) and concludes that this is a result of depositional conditions related to "micro-bathymetric" features. Red to maroon shales, siltstones, and green shale separate the limestone lithosomes of the Shawnee Group in the field. About 30 feet of a fine, silty, red sandstone and red shale sequence are referred to as a remnant of the Douglas Group (Larson, 1962, p. 2085).

Along a line from B to C which extends from the Nemaha Ridge to the southeastern flank of the Central Kansas Uplift, Adkison (1963) has described lithologic sample logs and drawn a geologic cross section. The Oread Limestones (ibid., p. 8) are described as pale orange to pale yellowish-brown and fossiliferous with fusulinids and crinoid parts as the most abundant fossils. Near B, he reports black shale of the lower Oread which is the Heebner equivalent; but to the west, the correlation of the Heebner is questionable because more than one bed of black shale is apparently present near the base of the Shawnee Group (ibid., p. 9). Over the western half of the cross section, the Shawnee Group is mostly fossiliferous limestone bearing crinoids, fusulinids, brachiopods, and bryozoans. Most of the Oread shales are gray, olive-gray, and black. The Douglas Group in the same area consists mainly of

medium gray to dark-gray shale and light-gray micaceous siltstone and very fine to fine-grained sandstone, although greenish-gray, pale brown, and grayish-red shale, and some limestone are present (p. 9).

Regional subsurface studies of the Pennsylvanian in southwestern Kansas and adjacent areas of Oklahoma, Texas and Colorado (Rascoe, 1962) reveal that the Shawnee Group is mainly limestone between the periphery of the Apishapa-Sierra Grande Arch and the Amarillo Uplift and outside the Anadarko Basin (ibid., Fig. 15, p. 1364); the limestone facies apparently extends into the Texas Panhandle through a narrow connection between the Amarillo and Apishapa uplifts. Rascoe (p. 1365) remarks that the Oread Limestone is widely extensive over both shelf and basin provinces. In the Anadarko Basin, the Elgin Sandstone, positioned between the Oread and Lecompton limestones, is widely extensive (Fig. 15, p. 1364, text p. 1365). Toward the Apishapa-Sierra Grande Uplift, the predominately carbonate facies of the Shawnee Group changes to an interbedded shale and limestone sequence; then to arkosic clastics that border the uplift. Some of the Virgilian arkosic sediments that flank the Amarillo-Wichita Uplift are considered equivalent to the Shawnee Group. The Douglas Group of the shelf area is principally terrigenous clastics and is developed between successions of predominately carbonate rocks. Red and gray sandy shales predominate in the Douglas although thin limestones occur in the unit in the west and southwest of the Central Kansas Uplift; sandstones are present in many places, but for the most part, are local in occurrence (pp. 1362, 1365).

According to Ball (1964, p.155), the Amazonia Limestone is discontinuous over much of the outcrop belt in Kansas but becomes continuous in a belt roughly parallel to the outcrop, generally 25 to 40 miles down dip. However, there are many areas in which the Amazonia is believed to be absent in the subsurface, but this is not true for the Toronto which is continuous. The Amazonia and Toronto both become absent in the same general area of outcrop in northern Oklahoma.

S. M. Ball kindly provided the writer with two subsurface cross sections of the Oread Formation in southern Kansas. One is from the outcrop westward along the Elk-Greenwood common boundary to south central Butler County. It shows that Toronto Limestone thickens a short distance in the subsurface to thicknesses observed in southern Woodson County, and that farther to the west it is up to 18 and perhaps 21 feet thick. The Snyderville varies from 40 to 68 feet in Greenwood and Elk counties but thins to less than 15 feet at the western end of the cross section. Red shale, siltstone, and sandstone described from cuttings in some of the wells are present in the Snyderville from the outcrop to eastern Butler County; calcareous shale alone is present in the last well of the cross section. Several thin (less than 5 feet thick), but obviously discontinuous, limestones are present in Snyderville overlain and underlain, in some cases at least, by red shale. Red shale, siltstone, and sandstone were noted immediately below the Toronto in some wells, and red shale was noted above the Amazonia Limestone in some occurrences.

The second cross section extends from the outcrop between Localities 17 and 19 westward to southwestern Cowley County. It shows that the Toronto Limestone which is very thin and discontinuous through Chautauqua County thickens to 7 and even 12 feet less than 25 miles down dip. The Snyderville Shale, highly variable in thickness along this line of section, is thickest at the western end of the cross section where it is almost 90 feet thick. Red shale, siltstone, and sandstone were described from cuttings obtained from several wells used in the cross section. Very thin (less than 5 feet) beds of limestone were noted in the Snyderville interval from several wells. One well revealed 2 such beds separated from the Leavenworth, Toronto, and each other by red shale and sandstone. Again red shale, sandstone, siltstone, and a few thin intercalated limestones are present beneath the Toronto Limestone in the upper portion of the Lawrence Shale.

Lukert (1949, pp. 140-143) published two cross sections revealing Oread and related rocks. One section extends across the southern part of Osage County, Oklahoma to northeastern Garfield County. The Toronto Limestone is present in northeastern Garfield and extreme western Noble County but is absent east of Sec. 2, T. 22N., R.2W. (Lukert, Plate II). Heebner black shale is not recognizable any farther east, but the Plattsmouth Limestone extends at least one township farther east than the Toronto (Lukert, Plate II). The second cross section extends from northeastern Garfield County northward into Kansas as far as central Marian County. The Plattsmouth

Limestone varies from 15 to 80 feet in thickness. It overlies the Heebner Shale which is less than 10 feet thick, black, and radioactive in part. The Leavenworth is very thin but recognizable, overlying the Snyderville Shale which is up to 200 feet in thickness near the center of the eastern county line of Grant County, Oklahoma. The Toronto Limestone is 10 to 20 feet thick. The Elgin Sandstone which lies slightly above the Plattsmouth Limestone, where developed, is the only lithosome in the middle Virgilian that can be traced across southern Osage County, Oklahoma to northeastern Garfield County, Oklahoma. The Douglas Group consists predominately of varicolored shales with a few thin limestones and with prominent sandstones in the lower part. The Amazonia (?) Limestone which rests about 30 feet below the top of the Douglas has been recognized as far south as northeastern Grant County, Oklahoma.

LOCAL STRATIGRAPHY

Southern Woodson County to Southern Elk County

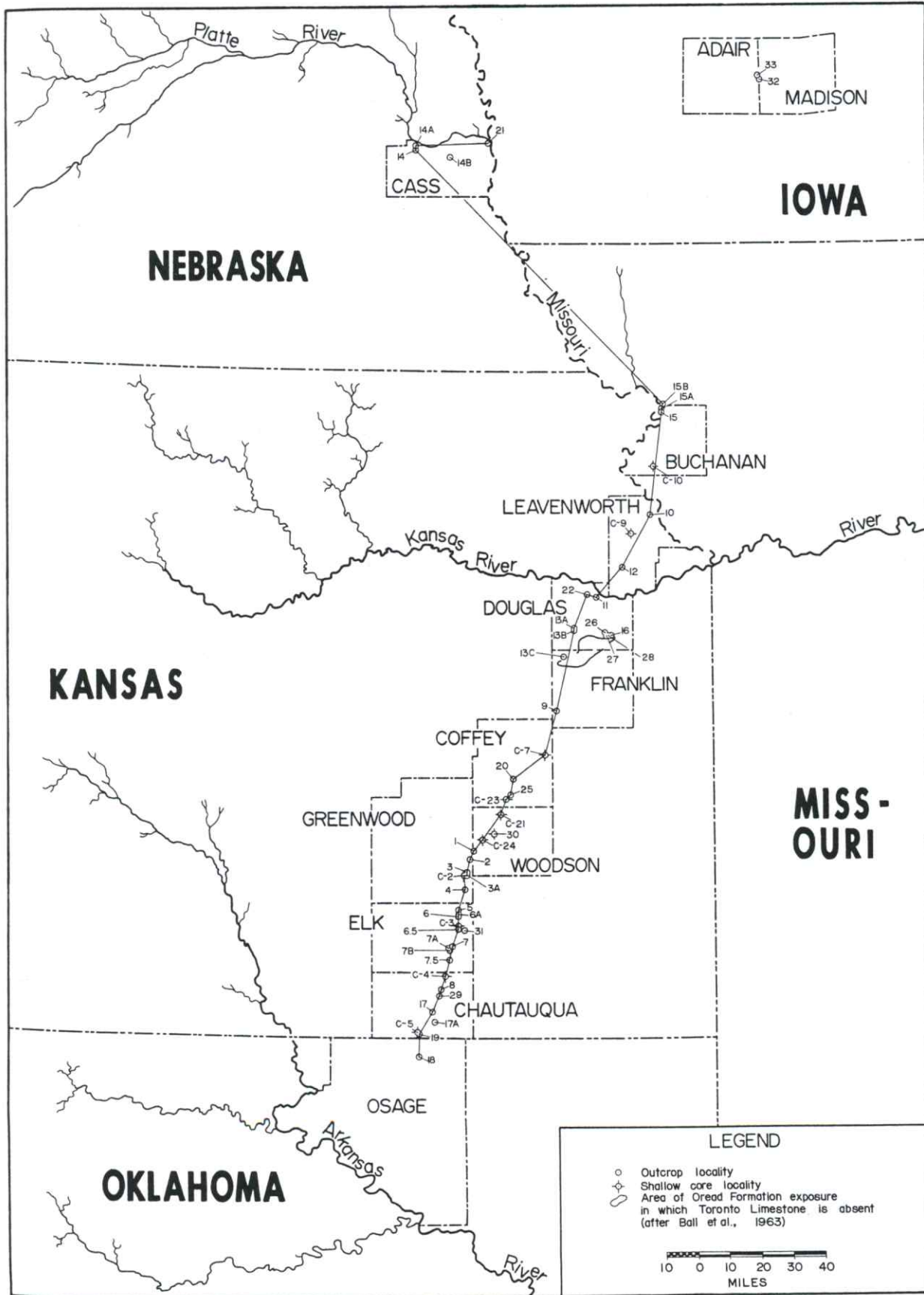
Exposures of the Oread Limestone from the type locality of the Toronto Limestone (Locality 1) southward to southern Elk County (Locality 7.5) reveal rather uniform stratigraphic characters in the Plattsmouth, Heebner, Leavenworth, and Snyderville Members, but the Toronto Limestone thins southward across the area.

The Plattsmouth Limestone is thin, wavy-bedded, light gray limestone about 10 to 18 feet thick containing a mixed biota of fusulinids, algal coated grains (some of the "Cryptozoon" type) and numerous brachiopod taxa. The Heebner Shale is 4 1/2 to 7 feet in thickness with the lower one to 3 feet being black fissile shale bearing condonts and plant remains; the upper part is gray to greenish or brownish with bryozoans, ostracods, crinoid parts, brachiopod remains, and the foraminifers Ammodiscus and Tetrataxis (Wagner and Harris, 1953; Verville, 1958). The Leavenworth Limestone is a single, dense, medium-dark gray bed about one to 1 1/2 feet in thickness.

The Snyderville Shale is variable in thickness across the area, ranging from about 40 to as much as 80 feet, but averaging between 50 and 60 feet. The unit is composed principally of red, green, and bluish shale with subordinate greenish-gray siltstone and sandstone. The lower few feet overlying the Toronto Limestone are generally pale greenish-gray shale which may contain ironstone concretions and are locally fossiliferous. This is followed by a variable succession of green and red shales and thin, fine-grained sandstone. Most of the siltstone

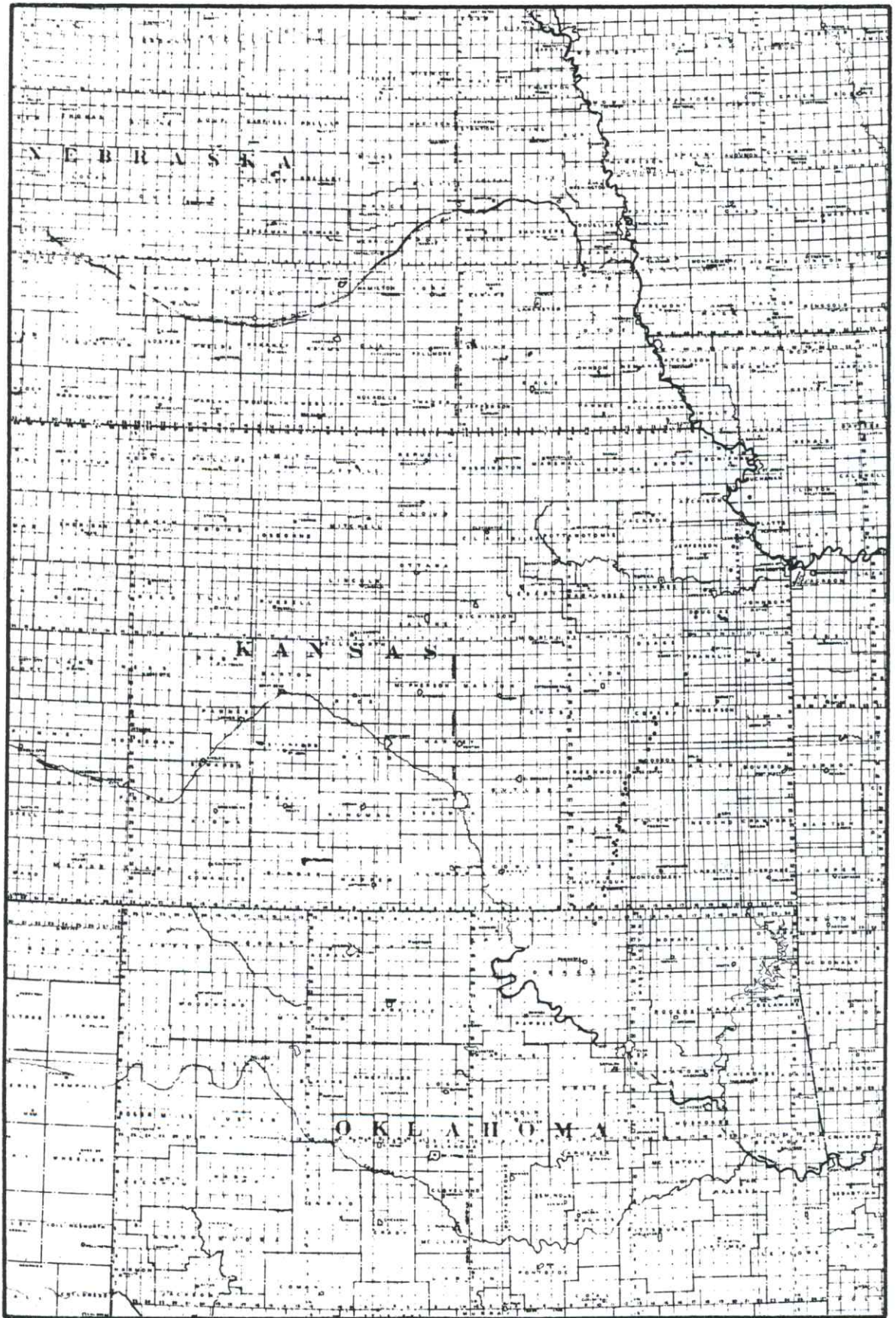
EXPLANATION OF FIGURE 3A

Location map of Toronto study sections. Solid line connecting the various localities denotes the line of reconstructed section. A map showing townships is also included (Figure 3B).



EXPLANATION OF FIGURE 3B

Map showing townships for reference in connection with localities cited by legal location.



and sandstone beds are less than one foot thick. None of the units can be traced entirely across the area. At Locality 7, several thin beds of lime pebble conglomerate are present in the Snyderville as well as thin beds of ripple-marked calcareous sandstone. In a few places such as S.15T.31S.R.12E., mud-cracked sandstones have been found, and a cross-bedded sandstone body about 20 feet thick is present in the same section. Locally, the uppermost foot of the Snyderville Shale is gray, calcareous, and very fossiliferous, bearing abundant chonetids (probably Neochonetes) together with fragments of other brachiopods, crinoid columnals, pelecypods, and bryozoans (Wagner and Harris, 1953). Except for the uppermost and lowermost parts, the terrigenous clastics in the Snyderville Shale have yielded no invertebrate animal macrofossils in this area.

At its type locality, the Toronto Limestone is about 13 feet thick. It contains two shale breaks, one about 1.3 feet below the top of the unit and another about 6 feet above the base. The lower shaly zone can be traced southward entirely across the area under discussion, but the upper shale is apparently a tongue of the Snyderville lithosome, interbedded with the Toronto Limestone at Localities 1 and 2. South of these localities, the limestone above the shaly zone is not present, probably the result of facies transition to shale.

At Locality 6A, limestone above the datum approximates 4 feet in thickness. To the north at Locality 5, however, only 1 foot of limestone is present above the datum, but the Toronto is poorly exposed and forms an escarpment at this locality. Thus it is likely that a portion of the section is

absent because of Quaternary erosion or poor exposure. South of Locality 6A, at Core 3 (not shown on cross sections), the Toronto is represented by two limestone beds, separated by a thin shale; both subjacent and superjacent shales are fossiliferous. Thus it is apparent that the upper Toronto is transitional to fossiliferous shale (bearing fusulinids) between Core 3 and Locality 6A.

It is also apparent in the southern Woodson to Elk County area that the Toronto Limestone and upper Lawrence (Wathena) Shale also show facies transition. The Upper Williamsburg Coal rests only a few inches beneath the Toronto from Locality 1 to Locality 3A, but is found progressively farther below the Toronto southward to Locality 7, its last known occurrence; although a thin carbonaceous streak present at Locality 8 may be its equivalent. The coal is absent at Locality 4 where it may have been eroded. Green fossiliferous calcareous shale is interbedded with and gradational to limestone between the coal and the datum. Moreover, fusulinids are abundant in the green shales and in limestones in contact with the shales. These relationships can be observed in most localities from Locality 3 southward to Locality 7.5 with the fusulinid-rich shale occupying progressively higher stratigraphic positions approaching the datum position at Locality 7.5 and the limestone thicknesses diminishing in the same direction. This is interpreted as a progressive facies change from limestone to terrigenous clastics in a southerly direction across this area. The only consistent marker beds in the area are the shaly zone within the Toronto and the coal seam.

The Toronto Limestone is absent approximately two miles east of Locality 6 at SE 1/4 Sec. 5 T.28S. R.15E. where it was evidently channeled, for it is present in exposures to either side of the anomaly.

Southern Elk to Northern Osage County, Oklahoma

Oread outcrops in southern Elk and Chautauqua counties, Kansas show member relationships similar to those in the southern Woodson to southern Elk County areas with the exception of the Toronto Limestone which is thin and discontinuous across the area. All of the Oread Limestones under discussion undergo facies changes to terrigenous clastics in northern Osage County, Oklahoma.

The Plattsmouth Limestone maintains its light bluish-gray, thin, wavy-bedded character southward to the Oklahoma line. At C. Sec. 33, T.33S, R.11E., it is almost 18 feet thick with thin, wavy beds at the top, but massive beds toward the center (Cooley, 1952, p. 12). The lower 4 feet contains thin, irregular beds with intercalated shale layers less than an inch in thickness. The faunal elements at this locality are dominated by brachiopods with fusulinids conspicuous at the top of the limestone, sparse gastropods present throughout the member, and corals especially noticeable near the base (Cooley, 1952, p. 13). At Locality 19, the Plattsmouth is again wavy-bedded and light bluish-gray containing large brachiopods and a solitary coral-rich zone near the base. At NW Sec. 14, T.35S., R.10E., the limestone is about 17 feet thick bearing brachiopods, bryozoans, and corals, but has been described as having an increased iron content at this locality

(Cooley, 1952, p. 27). The Plattsmouth is about 25 and 18 feet in thickness at SENE Sec. 24 and SESE Sec. 18, T.19N., R.10E. respectively; it carries a bryozoan, brachiopod, coral, and crinoid fauna at these exposures (Cooley, 1952, pp. 30-34). However, at SWSW Sec. 19, T.29N., R.10E., limestone identified as Plattsmouth (Cooley, 1952, p. 35) is only 2 1/2 feet thick, containing very abundant fusulinids and lesser amounts of brachiopod fragments. This limestone has not been recognized south of this locality.

From southern Elk to southern Chautauqua County, the Heebner Shale is 5 to 8 feet in thickness, consisting of a lower black shale zone with phosphatic nodules at the top and an upper bluish shale unit. Chonetid-type brachiopods and Conularia have been reported from the black shale near Locality 17 (Cooley, 1952, p. 14). The Heebner thickens near the Oklahoma line; it is about 53 feet in thickness 3 1/2 miles to the south (at SWSW Sec. 19, T.29N., R.10E.). It contains blue to gray shale with several thin sand interbeds and a fauna of corals, pelecypods, and crinoid remains at this locality which marks the southernmost point at which Plattsmouth Limestone has been recognized (Cooley, 1952, p. 36-37).

The Leavenworth Limestone maintains its medium dark gray, thin (1 to 1 1/2 feet), dense lime mudstone to the Oklahoma line. However, a thin (less than one foot) lime mud pebble conglomerate is present a few inches below the bed at several localities in Chautauqua County, Kansas (Localities 8 and 19), and in Sec. 3, T.28N., R.10E. in Osage County, Oklahoma.

A fusulinid-rich zone has been observed at the top of the Leavenworth at numerous places in northern Osage County. This limestone has been identified at NW 1/4 Sec. 18, T.27N., R.10E., which is the southernmost exposure of any of the Oread Limestones recognized in Oklahoma.

The Snyderville Shale is the most variable Oread member in terms of lithology and thickness in this southern area. It ranges from about 40 to 80 feet thick along the outcrop in Chautauqua and northern Osage counties. The unit is comprised mainly of red, green, blue, gray, and brown shales and sandy shales and subordinate sandstones, usually varying from less than a foot to several feet in thickness; however, sandstone bodies up to 30 feet thick occur locally (Locality 31) and thin lime pebbled conglomerates are present at several localities, in some cases immediately below the Leavenworth Limestone but well below this level as well (Locality 17 and SESW Sec. 15, T.34S., R.11E.). In a general way, the Snyderville succession consists of brown, blue, and gray shales in the lower part of the unit, followed by red shales with intercalated thin sandstones and some green shale in the upper part, succeeded by about one foot of blue shale immediately below the Leavenworth. Most of the lithologic units are very local in occurrence, for they cannot be correlated from one section to the next. Many of the sandstones are cross-bedded and some of them are obvious channel deposits (Locality 19). At Locality 29, the Snyderville is 79.5 feet thick with about 60 feet of the section being channel sandstone; these sands are not seen in nearby sections.

Macrofossils, except plant material, are not common in the Snyderville. At C. Sec. 33, T.33S., R.11E. near Locality 17, the upper foot of Snyderville is a blue shale bearing Chonetes. Chonetes was observed in the same stratigraphic position at NWSW Sec. 23, T.34S., R.11E. (between Localities 17 and 19) in an identical lithology, although 4 feet of blue shale and 6 feet of black shale underlie the fossil zone at this locality. Fossils, mainly linoproductids and derbyids, were found near the bottoms of cross-bedded linear sand bodies 10 to 20 feet thick in strata laterally equivalent to the middle portion of the Snyderville Shale in Secs. 28 and 23, T.28N., R.10E. about 3 miles south of Locality 18. Pelecypod molds occur at higher levels within the sand bodies. Ripple-marks and animal burrows were seen in the same exposures.

Wood fragments are incorporated in a thick, cross-bedded sandstone within the Snyderville in the NW Sec. 8, T.28N., R.10E. (near Locality 18).

The Toronto Limestone thins to a single bed of limestone that is discontinuous from the southern part of Elk County across Chautauqua County, and into northern Osage County, Oklahoma. It has not been recognized for certain south of the section in which Locality 18 is found, although it may be present in NW Sec. 28, T.28N., R.10E.

At Locality 7.5, the Toronto consists of two limestone beds, separated by a thin, fossiliferous shale. Attempts to trace these beds southward to ascertain to which of the two, if either, the single bed of limestone is equivalent, proved futile because the Toronto is absent (due to erosion) between Localities 8 and 7.5; a lime pebble conglomerate was seen in

the approximate stratigraphic position of the Toronto in exposures examined. Because the upper limestone bed is thicker and less argillaceous than the lower bed at Locality 7.5, it is probably stratigraphically equivalent to the single limestone bed at Locality 8.

There are numerous localities in the southern area where the Toronto Limestone is absent. The question arises as to whether the absence is due to stratigraphic onlap, facies transition to clastics, or erosion subsequent to deposition. Moore (1931, p. 253) concluded that the lower Oread limestone body (Toronto) is transitional to sandstone to the south and that the sandstone persists southward. Cooley (1952, p. 15) opined that Moore (1951, p. 71) correlated the Toronto Limestone with a sandstone 35 feet below the Leavenworth at Cen. Sec. 33, T.33S., R.11E., but Cooley was able to recognize the Toronto Limestone as a single bed, approximately one foot thick, 15 to 18 feet below this sandstone at Locality 17, about 1/2 mile to the south.

In NSW Sec. 23, T.34S., R.11E., between Localities 17 and 19, and in NW Sec. 14, T.35S., R.10E., between Localities 17 and 19, no limestone ascribable to the Toronto is present although the sections are of sufficient thickness to include the limestone. In the former, no evidence of an erosion surface has been found although the exposure is good, but the critical level is covered in the latter (Cooley, 1952, pp. 48-49). At Locality 31, however, the Toronto can be recognized and traced laterally for only a few yards. There a channel sandstone, which has been cut through the limestone, can be observed. Thus there is indisputable evidence in

support of only one of the three hypotheses. However, regional facies change to clastics has been demonstrated for the Toronto in this southern area; so that it is likely that local absences of limestone in some exposures are a result of transition to terrigenous deposits. Fossiliferous shales are developed beneath the Toronto Limestone at these southern localities; thus it appears that absence because of stratigraphic onlap is the least likely hypothesis that can be invoked to explain the local absences of the Toronto Limestone.

The uppermost part of the Lawrence Shale in this southern area is a facies equivalent of Toronto Limestone farther north (see Figs. 4 and 10). For this reason, these shales were included in the study.

Southern Woodson County to Northern Franklin County

Significant trends in a northerly direction across this area in the Oread and Lawrence formations include a decrease in thickness of Oread terrigenous clastics, which is due to thinning of the Snyderville Shale, and a rather progressive increase in the stratigraphic interval between the Upper Williamsburg Coal and the Toronto Limestone.

Except for one local area, the Plattsmouth is continuous throughout the area. The approximate thickness of the Plattsmouth in this region is 20 feet; a complete thickness of the Plattsmouth is rarely observed because it generally caps the Oread escarpment. It is light-gray, thin, irregularly wavy-bedded with the individual beds ranging from 2 inches to one foot in thickness. Thicker parts of a bed are commonly in

contact with thinner parts of adjacent beds. Numerous brachiopod genera, bryozoans, solitary corals, echinoderms, mollusks, and complex coated grains described as "Ottonosia" are present at various stratigraphic positions in the Platts-mouth in Franklin County (M. Ball, 1953, p. 44). The Platts-mouth Limestone is absent and its position is occupied by fossiliferous green shale in west-central Woodson County (Ball, 1964, p. 235).

The Heebner Shale, like the underlying Leavenworth Limestone, is continuous and uniform across the area. It is 3.3 feet thick at Locality 20 where it consists of 1.8 feet of black fissile carbonaceous shale, in contact with the Leavenworth, overlain by 1.6 feet of gray to green clayey shale. Elsewhere it is up to 8 feet thick (M. Ball, 1953, p. 41) containing the same lithologic succession with the exception that in some exposures 1 to 3 inches of gray siltstone separate the black shale from the Leavenworth. Conodonts are the only animal fossils found in the black shale although Chonetes and other brachiopods are found in the upper shale.

The Leavenworth is a single bed of blue-gray hard limestone present in all exposures studied.

The Snyderville Shale retains the lithologies described for the southern Woodson to southern Elk County area northward to about the Woodson-Coffey County line where red shale and sandstone, typical of the southern region, are no longer present. Coincident with the facies change is an overall thinning of the unit from its 40 to 80 range in southern Kansas to a range of about 10 to 30 feet in the southern Woodson

to northern Franklin County region. Tan to blue, gray, or green shale, silty claystone, and infrequent siltstones make up the Snyderville. In NW Sec. 18, T.18S., R.18E., about one mile north of Williamsburg, Kansas, M. Ball (1953, p. 84) described a 0.5 foot limestone 6.5 feet below the Leavenworth and 12.1 feet above the Toronto. Gray, flaky shale underlies the limestone and overlies the Toronto with ochre shale, bearing calcareous concretions developed between. Ball et al (1963, p. 52) report 3 thin (0.5 foot) limestone beds separated by gray shales and gray siltstones within the Snyderville about 5 miles north and 2 miles east of Williamsburg. The upper part of the Snyderville at this locality bears gray to tan siltstone with small calcareous nodules and the lower limestone, which lies 4 feet above the Toronto, contains gastropods and pectenoid clams. Claystones 8.5, 3.5, and 17 feet thick respectively were reported by Ball et al (1963, p. 34) at 3 localities (C.E.L. Sec. 31 and SWNW Sec. 18, T.18S., R.18E., SW corner Sec. 25, T.17S., R.17E.) in southwestern Franklin County. It may be significant that the area of claystone and limestone development within the Snyderville are in part coincident.

Macrofossils, especially Derbyia and Chonetes, were collected from the upper few inches of the Snyderville at Locality 20.

The Toronto Limestone thickens from the type locality (Locality 1) to almost 18 feet at Locality 20, the thickest Toronto exposure known to the writer. The datum shale parting or shale bed can be traced across the area. A shaly zone at

the 29.0 foot level in Core 7 was identified as the datum interval. An Osagite bed caps the section at Locality 25 and can be recognized at Locality 20. At Locality 9, a massive bed bearing Cryptozoon? coated grains, large crinoid particles, and abundant elongate fusulinids is present immediately above the datum shale. This same key lithology can be recognized at Localities 13, 22, and 11; and thus it serves to substantiate the choice of a datum. At Locality 9, the Toronto is 9 feet thick, but elsewhere in the same vicinity (C.E.L. Sec. 31, T.18S., R.18E.; SW Sec. 23, T.17S., R.17E.) it is 11.0 and 13.0 thick, respectively. M. Ball (1953, p. 57, p. 83) reports a 2-foot crinoidal hash bed at the top of the Toronto. He shows a photomicrograph of the bed (Fig. 18, p. 40) which includes profuse crinoidal debris and scattered brachiopod shells. Elsewhere thin limestones at the top of the Toronto bearing clams such as Pleurophorus and Nucula have been reported from the same general area (SW Cor. Sec. 25, T.17S., R.17E., Ball et al, 1963, p. 52).

The upper part of the Lawrence shale contains a thin, discontinuous limestone that averages 18 inches in thickness and lies approximately 30 feet below the base of the Toronto Limestone in Franklin, Coffey, and Woodson counties (Bowsher and Jewett, 1943, p. 32). This unit is referred to as the Amazonia? Limestone (Ball, 1964). At an exposure near Locality 9, a coal bed 0.9 foot thick lies directly above the Amazonia? Limestone within the Wathena Shale, separated from the Toronto by 32 feet of shale. Bowsher and Jewett named this the Upper Williamsburg Coal (Bowsher and Jewett, 1943, p. 55). Southward into Woodson County the coal rises strati-

graphically and is situated immediately beneath the base of the Toronto Limestone at Locality 1. Westward from Williamsburg, the stratigraphic relationships are similar; at an exposure 3 miles south of Quenemo a coal bed immediately subjacent to the Toronto Limestone has been correlated with the Upper Williamsburg Coal (Bowsher and Jewett, 1943, p. 56). Although not perfectly continuous, this coal bed is present from north-central Douglas southward to Elk County. The greatest thickness of the coal is in northwest central Franklin County (E.1/2 Sec. 16, T.26S., R.18E.) where it is 24 to 26 inches thick, containing a three-inch to four-inch clay shale seam in the middle (Bowsher and Jewett, 1943, p. 55). The coal bed thins to the north and west away from its thickest occurrence. Bowsher and Jewett (1943, p. 56) described the coal as ". . . massive but thinly-bedded, bituminous coal, which is of variable clay content and may become rather shaly in places." Ball (1953, p. 51) notes that the coal averages about 1.5 feet in thickness in southwestern Franklin County and that clay partings within the coal are common.

This interval beneath the base of the Toronto and above the Upper Williamsburg Coal is a silty to clayey, tan to gray shale sequence containing occasional siltstone beds and thin coal seams (Ball, 1953, p. 35). These shales are commonly flaky to papery, silty, and bear goethite and calcareous concretions (Locality 9; SW 1/4 Sec. 14, T.18S., R.19S.). In addition, (Ball, 1953, p. 69-85), they quite typically are micaceous and bear plant fragments (S.C.L. Sec. 5, T.18S., R.18E.; NE 1/4 Sec. 33, T.17S., R.18E.) and thin

coal seams (Ball, 1953, p. 35). The writer observed gray, silty, papery shales with intercalated thin coal lenses and plant fragments above the Upper Williamsburg Coal at Locality 6A and gray, papery shales in the same stratigraphic position at Locality 25. No invertebrate animal megafossils have been reported from this lithology.

Beneath the Upper Williamsburg Coal, but above the Amazonia? Limestone, is a zone of grayish-red terrigenous mudstone that forms a marker horizon that extends, although not absolutely continuous, from Buchanan County, Missouri southwest to Franklin County, Kansas (Bowsher and Jewett, 1943, Fig. 8, pp. 30-31; Ball, 1964, p. 163). A similar facies occurs in Woodson County and is locally developed as far southwest as the Toronto Limestone was traced (Ball, 1964, p. 163).

Northern Franklin and Southern Douglas Counties

This is the area in which the Toronto Limestone is locally absent (see Fig. 3A). The northern and western limits of this area in southern Douglas County are defined by the so-called Worden fault (Rich, 1932; O'Conner, 1960, p. 65,67). Evidence cited for the fault consist of abrupt termination of the Toronto Limestone, the presence of the Plattsmouth Limestone at several places south of the anomalous line in the approximate position of the Toronto Limestone north of the fault (O'Conner, 1960, Fig. 8A, p. 68), exposures of faulted Leavenworth Limestone showing 5 to 10 feet of vertical displacement, and steeply tilted beds of Lawrence Shale along the

proposed fault-flexure zone (O'Conner, 1960, p. 67).

Laughlin (1957) has shown that the Worden fault, or fault zone, probably extends along a north-trending line into Secs. 24 and 25, T.15S., R.18E. in northern Franklin County. Ball et al (1963, p. 37) describe the structure. To the west (upthrown side), a normal Oread sequence is present. To the east (downthrown side), the Toronto Limestone is absent although the other Oread members are present. The Heebner Shale, which averages about 6 feet in thickness elsewhere in the area, is about 17 feet thick on the downthrown side of the fault; the base of the Toronto on the upthrown side of the fault is about 30 to 40 feet above the top of the Leavenworth on the downthrown side. Rich (1932) noted that the Heebner Shale is about 16 feet thick to the south of the Worden fault in Douglas County but 6 feet elsewhere; and O'Conner (1960, p. 40) stated that the Leavenworth Limestone is 0.8 to 2 feet thick in the region, except along and south of the fault where it is locally up to 3.4 feet in thickness.

Patterson (1933) mapped the Baldwin area and reported the following (pp. 31-32). The Toronto Limestone was eroded prior to Snyderville deposition in the Baldwin area and for at least 10 miles to the southwest of Baldwin. Erosion was greatest near Baldwin (Locality 16) where 80 feet of Lawrence Shale were eroded. Locality 16 reveals a lime pebble conglomerate overlain by 35 feet of Snyderville Shale resting on the Ireland Sandstone. Beds equivalent to the Snyderville deposited above the unconformity are mainly shale near Baldwin, but to the southwest sand was deposited.

Rich (1932) explained the anomaly by: (1) uplift of the area south of the postulated fault so that the Toronto either was not deposited or was eroded after deposition; (2) reversal of movement with depression of the area south of the fault during Leavenworth and Heebner deposition; (3) deposition of Plattsmouth Limestone over the entire area, and finally (4) post-Plattsmouth faulting with downdrop to the south.

Patterson (1933, p. 32) states:

"Warping over the channel filled with shale deposits suggests that compaction had not been finished by upper Oread time. The channel, practically filled with shaly deposits for the most part, in settling, warped and faulted the upper Oread beds. Faulting followed the north face of the old valley or channel where it was high, steep, and straight, just north of Baldwin."

In order to explain the structural and stratigraphic anomalies in the Baldwin area, Rich suggested that offset relations along the Worden fault were reversed between the time of deposition of the Toronto and the Plattsmouth Limestones.

The writer offers the following hypothesis which accounts for the observed relationships without reversing movement along the fault. The events include: (1) deposition of the Toronto Limestone over the entire area followed by subaerial exposure; (2) down-to-the-south faulting along the Worden fault, creating a topographic low along which stream erosion removed the Toronto Limestone and upper part of the Lawrence Shale; (3) deposition of the Leavenworth Limestone and Heebner Shale over the entire area with local thickening of both in the old channel; (4) deposition of Plattsmouth

Limestone throughout the area; and finally (5) post-Platts-mouth down-to-the-south movement along the same fault.

This hypothesis accounts for the absence of limestone conglomerate and lack of anomalous thickening in the Snyderville Shale along the present upthrown side of the fault which Rich's hypothesis does not. It also explains the lack of abrupt facies changes in the Toronto in proximity to the fault which, if present, would suggest uplift of the Toronto south of the fault during the time of Toronto deposition.

It seems more than coincidental that the area of Toronto absence coincides geographically with the underlying Ireland Sandstone. A map depicting the net thickness of sandstone above the Haskell Limestone (Saunders, 1959, Plate 1) shows that thick sandstones underlie the Worden fault. The trend of the sand body changes abruptly near the southwestern corner of Douglas County. Part of this sand mass is the so-called Ireland Sandstone. It seems likely that the Worden fault may have been in existence prior to Ireland deposition and may have exerted primary topographic control over the localization of the channel in southern Douglas County. Thus it appears likely that the geographic coincidence of the Ireland Sandstone, area of stratigraphic anomalies in the Oread Limestone, and position of the Worden fault are not merely fortuitous.

Laughlin (1957, p. 73) reports a terrigenous sandstone 17.4 feet beneath the Leavenworth on the downthrown side of the Worden fault in northwestern Franklin County (NW Sec. 19, T.15S., R.19E.) which may well be a post-Toronto-pre-Leavenworth stream channel deposit laid down within the area of Toronto absence.

Although lesser differential compaction over the area of thicker sandstone deposition compared to greater compaction in areas of thicker shale deposition may (and probably does) account for some of the stratigraphic anomalies in the Oread Limestone in northern Franklin and southern Douglas counties (see Ball et al, 1963), it is probably not the major factor involved in the development of the Worden fault and related stratigraphic anomalies.

West of the Worden fault there are other stratigraphic peculiarities in the Oread. The Toronto Limestone is absent from some exposures although the rest of the Oread is typically developed. At one locality (SE corner Sec. 29, T.15S., R.18E.), Heebner black shale rests directly on the Toronto Limestone with both the Leavenworth Limestone and Snyderville Shale absent. However, the Leavenworth is observable less than a mile away to the north (CNL Sec. 29, T.15S., R.18E.) and to the south (C.W.L. Sec. 32, T.18S., R.18E.).

A thin coal seam, only an inch or so in thickness, is present near the top of the Snyderville Shale in northwestern Franklin County (NW corner Sec. 5, T.16S., R.18E.). Less than one-half mile away a thin limestone bed (less than one foot thick) is separated from the Leavenworth Limestone by one foot of shale (C.NW.L. Sec. 5, T.16S., R.18E.). The limestone is fossiliferous, yielding Derbyia, Canocrinella, Enteletes, and myalinids.

Northern Douglas and Leavenworth Counties, Kansas

The Plattsmouth Limestone is present throughout Douglas and Leavenworth counties. It is 15 feet thick at Locality 22 near Lawrence, Kansas, where it is light gray, wavy-bedded in thin layers with shale partings, and contains persistent zones of dark chert about 6 and 11 feet above the base (Moore and Merriam, 1959, p. 10). Common fossils are fusulinids, algae, brachiopods, corals, bryozoans, crinoid fragments, and molluskan remains. The limestone averages about 18 feet in Douglas County and 15 to 17 feet in Leavenworth County (O'Conner, 1960, p. 41; Reynolds, 1957, p. 32; McLaren, 1952, p. 46). The lithology of the member is generally similar to that described above throughout the area.

The Heebner Shale is about 4 to 8 feet throughout both counties. It contains a lower black carbonaceous shale unit 2 1/2 to 4 feet thick, bearing phosphatic nodules and laminations, conodonts, and scattered pectenoid clams (Moore and Merriam, 1959, p. 10; O'Conner, 1960, pp. 40-41; Reynolds, 1957, p. 32; McLaren, 1952, p. 45). The black zone is overlain by gray to olive shale containing sparse brachiopods.

The thin but ever present Leavenworth Limestone consists of a single, massive, dark blue bed, underlain by about 1/2 foot of dark gray calcareous shale bearing Crurithyris and Chonetes at Locality 22.

The Snyderville Shale is about 10 to 15 feet thick in Douglas County where it consists chiefly of light bluish to greenish-gray, blocky, un laminated, argillaceous and silty shale, claystone, and siltstone (O'Conner, 1960, p. 38).

In southwestern Leavenworth County, it is an olive-gray, blocky, clayey to silty shale (Reynolds, 1957, p. 31) commonly 10 to 12 feet thick. In northwestern Leavenworth County, it ranges from 10 to 17 feet in thickness, consisting of blocky clay shale; it is green throughout the lower half, blue-gray in the middle, but gray or brown in the upper few feet (McLaren, 1952, p. 44). No fossils have been recovered from the Snyderville in the Douglas-Leavenworth County area except for the upper few inches immediately below the Leavenworth Limestone.

The writer has examined the Toronto Limestone in northern Franklin and southern Douglas counties, to the west of the area in which it is absent, and recognized the shaly limestone or thin shale zone that has been used as a datum in the southern part of Kansas. The massive limestone bed bearing large Cryptozoon? structures, large crinoid columnals, and abundant elongate slender fusulines can be recognized at Localities 13C, 13B, 13A, 22, and 11. Although the shale parting is present at Locality 12, the Cryptozoon? zone is absent. The Toronto is about 10.5 feet thick at Locality 22, and about the same thickness in southwestern Leavenworth County (Reynolds, 1957). A thin nodular chert is typically present in upper few feet of the unit in Douglas and southwestern Leavenworth counties (Reynolds, 1957; O'Conner, 1960, p. 38). In northeastern Leavenworth County, McLaren states that the Toronto ranges from 5 to 8 feet in thickness. The shale datum is apparently present at Locality 10. The thin, wavy-bedded lime mudstones present at the top of the Toronto at this locality are reportedly not common in northeastern Leavenworth County (McLaren, 1952, p. 88).

The upper part of the Lawrence Shale to the west and north of the area of Toronto absence, in southern Douglas and northern Franklin counties, is somewhat transitional between rather distinct but widely extensive stratal sequences to the north and to the south. Ball et al (1963, p. 30) state: "In Franklin County and several other counties south of Doniphan County, the occurrence of a zone of limestone lenses in the upper part of the Lawrence Shale is common and characteristic. It has become common practice to correlate these limestone lenses with the Amazonia Limestone (Hinds and Green, 1915, p. 31, 170) whose type section is in southern Andrew County, Missouri." O'Conner (1960, p. 37) commented that the Amazonia Limestone is doubtfully recognized throughout most of the outcrop area in Douglas County, but noted that a thin limestone, seen on drillers' logs in the shallow subsurface, is possibly Amazonia. He further stated (p. 37) where a limestone is not recognized on the outcrop, it might be represented by a zone of carbonate caliche-like nodules 20 to 45 feet below the top of the Lawrence. Reynolds (1957, p. 28) reported possible Amazonia Limestone in southwestern Leavenworth County, but indicated that it occurs only at scattered localities. McLaren (1958, p. 37) stated that the Amazonia does not crop out in northeastern Leavenworth County.

In Douglas County, that part of the upper Lawrence between the Toronto and Amazonia? Limestone is chiefly shale, ranging from 20 to 40 feet in thickness (O'Conner, 1960, p. 37). It contains the thin Upper Williamsburg Coal which has been correlated as far north as Locality 13B where it is present about 10 feet below the Toronto Limestone (O'Conner, 1960, p. 37).

A zone of red shale or mudstone crops out about 13 feet below the Toronto in extreme northwestern Franklin County (Ball et al, 1963, p. 32). Red shale, about one to 4 feet thick, in the same stratigraphic position has been reported throughout northern Kansas 10 to 25 feet beneath the Toronto Limestone (Bowsher and Jewett, 1943, pp. 30, 31); Patterson, 1933, p. 27; Ball, 1964, p.163). At Locality 22, the red bed is 1.8 feet thick, containing calcareous nodules with septarian veins (Moore and Merriam, 1959, p. 10); it is overlain by 3 feet of blocky, unlaminated blue clay, followed by a thin coal; then about 4 feet of bluish-gray, laminated, silty clay; 2 feet of fine-grained micaceous sand, and finally 2 feet of laminated, bluish-gray shale containing crinoid columnals and inarticulate brachiopods near the top (Moore and Merriam, 1959, p. 10). Patterson (1933, p. 29) reported marine fossils--poorly preserved Cytherella-like ostracodes, Hyperammina, and Ancistrum (holothurian parts)--from the red shale in the city of Lawrence and said that Trochiliscus, reportedly fresh water algae, are present in samples examined throughout the area. Stratigraphic sections measured and described by Reynolds (1957, pp. 62-78) in southwestern Leavenworth County reveal a red mudstone (0.7 to 2.0 feet thick) about 20 to 25 feet beneath the Toronto Limestone. The red mudstone is underlain by up to 15 feet of olive-gray blocky, clayey shale but overlain by gray to blue, silty micaceous shale, which is calcareous and fossiliferous near the top (Localities 22, 11, 12, and 10). Beneath the red mudstone and blocky, clayey shale, the upper Lawrence, in Douglas and Leavenworth counties, consists mainly of blue to gray and

olive, silty to sandy shale with intercalated thin, lenticular, micaceous sandstones (Reynolds, 1957, pp. 62-78; Patterson, 1933). One fairly persistent coal bed up to 8 inches thick, the Lower Williamsburg, extends northward from central Franklin County. It is 30 to 60 feet beneath the Toronto, reportedly equivalent to part of the Ireland Sandstone (Ball, 1964, p. 145). This coal may extend as far north as southwestern Leavenworth County (Reynolds, 1958, p. 26-27). According to Bowsher and Jewett (1943, Fig. 8, p. 31) there are numerous thin discontinuous coals in the upper part of the Lawrence in Douglas and Leavenworth counties, some below - and others above - the mudstone key bed.

Northwestern Missouri

The Oread Formation, where not covered by glacial drift, is exposed in the counties of Platte, Buchanan, Holt, Andrew, DeKalb, Gentry, Nodaway, and possibly Worth in northwestern Missouri (Howe and Koenig, 1961, p. 111). The lower part of the succession is well exposed along the Missouri River bluffs at St. Joseph, Missouri.

The Plattsmouth Limestone of northwestern Missouri varies from 17 to 35 feet in thickness, is thin, wavy-bedded with shaly partings and contains chert layers (Hinds and Green, 1915, p. 171). The Heebner Shale, 4 to 6 feet thick, has a black carbonaceous component at the base, which is overlain by a lighter gray shale in the upper part.

Except for one small area where the Toronto Limestone alone is absent, the Leavenworth, Snyderville, and Toronto

members of the Oread are all present in northwestern Missouri but show variations when compared to the Kansas outcrops, previously discussed, that are significant in terms of depositional environments. For this reason, variation within the upper Lawrence to Leavenworth interval will be discussed concomitantly for this area.

The Lawrence Shale thins from south to north across the Missouri area, and the upper 10 to 20 feet contain a prominent bed of red shale identified from outcrops and drill records (Hinds and Green, 1915, p. 170). The Amazonia Limestone is 25 to 100 feet beneath the Toronto, the interval decreasing along the Missouri River from south to north (Hinds and Green, 1915, p. 170).

At Atchison, Kansas, the Leavenworth Limestone is one foot, 9 inches thick where it apparently consists of a single bed. The Toronto Limestone (10 feet thick) is overlain by 9 feet of Snyderville Shale and underlain by 25 feet of shale, a 16 to 18 inch coal seam, followed by 30 feet of shale, but no exposure of Amazonia Limestone (Hinds and Green, 1915, p. 176).

Directly across the Missouri River at Rushville, southern Buchanan County, 3 feet of Toronto Limestone are exposed, underlain by 60 feet of covered interval superjacent to 3 feet, 8 inches of limestone, identified as Amazonia. (Hinds and Green, 1915, p. 175.)

Near Halls, central Buchanan County, the Leavenworth is one foot, 9 inches thick, the Snyderville interval is 25 1/2 feet, and the Toronto is 7 feet. An 8-foot section

of blue shale followed by a covered interval of 57 feet overlies 5 feet of Amazonia Limestone. (Hinds and Green, 1915, p. 175.)

At St. Joseph (Locality 15), the Leavenworth Limestone is 2 feet, 4 inches thick in two beds separated by a shaly parting. The Snyderville Shale is 9 to 15 feet thick and the Toronto is 6 to 7 feet in thickness. The Amazonia Limestone is 34 to 45 feet below the Toronto Limestone (Hinds and Green, 1915, p. 178).

The Snyderville is greenish-tan at Locality 15, and unfossiliferous; but at Locality 15A, one mile to the north, the member is dark bluish-gray and contains an abundant fauna of Myalina, many of which are paired. Less than 1/2 mile to the north of Locality 15A on the Buchanan-Andrew County line, the Toronto Limestone is not present, although the Leavenworth-Plattsmouth interval appears no different than at Localities 15 and 15A. A cross-stratified, terrigenous sandstone-lime pebble conglomerate is found at the base of an approximately 30-foot section of blue-gray shale beneath the Leavenworth. The upper few inches of Wathena-Snyderville Shale at this locality bear Derbyia crassa and Juresania in abundance.

In a quarry and railroad cut north of Amazonia, Hinds and Green (1915, p. 180) described a section of Oread Limestone nearly 50 feet thick which is no longer exposed. The Leavenworth Limestone consists of 2 beds, 7 and 9 inches thick, separated by a prominent bedding surface. A 17-foot covered slope with blue argillaceous shale at the base rests

on the Toronto Limestone which is 5 feet, 10 inches thick, consisting of 3 limestone and 3 prominent interstratified shale beds; the thickest limestone bed is 2 feet and the thinnest shale is 6 inches.

Near the mouth of the Nodaway River, west of Amazonia (Hinds and Green, 1915, p. 181), the Leavenworth again consists of 2 beds. The Heebner contains a lower 3-foot unit of black butuminous shale and 2 feet of blue-gray argillaceous shale. The Plattsmouth, which consists of thin wavy-bedded limestone with shale partings, is 20 feet thick.

In a well drilled at Savannah, Missouri (Hinds and Green, 1915, p. 182), the Toronto Limestone is 4 feet thick. It is overlain by 12 feet of red clay shale. A shale zone 25 feet thick, containing some red shale, is developed between the Toronto and Amazonia limestones, the latter being 13 feet thick.

A red shale or mudstone bed 10 to 20 feet beneath the top of the Wathena Shale is present in practically all outcrops and recorded on many drill logs in northwestern Missouri (Hinds and Green, 1915, p. 170). Ball (1964, p. 163) reports red mudstone in all Missouri and Doniphan County, Kansas exposures that he studied. He (Ball, 1964) says that terrigenous siltstone and fine-grained sandstone are locally developed in the upper Lawrence or Wathena Shale from extreme southwestern Buchanan, Missouri, southwestward.

The Toronto shale zone or parting used as a stratigraphic datum is seemingly present at Localities 15 and 15A at St. Joseph, Missouri.

Southeastern Nebraska

Approximately 120 miles of younger rocks separate complete exposures of Toronto Limestone, examined by the writer at Locality 14A in Cass County, Nebraska, and Locality 15A in Buchanan County, Nebraska. Regional variation in terms of thickness in Shawnee and Douglas rocks between Kansas and Nebraska is as follows: The Shawnee group averages 325 feet in thickness in Kansas but is 175-250 feet in Nebraska; the Douglas group, however, is about 250 feet thick at the type locality in Douglas County, Kansas, about 150 feet in the subsurface of southeastern Richardson County, Nebraska, but only 60 feet in the Weeping Water Valley of Nebraska (Condra, 1949, pp. 20-27). The Oread Formation is around 47 feet thick in Nebraska compared to 45-50 feet in east central Kansas (Condra, 1949, p. 28), but is much thicker in southern Kansas where the Snyderville Shale thickens considerably.

The basal limestone member of the Oread Formation in Nebraska was originally called the Weeping Water (Condra and Bengston, 1915, p. 10) but was later tentatively correlated with the Toronto Limestone of Kansas (Condra and Reed, 1937, p. 62; Condra, 1949, p. 26; Moore, 1949, p. 147). However, recent subsurface work by Ball (1964, p. 178) has substantiated the correlation of the Toronto Limestone of Kansas with the Weeping Water Limestone of Nebraska and, because the former has priority (Haworth and Piatt, 1894, p. 162), it is used in the following discussion.

Near Wathena, Kansas, the Toronto Limestone is 6 to 7 feet thick, the Snyderville is 15 feet but covered, the Heebner

Shale is 5 feet, containing a lower black unit and an upper bluish-gray, and the Plattsmouth Limestone is 18 to 20 feet thick (Condra and Reed, 1937, pp. 12-13).

At Amazonia, Missouri, Condra and Reed (1937, pp. 17-18) describe 2 beds in the Leavenworth that contain fusulines and *Cryptozoon?*, the Snyderville Shale as being a 12 to 15-foot thick section of greenish-gray argillaceous shale that is covered at the base, and the Toronto Limestone as being 5 feet, 10 inches to 6 feet, 8 inches in thickness. Included in the Toronto are an upper one-foot bed of argillaceous platy limestone containing Osagia and a lower 5-foot section of light gray to brownish-gray, massive, fossiliferous limestone, bearing fusulinids.

Along Heebner Creek (east side Sec. 10, T.10N., R.12E.), an Oread exposure reveals 14 feet of Plattsmouth Limestone, about 6 feet of Heebner Shale with 3 feet of black carbonaceous shale at the base, overlain by 3 feet of bluish-gray argillaceous shale. The Snyderville Shale is 11 to 12 feet thick, containing greenish-gray, and calcareous shale in the upper 2 to 3 feet; the middle and lower part is massive red, clayey shale; many Chonetes occur near the top of the Snyderville. The Toronto Limestone is at least 5 feet thick, consisting of light bluish-gray, dense limestone at the top and argillaceous limestone in the lower part. (Condra and Reed, 1937, p. 32).

A well, drilled about 4 miles north and one mile east of the Heebner Creek section, revealed 2 feet of Leavenworth Limestone, underlain by 14 feet of Snyderville Shale and

8 feet of Toronto Limestone (Condra, 1939, p. 4). The upper 8 feet, 6 inches of Snyderville is calcareous, massive, bluish-gray shale, underlain by 5 feet, 6 inches of shale that is brownish at the top, maroon in the middle, and mottled blue-brown at the base. The Toronto is gray, but shaly at the top and base, with fossils throughout. Two feet of gray fossiliferous shale underlie the Toronto and overlie 7 feet of red and yellowish shale with blue mottling which rests on 4 feet, 6 inches of reddish shale, followed by bluish-gray shale with coal-like bands.

In northern Cass County, west of South Bend on Pawnee Creek, the Oread Limestone is well exposed in Johannson's Quarry and elsewhere in the same general area (Condra, 1930, p. 37). The Heebner Shale is about 6 feet thick beneath basal Plattsmouth in the quarry although black fissile shale was noted about one mile to the south on Pawnee Creek. The dense Leavenworth Limestone is one foot, 10 inches thick, overlying about 12 feet of Snyderville Shale which consists of an inch or so of green shale at the base, succeeded by a thick zone of red shale, capped by several feet of bluish to greenish shale at the top. The Toronto Limestone is about 9 feet thick, the upper 4 feet of which consists of limestones with little shale, but the basal 5 feet is interbedded or mixed shale and limestone. The upper few inches of Lawrence Shale is gray at the top, but the remainder is largely a red shale, about 21 feet thick, that is developed above the Cass Limestone (Condra, 1930, p. 39; Ball, 1964, p. 186). In some cases some of the red material from the Lawrence has been reworked into the basal few inches of the Toronto Limestone.

At Ashland, 5 miles west and one mile north of the Pawnee Creek section, Condra (1930, p. 40) reports 4 feet, 6 inches of Heebner with ". . . lower zone . . . dark, fissile, weathered brownish . . ." overlain by bluish shale. The Leavenworth is about one foot, 6 inches thick. The Snyderville Shale is about 12 feet thick with an upper 2 to 3-foot zone of bluish shale; a maroon, mottled-maroon, and bluish-gray interval with an 8 to 10 inch section of bluish-green shale at the base.

The Toronto Limestone is about 9 feet thick in the Ashland section. It contains an upper unit of limestone with little shale about 5 feet thick, and lower mixed shale and limestone sequence. The Lawrence Shale is about 20 feet thick at this locality with yellowish-gray zone at the top, a thick maroon shale in the middle, and a lower bluish shale. The Lawrence Shale rests on about 15 feet of Cass Limestone.

The Oread Limestone is exposed in the Missouri River Bluffs southeast of Plattsmouth, Nebraska (SE 1/4 Sec. 20 and E 1/4 Sec. 29, T.12N., R.14E.) (Condra and Reed, 1938, p. 11). The Plattsmouth Limestone is about 10 feet thick, overlying 5 feet of Heebner Shale that is bluish-gray and argillaceous in the upper part but black and fissile below. The Leavenworth Limestone is dark bluish-gray and one foot, 6 inches thick. The 12 to 14-foot thick Snyderville Shale is bluish at the top where it reportedly contains limestone seams; the middle is maroon, but the basal 3 feet are greenish-blue and argillaceous. The Toronto Limestone is described as gray, massive, fossiliferous limestone, that is argillaceous in the lower part and about 7 feet in thickness. The Lawrence Formation is approximately 10 feet thick and consists of gray shale above with

maroon shale in the middle (Condra and Scherer, 1939 in 1958, p. 14).

Exposures of Toronto examined by the writer in Nebraska (Localities 14, 14A and 21) are all very similar and it is likely that bed for bed, correlation can be demonstrated in all 3. Sections described at Ashland by Condra (1930) and south of Plattsmouth by Condra and Reed (1938) are very similar and indicative of lateral homogeneity for the Toronto in Nebraska.

The Amazonia Limestone of Kansas and Missouri and the Cass Limestone of Nebraska are not continuous across the 100-mile wide belt of younger rocks that separate the outcrop areas. Ball (1964, p. 186) comments that the Cass Limestone of Nebraska may be represented by limestones and interbedded shale, developed locally in northwest Missouri exposures of the lower 30 feet of Robbins-Ireland Member. According to Ball (1964, p. 72), the Douglas Group includes about 33 percent limestone in the subsurface of northeastern Kansas and southeastern Nebraska, and the Cass and Amazonia limestones are probably continuous in the area of shale-limestone facies of the Douglas.

Southwestern Iowa

Oread exposures are limited and widely separated in southwestern Iowa, but certain outcrops have been definitely identified as Oread and all the limestone members of the Oread are present except possibly the Toronto Limestone. The latter has been tentatively recognized by Hershey et al

(1960) although the correlation has not been confirmed with subsurface studies. Even if the correlation could be shown, which is unlikely, the Toronto is in a different facies in Iowa than observed elsewhere.

An exposure of Plattsmouth-Leavenworth is present at a waterfalls on the Nishnabotna River near Lewis, Cass County, Iowa (NESE NE Sec. 16, T.7S., R.37W.) (Condra and Reed, 1937, p. 38, 39; Hershey et al, 1960, p. 53). The Plattsmouth section is 10.5 feet thick at this locality but incomplete; it contains two shale beds, one 2.4 feet thick and another 1.1 feet thick. The Heebner Shale is 2.4 feet, represented at the base by 0.8 of black fissile shale overlain by 1.6 feet of olive-gray shale. The Leavenworth Limestone is represented by an upper 0.8 foot limestone, a thin, dark shaly parting zone, and a lower 2.2 foot dark limestone bed. No exposure of Toronto Limestone was found.

In a small tributary of the Middle River in Adair County in the NENE Sec. 1, T.75N., R.30W., an exposure of Oread Limestone reveals an incomplete section of Plattsmouth, but complete exposures of Heebner and Leavenworth and units that have been tentatively correlated with the Snyderville Shale and Toronto Limestone (Hershey et al, 1960, p. 42). The Plattsmouth is 8.3 feet thick at this exposure and contains a shale bed at least 4 feet thick at the top of the unit. The Heebner Shale is 3 feet thick with a lower 0.4 foot olive-shale zone, a 1.3 foot bed of black fissile shale, and an upper 1.3 foot bed of olive shale. The Leavenworth Limestone, 1.1 feet thick, is medium bluish-gray and contains

conspicuous Ottonosia. About 6.7 feet of dark blue-gray shale with abundant Derbyia at the top underlies the Leavenworth and overlies a 0.3 foot zone of olive shale that overlies 1.1 feet of red-maroon silty, blocky shale. A bed of nodular, sandy to silty, light gray limestone about 2 feet, 9 inches thick has been tentatively correlated as the Toronto Limestone (Hershey et al 1950, p. 42). A red shale zone about 3.3 feet thick underlies the limestone.

In another tributary of the Middle River in Madison County (C.W.L. NW Sec. 7, T.75, R.29W.), lowermost Plattsmouth, Heebner, Leavenworth, and possibly Snyderville, are exposed. A 6-inch bed of dark gray limestone containing Lingula is separated subjacently from the Leavenworth by one foot, 10 inches of olive shale.

At Plattsmouth, Nebraska (Condra and Reed, 1937, p. 28), the Plattsmouth Limestone is 16 feet thick consisting of gray, wavy-bedded limestone with shaly partings; a single shale bed 5 to 7 inches thick was reported from the section. The Plattsmouth is 14 feet thick and mostly limestone with several thin, 3 to 6-inch shale beds in the Weeping Water Valley of Nebraska (Condra and Reed, 1937, p. 32). At the mouth of the Nodaway River in northwest Missouri, the Plattsmouth is described as 20 feet of limestone; no shale beds were described (Condra and Reed, 1937, p. 17).

In Iowa, however, the Plattsmouth Limestone contains argillaceous limestone beds that grade northward and eastward to calcareous shale (Hershey et al, 1960, p. 21, 22). In Montgomery County, the Plattsmouth is 20 feet thick and contains, in part, a thick section of argillaceous limestone.

In Cass County, where it is 13 feet thick, the Plattsmouth contains one 4-foot bed of calcareous shale. In Madison and Adair counties, a 7 to 8-foot bed of calcareous shale is present in the Member.

The Heebner Shale is 5 feet thick in Montgomery County but 2.5 and 3 feet thick in Cass and Adair counties, respectively (Hershey et al, 1960, p. 22). This shale member is characterized by a thin olive clay shale near the base and a thicker olive clay shale at the top, separated by black fissile shale.

The Leavenworth is a single bed of bluish-gray limestone, except for the Lewis exposure, containing abundant large Ottonosia (Hershey et al, 1960, p. 22).

Snyderville has been equivocally recognized at a single exposure in Iowa (Locality 33). At the same locality, a 2-foot thick nodular sandy limestone 8 feet beneath the Leavenworth may be a facies equivalent of the Toronto. A similar limestone bed is reportedly present in the subsurface of Cass and Montgomery counties, but lateral continuity has not been established between these localities and with the Kansas-Nebraska Toronto Limestone, so that the Iowa occurrences of Toronto must remain a subject for future study.

Figure 4 is a restored cross section depicting the stratigraphic relationships between the upper part of the Lawrence Shale, the Toronto Limestone, the Snyderville Shale, and the Leavenworth Limestone.

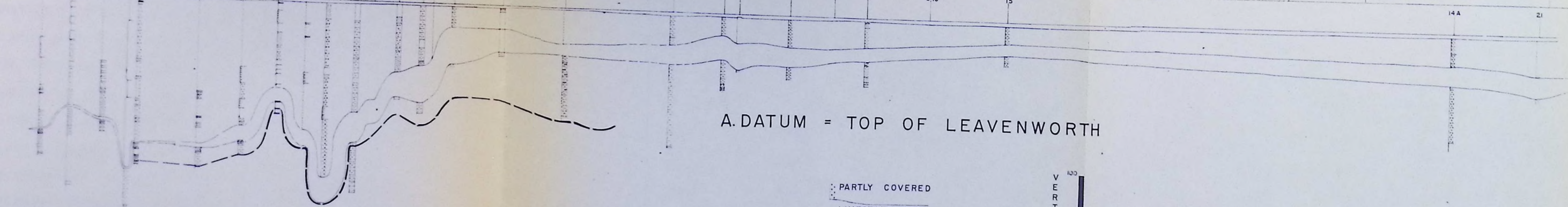
EXPLANATION OF FIGURE 4

Restored cross-sections of upper part of the Lawrence Formation, Toronto Limestone, Snyderville Shale, and Leavenworth Limestone.

SOUTH
OKLAHOMA KANSAS

NORTH
MISSOURI NEBRASKA
IOWA

OSAGE CHAUTAUQUA ELK GREENWOOD WOODSON COFFEY FRANKLIN DOUGLAS KANSAS MISSOURI LEAVENWORTH BUCHANAN MISSOURI NEBRASKA CASS



LEAVENWORTH LS.
SNYDERVILLE SH.
TORONTO LS.
LAWRENCE SH.

A. DATUM = TOP OF LEAVENWORTH

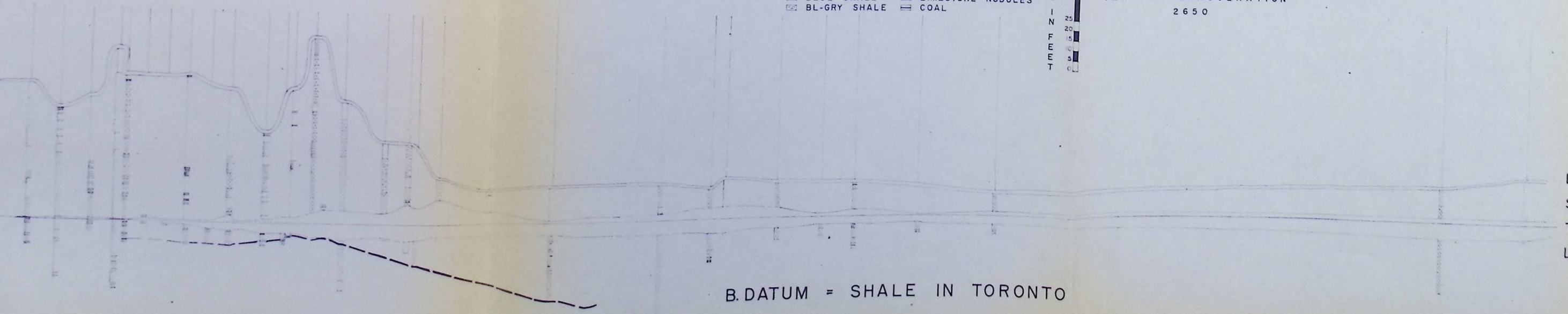
PARTLY COVERED
LIMESTONE BODY
COVERED INTERVAL

- | | |
|--------------|---------------------|
| RED SHALE | SILTSTONE |
| BROWN SHALE | SANDY SHALE |
| TAN SHALE | SANDSTONE |
| GREEN SHALE | X-BDD SANDSTONE |
| GRAY SHALE | LIME OR MUD PEB GGL |
| BLUE SHALE | LIMESTONE NODULES |
| BL-GRY SHALE | COAL |

VERTICAL SCALE IN FEET

HORIZONTAL SCALE IN MILES

VERTICAL EXAGGERATION 2650



LEAVENWORTH LS.
SNYDERVILLE SH.
TORONTO LS.
LAWRENCE SH.

B. DATUM = SHALE IN TORONTO

MACROFOSSILS

In order to supplement and refine faunal observations made at the outcrop, macrofossils were collected for laboratory study. Although fossiliferous shales can be sampled quantitatively by taking bulk samples (Imbrie, 1955), limestone beds have to be broken apart and the rock fragments examined in the field for fossil content. Such procedure is time consuming and results chiefly in the recovery of fragments of fossils. Thus, faunal collections from the Toronto Limestone are qualitative at best and consist mainly of incomplete specimens. In spite of these limitations, however, macrofossil studies of the limestone were found to be a source of valuable data pertinent to an interpretation of depositional environments. Identifications were made mainly by reference to the literature. A list of macrofossil taxa identified in the studies is shown on Table 1.

Identifications of fossilized plant leaves and wood were made at the outcrop. "Cryptozoon," Osagia, and crinkly stromatolites are described in the chapter on petrography and their abundances are recorded in the point-count data.

Three species of fusulinids are of volumetric importance in the Toronto Limestone (two species of Triticites and one species of Kansanella (George Sanderson, personal communication)). Field observations were limited to a description of presence or absence of fusulinids and the predominant growth form. Commonly an elongate subcylindrical form (Kansanella) was found to be most abundant above the shale zone or parting used as a datum for construction of the

restored section. Robust forms (Triticites) were common below the datum.

Only 2 genera of sponges were identified from the limestone. One is the genus Girtyocoelia, reported from Locality 1 only. The second genus is Coelcladia which has been seen in a number of thin sections from several localities and is almost invariably coated by stromatolitic growth of the "Cryptozoon" type.

Identification of bryozoans was limited to 3 forms--fenestrate, ramose, and encrusting. The point-count data reveals the abundance of the 3 bryozoan types in the limestones, but additional information regarding their occurrence is listed with macrofossil data.

The most taxonomically diverse phylum within the Toronto Limestone is the Brachiopoda. At least 33 brachiopod species were recognized. Certain brachiopods, notably Neochonetes, Derbyia, and Crurithyris, are most abundant in shales and shaly limestones. They generally occur in great numbers, and are associated with few other taxa.

Two different morphotypes of the genus Rhipidomella are present. One can be ascribed to R. carbonaria (Swallow), but the other is transverse in outline, resembling R. transversa (King) described from the Permian of the Glass Mountains of West Texas (King, 1930, p. 44). Internal features of the shell, dental lamellae and medium septum are sharply distinct from those of Enteletes so that this form is not a juvenile Enteletes.

Although the productoid generic revisions of Muir-Wood and Cooper (1960) were inserted in place of the old generic

names where possible, the new classification has little practical application to fragmental specimens from limestones. Muir-Wood and Cooper discriminate the different genera on the basis of such characters as the presence or absence of spines along the hinge line and wings of the pedicle valve (Dictyoclostidae) and features seen on the brachial valve (Echinoconchidae). When working with fragmentary specimens, such characteristics rarely can be observed. The older work of Dunbar and Condra (1932) was found to be a much more practical approach.

The second most taxonomically diverse phylum encountered was the Mollusca, although most of the specimens were obtained from the Wathena Shale which is, in part, a lateral equivalent of the Toronto Limestone in southern Kansas. Three classes are represented--cephalopods, pelecypods, and gastropods. A single cephalopod specimen was found. Approximately 19 pelecypod genera and 12 gastropod genera were identified. Probably many more pelecypod genera than listed are present, but the thinness and fragmental nature of the shells allows few of them to weather out as identifiable fossils. In addition, many of the aviculopectinoid genera and species are discriminated on the basis of characters of the ligament area which can be observed rarely. Because of questionable identification, the genus Aviculopecten, for example, is placed in quotes. Complete gastropod specimens were also difficult to obtain and the taxa identified in no way approximates the total variety of gastropod morphotypes present in the Toronto Limestone. However, certain beds of the Toronto

are characterized by presence of molluscs with brachiopods, echinoderms, and corals being excluded so that, in spite of its scantiness, the data are of environmental significance.

Trilobite parts are not abundant in the Toronto and were collected or observed at only a few places. They are all pygidia, and are referred with reservation to the genus Ditomopyge. Small, slipper-shaped pits occurring mainly on myalinid pelecypod shells are identified as acrothoracic barnacle excavations which have been reported from the Pennsylvanian of Texas by Fisher and Rodda (1962).

Echinoderm remains consist almost exclusively of disarticulated crinoid columnals and plates, and echinoid plates and spines. Several crinoid calices were collected. The point-count data reveal the abundance of these remains in the limestones, but field identifications are listed for occurrences in shales.

TABLE 1

LIST OF MACROFOSSIL TAXA

Foraminifers

Fusiform fusulinids
Robust fusulinids

Sponges

Coelcladia sp.
Girtyocoelia sp.

Corals

Lophophyllidids
Syringopora sp.

Bryozoans

Fenestrate
Ramosae
Encrusting

Brachiopods

- Lingula sp.
cf. Orbiculoidea sp.
Rhipidomella carbonaria (Swallow, 1858)
Rhipidomella sp. aff. R. transversa King, 1931
Enteletes sp.
Wellerella sp. cf. W. osagensis (Swallow, 1858)
Derbyia crassa s.l. (Meek and Hayden, 1859)
Derbyia sp. cf. D. bennetti (Hall and Clarke, 1892)
Derbyoides sp. cf. D. nebrascensis Dunbar and Condra, 1932
Meekella striatocostata (Cox, 1857)
Neochonetes granulifer s.l. (Owen, 1853)
cf. Chonetina flemingi (Norwood and Pratten, 1855)
cf. Lissochonetes geinitzianus (Waagen, 1884)
Hystriculina wabashensis (Norwood and Pratten, 1855)
 = Marginifera wabashensis (Norwood and Pratten)
Hystriculina hystricula (Dunbar and Condra, 1932)
 = Marginifera hystricula Dunbar and Condra, 1932
Marginifera splendens (Norwood and Pratten, 1855)
Retaria lasallensis (Worthen, 1873)

Antiquatonia portlockiana s.l. (Dunbar and Condra, 1932)
 = Dictyoclostus portlockianus s.l. Dunbar and Condra
Reticulatia huecoensis (King, 1931)
 = Dictyoclostus americanus Dunbar and Condra, 1932
Echinaria semipunctatus (Shepard, 1838)
 = Echinoconchus semipunctatus (Shepard)
Echinaria sp. cf. E. moorei (Dunbar and Condra, 1932)
 = Echinoconchus moorei (Dunbar and Condra)
Juresania nebrascensis (Owen, 1952)
Juresania sp. cf. J. ovalis (Dunbar and Condra, 1932)
Linoproductus prattenianus (Norwood and Pratten, 1855)
Linoproductus spp.
Cancrinella sp. cf. C. boonensis (Swallow, 1858)
Teguliferina armata (Girty, 1908)
Leptalosia ovalis Dunbar and Condra, 1932
Neospirifer sp. cf. N. dunbari King, 1933
Crurithyris planoconvexa (Shumard, 1855)
 = Ambocoelia planoconvexa (Shumard)
Cond Rathyris sp. cf. C. perplexa (McChesney, 1860)
 = Squamularia perplexa (McChesney)
 = Phyricodothyris perplexa (McChesney)
Punctospirifer kentuckyensis (Shumard, 1855)
Hustedia mormoni (Marcou, 1858)
Composita sp. cf. subtilita (Hall, 1852)
Beecheria bovidens (Morton, 1836)
 = Dielasma bovidens (Morton)

Pelecypods

Solemya sp. cf. S. radiata Meek and Worthen, 1860
Nucula (Nuculopsis) girtyi Schenk, 1934
Nuculana bellistriata (Stevens)
Parallelodon sp. cf. P. obsoletus (Meek, 1871)
Parallelodon sp. cf. P. sangamonensis (Worthen, 1890)
"Aviculopecten" spp.
 cf. Acanthopecten sp.
Streblochondria sp.
Camptonectes? sp.
 cf. Pseudomonotis sp.
 cf. Pterinopectinella sp.
 cf. Posidonia sp.
Pteria sp. cf. P. longa (Geinitz, 1866)
Promytilus sp.
Myalina (Orthomyalina) slocomi Sayre, 1931
Myalina sp.
Septimyalina sp. cf. S. scitula Newell, 1942
Schizodus sp.
Wilkingia terminale (Hall, 1852)
 = Allorisma terminale (Hall, 1852)

- Wilkingia sp.
= Allorisma sp. cf. authors
cf. Pleurophorus sp.
Aviculopinna sp.
Astartella sp. cf. A. concentrica (Conrad, 1842)

Gastropods

- Bellerophon (Pharkidonotus) percarinatus (Conrad, 1842)
Bellerophon sp. cf. B. singularis Moore, 1941
cf. Knightites (Retispira) sp.
Euphemites carbonarius (Cox, 1857)
Goniasma sp.
Murchisonia sp.
Glabrocingulum sp.
Phymatopleura sp.
Straparolus (Amphiscapha) sp.
Straparolus (Euomphalus) sp.
Naticopsis (Jedria) ventracosa (Norwood and Pratten, 1855)
Naticopsis sp.
"Pseudozygopleura" sp.
"Hemizyga" sp.
cf. Meekospira sp.

Cephalopods

- Pseudorthoceras - type

Arthropods

- cf. Ditomopyge sp.
Acrothoracic barnacle borings

CLAY MINERALOGY

Clay minerals present in the Toronto Limestone were identified from X-Ray diffraction patterns of the <2 micron size fraction. The clay mineral samples were extracted from the limestone samples by the preparation of insoluble residue using dilute solutions of formic, acetic, and citric acids. Both untreated and ethelene glycolated, oriented samples were X-rayed.

The clay mineral suite identified from the Toronto includes: illite (10\AA), mixed layer illite-montmorillonite (11.5\AA), kaolinite (7\AA , 3.56\AA , 1.38\AA), and a mineral referred to as chlorite ($14-14.2\text{\AA}$, 7\AA , 3.53\AA).

In an attempt to investigate regional trends in the relative proportions of the various minerals, the areas of the first order peaks of illite, mixed layer illite-montmorillonite, and kaolinite, together with the area of the second order peak of chlorite were measured with a planimeter. The relative proportion of kaolinite to chlorite was estimated by computing the peak height ratio of the 3.53\AA chlorite peak to the 3.56\AA kaolinite peak. This ratio was then used in calculating the proportions of the area of the 7\AA peak ascribable to kaolinite and chlorite.

A diagram of the peak area proportions of the 4 minerals shows that they are all widely distributed. Illite and mixed layer illite-montmorillonite are ubiquitous in occurrence from Oklahoma across Kansas and northeastern Oklahoma to Nebraska. Chlorite is almost as widespread as

illite and mixed layer clays, but of the 4 minerals chlorite is the most variable. Kaolinite, however, is not present in any of the Nebraska samples that were analyzed. It occurs in a small quantity at Locality 15 at St. Joseph, Missouri, and is present in small amounts at each locality southward across Kansas to the vicinity of Localities 3 to 6 in Greenwood and northern Elk counties. South of this area, the kaolinite content of the clay fraction steadily increases to the southernmost outcrop at which Toronto Limestone was recognized. The region of increasing kaolinite content is also characterized by transition from the thalassigenous limestone to terrigenous shales and sandstones.

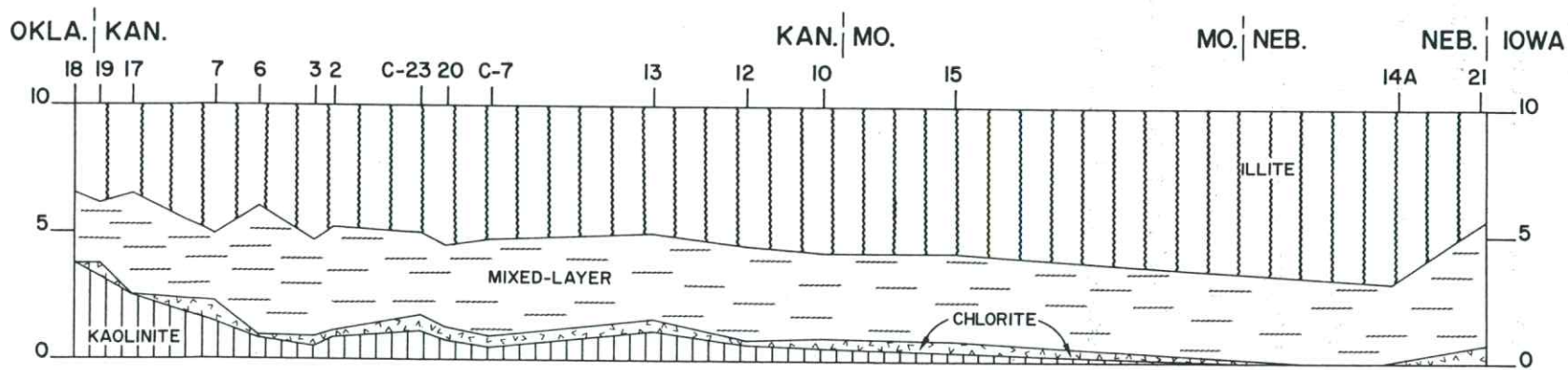
The progressive increase in abundance of kaolinite from north to south, in addition to concomitant facies change to fine clastics, is evidence for a terrigenous origin of the kaolinite. The southern part of the present Toronto outcrop was either closer to the shoreline, closer to the source of kaolinite, or both.

The progressive decrease in abundance of kaolinite in a northerly direction may be because the northern part of the present Toronto outcrop either was farther offshore, farther from the source of kaolinite, or both. However, X-ray diffraction patterns of the red shale in the Snyderville at Locality 14 yielded only degraded illite which suggests that the terrigenous clastic source to the north was not shedding kaolinite to the area in question.

Thus, at least 2, and possibly 3, land areas were

EXPLANATION OF FIGURE 5

Diagram of clay mineral distribution within the Toronto Limestone. The vertical scale is proportionate, based on peak areas.



furnishing detritus during the time of Toronto deposition. A low-lying northern region contributed only minor amounts of clastics. An eastern area, the Ozark region, contributed some material as suggested by the presence of kaolinite in most of the Toronto exposures of Kansas. The third clastics source was probably the Arbuckle Mountains to the south which, along with the Wichita and Amarillo mountains, furnished vast quantities of terrigenous detritus including arkosic material to the Virgilian depositional areas.

CARBONATE PETROLOGY

Opening Statement

Much has been learned in the past decade concerning the depositional environments of Recent carbonate sediments, and geologists have made use of this knowledge in reconstructing the depositional environments of ancient carbonate rocks. Two basic assumptions have been made in connection with applying principles gained from studies of Recent carbonate sediments to ancient strata. First, ancient sediments are the products of depositional environments and contain properties which allow environmental reconstructions, except where diagenesis has severely obliterated the primary features. Secondly, studies of Recent sediments allow the formation of principles which can be used to make inferences concerning depositional conditions of ancient sediments.

The approach to the problem of gathering the data from the Toronto Limestone was with the objective of reconstructing the depositional history of the unit. Thus, petrographic investigation was limited to those parameters that were considered to afford insight into depositional history of the limestone. These variables were used, erecting a classification designed to reflect features of depositional conditions.

In terrigenous clastics, grain size studies are fundamental because the grains are transported to the site of deposition from an external source area; with thalassigenous carbonates, however, the source area is internal.

There are so many different factors governing the sizes of carbonate particles that grain-size distribution and coefficients computed therefrom cannot be used, in general, to infer relative current strength or persistence (Purdy, 1963, p. 339). However, the presence or absence of carbonate mud is of fundamental importance because it serves as an index to current strength (Dunham, 1962, p. 111; Purdy, 1963, p. 339). In addition, carbonate grains, coarser than mud-size, generally remain near the site of their production (Ginsburg, 1956; Purdy, 1963). Thus, the determination of the constituent composition of carbonate rocks provides the data from which inferences can be made regarding their depositional environments.

The basic components of unaltered pure carbonate rocks are: (1) carbonate mud, (2) carbonate spar, (3) grains, skeletal and non-skeletal, (4) frame, and (5) fixed sediment. Carbonate mud is distinguished from grains on the basis of particle size; this distinction is analogous to the distinction between matrix and grains in sandstone (Pettijohn, 1957, p. 284; Dunham, 1962, p. 113). Because they can be recognized in thin sections and, more importantly, because the distinction between clay-and-coarser-sized particles is important environmentally, particles larger than approximately 0.062 mm. *no adequate reasoning.* are defined as grains. Carbonate spar is the translucent cementing material that generally fills pores, intergranular areas, and cavities within the sediment. Frame is defined as carbonate deposits bound together during deposition (intergrown skeletal material). Fixed sediment is a mat or mat-like

accumulation made of originally loose particles (grains or mud); it shows definite evidence of organization analogous to algal stromatolites (includes algal films and mats) of modern seas. The distinctions among these basic groups are essential in making genetic interpretations of carbonate deposits.

Compositionally, the Toronto Limestone is made up essentially of the calcareous skeletons of invertebrate organisms and derivatives of them. As a basis for making inferences concerning depositional environment(s) of this limestone, the identifications and relative abundances of the various skeletal (and non-skeletal) constituents of this unit are essential. In addition, the identification of the various terrigenous components incorporated in the limestone should not only reveal information concerning the depositional environment but afford some insight into the nature of continental terrains that bordered the Mid-Continent epicontinental sea.

The carbonate component classification utilized by the writer is shown in Table 2. The following section is an abbreviated description of diagnostic petrographic properties of the components of the Toronto Limestone.

TABLE 2

CARBONATE COMPONENT CLASSIFICATION
FOR THE TORONTO LIMESTONE

- I. Depositional Components
 - A. Grains
 - Skeletal
 - Various Invertebrate Animal Taxa
 - Various Plant Taxa
 - Non-Skeletal
 - Intraclasts
 - Pelletoids
 - Algal-coated Grains (Oncolites)
 - B. Frame
 - Intergrown Skeletal Material
 - C. Fixed Sediment
 - Algal Mat (Stromatolites)
 - D. Mud
- II. Diagenetic Components
 - A. Calcite Spar
 - B. Chert
 - C. Dolomite

Skeletal Grains

Epimastopora

Epimastopora is a green dasyclad alga that appears in thin section as straight unbranching fragments perforated by numerous closely spaced round pores arranged in irregular rows. The fragments probably represent pieces of calcareous crust developed around the tips and outer portions of branches (Johnson, 1946, p. 1095; 1961, p. 127). The microstructure of the fragments is mosaic calcite with the pores infilled by mud. The microstructure and radial symmetry of the segments are evidence that the plant is a dasyclad.

Platy Algae

Wavy, plate-shaped fragments of a calcareous alga are present whose morphologic features resemble the genera, Ivanovia Khvorova 1946, Anchicodium Johnson 1946, and Eugonophyllum Konishi and Wray 1961. The cellular microstructure of mosaic calcite spar with small elongated cells in parallel arrangement developed perpendicular to the plate on both sides is characteristic. Although seldom preserved, owing to recrystallization or replacement, the cells or utricles most closely resemble the genus Eugonophyllum (Konishi and Wray, p. 660, Text. Fig. 1, Pl. 75) and are tentatively referred to that genus. According to Konishi and Wray (1961, p. 659), Eugonophyllum, Anchicodium, and Ivanovia are closely related green codiacean genera.

Tubiphytes

This is an irregular tubular shaped organism identified as Tubiphytes Maslov which occurs in many Toronto slides. In thin section, it is easily identified by faint, irregular laminae of very fine-grained, dark-colored carbonate that is alternately lighter and darker. In some occurrences, the interior sinuous cavity contains a clear calcite interior lining whereas it is lacking in others. Maslov (1956, p. 82) describes genus as a questionable blue-green alga and Johnson (1961, p. 286) comments that it is probably not an alga but a hydrozoan. The organism in growth position encrusts Syringopora and loose skeletal debris. It also occurs as irregular branching tubes in growth position within cavities formed beneath organic mats (probably blue-green algal), and is seen as free particles resulting from decomposition of its organic support. In some occurrences, it is intimately associated with organically coated grains (probably the form genus, Osagia).

Stromatolites

The terms stromatolite and oncolite are generally used to distinguish respectively between laminated organic structures that grew attached to the depositional surface from those that were not attached (Logan, Rezak, and Ginsburg, 1960, p. 2). The stromatolites vary from laminated flat-lying mats to complex heads, whereas oncolites consist of laminations developed about a detrital nucleus. Both types occur within the Toronto, but in addition to this, another form is present that is somewhat intermediate between the two.

Twenhofel (1919, pp. 348-352) described the genera, Ottonosia and Osagia, two types of laminated concretionary organic structures found in certain Lower Permian limestones in Kansas. In 1917, Pia divided the Spongiosstromata into two subfamilies, the Stromatolithi and the Oncolithi (Logan, Rezak, and Ginsburg, 1960, p. 2) Pia placed, among others, Cryptozoon Hall in the Stromatolithi and Osagia Twenhofel and Ottonosia Twenhofel in the Oncolithi.

There are 4 types of organic stromatolites and oncolites within the Toronto. First there are small bean-shaped or ellipsoidal colonies consisting of nuclei of skeletal particles around which fine concentric, wavy, calcareous laminae have been formed. Cornuspirid foraminifers (Apterrinella and Hedraites) commonly occur in these small pelletoidal colonies. Johnson (1946, p. 1104, Table 3) identified similar colonies from the Toronto Limestone as Osagia sp. Twenhofel. He also observed (Johnson, 1946, p. 1103) that encrusting foraminifers and the alga, Girvanella, are common in Osagia colonies from the Pennsylvanian and Permian of Kansas. Johnson and Konishi (1956, p. 80) state that Osagia Twenhofel 1919 is a form-genus, Henbest (1963, p. 35) concluded that foraminifers are not essential for the existence of Osagia because some of the colonies lack foraminifers. In addition, Henbest retains Osagia Twenhofel as a form-genus and excludes foraminifera from the genus taxonomically for the sake of nomenclatural stability. Certain of the pelletoidal agaloid accretions from the Toronto are concluded to be virtually identical in form to the genus Osagia Twenhofel 1919, emend. Henbest 1963. (Compare Johnson,

1946, Pl. 4, Figs. 3-5, Pl. 5, Figs. 5-6, Pl. 7, Fig. 3, Pl. 10, Fig. 2-3; Johnson, 1963, Pl. 22, Figs. 1-4; and Henbest, 1963, Pl. 6.)

As seen in thin section, the Osagia-type colony consists of a shell fragment nucleus around which, symmetric to asymmetric, dark, threadlike, incipient to distinct fine-grained carbonate laminae occur. In some cases, bits of shell debris and/or quartz grains have been bound into the colony. Encrusting foraminifers, notably cornuspirid types, are present as colonial associates. In addition, the dark sinuous tubes of the alga (Girvanella) are often intertwined in (or bored into) the colony.

A second type of organically coated grain is present in the Toronto Limestone. It has been described in the literature as Ottonosia (Ball, Ball and Laughlin, 1963, p. 52). This is typically a larger form with a somewhat different morphology and microstructure than either Osagia Twenhofel or Ottonosia Twenhofel (Twenhofel, 1919, Fig. 3; Johnson, 1946, Pl. 4, Fig. 6, Pl. 5, Fig. 1-2; Johnson, 1961, Pl. 88, Figs. 1-2; Johnson, 1963, Pl. 80, 6 figs; and Henbest, 1963, pp. 35-37). The type present in the Toronto is typically many times larger than the Osagia form. Like Osagia, it is the result of colonial growth around fossils or skeletal grains. However, in contrast to Osagia the laminae are wrinkled and visible in hand specimens and the encrustations developed about the nuclei vary from thin, nearly flat, wavy, laminated crusts through individual nodules to composite forms with highly irregular shapes.

They most closely resemble certain species of Cryptozoon Hall as described and figured by Johnson (1940, Pl. 7, Fig. 2, Pl. 8, Fig. 1, Pl. 9, Fig. 1; 1946, pp. 1105-1106, Table 4, p. 1106, Pl. 8, Figs. 102, Pl. 9, Fig. 5; 1963, Pl. 27). Pia (1926, in Johnson, 1940, p. 579) concluded that the colonies were probably built by several algal species living together.

In thin section, the encrusting complex contains a skeletal grain nucleus enclosed by irregular, wavy laminae, formed by alternations of calcite spar and dark fine-grained carbonate. Encrusting bryozoans are commonly in attached position within the colony. Other colonial organisms associated with the colonies include cornuspirid foraminifers and spirorbid worm tubes.

In some cases, Osagia-type and Cryptozoon-type colonies appear to be intergradational. At some localities, it is apparent that the colony was initiated as mononucleate algaloid growths, but adjacent colonies later became fused. Thus, colonies began as Osagia and coalesced to form Cryptozoon?

The third type of algaloid form present in the Toronto Limestone is a biscuit-shaped colony that is similar to certain blue-green algal forms described from the Recent of southern Florida by Ginsburg (1960, Figs. 1-11), and from Alacran by Hoskins (1963, Pl. 19, Fig. 13, p. 119) who failed to recognize the forms as blue-green algal oncolites. The Pennsylvanian colonies contain a skeletal grain nucleus enclosed by thin, regular laminations formed by the

alternations of fine-grained detrital carbonate particles and calcite spar. Some of the biscuits have a concavity on one side which is an additional similarity to those described by Ginsburg (1960, Figs. 2 and 11). As a matter of fact, the biscuits in the Toronto are better analogs than those figured by Ginsburg.

Organic, mat-type structure is present at two Toronto localities and is the fourth algaloid type. It consists of thin, wavy laminae that occur as thin, discontinuous stringers, generally less than one foot in length. They typically are wrinkled into small domes forming intervening cavities into which stoloniferous Tubiphytes Maslov has later grown. Thin mat horizons are commonly only several millimeters in thickness at most and are separated from each other in the vertical direction by one-half to several millimeters of muddy sediment.

A stromatolite is ". . . any laminated sedimentary structure possibly formed* as a result of algal activity" (Donaldson, 1963, p. 6). This definition is accepted by the writer because the colonial complex of filamentous and unicellular green (Chlorophyta) and blue-green (Cyanophyta) algae, probably responsible for the construction of stromatolites, are seldom preserved (Logan, Rezak, and Ginsburg, 1960, p. 2). Rezak (1957, p. 129) and Logan, Rezak and Ginsburg (1960, p. 2) distinguish fossil algae from stromatolites because only the former have discernable microstructure. The latter is a laminated, sedimentary structure whose megastructural and microstructural attributes allow the inference as to an algal origin (Donaldson, 1963, p. 6; Logan, Rezak and Ginsburg, 1960, p. 2).

*Italics by A.R.T.

Stromatolite form is not the sole product of organic mat activities but, in addition, is strongly influenced by physical environmental factors (Bradley, 1929 in Cloud, 1942, p. 366). In addition, many species of algae may participate in algal mat growth (Pia, 1933 in Cloud, 1942, p. 365). Thus, binomial treatment of algal stromatolites is not only inadequate in terms of expressing environment differences (Logan, Rezak, and Ginsburg, 1960, p. 4) but is inconsistent with modern concepts of biological taxonomy. Because of this, recent classifications of stromatolites are descriptive and are based upon geometry of the deposits (Cloud, 1942, p. 366; Logan, Rezak and Ginsburg, 1960, p. 9; Donaldson, 1963, p. 7). A descriptive or morphotypic classification as suggested by Cloud (1942, p. 366) using the form designations in a vernacular sense without italics or the descriptive adjective classification of Donaldson (1963, p. 7), is preferred to the classification scheme of Logan, Rezak, and Ginsburg (1960, 1963) because the latter, although descriptive in theory, carries some inherent genetic implications that demand its application with caution.

A stromatolite classification for forms found in the Toronto Limestone is as follows:

Pelletoidal stromatolites (*Osagia* Twenhoffel):

(*Osagia*) small, concentrically laminated,

individual forms with a skeletal grain nuclei,

may contain associated cornuspirid foraminifers

and Girvanella.

Nodular stromatolites (Cryptozoon Hall of Johnson): ("Cryptozoon") individual to composite forms with wavy laminations enclosing skeletal grain nuclei; may contain associated encrusting bryozoans, Spirorbis or cornuspirid foraminifers.

Biscuit-shaped stromatolites (Pycnostroma Gurich): (algal biscuits) individual forms with skeletal grain nucleus within well-developed regular concentric laminae of spar and mud, commonly with a concavity on one side.

Crinkly stromatolites (Weedia Walcott): (algal mat) thin laterally discontinuous laminations with common low domal upwarplings.

Apterrinella

An encrusting tubiform foraminifer (Plate XIIB) is present that is commonly attached to skeletal grains and present in Osagia colonies. It can be recognized in thin section by its wall structure of dark homogenous, very fine-grained (microgranular) carbonate and by the circular to elliptical shape of chamber in random thin sections. This form is probably a representative of the genus Apterrinella (Cushman and Waters, 1928) (see Henbest, 1963).

Fusulinids

Two fusulinid genera, Kansanella (one species) and Triticites (two species) are present in the Toronto Limestone

(Sanderson, 1963). Fusulinids can be identified by their generally fusiform or spindle shape with chambers developed by coiled growth about an elongated central axis. The shell wall is composed of finely granular, equidimensional calcite crystals. The shell wall of both genera is made up of two layers, an external thin, dark layer, termed the tectum, and an inner relatively thick layer, called the keriotheca, characterized by alternating parallel dark and light lines oriented normal to the tectum. The Kansanella test is generally elongated fusiform to almost subcylindrical, commonly 6 to 10 mm. in length and one to 2 mm. wide. Two Triticites species are present, both of which are smaller than the single Kansanella species. One is an inflated or robust test 5 to 6 mm. long and 2.5 to 4.5 mm. wide. The second Triticites species averages 5 mm. in length and 2 mm. in width. Kansanella and Triticites were not separated in constituent particle determination because of the difficulty of discrimination in random thin sections.

Other Foraminifers

All foraminifers, exclusive of the fusulinids and the cornuspirid form (Apterrinella) described above, are included in this category. Encrusting types include: an small, irregular, tubiform type (aff. Hedraites); the larger, massive, irregular tubiform type (Apterrinella); a flask-like form (Tuberitina) which is commonly seen attached to brachiopod shells and oncolites; and Tetrataxis, a multi-chambered form. Large, thick-walled, mobile forms are present, including: Climmacamina, a paleotextularid;

Bradyina, an involute form; and Globivaluvulina, a sub-globular form. Small, planispiral, irregularly coiled forms are Hemigordius and Cornuspira?. Small miscellaneous forms are present; these include Syzrania, Endothyra, Endothyranella, Spiroplectamina, and Turrispira?.

Fenestrate Bryozoans

Lacy bryozoan colonies are attached at their bases to shells and skeletal particles. Autopores and acanthopores are contained on parallel slender branches that are interconnected by crossbars (dissepiments). The fenestrate cryptostome wall consists of three fundamental parts (Elias and Condra, 1957): an inner layer (colonial plexus) that appears white and structureless in thin section; laminated sclerenchyma whose laminae are similar to the laminated calcite in brachiopod shells; and transverse filaments or spicules which traverse the laminated sclerenchyma with the laminae curved about them in the direction of growth. The colonial plexus is continuous from the tips of the branches to the base of the colony and is enclosed by laminated sclerenchyma.

Ramose Bryozoans

This category is based upon a slender, pencil-shaped, branching or unbranching, growth form. By far the most common Toronto representative is the rhomboporid-type which has a thin-walled, immature region trending parallel to the axis of the colony; the diameter of the tube-like autopores increases to points where the tubes then curve abruptly into a thicker mature region, containing numerous small acanthopores. In transverse section, the walls between the autopores in the

central immature region are thin with polygonal outlines whereas the peripheral mature region is thick-walled. The ramose bryozoan wall generally has the appearance of thinly laminated calcite in thin section.

Encrusting Bryozoans

Encrusting bryozoans are commonly seen in nodular stromatolite colonies and as sheet-like growths on shells and skeletal particles. The commonest form is the fistuliporoid type which consists of autopore tubes separated by broad spaces occupied by vesicular interzooecial cells (coenosteum). In thin section the fistuliporoid wall is generally thin, very dark, and has a fine microgranular appearance.

Brachiopod Shells (articulates)

Fossil brachiopod shells have two layers: an outer carbonate layer with a fibrous texture, the fibers being oriented normal to the shell surface; and an inner carbonate layer made up of thin calcite fibers which are disposed at low angles to the outer layer (Williams, 1956). Three general types of articulate shells are known--punctate, pseudopunctate, and impunctate. Longitudinal sections of punctate shells (Beecheria, Rhipidomella and Punctospirifer) reveal that the punctae are oriented normal to the shell surface, and the inner carbonate layer is fine-textured with fibers, being continuous but bowed-up very gently around the punctae. Pseudopunctate shells, in longitudinal section, are characterized by the presence of dark calcite rods (present only in the inner layer) that are shorter and of greater diameter than

punctae and are usually inclined at slight angles to one another as well as to the shell margin. In addition, the enclosing fibers of the inner layer are coarser and much more strongly arched, adjacent to the pseudopunctae. Common pseudopunctate representatives in the Toronto are Derbyia, Meekella, Neochonetes, marginiferids, and dictyoclostids. Impunctate shells are dense with an inner layer of coarse fibers somewhat like that of the pseudopunctate shell. Common impunctate genera are Composita, Neospirifer, and Crurithyris. Some impunctate representatives, such as Composita and Neospirifer, have a third calcareous layer of prismatic calcite which resulted from modification of the inner carbonate layer (Williams, 1956). The brachiopods were not subdivided because of the impossibility of assigning small fragments to a subdivision category.

Brachiopod Spines

Brachiopod spines were treated as a separate category because they serve as an index to the presence of productids and chonetids. Originally, they were hollow centered with a thick inner fibrous carbonate layer and a thin outer fibrous layer with the fibers oriented normal to the surface of the inner layer. The outline is circular in sections normal to long dimension, and rodlike in tangential cuts, with sections intermediate between the two, being elliptical.

Molluscs

Most molluscan shells consist of mosaic sparry calcite, which is a result of alteration of original shell

structure. This is in sharp contrast to brachiopods which invariably have a characteristic microstructure as described above. The lack of shell structure preservation in molluscan remains is related to the instability of original components of the shell. The most plausible explanation seems to be that the original composition of most altered molluscan shells was aragonite which has subsequently been altered to calcite. To the contrary, those molluscan shells whose microstructure is preserved were probably originally composed of the more stable calcite as were articulate brachiopod shells.

Altered Toronto molluscan remains consist of two general types. In one case, mosaic calcite spar is characterized by highly irregular crystal shapes and boundaries without systematic arrangement of the crystals according to size. In the second case, the spar grains tend to have planar boundaries and the smaller crystals are confined to the edges of shell with the grain-size being the coarsest along a central zone parallel to both shell margins. Case one may be the result of either inversion or aragonitic material to calcite or irregular replacement of aragonite by calcite, but case two is probably the result of dissolution of aragonitic material forming a mold, followed by later infilling of the cavity by calcite spar in much the same way that carbonate rock cavity types are filled by spar (Sanders, 1951; Bathurst, 1958).

Pelecypods can be distinguished from gastropods on the basis of shell shapes; however, the two classes were grouped for statistical treatment. In a few rare instances,

prismatic layered pelecypod shells were observed which appeared as prisms in vertical sections or as a polygonal-shaped cellular network in horizontal sections. Myalina has a thick shell with a distinctive microstructure which allows it to be distinguished from other molluscs, but for the most part it was not possible to identify molluscan taxa lower than class level.

Thus there was no difficulty in discrimination between brachiopods and molluscs in thin section, but the distinction between platy algae (Eugonophyllum) and molluscan fragments posed a problem in many cases. Generally shape and ornamentation allow molluscan shells to be differentiated from undulant, elongated platy algae with marginal utricles.

Echinoderm Plates and Columnals

Criteria for the recognition of echinoderm remains in thin section are unit extinction of individual test components when viewed with crossed polarized light and homogenous reticulate texture. Horizontal sections of crinoid columnals are circular, and vertical sections are rectangular. Echinoderm plates are generally polygonal in outline.

Echinoid Spines

Echinoid spines can be recognized by their circular to elliptical outline in combination with a relatively large internal opening enclosed by a complex symmetrical porous structure of a trellis network, having the appearance of a wheel with ornate spokes.

Trilobites

Trilobites as seen in thin section are generally disarticulated, appearing as small fish-hook or S-shaped objects with a homogeneous shell structure characterized by undulatory extinction and brownish-orange color when viewed with cross-polarized light. All Toronto specimens are referred to the genus Ditomopyge.

Ostracodes

Ostracode shells are generally smaller and thinner than pelecypod or brachiopod shells. In addition, articulated shells characteristically show partial to complete overlap of the two valves. Migrating extinction under cross-polarized light is also a diagnostic character.

Miscellaneous Skeletal

Quantitatively less important constituents of the Toronto Limestone include the solitary lophophyllid and colonial Syringopora corals, the sponges, Coelcladia and Girtyocoelia, and calcareous sponge spicules.

Lophophyllid corals can be distinguished from bryozoans, with which they might be confused, on the basis of general shape and the presence of thick imbricate septae and thickened epitheca as seen in thin section. The internal cellular network of the bryozoans is generally much finer in size and less intricate as compared to the corals. Coelcladid sponges were recognized by their spongy microstructure composed of a skeletal wall (spar) and canal filling (mud). In addition, Coelcladia has a circular outline and a moderately

large central cavity. The sponge genus, Girtyocoelia, is composed of several subspherical chambers arranged along a straight axis. The chamber walls are composed of calcite spar. Small monaxon sponge(?) spicules of calcite composition can be identified in some cases although they are quantitatively unimportant.

Unknown Skeletal

Skeletal grains that could not be identified with reasonable certainty and skeletal material of unknown origin were grouped in this category.

Nonskeletal Components

Nonskeletal components of the Toronto Limestone include grains (intraclasts, pelletoids, and terrigenous quartz), mud matrix, and post-depositional components (calcite spar, dolomite rhombs, and chert).

Intraclasts

Folk (1962, p. 63) defines the term intraclast, as ". . . fragments of penecontemporaneous, generally weakly consolidated carbonate sediment that have been eroded from adjoining parts of the sea bottom and redeposited to form a new sediment (hence the term 'intraclast', signifying that they have been reworked from within the area of deposition and within the same formation. It does not refer to single fossils, oolites, or pellets, momentarily laid down and then picked up, but only to clusters of such grains bonded together by welding, by carbonate cement, or lime mud--proving that they had once been a part of a coherent sediment."

Fragments of carbonate sediments, essentially identical in composition to the sediments in which they are enclosed, are present in the Toronto Limestone. Several types of intraclasts are present. The first type is that of angular, argillaceous lime mudstone fragments. The second type consists of lime mudstone fragments containing fusulinids, echinoderm remains, and brachiopod fragments which show truncation of skeletal grains along the edges of the intraclast; in addition, there are encrusting bryozoans and "Cryptozoon" growth on the clast. The third intraclast group is made up of elongated lime mudstone fragments that resemble the surrounding matrix. Because they are discreet particles that possess lamination, the attitude of which is contrary to gravity, the fragments are clearly clasts of rock. Well-sorted calcarens (carbonate sand grains) cemented by calcite spar are the fourth intraclast type. All four sediment fragment types are of a composition that is identical to the enclosing sediment; hence they qualify as intraclasts in accordance with Folk's definition. All four types were grouped as a single category for point counting convenience because they do not occur with a high degree of frequency.

Pelletoids

These are small ellipsoidal aggregates of carbonate mud with a homogeneous internal structure. In some cases, they may be invertebrate faecal pellets, but some of them may be small intraclasts.

Terrigenous Sand and Silt

Quartz sand and silt are present at the base of the Toronto Limestone at a few localities. The particles are angular to subrounded and range in size from 0.06 to 0.2 mm.

Mud

Microcrystalline calcite, as well as skeletal particles and terrigenous detritus less than 0.06 mm. in particle diameter, are the components of mud. Skeletal grains within the Toronto are gradational in size from unbroken or articulated specimens to skeletal particles which are of silt-and-finer-sizes. The particle size of 0.06 mm. was used as an arbitrary cutoff because it marks the approximate lower limit above which skeletal grain types can be identified with reasonable certainty, and, more importantly, it has environmental significance in terms of hydraulic behavior. Smaller particles may be transported more easily than larger ones so that the percentage of fine material in a rock is a crude index of relative current strength (Purdy, 1963, p. 339).

Calcite Spar

Clear, crystalline calcite that fills inter-and-intra-granular voids can be distinguished from microcrystalline calcite mud in most cases by its larger crystal size and clarity. However, in well-sorted, fine carbonate sands the distinction is more difficult because the grain size of spar is dependent upon the size of the pore space, other factors being equal. This distinction did not pose a serious problem in the Toronto study because fine carbonate sands are rare.

Post-Depositional Alteration

Most Toronto Limestone thin sections show a high degree of alteration of original material. In many cases, mud-supported lime mudstones contain small patches of sparry calcite of irregular size and shape that grade gradually into surrounding mud areas. There is no evidence that the patches have resulted from recrystallization of skeletal components, nor is there any textural evidence that they are filled cavities (see Sander, 1951; Bathurst, 1958). In such cases where the original composition of the matrix was apparent, even though an original mud matrix had been recrystallized, it was tabulated as mud. However, if the alteration was so advanced that matrix and skeletal grains were both affected, the altered material was grouped into a special category as recrystallized matrix.

Clearly secondary components include dolomite and chert. Small euhedral rhombs of the mineral dolomite are developed, not only in the matrix of the rock, but are present within skeletal structures. If dolomitization was minor and original composition could be inferred with reasonable certainty, dolomite was ignored in the point counts. However, if dolomitization was advanced to the extent of masking original composition, it was also tabulated as recrystallized matrix.

Chert, as seen at the outcrop, occurs as nodules and smaller lenticular masses. In thin section, it was observed in all stages of replacement from partial replacement of skeletal remains with rock matrix little affected through

complete replacement of skeletal material and matrix. Because of its probable secondary origin, the percentage of chert was not determined.

POINT COUNT ANALYSES

METHOD

The approach in this study was to identify and estimate the percentages of as many different grain-and-matrix types as possible. Through observed lateral and vertical variations of constituent composition and through deductions concerning the environmental significance of the different grain-and-matrix types, it appeared that significant inferences could be made with respect to paleoenvironments.

Several hundred thin sections, oriented normal to bedding surfaces, were prepared. They were examined in plane and cross-polarized light with a student model Leitz petrographic microscope. After a survey of each thin section, in which as many different grain types were identified as was possible, a point-count data sheet was prepared (Table 3). One hundred and forty thin sections were selected for percentage estimations of grain-and-matrix-types (Fig. 6). A Swift Automatic Point-Counter was utilized in obtaining a volumetric estimate of the various components in sample.

As a means of determining the number of counts that were to be made for each slide, in order to obtain reproducible results, point counts of 250, 500, and 1000 points each were made on several duplicate thin sections of beds from different localities. From these studies, it was concluded that about 500 counts per slide had to be made because variation between duplicate samples from the same bed at the same locality significantly exceeded operator error for 500 points,

TABLE 3

POINT COUNT DATA SHEET
(TORONTO LIMESTONE)

Thin Section # Date	Facies	Start	End	Freq.	I. %	T. %
1. Epimastopora						
2. Platy algae						
3. Tubiphytes (w/ or w/o walls)						
4. Dark coated grains						
5. Laminated coated grains						
6. Encrusting complex (note type)						
7. Calcitornella (tn. vs. tk. walls)						
8. Fusulinids						
9. Other forams						
10. Sponges (tests vs. spicules)						
11. Corals (colonial vs. solitary)						
12. Fenestrate bryozoans						
13. Ramose bryozoans						
14. Encrusting bryozoans						
15. Brachiopod shells						
16. Brachiopod spines						
17. Mollusks (specify types)						
18. Echinoderm pls. & cls.						
19. Echinoid spines						
20. Trilobites						
21. Ostracodes						
22. Unknown skeletal						
23. Total skeletal		X	X		X	
24. Spar cement						
25. Mud						
26. Recrystallized matrix (specify)						
27. Lithoclasts						
28. Pelletoids						
29. Dolomite rhombs						
30. Terrigenous quartz (slt. vs. sd.)						
31. Chert						
32. Miscellaneous non-skeletal						
33. Total non-skeletal		X	X		X	
TOTAL:		X	X		X	

Mud-, grain-, or frame-support _____
 Articulation, fragmentation _____
 Particle size _____
 Sorting _____
 Wear _____
 Boring _____
 Bedding _____
 Burrows _____
 Cavities (intergrain, sheltered, roofed, w/ or w/o sediment floors) _____
 Geopetals _____
 Kind, thickness, and uniformity of coating _____
 Rock type _____
 Comments _____

but did not exceed operator error for 250 points.

Grains larger than 0.06 mm. were identified because the limit of identifications on which confidence can be placed is reached at approximately this size. Thus detrital material finer than 0.06 mm. was grouped with finer material as mud.

In point counting, a series of equally spaced traverses were made across the thin section such that a total of 500 stops or points were accumulated. At each stop, the particle larger than 0.06 mm. beneath the ocular cross-hair was identified as to grain type, if possible. Particles of organic origin which could not be assigned to one of the skeletal grain categories with reasonable confidence were tabulated as unknown skeletal.

Tabulation Conventions

For the purposes of determination of constituent composition of Toronto carbonate rocks, several tabulation conventions were established in addition to those discussed previously. Skeletal grains encrusted by stromatolitic material (*Osagia* or "Cryptozoon") were tabulated as stromatolites if ten percent or more of the fragment was observed to be encrusted. If a skeletal constituent was encrusted by foraminifers or the organism Tubiphytes, tabulation was dictated by the position of the cross-hairs because encrusting foraminifers and certain types of algae can grow on living organisms. Algal mat was tallied as such only when sediment inferred to have been controlled by the living mat

EXPLANATION OF FIGURE 6

Restored cross-section of the Toronto Limestone showing
thin section coverage and samples used in statistical analyses.

SOUTH

OKLAHOMA KANSAS

OSAGE 18 CHAUTAUQUA 17

ELK 65 6A5

GREENWOOD 4C-2 3A 3 2

WOODSON IC-24 C-21

COFFEY C-7

FRANKLIN 9

DOUGLAS 22 11

LEAVENWORTH C-9 12

PLATTE C-10 10

BUCHANAN 15

15A 15B

MISSOURI, NEBRASKA

CASS 14 14A

NORTH NEBRASKA, IOWA 21

DATUM

DATUM

THIN SECTION CONTROL

- Used in statistical computations
- ◆ Not used in statistical computations

VERTICAL EXAGGERATION
8250

HORIZONTAL SCALE
IN MILES

0 5 10 15 20 25

0
1
2
3
4
5
6
7
8
9
10

VERTICAL SCALE
IN FEET

VERTICAL EXAGGERATION
2100

0
5
10

VERTICAL SCALE
IN FEET

DATUM

DATUM

NOT TO SCALE

was encountered. Layers of normal sediment between mat layers were analyzed as detrital sediments. In valved organisms (e.g. pelecypods, gastropods, and ostracodes), the void space within the valves was tallied as skeletal material of the organism in question only when the valves were closed. Points within voids that were surrounded by skeletal carbonate of a solitary or colonial organism (e.g., foraminifer chambers, gastropod interiors, and open spaces within corals and bryozoans) were tabulated as skeletal.

TAB 2

TABLE 4
 CONSTITUENT COMPOSITION OF 140 SELECTED THIN SECTIONS
 OF THE TORONTO LIMESTONE*

Sample Number	Epimastopora	Platy Algae	Tubiphytes	Osagia	Algal Mat	*Cryptozoon*	Apterrinella	Fusulinids	Other Forams	Fen. Bryozoans	Ramose Bryozoans	Encr. Bryozoans	Brach. Shells	Brach. Spines	Mollusks	Echinoderm Segs.	Echinoid Spines	Trilobites	Ostracodes	Unknown Skel.	Spar Calcite	Mud	Intraclasts	Terrig. Silt
L-18-1	000	000	000	000	000	000	000	000	002	000	000	000	54.4	128	018	088	002	000	004	016	188	008	000	002
L-17-2	000	000	000	000	000	000	038	010	000	048	000	004	158	020	014	100	000	000	004	018	012	512	000	000
L-8-1	000	000	000	000	000	000	020	022	004	058	000	008	186	006	006	166	000	002	002	066	008	444	000	002
L-7-1	000	000	000	020	000	000	048	012	008	042	018	000	088	000	092	104	000	002	002	104	004	450	006	000
L-7-1	000	000	000	000	000	000	034	010	040	010	000	000	038	000	020	052	010	000	002	094	022	664	000	000
L-7-3	000	000	000	000	000	000	010	004	000	010	006	000	098	008	044	046	000	000	000	116	026	632	000	000
L-7-3	000	000	000	000	000	000	018	006	004	030	000	000	144	000	062	078	000	002	002	046	024	582	000	002
L-6.5-1	000	000	000	000	000	000	006	000	002	086	000	004	060	000	055	068	002	000	002	139	043	533	000	000
L-6.5-2	000	000	000	000	000	000	006	014	000	090	000	000	016	002	022	058	002	006	000	118	008	658	000	000
L-6.5-3	000	000	000	000	000	000	002	006	000	084	006	000	100	012	048	184	000	000	000	074	026	458	000	000
L-6.5-3	000	000	000	002	000	000	004	002	006	076	006	000	154	016	088	110	000	000	000	070	038	428	000	000
L-6.5-6	000	000	000	000	000	012	030	070	000	016	008	000	018	004	126	012	000	000	000	046	000	658	000	000
L-6.5-6	000	000	000	022	000	000	024	372	000	022	000	000	042	000	026	018	000	000	002	420	000	372	000	000
L-6A-1C	000	000	000	000	000	000	000	004	002	014	074	026	066	000	048	006	000	000	000	168	028	548	000	000
L-6A-2	000	000	000	002	000	000	000	174	004	008	004	000	018	000	024	108	000	000	002	124	200	342	000	000
L-6A-5	000	000	000	022	000	000	044	012	002	062	000	000	034	000	088	140	000	000	000	168	044	424	000	000
L-6A-5	000	000	000	062	000	000	002	018	000	070	000	012	034	004	062	114	002	010	000	140	042	412	000	000
L-6A-7	000	000	000	038	000	000	008	006	000	066	004	000	112	014	014	142	000	006	002	118	020	450	000	000
L-6A-7	000	000	000	028	000	000	000	030	000	060	024	002	146	014	032	132	002	000	002	058	012	468	000	000
L-6A-9	000	000	012	002	000	000	000	028	004	008	000	000	018	000	164	030	002	000	000	056	002	674	000	000
L-6A-10	000	000	000	020	000	122	000	008	000	002	000	000	006	000	090	004	000	000	002	018	000	738	000	000
L-6A-11	000	000	000	000	000	226	000	022	000	002	000	000	000	000	024	010	000	000	000	012	000	704	000	000
L-6A-11	000	000	000	014	000	002	000	508	000	008	000	000	036	000	000	026	000	002	000	014	000	390	000	000
L-4-1	000	000	000	034	000	086	000	098	002	036	016	000	012	002	088	002	000	000	000	076	016	530	002	000
L-4-2	000	000	000	018	000	000	000	022	000	012	000	000	000	000	068	000	000	000	002	050	002	826	000	000
L-4-3	000	000	000	062	000	000	002	018	006	052	000	000	014	000	038	000	000	000	002	088	004	714	000	000
L-4-4	000	002	000	020	000	000	000	000	000	062	000	000	054	000	106	096	010	006	000	112	058	474	000	000

*Percentages as determined by point-counting. Example: brachiopod shell percentage for sample L-18-1 is 54.4.

L-4-5	000	000	000	054	000	000	000	038	000	060	002	006	076	012	054	172	000	004	090	090	028	410	000	000
L-4-6	000	000	000	028	000	000	000	010	008	024	000	000	012	006	122	004	000	000	012	090	000	684	000	000
L-4-8	004	000	004	088	000	000	000	012	000	050	004	000	014	000	088	016	000	000	002	090	002	626	000	000
L-4-9	000	002	000	036	000	000	000	050	000	022	000	000	020	000	066	004	004	000	000	058	002	736	000	000
L-4-10	000	006	000	040	000	062	000	040	000	020	000	000	024	000	036	002	000	000	004	040	006	714	000	000
L-3-1	000	000	000	028	000	000	000	014	002	028	000	000	002	000	078	006	000	000	000	070	004	768	000	000
L-3-2	000	000	000	000	000	000	006	000	000	106	000	000	020	006	008	292	000	000	000	072	446	022	020	000
L-3-4	000	000	012	008	000	010	000	004	000	064	000	004	044	000	116	050	000	004	000	136	006	542	000	000
L-3-5	000	000	000	002	000	000	000	016	002	020	000	000	012	000	136	014	000	000	004	108	006	680	000	000
L-3-6	000	000	004	000	000	298	000	006	000	008	000	000	002	000	016	006	000	000	000	076	024	556	004	000
L-3-6	000	000	018	076	000	000	000	000	000	022	000	000	004	000	098	008	000	000	002	124	000	648	000	000
L-3-7	000	000	002	092	000	098	000	023	000	022	000	000	006	000	068	002	000	010	006	086	000	584	000	000
L-3-9	000	000	000	144	000	032	000	000	000	000	000	000	016	000	042	016	000	000	022	064	000	684	000	000
L-1-1A	000	000	000	046	000	000	000	006	008	016	000	004	012	004	152	018	004	000	000	084	012	634	000	000
L-1-1B	000	000	000	042	000	000	002	000	004	008	000	000	000	000	130	008	000	000	000	032	000	774	000	000
L-1B-1	000	000	000	058	000	290	000	000	000	014	000	006	002	000	000	002	000	000	000	060	000	567	000	000
L-1-1C	000	000	006	014	000	106	000	008	002	044	000	004	000	000	126	018	000	000	000	058	004	610	000	000
L-1B-1	000	000	000	020	000	224	004	000	000	016	000	000	000	000	060	006	000	000	002	018	002	648	000	000
L-1B-1	000	000	016	012	000	142	002	000	006	004	000	000	002	002	102	016	000	000	004	026	000	666	000	000
L-1B-1	000	000	006	004	000	000	000	000	000	010	000	000	000	000	108	002	000	000	000	026	006	838	000	000
L-1B-3	000	000	006	064	000	000	000	000	002	042	000	002	000	004	096	008	004	000	002	064	012	684	000	000
L-1B-8	000	000	000	000	000	000	000	000	000	162	000	000	022	000	000	060	000	000	002	032	000	722	000	000
L-1A-9M	000	000	000	420	000	000	000	000	000	004	008	000	046	000	006	010	000	000	002	014	146	344	000	000
L-1A-9M	000	000	016	086	000	000	006	006	012	046	000	000	048	000	000	060	000	000	016	100	096	504	004	000
L-1-9	000	000	020	190	000	000	000	000	002	030	000	000	024	000	100	006	000	000	000	106	038	484	000	000
L-1-9	000	000	010	062	018	000	000	002	004	016	000	000	024	000	080	012	002	000	004	030	002	734	000	000
L-1-9	000	000	006	148	000	000	002	000	008	012	000	000	012	000	164	006	000	000	006	038	022	576	000	000
L-1-9	000	000	002	310	000	000	000	000	000	000	000	000	004	000	074	000	000	000	002	020	018	572	000	000
L-23-2	000	000	000	246	000	000	000	000	008	002	000	000	002	000	012	006	000	000	002	064	012	626	000	002
C-23-16	000	000	000	642	000	000	000	000	006	000	000	004	002	012	006	000	000	000	016	306	000	006	000	000
C-23-21	000	000	000	026	000	000	002	000	004	012	000	000	000	000	072	004	000	000	004	100	006	770	000	000
C-23-25	000	000	000	036	000	000	004	000	002	028	000	002	000	000	050	010	000	000	000	072	000	796	000	000
C-23-32	000	000	000	054	000	000	002	000	006	080	000	000	004	000	066	026	002	000	006	122	018	614	000	000
C-23-43A	000	000	006	136	000	000	004	002	006	026	000	000	008	000	010	038	000	000	002	064	008	690	000	000

C-23-36	000	000	000	064	000	000	000	000	000	094	000	000	146	002	010	114	000	002	002	126	024	410	000	006
C-23-50B	018	000	012	072	000	000	000	006	010	032	000	000	006	000	010	014	000	000	000	110	002	708	000	000
C-23-56	000	000	000	042	000	000	000	010	006	032	000	002	024	000	012	034	002	000	004	088	000	742	000	002
C-23-60	000	000	000	074	000	000	000	018	002	026	000	000	062	000	002	006	000	000	004	080	000	664	000	062
L-25-5U	000	000	022	036	000	000	000	018	002	014	000	000	014	000	114	014	002	000	000	066	000	698	000	000
L-20-1	000	000	000	214	000	000	000	002	002	024	000	022	016	000	030	018	002	000	004	122	008	550	006	000
L-20-3	000	000	000	618	000	000	000	000	002	032	000	000	004	000	018	038	000	000	000	064	224	000	000	000
L-20-5U	000	002	000	046	000	000	000	000	014	140	000	006	006	004	000	078	004	000	004	040	014	642	000	000
L-20-5MP	000	000	000	000	000	000	000	010	000	062	000	000	010	000	000	034	000	000	000	062	006	816	000	000
L-20-5LP	000	000	000	004	000	000	000	000	000	180	000	000	002	000	000	242	000	000	008	048	000	516	000	000
L-20-7U	000	002	000	060	000	000	000	000	002	058	000	000	008	000	002	026	000	000	002	170	036	634	000	000
L-20-7LP	000	000	000	160	000	000	000	060	018	020	000	000	000	002	000	000	002	000	002	2080	008	648	000	000
C-7-34.6	000	000	000	164	000	000	000	048	000	028	000	000	016	000	022	002	000	000	000	048	042	620	000	010
C-7-32.1	000	000	010	110	000	018	000	000	004	044	000	000	024	006	000	016	000	000	000	036	030	702	000	000
C-7-29.2	000	000	000	000	000	136	000	000	000	026	000	006	006	000	000	042	000	000	004	068	000	712	000	000
C-7-26.8	000	000	010	052	000	000	002	118	000	098	000	006	000	000	002	058	000	000	002	054	004	594	000	000
C-7-25.8	000	000	000	004	000	000	000	000	000	036	000	002	000	000	000	022	000	000	002	066	000	858	000	000
L-9-1	000	000	000	020	000	140	000	000	000	034	000	000	042	002	000	098	000	000	000	078	000	586	000	000
L-9-2	000	000	000	016	000	104	000	022	000	060	000	008	016	000	000	052	000	000	002	076	000	640	000	004
L-9-2	000	000	000	010	000	066	000	010	000	044	000	002	002	002	002	026	000	000	008	056	000	768	000	004
L-9-4	000	000	008	016	000	000	000	000	000	008	000	000	026	000	022	010	000	000	000	040	000	854	000	000
L-9-7	006	000	000	122	000	000	000	050	000	016	000	000	074	000	000	048	000	000	002	046	000	620	000	004
L-9-7	006	000	000	226	000	000	000	058	000	012	000	000	062	006	004	048	002	000	002	040	000	530	000	000
L-13-1B	000	000	000	072	000	000	000	000	000	186	004	004	000	002	006	052	000	000	006	204	078	382	004	000
L-13-1C	000	000	000	012	000	000	000	000	000	098	000	012	090	000	000	244	000	000	000	126	016	402	000	000
L-13-2	000	006	010	022	000	020	000	022	000	036	000	000	018	000	052	018	000	000	002	054	004	736	000	000
L-13-3	000	008	000	014	000	000	000	018	000	002	000	000	014	000	130	020	002	000	000	078	000	714	000	000
L-13-5	000	006	008	044	000	000	000	018	016	022	000	000	018	000	014	014	000	000	006	132	014	686	000	000
L-22-1	000	000	000	000	000	000	000	000	000	000	000	000	000	000	004	000	000	000	002	010	000	958	036	000
L-23-3U	000	000	000	014	000	144	000	054	000	026	000	008	004	000	094	042	000	000	000	026	006	582	000	000
L-22-3LP	000	000	000	016	000	270	000	084	000	024	000	000	012	000	128	070	000	000	000	050	136	210	000	000
L-22-4T	000	000	000	022	000	000	000	076	000	022	000	018	004	000	120	046	000	000	002	038	014	638	000	000
L-22-4B	000	000	000	000	000	000	000	000	000	038	000	004	040	000	000	050	004	000	000	046	004	814	000	000
L-22-5AT	000	010	008	004	012	260	000	000	009	004	000	000	000	000	042	000	000	000	000	046	012	600	000	000

L-22-5A	000	000	000	004	000	000	000	004	000	026	002	004	014	000	050	090	000	000	000	012	004	790	000	000	
L-22-5B	000	000	000	038	000	104	000	000	004	018	000	000	012	002	066	008	000	000	000	056	002	690	000	000	
L-22-5C	000	008	004	080	000	000	000	000	010	024	000	010	012	018	028	032	000	002	000	050	014	706	000	000	
L-11-1	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	016	000	978	000	006	
L-11-2	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	006	028	182	418	024	000
L-11-3	000	000	000	000	000	000	000	000	000	000	000	000	000	000	004	000	000	002	000	050	000	942	000	000	
L-11-4	000	000	000	124	000	000	000	000	000	202	002	012	016	006	006	134	002	000	002	104	312	078	000	000	
L-11-4M	000	000	000	080	000	004	000	100	000	042	004	008	008	000	006	070	002	000	000	132	000	544	000	000	
L-11-4B	000	000	000	022	000	000	000	000	002	134	004	004	026	000	000	046	000	000	000	056	000	606	000	000	
L-11-5	000	000	000	000	000	000	000	000	000	070	004	000	038	002	000	102	008	000	000	084	000	712	000	000	
L-11-6	000	000	004	208	000	000	000	000	002	004	000	000	036	000	104	008	000	000	006	090	000	538	000	000	
L-11-6T	000	000	000	016	000	000	000	004	000	054	002	000	032	002	000	066	000	006	002	064	000	752	000	000	
L-11-7	000	000	004	004	000	000	000	000	004	010	000	000	026	000	000	010	000	000	000	046	000	896	000	000	
L-11-8T	000	012	026	052	000	000	000	000	002	004	000	000	036	002	006	030	000	000	000	140	058	632	000	000	
L-11-8B	000	000	000	310	000	000	000	042	002	004	000	000	096	004	002	044	012	000	000	052	000	398	000	034	
L-12-2	000	004	000	054	000	000	000	054	000	130	000	006	014	000	024	060	000	000	000	108	000	546	000	000	
L-12-2	006	000	000	130	000	000	000	032	000	180	000	014	006	000	000	030	000	002	000	092	000	508	000	000	
L-12-4U	008	000	000	076	000	000	000	044	000	042	000	002	006	000	004	014	002	000	006	090	000	706	000	000	
L-12-4M	000	000	000	044	000	000	000	024	000	018	000	000	008	000	036	026	000	000	004	054	000	786	000	000	
L-12-4B	000	002	000	074	000	000	000	040	004	008	000	000	036	012	036	014	000	000	004	074	000	696	000	000	
L-12-4	000	026	006	014	000	000	000	000	008	014	008	000	018	002	208	004	000	000	002	052	018	620	000	000	
L-12-5	000	000	000	000	000	000	000	026	000	002	000	000	030	000	000	016	000	000	000	044	000	782	000	090	
L-10-1	000	000	000	000	000	000	000	000	000	000	000	000	000	000	004	000	000	000	000	008	000	986	000	000	
L-10-1	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	004	002	000	988	000	000	
L-10-2	000	000	000	000	000	000	000	000	000	000	000	000	000	000	044	002	000	000	008	044	016	884	000	000	
L-10-3	000	000	000	344	000	000	000	016	000	104	000	012	040	004	000	122	000	000	002	060	218	076	002	000	
L-10-3	000	000	000	234	000	000	000	024	000	138	008	010	088	010	000	124	000	004	000	106	044	206	000	000	
L-10-4	000	000	000	000	000	000	000	000	000	010	000	000	060	000	000	206	004	000	000	140	000	580	000	000	
L-10-4	000	000	000	000	000	000	000	000	000	022	000	000	050	000	000	192	000	000	000	162	000	574	000	000	
L-10-5	000	000	000	042	000	000	000	060	006	050	000	000	018	006	098	024	000	000	000	140	002	530	024	000	
L-10-5	000	000	000	106	000	000	000	034	000	028	000	000	038	002	036	032	002	000	022	084	002	634	000	000	
L-15-1	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	914	000	086	
L-15-2	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	002	000	990	000	006	

L-15-3	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	004	004	000	996	000	000
L-15-4	000	000	000	044	000	000	008	060	002	038	000	000	058	008	076	012	000	000	004	030	000	660	000	000
L-21-1	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	014	030	040	916	000	000
L-21-2	000	000	000	000	000	000	006	000	018	000	000	000	000	000	052	002	000	000	012	122	006	782	000	000
L-21-8	000	000	000	000	000	000	000	000	000	022	000	002	038	002	014	230	004	000	000	024	048	616	000	000
L-14A-1	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	000	010	044	022	920	000	004
L-14A-2	000	000	000	244	000	000	000	000	000	000	000	000	014	000	024	010	000	000	000	128	080	454	000	002
L-14A-4	000	000	000	124	000	000	002	026	000	012	000	000	028	008	000	016	002	000	000	038	000	742	000	000
L-14-2	000	000	000	000	000	000	000	000	002	000	000	000	000	000	176	000	000	000	006	050	010	754	002	000
L-14-4	000	000	000	232	000	000	000	000	002	002	000	000	022	002	014	002	000	000	000	042	000	682	000	000
C-7-27.4	000	000	000	160	000	000	002	000	000	150	000	002	002	000	000	194	000	000	002	028	028	426	006	000

FACIES RECOGNITION

In examining ancient carbonate rocks for the purpose of reconstructing depositional environments, it is imperative that distinctions be made between depositional and diagenetic features. Thus the rock is viewed as an altered sediment whose original sediment type can be reconstructed if diagenetic modifications have not been severe. In this way, we can hopefully make extrapolations from an ancient rock sequence such as the Toronto to its original sediment types. These reconstructed sediments may be classified on the basis of their various components into a hierarchy of sediment types. From this classification scheme suites of sediment are grouped into various categories, termed depositional facies, interpreted as being indicative of different depositional environments.

Each genetic unit or sequence of carbonate rocks such as the Toronto Limestone, Leavenworth Limestone, Glen Rose Limestone, Muav Limestone, etc. is a separate problem in sediment type classification because organisms comprise a significant percentage of these rocks and due to evolution, biogeography, and environmental differences the organisms vary from one unit or sequence to the next.

With data involving as many variables as was utilized in facies recognition within the Toronto Limestone, the only form of analysis which can give contemporaneous consideration to all parameters is the statistical approach. A statistical method called factor analysis was used in the Toronto study. It has been employed very successfully in previous investigations of modern - as well as ancient - sediments (Purdy and

Imbrie, 1962; Imbrie, 1963; and Pusey, 1964). Thus, the method is considered to have been tested sufficiently so that results of a factor analysis might be considered as reliable and a worthwhile endeavor in interpreting Toronto data.

After thorough examination of several hundred thin sections of the Toronto Limestone, in which the attempt was made to identify as many variables as possible, those samples interpreted as being sufficiently well preserved were selected for point-count analyses (Fig. 6). Upon completion of analytical treatment of each of the 140 slides selected for point-count determinations, it was apparent that some of the categories were encountered so infrequently that they should be omitted from statistical computations. The data were then re-tabulated prior to key-punching.

The objectives of the factor analyses were: (1) to explore the relationships among variables, and (2) to examine the relationships among cases or samples. The computational steps and analyses performed in (1) the R-mode (between variables) and (2) the Q-mode (between samples) are listed below:

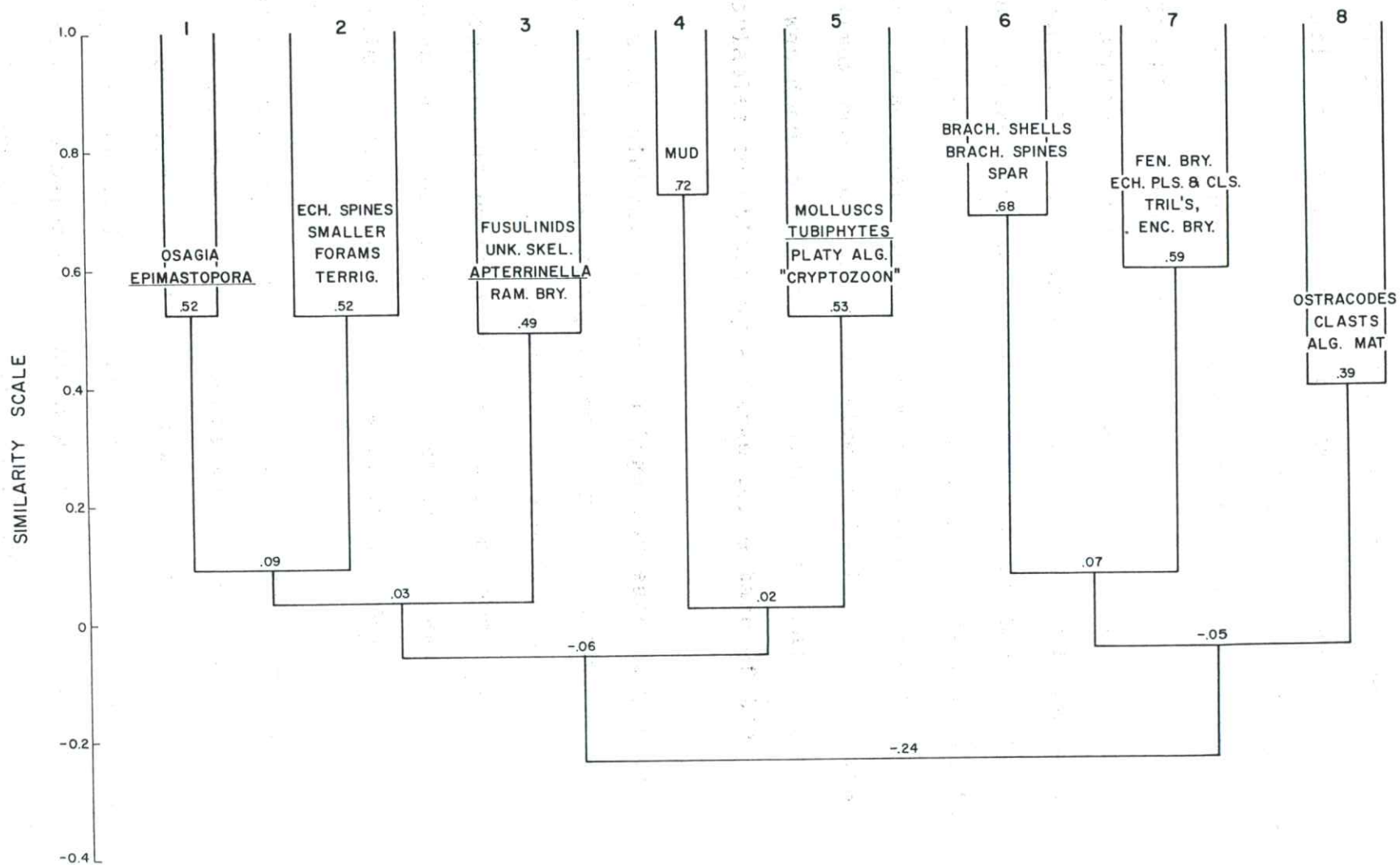
R-mode	Q-mode
(1) r-matrix	(1) cos matrix
(2) initial factor matrix	(2) initial factor matrix
(3) rotated factor matrix	(3) rotated factor matrix

The computations were made using the techniques of Imbrie (1963) and an IBM 7090 computer. A hierarchial classification

EXPLANATION OF FIGURE 7

Hierarchy diagram (R-mode) depicting relationships among constituent particles in the Toronto Limestone.

FACTOR REACTION GROUPS
(ASSOCIATIONS)



of the R-mode factor analysis was constructed by computing mean similarities between the factor reactor groups. The variable dendrogram (Fig. 7) indicates that the constituent components of the Toronto Limestone tend to occur in eight reaction groups as diagrammed.

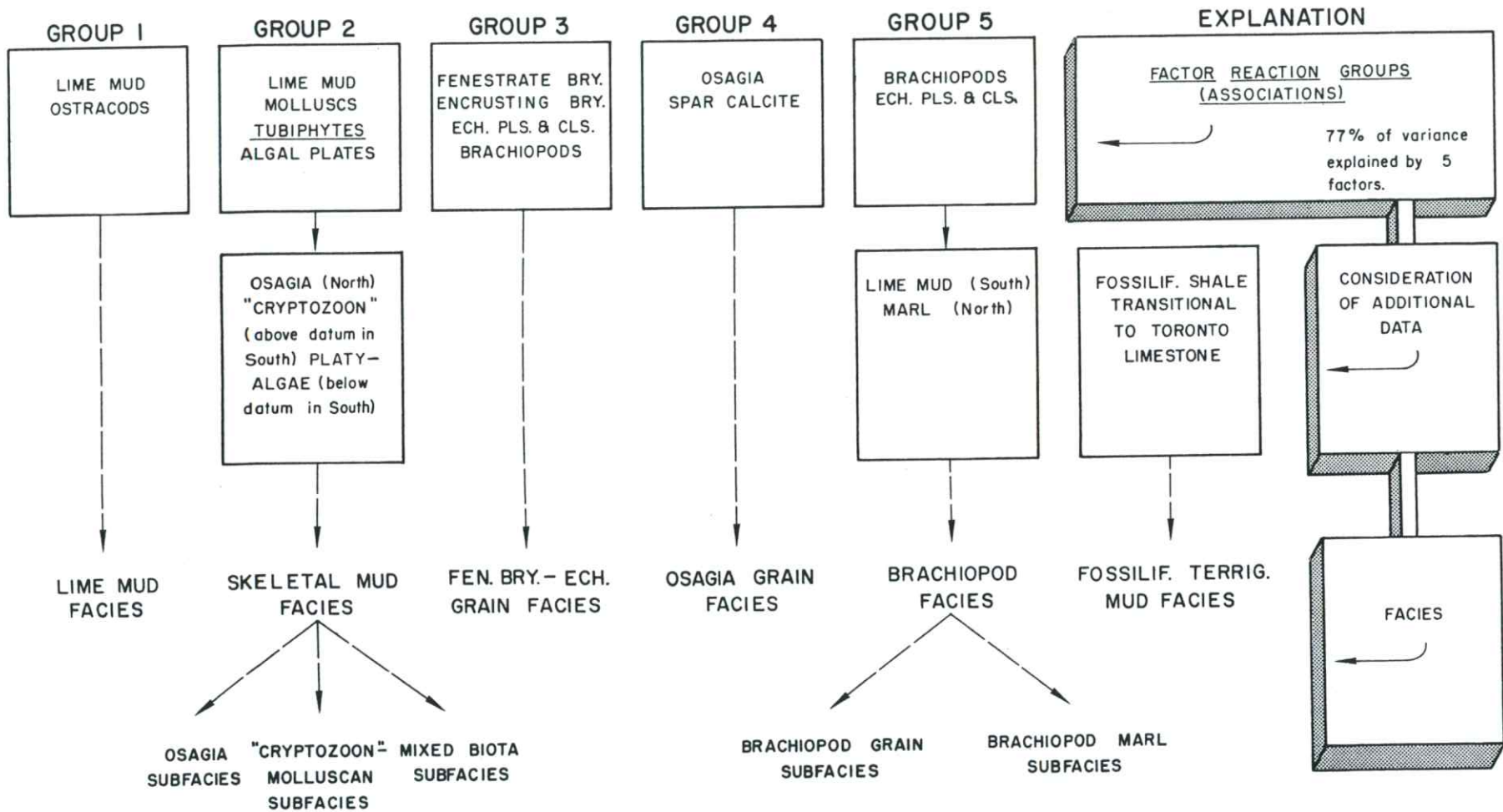
Two separate Q-mode analyses were made with 10 factors being extracted in each. In the first analysis the raw-data matrix was utilized in the computations, but in the second case the raw-data matrix was transformed before making statistical analyses so that the data were recorded as a percent of the maximum value of the respective variables. The transformation was done to eliminate the disproportionate influence of variables constituting a large percentage of the samples.

The three highest factor loadings for each sample in the two Q-mode analyses were plotted on restored cross-sections. No significant variations were noted in analysis of the untransformed rotated factor matrix because one of the variables, mud, bulks large in most of the samples. This was eliminated by analyzing transformed data.

The samples were sorted into 10 groups according to the factor on which each sample was weighted or loaded the highest. The point-count data sheets were then examined visually in an effort to determine which variables reacted together within the different factors in the Q-mode analysis. Recognition of the parameters which were complimentary in each of the factors allowed evaluation of the different factors for purposes of facies delineation. A total of five

EXPLANATION OF FIGURE 8

Diagram showing sedimentary facies of the Toronto Limestone and equivalent shale.

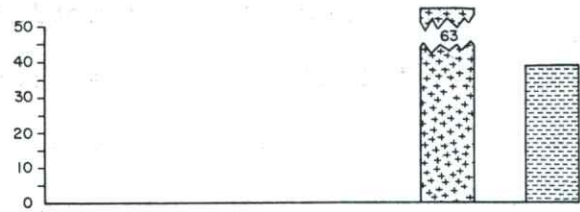
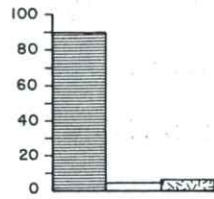


EXPLANATION OF FIGURE 9

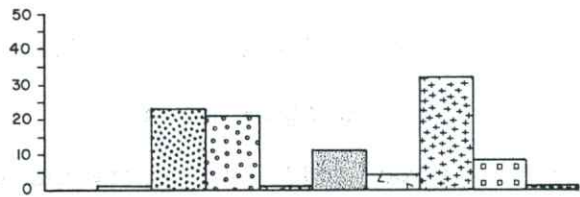
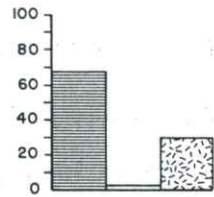
Histograms showing the rock and biotic composition of the five facies and three subfacies within the Toronto Limestone. The histograms at the left show the composition in terms of mud (MU), spar (SP), and skeletal grains (SK). The histograms on the right illustrate the composition of the skeletal grains in terms of 10 biotic constituents. (Platy algae = PA, Tubiphytes = TU, Osagia = Oa, "Cryptozoon" = Cy, Apterrinella = Ap, Fenestrate Bryozoans = FB, Brachiopod Shells = BS, Molluscs = Mo, Echinoderm fragments - mainly crinoids = EF, and Ostracodes = Os).

- A. Osagia Grain Facies
- B. Brachiopod Facies
- C. Fenestrate Bryozoan-Echinoderm Grain Facies
- D. Skeletal Mud Facies, Osagia Subfacies
- E. Skeletal Mud Facies, Mixed Biota Subfacies
- F. Skeletal Mud Facies, "Cryptozoon"-Molluscan Subfacies
- G. Lim. Mud Facies

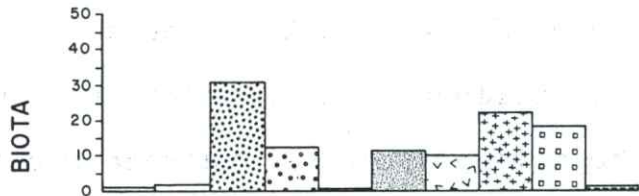
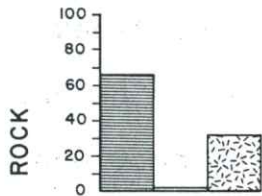
G.



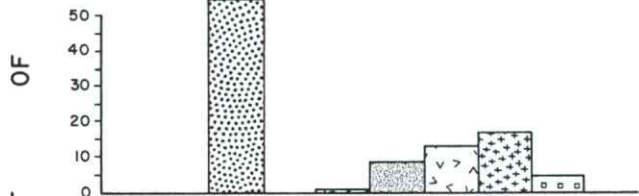
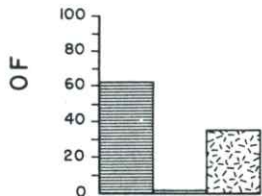
F.



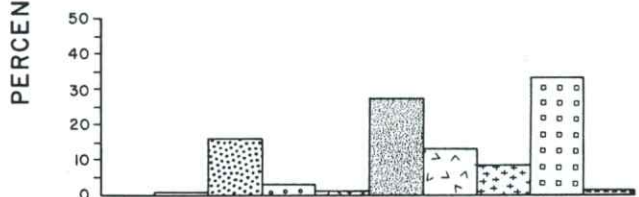
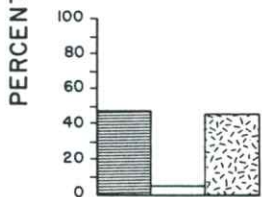
E.



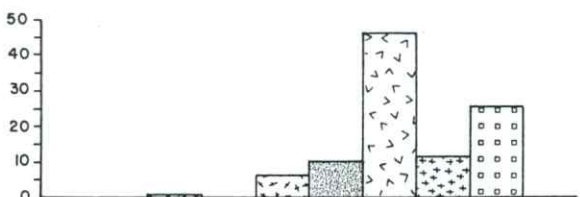
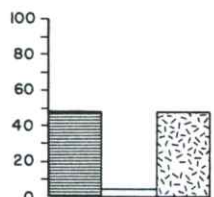
D.



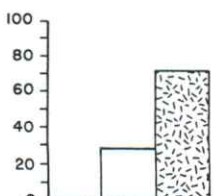
C.



B.



A.



MU SP SK

PA TU Oa Cy Ap FB BS Mo EF Os

factors was interpreted as forming distinctive nuclear groups of facies significance. Consideration of additional data which were not factored as well as geographical trends of the factor loading plots resulted in the delineation of a sixth facies and a subdivision of one facies into three sub-facies and another into two sub-facies. A diagram of the facies assignment procedure is shown in Figure 8.

Figure 9 is a diagram showing the lithologic and biologic composition of the facies and sub-facies which were point-counted. Figure 10 is a restored cross section of the Toronto and contiguous strata showing the distribution of facies.

EXPLANATION OF FIGURE 10

Restored cross-section of the Toronto Limestone showing
sedimentary facies.

SOUTH

OKLAHOMA KANSAS

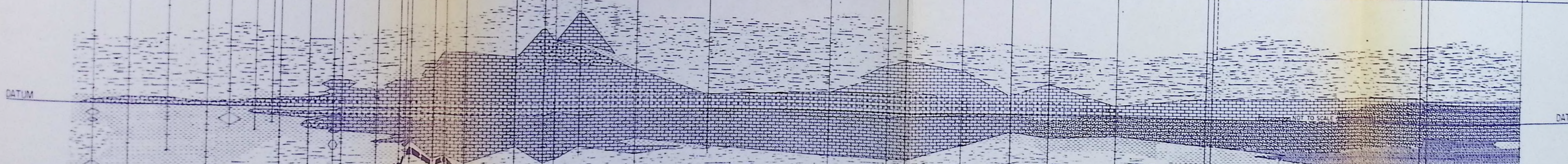
NORTH

KANSAS, MISSOURI

MISSOURI, NEBRASKA

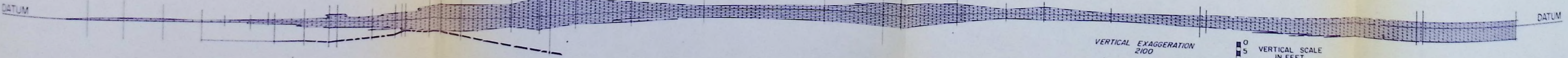
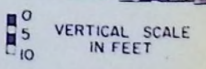
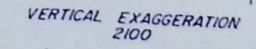
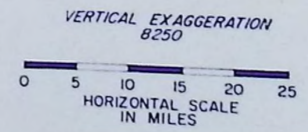
NEBRASKA, IOWA

OSAGE 18 CHAUTAUQUA 17 ELK 65 6A5 GREENWOOD 4C-2 3A 3 2 WOODSON C-24 C-21 COFFEY C-7 FRANKLIN 9 DOUGLAS 13A 22 11 LEAVENWORTH 12 C-9 PLATTE C-10 BUCHANAN 15 15A 15B CASS 14 14A 21



EXPLANATION

- | | | | |
|--|-------------------------------------------------------|--|-------------------------------------------------------------|
| | SKELETAL MUD FACIES, OSAGIA SUBFACIES | | BRACHIOPOD FACIES |
| | SKELETAL MUD FACIES, MIXED BIOTA SUBFACIES | | BRACHIOPOD GRAIN SUBFACIES |
| | SKELETAL MUD FACIES, MOLLUSCAN-"CRYPTOZOON" SUBFACIES | | BRACHIOPOD MARL SUBFACIES |
| | LIME MUD FACIES | | CLAY AND SILT, MARINE FOSSILS |
| | OSAGIA GRAIN FACIES | | CLAY WITH SOME SILT AND SAND, BRACKISH TO TERRESTRIAL BIOTA |
| | FENESTRATE BRYOZOAN-ECHINODERM GRAIN FACIES | | TERRIGENOUS SAND |
| | | | COAL |



FACIES DESCRIPTIONS AND ENVIRONMENTS OF DEPOSITION

Fossiliferous Terrigenous Mud Facies

Description

Marine shales are present contiguous with and subjacent to the Toronto Limestone in southern Kansas from southern Woodson County southward into Osage County, Oklahoma, and from Douglas County in northern Kansas to Buchanan County in Missouri.

In Greenwood and Elk counties, Kansas, green shale is present above the thin coal zone and these shales are interbedded with limestone beds of the Toronto. Progressive replacement of limestone beds by green fossiliferous shale in a southerly direction is indicative of facies change from limestone to fine clastics.

The shale interval between the Toronto Limestone and the coal bed at Locality 1 in Woodson County varies from a quarter of an inch to several feet over distances of approximately 100 yards; shale is blue-gray and contains the macrofossils Derbyia (abundant), Juresania, Composita (common), and a few rhomboporid bryozoans. This shale becomes gray-green between Localities 1 and 3. At Locality 3, it has yielded the brachiopods Derbyia crassa (abundant), Composita, and Crurithyris. Insoluble residues of the same bed contain conodonts (Cavusghathus) and Ammodiscus, a small, planispiral, agglutinated foraminifer.

Coal is not present beneath the Toronto Limestone at Locality 4 and the presence of thin sands interbedded with

the fossiliferous green shales suggests the possibility of erosion of the coal. The green shale bed above the basal limestone stringer at Locality 4 contains a profuse accumulation of small, robust fusulinids which is associated with Neochonetes (abundant), Echinoconchus, Antiquatonia, Derbyoides, and echinoid plate fragments; green shales beneath the fusulinid shale contain brachiopod fragments and spines. A lophophyllidid coral was collected from a calcareous zone within the shale.

At Locality 5, the fusulinid-rich shale is developed at the base of the Toronto Limestone. It rests on a thin green shale which, in turn, overlies a blue-gray shale sequence capped by a brown oxidized zone. A coal bed is present beneath the blue-gray shale. The oxidized zone suggests emergent conditions subsequent to coal and blue-gray shale deposition and prior to inundation by marine waters.

The fusulinid-rich shale, present at the base of the Toronto Limestone at Locality 5, has also been observed at Localities 6, 6A, 6.5, 7A, 7B, and 7.5. Macrofossils collected from this lithology at Locality 5 include Myalina (Orthomyalina), Composita, Punctospirifer, Neochonetes, Neospirifer, Derbyoides, Derbyia, Echinoconchus, and Antiquatonia, crinoid columnals, echinoid spines, lophophyllidid and syringoporid corals and bryozoans. A thinner (0.4 foot) bed of shale beneath the fusulinid-rich shale contains the pelecypods Pleurophorus, Posidonia, and "Aviculopecten" in addition to encrusting bryozoans and abundant Composita.

Ostracodes identified from the fusulinid shale were Pseudo-
bythocypris, Healdia, Bairdia, Amphissites, and Moorites.
Ammodiscus was recovered in insoluble residues of both shales.
A five-foot bed of blue-gray, silty shale, bearing coalified
plant remains, occurs between the fossiliferous shales and
the coal seam.

The same sequence as described above also attains at
Locality 6A with two notable exceptions. First, thin,
stringy, current-rippled calcareous sandstones and green
sandy shales bearing "Aviculopecten", Nuculana, Posidonia,
Myalina, and plant fragments are interstratified with the
blue-gray shale bearing plant fragments. Several specimens
of the ostracode Jonesina were the only invertebrate remains
extracted from the blue-gray shale zone. The sandstone beds
are less than a foot thick and persist laterally for dis-
tances of 20 to 50 feet or so.

At Localities 6.5, and 7, the fusulinid-rich shale
is intercalated between a basal bed of Toronto Limestone and
a bed of Myalina-rich shale which rests on a blue-gray shale
overlying a thin coal. Jonesina was the only invertebrate
fossil recovered from the blue-gray shale ^{above?} superjacent to the
coal.

Megafossiliferous green shales with occasional thin
limestone platy-to-nodular zones are present beneath the
Toronto Limestone as far south as Locality 18 in Osage
County, Oklahoma.

At Locality 18, a 0.3 foot thick limestone occurs about 10 feet beneath a thicker limestone considered to be equivalent to the Toronto Limestone. The thin limestone contains Myalina (Orthomyalina), crinoid columnals, rhomboporid bryozoans, "Aviculopecten", and brachiopod fragments. The shales developed between the two limestones have not yielded megafossils but the foraminifer Involutina is abundant in them.

Examination of the Oread sequence at Locality 23, two miles south of Locality 18, has revealed Leavenworth Limestone an approximate 50-75 foot section of interbedded red shale and sandstone, a cross-bedded sandstone, less than 10 feet thick, containing small current ripples and pelecypods (only in the basal few inches), and a thin, silty limestone several inches thick which is separated from the overlying sandstone by several inches of green shale. Fossils found in the limestone include Derbyia, Neochonetes, Myalina (Orthomyalina), Nuculana, Edmondia, rhomboporid bryozoans, and crinoid columnals. In addition, an almost complete crinoid calyx was collected from the limestone. At least several feet of green shale is present beneath the limestone followed by a partially covered red shale section 60-90 feet thick which is underlain by a sandstone body, in excess of 10 feet thick, characterized by festoon crossbedding.

For the most part, shales above the Toronto Limestone southward from Coffey County, Kansas, have yielded few fossils and these were found only in the lower few feet of the

Snyderville. Ammodiscus (abundant), brachiopod spines, Cavellina, Healdia, Pseudobythocypris, and cf. Bairdia were identified from washed shales at Locality 18. The brachiopod Crurithyris and ostracodes Cavellina, Healdia, Bairdia, and Hollinella were identified from the lower four feet of Snyder-ville at Locality 8. Pseudobythocypris and Cavellina were identified from a two-foot bed of green shale resting on the Toronto at Locality 1; the green shale is overlain directly by a nonfissile, blocky red shale that has yielded charophyte oogonia. Charophyte oogonia were found in the red shale overlying the Toronto at Locality 6A.

At Localities 25, 20, 9 and 13, the Toronto Limestone rests on unfossiliferous shales. However, from Locality 22 near Lawrence, Kansas, northward to St. Joseph, Missouri, the shale beneath the Toronto is fossiliferous in the upper part. Crinoid columnals and inarticulate brachiopods are present at Locality 22 in the upper several inches of a two-foot shale zone subjacent to the Toronto.

No fossils were found in the Snyder-ville Shale from Locality 1 northward to Locality 13. At Localities 13 and 22, worn fish teeth and gastropod fragments were gathered from the basal few inches of the shale and a few specimens of the ostracodes "Jonesina", Cavellina, and Bairdia were recovered from this zone at Locality 22. At Locality 15A, paired and unpaired specimens of Myalina abound; microscopic examinations revealed brachiopod spines, Ammodiscus, a juvenile Myalina, and the ostracodes Cavellina, Healdia, Pseudo-bythocypris, and Bairdia.

The only other fossiliferous zone present in the Snyderville occurs as a thin (six inches or so) zone subjacent to the Leavenworth Limestone at most localities examined in Kansas, Missouri, Nebraska, and Iowa.

Fossiliferous marine shale is present beneath the Toronto Limestone from Locality 15 where it is three feet thick to Locality 10 where it is two feet thick. In addition, marine fossils have been observed in the upper few inches of Lawrence Shale at Locality 22.

Depositional Environment

Quiet water deposition is indicated for the fossiliferous terrigenous mud facies. This is indicated not only by the large proportion of mud, but by the excellently preserved external morphology of fossils. The fine-grained terrigenous materials were apparently derived from the elevated land areas in southern Oklahoma and Arkansas and from the southwestern portion of the Ozark Dome. This is indicated by directional features in the Vamoosa Formation in northern Oklahoma, which is in part laterally equivalent to the Toronto Limestone. Hicks (1960) has shown that cross-stratification readings in sandstone channels of the Vamoosa suggest prevailing westward and southwestward movement in northern part of Osage County, Oklahoma, but a northwestward trend is evident in northern Creek and southern Osage counties in the same state. Thus, a major locus of terrigenous influx into the Kansas presumably lay in west central portion of Osage County or possibly slightly farther west. This is in agreement with thickening trends

in the Snyderville Shale interval. It is here suggested that a delta or deltaic complex was in existence in the western Osage County area during deposition of the Toronto Limestone and oscillation patterns in deltaic sedimentation through distributary shift allowed carbonate deposition to encroach into northern Oklahoma during Toronto deposition.

By analogy with Recent stream influence on marine waters, stream discharge was probably laden with relatively high concentrations of nutrient elements (compounds of phosphorus, nitrogen, silica, and organic carbon). Emery and Stevenson (1957, p. 693) state,

"The relatively high concentration of nutrients in estuaries and lagoons is evidently the result of nearness to the supply provided by the land runoff and the continuous replacement of nutrient-rich water to growing plants. The continuous supply of nutrients and the presence of shallow bottom in the photosynthetic zone lead to concentrated life off the rivers."

The writer has seen thriving marine benthonic faunas near the mouths of streams in southern British Honduras where bottom salinities are marine (30‰) but surface waters are brackish (10-15‰). The sessile pelecypod Myalina (Orthomyalina) sp. apparently occupied a niche analogous to the modern bay oyster of the Gulf Coast, Crassostrea virginica. The lack of a diverse fauna in accompaniment with Myalina suggests restricted conditions of circulation undoubtedly brackish water. The brachiopods, Neochonetes,

Crurithyris, Linoproductus, and Derbyia, and rhomboporid bryozoans and cinroids are commonly intercalated in the section with Myalina although they seldom occur in the same bed. The brachiopod, bryozoan, and crinoid association lived on bottoms adjacent to the gregarious Myalina populations, but in areas subjected to more nearly normal marine waters.

Marine shales occur elsewhere in the succession such as at Localities 10 and 15, and interbedded with marl at Locality 21. These accumulations are also a probable result of nutrient-rich terrigenous influx from the land areas.

Brachiopod Facies, Brachiopod Grain Subfacies

Description

From southern Elk County, Kansas, to the southern limit of its outcrop, the Toronto Limestone consists of a single discontinuous brown (weathered) to medium or dark gray limestone. This facies extends northward to Locality 6. The facies ranges from 0 to several feet in thickness. It is composed mainly of brachiopod shells and spines and echinoderm segments with the long dimensions of the skeletal grains aligned parallel to the bedding in two southernmost localities but becoming progressively more heterogenous in arrangement northward; no fossils were observed in growth position. The shale beneath the limestone in this region has yielded brachiopods, bryozoans, echinoderm parts, pelecypods, and gastropods.

The mud-sized fraction of the brachiopod facies averages 48 percent of the total rock by volume and skeletal grains also total 48 percent. The dominant component of this facies are brachiopods which constitute 16 percent of the rock but 34 percent of the biota; second in abundance are echinoderm plates and columnals which occupy nine percent of the rock and 18 percent of the biota. Fenestrate bryozoans, 3.5%R*, 7%B*, and molluscs, 4%R, 8%B, are other common skeletal components. Because of their small size, foram tests seldom make up as much as one percent of the thin sections of the Toronto Limestone even though they are present in most of the samples; however, the encrusting foram Apterrinella makes up 2%R, 3%B, of the brachiopod facies. It seldom occurs as free particles, but is commonly attached to brachiopod shells which evidently provided a smooth substrate for the forams.

Field examination of slabs of Toronto Limestone at Locality 18, Osage County, Oklahoma, revealed the following faunal observations. Brachiopods present include Linoproductus, Chonetes, Antiquatonia, and large specimens of Derbyia. All are fairly abundant and large broken spines, apparently from Linoproductus and Antiquatonia, are very conspicuous. Stout spines apparently were used for support by the aforementioned genera to enable them to escape undesirable conditions at the sediment-water interface and to remain in a fixed position for feeding activities. Derbyia lacked a pedicle but was

*Abbreviations used in connection with grain types percentage:

%R - percent of total rock by volume
%B - percent of total biota by volume

TABLE 5

VOLUMETRIC COMPOSITION OF BRACHIOPOD
GRAIN SUBFACIES, BRACHIOPOD FACIES

n = 8	Biota Mean	Rock Mean	Standard Deviation	Observed Range
<u>Epimastopora</u>	0	0	0	0
<u>Platy Algae</u>	0	0	0	0
<u>Tubiphytes</u>	0	0	0	0
<u>Osagia</u>	0.5	0.25	0.7	0-2.0
<u>Algal Mat</u>	0	0	0	0
<u>"Cryptozoon"</u>	0	0	0	0
<u>Apterrinella</u>	4.6	2.17	1.7	0-4.8
<u>Fusulinids</u>	1.7	0.80	0.7	0-2.2
<u>Other Forams</u>	1.6	0.75	1.3	0-4.0
<u>Fenestrate Bryozoans</u>	7.5	3.55	2.9	0-8.6
<u>Ramose Bryozoans</u>	0.6	0.30	0.6	0-1.8
<u>Encrusting Bryozoans</u>	0.4	0.20	0.3	0-0.8
<u>Brachiopod Shells</u>	35.1	16.45	6.1	3.8-54.4
<u>Brachiopod Spines</u>	4.3	2.02	4.4	0-12.8
<u>Molluscs (Pe. & Ga.)</u>	8.3	3.89	3.0	0.6-9.2
<u>Echinoderm Fls. & Cls.</u>	18.7	8.77	3.8	4.6-16.6
<u>Echinoid Spines</u>	0.4	0.17	0.3	0-1.0
<u>Trilobites</u>	0.2	0.07	0.1	0-0.2
<u>Ostracodes</u>	0.5	0.22	0.1	0-0.4
<u>Unknown Skeletal</u>	15.9	7.49	4.6	1.6-13.9
<u>Total Skeletal</u>		46.10		
<u>Mud</u>		47.81	10.6	0.8-66.4
<u>Spar Calcite</u>		4.09	6.1	0.4-18.8
<u>Intraclasts</u>		0.07	0.2	0-0.6
<u>Terrigenous Silt</u>		0.07	0.1	0-0.2

apparently able to attach its pedicle(?) valve to solid objects in order to attain support and stability. Molluscs observed include abundant small elongated clam, Nuculana, which apparently was a burrower, the mobile pelecypod "Aviculopecten", and disarticulated large Myalina (Orthomyalina) valves as well as specimens of the gastropod Euphemites. Myalina was a sedentary form that may have been attached to the substrate by a byssus (analogy with the Recent mytilacids such as VolSELLa and Brachiodontes). Abundant pelmatozoan parts, presumably crinoid, with radial ridges or crenellas well preserved on the joint faces of columnals are evidence that these particles are not worn or abraded. Likewise, few if any of the brachiopod or mollusc shells appear abraded. Other faunal elements seen at Locality 18 are rhomboporid and encrusting bryozoans (attached to Myalina shells).

Additional mega-faunal elements were recognized at other localities. At Locality 17, Crurithyris and Astartella and a few scattered fusulinids were noted, and Composita was found at Locality 8. Hystriculina wabashensis and Rhipidomella carbonaria were observed at Locality 7. Crurithyris, Composita, and Rhipidomella had pedicles for attachment and support. Hystriculina was spinose and lived suspended off the bottom. The compact, rigid fusulinid test suggests that the organism was probably adapted for vagile existence on plants. Astartella was a mobile clam and probably could burrow short distances into the muddy bottom.

At Localities 17-19, the brachiopod facies is a coquina-like accumulation of compressed and flattened brachiopod shells, mostly pseudopunctate forms; and spines; crinoid columnals, and rhomboporid bryozoans are scattered through the shelly material. Brachiopod shells decrease in abundance from south to north in the facies and mud-sized carbonate increases in the same direction.

Depositional Environment

The accumulation of fusulinids, bryozoans, brachiopods, and crinoid parts in this facies is indicative of marine conditions. Furthermore, the presence of a diverse fauna is suggestive of warm temperatures. The presence of suspension feeding organisms including crinoids, bryozoans, and brachiopods, indicates a relatively slow rate of sedimentation with sufficient quantities of nutrient food for the existence of filter feeding organisms. The fragmental condition of much of the skeletal matter was a result of scavenging activities of trilobites, echinoids, holothurians, and probably worms and fish. The progressive increase in mud matrix in this facies, in a northerly direction, and its thoroughly burrowed state, indicate a decrease in substrate stability in the same direction. However, the rate of sedimentation was nevertheless slow and uniform as suggested by the development of encrusting forams (Apterrinella) on shell debris, the clastic nature of the shell material, and disruption and homogenization by infaunal elements. Dasycladacian algae (Epimastorpora) occur in places, although in minor amounts; their presence indicates

relatively shallow, illuminated waters.

The presence of mud and lack of worn skeletal grains indicates depositional conditions with little persistence of wave action, although some current movement must have been operative in order to deliver nutrients and remove waste.

Brachiopod Facies, Brachiopod Mud Subfacies

Description

Localities 14, 14A, and 21, all in Nebraska, contain in the lower half a skeletal rich olive to green, shaly limestone to limey shale that is abundantly fossiliferous. This facies is approximately five feet thick and is developed above unfossiliferous shales of the Lawrence Formation. The facies contains abundant specimens of a fairly diverse fauna that weathers out as complete specimens. The contact with the Lawrence Shale appears to be disconformable at Locality 14A for pieces of red shale appear to have been reworked into the basal few inches of Toronto. The upper contact with the overlying limestone, however, is transitional; the gradation being completed within several inches. Thin sections, representative of this facies, could not be obtained owing to the shaly nature of the beds.

In the field, the facies appears as an interbedded sequence of nodular to platy limestone and calcareous shale. Some of the limestone lenses are up to three inches thick but extend laterally only for a foot or so. Fossils in this facies are well-preserved. Articulated brachiopod shells

are particularly abundant; many specimens are complete and contain well-preserved ornamentation. Much or most of the elongate and platy shells and shell fragments lie parallel to the bedding. Crinoid columnals are common as are fenestrate and ramose bryozoans. Encrusting bryozoans were observed on some shelly material. Lophophyllidid corals, although not abundant, are nevertheless present throughout the vertical extent of the facies, as are fusulinids. Brachiopods identified from the beds include: Composita, Hustedia, Marginifera splendens, Antiquatonia, Retaria lasallensis, Linoproductus prattenianus, Derbyia crassa, Crurithyris, Neochonetes granulifer, and Punctospirifer. The only mollusc recovered from the facies was the pectinoid clam, Streblochondria. Although Crurithyris occurs throughout the facies, it is also found in coquinoid occurrences in thin, platy, limestone stringers with most other forms excluded.

Insoluble residues and thin sections of this facies revealed partial silicification of brachiopod shells and crinoid columnals.

Locality 21 contains more shale and less limestone than Locality 14A which suggests that the basal Toronto is undergoing facies transition to shale in the Platte River Valley area.

There are now no accessible exposures of Toronto Limestone between the Platte River Valley of Nebraska and the Missouri River section (Locality 15) at St. Joseph, Missouri; however, it is possible that the shelly marl facies is a lateral equivalent of the green shelly shale present beneath the Toronto Limestone at Locality 15.

Depositional Environment

The subfacies accumulated under marine conditions as suggested by the presence of fusulinids, solitary corals, echinoderm segments, and a diverse brachiopod fauna. The presence of shale and lime mud together with unbroken and unworn brachiopod shells suggests deposition beneath or away from severe wave action and in an environment in which scavenging was not intense. Thus, although the waters must have been shallow, they were not rough.

Crurithyris, which is abundant in this facies, is always present in shaly beds which suggests that they could not only tolerate terrigenous muds but may have preferred them. The same was apparently true for Neochonetes as well.

Echinoderm-Fenestrate Bryozoan Grain Facies

Description

A massive brown bed of bioclastic limestone, containing abundant echinoderm debris, scattered brachiopod shells, large "Cryptozoon" oncolites, and fusiform fusulinids (Kansanella), has been recognized at Localities 9, 13A, 22, and 11 in Kansas. A similar lithology has been noted near the same stratigraphic position as far south as Locality 6.5 and northward to Platte County in Missouri. This facies averages slightly less than two feet in thickness. In some places, the facies is developed above the shaly interval used as a datum but in other locales, it is developed below as well as above the marker zone.

TABLE 6

VOLUMETRIC COMPOSITION OF
ECHINODERM-FENESTRATE BRYOZOAN GRAIN FACIES

n = 32	Biota Mean	Rock Mean	Standard Deviation	Observed Range
<u>Epimastopora</u>	0.04	0.02	0.1	0-0.6
<u>Platy Algae</u>	0.04	0.02	0.1	0-0.4
<u>Tubiphytes</u>	0.2	0.09	0.3	0-1.2
<u>Osagia</u>	18.2	5.11	7.3	0-34.4
<u>Algal Mat</u>	0	0	0	0
<u>*Cryptozoon*</u>	2.1	3.2	1.01	0-14.0
<u>Apterrinella</u>	0.2	0.11	0.2	0-0.8
<u>Fusulinids</u>	3.4	1.58	2.8	0-11.8
<u>Other Forams</u>	0.2	0.10	0.3	0-1.4
<u>Fenestrate Bryozoans</u>	19.1	9.02	4.9	1.0-20.2
<u>Ramose Bryozoans</u>	0.4	0.21	0.5	0-2.4
<u>Encrusting Bryozoans</u>	0.9	0.39	0.5	0-1.4
<u>Brachiopod Shells</u>	0.6	4.51	4.6	0-15.4
<u>Brachiopod Spines</u>	0.8	0.37	0.5	0-1.6
<u>Molluscs (Pe. & Ga.)</u>	5.7	2.67	3.7	11.6-0
<u>Echinoderm Fls. & Cls.</u>	23.8	11.20	7.0	1.8-29.2
<u>Echinoid Spines</u>	0.3	0.13	0.2	0
<u>Trilobites</u>	0.3	0.14	0.3	0
<u>Ostracodes</u>	0.3	0.15	0.2	0-0.8
<u>Unknown Skeletal</u>	21.9	10.29	4.0	4.0-20.4
<u>Total Skeletal</u>		47.12		
<u>Mud</u>		48.17	8.0	2.2-76.8
<u>Spar Calcite</u>		4.39	9.8	0-44.6
<u>Intraclasts</u>		0.08	0.4	0-2.0
<u>Terrigenous Silt</u>		0.04	0.1	0-0.6

On weathered surfaces crinoid columnals, fusulinids, brachiopod shells, and "Cryptozoon" oncolites stand out in relief showing some evidence of orientation of elongate grains parallel to bedding surfaces.

Skeletal grains make up 48% of the rock and an identical percentage of mud-sized component is present. Echinoderm segments are the most abundant skeletal element constituting 11% of the rock and 24% of the biota. Fenestrate bryozoans are also abundant comprising 9%R or 20%B. *Osagia* oncolites 5%R, 11%B, and brachiopod shells 4%R, 9%B are next in order of abundance. Other significant components in this facies are molluscs, "Cryptozoon" oncolites and fusiform fusulinids but generally they are present in amounts not exceeding 3%R or 6%B.

The predominance of crinoid columnals relative to plates suggests that the pelmae were long with the calyx reaching upward into waters above the sediment surface. Seemingly long crinoid pelmae would provide an ideal habitat for other suspension feeding organisms such as encrusting bryozoans, spinose brachiopods, and perhaps even fusulinids. When oriented with its long axis directed into a current, the streamlined fusulinid test would have offered minimal resistance to water movement.

Thin section study has revealed that much of the skeletal material is fragmental, some echinoderm ossicles appear to be worn, and many brachiopod shell fragments and crinoid parts have incipient *Osagia* coatings although thick *Osagia* coated grains are present occasionally. The coatings

are commonly developed concentrically about their skeletal nuclei. No composite Osagia coated grains were observed. The Osagia coatings are characteristically dark gray and dusty in appearance and consist of a series of vague, irregular, concentric laminae. Often times the host particle will have a ragged bored periphery and it is obvious that the Osagia contained some taxa (green or blue-green algae) within its colony that bored into the nuclei. Dark Girvanella tubes are commonly found within the Osagia colonies as well as tests of the encrusting foram Hedraites. Girvanella and Hedraites are not present in all Osagia oncolites which is proof that they were accessory components of the colonies.

Large egg-sized, wad-like oncolites, up to several inches in length, commonly referred to as Ottonosia or "Cryptozoon" have been collected from the echinoderm-bryozoan facies at several localities (22, 11 and 9). They do not resemble Osagia in external form or microstructure as observed in thin section. The "Cryptozoon" masses generally have a skeletal grain nucleus but the coatings are commonly disposed asymmetrically about the nucleus. The encrusting complex consists of alternating layers of dark, dusty, apparently mud-sized carbonate and irregular, crinkly, sparry layers. Encrusting bryozoans and forams are commonly included within the coatings. Brachiopod shells, large echinoderm particles, and calcareous sponge tests form nuclei of these colonies, but in many cases the encrusting mass

apparently was able to expand and extend out from its nucleus over the surrounding muddy sediments. The latter seemingly suggests that the colonies were probably algal rather than encrusting sponges.

A large fragment of material identical to the lithology of the enclosing rock was found at Locality 22. It has an attached encrusting bryozoan. The host particle contains a fusulinid and brachiopod shell which obviously had been beveled or abraded prior to growth of the bryozoan. Because the latter is developed upon the mud-matrix portion of the host particle as well as over the truncated brachiopod shell, it is clearly indicated that the host was a fragment of lithified rock upon which the bryozoan grew.

Examination of numerous thin sections revealed swirled mud and skeletal material which attest to the burrowing activity of an infauna.

Macrofossils commonly collected from the facies include: the brachiopods Composita, Antiquatonia, Neochonetes, H. wabashensis, Derbyia, Punctospirifer, Neospirifer, and Hustedia; lophophyllidid corals; and the molluscs Wilkingia and Naticopsis.

X-ray diffraction patterns of insoluble residue from this facies reveal the presence of goethite and pyrite. It seems likely that the goethite has resulted from weathering of pyrite, and the characteristic rusty brown appearance of the Toronto on the outcrop is a result of weathering of pyrite.

A shaly marker horizon was used for a datum in the

Toronto study. In the southern part of the outcrop, several thin shaly zones appear in the section but they do not persist to the north. Knowledge of details in the stratigraphic succession, thicknesses, and paleontology have permitted the recognition of the datum in southern Kansas. The datum shale has yielded Composita, Antiquatonia, echinoderm columnals, and lophophyllidid corals at numerous localities in Kansas. Encrusting bryozoan colonies up to four inches in diameter with a flat base and broad domal top have been collected from this horizon at Localities 7, 6A and 25. The presence of bryozoans and corals in a shaly zone seemingly presents a problem because these organisms are suspension feeders, presumably preferring clear water. The lack of increased silt content relative to clay in this zone compared to other shale intervals in the limestone, indicates that the shale may have resulted from a decrease in the rate of production of carbonate with terrigenous influx remaining essentially constant. This would account not only for the presence of the sessile suspension feeders but for the lack of silt-or-sand-sized terrigenous material that would be expected if the shale deposition was associated with a regression or a rapid influx of clastics. As thus interpreted, the Toronto datum zone represents a pause in carbonate deposition, possibly due to climatic fluctuation, with terrigenous influx remaining constant.

Depositional Environment

The presence of fusulinids, sponges, horn corals, and numerous brachiopod genera in addition to the dominant faunal components, crinoids and fenestrate bryozoans, is indicative of open marine waters of optimum salinity for the Toronto Limestone. The dominance of filter feeding organisms in this facies suggests a relatively slow rate of sedimentation and some current delivery which provided nutrients and plankton. A slow rate of sedimentation is also indicated by the fragmented nature of the skeletal material which suggests that the rate of sedimentation did exceed the rate of reworking-burrowing and scavenging. *Osagia* coated grains are common and ubiquitous in the facies and are suggestive of relatively clear, well-lit, and periodically agitated conditions.

It is within this facies that the thin shaly zone used as a datum for stratigraphic reconstruction occurs. Lophophyllidid corals and encrusting bryozoans colonies were found at numerous localities in the datum shale and may appear paradoxical because suspension feeding organisms generally do not prosper in areas of rapid mud sedimentation. The widespread occurrence of the shaly zone, however, suggests unique depositional conditions. It seems likely that the shaly zone accumulated during a period in which there was a decline in carbonate sedimentation with terrigenous influx remaining essentially constant. This would account not only for the presence of sessile suspension feeding organisms and widespread distribution of the zone, but, in addition, explains the lack of increase in grain size that might be anticipated

if the shale zone was associated with a regression or a rapid influx of clastics.

In general, the crinoidal debris in this facies is not only more abundant than in the other Toronto facies, but, in addition, is much larger. Crinoid columnals, for example, are about twice the size they are elsewhere. Thus, ecological conditions were more suitable for crinoids during deposition of this facies. But what were the factors that were more favorable--probably greater depth, less turbidity, and better water circulation for food supply, to name a few.

Many of the *Osagia* nuclei were bored beneath the coatings (see Plate XXII). This is such commonplace in *Osagia* colonies that it is the rule rather than an exception. It seems reasonable to assume, therefore, that some component of the colony was responsible. Green algal tubes or borings have been observed in mollusc shells from various places in modern seas such as northern British Honduras (Pusey, 1964), Baffin Bay, Texas (Dalrymple, 1964), and the Bahamas (Purdy, 1963); thus it is probable that the Pennsylvanian borings were excavated by green algae also.

Osagia Grain Facies

Description

At Localities 20 and 25 in southern Coffee County, Kansas, the upper part of the Toronto Limestone contains a massive bed of chalky white limestone several feet thick. The bed lacks internal stratification features and appears homogeneous. Vertically oriented tube-like structures that

TABLE 7

VOLUMETRIC COMPOSITION OF
OSAGIA GRAIN FACIES

n = 2	Biota Mean	Rock Mean	Standard Deviation	Observed Range
<u>Epimastopora</u>	0	0	0	0
<u>Platy Algae</u>	0	0	0	0
<u>Tubiphytes</u>	0	0	0	0
<u>Osagia</u>	86.1	63.00	1.7	61.8-64.2
<u>Algal Mat</u>	0	0	0	0
<u>*Cryptozoon*</u>	0	0	0	0
<u>Apterrinella</u>	0	0	0	0
<u>Fusulinids</u>	0	0	0	0
<u>Other Forams</u>	0.1	0.10	0.1	0-0.2
<u>Fenestrate Bryozoans</u>	2.5	1.90	1.8	0.6-3.2
<u>Ramose Bryozoans</u>	0	0	0	0
<u>Encrusting Bryozoans</u>	0	0	0	0
<u>Brachiopod Shells</u>	0.5	0.40	0	0.4-0.4
<u>Brachiopod Spines</u>	0.1	0.10	0.1	0-0.2
<u>Molluscs (Pe. & Ga.)</u>	2.1	1.50	0.4	1.2-1.8
<u>Echinoderm Pls. & Cls.</u>	3.1	2.20	2.3	0.6-3.8
<u>Echinoid Spines</u>	0	0	0	0
<u>Trilobites</u>	0	0	0	0
<u>Ostracodes</u>	0	0	0	0
<u>Unknown Skeletal</u>	5.4	4.00	3.4	1.6-6.4
<u>Total Skeletal</u>		73.20		
<u>Mud</u>		0	0	0
<u>Spar Calcite</u>		26.50	5.8	22.4-30.6
<u>Intraclasts</u>		0.30	0.4	0-0.6
<u>Terrigenous Silt</u>		0	0	0

are 1 1/2 to 2 1/2 inches in diameter and transcend the bed completely are characteristic of this facies. Several of these structures yielded large complete specimens of the clam Wilkingia (formerly called Allorisma) that were adjudged to be in growth position; thus the structures are interpreted as large burrows made by Wilkingia.

Osagia coated grains make up 63% R and 86% B. Fenestrate bryozoans, echinoid plates, and mollusc shells each do not exceed much over 2 percent R or 3 percent B. Other minor components are brachiopod shells, smaller forams, and brachiopod spines, listed in order of decreasing abundance. The nuclei of the Osagia coated grains are rounded skeletal fragments, chiefly molluscan, but also echinoderm parts, bryozoans, brachiopods, and smaller forams. The Osagia coated grains occur as single entities; composite Osagia coated grains were not observed. The facies is grain-supported, and is cemented with sparry calcite. In some places, some mud is present but it was apparently introduced by the actions of burrowing organisms.

Large well-developed Wilkingia burrows are conspicuous at Locality 25. Although they extend completely through the bed, they do not penetrate into the underlying strata which may indicate that the lower beds were lithified prior to deposition of the Osagia facies. In addition, the limestone beds beneath the Osagia facies at Locality 25 have a honey-comb appearance with the open spaces being filled with green clay. It appears likely that this resulted from subaerial exposure of the Toronto Limestone prior to deposition of the Osagia

facies. Lithification and solution were accomplished sub-aerially and the latter was responsible for development of interconnected pore spaces within the limestone which were later filled with green clay prior to encroachment of marine waters and deposition of the Osagia facies. dolomite

Depositional Environment

The grain-supported, sparry calcited-cemented, Osagia grain facies accumulated under conditions not favorable for the deposition of mud, but certainly favorable for the development of algal coatings. It is apparent that the environment was one of clear, but agitated waters. Nuclei of many Osagia coated grains were abraded and rounded prior to development of coatings. This is direct evidence of agitated conditions. The nuclei of the coated grains (mollusc, platy algae, and echinoderm segments) suggests marine conditions and probably not highly restricted. Large Wilkingia burrows which extend vertically through the facies attest to the unconsolidated nature of the sediment during or shortly after its accumulation. The presence of Osagia coatings and their concentricity about their nuclei suggest well-lit, agitated, and shallow waters.

Algal biscuits, so similar in size, shape, and structure to Recent forms from southern Florida and the Bahamas (Ginsburg, 1960) that they are clearly analogous, occur in a thin zone above the Osagia facies. This suggests that the Osagia facies was a shoal water deposit with algal biscuits accumulating in extremely shallow (probably less than 15 feet, by analogy with the Recent forms described by Ginsburg) near shore zone or lagoon.

Skeletal Mud Facies, Mixed Biota Subfacies

Description

The approximate lower half of the Toronto Limestone extending from northern Elk County to northern Leavenworth County, Kansas, is a light gray (fresh) to buff or brown (weathered) thin-bedded limestone containing a relatively diverse biota. It ranges from about three feet to almost six feet in thickness. In general, this facies consists of coarse to finely comminuted fossils with a matrix of lime mud. The concentration of fossils is variable so that, in places few biotic grains are observable whereas a matter of a few inches away, vertically or laterally biotic grains are abundant; these relationships are transitional in almost every case.

Beds in this facies commonly vary from several inches to six inches in thickness although they may exceed a foot or so in some exposures. The bedding surfaces are planar and contain a slightly greater percentage of shale than present within the beds. Individual beds cannot be traced laterally for more than a few feet to a few hundred feet before they become vague and merge or disappear in beds of the same type. No structures ascribable to scour and fill or cross-stratification were observed in this subfacies.

The mixed biota subfacies immediately above the Lawrence Shale (Localities 20, 9, 13, 22, 11 and 12) contains abundant *Osagia* coated skeletal grains, fusulinids, and small brachiopods (especially *Neochonetes* and *Rhipidomella carbonaria*).

TABLE 8

VOLUMETRIC COMPOSITION OF MIXED BIOTA
SUBFACIES, SKELETAL MUD FACIES

n = 55	Biota Mean	Rock Mean	Standard Deviation	Observed Range
<u>Epimastopora</u>	0.2	0.08	0.3	0-1.8
<u>Platy Algae</u>	0.5	0.16	0.4	0-2.6
<u>Tubiphytes</u>	1.3	0.42	0.6	0-2.6
<u>Osagia</u>	19.8	6.59	7.6	0-31.0
<u>Algal Mat</u>	2.5	0.82	5.7	0-42.0
<u>"Cryptozoon"</u>	7.5	2.51	6.5	0-29.8
<u>Apterrinella</u>	0.4	0.13	0.5	0-3.0
<u>Fusulinids</u>	9.6	3.20	8.4	0-50.8
<u>Other Forams</u>	0.8	0.28	0.4	0-1.8
<u>Fenestrate Bryozoans</u>	6.8	2.25	2.4	0-16.2
<u>Ramose Bryozoans</u>	0.2	0.06	0.2	0-0.8
<u>Encrusting Bryozoans</u>	0.2	0.08	0.3	0-1.8
<u>Brachiopod Shells</u>	6.6	2.19	1.9	0-9.6
<u>Brachiopod Spines</u>	0.4	0.12	0.3	0-1.8
<u>Molluscs (Pe. & Ga.)</u>	14.4	4.79	5.3	0-20.8
<u>Echinoderm Pls. & Cls.</u>	6.3	2.10	2.0	0-9.0
<u>Echinoid Spines</u>	0.2	0.08	0.2	0-1.2
<u>Trilobites</u>	0.1	0.04	0.2	0-1.0
<u>Ostracodes</u>	0.07	0.24	0.3	0-1.6
<u>Unknown Skeletal</u>	21.4	7.11	5.9	1.2-42.0
<u>Total Skeletal</u>		33.25		
<u>Mud</u>		65.65	11.3	34.4-89.6
<u>Spar Calcite</u>		1.21	2.5	0-14.6
<u>Intraclasts</u>		0.03	0.2	0-1.0
<u>Terrigenous Silt</u>		0.40	1.5	0-9.0

This zone, commonly only several inches thick, is much more fossiliferous than the bulk of the facies. The mud matrix at the base of the Toronto generally contains fine terrigenous silt and particles of terrigenous silt are present in the Osagia coatings suggesting that the Osagia coating had adhesive qualities similar to the mucilagenous properties of Recent blue-green algal stromatolites. The Osagia coatings are developed more or less symmetrically about the nuclei, there is little preference in terms of preferred nuclei, and the coated grains are developed as single grains. Many of the fusulinids are broken and appear worn, as if by mechanical abrasion.

This subfacies shows a mean skeletal grain percentage of 33% and 66% mud. More different grain types were recognized from this subfacies than any other Toronto facies or subfacies. Osagia coated grains make up 7% R. and 20% B. Fusulinids, fenestrate bryozoans, brachiopod shells, molluscs, and echinoderm segments are present in amounts with means varying from not less than two to not more than five percent of the total rock. Epimastopora, platy algae, and Tubiphytes are characteristic components of this facies although their volumetric contribution to the total rock is less than one percent. Epimastopora appears as fragmental remains, evidently due to postmortem disintegration of the parent plant. Tubiphytes is usually found to be attached to skeletal particles and was obviously a tubular organism that encrusted foreign objects but could grow outward from the object. This is in contrast with the adherent encrusting foram, Apterri- nella, which it most closely resembles. Algal plates, most

closely resembling the genus, Eugonophyllum, are found throughout the geographic extent of this facies. On weathered outcrops, they appear as thin, wavy, potato-chip like objects, usually with their long dimension aligned parallel to the bedding. Bilateral symmetry of the plates is evidence that the alga was an upright rather than an encrusting form (Pray and Wray, 1962, p. 216). The plates were apparently thin but broad and without segments or pores that would have permitted them to grow under agitated water conditions. It appears that where large plates are present and abundant that they must be very near the place of growth and their bedded character was merely the result of compaction of the plant upon burial. At Localities 6A and 22, particularly, platy algae were conspicuous at places on weathered bedding facies. It appears likely that the alga may have been common in the facies but burrowing and scavenging activities of the infauna destroyed their record for the most part. This is suggested by the numerous small blades of spar present in the facies which could not be assigned to either the molluscan or platy algal categories.

Stringy, discontinuous, crinkly, encrusting laminae have been observed in this subfacies at Localities 1 and 22. They may be blue-green algal mats for they lack internal structure and consist of pellets of mud and small skeletal detritus that were evidently trapped and fixed. Spar filled cavities beneath concavities in these structures (Locality 1) contain Tubiphytes which attached to the roof of the cavities and grew downward into the open spaces beneath. The cavities

were filled with spar as one of the final diagenetic processes.

This subfacies contains a small orthid (dalmanellacid) brachiopod tentatively referred to the genus, Rhipidomella, which is not R. carbonaria. This small brachiopod is abundant, especially in the upper portion of the facies, and was noted at the following Localities: 12, 11, 22, 13A, 9, 20, 25 and 1. It bears some resemblance to Rhipidomella transversa King 1931.

Megafossils identified from the subfacies are numerous. The brachiopods include: Meekella, Composita, Neochonetes, Neospirifer, Rhipidomella, Linoproductus, Beecheria, Hystriculina, Cond Rathyris, Wellerella, Echinoconchus, Cancrinella, Hustedia, Derbyia, Derbyoides, Antiquatonia, and Crurithysis. The molluscs include: Wilkingia, "Aviculopecten", Parallelodon, Naticopsis, cf. Glabrocingulum, and Camptonectes?. Lophophyllid and syringoporid corals are present in addition to coelcladid and Girtyocoelia sponges, crinoids, fusulinids, and encrusting, ramose, and fenestrate bryozoans.

The contact with the overlying fenestrate bryozoan-echinoderm grain facies is gradational.

Depositional Environment

The mixed biota subfacies contains fusulinids, solitary corals, fenestrate and encrusting bryozoans, a varied brachiopod fauna, and crinoidal debris which indicate an open marine environment. The presence of the algae, Osagia,

Eugonophyllum, Girvanella, and Tubiphytes, in this facies indicates well-lit waters. The diverse fauna is indicative of conditions favorable for benthonic organisms such as good water circulation with an abundant food supply. The high percentage of mud present and the regular even bedding indicate that water motion must have not been rigorous enough to repeatedly disturb the bottom.

As noted above, the base of the Toronto Limestone contains a thin skeletal grain-rich zone at numerous localities from Coffey County to Leavenworth County, Kansas. Terrigenous silt is not only present in the matrix but some grains are included in Osagia coatings. This indicates that Osagia must have been a blue-green algal association with sediment-fixing properties. This thin zone is commonly developed on top of nonmarine beds and is probably a thin shore zone accumulation.

Many of the Osagia-coated skeletal grains present in this subfacies appear disfigured beneath the coatings. The irregular pits and holes are invariably filled with Osagia. Skeletal grains lacking coatings generally have smooth unaltered peripheries. Thus, the Osagia colonies are interpreted to have contained colonial components, probably green algae, that bored into the nuclei. Some nuclei are so badly bored that they were at first considered to have been recrystallized. Plate XIV, Fig. B, shows several fusulinids in different stages of alteration; were it not that transitional specimens are present, some of the fusulinids would never have been recognized. Borings associated with Osagia colonies are so common in this subfacies as to suggest that the origin of

some of the lime mud may have resulted through coating and complete boring of skeletal grains followed by disintegration of the *Osagia* colonies upon destruction of the nuclei by boring algae.

Organic crusts in this subfacies (see Plate XVI, Fig. A and Plate XVII, Fig. b) have been seen at several localities (notably 6A, 1, and 22). These crusts are made of mud-sized carbonate grains that appear to have been trapped and fixed. Thus they strongly resemble blue-green algal mats so common in intertidal areas of modern ponds, lakes, and oceans, and a similar origin is indicated.* Some of the mats were wrinkled and produced small cavities beneath them in which a tubular encrusting organism Tubiphytes grew. Tubiphytes has been presumed to be a calcareous alga. However, the presence of the organism in cavities indicates that it may have been able to thrive in the absence of light and may not have been alga but was perhaps a hydrozoan.

*The writer has observed some interesting and pertinent growth habits of blue-green algal "pond scum" in an irrigation reservoir near Houston, Texas. The scum develops a mat-type growth habit along the sides of the canal in quiet waters. In the center of the canal, the current is too swift for mat development but attached oncolite-type growth takes place on sticks or twigs that protrude above the bottom. Elsewhere true free-forms or oncolites occur in calm water areas; it is clear that these are formed by dislodging of the attached forms and transportation to areas of quiet-water where growth continues. It seems reasonable that some of the "Cryptozoon"-type forms present in the Toronto may have originated in a somewhat similar manner; a burrowing infauna might have destroyed most of the evidence of algal mats, but growth of some of the algal colonies on large nuclei that projected above the bottom would be preserved. Thus, it may well be that the oncolites formed under normal marine conditions where a healthy infauna prevailed and stromatolites were restricted to those facies where the environment was inhospitable for an infauna--i. e., brackish or hypersaline environments.

If the crusty organic mats are indeed algal stromatolites it is possible that they developed in extremely shallow waters (less than six feet or so) as Recent stromatolites do. Cracks in the mud beneath the crusty mats and the blocky nature of this mud may have resulted from shrinkage and consequent drag of the mat over partially dehydrated lime mud. This would suggest subaerial exposure that would account for the features described. If these observations and interpretations are correct, then the mixed biota subfacies must have been deposited in exceedingly shallow yet "normal" marine waters. It might be argued that the medium to thick, but discontinuous bedding characteristics of this facies are a consequence of deposition in very shallow waters with local muddy shoals. The clotty or coherent nature of mud in this subfacies suggests that mucilaginous organic material (blue-green algae?) may have completely covered the bottom and protected the fine sediments from the winnowing activities of waves and currents.

Skeletal Mud Facies - Molluscan-"Cryptozoon" Subfacies

Description

This subfacies is developed above the echinoderm-fenestrate bryozoan grain facies in the northern Elk County to Coffey County, Kansas, region. It is very closely related to the two afore described subfacies, but does not contain as many Epimastopora, Eugonophyllum, and brachiopod grains as the mixed biota subfacies or the Osagia-rich subfacies. In addition, it has several percent more molluscan and "Cryptozoon" material than its subfacies relatives.

TABLE 9

VOLUMETRIC COMPOSITION OF
SKELETAL MUD FACIES, MOLLUSCAN-^{*}CRYPTOZOON^{*} SUBFACIES

n = 19	Biota Mean	Rock Mean	Standard Deviation	Observed Range
<u>Epimastopora</u>	0	0	0	0
<u>Platy Algae</u>	0	0	0	0
<u>Tubiphytes</u>	0.5	0.15	0.4	0-1.6
<u>Osagia</u>	15.0	4.56	6.8	0-24.6
<u>Algal Mat</u>	0	0	0	0
<u>[*]Cryptozoon[*]</u>	14.7	4.46	8.7	0-29.0
<u>Apterrinella</u>	0.3	0.08	0.1	0-0.4
<u>Fusulinids</u>	6.2	1.87	4.4	0-17.4
<u>Other Forams</u>	0.9	0.27	0.3	0-0.8
<u>Fenestrate Bryozoans</u>	7.4	2.24	1.7	0.2-6.2
<u>Ramose Bryozoans</u>	1.6	0.49	1.7	0-7.4
<u>Encrusting Bryozoans</u>	0.8	0.24	0.6	0-2.6
<u>Brachiopod Shells</u>	2.7	0.82	1.5	0-6.6
<u>Brachiopod Spines</u>	0.1	0.04	0.1	0-0.4
<u>Molluscs (Pe. & Ga.)</u>	20.6	6.24	4.7	0-15.2
<u>Echinoderm Fls. & Cls.</u>	5.0	1.51	2.4	0-10.8
<u>Echinoid Spines</u>	0.1	0.03	0.1	0-0.4
<u>Trilobites</u>	0	0	0	0
<u>Ostracodes</u>	0.4	0.13	0.2	0-0.4
<u>Unknown Skeletal</u>	23.7	7.19	3.8	1.8-16.8
<u>Total Skeletal</u>		30.32		
<u>Mud</u>		67.79	13.6	34.2-85.8
<u>Spar Calcite</u>		1.63	4.5	0-20.0
<u>Intraclasts</u>		0.04	0.1	0-0.6
<u>Terrigenous Silt</u>		0.01	0	0-0.2

The "Cryptozoon"-molluscan subfacies is present only in southern Kansas but is absent south of south Elk County. At Locality 6A, one bed included within it is a grain-supported, spar-cemented, fusulinid-rich limestone about one foot thick that is characterized by well-developed scour-and-fill-cross-stratification. North of Locality 6A, however, the "Cryptozoon"-molluscan subfacies is more homogeneous containing about 30% skeletal debris and 68% mud.

Macrofossils collected from this subfacies are chiefly brachiopods although a solitary coral and a few molluscs were observed. The brachiopods include: Derbyia, Hystriculina, Crurithyris, Antiquatonia, Rhipidomella carbonaria, Meekella, Neochonetes, Condrathyris, Neospirifer, Hustedia, Echinoconchus, Composita, and Linoproductus. The molluscs are Wilk-
ingia, Aviculopinna, and naticopsid and pseudozygopleurid gastropods. Lophophyllidid corals, bryozoans, and echinoderms were observed also.

Depositional Environment

The high percentage of lime mud and thin, even bedding suggest quiet waters. The limited geographic distribution of the subfacies indicates that the seas were not as widespread during deposition of the molluscan-"Cryptozoon" subfacies and they were probably not as subject to wave action as intense as might be suspected for the mixed biota subfacies owing to the reduced fetch. Thus, shallow waters probably covered the sediments. The waters were apparently open marine for good marine indicators such as corals, bryozoans, brachiopods, and

echinoderms are present throughout these beds. In addition, the only cephalopod collected from the Toronto was taken from this subfacies at Locality 1; cephalopods are invariably found in open marine beds elsewhere in the geologic column and thus offer corroborative evidence. Other indications of extremely shallow waters for this subfacies are provided by a slender fusulinid grainstone that is characterized by scour and fill cross-bedding at Locality 6A and by grainstones at Locality 3.

The algal biscuits, discussed previously, occur at the top of this subfacies at Locality 20. Their presence clearly indicates very shallow depositional conditions.

Of all the Toronto facies or subfacies, the "Crypto-zoon"-molluscan subfacies is the most heterogeneous in terms of fabric and rock type. This is presumptive evidence of generally shallow nearshore waters.

Skeletal Mud Facies - Osagia-rich Subfacies

Description

This subfacies is laterally equivalent to the mixed biota subfacies, extending from northern Leavenworth County, Kansas, to the Platte River Valley in Nebraska. It ranges from two to about four feet in thickness.

The Osagia-rich subfacies contains about 35% skeletal grains and 62% mud. The most abundant biotic element is Osagia which constitutes 13% R. and 38% B. Fusulinids, fenestrate bryozoans, brachiopod shells, and molluscs each make up two to five percent R. and six to 12% B. The chief

TABLE 10

VOLUMETRIC COMPOSITION OF OSAGIA SUBFACIES,
SKELETAL MUD FACIES

n = 6	Biota Mean	Rock Mean	Standard Deviation (R)	Observed Range (R)
<u>Epimastopora</u>	0	0	0	0
<u>Platy Algae</u>	0	0	0	0
<u>Tubiphytes</u>	0	0	0	0
Osagia	36.9	13.20	8.8	4.2-24.4
Algal Mat	0	0	0	0
Cryptozoon	0	0	0	0
<u>Apterrinella</u>	0.5	0.17	0.3	0-0.8
Fusulinids	8.4	3.00	2.7	0-6.0
Other Forams	0.5	0.17	0.2	0-0.6
Fenestrate Bryozoans	6.1	2.17	2.0	0-5.0
Ramose Bryozoans	0	0	0	0
Encrusting Bryozoans	0	0	0	0
Brachiopod Shells	8.1	2.97	1.6	1.4-5.8
Brachiopod Spines	1.2	0.43	0.3	0-0.8
Molluscs (Pe. & Ga.)	12.6	4.13	3.8	0-9.8
Echinoderm Pls. & Cls.	4.5	1.60	1.1	0.2-3.2
Echinoid Spines	0.2	0.07	0.1	0-0.2
Trilobites	0	0	0	0
Ostracodes	0.2	0.10	0.2	0-0.4
Unknown Skeletal	21.0	7.70	4.8	3.0-14.0
Total Skeletal		35.71		
Mud		61.70	10.6	45.4-74.2
Spar Calcite		1.40	3.2	0-8.0
Intraclasts		0.40	1.0	0-2.4
Terrigenous Silt		0.03	0.1	0-0.2

distinctions between this subfacies and the mixed biota subfacies are the greater percentage of *Osagia* in the former, and the presence of Epimastopora, Tubiphytes, and platy algae in the latter.

On outcrop, the *Osagia*-rich subfacies is light gray when fresh, weathering buff to brown. Green shale stringers are common. Skeletal material is patchily distributed; in some places it is sparse but abundant in others; these gradations occur within a single bed at Localities 10 and 15. This subfacies appears as a single massive bed at Locality 15 but where deeply weathered, other bedding surfaces may appear although they are not strongly developed. It is represented by several beds in Nebraska.

Megafossils identified from the *Osagia*-rich subfacies are mainly brachiopods. The brachiopods present include: Composita, Neospirifer, Antiquatonia, Hystriulina, Lino-productus, and Neochonetes. The molluscs "Aviculopecten" and Myalina are present in the basal inch or so of the limestone at Locality 10.

Depositional Environment

This subfacies is characterized by the comminuted texture of skeletal grains and abundance of *Osagia* coated grains. This latter suggests better illuminated, more turbulent, and presumably shallower waters during deposition of the *Osagia* subfacies as compared to the mixed biota subfacies. The fauna is nonetheless marine although it appears to have been not quite diverse as in the mixed biota subfacies; this suggests slightly more restricted conditions,

probably lower salinities, than those attending the deposition of the mixed biota subfacies. Supporting evidence for the latter interpretation may be inferred from the relatively high percentage of molluscan shells in this facies, many of which are coated with *Osagia*, present at Localities 14 and 14A.

Lime Mud Facies

Description

From Douglas County, Kansas to Buchanan County, Missouri, and in Cass County, Nebraska, a unit of lime mud bearing only ostracodes and molluscs occurs at the top of the Toronto Limestone. The mudstone varies from approximately a foot or so to several feet in thickness. At Localities 22 and 11 at Lawrence, Kansas, the contact between the lime mud facies and the underlying fenestrate bryozoan-echinoderm grain facies is irregular and wavy, with immediate local relief of one-half foot or thereabout. Bedding within the mudstone facies at these localities is thin, irregular, and discontinuous with lithologic associations separated by bedding surfaces. Elsewhere the contact with the underlying beds is an apparent planar bedding surface (Localities 14 and 15), or, apparently, is transitional (Locality 12).

At the outcrop, the facies is a light gray homogenous mudstone that locally contains intraclasts or mud pebble conglomerates. Fossils recovered from the facies include sponge spicules, ostracodes, Bellerophon (Pharkidonotus)

TABLE 11

VOLUMETRIC COMPOSITION OF
LIME MUD FACIES

n = 11	Biota Mean	Rock Mean	Standard Deviation	Observed Range
<u>Epimastopora</u>	0	0	0	0
Platy Algae	0	0	0	0
<u>Tubiphytes</u>	0	0	0	0
Osagia	0	0	0	0
Algal Mat	0	0	0	0
"Cryptozoon"	0	0	0	0
<u>Apterrinella</u>	0	0	0	0
Fusulinids	0	0	0	0
Other Forams	0	0	0	0
Fenestrate Bryozoans	0	0	0	0
Ramose Bryozoans	0	0	0	0
Encrusting Bryozoans	0	0	0	0
Brachiopod Shells	0	0	0	0
Brachiopod Spines	0	0	0	0
Molluscs (Pe. & Ga.)	19.2	0.51	1.3	0-4.4
Echinoderm Fls. & Cls.	7.5	0.02	0.1	0-0.2
Echinoid Spines	0	0	0	0
Trilobites	7.5	0.02	0.1	0-0.2
Ostracodes	13.2	0.35	0.4	0-1.4
Unknown Skeletal	63.8	1.76	1.8	0-5.0
Total Skeletal		2.66		
Mud		90.64	6.6	41.8-99.6
Spar Calcite		2.16	5.5	0-18.2
Intraclasts		0.45	1.0	0-2.6
Terrigenous Silt		0.89	2.6	0-8.6

sp., Euphemites sp., Murchisonia sp., Nuculana sp., Goniasma sp., Wilkingia terminale, Solemya cf. S. radiata, "Aviculopecten" sp., Myalina sp. cf. M. (Orthomyalina) slocomi, and Septimyalina sp. cf. S. scitula. In addition, irregular impressions occur at places in the facies; the impressions are elongate and sinuous and reminiscent of kelp or brown algae of the laminarian type of modern intertidal zones.

Lime mud constitutes about 80 to 95 percent of the facies. Skeletal debris, chiefly molluscs and ostracodes, are present in amounts ranging from 5 to 20 percent. At Locality 11, local lenses of well-sorted unidentifiable skeletal debris (calcarens) occurs which is cemented by sparry calcite. These lenses contain intraclasts and patches of calcarens with a lime mud matrix.

Depositional Environment

The lime mud facies accumulated under conditions that departed significantly from open marine conditions. The contact with the underlying fenestrate bryozoan-echinoderm grain facies is interpreted as at least locally disconformable and was a result of erosion, probably on an exposed marine flat (perhaps a tidal flat). The well-sorted calcaren-sparite (my term) with their included intraclasts are most probably beach deposits. The predominantly molluscan fauna suggests environmental conditions for which corals, bryozoans, brachiopods, and echinoderms were not adapted--these conditions must have involved restricted marine conditions. The lithologies and microfaunas of the overlying beds in addition to analogies with modern facies patterns all suggest brackish water conditions.

CYCLIC SEDIMENTATION

Kansas Cyclothems

In Kansas, three basic types of simple sedimentary cyclothems and two types of megacyclothems or cycles of cyclothems have been recognized in the Pennsylvanian-Lower Permian sequence. The cyclothems appear in different parts of the column and have been named for the groups of strata in which they occur. (Moore, 1950.)

The simple cyclothems include the Cherokee (Desmoinesian), Wabaunsee (Virgilian), and Council Grove (Wolfcampian) types. The Cherokee cycle contains a basal sandstone which is succeeded by an ascending sequence that includes a shale, an underclay, a coal, a black shale, a limestone, and a marine shale; individual cyclothems can be traced for great distances with the most persistent units being coal beds and overlying black shales. The Wabaunsee cyclothem consists of a sandstone, shale, coal, shale, limestone, and shale in successional order; the cyclothem is distinguished by the lack of black platy shale and the extreme lateral persistence of thin coal beds and especially the limestones. The Council Grove cyclothem is similar to the Wabaunsee type but differs from the latter in having a persistent red shale in place of the sandy deposits; the cyclothem is mainly distinguished by the persistent red shales and limestones.

The complex cycles are the Shawnee (Virgilian) and Chase (Wolfcampian) types. The Shawnee megacyclothem, of which the Oread megacyclothem is a representative, consists

of five limestones and intervening shales--lower limestone (Toronto), shale (Snyderville), middle limestone (Leavenworth), black shale (Heebner), upper limestone (Plattsmouth), shale (Heumader), super limestone (Kereford), shale (Jackson Park), fifth limestone (Clay Creek), and shale. The middle limestone, black shale, and upper limestone are present in 15 of 16 recognized Shawnee ^{type} megacyclothems (Weller, 1958). The middle limestone is the only one of the three members missing from a single megacyclothem although the lower limestone is present in only seven of the 16 examples. The super limestone is present in 10 and the fifth limestone in three of the complex cyclothems. The Chase type megacyclothem differs from the Shawnee type principally in lacking a black shale member.

Published Theories on the Origin of Cyclothems

Numerous theories have been proposed to account for the origin of cyclothems. The most acceptable of these are summarized below:

- (1) Differential Uplift Theory (Hudson, 1924) - each cyclothem was explained by differential uplift of the source area followed by denudation with gradual subsidence of the depositional basin.
- (2) Intermittent Subsidence Theory (Stout, 1931) - intermittent though progressive subsidence of the depositional basin; with very slow subsidence--coal swamp formed; rapid subsidence--deposition of marine limestone

in shallow transgressive sea; decrease in rate of subsidence--maximum basin depth attained and shale and sandstone deposited concomittantly in sea; and, very slow subsidence--depositional surface built up to or above sea level with deposition first of limestone and then of claystone.

- (3) Diastrophic Control Theory (Weller, 1930, 1956, and 1957 - diastrophic cycles that involve both the depositional basin as well as the source areas; pulsating uplift and depression of large continental areas, the magnitude increasing from basin to land areas; the mechanism involved cyclic expansion and contraction of a subcrustal layer (Weller, 1956, pp. 44-46).
- (4) Glacial Control Theory (Wanless and Shepard, 1936) - the evidence of world-wide sea-level changes during the Pleistocene due to alternate advance and retreat of glaciers was used in postulating an analogous mechanism of control for late Paleozoic cyclothems; they postulated continued subsidence in the depositional basin coupled with sea-level fluctuations brought about by continental glaciation in the southern hemisphere.
- (5) Deltaic Shift Theory (D. Moore, 1959) - interplay of a shallow epicontinental sea

and deltas; abandonment of old deltas and initiation of new ones with continued regional subsidence slower than deltaic deposition but continuing after the older deltas built up above sea level gradually resulted in transgression of the older deltaic plains.

- (6) Climatic Fluctuation Theory (Brough, 1928; Beerbower, 1961) - increase in rainfall would increase flood discharges and erosion if upland vegetation was not abundant, whereas if vegetational cover was abundant increased rainfall might result in denser vegetational cover and decreased flood discharges; variations in temperature in connection with precipitation changes would produce complications in discharge, vegetation and weathering; eustatic sea level fluctuations and diastrophic events can also take place but the ultimate control is theorized as being due to climatic cycles.

Principal Considerations in the Development of an Acceptable Theory of Cyclothem Origin

- (1) Cyclic fluctuations in late Paleozoic sedimentation differs from cycles in rocks both younger and older than late Paleozoic in that only in the late Paleozoic are cyclothems so widespread, so definite, and so numerous.

(2) The cyclical nature of late Paleozoic beds has been recognized in an almost continuous belt from Pennsylvania to California. In addition, they have been described in Europe, Asia and Australia, and they may also occur in Africa and South America. Thus, late Paleozoic cyclothem are world-wide in occurrence.

(3) Cyclothem characteristics vary from basin to basin, region to region, etc. and within stratigraphic intervals of the same age. Moore (1959, p. 42-45) has emphasized the stratigraphic equivalence of certain Pennsylvanian rock units in states ranging from Oklahoma to West Virginia and Pennsylvania. Stratigraphic studies across the continent have shown that marine limestones prevail in Arizona, New Mexico, and Kansas but farther east calcareous shales are more prominent than limestones, and marine fossils are typically found in terrigenous sediments of Illinois, Ohio, and West Virginia (Wanless, 1950, p. 20-21). In addition, there is a fairly progressive change from an almost totally marine column in Arizona and southwestern New Mexico to a column that is about half marine in Kansas, one-fourth marine in Illinois, and is a maximum of about five percent marine in West Virginia (Wanless, 1950, p. 20). Thus terrigenous sands, silts, and shales, mostly nonmarine, and intercalated coal seams are prevalent in the Appalachian cyclothem; however, they are replaced laterally to the west in the Eastern and Western Interior Basins by marine limestones and calcareous shales, with coals and nonmarine clastics playing a lesser role.

However, within any of the regional segments, local facies variations may exist.

As an example, consider briefly the characteristics of Desmoinesian strata. In the Appalachian Region sandstones, shales, and coals predominate and limestones are scarce (Allegheny Series). In the Eastern Interior Basin, sandstones are much less prominent but limestones are well developed and coal beds are characteristic although slightly less numerous. In the Western Interior Basins, terrigenous clastics predominate although well-developed limestones are intercalated in the section and coal beds are not as well developed as in the Appalachian and Eastern Interior Basins. The Desmoinesian of the Paradox Basin of the Four Corners Region is represented on the west by cyclothems made up of black shale, dolomite, limestone, anhydrite, salt, and very thin sands and silts (Paradox Formation); on the eastern side of the basin arkosic and clastic debris dominate over carbonates and grade into the evaporite section (Peterson and Ohlen, 1962, p. 70). These relationships are suggestive of a climatic gradient from east (humid region) to west (arid region).

Postulated Cause of Late Paleozoic Cyclothems

The cyclothems of the Pennsylvanian and Permian are unique when compared with cyclothems present in other parts of the geological column in that the former are so thin, yet so definitive, so laterally extensive and so numerous. The world-wide occurrence of the cyclothems means that the ultimate cause of cyclicity must have been operative on a world-wide scale. Regional variations in lithology are taken as

proof of local climatic and tectonic influence. The essential flatness of the land surfaces in many regions is indicated by great geographic extent of individual beds of coal, some having been traced for several hundred miles in the eastern portion of the United States. All of this leads to the inescapable conclusion of the advance and retreat of shallow seas onto most if not all of the continents during the Pennsylvanian. However, it is clear that cyclothems were developed through oscillations of the seas across the continents not only in the late Paleozoic but throughout geologic time.

The uniqueness of late Paleozoic cyclothems is viewed by the writer as a consequence of the unique interplay of several factors and not to any abnormal process of the time. The presence of cyclothems of the same age in widely separated parts of the world can only be explained by an underlying cause that affected deposition world-wide. The Pleistocene record has clearly shown how deposition can be modified and controlled by eustatic sea level fluctuations caused by the waxing and waning of glaciers. There is evidence of widespread carboniferous glaciation in the southern hemisphere (Wanless, 1963) so that appeal to glaciation as the underlying control on sea level fluctuations is plausible.

Perhaps the most significant factor in causing the unique development of the Pennsylvanian-Permian cyclothems was not sea level fluctuations per se, but the fact that they were operative during a period of continental evolution when large epicontinental seas were extensive not only in North America, but in Europe, Asia, Australia and perhaps other

continents as well. (The lack of cyclothems in the Pleistocene that would compare in geometry with those of the later Paleozoic may be attributed to evolution of the continents which had eliminated all the epicontinental seas by Pleistocene time). It is significant that numerous well-developed Plio-Pleistocene cyclothems containing terrigenous sandstones and mudstones, lignites, and limestones have recently been reported from New Zealand (Vella, 1963a, 1963b). Four major Pleistocene sedimentary sequences are present in the Gulf Coastal Plain of Texas that correspond with the major glacial and interglacial stages (Bernard, LeBlanc, and Major, 1962); thus the existence of Pleistocene cyclothems has been demonstrated.) Frequent movements of the strand line back and forth across the epicontinental depositional basins, at rates that generally exceeded the rate of supply of terrigenous detritus would have through the extreme energy conditions at the shoreline, tended to eliminate topographic irregularities and produced very gently seaward sloping depositional surfaces. If the probability of differing rates of sediment supply and basinal subsidence are considered not only for the different continents of the world but for the different regions and even local areas within these, then it is easy to visualize that variations in types, kinds, and numbers of cyclothems would result.

As thus conceived, the writer's theory is based upon the formation of sedimentary cycles by eustatic changes of sea-level affecting slowly subsiding depositional basins as

advocated by Wanless and Shepard (1936) but with differing rates in subsidence and sediment supply for different regions and different locales within a region as well as climatic variations superimposed on eustacy so that the result would be variations in number, types, and kinds of cyclothems. It is also conceivable that major tectonic movements could effect some sea-level changes but not enough to be considered as the main control mechanism.

In the northern Midcontinent region of the United States, the transgressions and regressions moved over a surface of many thousands of square miles in area. Terrigenous sediments were generally deposited near the shoreline or in nonmarine environments and were laid down as sheet-like deposits because the combinations of sea level fluctuations and basinal subsidence commonly exceeded the rate of supply of land derived sediments. The limestones were generally deposited offshore in the shallow seas where the rate of influx of terrigenous sediment supply and distribution of these materials in the seas was such that generally equilibrium conditions were attained. The portions of the basin farthest seaward were generally lower in elevation than the shoreward zones (basin periphery) as a consequence of the depositional pattern. Thus, the surfaces over which the transgressions and regressions moved sloped gently and evenly seaward just as a bathtub slopes toward its drain. The sediments deposited in such a sea must be time-transgressive although the surfaces of synchronicity may pass through the beds at very low angles.

The lack of consistency and uniformity in the development of the cyclothem in Kansas and elsewhere can be attributed to variations of geography, climate, and tectonics from region to region as well as the dynamics of the aforementioned factors and others in the stratigraphic succession of any region. Certainly sea level fluctuations are not to be postulated for each cyclothem seen in the column because oscillations may also be caused by variations in the rates of subsidence and supply of sediments. Deltaic deposition, for example, coupled with uniform subsidence can result in oscillations of the sea due to shifting of distributaries and sub-elevation in areas of previous heavy sedimentation (Scruton, 1961). Deltas played a significant role in deposition in the Kansas Sea but distributary shifts cannot be invoked to explain the development of the Oread, and other megacyclothem, sequences. Deltas were most certainly present in northern Oklahoma during Oread deposition, but regional stratigraphic evidence in addition to the differing lithologic character of each of the Oread members can only be explained by rapid fluctuations of regional base level due to eustatic fluctuations of sea level.

The existence of different types of cyclothem in the Kansas Pennsylvanian-Permian succession is undoubtedly a consequence of a changing sedimentary framework and climate through time. The Pennsylvanian and Permian beds of the northern Midcontinent Region constitute a major transgressive-regressive couplet which is a genetic unit of sedimentation.

Beds of Desmoinesian Age represent a stage in regional transgression in Pennsylvanian time. The transgression reached its maximum extent during the Missourian and marine beds of this age are well developed not only in Kansas but in the Eastern Interior region of Illinois. Regional regression began in the Virgilian and continued through the Permian as evidenced by the widespread deposition of evaporites and red beds during the Leonardian and Guadalupian. In view of these changing conditions of sedimentation through time, the recognition of different types of cyclothems in the succession is to be expected.

In summary, the uniqueness of Late Paleozoic cyclic sedimentation as compared to cyclicity elsewhere in the geological column is indicative of the interplay of several major factors. These are sea level fluctuations, a stage in evolution of the continents when vast epicontinental seas flooded the interiors of continents, and tectonism expressed by subsidence of the basins and elevation of adjacent areas which served as source terrains for terrigenous detritus. Thus, each and every cyclothem is not to be interpreted as a result of eustatic sea level fluctuation. Different rates of subsidence and sediment supply within a given basin in conjunction with eustatic sea level fluctuations would complicate the picture in terms of the number of cyclothems recorded by sedimentation.

SEDIMENTOLOGIC SIGNIFICANCE OF THE
TORONTO LIMESTONE AND ASSOCIATED UNITS

General

During Virgilian time, Kansas and parts of surrounding states were occupied by a shallow interior (epeiric) sea. Highland areas at the west of the seaway included the Ancestral Rocky Mountains, the Apishapa Uplift, and the Sierra Grande Arch. The Amarillo, Wichita, and Arbuckle Uplifts were highland areas to the south as were the Ouachita Mountains which had been uplifted prior to the Virgilian. To the north, the Siouxia Arch was a low lying land area and to the east, the low plains of the Ozark Dome formed the margin of the sea. At times, the seaway may have been connected with the Illinois Basin across Iowa; however, regional thinning and facies changes within the Virgilian units from Kansas to Iowa indicates that connection with the Illinois Basin was a periodic rather than a permanent feature. Evaporites are present in the Virgilian of the Hartville Uplift and in the Powder River Basin. Thus, the main access of marine waters into Kansas was through a narrow connection, here termed the Panhandle Straits, between the Apishapa-Sierra Grande and Amarillo massifs.

The Toronto Limestone, Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone can be recognized widely throughout Kansas. In southwestern Nebraska, Red Willow County, the Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone are present but the Toronto is not. In

southwestern Kansas, the various members of the Oread have been recognized to the Oklahoma line. Rascoe (1962, p. 1364) has noted that the Oread Limestone is extensive over both the Kansas shelf and Anadarko Basin. A predominantly carbonate composition of the Shawnee Group (in part Oread) exists between the Amarillo and Apishapa-Sierra Grande uplifts, but it changes toward each of these positive areas to an interbedded limestone and shale and, finally, passes into arkosic clastics that mantle the massifs.

The Kansas Sea may have been connected with the Illinois Basin during deposition of the Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone for these three members are well-developed in southwest Iowa. The Toronto Limestone, however, is absent at the localities where the members listed above are present. The stratigraphic position of the Toronto is represented by shales at the same localities.

Hydrographic properties such as waves, tides, and currents were almost certainly not as pronounced in the Kansas interior sea as those observed in the marginal seas of the Florida-Bahama region today. Ginsburg (1964, p. 564) shows a mean tidal range of about two feet for the Florida Reef Tract and an abrupt decline of tidal range at the Florida Keys into Florida Bay where the mean tidal range is less than 0.2 foot. The Kansas Sea was many miles away from oceanic waters where large waves and tides and strong currents are generated. This deduction is substantiated by the relative lack of high energy deposits, beach and shoal, in the Toronto, Leavenworth, and Plattsmouth limestones as compared with modern sediments of

the Florida-Bahama region.

From studies of the Recent, it has been found that deltas are especially characteristic in seas where the tidal range is insignificant, for example, in the Mediterranean (Rhône, Ebro, Po, Nile, etc.) in the Baltic (Weichsel), and in the Gulf of Mexico (Mississippi), because such conditions do not permit wide dispersal of sediment carried to the sea (Guilcher, 1964, p. 620). The role of deltas in the sedimentary framework of the Mid-Continent Pennsylvanian was an important one, especially in eastern Oklahoma where the carbonate units, so widespread in Kansas, undergo facies change to clastics brought in from the highland areas to the south.

Toronto Limestone

Sedimentary Framework

Deposition of the Toronto Limestone began following a period of regression and emergence after deposition of the Amazonia Limestone. The Amazonia lies about 40 feet beneath the Toronto. Widespread unfossiliferous red shale and bluish-gray silty shales bearing woody plant material, charophyte oogonia, and smooth-shelled ostracodes are evidence of continental to marginal marine sedimentation prior to Toronto deposition. The Upper Williamsburg coal is present in the same interval; coal is present in the same stratigraphic position in the subsurface of Kansas as far west as Wichita, approximately 50 miles basinward of the outcrop belt. Thus the Wathena Shale must represent a regression during which

coastal plain clastics deposition prevailed. The widespread occurrence of coal and the fact that the coal is apparently a single stratigraphic equivalent bed (no two coal beds have been observed in any section) makes it similar in geometry to certain peat deposits in the Chenier Plain of Louisiana (Gould and Morgan, 1962, pp. 292-326). In addition, the remainder of the sequence so similar to the lithologic sequence seen in the Chenier Plain that this Pennsylvanian coal is considered to be an analog of the Chenier Plain peats; that is, it represents a marshland surface built up in an area that probably bordered a relatively large delta. This delta was situated in western, or west of, Osage County, Oklahoma, because directional trends in channel sandstones of continental origin in the Vamoosa Formation, in part stratigraphically equivalent to the Lawrence and Oread formations, converge from northwest, and southwest flowing direction in central Osage County (Hicks, 1963). As thus interpreted, the present outcrop line of the upper Lawrence Shale, Toronto Limestone, and Snyderville Shale transects the interdeltic plain marsh deposits of the upper part of the Lawrence Formation in central and southern Kansas and cuts across the upper or subaerial portion of the Vamoosa delta in Osage County, Oklahoma. This explains why coals analogous to the interdistributary peats of the modern Mississippi River delta have not been found in Oklahoma.

Deposition of the Toronto Limestone began with a rapid transgression of a marine sea over the deltaic and interdeltic plain sediments of the upper Lawrence Shale.

Rapid transgression is indicated by the general lack of a well-developed and thick marine clastic interval at the base of the Toronto over most of central and southern Kansas; a thin zone (less than 6 inches in thickness) of abundant small robust fusulinids and brachiopod shells (mainly Neochonetes and Derbyia) with a matrix of terrigenous silt and lime mud is present at the base of the Toronto in this region. Most of the skeletal material from this zone bears *Osagia* coatings. The zone is interpreted as littoral and near littoral zone accumulation.

In southern Kansas, the Toronto Limestone grades or intertongues with marine and brackish water shale and sand deposits. The major source of this terrigenous material was apparently supplied by the mountainous areas (Arbuckles and possibly the Ouachitas) of southern Oklahoma and Arkansas. In northeastern Kansas and northwestern Missouri, marine to brackish water shales occur at the base of the Toronto Limestone. The Ozark Dome presumably furnished most of the clastics. However, in Nebraska the shaly material present in the lower part of the Toronto must have been provided by the Siouxi land mass.

Thus, as the Toronto transgression passed over the former sites of coastal plain deposition in the Lawrence Shale, the rate of supply of terrigenous sediment was not able to keep pace with the relatively rapid rise of sea level so that carbonate deposition commenced. As thus interpreted, the relationship of thalassigeneous carbonate and terrigenous clastic sedimentation is analogous to present

conditions of sedimentation in southern British Honduras:

(1) in southern British Honduras terrigenous sands and muds are accumulating at and near shore in those areas where terrigenous material is available, and carbonate deposition is taking place offshore where the rate of terrigenous influx is low; and (2) in northern British Honduras a negligible amount of terrigenous detritus is supplied to the sea so that carbonate deposition can take place up to the shore line. In this respect, the conditions of Toronto Limestone deposition are analogous to those seen in British Honduras today. Thus, other factors being equal, the major factor involved in the deposition of carbonate sediments is related directly to the rate of terrigenous sediment supply to a basin.

The environmental factors interpreted to have exerted a greater influence than others in the development of the Toronto Facies include: (1) the rate of detrital sediment supply from the land areas; (2) the supply of nutrient minerals furnished to the sea by runoff from the land; (3) salinity which is related to circulation within the basin and to climate; and (4) turbulence which is related not only to depth but to circulation patterns.

The parameters listed above are interpreted as the major parameters responsible for facies variations. However, the ultimate controls on the deposition of the Toronto Limestone must have included: (1) subsidence in the region of the Kansas Sea; (2) transgression of marine waters, followed later by regression; (3) climatic influence; (4) evolutions of organisms; and (5) biogeography.

There are indications that the framework of Toronto deposition involved essentially a delta or deltaic complex in northern Oklahoma where terrigenous deposition prevailed, a near delta region of land derived mud deposition adjacent to the delta in southern Kansas, and a region of carbonate deposition that occupied most of Kansas and adjacent parts of Nebraska, Missouri and possibly southwestern Iowa.

Environmental Significance of Terrigenous Facies

As stated above, the clastic sequence in Oklahoma equivalent to the Toronto Limestone is interpreted as the upper reaches or subaerial plain of a delta. This is based upon the convergence of channels in Osage County, the association with the channels of unfossiliferous red and green shales which are apparent flood plain rather than interdistributary channels, and the lack of coals in association with the channels which would be evidence of interdistributary deposition. One important feature of some of these channels in Osage County noted by the writer, is the presence of fossiliferous zones in the bottoms of the channels. The fossils include bryozoans and brachiopods which are indicative of marine conditions. This may not be as paradoxical as it appears when seasonal invasions by wedges of dense, marine waters along channel bottoms is considered. The wedge effect is caused by less dense, low salinity, water flowing over more dense saline water. In northern British Honduras, salt water has been observed as much as 50 miles upstream in the New River during the dry season (Pusey, 1964,

p. 36); further, the occurrence of halophilic red mangroves at least 50 miles upstream in Rio Hondo River suggests that salt water penetration is not short lived. Seasonal wedge effects are also characteristic of the Mississippi River delta (Lankford and Shepard, 1960, p. 416). Thus, the presence of marine fossils in the bottoms of sandstone channels of the Vamoosa Formation in the subaerial topset plain of the delta system has modern analogs.

The relationship of the marine shale beds, laterally equivalent to the Toronto Limestone, with the Vamoosa delta in southern Kansas and northern Oklahoma is interpreted as being analogous to the modern Atchafalaya Bay and surrounding environments which are situated intermediate between the Chenier Plain and the birdfoot delta of the Mississippi River (Gould and Morgan, 1962, Fig. 1, app. p. 287). The Atchafalaya River, the principal distributary of the Mississippi, enters Atchafalaya Bay. However, little sand reaches the bay for the coarse sediments are trapped in its delta located in Grand Lake which lies about 50 miles inland (Fisk, 1956, p. 6); silt and clay are discharged into Atchafalaya Bay and are swept by currents alongshore westward as far as the Sabine River. The marine shale facies in the Toronto interval of southern Kansas and northern Oklahoma is interpreted as having been deposited in a nearshore embayment bordering a deltaic complex such as that described above.

The marine terrigenous mud facies is the most variable of all the Toronto facies in terms of biota. In areas where interfingering with limestone is most pronounced, fusulinids

are very abundant in the facies, and below them brachiopods such as Antiquatonia, Derbyia and Neochonetes are present above the coal. Thus, the fusulinids are not interpreted to have lived exclusively far offshore as has been thought, but were probably ubiquitous. The fusulinids present in the shale are generally small forms that likely lived on non-calcareous plants which kept them free from the unstable muddy substrate.

Elsewhere the terrigenous mud facies lacks abundant fusulinids and is characterized by beds containing abundant myalinid clams that are intercalated with beds bearing abundant Crurithyris, Neochonetes, and Derbyia. These alternations are interpreted as a record of fluctuating salinities, probably due either to shifts in deltaic distributaries or perhaps to climatic variations. The brachiopods lived in areas where marine waters frequented the bottoms, and myalinids are interpreted to have lived on adjacent bottoms attended by brackish waters. In this respect, the myalinids were sessile brackish water organisms that occupied an environment similar to the modern day oyster Crassostrea of Atchafalaya Bay (Termier and Termier, 1963, Fig. 150, p. 263). This situation may be analogous to the fluctuation of salinities during alternating several-year periods of drought and normal conditions along the upper Texas Gulf Coast. During normal years, the salinities of the bays are brackish and the macrofauna is almost exclusively molluscan, but during periods of extended drought the salinities of parts of the bays may approach values of the open Gulf and some Gulf

organisms including small corals invade into the lower parts of the bays (Dr. Thomas E. Pulley, personal communication). Cyclic conditions due to this or to deltaic distributary shifts are thus postulated for the faunal variations in the terrigenous mud facies in the Toronto Limestone.

In summary, the terrigenous mud facies was deposited in shallow, quiet, nearshore waters of variable salinities very close to an active delta. It may be considered as a delta-influenced facies. The main part of the delta probably lay in western or west of Osage County, Oklahoma, as suggested by facies relationships seen at the outcrops.

Environmental Significance of Thalassigenous Facies

A brachiopod-rich zone occurs at both ends of the Toronto outcrop in association with marine shales. The southern occurrence has been termed the brachiopod grain sub-facies because of its high content of brachiopod grains and minor amount of matrix material which is lime mud. At the north, the brachiopod facies contains a relatively high proportion of clay and has been termed the brachiopod marl sub-facies.

Both subfacies accumulated in relatively quiet waters. This is indicated by the preservation of whole and articulated specimens of brachiopods and clams which show little abrasion. External ornamentation such as spines and ribbing is preserved in detail. In addition, a complete crinoid calyx with arms, cup, and column intact was found at the southern end of the outcrop in Oklahoma. The mud matrix present in the facies is additional evidence for quiet water deposition.

The close association of the brachiopod facies with marine shales is interpreted as a consequence of increased nutrient supply in and near the areas of terrigenous influx postulated in Oklahoma and in Nebraska. The vertical sequences in the measured sections suggest that the brachiopod facies accumulated seaward from the areas of marine shale deposition where the rate of terrigenous influx was lower and where the waters were open marine, but had communication with nutrient laden waters coming off the land.

The lack of algae in the brachiopod facies was probably a consequence of relatively high turbidity more than any other factor because algae are present in limestone that accumulated slightly seaward of both subfacies.

The skeletal mud facies was deposited away from the places of greater terrigenous mud influx. It is characterized by fragmented skeletal grains from various organisms. Many of the grains have incipient to well-developed *Osagia* coatings on them. Examination of numerous thin sections of this facies has revealed a predominantly clastic texture of the skeletal remains. Two causal factors can be cited that account for the disarticulated and fragmented remains. These are biological activity and water motion.

Biological activity includes the processes of feeding, excretion, burrowing, and encrusting. Many organisms such as worms, clams, some gastropods, and holothurians burrow into the bottom in search of food or for shelter. Carnivores and scavengers may fragment skeletal material in search of food--the organisms involved include arthropods, gastropods,

pelecypods, holothurians, echinoids, starfish and fish.

Studies of Recent carbonate muds in Northern British Honduras (Pusey, 1964, p. 211) resulted in the conclusion that most of the mud is of skeletal origin due to: (1) skeletal disintegration and (2) skeletal abrasion. Most shells of organisms consist of a mixture of carbonate and organic matter. Decay of the organic matter through bacterial action or oxidation may result in the breakdown of skeletal parts into material of mud size. Abrasion in agitated waters may also account for the production of mud. The amount of worn skeletal sands in the Toronto Limestone are too small to postulate the origin of much mud by the abrasion process. However, one characteristic of most of this facies is gradation from sand and coarser-sized skeletal grains to mud-sized carbonate; and even the distinction between grains and mud had to be based on size alone. Thus, it seems certain that much carbonate mud present in the Toronto Limestone was a product of the breakdown of skeletal material. This could be accomplished in the following ways: (1) through the feeding activities of scavengers; (2) through bacterial attack of organic materials within the grains, and (3) by the boring activities of sponges and green and blue-green algae. The first two cases are self evident; however, let us elaborate upon the latter. Petrographic observations of many *Osagia* coated grains reveal that the nuclei of these oncolites are commonly bored. All gradations from incipient to complete boring were encountered. The material within the *Osagia* colony was bound together by mucilaginous material, thus the colonies were susceptible to disintegration upon

death of the colonies. In this way, many bits and fragments of *Osagia* colonies occur in the Toronto Limestone serving as evidence for the breakdown process.

There is no conclusive evidence of physico-chemical precipitation of carbonate muds in the Recent today, and the carbonate muds present in the Toronto Limestone are easily accounted for without having to invoke the process.

The presence of *Osagia* coated skeletal grains in the skeletal mud facies suggests shallow and better illuminated waters than attended the deposition of the brachiopod facies. However, the development of *Osagia* coatings concentrically about the nuclei in this facies suggests overturning of the grains during growth of the *Osagia*. Thus, these bottoms must have been subjected periodically, at least, to moderate wave or current agitation.

The light gray color of unweathered samples from this facies is indicative of generally very low reducing to perhaps slightly oxidizing conditions. This also indicates that the bottom was at least periodically subjected to some wave or current activity.

The presence of a relatively high proportion of mud-sized carbonate in this facies and numerous *Osagia* coated grains may not be as paradoxical as it appears if much of the mud was generated on the bottom through skeletal decomposition, and algal coating, boring and breakdown as postulated. Thus the high percentage of carbonate mud observed in these rocks may not be a true index to relative current strength. It has long been known that fine sediments are much harder

to erode once they have been deposited than are coarser materials (Hjulstrom, 1935). In addition to small grain size, carbonate muds often contain a great deal of mucilaginous organic matter that would further impede erosion at the bottom.

The three subfacies of this facies--Osagia-rich subfacies, mixed biota subfacies, and the molluscan-"Cryptozoon" subfacies--were deposited under slightly different conditions.

The Osagia-rich subfacies contains more coated grains and less mud than its relatives. This suggests better conditions of illumination and increased substrate mobility for the Osagia-rich subfacies as compared to the other subfacies.

The mixed biota subfacies is characterized by the presence of Eugonophyllum plates although they are not abundant, some Epimastopora fragments, and a crusty organic mat which is developed locally. The mat is apparently closely akin to true algal stromatolites which in the Recent are best developed in the intertidal zone; however, poor development of the mat in the Toronto is interpreted as a consequence of mat development in marine waters where it is not likely to be well-preserved because of (either of) the abundance of burrowing organisms under such conditions or the lack of proper light requirements.

The molluscan-"Cryptozoon" subfacies contains a few interbeds of grainstone (crinoid-bryozoan and fusulinid) in southern Kansas. The fusulinid grainstone contains scour and fill structures which are suggestive of shallow,

agitated conditions. Rapid lateral variation in lithology of this facies is suggestive of nearshore depositional conditions.

The Osagia grain facies is intercalated within the molluscan-"Cryptozoon" subfacies. The Osagia coatings are well-developed and concentric about the nuclei which are broken and rounded skeletal grains. These observations together with the absence of mud are indicative of extremely shallow, agitated, and clear marine waters.

Suspension feeding bryozoans, crinoids, and solitary corals are more abundant in the fenestrate bryozoan-echinoderm grain facies than in any other Toronto Limestone facies. The crinoid columnals are also larger in this facies. The mud content of the facies is less than in any of the other facies except the Osagia facies. The above faunal characteristics are indicative of relatively clear, open marine waters with an abundant supply of suspended food. These characteristics, in addition to the relations of this facies to the others as revealed in measured sections and on the restored cross section, indicate that the fenestrate bryozoan-echinoderm grain facies accumulated in that portion of the sea that was subjected most fully to open circulation. The fusulinids present in this facies are elongate and sub-cylindrical--it is hypothesized that the slender fusulinids may have lived on crinoids and the streamlined nature of the test made it difficult for waters to strip the fusulinids off the crinoids because the fusulinids kept themselves

oriented with their long dimension directed parallel to the direction of water movement. These fusulinids are to be contrasted with the more robust forms that occur in the mixed biota and *Osagia*-rich subfacies.

The lime mud facies is the most restricted of all the Toronto facies. Mud pebble conglomerates, local grainstones, and irregular cut and fill bedding characterize the facies. They indicate extremely shallow, brackish waters with alternating periods of inundation and subaerial exposure. An ostracode and molluscan (*Myalina* sp., *Bellerophon* sp., *Nucula* sp., and *Nuculana* sp.) fauna are characteristic of this facies.

Consideration of Water Depths

Water depth does not appear to have been a serious limiting factor in the genesis of the Toronto facies. Because the Toronto was deposited in association with an advance and retreat of the sea, water depths probably varied. It is impossible to demonstrate absolute water depths, although it is possible to suggest reasonable maximum depths based primarily on the depth ranges of algal groups present in modern seas whose ancestral forms presumably are present in the Toronto Limestone.

The lime mud facies contains mud pebbles, cut and fill structures, and winnowed zones, all of which are found on modern mud flats. Thus, extremely shallow water and probably intermittent subaerial exposure are suggested for this facies.

The terrigenous mud contains thin interbeds of well sorted terrigenous sandstone in many places and is in contact with woody land plant bearing bluish papery shales and red mudstone bearing charaphyte oogonia in other localities. These associations suggest very shallow, nearshore conditions for the marine shale.

The brachiopod grain facies generally lacks evidence of wave or current action in most of the exposures examined. However, at Localities 7A and 7B in Elk County, Kansas, sorted brachiopodal and crinoidal packstones and mud pebbles are present in the upper few inches of a bed in this facies. This suggests extremely shallow water conditions for development of these features.

The mixed biota subfacies of the skeletal mud facies contains *Osagia* coated grains which are likely of blue-green algal origin because they were formed by an organism which had the ability to fix sediment, and the only organisms present in modern seas that can do this are blue-green algae. Moreover, borings beneath the *Osagia* coatings are analogous to those produced by the activities of boring green and blue-green algae of Recent seas. In addition, codiacian and dasycladacean algal plates, and crusty mats, which were probably formed by blue-green algae are also present in this subfacies. Ginsburg (1964, p. 22) states that modern blue-green algae may extend to depths of 120 feet below sea level in the Recent and algal mats or scums are present between the high water zone and 100 feet or so. Present day green algae are restricted to the tropics with codiacians living

at depths ranging from zero to 400 feet and the dasycladaceans from zero to 150 feet (Ginsburg, 1964, p. 24). Thus, ignoring possible changes of habitats through time, it appears that the mixed biota subfacies accumulated in waters up to about 100 feet deep at maximum. Judging from its stratigraphic relationships with the terrigenous mud facies, blue shales with woody land plants, and the coal bed, this subfacies may have been deposited in waters of less than 50 feet in depth and possibly as shallow as 20 to 30 feet. It is contended that water depths had to be sufficient to allow for marine conditions to be maintained by circulation.

The molluscan-"Cryptozoon" subfacies also contains blue-green algae (*Osagia*) coated grains, many nuclei of which are riddled by boring green or blue-green algae. In addition, clean, grain-supported skeletal sands with worn grains are present in the facies and algal biscuits strikingly similar to Recent algal oncolites are present. Thus, water depths were probably less than 50 feet during deposition of this subfacies and possibly less than 20 feet in places.

The *Osagia*-rich subfacies is interpreted to have been deposited at depths that may not have exceeded those prescribed for the two subfacies described above. Values of less than 10 feet in places were likely for the facies is overlain conformably by the lime mudstone facies.

The *Osagia* facies contains rounded, thickly coated skeletal grains. Very shallow agitated waters probably

attended the formation of this facies. It is enclosed within the molluscan-"Cryptozoon" subfacies and is immediately subjacent to a bed containing algal biscuits.

The fenestrate bryozoan-echinoderm grain facies contains some *Osagia* coated grains and a few occurrences of dasycladacian algae. It also contains the largest and most abundant crinoid columnals and corals seen anywhere in the Toronto. This facies is considered generally to have accumulated in the deepest waters of any of the facies encountered, but based on the algal analogy it was deposited in waters of 100 feet or thereabouts as a maximum.

Although water depth was not a serious limiting factor in controlling facies patterns, as was circulation, a range of depths existed. We have seen, for example, that by comparison with modern algal groups water depths during deposition of the Toronto Limestone may have been as deep as 100 feet for some of the facies. The abrupt change in lithology from shale to limestone and back to shale in the Toronto cyclothem with areas where intertonguing does not exist suggests a rapid change in conditions of sedimentation. The fact that these relationships exist widely in the subsurface of Kansas means that the surface on which the Toronto Limestone was deposited must have been essentially flat with perhaps a gentle slope toward the basin center. Thus, by a slight change in relative sea level the pre-Toronto surface could have been transgressed rapidly as is suggested by the facies patterns within the limestone. It is very difficult indeed to account for the entry of

marine waters by subsidence alone for it would have to have taken place over a surface of many thousands of square miles, and furthermore, would have to have been pulsating in order to account for all the cyclothems seen in the Kansas column. Definite nonmarine shales immediately underlie and overlie the Toronto Limestone as shown by their lack of marine fossils but presence of charophytes, smooth-shelled ostracodes, and plant leaves. The skeletal mud and fenestrate bryozoan-echinoderm grain facies are considered to have been deposited in fairly open marine waters because they contain diverse faunas; in order to maintain open marine conditions the bottoms must have been covered by waters of sufficient depth to maintain good circulation. It is contended that waters were generally 50 feet or so in depth. In some areas the fenestrate-bryozoan echinoderm grain facies is overlain directly by the lime mud facies which shows evidence of sub-aerial exposure. This is taken as an indication that sea level must have dropped during the final stages of Toronto deposition. That sea level change may have been the cause for the Toronto cyclothem is further indicated by the presence of sandstone channels which have completely removed the Toronto Limestone but were later followed by Leavenworth Limestone deposition over the sites of channeling. The presence of mud pebbles in the upper part of the Toronto Limestone as well as the presence of charophytes in the shales immediately overlying the Toronto are evidence that the channel sands are probably nonmarine in origin.

As thus interpreted, the deposition of the Toronto Limestone commenced during a rise in sea level. Limestone was allowed to accumulate without much contamination because the sites of terrigenous sedimentation were restricted to near land areas (see Fig. 11).

At the end of Toronto deposition, sea level was lowered but deposition was not able to keep pace with the regression as suggested by the lack of a widespread marine unit at the top of the Toronto. It would appear that sea-level lowering may have been accompanied by climatic changes which affected the rate of terrigenous influx allowing the upper part of the Toronto to become subaerially exposed. Later alluvial deposition spread terrigenous detritus over the Toronto Limestone prior to the next transgression that resulted in deposition of the Leavenworth Limestone. That sea level was lowered following Toronto sedimentation is evidenced not only by the nonmarine aspects of the Snyderville Shale, but by widespread channeling which accompanied it.

Kansas Megacyclothem and Illinois Cyclothem
Compared and a Postulated Common Origin

The Leavenworth Limestone is more widespread than the Toronto Limestone and this together with the extreme lateral persistence of the Leavenworth facies compared to those of the Toronto suggests greater inundation during deposition of the Leavenworth Limestone. Examination of the Oread Limestone in southwestern Iowa reveals well developed Leavenworth

Limestone and Heebner Shale (including black shale). The Toronto Limestone, however, is not present and the Plattsmouth Limestone contains interbeds of shale that suggest facies change to clastics. Comparison (see Fig. 13) of the Kansas megacyclothem with the Illinois cyclothem (Macoupin type) reveals identical sequential development of its middle limestone, black shale and upper limestone members to the middle limestone, black shale, and upper limestone of the Kansas megacyclothem (Leavenworth, Heebner, and Plattsmouth members of the Oread megacyclothem). If these members are correlative, this would mean the Toronto Limestone was not developed in Illinois, but may have had a marginal or non-marine equivalent in Illinois. The writer does not subscribe to the concept of a Kansas megacyclothem as being nothing more than an expanded single cyclothem, but as a cycle of cyclothem as originally interpreted by Moore (1936, 1950). Moore (ibid.) has considered the Toronto to Plattsmouth interval to include three cyclothem, however, as we shall see in the succeeding paragraphs this sequence includes only two cyclothem.

Thus, the Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone as a sequence correspond to the middle limestone, black shale, and upper limestone members of the Illinois cyclothem. Stratigraphic evidence in Iowa indicates a more widespread occurrence of the above mentioned members of the Oread Limestone so that general correspondence of the lower part of a Kansas megacyclothem and the Illinois cyclothem may be a result of lateral equivalence. The absence

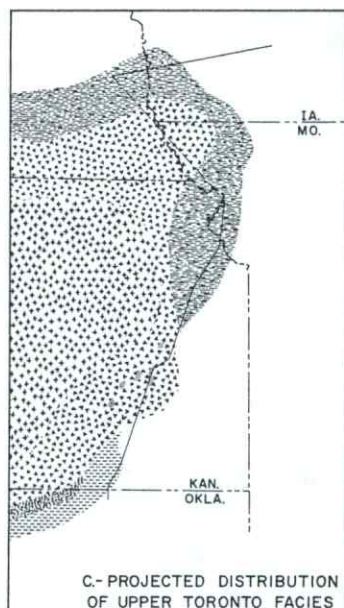
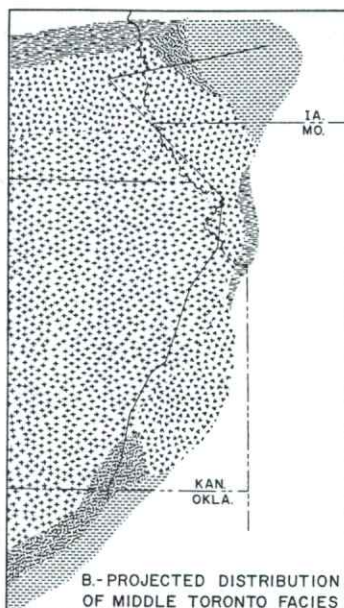
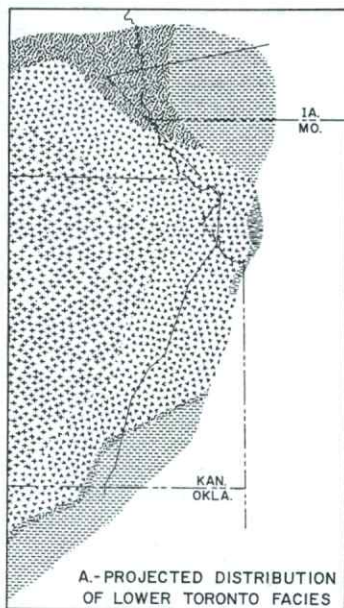
of Toronto Limestone in Iowa is probably a result of lesser extensive inundation as compared to the Leavenworth, Heebner, and Plattsmouth members. Therefore, it is suggested that the Oread megacyclothem is a product of changes in regional base level most probably due to sea level fluctuations. The Oread sequence fits well into the four-phase cycle scheme proposed by Wheeler and Murray (1957). They attribute sea cycles to eustatic changes induced by a four-phase glacial cycle as proposed by Simpson (1940). Although a single four-phase glacial cycle explains the sequence, two separate cyclothem are involved.

The first phase of the cycle would be a result of a maximum drop in base level resulting in complete marine withdrawal and regional sub-aerial erosion. The second phase would be a consequence of moderate elevation of base level due to an intermediate rise in sea level; the Toronto Limestone would be a product of deposition during this phase. The third phase is judged to be a lowering of base-level due to a sea-level drop and would result in deposition of the Snyderville Shale. The fourth phase is a product of maximum rise in sea level a consequence of which would be widespread deposition of the Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone. This would explain the blanket facies patterns in the Leavenworth Limestone and Heebner Shale as compared to the Toronto Limestone. The maximum advance of the sea resulted in confluence of the Kansas Sea with the Illinois Basin. At highest sea level, Leavenworth lime deposition was probably choked off by toxic

conditions that resulted in deposition of the Heebner Shale. This is hypothesized to have been a result of inundation of vast coastal swamps and forests by the maximum advance of the sea. Drowning of areas of heavy vegetation would result in the decay of much organic matter that could be carried into the seas--producing stagnant conditions. Adjustment of the flora of the coastal land areas to the high stand of sea level would result in a diminishing contribution of organic detritus to the seas so that in time stagnant conditions would be dissipated and normal marine organisms could populate the bottoms. Thus, carbonate deposition would replace clastic deposition as a result of the increased population turnover rate of lime generating organisms. This would result in deposition of the Plattsmouth Limestone in widespread, openly circulated, deeper waters, which accounts for the maximum diversity in brachiopod and coral faunas and largest individuals of the same seen in any of the Oread Limestones.

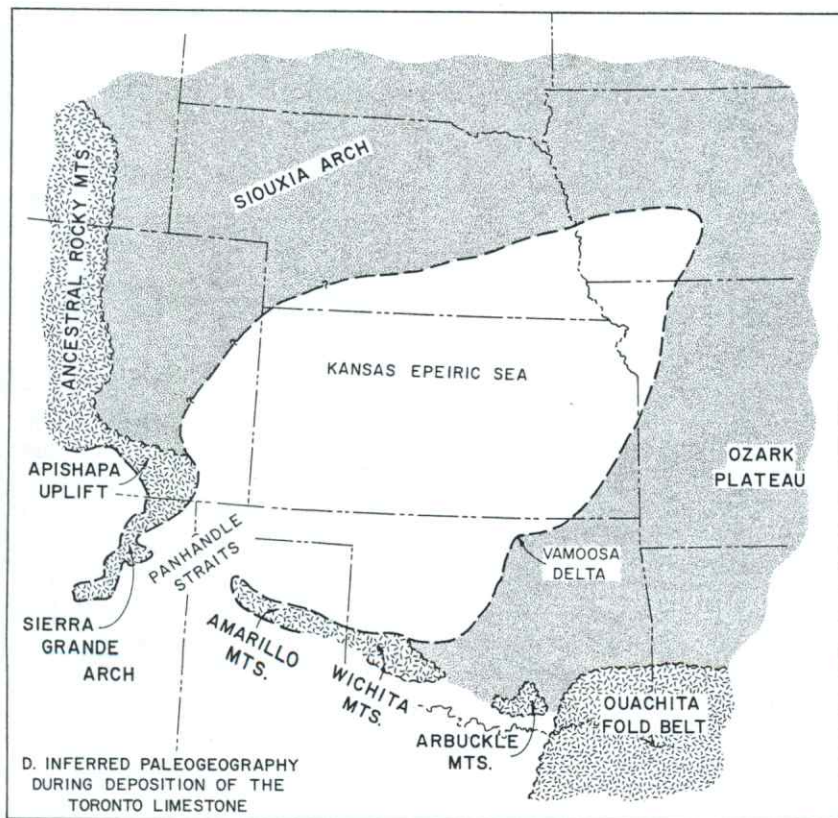
EXPLANATION OF FIGURE 11

- A., B., C. - Projected distribution of facies within the Toronto Limestone, illustrating the geographic relationships among the facies.
- D. - Inferred paleogeographic setting during deposition of the Toronto Limestone.



EXPLANATION

- LIME MUD FACIES
- SKELETAL MUD FACIES
- BRACHIOPOD FACIES
- MARINE SHALE FACIES
- OSAGIA GRAIN FACIES
- FENESTRATE BRYOZOAN - ECHINODERM GRAIN FACIES
- LINE OF OUTCROP



EXPLANATION

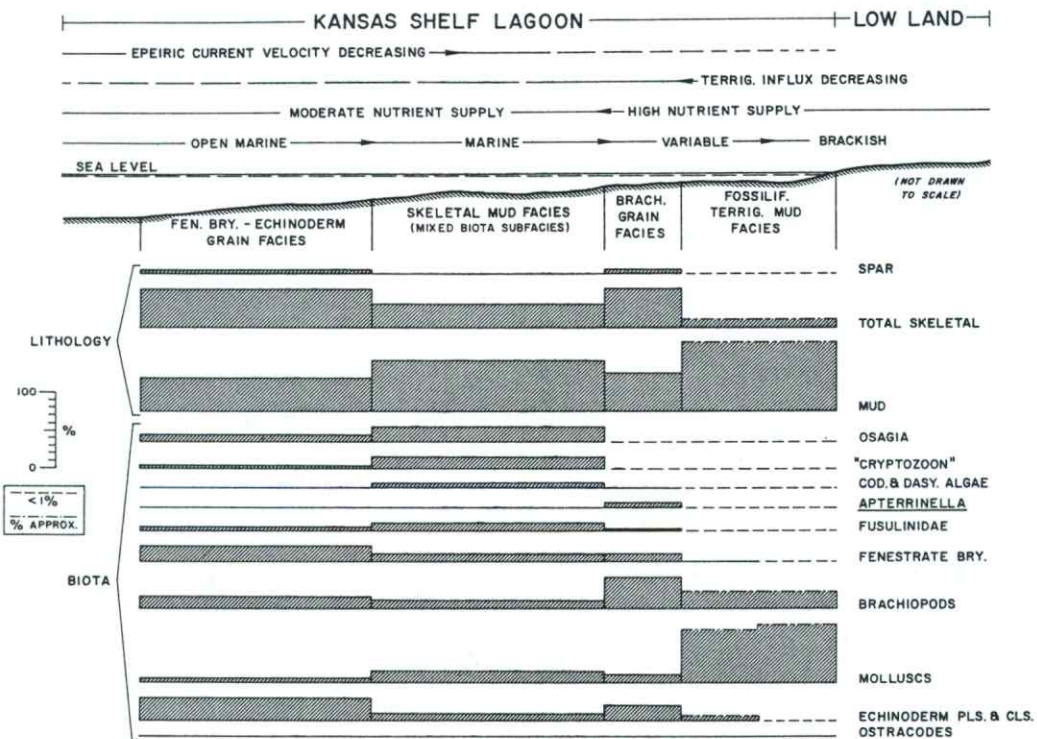
- PROBABLE HIGHLAND AREAS
- PROBABLE LOWLAND AREAS
- INFERRED SHORELINE

EXPLANATION OF FIGURE 12

Reconstruction of facies and their interrelationships in the Toronto Limestone. Upper diagram extends from the Vamoosa delta in northern Oklahoma due north to central Kansas. Lower diagram extends from east to west from northwestern Missouri into northern Kansas. Both drawings were done only for illustrative purposes.

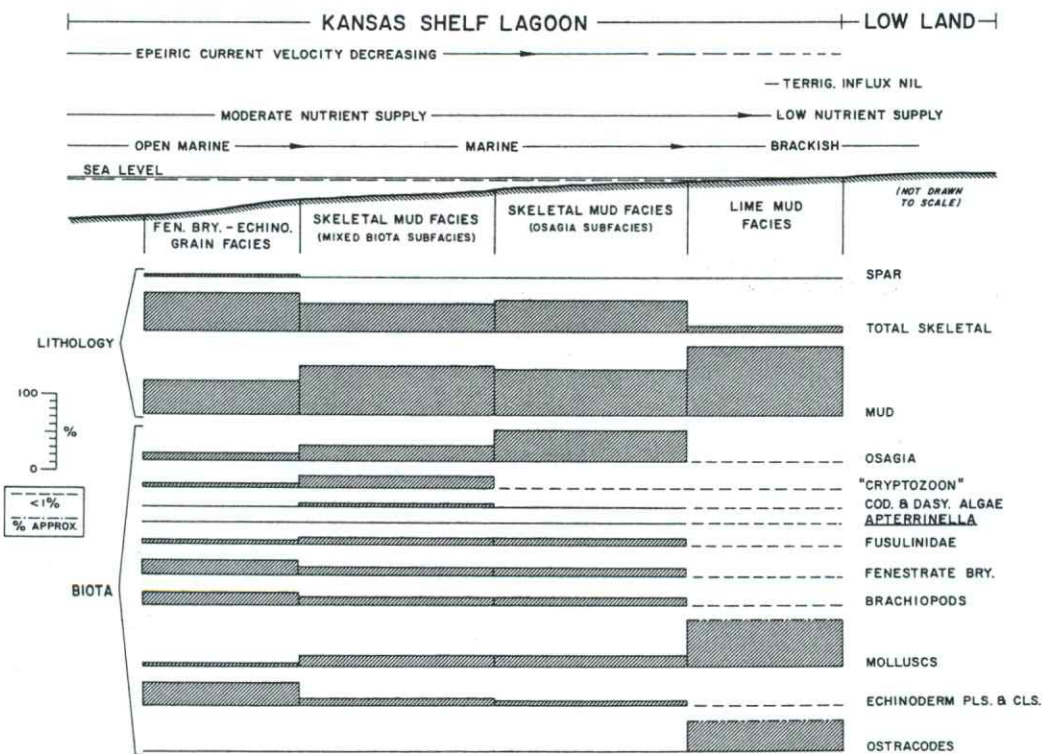
NORTH

SOUTH



WEST

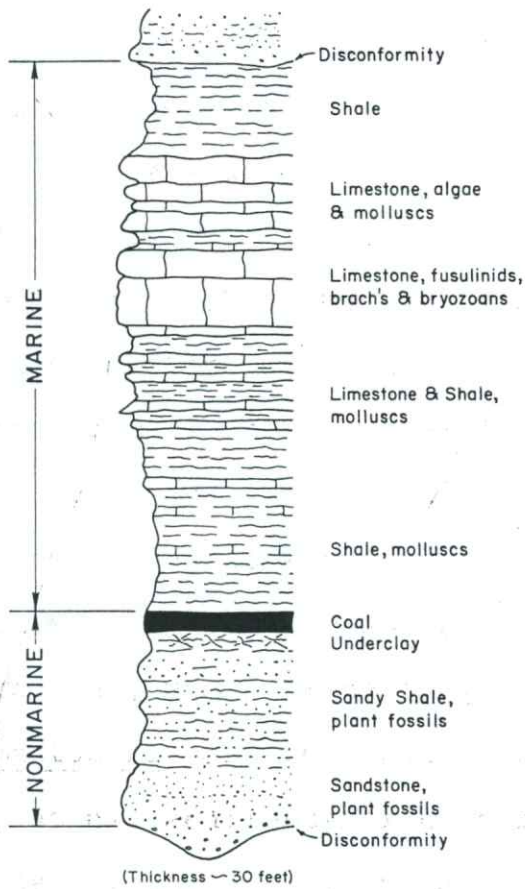
EAST



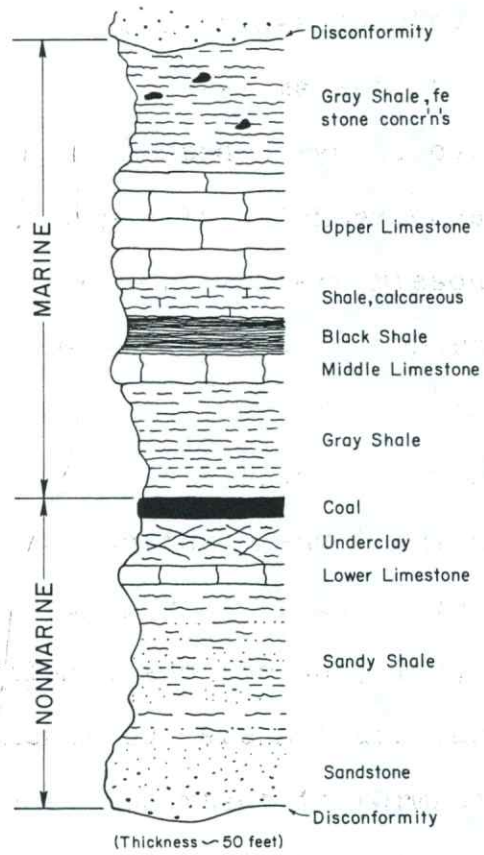
EXPLANATION OF FIGURE 13

Diagrammatic representation of Kansas (after Moore, 1959) and Illinois (after Weller, 1958) simple cyclothem and the lower part of the Oread megacyclothem. Diagram on lower right is an interpretation of the ultimate cause of the two simple cyclothem comprising the lower Oread based on Wheeler and Murray's concept of a four phase glacial cycle.

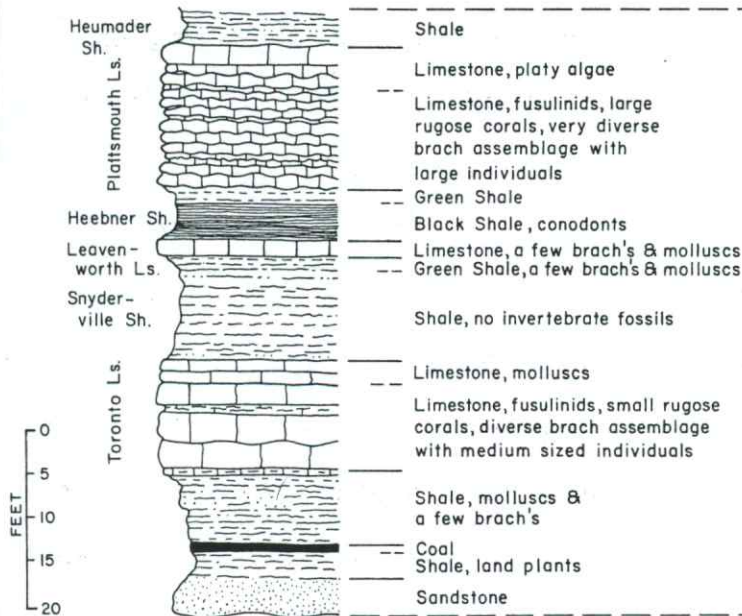
Kansas Cyclothem



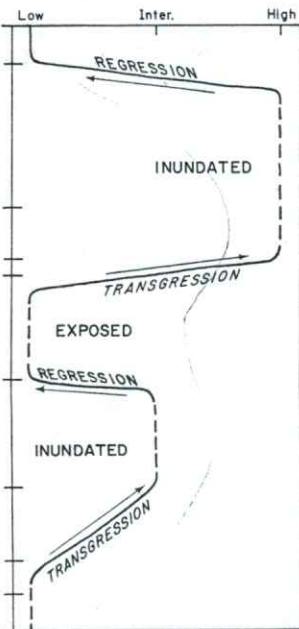
Illinois Cyclothem



Oread Megacyclothem (Lower Part)



Sea Level (Eustatic)



EPILOGUE

In the main, the Toronto Limestone is mud-supported containing an admixture of particulate skeletal material derived from a diverse biota. Grain-supported clean calcarenites occur only locally in the outcrop belt which extends from northern Oklahoma across Kansas to northwestern Missouri and southeastern Nebraska. Invertebrates which were important contributors in terms of skeletal grains included: molluscs (pelecypods and gastropods), brachiopods, crinoids, echinoids, bryozoans (fenestrate, ramose, and encrusting), and fusulinids. Small mobile and encrusting forams, Tubiphytes (a probable hydrozoan), platy algae (Eugonophyllum), and the dasyclad, Epimastopora, are persistent components but are not abundant. Encrusting, sediment-fixing organisms, important in formation of the limestone, were an accretionary form referred to as *Osagia* and so-called "Cryptozoon" (\sim *Ottonosia*). Oolites have not been found in the Toronto Limestone and mud pellets, although preserved in places, are rare. Thus the Toronto may be termed a skeletal limestone.

The role of secretory colonial organisms was minor in the genesis of Toronto sediments. Encrusting forams are present on some of the skeletal grains and in some coated grains, and encrusting bryozoans occur within some "Cryptozoon" coatings and are developed on shell fragments. Colonial syringoporid corals were found in small discontinuous lenses at only one locality.

Many of the skeletal grain nuclei of *Osagia* coatings are bored (almost certainly of algal origin) and, in some

cases, the nuclei are completely riddled with borings. It was also noted that many bored grains lack *Osagia* coatings. Borings analogous to these have been reported from modern shallow water carbonate sediments (Pusey, 1964, p. 67, p. 82). The presence of bored grains in the Toronto Limestone is suggestive of very shallow depositional conditions and a slow depositional rate. In addition, the process of algal boring may have been very important in breakdown of shell material not only into sand and coarser-sized fragments but to mud-sized particles as well.

The Toronto Limestone is bedded with individual beds ranging from several inches to several feet in thickness. The lime mud facies shows cut and fill-type bedding and similar bedding was found locally in the molluscan-"Cryptozoon" subfacies. However, for most other facies, the bedding surfaces are mainly planar. The origin of the latter bedding type is very much in question. A thin shale zone containing encrusting bryozoans and lopophyllidid corals is present in the middle portion of the Toronto. Ecological considerations (growth habits and feeding types) suggest a slow rate of deposition for this interval rather than a rapid influx of clastics. As noted above, algal coating (*Osagia*) and algal boring suggests a slow depositional rate - the rate of sedimentation was slower than the rate of coating and boring. Thus it may be that the bedding surfaces in the Toronto are records of minor disconformities caused by pauses in carbonate deposition.

Carbonate facies within the Toronto Limestone are not simply belts that migrated symmetrically in and out with the transgression and regression. The oscillation of the strand was too rapid for deposition to keep pace, probably a consequence of an almost flat depositional surface. The bulk of Toronto Limestone sedimentation took place following a rapid transgression. Lime deposition was allowed in those areas free from terrigenous influx - mainly offshore areas. This also indicates that the rate of deposition of the Toronto was relatively slow. The establishment of facies tracts in the Toronto came after inundation and was in response to terrigenous influx, salinity patterns, nutrient element distribution, and energy relationships. Faunal considerations indicate open marine conditions offshore, decreasing shoreward. These relationships plus the wide lateral continuity of the Toronto are indicative of deposition on an open shelf without a barrier.

As thus interpreted, the facies of the Toronto Limestone do not fit into a phase scheme in which the various facies represent particular stages of transgression and regression - that is, the sequence is not that of deposits that were accumulated at a given locality during the advance of the sea which was repeated in reverse order during retreat of marine waters.

Cementation of the Toronto Limestone was evidently a one-stage affair for only a single generation of calcite spar is developed in voids and cavities. This is hypothesized to be in contrast to the cementation of modern inter-

tidal beach rocks of Florida, the Bahamas, and British Honduras where carbonate needles have locked the grains in place and second stage cementation should result in blocky spar infill if the deposit is transgressed so that it becomes situated beneath the ground water table (see Ginsburg, 1957, pp. 95-98). The presence of shale lithosomes between the Toronto Limestone and adjacent limestones is the probable reason that a single generation of spar cement occurs in the Toronto.

At a number of places along the outcrop between northern Oklahoma and northwestern Missouri, the Toronto Limestone was channeled prior to deposition of the Leavenworth Limestone which is continuous across the region. The association of the channel deposits with red shales bearing charophyte oogonia is interpreted as being indicative of alluvial channeling. The Leavenworth Limestone and the black Heebner Shale which overlies it show greater lateral continuity of facies than the aforementioned Oread members. The lower part of the Oread megacyclothem - Wathena Shale, Toronto Limestone, Snyderville Shale, Leavenworth Limestone, Heebner Shale and Plattsmouth Limestone - are explained by two eustatic sea-level cycles. A portion of the Wathena, the Toronto, and much of the Snyderville were deposited during one eustatic sea level oscillation (intermediate inundation) and the Leavenworth, Heebner, and Plattsmouth were laid down during a second sea level fluctuation (greatest inundation).

CONCLUSIONS

1. The Toronto Limestone is composed essentially of the calcium carbonate hard parts from the skeletons of marine organisms and calcium carbonate mud, although some fine terrigenous material is present in the limestone.

2. A total of five facies were recognized within the limestone proper - lime mud, skeletal mud (mixed biota subfacies, "Cryptozoon"-molluscan subfacies, and Osagia subfacies), fenestrate bryozoan-echinoderm grain, Osagia grain, and brachiopod (brachiopod grain subfacies and brachiopod marl subfacies); the facies changes are transitional. A sixth facies - fossiliferous terrigenous mud facies - is transitional to the Toronto Limestone.

3. The above facies were deposited during a single transgression and regression of the sea as a probable result of sea level changes brought about by glaciation.

4. Environmental factors that exerted the greatest control over the development of the Toronto facies are interpreted to have been terrigenous influx (sediment and nutrients), water circulation, and agitation. Water depths were not a major environmental factor but available evidence is indicative of conditions that ranged from intermittent exposure in mud flat areas to maximum depths which probably did not exceed 100 feet, but are thought to have been much less than that.

5. The environmental framework was essentially that of an extremely shallow tropical sea where terrigenous

deposition prevailed in and near deltas along or near the shoreline and carbonate deposition predominated in areas away from terrigenous dominance.

6. The sea was characterized by open marine salinities considered to be generally well below hypersalinity and above that of hyposalinities except in, or near, areas under the influence of fresh water run-off from the land. This is indicative of an open shelf with no restricting barrier seaward of the outcrop belt.

7. The terrigenous mud facies was deposited in a shallow, quiet, nearshore environment of fluctuating salinities very close to an active delta, possibly as a prodelta facies. The brachiopod facies was deposited slightly seaward from the marine shale in an environment that was far enough seaward to be marine, but close enough shoreward to benefit from the nutrient materials furnished to the sea by fresh water run-off. The skeletal mud facies was deposited seaward or away from terrigenous sediment influx; this was an area of shallow, relatively clear water, occasionally frequented by currents that swept the bottom. The fenestrate bryozoan-echinoderm grain facies was deposited seaward and marginal to the skeletal mud facies; it was subjected to clear open marine waters with some turbulence. The Osagia facies was deposited in very shallow, clear, turbulent waters in local areas surrounded by skeletal mud deposition. In areas where there was little or no terrigenous influx, a lime mud accumulated along the strand as a mud flat deposit.

8. Compositionally the Toronto Limestone facies are skeletal limestones as opposed to non-skeletal limestones. The latter are typified in modern seas by the Bahamian model which contains facies tracts of oolites, composite grains (grapestone), pelletal muds, and lime muds (Purdy, 1963). This facies assemblage is not present in the Toronto. No modern environmental settings are known to the writer that are exactly analogous to Toronto deposition although the northern British Honduras carbonate sedimentary facies are skeletal in nature (Pusey, 1964) and bear some resemblance to the Toronto in terms of shelf carbonate facies development.

9. Plant leaves are present in the Lawrence Shale beneath the Toronto Limestone and charophytes are present in the Snyderville Shale above, serving as testimony to the advance and retreat of marine waters that resulted in Toronto deposition. In addition, the Toronto has been channeled at several places along the outcrop belt with the overlying Leavenworth undisturbed above, evidencing the lowering of base level following Toronto sedimentation.

10. The Toronto Limestone is not as laterally extensive as the Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestone. Moreover, the facies within the Toronto are not as extensive as those present with the Leavenworth, Heebner, and Plattsmouth, although the latter has not been studied in detail. This is indicative of a lesser rise of sea level for the Toronto cycle compared to the cycle that resulted in deposition of the Leavenworth, Heebner, and Plattsmouth.

11. The Toronto through Plattsmouth members of the Oread megacyclothem are thought to be a product of two eustatic sea level cycles (four phases). The Kansas Sea may have been united with the Illinois basin in time of Leavenworth, Heebner, and possibly Plattsmouth deposition during the maximum advance of the sea; the Toronto Limestone was probably deposited during a time of intermediate sea level rise with no marine accumulation in northern Illinois.

12. The present line of Oread outcrop from Oklahoma to northern Kansas is generally at a low angle to depositional strike; the Oklahoma exposures are nearest the old shore line.

APPENDIX I

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APPENDIX

List of localities shown on Figure 4.

- L-18 NW 1/4 NE 1/4 Sec. 7, T. 28 N., R. 10 E., Osage Co., Oklahoma. Exposure in bar ditch at corner in county road about 5 miles south of state line.
- L-19 SW 1/4 NE 1/4 Sec. 12, T. 35 S., R. 10 E., Chautauqua Co., Kansas. Exposure in road gutter near base of hill 1-1/2 miles northeast of Elgin, Kansas.
- C-5 NW 1/4 NE 1/4 Sec. 12, T. 35 S., R. 10 E., Chautauqua Co., Kansas. Shallow core drilled west of road.
- L-17A NW 1/4 SW 1/4 Sec. 23, T. 34 S., R. 11 E., Chautauqua Co., Kansas. Exposure of Plattsmouth Limestone, Heebner Shale, Leavenworth Limestone, and Snyderville shale in road cut on north side of hill; no Toronto Limestone present.
- L-17 NE 1/4 NW 1/4 Sec. 4, T. 34 S., R. 11 E., Chautauqua Co., Kansas. Exposure in road ditch at corner along country road.
- L-29 NE 1/4 Sec. 12, T. 33 S., R. 11 E., Chautauqua Co., Kansas. Exposure on hillside along east side of county road beneath large massive sandstones.
- L-8 CEL Sec. 36, T. 32 S., R. 11 E., Chautauqua Co., Kansas. In ditch on left side of road atop small hill immediately south of larger hill capped by Plattsmouth Limestone.
- C-4 SE 1/4 NW 1/4 Sec. 8, T. 32 S., R. 12 E., Chautauqua Co., Kansas. Shallow core locality.
- L-7.5 SW 1/4 Sec. 16, T. 13 S., R. 12 E., Elk Co., Kansas. Exposure in road ditch on east side of county road on north slope of hill, 1-1/2 mile south of Longton, Kansas.
- L-7 NE 1/4 SW 1/4 Sec. 27, T. 30 S., R. 12 E., Elk Co., Kansas. Exposure in bar ditch on west side of county road, about 1-1/2 mile north of Longton, Kansas.
- L-6.5 E.L. SE 1/4 NW 1/4 Sec. 6, T. 30 S., R. 12 E., Elk Co., Kansas. Exposure in cutbank of stream, 100 yards west of road.
- L-6 NW 1/4 NE 1/4 Sec. 12, T. 29 S., R. 12 E., Elk Co., Kansas. Exposure in roadcut at intersection of two county roads.
- L-6A SE 1/4 SE 1/4 Sec. 1, T. 28 S., R. 12 E., Elk Co., Kansas. Exposure in roadcut on south side of east-west trending road.

- L-5 S.L. NE 1/4 Sec. 36, T. 28 S., R. 12 E., Elk Co., Kansas.
Exposure in bar ditch at break in slope along east-west trending road and in trench silo a few yards south of road.
- L-4 CSL Sec. 29, T. 27 S., R. 13 E., Greenwood Co., Kansas.
Exposure in bar ditch near base of hill on east-west trending road.
- C-2 NW 1/4 SW 1/4 Sec. 5, T. 27 S., R. 13 E., Greenwood Co., Kansas. Shallow core locality.
- L-3A SW 1/4 NW 1/4 Sec. 4, T. 27 S., R. 13 E., Greenwood Co., Kansas. Exposure in cutbank of stream on Hibbard's farm.
- L-3 CSL SW 1/4 Sec. 33, T. 26 S., R. 13 E., Greenwood Co., Kansas.
Exposure along stream adjacent to county road.
- L-2 NE 1/4 SW 1/4 Sec. 10, T. 26 S., R. 13 E., Greenwood Co., Kansas. Exposure in quarry adjacent to county road.
- L-1 CNL NW 1/4 Sec. 35, T. 25 S., R. 13 E., Woodson Co., Kansas.
Exposures in road cut along U. S. Highway 54 and in quarry about 200 yards due south of roadcut; Toronto type locality.
- C-24 CSL Sec. 8, T. 25 S., R. 14 E., Woodson Co., Kansas. Shallow core locality.
- L-30 S.L. Secs. 35 and 36, T. 24 S., R. 14 E., Woodson Co., Kansas.
Outcrop study.
- C-21 SW 1/4 SE 1/4 Sec. 31, T. 31 S., R. 15 E., Woodson Co., Kansas. Shallow core locality.
- C-23 CN 1/2 SW 1/4 Sec. 4, T. 23 S., R. 15 E., Coffey Co., Kansas.
Shallow core locality.
- L-25 CL Secs. 34 and 35, T. 22 S., R. 15 E., Coffey Co., Kansas.
Road cut on U. S. Highway 75, 1/2 mile south of Gridley, Kansas, turnoff.
- L-20 C SE 1/4 Sec. 2, T. 22 S., R. 15 E., Coffey Co., Kansas.
Exposure in small quarry about 200 yards north of east-west county road.
- C-7 CSL Sec. 32, T. 20 S., R. 17 E., Coffey Co., Kansas. Shallow core locality.
- L-9 W 1/2 Sec. 24, T. 18 S., R. 17 E., Franklin Co., Kansas.
Exposures on west side of U. S. highway 50 on either side of intersection with county road.

- L-13C WL NW 1/4 Sec. 32, T. 15 S., R. 18 E., Franklin Co., Kansas.
Roadcut on county road just south of angular intersection.
- L-13B SW C. SE 1/4 Sec. 14, T. 14 S., R. 18 E., Douglas Co., Kansas.
Roadcut on east-west road cut on east side of due south extension of Lone Star Lake.
- L-13A NW 1/4 Sec. 14, T. 14 S., R. 18 E., Douglas Co., Kansas.
Exposure above and west of dam at Lone Star Lake and along road south of dam site.
- L-26 NW 1/4 Sec. 28, T. 14 S., R. 20 E., Douglas Co., Kansas.
Exposure in quarry adjacent to county road.
- L-27 SWC NW 1/4 Sec. 27, T. 14 S., R. 20 E., Douglas Co., Kansas.
Exposure in quarry several hundred yards west of curve on county road.
- L-28 Same location as L-27. Exposure is roadcut on county road at curve at north edge of hill.
- L-16 SW 1/4 NE 1/4 Sec. 27, T. 14 S., R. 20 E., Douglas Co., Kansas.
Exposure in ditch along road on north slope of hill.
- L-22 C NW 1/4 Sec. 21, T. 12 S., R. 19 E., Douglas Co., Kansas.
Exposure in roadcut along Turnpike just east of county road overpass, outside city of Lawrence.
- L-11 NW 1/4 Sec. 36, T. 12 S., R. 19 E., Douglas Co., Kansas.
Exposure in city of Lawrence at roadcut northwest of University of Kansas campus.
- L-12 CSL NW 1/4 Sec. 8, T. 11 S., R. 21 E., Leavenworth County, Kansas. Exposure in roadcut along State Highway 16, one mile west of Tongonoxie, Kansas.
- C-9 CNL Sec. 26, T. 9 S., R. 21 E., Leavenworth Co., Kansas.
Shallow core locality.
- L-10 NW 1/4 NW 1/4 Sec. 22, T. 8 S., R. 22 E., Leavenworth Co., Kansas. Exposure in roadcut atop hill on State Highway 7; Leavenworth type locality.
- C-10 CSL Sec. 22, T. 55 N., R. 37 W., Buchanan Co., Missouri.
Shallow core locality.
- L-15 NE 1/4 NW 1/4 Sec. 31, T. 58 N., R. 35 W., Buchanan Co., Missouri. Exposure in bluff above abandoned Huemader's Quarry.

- L-15A NW margin Sec. 30, T. 58 N., R. 35 W., Buchanan Co., Missouri. Exposure in bluff adjacent to Missouri River near Andrew County line.
- L-15B SW 1/4 Sec. 19, T. 58 N., R. 35 W., Andrew Co., Missouri. Exposure in stream cut along Andrew-Buchanan Co. line, just south of road.
- L-14B CNL Sec. 5, T. 10 N., R. 12 E., Cass County, Nebraska. Exposure in roadcut on west side of Cedar Creek, 1.7 miles east of Weeping Water, Nebraska.
- L-14A SW 1/4 NW 1/4 Sec. 15, T. 12 N., R. 10 E., Cass Co., Nebraska. Exposure in Johansen's Quarry on Pawnee Creek, west of South Bend, Nebraska.
- L-21 Central portion Sec. 6, T. 12 N., R. 14 E., Cass Co., Nebraska. Exposure along railroad tracks northeast of Plattsmouth, Nebraska.
- L-33 NE 1/4 NE 1/4 Sec. 1, T. 75 N., R. 30 W., Adair Co., Iowa. Exposure in valley walls of small tributary of Middle River.
- L-32 SW 1/4 NW 1/4 Sec. 7, T. 75 N., R. 29 W., Madison Co., Iowa. Small outcrop adjacent to road bridge on south side of east-west trending stream.

Additional Oklahoma Exposures

- L-18d W.L. SW 1/4 Sec. 8, T. 28 N., R. 10 E., Osage County, Oklahoma. Road ditch on south side of hill. Sequence similar to that at 18; channel sand above limestone contains wood fragments.
- L-18b SE 1/4 Sec. 20, T. 28 N., R. 10 E., Osage County, Oklahoma. Exposure in road cut on north side of hill. Channel sandstone with fossiliferous zone at bottom, Leavenworth Limestone crops out about 60 feet above sandstone.
- L-18c SW 1/4 NW 1/4, T. 28 N., R. 10 E., Osage County, Oklahoma. Exposure in road cut at side of break of hill. Channel sandstone with fossiliferous zone at base.
- L-18a C.N.L. Sec. 33, T. 28 N., R. 10 E., Osage County, Oklahoma. Exposure in road ditch at break in hill on north side. Fossiliferous zone about 0.3 foot thick. May be furthest south exposure of Toronto Limestone.

APPENDIX III

DESCRIPTION OF OUTCROP SECTIONS

Locality 18

- 18.0 SHALE: gray, weathers olive, nonfissile; no fossils observed 1.0~~7~~
- 18.1 LIMESTONE: medium gray, weathers rusty brown; skeletal debris abundant; one bed with several thin, planar partings. Fossils: Linoproductus prattenianus, Derbyia sp., Antiquatonia portlockiana, Neochonetes sp., Euphemites carbonarius, Myalina (Orthomyalina) slocomi; Nuculana bellistriata, "Aviculopecten" sp., crinoid columnals, ramose bryozoans, encrusting bryozoans (on Myalina valve) 0.6
- 18.2 SHALE: olive-brown, weathers brown; nonfissile; calcareous concretions. No fossils observed 0.7
- 18.3 SANDSTONE: tan to rusty brown; very fine-grained; calcareous; fucoids on upper surface. No fossils seen 0.7
- 18.4 SHALE: olive-brown to greenish gray; silty; blocky to chippy. No fossils observed. 0.4
- 18.5 SANDSTONE: tan to brown; very fine grained; micaceous. No fossils seen. 0.4
- 18.6 SHALE: greenish gray; chippy to blocky. No fossils seen. 4.9
- 18.7 SANDSTONE: rusty brown; very fine grained; numerous vertically oriented burrows about 1/4 inch in diameter; small scale cross-laminations. No fossils seen. 1.1
- 18.8 SHALE: olive to gray; chippy. No fossils seen 2.6
- 18.9 LIMESTONE: rusty brown, weathered; skeletal debris abundant. Fossils: Myalina (Orthomyalina) slocomi, "Aviculopecten" sp., crinoid columnals, brachiopod spines, and ramose bryozoans 0.3
- 18.10 SHALE: green, chippy. No fossils seen 1.0~~7~~

LOCALITY 18

LOCALITY 19

LOCALITY 17

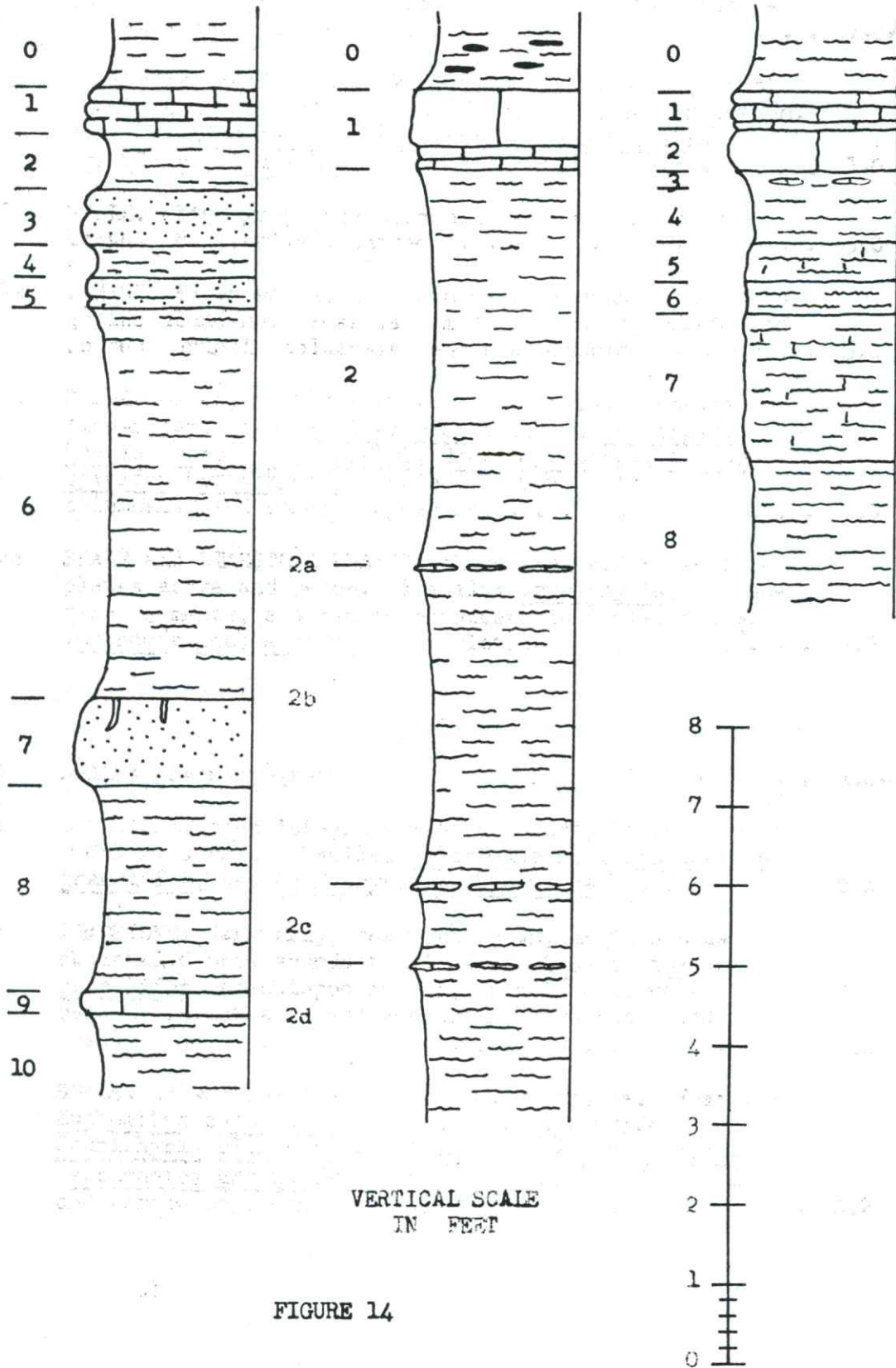


FIGURE 14

Locality 19

- 19.0 SHALE: light gray-green; small discoid clay-ironstone concretions. No fossils seen. 1.0/
- 19.1 LIMESTONE: medium to dark gray, weathers brown; much skeletal debris; single bed; fucoids present on bottom. Fossils: Linoproductus prattenianus, Neochonetes granulifer, Crurithyris, and crinoid columnals 1.0
- 19.2 SHALE: olive gray, weathers olive brown; chippy when fresh. No fossils observed. 5.0
- 19.2a LIMESTONE: brown; discontinuous platy nodules; skeletal grains abundant. Fossils: small gastropod, brachiopod spines, crinoid columnals, and rhomboporid bryozoans . . . 0.1
- 19.2b SHALE: olive, weathers brown; nonfissile. Fossils (lower part only): Bellerophon sp., cf. Meekospira, Nucula (Nuculopsis) girtyi, Crurithyris sp., Punctospirifer kentuckyensis, crinoid calyx, crinoid columnals, and ramose bryozoans. 4.0
- 19.2c SHALE and LIMESTONE PLATES: olive gray with limestone plates above and below. Fossils: Crurithyris, echinoderm segments, and ramose bryozoans in limestone; M. (Orthomyalina) slocomi above plates. 1.2

Locality 17

- 17.0 SHALE: greenish-gray; nonfissile. No fossils seen . . . 1.0/
- 17.1 LIMESTONE: greenish-gray, weathers rusty brown; rubbly nodular, shaly. Fossils: Astartella sp., Neochonetes granulifer, and Crurithyris planoconvexa 0.4
- 17.2 LIMESTONE: dark gray, weathers brown; argillaceous; skeletal debris abundant. Fossils: Neochonetes granulifer, brachiopod spines, crinoid columnals; ramose, fenestrate, and encrusting bryozoans; and fusulinids 0.4
- 17.3 SHALE: brown; calcareous; limestone nodules. Fossils: Euphemites carbonarius, myalinids, Neospirifer Crurithyris planoconvexa, Antiquatonia portlockiana, Neochonetes granulifer, crinoid columnals, fenestrate and ramose bryozoans 0.2

- 17.4 SHALE: greenish-gray; small calcareous nodules. Fossils: Neochonetes granulifer, Linoproductus, and ramose bryozoans. 0.7
- 17.5 SHALE: rusty brown; calcareous. Fossils: Phymatopleura sp., M. (Orthomyalina) slocomi, Neochonetes sp., Derbyia cf. O. crassa, crinoid columnals and brachial plates, acrothoracian barnacle bores in myalinids, and ramose bryozoans. 0.5
- 17.6 SHALE: greenish-gray, chippy. Fossils: cf. Acanthopecten meeki, Crurithyris planoconvexa, and crinoid columnals and brachial plates 0.4
- 17.7 SHALE: brownish gray; calcareous; very fossiliferous. Fossils in upper half: Phymatopleura sp., Neochonetes granulifer, derbyids, Crurithyris planoconvexa, and ramose bryozoans. Fossils in lower half: cf. Euphemites carbonarius, Straparolus (Amphiscapha) sp., Myalina, derbyids, Crurithyris planoconvexa, encrusting bryozoans, and crinoid segments 1.9
- 17.8 SHALE: olive-green to olive-brown; blocky. Fossils: crinoid columnals and brachial plates 1.87

Locality 8

- 8.0 SHALE: light gray to light green; nonfissile. Fossils: small pelecypod steinkerns and scattered Crurithyris sp. 1.07
- 8.1 LIMESTONE: medium gray, weathers brown; argillaceous; skeletal rich. Fossils: Linoproductus prattenianus, Neochonetes granulifer, Crurithyris planoconvexa, Composita sp., derbyid, crinoid columnals, fusulinids, ramose bryozoans. 0.5
- 8.2 SHALE: grayish brown; nonfissile; limestone nodules and plates. Fossils: Crurithyris planoconvexa, Neochonetes granulifer, Punctospirifer sp., and Rhipidomella carbonaria. 0.8
- 8.3 SHALE: olive-brown; nonfissile. Fossils: Crurithyris planoconvexa. 1.5
- 8.4 SHALE; with limestone plates: olive brown; limestone nodules argillaceous and fossiliferous. Fossils: Crurithyris planoconvexa. 0.7

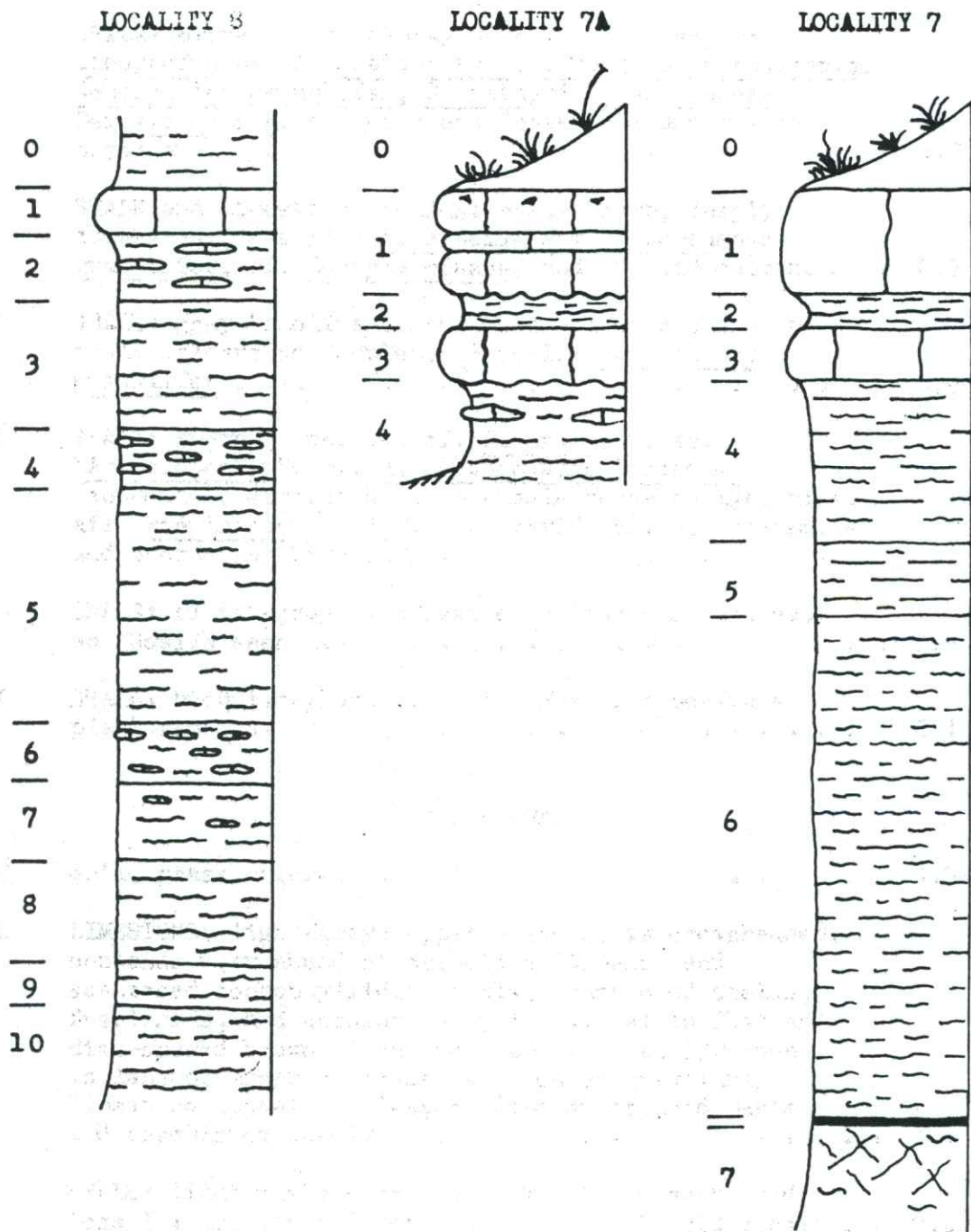


FIGURE 15

- 8.5 SHALE: olive-green; blocky to chippy. Fossils: Linoproductus cf. prattenianus, Juresania nebrascensis, Neochonetes granulifer, Crurithyris planoconvexa, Derbyia crassa, crinoids and fenestrate and ramose bryozoans. 2.7
- 8.6 SHALE and Limestone nodules: rusty brown, deeply weathered. Fossils: Astartella sp., Neochonetes granulifer, cf. Derbyia crassa, and crinoid columnals. . . 0.7
- 8.7 SHALE: gray to olive-brown, weathers brown; scattered small calcareous nodules. Fossils: Neochonetes granulifer 0.9
- 8.8 SHALE: brown. Fossils: cf. Pleurophorus sp., "Aviculopecten" sp., M. (Orthomyalina) slocomi (abundant), acrothoracian barnacle bores on myalinids, aff. Pterinopectinella sp., derbyid, crinoid columnals, and encrusting bryozoans 1.2
- 8.9 SHALE: bluish-gray; nonfissile; calcareous nodules. No fossils seen. 0.5
- 8.10 SHALE: brownish-gray; plastic. Fossils: possible plant remains. 1.1

Locality 7A

- 7A.0 Soil, grass covered. 1.0~~4~~
- 7A.1 LIMESTONE: light-gray; upper 9 inches is crossbedded, contains very abundant crinoid columnals, and scattered lophophyllidid corals, brachiopod shells, fusulinids, and angular, equidimensional to flat and disc-shaped brown limestone pebbles up to 1/2 inch in length; lower 3 inches is greenish gray marly limestone containing lesser abundant crinoid parts and brachiopod shells. 1.2
- 7A.2 SHALE: light rusty brown to gray, highly weathered; Fossils: crinoid columnals and lophophyllidid corals . . 0.4
- 7A.3 LIMESTONE: brownish-gray; fewer skeletal grains than in upper bed and more lime mud. Fossils: crinoid columnals, Crurithyris sp., and small lacy bryozoans. Lower surface of this bed is irregular 0.6

7A.4	SHALE: olive green; very abundant fusulinids; fusulinid-bearing lime nodules up to several inches in length.	1.07
Locality 7		
7.0	Soil, grass-covered.	1.07
7.1	LIMESTONE: medium dark gray; skeletal grains abundant. Fossils: <u>Antiquatonia portlockiana</u> , cf. <u>Hystriculina wabashensis</u> , <u>Neochonetes granulifer</u> , <u>Crurithyris planoconvexa</u> , <u>Rhipidomella carbonaria</u> , fusulinids, crinoid fragments, and bryozoans	1.2
7.2	SHALE: olive-green, weathers brown; fossiliferous. Fossils: <u>Neochonetes granulifer</u> , cf. <u>Hystriculina wabashensis</u> , <u>Composita subtilita</u> , <u>Punctospirifer</u> sp., <u>Crurithyris planoconvexa</u> , <u>Rhipidomella carbonaria</u> , fenestrate bryozoans, lophophyllidid corals, and crinoid columnals.	0.4
7.3	LIMESTONE: medium dark gray, scattered skeletal grains. Fossils: <u>Neochonetes granulifer</u> , <u>Crurithyris</u> sp., <u>Neospirifer</u> sp., derbyid, <u>Juresania</u> sp., <u>Echinoconehus</u> , cf. <u>E. moorei</u> , <u>Cancrinella</u> cf. <u>boonensis</u> , <u>Composita</u> sp., crinoid columnals, <u>Ditomopyge?</u> sp.	0.6
7.4	SHALE: greenish brown; calcareous; fossiliferous. Fossils: <u>Myalina</u> (O.) <u>slocomi</u> , <u>Neochonetes granulifer</u> , <u>Crurithyris planoconvexa</u> , <u>Neospirifer</u> sp., <u>Rhipidomella carbonaria</u> , <u>Derbyoides</u> cf. <u>D. nebrascensis</u> , <u>Derbyia</u> cf. <u>D. crassa</u> , <u>Antiquatonia portlockiana</u> var. <u>crassicostatus</u> , <u>Hystriculina</u> cf. <u>H. wabashensis</u> , <u>Marginifera</u> cf. <u>M. splendens</u> , <u>Punctospirifer</u> cf. <u>P. kentuckyensis</u> , <u>Echinoconchus</u> cf. <u>E. semipunctatus</u> , <u>Leptalosia ovalis</u> , crinoid segments, ramose and encrusting bryozoans, and very abundant fusulinids	1.9
7.5	SHALE: olive-brown, blocky. Fossils: <u>Myalina</u> (O.) <u>slocomi</u> (common), <u>Schizodus</u> sp., aff. <u>Pseudomonotis</u> sp., cf. <u>Juresania</u> sp., <u>Punctospirifer</u> sp., <u>Composita subtilita</u> , cf. <u>Derbyia crassa</u> , crinoid columnals, fenestrate bryozoans, and a few fusulinids	0.8
7.6	SHALE: olive-brown to bluish gray. Fossils: carbonized plant remains on bedding surfaces	5.8
7.7	COAL: thin streak.	0.1

7.8 CLAY: bluish-gray, plastic 0.7

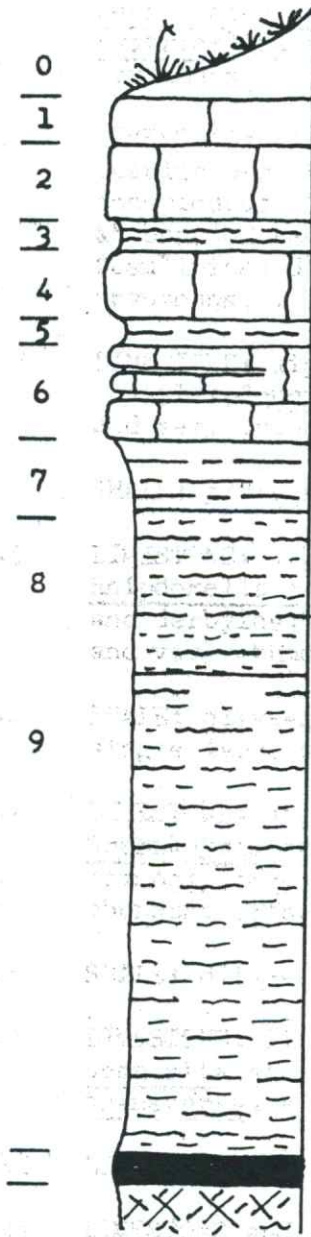
Locality 6.5

- 6.5.0 Soil, grass-covered. 1.0~~7~~
- 6.5.1 LIMESTONE: medium gray, skeletal grains in lime mud.
Fossils: Crurithyris sp. (abundant). 0.5
- 6.5.2 LIMESTONE: medium gray. Fossils: Crurithyris sp.,
Neochonetes sp., dictyoclostids, and Aviculopinna. 0.8
- 6.5.3 SHALE: gray-green. 0.3-0.5
- 6.5.4 LIMESTONE: medium gray, scattered skeletal grains.
Fossils: Crurithyris sp. 0.7
- 6.5.5 SHALE: gray-green. 0.3-0.4
- 6.5.6 LIMESTONE: medium gray with gray-green SHALE partings.
Fossils: Composita sp., Hustedia, Linoproductus sp.,
dictyoclostids, and abundant fusulinids at base. 1.0
- 6.5.7 SHALE: gray-green. Fossils: abundant fusulinids 0.7
- 6.5.8 SHALE: blue-gray. Fossils: very abundant single
valves of Myalina sp. 1.0
- 6.5.9 SHALE: blue-gray, no fossils seen. 5.2
- 6.5.10 COAL 0.4

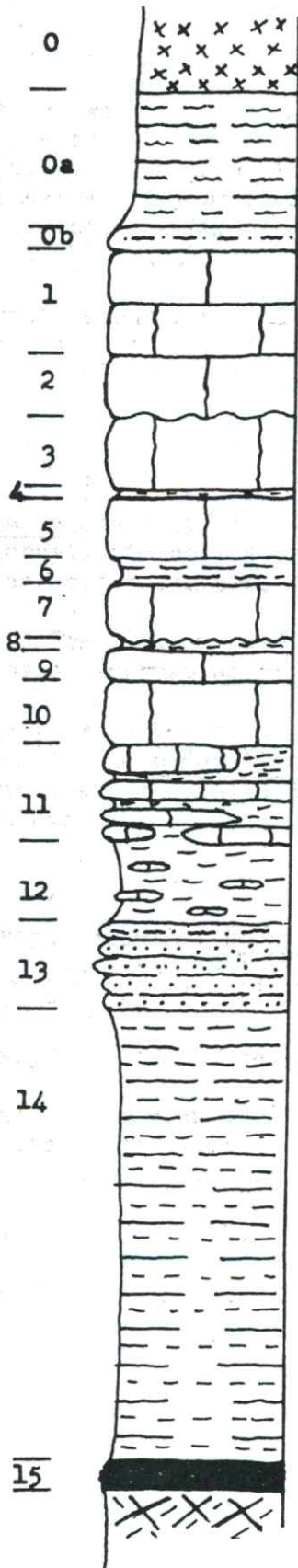
Locality 6A

- 6A.0 SHALE: red, deeply weathered. No fossils seen 0.6~~7~~
- 6A.0a SHALE: olive-green; silty to sandy. No fossils seen 1.5
- 6A.0b SILTSTONE: gray-green, weathers brown. Fossils:
"Aviculopecten" sp., Myalina sp., Juresania sp.,
Neochonetes sp., Neospirifer sp., Composita sp.,
ramose and fenestrate bryozoans. 0.3

LOCALITY 6.5



LOCALITY 6A



LOCALITY 5

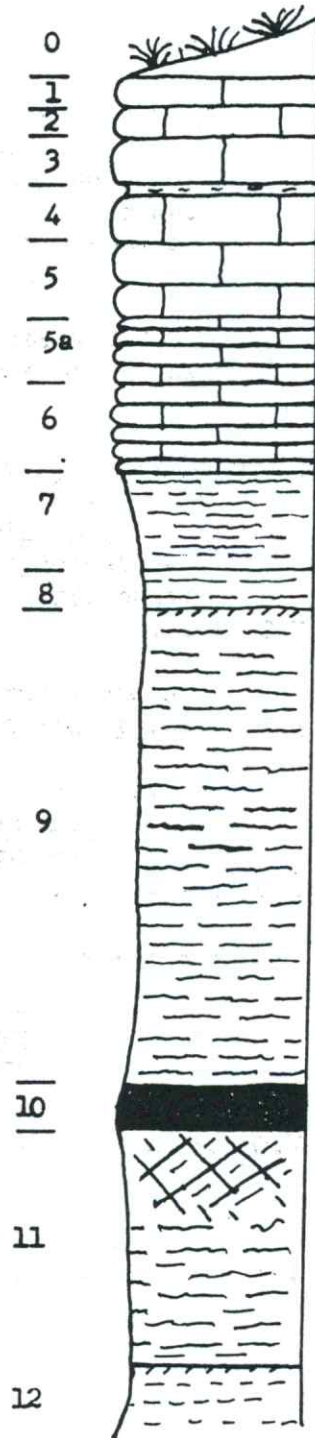


FIGURE 16

- 6A.1 LIMESTONE: reddish-brown; deeply weathered; crumbly; green shale partings. Fossils: Composita subtilita; numerous complete specimens; Neospirifer spp.; Neochonetes granulifer; Linoproductus spp.; Hystriaculina wabashensis; and ramose and encrusting bryozoans. 1.2
- 6A.2 LIMESTONE: light gray, weathering rusty brown; fusulinid-rich bed; scour and fill structures conspicuous; irregular discontinuity-like surface at base of bed. Fossils: very abundant subcylindrical fusulinids; dictyoclostids, crinoid parts, and ramose bryozoans. 0.7
- 6A.3 LIMESTONE: light gray; scour and fill structures. Fossils: Crurithyris sp., common; fenestrate bryozoans, and very abundant crinoidal debris 0.8
- 6A.4 SHALE: gray-green. 0.1
- 6A.5 LIMESTONE: light gray. Fossils: Crurithyris sp., Rhipidomella carbonaria, marginiferids, dictyoclostids, and derbyids; lophophyllidid corals; ramose bryozoans; and very abundant crinoid columnals. 0.7
- 6A.6 SHALE: olive-green. Fossils: crinoid columnals and a single large bun-shaped encrusting bryozoan colony . . . 0.3
- 6A.7 LIMESTONE: light gray; wavy bottom of bed. Fossils: Crurithyris sp., common; Rhipidomella carbonaria, common; large dictyoclostid; fusulinids; and very abundant crinoid columnals 0.6
- 6A.8 SHALE: olive-green 0.1
- 6A.9 LIMESTONE: light gray. Fossils: Neospirifer sp., Composita sp., Neochonetes sp., Rhipidomella aff. R. transversa; algal plates; and fusulinids 0.4
- 6A.10 LIMESTONE: light gray; similar to bed above. 0.7
- 6A.11 LIMESTONE and SHALE: olive-green to light gray; fusulinid-rich limestone and olive-green fusulinid-rich shale 1.1
- 6A.12 SHALE: olive-green; abundant fusulinids. 0.9
- 6A.13 SANDSTONE: light brown; calcareous 1.1

6A.14	SHALE: blue-gray, silty. Fossils: coalified plants. . .	5.0
6A.15	COAL	0.3

Locality 5

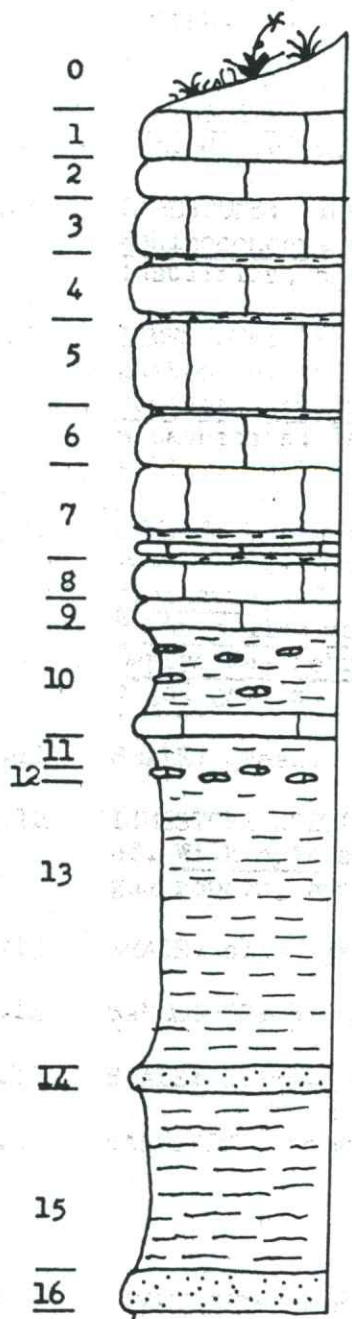
5.1	LIMESTONE: weathered, rusty brown; skeletal grains. Fossils: derbyid, cf. <u>Hystriculina wabashensis</u> , <u>Crurithyris?</u> sp., <u>Meekella</u> sp., chonetids, lophophyllid coral, and fusulinids.	0.3
5.2	LIMESTONE: weathered; rusty brown; skeletal grains. Fossils: <u>Antiquatonia portlockiana</u> , cf. <u>Hystriculina wabashensis</u> , dictyoclostids, bryozoans, gastropods, crinoidal debris	0.3
5.3	LIMESTONE: light bluish-gray; weathers brownish gray. Fossils: cf. <u>Aviculopinna</u> sp., <u>Rhipidomella carbonaria</u> , <u>Composita</u> sp., <u>Condathyris</u> sp., fusulinids, bryozoans, and crinoid parts.	0.6
5.4	LIMESTONE: light brownish-gray; abundant skeletal grains. Fossils: cf. <u>Hystriculina wabashensis</u> , <u>Hustedia</u> sp., <u>Composita</u> sp., <u>Condathyris</u> cf. <u>perplexa</u> , <u>Neochonetes granulifer</u> , <u>Neospirifer</u> sp., <u>Linoproductus</u> spp., crinoid columnals, and fusulinids.	0.6
5.5	LIMESTONE: light brownish-gray; fine skeletal debris conspicuous. Fossils: cf. <u>Hystriculina wabashensis</u> , <u>Punctospirifer</u> sp., <u>Neospirifer</u> sp., <u>Hustedia</u> sp., <u>Composita</u> sp., chonetids, fusulinids, crinoid parts, and algal crusts.	0.8
5.6a	LIMESTONE: same as above, but thin bedded. Fossils: cf. <u>Hystriculina wabashensis</u> , <u>Neochonetes granulifer</u> , <u>Neospirifer</u> sp., crinoid segments, fusulinids, and gastropods	0.7
5.6	LIMESTONE: light gray. Fossils: derbyids, <u>Composita</u> sp., chonetids, lophophyllid corals, fenestrate and ramose bryozoans, and fusulinids	0.9
5.7	SHALE: olive-green, weathers tan; fossiliferous. Fossils: <u>Myalina</u> (<u>Orthomyalina</u>) <u>slocomi</u> , <u>Composita subtilita</u> , <u>Punctospirifer</u> sp., <u>Neochonetes granulifer</u> , <u>Derbyoides</u> cf. <u>D. nebrascensis</u> , <u>Derbyia crassa</u> , <u>Echinoconchus</u> cf. <u>E. semipunctatus</u> , <u>Antiquatonia portlockiana</u> var. <u>crassicostatus</u> ; crinoid columnals,	

	brachial plates and a calyx; echinoid plates and spines; fenestrate, rhomboporid, and encrusting bryozoans; syringoporid and lophophyllidid corals . . .	1.0
5.8	SHALE: olive green, weathers tan. Fossils: scattered fusulinids at top but none at bottom; <u>Pleurophorus</u> sp., <u>Posidonia</u> sp., and aviculopectinid mold; <u>Composita subtilita</u> and encrusting bryozoans.	0.4
5.9	SHALE: olive-green to grayish; brown iron-oxide zone at top, possible weathered surface. Fossils: coalified land plants	5.0
5.10	COAL:	0.4
5.11	UNDERCLAY: bluish-gray; massive; plastic. No fossils seen.	2.5
5.12	SHALE: bluish-gray; blocky to indurated; top contains iron-oxide streak	1.0 4

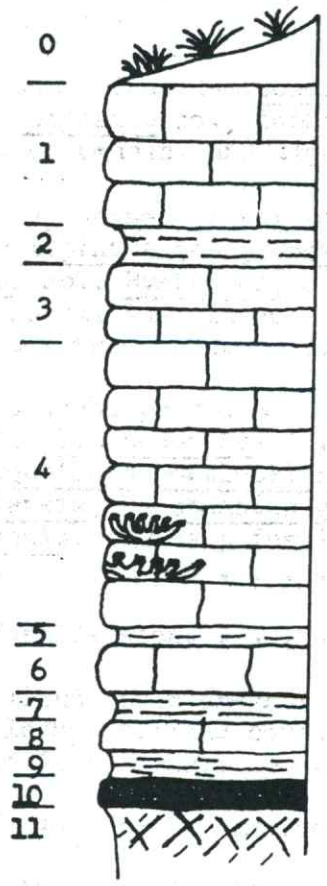
Locality 4

4.1	LIMESTONE: light tan, weathering brown; skeletal grains. Fossils: <u>Neospirifer</u> sp., <u>Hystriculina wabashensis</u> , <u>Neochonetes</u> sp., dictyoclostids, fusulinids, and algal coated grains	0.5
4.2	LIMESTONE: tan, weathering brown. Fossils: ramose bryozoans; fusulinids, crinoid columnals, and algal coated grain.	0.4
4.3	LIMESTONE: tan, weathering brown; abundant skeletal grains. Fossils: <u>Neospirifer</u> sp., fusulinids, crinoid columnals, fenestrate bryozoans, ramose bryozoans, and algal coated grains.	0.6
4.4	LIMESTONE: light gray; large skeletal grains. Fossils: <u>Hystriculina wabashensis</u> , <u>Neochonetes</u> sp., <u>Hustedia</u> sp., <u>Composita?</u> sp., encrusting bryozoans, crinoid columnals, and gastropods	0.6
4.5	LIMESTONE: light brownish gray. Fossils: cf. <u>Hystriculina wabashensis</u> , <u>Hustedia</u> sp., <u>Derbyia</u> sp., fusulinids, bryozoans, crinoid parts, and a few fusulinids.	0.9

LOCALITY 4



LOCALITY 3A



LOCALITY 3

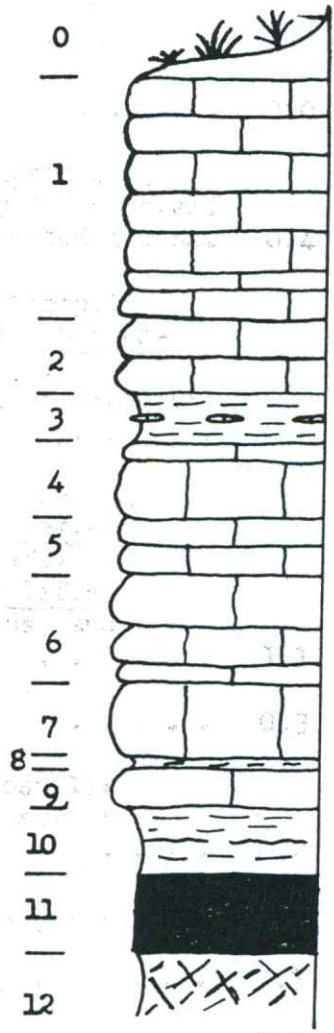


FIGURE 17

4.6	LIMESTONE: light brownish gray, dense. Fossils: fusulinids, algal coated grains, and a calcareous sponge.	0.5
4.7	LIMESTONE: light brownish gray, dense. Fossils: <u>Neospirifer</u> sp., <u>Meekella</u> sp., fusulinids, algal coated grains, and a trilobite fragment	1.0
4.8	LIMESTONE: light brown. Fossils: <u>Condrathyris</u> sp., <u>Echinoccnchus</u> sp., <u>Composita</u> sp., lophophyllidid coral, fusulinids, crinoid columnals, and algal coated grains.	0.4
4.9	LIMESTONE: light gray, dense. Fossils: naticopsid gastropod, aff. <u>Planispina armata</u> , <u>Meekella striatocostata</u> , <u>Neospirifer</u> sp., <u>Hystriculina</u> cf. <u>H. wabashensis</u> ; large fusulinids, large algal structures; echinoid spines, and crinoid columnals.	0.3
4.10	LIMESTONE and SHALE: light gray limestone, grading into shale. Fossils: <u>Echinoconchus</u> cf. <u>E. semi-punctatus</u> , cf. <u>Antiquatonia portlockiana</u> , aff. <u>Hystriculina wabashensis</u> , <u>Neochonetes granulifer</u> , <u>Derbyoides nebrascensis</u> , abundant fusulinids, and algal grains.	1.1
4.11	SHALE: green. No fossils seen.	0.3
4.12	LIMESTONE NODULES: light greenish-gray. Fossils: cf. <u>Wilkingia</u> sp., lophophyllidid coral, fusulinids, gastropods, and crinoid columnals	0.2
4.13	SHALE: olive-green. No fossils observed.	2.9
4.14	SANDSTONE: olive, silty. No fossils seen	0.3
4.15	SHALE: olive. No fossils found	1.9
4.16	SANDSTONE: brown, fine-grained. No fossils seen.	0.4

Locality 3A

3A.1	LIMESTONE: light gray. Fossils: abundant crinoid columnals	1.5
3A.2	SHALE: olive-green. Fossils: lophophyllidid corals	0.4
3A.3	LIMESTONE: light gray	0.8

- 3A.4 LIMESTONE: light gray; fairly massive unit. Fossils: crinoid columnals, a few fusulinids, Condrathyris sp., Neospirifer sp.; and, syringoporid corals which occur as lenses up to one foot thick and up to 5 feet in length with the colonies in growth position. 3.0
- 3A.5 SHALE: green, calcareous. Fossils: fusulinids, crinoid columnals, and brachiopod shells 0.2
- 3A.6 LIMESTONE: light gray; fine skeletal grains. Fossils: fusulinids, crinoid columnals, brachiopods, and solitary corals. 0.5
- 3A.7 SHALE: green; calcareous. Fossils: fusulinids, crinoid columnals and brachiopods. 0.3
- 3A.8 LIMESTONE: light gray, dense. Fossils: Derbyia sp., Neospirifer sp., fusulinids, and crinoid columnals . . . 0.3
- 3A.9 SHALE: blue-gray. Fossils: coalified plant remains. . . 0.3
- 3A.10 COAL: black, brittle 0.3

Locality 3

- 3.1 LIMESTONE: light gray, weathers brown; skeletal grains. Fossils: gastropods, Echinoconchus cf. E. semipunctatus, Neochonetes granulifer, cf. Meekella sp., Composita sp., derbyids, Antiquatonia portlockiana, crinoid columnals; encrusting ramose and fenestrate bryozoans; fusulinids and lophophyllidid corals. 2.5
- 3.2 LIMESTONE: light gray, weathers rusty brown; coarser skeletal grains than above. Fossils: Linoproductus spp., Echinoconchus semipunctatus, Antiquatonia cf. A. portlockiana, Hustedia cf. H. mormoni, Neospirifer sp., Neochonetes granulifer, Neospirifer sp., Derbyia cf. D. crassa, Hystericulina wabashensis, cf. Planispina armata; encrusting, pennireteporid, ramose bryozoans; crinoid columnals and lophophyllidid corals. 0.8
- 3.3 SHALE: green, weathers brown. Fossils: Crurithyris planoconvexa and crinoid debris in limestone nodules near middle of unit. 0.5

- 3.4 LIMESTONE: light brownish-gray; skeletal. Fossils: Neospirifer sp., Hustedia mormoni, Rhipidomella carbonaria, Rhipidomella aff. R. transversa, Linoproductus cf. L. prattenianus, aff. Reticulatia huecoensis, Composita subtilita, Punctospirifer sp., Neochonetes granulifer, Ditomopyge? sp.; crinoid columnals; pennireteporid and rhomboporid bryozoans; fusulinids, algal coated grains, and lophophyllidid coral. 0.8
- 3.5 LIMESTONE: light gray, weathers brown; dense. Fossils: Hustedia mormoni, cf. Antiquatonia portlockiana, Neospirifer sp., Rhipidomella carbonaria, Condrathyris cf. C. perplexa; fenestrate, ramose, and encrusting bryozoans; lophophyllidid corals; crinoid columnals and fusulinids 0.6
- 3.6 LIMESTONE: light buff; skeletal grains in dense matrix. Fossils: derbyids, Ditomopyge? sp., algal coated grains, fusulinids, gastropods, and brachiopods . 1.1
- 3.7 LIMESTONE: medium gray, weathers brown; dense. Fossils: cf. Meekella sp., Hustedia sp.; large black fusulinids and algal coated grains 0.8
- 3.8 SHALE: olive-green, weathers brown. No fossils seen . . 0.1
- 3.9 LIMESTONE: light to dark gray; dense. Fossils: derbyids, Composita sp., Hustedia sp., lophophyllidid corals, fusulinids, and algal coated grains. 0.4
- 3.10 SHALE: olive-green, weathers brown. Fossils: Composita subtilita, Crurithyris planoconvexa, Derbyia crassa, and encrusting bryozoans 0.7
- 3.11 COAL: black. 0.8
- 3.12 CLAY: bluish-gray, plastic, probably underclay. No fossils

Locality 2

- 2.1 LIMESTONE: light gray, weathers brown; coarse skeletal grains. Fossils: cf. Wilkingia sp., Aviculopinna sp., Linoproductus cf. L. prattenianus, cf. Composita sp., algal coated grains, crinoid columnals, gastropods, and fusulinids. 0.6

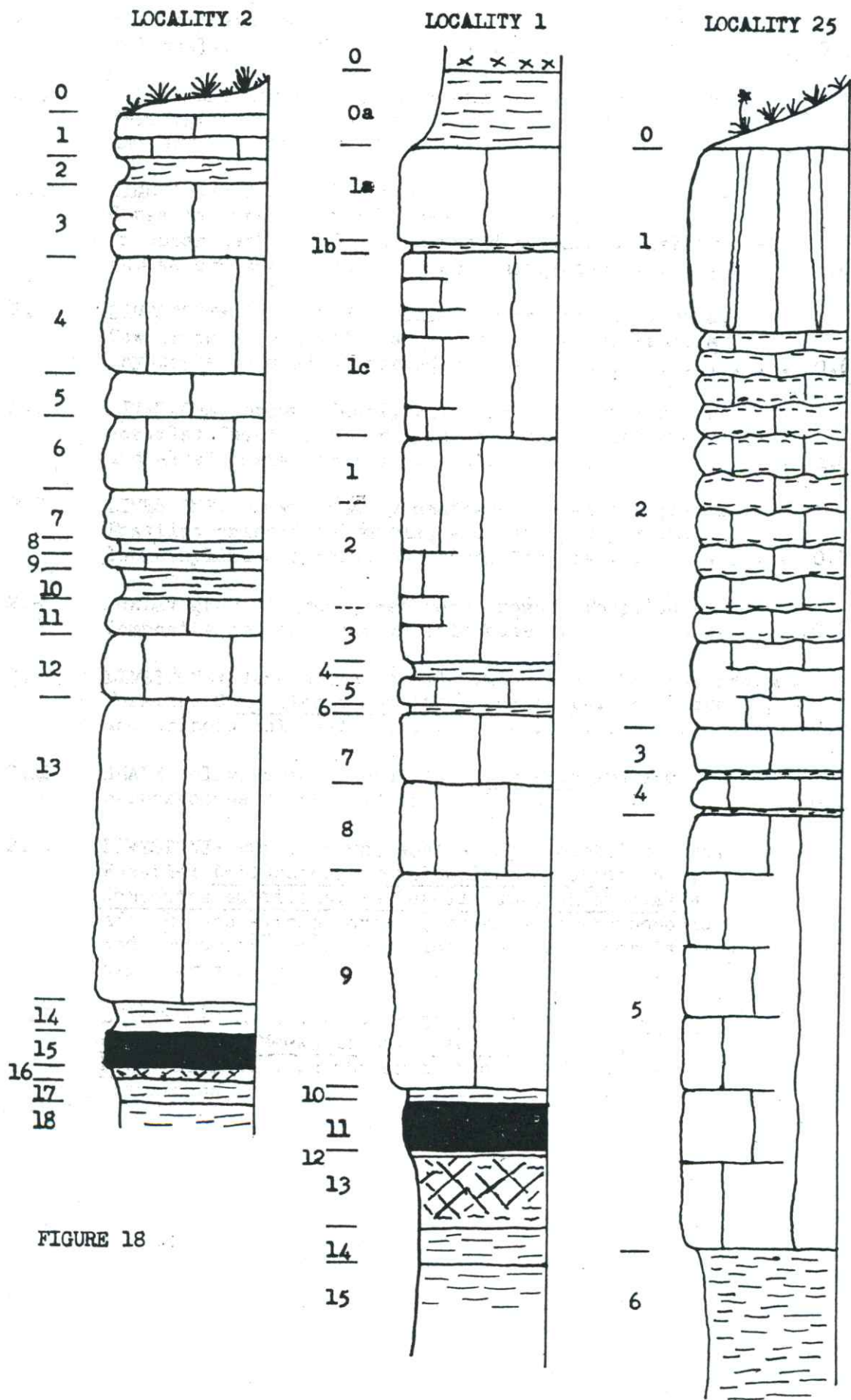


FIGURE 18

- 2.2 SHALE: green, weathers brown. Fossils: crinoid columnals. 0.3
- 2.3 LIMESTONE: light gray, weathers rusty brown; dense. Fossils: fusulinids, bryozoans, crinoid columnals, and brachiopods. 0.9
- 2.4 LIMESTONE: light brownish-gray, weathers rusty brown; dense in lower part with skeletal grains conspicuous in upper part. Fossils: crinoid columnals, pelecypods, ramose bryozoans, and fusiform fusulinids. 1.6
- 2.5 LIMESTONE: light gray, dense. Fossils: fusulinids, few crinoid columnals, algal coated grains, ramose bryozoans, and algal coated grains 0.6
- 2.6 LIMESTONE: brown, deeply weathered; skeletal grains. Fossils: fusulinids, crinoid columnals, gastropods, and algal coated grains. 1.0
- 2.7 LIMESTONE: brown, deeply weathered, skeletal grains. Fossils: crinoid columnals, encrusting bryozoans, lophophyllidid corals, and algal "crusts". 0.7
- 2.8 SHALE: grayish-green, weathers brown. Fossils: Composita sp. and crinoid columnals. 0.2
- 2.9 LIMESTONE: dark brown, deeply weathered; skeletal grains. Fossils: Composita subtilita, Neochonetes sp., derbyid, and crinoid columnals. 0.2
- 2.10 SHALE: olive-green. Fossils: Composita sp. and carbonaceous plant remains 0.4
- 2.11 LIMESTONE: rusty brown, weathered; skeletal grains. Fossils: Antiquatonia portlockiana, Hustedia sp., Composita subtilita, Wellerella sp., Rhipidomella aff. R. transversa; crinoid columnals; rhomboporid and encrusting bryozoans; lophophyllidid corals; and algal crusts 0.5
- 2.12 LIMESTONE: medium to dark gray. Fossils: Hystriaculina wabashensis, Meekella sp., Neospirifer sp., cf. Derbyoides sp.; rhomboporid bryozoans; and a few fusulinids 0.9

2.13	LIMESTONE: medium brownish-gray. Fossils: <u>Naticopsis</u> sp., " <u>Aviculopecten</u> " sp., <u>Linoproductus</u> spp., <u>Echinoconchus</u> cf. <u>E. seminunctatus</u> , <u>Juresania nebrascensis</u> , <u>Antiquatonia portlockiana</u> , <u>Meekella</u> cf. <u>M. striatocostata</u> , <u>Composita</u> sp., <u>Beecheria bovidens</u> , <u>Crurithyris</u> sp., <u>Neospirifer</u> sp., <u>Rhipidomella</u> aff. <u>R. transversa</u> , <u>Derbyia crassa</u> ; rhomboporid and fenestrate bryozoans; lophophyllid coral; fusulinids; and algal "crusts".	4.2
2.14	SHALE: medium gray. No fossils	0.4
2.15	COAL: black, chunky	0.5
2.16	SHALE: black, bituminous; plant leaf remains.	0.2
2.17	SHALE: dark gray; carbonaceous.	0.3

Locality 1

1.0a	SHALE: red. No fossils seen.	0.5 4
1.0b	SHALE: green. No fossils seen.	1.2
1.1a	LIMESTONE: light gray, weathers brown; irregular brown markings at top of bed may be burrows. Fossils: cf. myalinids and large linoproductids.	1.3
1.1	LIMESTONE: light brownish gray, dense. Fossils: gastropods, <u>Rhipidomella carbonaria</u> , <u>Neospirifer</u> sp., <u>Linoproductus</u> spp., fenestrate bryozoans, crinoid columnals, small fusulinids, lophophyllid corals, and "Cryptozoon".	1.5
1.2	LIMESTONE: light brownish gray, weathers brown. Fossils: aff. <u>Reticulatia huecoensis</u> , <u>Neospirifer</u> sp., crinoid debris, fusulinids, bryozoans, and "Cryptozoons"	
1.3	LIMESTONE: light brownish gray, weathers rusty brown; argillaceous. Fossils: more crinoid debris than in beds above; <u>Reticulatia huecoensis</u> , <u>Antiquatonia portlockiana</u> , <u>Hustedia</u> cf. <u>H. mormoni</u> , <u>Neospirifer</u> sp., encrusting bryozoans, fusulinids, and horn corals . . .	0.7
1.4	SHALE: grayish green, weathers brown. Fossils: small brachiopods, molluscs, and carbonaceous plant remains	0.2

- 1.5 LIMESTONE: light brown, weathers rusty brown. Fossils: Antiquatonia portlockiana, Hystriculina wabashensis, Hustedia cf. H. mormoni, Composita subtilita, Punctospirifer cf. P. kentuckyensis, Neochonetes granulifer; cf. Crurithyris sp., Rhipidomella carbonaria, lophophyllid coral, and crinoid columnals. Bed permeated by irregular clay-filled tubes, either burrows or borings and more likely the former. 0.4
- 1.6 SHALE: olive-green, weathers brown. Fossils: carbonaceous streaks and fossil molds. 0.2
- 1.7 LIMESTONE: very light brownish gray, weathers brown. Fossils: Wellerella sp., Derbyia sp., Neochonetes granulifer, Crurithyris planoconvexa, Neospirifer sp., Rhipidomella carbonaria, Rhipidomella aff. R. transversa, Composita subtilita, Hustedia mormoni, Hystriculina wabashensis, cf. Antiquatonia portlockiana, aff. Reticulatia huecoensis, Cond Rathyris sp., lophophyllid corals, Ditomopyge? sp., and crinoid columnals 1.0
- 1.8 LIMESTONE: light brownish gray, weathers brown. Fossils: Camptonectes? sp., Hystriculina wabashensis, Hustedia cf. H. mormoni, Meekella sp., Neochonetes granulifer, Cond Rathyris sp., Wellerella sp., Neospirifer sp., Rhipidomella aff. R. transversa, Cancrinella boonesis, Composita subtilita, fenestrate bryozoans, lophophyllid corals, Ditomopyge? sp., algal growths; abundant crinoidal debris and fusulinids. 1.2
- 1.9 LIMESTONE: light gray with darker colored argillaceous stringers and lenses with lenticular occurrences of Osagia coated skeletal grains; small organic layers of algal mats in stringers up to 1-1/2 feet in length occur near top of bed. Fossils: robust fusulinids occur throughout bed. Fossils in upper foot: Meekella cf. M. striatocostata, Neochonetes granulifer, Cond Rathyris cf. C. perplexa, Neospirifer sp., derbyid, Planispina armata, Linoproductus spp., Wellerella cf. W. osagensis, Rhipidomella aff. R. transversa, fenestrate bryozoans and lophophyllid corals. Fossils in middle foot: Beecheria bovidens, Meekella cf. M. striatocostata, Neospirifer sp., Rhipidomella cf. R. transversa, and fenestrate bryozoans. Fossils in upper: Meekella sp., Composita sp., Neospirifer sp., derbyid, Linoproductus cf. L. prattenianus, and lophophyllid coral. 0.2

1.10	SHALE: bluish-gray. Fossils: <u>Juresania</u> cf. <u>J. nebrascensis</u> , <u>Composita subtilita</u> , <u>Derbyia crassa</u> , and rhomboporid bryozoans.	0.2
1.11	COAL: black, brittle	0.6
1.12	SHALE: black, fissile.	0.2
1.13	CLAY: bluish gray.	0.9

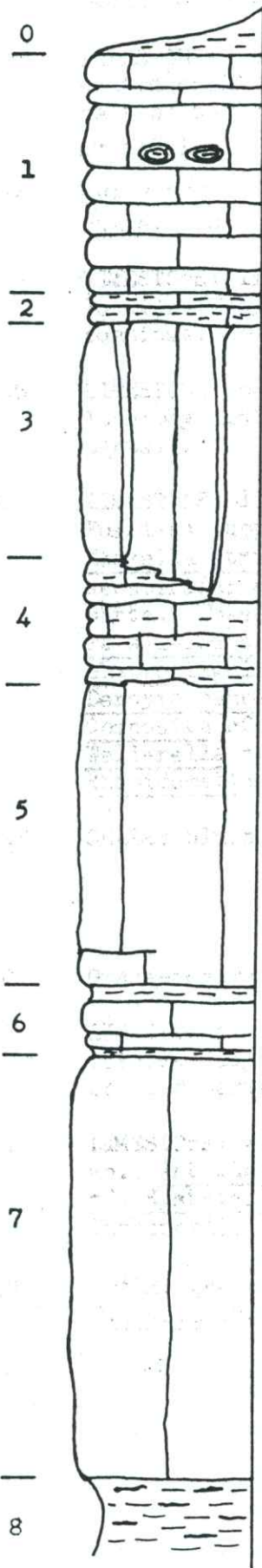
Locality 25

25.1	LIMESTONE: white; massive; vertically oriented grooves, probably clam burrow.	2.5
25.2	LIMESTONE: light gray to buff; shaly interbeds; individual limestone beds are discontinuous; surface of limestone is pitted and honey-combed with shale infill - suggestive of probably subaerial erosion soon after deposition.	5.5
25.3	LIMESTONE: continuous bed.	0.6
25.4	LIMESTONE: shale seam above and below; encrusting bryozoan masses, lophophyllidid corals, and crinoid debris abundant in zone.	0.6
25.5	LIMESTONE: light gray with patchy white areas; many coated grains; highly crinoidal in upper foot; upper surface of bed undulatory, suggestive of megaripples. Fossils: <u>Rhipidomella</u> aff <u>R. transversa</u> and <u>Entaletes</u> sp.	6.0
25.6	SHALE: bluish-gray; silty.	
25.7	COAL: black, chunky.	

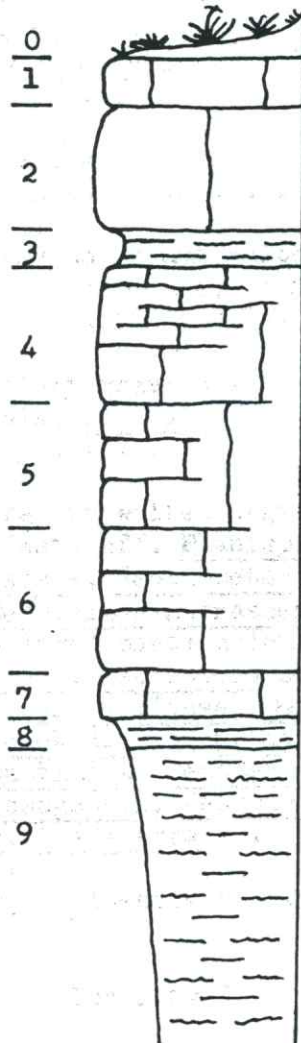
Locality 20

20.0	SHALE.	1.07
20.1	LIMESTONE: very light gray, weathers tan; local pockets of <u>Osagia</u> coated shell fragments; some green shale partings. Fossils: aviculopectinids, <u>Wilkingia</u> sp. (in burrow), <u>Myalina</u> cf. <u>M. (Orthomyalina) slocomi</u> ; <u>Bellerophon (Pharkidonotus) spp.</u> ; <u>Straparolus (Euomphalus) sp.</u> , <u>Linoproductus</u> cf. <u>L. prattenianus</u> ; <u>Juresania</u> aff. <u>J. nebrascensis</u> ; fenestrate bryozoans; and pecan-sized algal biscuits	2.9

LOCALITY 20



LOCALITY 9



LOCALITY 13

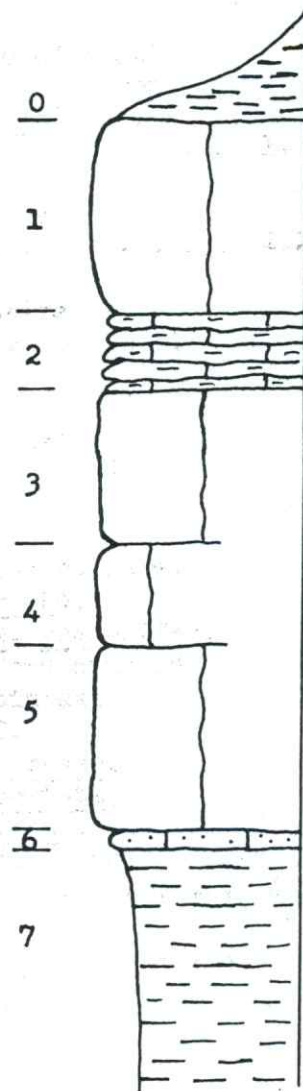


FIGURE 19

- 20.2 SHALE: green, weathers brown, calcareous. Fossils: myalinid fragment and linoproductid. 0.4
- 20.3 LIMESTONE: light gray to creamy white; sand of algal coated shell fragments. Fossils: Myalina sp. (upper part of bed); Linoproductus spp., and Juresania cf. J. ovalis. 1.7
- 20.4 SHALY LIMESTONE: light gray limestone and green shale. Fossils: crinoid columnals 2.2
- 20.5 LIMESTONE: light gray to creamy white, massive. Fossils: brachiopods, bryozoans, crinoid parts, algal coatings, and lophophyllidid corals. 4.1
- 20.6 LIMESTONE: medium light gray; shaly. Fossils: lophophyllidid corals, Composita sp., and crinoid parts. 1.0
- 20.7 LIMESTONE: light gray to white; argillaceous at base. Fossils: (upper 3 feet) aff. Planispina armata, Meekella striatocostata, Neochonetes cf. N. granulifer, Neospirifer sp., Derbyoides nebrascensis; and crinoid parts. Fossils in lower part: aviculopectinids, Parallelodon obsoletus, Naticopsis sp., cf. Glabrocingulum (G.) grayvillense, Derbyia crassa, Derbyia bennetti, Meekella cf. M. striatocostata, Composita cf. C. subtilita, Beecheria bovidens, Wellerella cf. W. osagensis, Neospirifer sp., and Rhipidomella aff. R. transversa 4.0
- 20.8 SHALE: bluish gray, no fossils seen.

Locality 9

- 9.0 Grass-covered slope.
- 9.1 LIMESTONE: brownish-gray, weathers dark brown. Fossils: algal coated grains, fusulinids, gastropods, crinoid parts and brachiopods. 0.5
- 9.2 LIMESTONE: weathered, brown. Fossils: cf. Naticopsis sp., Antiquatonia portlockiana, Neochonetes granulifer, cf. Hystriculina wabashensis, crinoid columnals, and lophophyllidid corals. 1.3
- 9.3 SHALE: greenish-gray, weathers brown. Fossils: Hustedia sp. and crinoid columnals 0.4

9.4	LIMESTONE: brownish gray, weathers brown; green shale partings. Fossils: fusulinids, gastropods, <u>Hustedia</u> sp., <u>Cond Rathyris</u> sp., <u>Neospirifer triplicatus</u> , and <u>Rhipidomella</u> aff. <u>R. transversa</u>	1.4
9.5	LIMESTONE: highly weathered. Fossils: fusulinids, brachiopods, and crinoid segments	1.3
9.6	LIMESTONE: weathered dark brown; less skeletal material than above. Fossils: cf. <u>Derbyoides</u> sp., <u>Neochonetes</u> sp., cf. <u>Meekella</u> sp., crinoid columnals, and fusulinids.	1.5
9.7	LIMESTONE: weathered brown; argillaceous and fine-grained. Fossils: <u>Neochonetes granulifer</u> , <u>Derbyia</u> cf. <u>D. crassa</u> , <u>Composita subtilita</u> , <u>Crurithyris</u> cf. <u>C. planoconvexa</u> , crinoid columnals, fusulinids (abundant), ramose bryozoans, and lophophyllid corals.	0.5
9.8	SHALE: brown, weathered	0.3
9.9	SHALE: greenish gray, silty and sandy. No fossils seen.	30.9

Locality 13

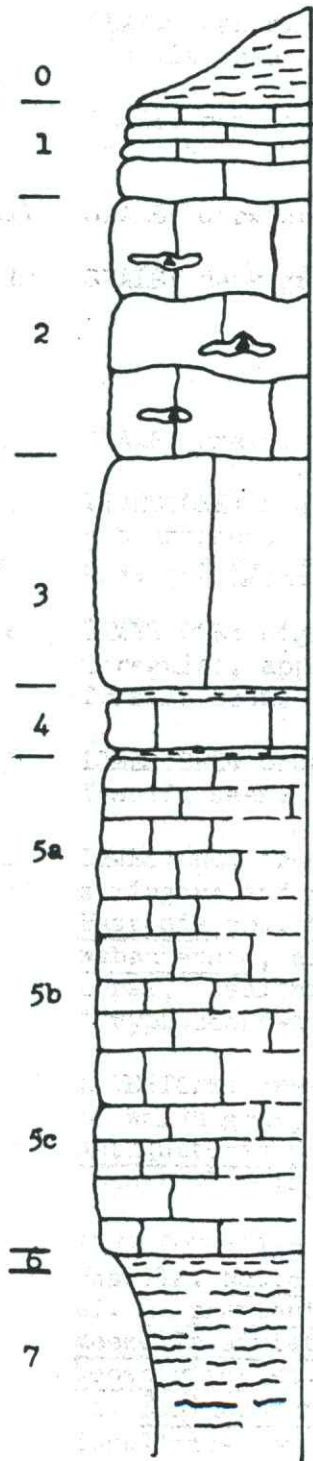
13.0	SHALE: greenish gray. No fossils seen.	1.0 4
13.1	LIMESTONE: light gray, weathers brown. Fossils: <u>Derbyia</u> sp. (encrusted by bryozoans), aff. <u>Echinoconchus</u> spp., crinoid columnals, lophophyllid corals, fusulinids, and "Cryptozoon"-type oncolites	2.3
13.2	LIMESTONE: light gray, weathered brown; argillaceous. Fossils: fusulinids, lophophyllid corals, and brachiopods.	1.0
13.3	LIMESTONE: light brownish-gray, weathers dark brown. Fossils: fusulinids and brachiopods	1.8
13.4	LIMESTONE: light brownish gray, weathers brown. Fossils: <u>Rhipidomella</u> aff. <u>R. transversa</u> , fusulinids, brachiopods, and crinoid stems.	1.2

13.5	LIMESTONE: white, weathers light brown; chalky. Fossils: <u>Rhipidomella</u> spp., robust fusulinids, and fusulinids and coated grains.	2.1
13.6	LIMESTONE: bluish-gray, weathers brown, argillaceous, and arenaceous. Fossils: fusulinids.	0.2
13.7	SHALE: bluish-gray; silty and sandy	1.0 7

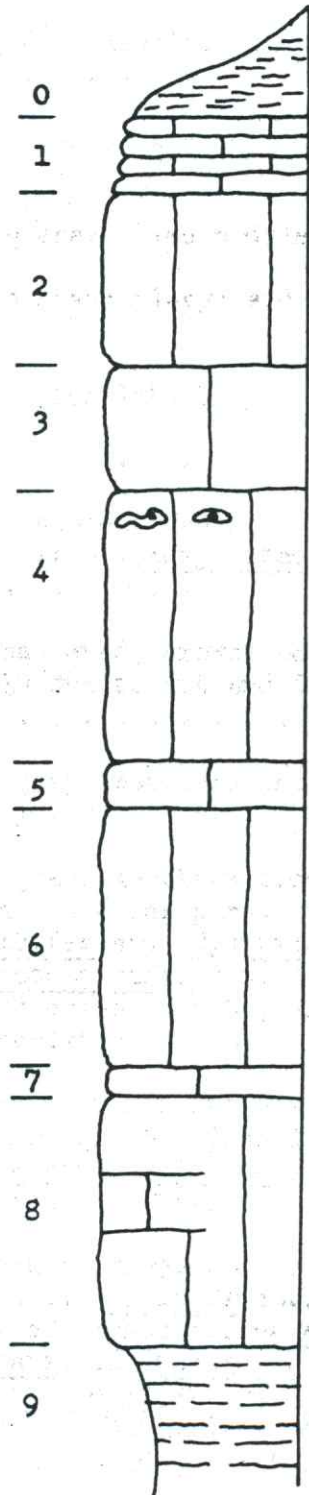
Locality 22

22.0	SHALE: greenish gray. No fossils seen.	1.0 7
22.1	LIMESTONE: weathered brown, nodular and rubbly. Fossils: <u>Bellerophon</u> (<u>Pharkidonatus</u>) sp., cf. <u>Knightites</u> (<u>Retispira</u>) sp., <u>Euphemites carbonarius</u> , <u>Murchisonia</u> (<u>M.</u>) sp., and myalinids	1.0
22.2	LIMESTONE: light brownish gray, weathers brown; irregularly bedded. Fossils: <u>Myalina</u> cf. <u>M. slocomi</u>	2.7
22.3	LIMESTONE: brownish-gray, weathers brown; fine-grained. Fossils: brachiopods, numerous fusiform fusulinids; crinoid debris; and, large "Cryptozoon"-type oncolites.	2.4
22.4	LIMESTONE: with shale break above and below; shale olive-green, weathers brown; limestone brownish gray, weathers rusty brown. Fossils: <u>Neospirifer</u> sp., and <u>Composita</u> cf. <u>C. subtilita</u>	0.8
22.5	LIMESTONE: light brown, weathers darker brown. Fossils: in upper half; <u>Wilkingia</u> sp., <u>Meekella</u> cf. <u>M. striatocostata</u> , <u>Composita</u> sp., <u>Neochonetes</u> cf. <u>N. granulifer</u> , <u>Neospirifer</u> sp., <u>Rhipidomella</u> aff. <u>R. transversa</u> , and lophophyllidid coral. Fossils in lower half: <u>Linoproductus</u> spp., <u>Retaria lasallensis</u> , <u>Composita</u> cf. <u>C. subtilita</u> , <u>Beecheria bovidens</u> , <u>Neospirifer</u> sp., and <u>Rhipidomella</u> cf. <u>R. transversa</u>	5.4
22.6	SHALE: calcareous, light to medium gray. Fossils: fusulinids, small brachiopods, clams, and crinoid parts	0.2
22.7	SHALE: light bluish-gray; silty to sandy lenses. No fossils seen	8.3

LOCALITY 22



LOCALITY 11



LOCALITY 12

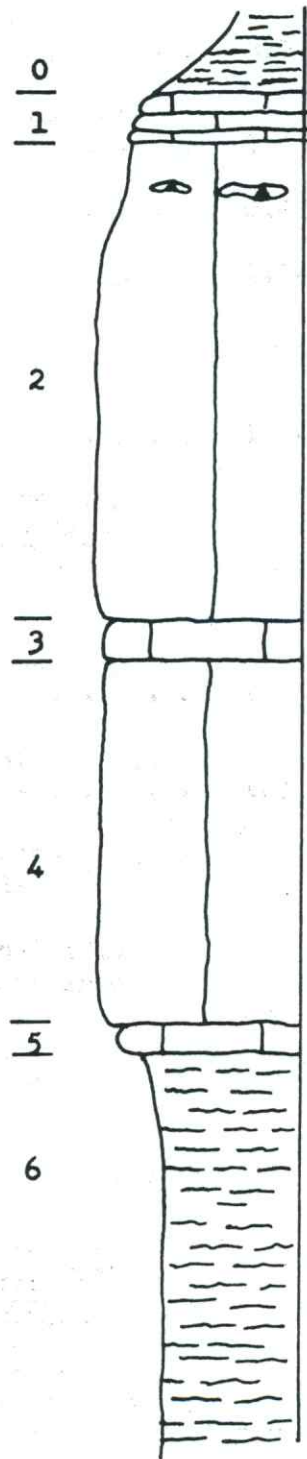


FIGURE 20

22.8	COAL: thin argillaceous smudge.	0.1
22.9	CLAY: dark bluish-gray, plastic, and blocky. No fossils observed.	3.0
22.10	SHALE: red, silty to sandy; zone of lime nodules at top. No fossils seen	1.8
22.11	SHALE: dark greenish gray; lime nodules	0.8
22.12	SHALE: dark greenish gray; platy; and silty	1.04

Locality 11

11.0	SHALE: greenish gray.	1.04
11.1	LIMESTONE: highly weathered, brown; rubbly, bedding not apparent. Fossils: cf. <u>Knightsites</u> (<u>Retispira</u>) sp., and <u>Myalina</u> sp.	0.8
11.2	LIMESTONE: highly weathered, brown; bedding irregular, apparently due to cut and fill. No fossils seen.	1.8
11.3	LIMESTONE: brownish gray, weathers brown. No fossils seen.	1.3
11.4	LIMESTONE: brownish gray, weathers brown; chert stringers and nodules in upper part. Fossils: <u>Hustedia</u> sp., <u>Neospirifer</u> sp., <u>Hystriaculina wabashensis</u> , cf. <u>Punctospirifer</u> sp., lophophyllid coral, fusulinids and crinoid parts; and, scattered "Cryptozoon"-type oncolites	2.8
11.5	LIMESTONE: gray shale partings above and below; brownish gray, weathers brown. Fossils: cf. <u>Antiquatonia portlockiana</u> , <u>Composita</u> sp., lophophyllid, and crinoid stems	0.5
11.6	LIMESTONE: light brownish gray, weathers rusty brown. Fossils: <u>Naticopsis</u> sp., <u>Wilkingia</u> sp., <u>Linoproductus</u> cf. <u>L. prattenianus</u> , cf. <u>Hystriaculina wabashensis</u> , <u>Meekella striatocostata</u> , cf. <u>Neochonetes granulifer</u> , <u>Neospirifer</u> sp., <u>Rhipidomella</u> aff. <u>R. transversa</u> , cf. <u>Echinoconchus</u> sp., lophophyllid corals, robust fusulinids, and Osagia coated grains.	2.7

- 11.7 LIMESTONE: brownish gray, weathers brown. Fossils: Rhipidomella aff. R. transversa, Neospirifer sp., algal coated grains, fusulinids, and crinoid parts. 0.3
- 11.8 LIMESTONE: brownish gray, weathers brown. Fossils: Derbyia sp., fenestrate bryozoans, lophophyllid corals, fusulinids, algal encrustations, and crinoid parts. 2.6
- 11.9 SHALE: greenish gray, silty to sandy. No fossils seen. 1.0~~7~~

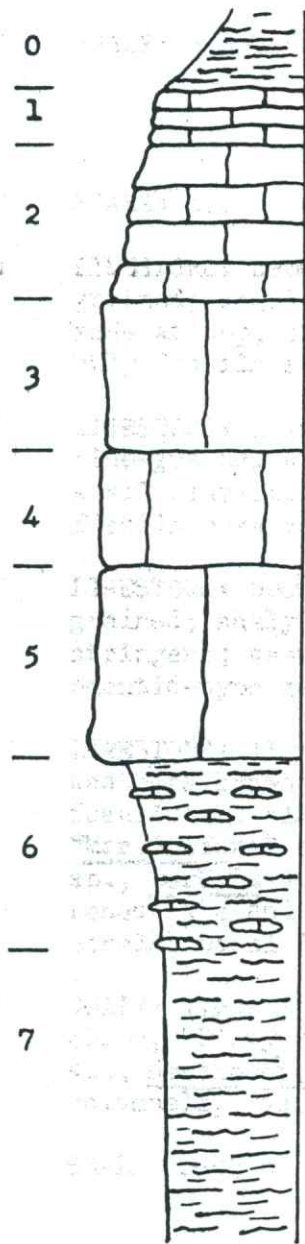
Locality 12

- 12.0 SHALE: greenish gray. No fossils seen. 1.0~~7~~
- 12.1 LIMESTONE: deeply weathered, brown. Fossils: Bellerophon (Pharkidonotus) sp., cf. Nuculana bellistriata, and Septimyalina cf. S. scitula 0.5
- 12.2 LIMESTONE: brownish gray, weathers brown; zone of tan chert nodules and stringers near top of massive bed. Fossils: myalinids, clams, and gastropods above chert; crinoid columnals, small fusulinids, and brachiopods in middle part; Wilkingia sp., Composita sp., Punctospirifer sp., Hustedia sp., marginiferids, Neospirifer sp., crinoid debris and bryozoans in lower half of bed 5.0
- 12.3 LIMESTONE: thin shale parting above and below; brownish gray, weathers brown. Fossils: Antiquatonia sp., and crinoid stems. 0.4
- 12.4 LIMESTONE: brownish gray, weathers brown. Fossils: Echinoconchus cf. E. moorei, aff. Planispina armata, Hystericulina wabashensis, cf. Cancrinella boonensis, Hustedia sp., Meekella cf. M. striatocosta, Composita cf. C. subtilita, cf. Chonetina sp., Beecheria bovidens, Neospirifer sp., Rhipidomella aff. R. transversa, fusulinids, crinoid parts, corals, bryozoans, and algal structures 3.8
- 12.5 LIMESTONE: bluish gray, weathers brown. 0.2
- 12.6 SHALE: bluish gray, sandy and silty. Fossils: "Aviculopecten" sp., cf. Posidonia sp., and phosphatic brachiopods. 6.0~~7~~

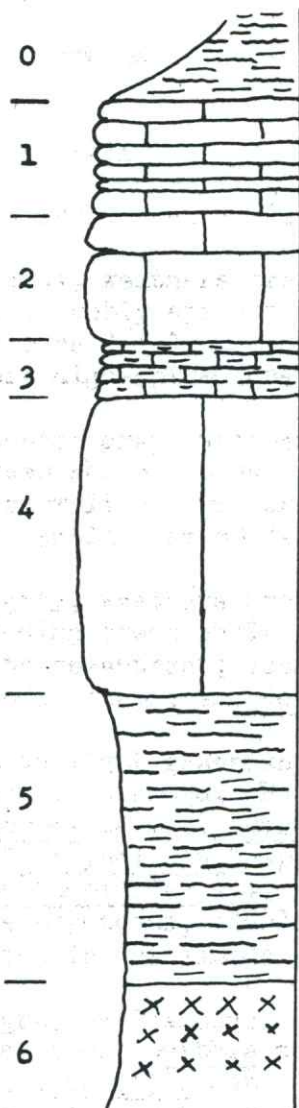
Locality 10

- 10.0 SHALE: light greenish gray; no fossils seen. 1.04
- 10.1 LIMESTONE: light gray, weathers light brown; fine-grained; nodular, rubbly; lithologically similar to unit 2; no fossils seen. 0.6
- 10.2 LIMESTONE: light gray, weathers light brown, fine-grained; numerous green shale laminae, flakes, and fillings; weathers slabby. Fossils: aff. Goniasma sp., Knightites (Retispira) sp., Wilkingia terminale, Nuculana bellistriata, Solemya sp. cf. S. radiata, "Aviculopecten" sp., Myalina sp. cf. M. (O.) slocomi, Septimyalina sp. cf. S. scitula. 1.6
- 10.3 LIMESTONE: light grayish buff, weathers light brown; fine-grained; numerous green shale laminae, flakes, and fillings; weathers slabby. Fossils: Linoproductus sp., aff. L. platyus, Echinoconchus sp., cf. E. semipunctatus, aff. Juresania sp., Antiquatonia portlockiana var. crassicostata, Hystriculina wabashensis, Composita sp., Chonetes granulifer, Chonetes spp., Neospirifer triplicatus; fenestrate bryozoans, and ramose bryozoans 1.6
- 10.4 LIMESTONE: greenish gray, weathers brown; green clay stringers; skeletal grains less abundant than in bed 3. Fossils: Linoproductus spp., aff. Juresania sp., Retaria lasallensis, Neospirifer "triplicatus", lophophyllid coral, Composita sp., Neospirifer sp., dictyoclostids, and crinoid columnals. 1.2
- 10.5 LIMESTONE: very light gray; weathers light brown; fine-grained with scattered skeletal grains; green shale stringers. Fossils: Composita subtilita, Neospirifer cf. triplicatus, Antiquatonia portlockiana, Hystriculina wabashensis, Linoproductus spp., derbyid, dictyoclostids, Wilkingia sp., crinoid detritus, and fusulinids (especially abundant in lower 1 foot); lower bed: Aviculopectinid, Myalinid, Derbya crassa. 2.0
- 10.6 SHALE with scattered carbonate-cemented nodules: green to greenish gray, silty to arenaceous. Fossils: Myalina (Orthomyalina) slocomi, Aviculopecten sp., cf. Streblochondria sp., cf. Posidonia sp., Composita cf. subtilita, cf. Juresania, Derbyia sp., crinoid columnals, and rhomboporid bryozoans 2.0

LOCALITY 10



LOCALITY 15



LOCALITY 14A

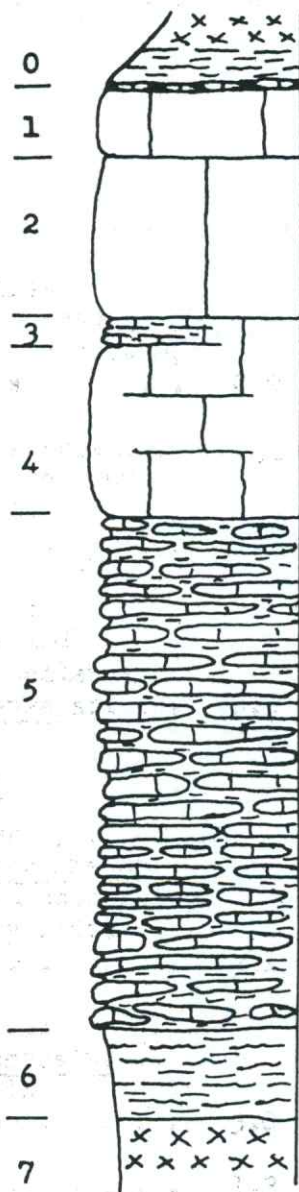


FIGURE 21

- 10.7 SHALE: greenish gray; silty; laminated to blocky; limestone nodules at several horizons; unknown shell fragments in limestone nodules. 5.0
- 10.8 SHALE: contains plant remains

Locality 15

- 15.0 SHALE: light greenish gray; no fossils seen 1.0~~7~~
- 15.1 LIMESTONE: brownish gray, weathers brown; fine-grained; argillaceous; rubbly appearance with nodular zone at top; appears more deeply weathered than unit 0, only fossils seen were high-spired gastropods 0.9
- 15.2 LIMESTONE: light brownish gray, weathers dark brown; fine-grained with green shale flakes, stringers, and small clay-filled burrow-like structures; only fossils observed were small clam molds. 1.6
- 15.3 LIMESTONE: brownish-gray, weathers brown; fine-grained; shaly, including green shale flakes and stringers; weathers to re-entrant; fossils: bellerophonid-type gastropods, clams, and Neochonetes sp. 0.6
- 15.4 LIMESTONE: light tan to light greenish gray, weathers brown; skeletal; one bed. Fossils: fusulinids, clams, Composita sp., Neospirifer sp., "Marginifera" spp., "Dictyoclostus" spp., Neochonetes sp., Derbyia sp., Punctospirifer sp., crinoid columnals, fenestrate and ramose bryozoans, and lophophyllid corals; basal foot rich in fusulinids 3.1
- 15.5 SHALE: light bluish gray; calcareous. Fossils: clams, "Dictyoclostus" spp., Derbyia sp., Composita sp., Neochonetes sp., Crurithyris sp., crinoid columnals, fossils less abundant toward base. 3.0
- 15.6 SHALE: red; no fossils seen 1.3

Locality 15A

Discussion: essentially same units in Toronto and upper Lawrence as at Locality 15. However, the Toronto appears highly weathered and leached there. Rounded flat limestone plates are present in a zone 6 inches thick at contact with Snyderville shale. One limestone nodule from this zone bears small elongate

pits that may be ascribed to acrothoracian barnacle bores. The lower Snyderville is dark bluish-gray, fissile, and silty with abundant Myalina sp. (some paired), some of which contain acrothoracian barnacle bores.

Locality 15B

Discussion: Toronto apparently absent, although Leavenworth, Heebner, and Plattsmouth present; approximately 30 feet of blue-gray shale below Leavenworth, overlying a cross-bedded limestone lithoclastic arenaceous to calcarenaceous sandstone that may be younger in age than the Toronto.

Locality 14A

- 14A.0 SHALE: lower inch or so green and blocky; red shale above. In places thin plates of fine-grained limestone lithologically similar to unit are present in green shale zone; plates are commonly an inch to 6 inches in length and resting on flat surfaces; the corners appear rounded. No fossils seen in shale or plates. 1.04
- 14A.1 LIMESTONE: light greenish gray, weathering same; fine-grained; flakes, stringers, and irregular tube-like concentrations of green shale (the latter are up to 1 mm. in diameter and random in orientation); upper surface of bed marked by small trails? and large irregular fractures (possible desiccation cracks) filled with green clay; some chert in this bed; only fossils seen were scattered high-spired gastropods. . .
- 14A.2 LIMESTONE: light greenish gray, weathers light tan; fine-grained, laminated, and lacking skeletal grains at top; skeletal particles increasing toward base of unit where they are abundant; tan shale partings in lower half of unit; tube-like concentrations of shale like those of unit 1; fossils: paired Composita sp., Neospirifer sp., crinoid columnals, and possibly coated grains. 1.7
- 14A.3 LIMESTONE, to calcareous SHALE: light greenish gray; weathers tan; shale lenses in and out but generally forms re-entrant; no fossils seen. 0.3

- 14A.4 LIMESTONE: greenish gray to light buff; fine-grained; shaly; much stratified skeletal debris; almost coquinoid in places; gradational to subjacent unit; fossils: paired Neospirifer sp., dictyoclostids, Linoproductus spp., Crurithyris sp., paired Composita sp., Neochonetes sp., fusulinids, and crinoid particles. 1.8
- 14A.5 LIMESTONE and SHALE: shaly, nodular to platy limestone and calcareous shale with limestone plates and nodules; greenish gray, weathers tan; limestone mainly coquinoid layers of brachiopod shells with fine-grained matrix; some limestone lenses up to 3 inches thick but only a foot or so in length; red and green shale mottles in basal foot; fossils: Upper: Derbyia crassa, Neospirifer sp., Crurithyris planoconvexa, Chonetes granulifer, Punctospirifer kentuckyensis, Composita subtilita, Hustedia mormoni, Marginifera cf. splendens, Antiquatonia portlockiana, aff. Retaria lasallensis, Linoproductus prattenianus, crinoid columnals and brachial plates, rhomboporid bryozoans, and fenestrate bryozoans. Lower: Streblochondria sp., Derbyia crassa, Crurithyris, Chonetes granulifer, Punctospirifer kentuckyensis, Composita subtilita, cf. Retaria lasallensis, fenestrate bryozoans, encrusting bryozoans, and Linoproductus cf. prattenianus, rhomboporid bryozoans, and lophophyllidid coral 5.3
- 14.6 SHALE: medium gray to greenish gray; blocky; absent in places where red shale present in basal part of unit 5; no fossils seen. 1.0
- 14.7 SHALE: red; blocky; no fossils seen. 1.0/

Locality 21

- 21.1 SHALE: highly weathered, yellowish brown; contains abundant flattened nodules of dense lithographic limestone. No fossils seen. 0.8
- 21.2 LIMESTONE: brownish gray; sublithographic; several thin beds. No fossils seen. 0.6

LOCALITY 21

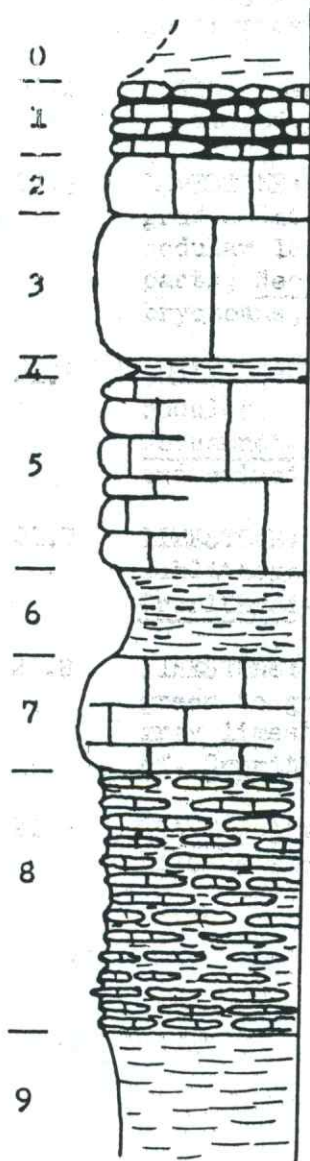
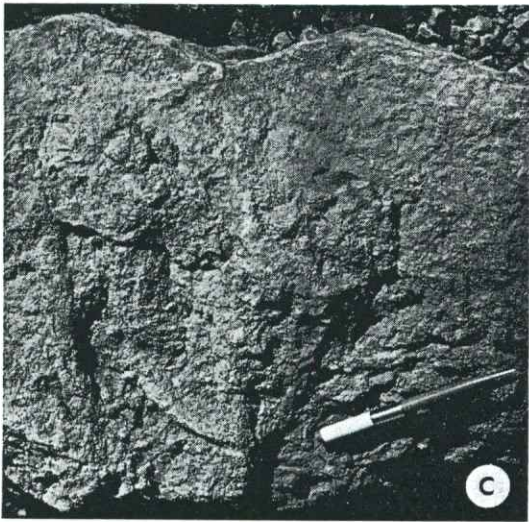
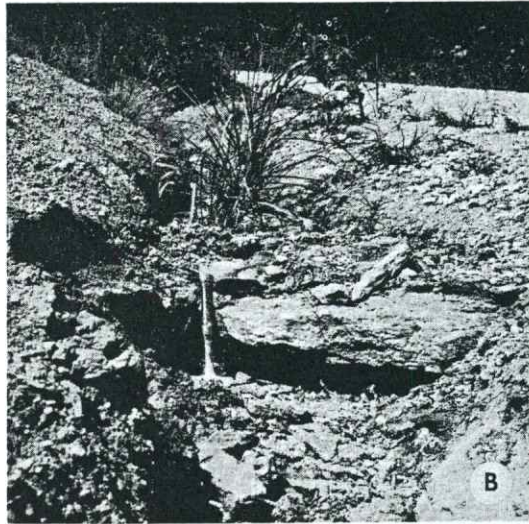


FIGURE 22

- 21.3 LIMESTONE: light grayish tan; weathers rusty brown; upper few inches of shell coquina; many pelletoidal and algal grains. Fossils: Composita sp., and gastropods. 1.5
- 21.4 SHALE: greenish-gray, silty; platy. Fossils: scattered crinoid parts 0.2
- 21.5 LIMESTONE: light yellowish brown, weathers brown; grades laterally from massive resistant bed to lensy-nodular less resistant bed. Fossils: abundant crinoid parts; Neochonetes sp., dictyoclostids, fenestrate bryozoans, Composita sp., and ramose bryozoans. 2.1
- 21.6 SHALE: greenish gray; calcareous with some limestone nodules. Fossils: dictyoclostids, Composita sp., Neochonetes sp., Crurithyris sp., cf. Neospirifer sp., and crinoid segments. 0.9
- 21.7 LIMESTONE: light creamy gray, weathers rusty brown; sublithographic. Fossils: Composita sp., Hustedia sp., Crurithyris sp., gastropods, and crinoid parts. 1.2
- 21.8 LIMESTONE: nodular and interbedded mixture of olive green to greenish gray silty shale and light brownish gray limestone. Fossils: Neochonetes sp., dictyoclostid, cf. Crurithyris sp., clams and crinoid parts. 2.7
- 21.9 SHALE: olive green to greenish gray; silty. No fossils seen. 1.0~~4~~

EXPLANATION OF PLATE I

- A. The Toronto Limestone consists of a single bed (Uppermost bed in photograph) at this exposure, Locality 18, Osage County, Oklahoma. Two thin sandstone beds are present beneath the Limestone, one slightly above and the other below the hammer.
- B. Outcrop of Toronto Limestone at Locality 19, southern Chautauqua County, Kansas. Green shales are exposed above and below the bed.
- C. Burrow casts on the bottom of the Limestone at Locality 19.
- D. Toronto Limestone at Locality 8, northern Chautauqua County, Kansas. Green shales present above and below the limestone bed at this locality are fossiliferous. From the vicinity of this locality southward to Locality 18, the Toronto Limestone is represented by a single discontinuous bed of limestone.

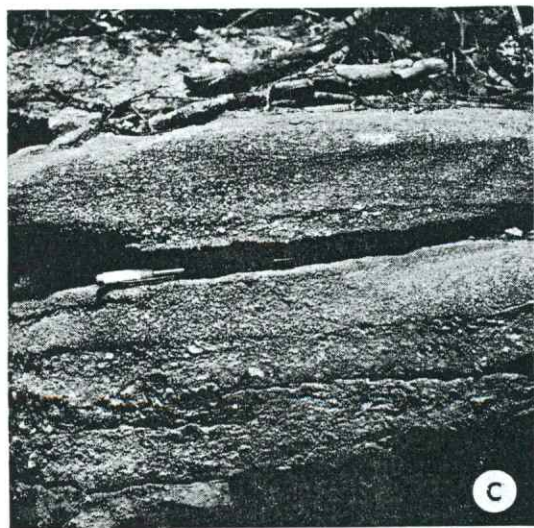
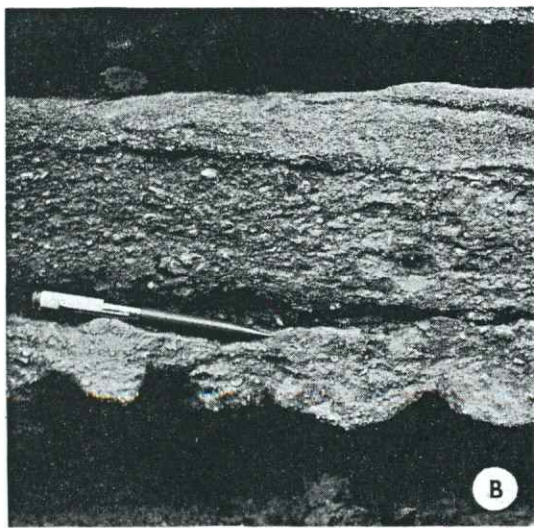


EXPLANATION OF PLATE II

- A. Exposure of Toronto Limestone, Locality 7A, Elk County, Kansas, revealing two limestone units, one above the hammer handle and another below it. The limestones are separated by a thin calcareous shale. The upper limestone is mainly a crossbedded packstone, containing sorted crinoidal debris and lime mudstone clasts. The lower limestone is a wackestone. At Locality 7, less than one-half mile from Locality 7A, the upper limestone does not contain clasts and is not crossbedded.

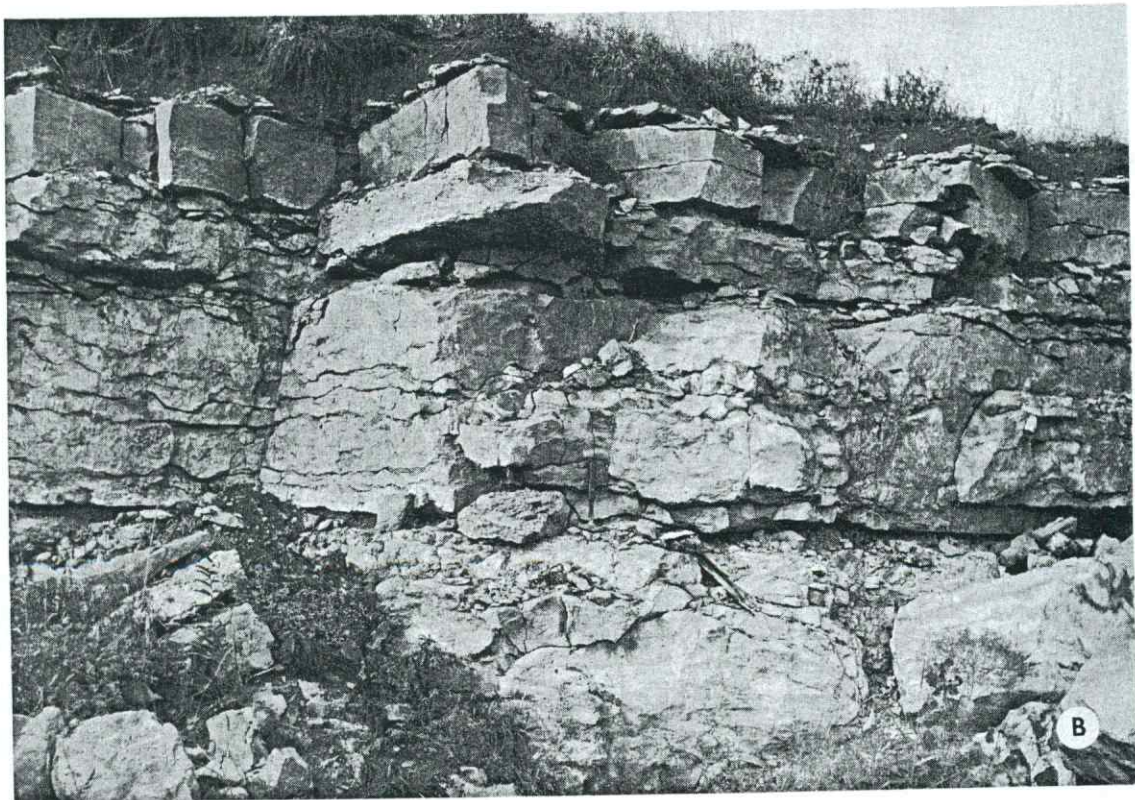
- B. Close-up of lower part of top limestone at geopick handle in A. Corrugated profile of bed base was produced by burrowing organisms which were active in the limestone but reworked part of the underlying soft shale. Crinoid debris is conspicuous.

- C. Close-up of upper part of top limestone bed to the right of the geopick handle in A. Gentle cross-laminations and well-sorted skeletal debris, chiefly crinoid parts, are evident above pencil. The upper part of the bed in this photograph is well-sorted. Less than one mile from this locality the Toronto Limestone is not grain-supported, lacks mudstone clasts, and is not cross-bedded.



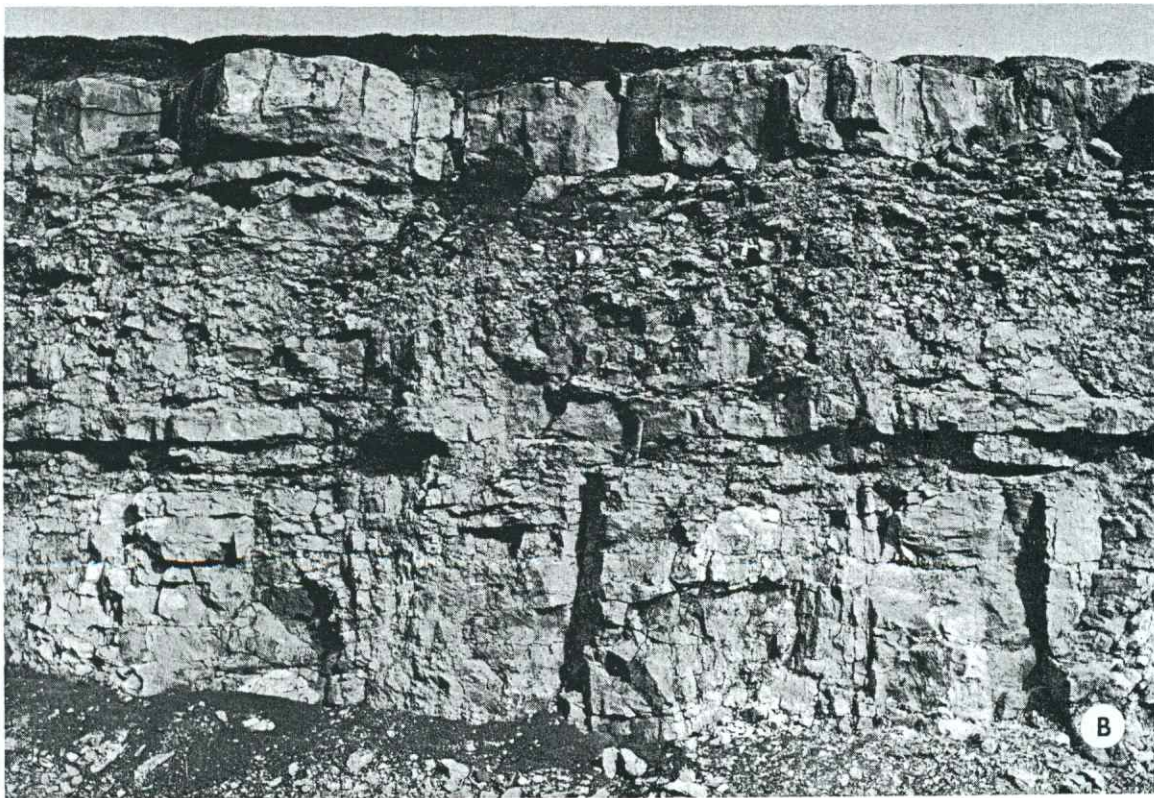
EXPLANATION OF PLATE III

- A. View of the Toronto Limestone at Locality 1, Woodson County, Kansas. Even, discontinuous, medium bedding near the base of the limestone (skeletal mud facies, mixed biota subfacies) with uneven, discontinuous, thin to medium bedding above hammer (skeletal mud facies, molluscan-"Cryptozoon" subfacies). Reentrant (arrow) is the shaly zone used as datum. It is in the fenestrate bryozoan-echinoderm grain facies. Upper part of the Toronto is absent due to recent erosion.
- B. Upper part of Toronto Limestone at Locality 2, Greenwood County, Kansas. Shaly datum zone at level of head of hammer. Uneven, discontinuous, thin to medium bedding above hammer with shaly material concentrated along bedding surfaces. Uppermost even, continuous, thick bed has yielded a few linguloid brachiopods in addition to Aviculopinna, Linoproductus, and Composita. A green shale bed bearing a few smooth-shelled ostracodes overlies the limestone.



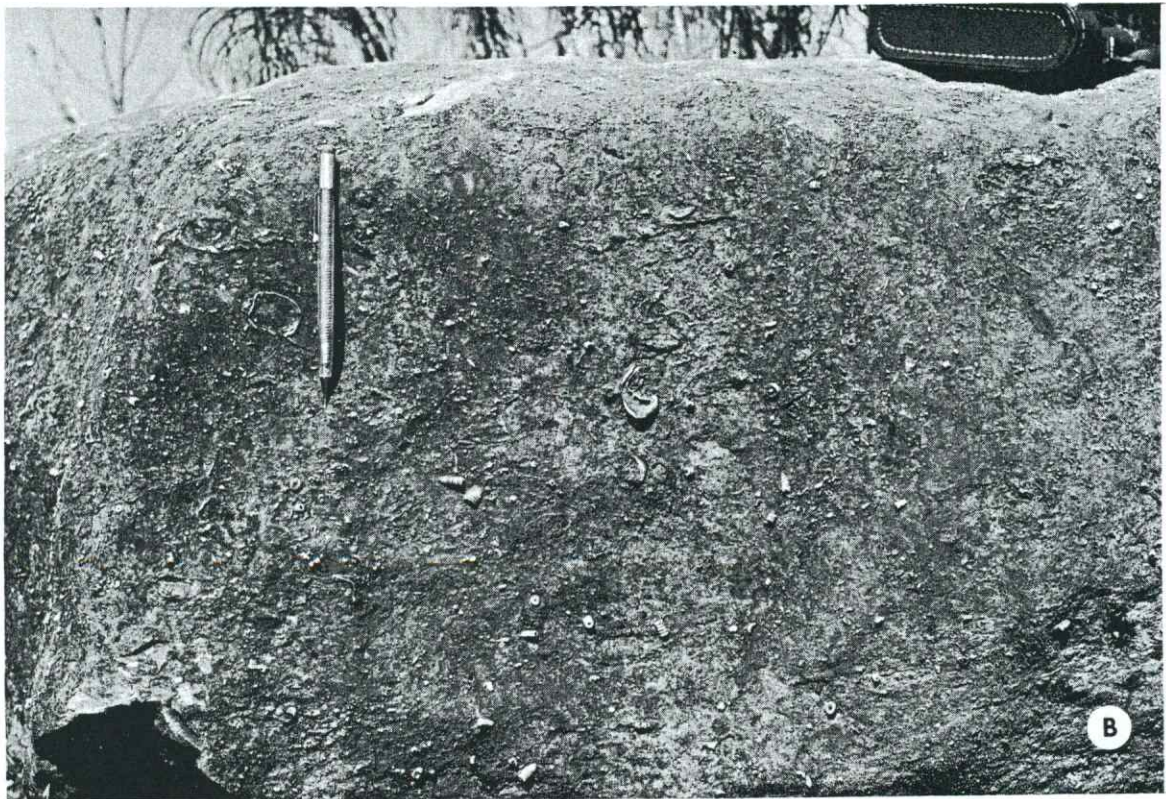
EXPLANATION OF PLATE IV

- A. Irregular, sharp contact of echinoderm-fenestrate bryozoan grain facies with overlying molluscan-"Cryptozoon" subfacies at Locality 1, Greenwood County, Kansas. "Cryptozoon" encrusted grains are evident above knife. Partial crinoid columns are aligned parallel to the bedding in the echinoderm-fenestrate bryozoan grain facies.
- B. The Toronto Limestone at one of its thickest exposures, Locality 25, Coffey County, Kansas. The Snyderville Shale overlies the uppermost massive bed which is an "Osagite" (Osagia grain facies); vertical grooves are large burrows formed by a clam (*Wilkingia*). Shaly zone above hammer and below "Osagite" is the molluscan-"Cryptozoon" subfacies. It contains irregular, discontinuous beds with irregular, honeycomb-like holes filled with green clay; this zone may have been subaerially exposed and weathered prior to inundation and deposition of the Osagia facies. The shaly datum zone is at hammer level; it contains encrusting bryozoan oncolites and small horn corals, which because of their feeding types, are suggestive of a slow rate or pause in lime mud deposition. The even, continuous bed of limestone above the hammer and approximately a foot of limestone below the hammer constitute the fenestrate bryozoan-echinoderm grain facies at this Locality. The lower portion of the limestone is assigned to the mixed biota subfacies. The contact of the Toronto Limestone and Lawrence Shale occurs near the bottom of the photograph. The upper part of the Lawrence Shale at this Locality is a blue silty shale bearing a few smooth-shelled ostracodes.



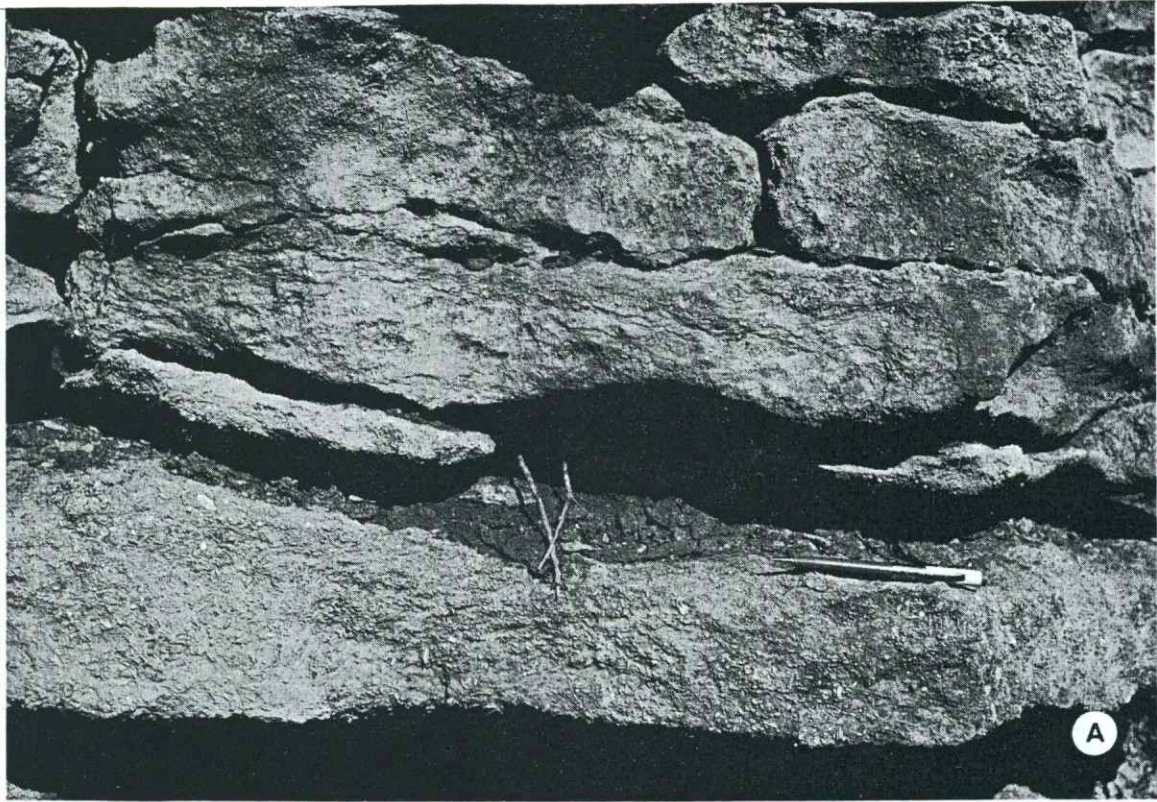
EXPLANATION OF PLATE V

- A. Massive, dense bed of echinoderm-fenestrate bryozoan facies overlying shaly zone (datum) and mixed biota subfacies of skeletal mud facies at Locality 9, Franklin County, Kansas. Small dalmanellacid brachiopods (Rhipdomella aff. transversa) are abundant in the zone beneath geopick. Compare this photograph with that of Plate VII, Figure VII; there is no doubt that both are identical in lithology and are probably the same bed.
- B. Close-up of uppermost bed in A. Conspicuous skeletal grains include crinoid columnals, productoid brachiopod shells (Antiquatonia) and lophophyllidid coral. Numerous elongate subcylindrical fusulinids are evident. The lack of parallelism of elongate skeletal grains is due to activities of burrowing organisms that disrupted bottom sediments. Large "Cryptozoon" coated grains occur in this bed although they cannot be seen in the photograph.



EXPLANATION OF PLATE VI

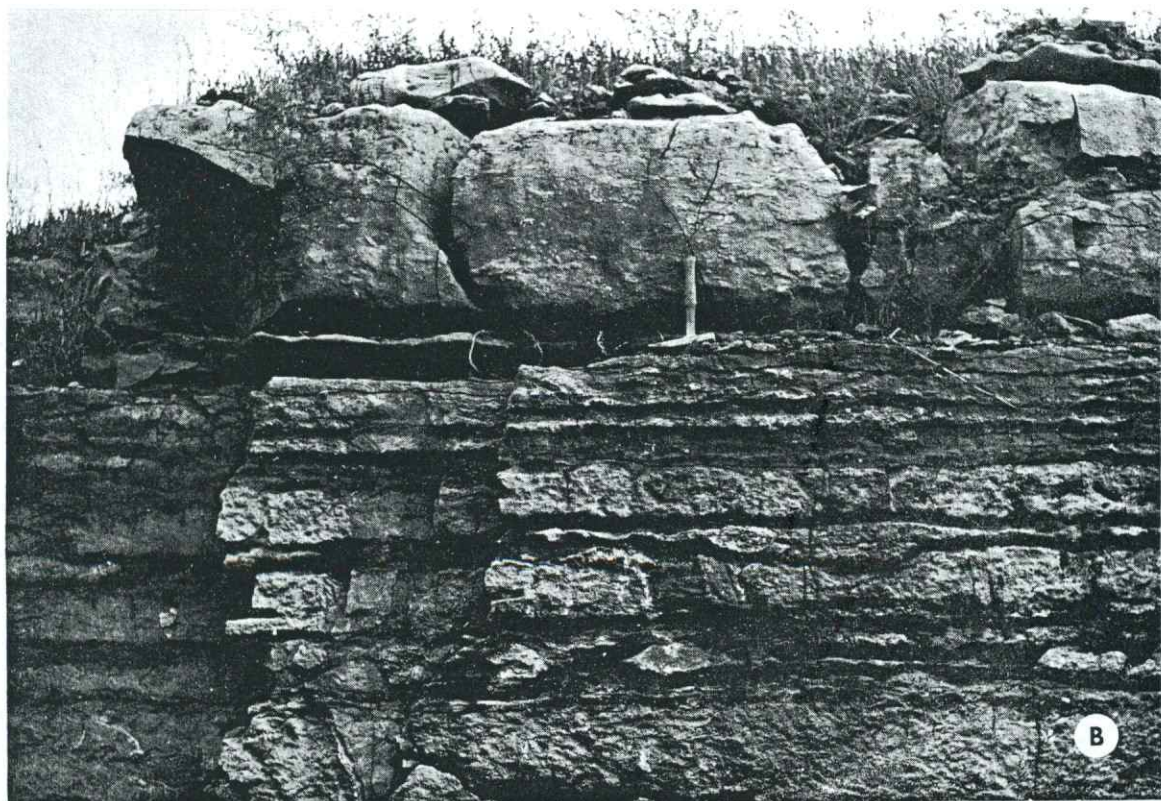
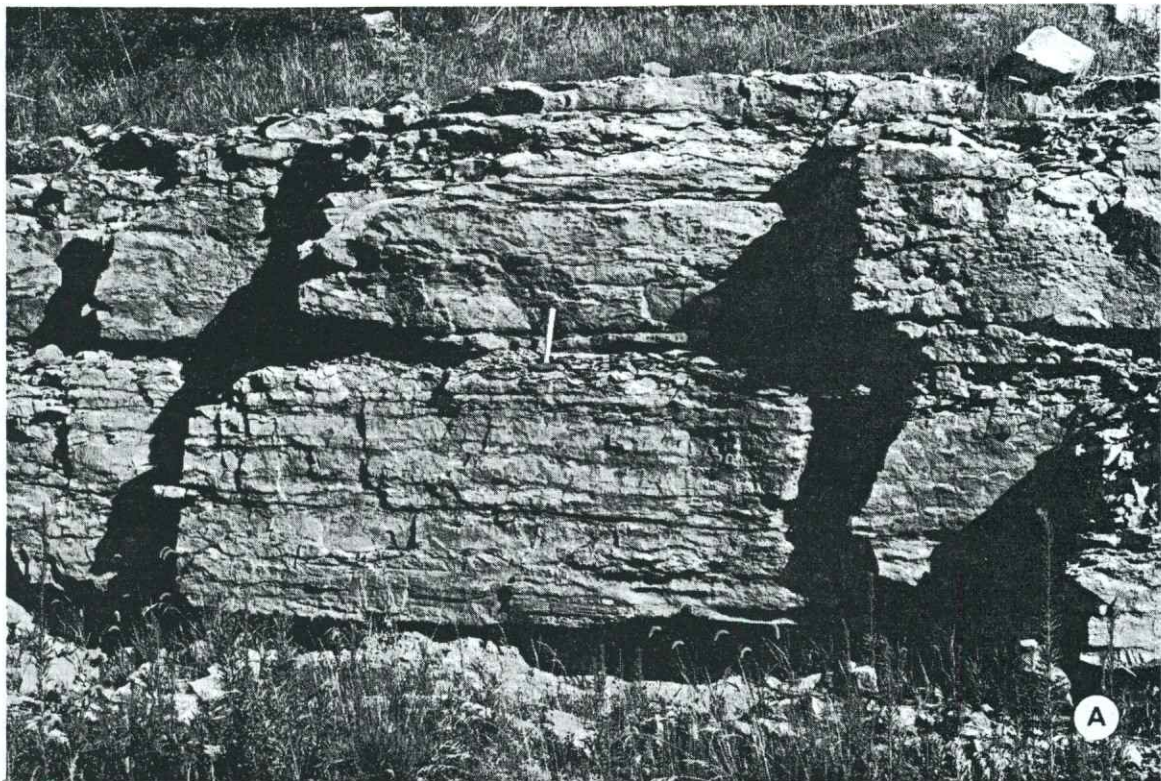
- A. Basal beds of Toronto Limestone, Locality 9, Franklin County, Kansas. Pencil rests on skeletal grain rich bed containing abundant robust fusulinids and chonetids; most skeletal material within this bed is coated by *Osagia*. Irregular beds (skeletal mud facies, mixed biota subfacies) overlying the basal bed contain fewer skeletal grains and *Osagia* coatings are not abundant. The Lawrence Shale, in sharp contact with the basal limestone bed, does not contain marine fossils at this locality. Similar basal *Osagia*-rich beds have been recognized at several localities in central Kansas resting on nonmarine shale. It probably represents strand-line and near strand-line deposition in the transgressive phase of Toronto deposition.
- B. Outcrop of upper Lawrence Shale and Oread Limestone at Locality 22, near Lawrence, Kansas. In ascending order, Lawrence Shale, Toronto Limestone, Snyderville Shale, Leavenworth Limestone, Heebner Shale, and basal beds of Plattsmouth Limestone which cap the hill.



EXPLANATION OF PLATE VII

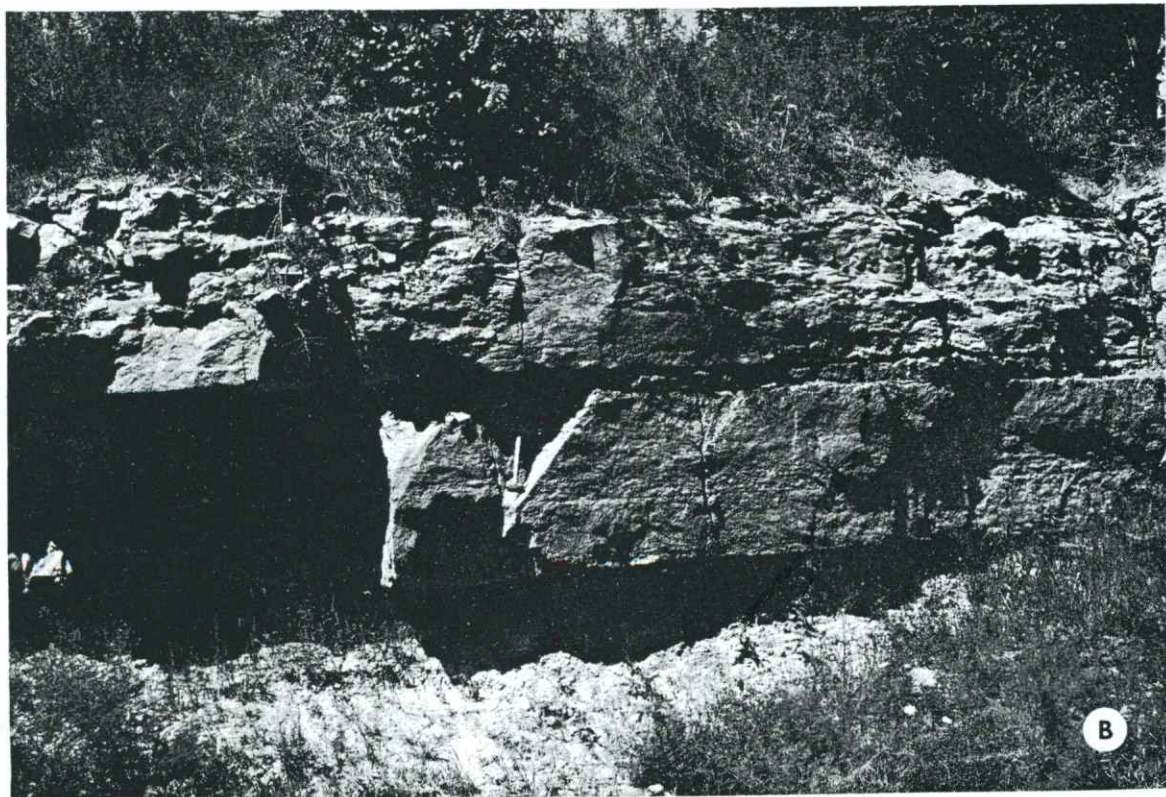
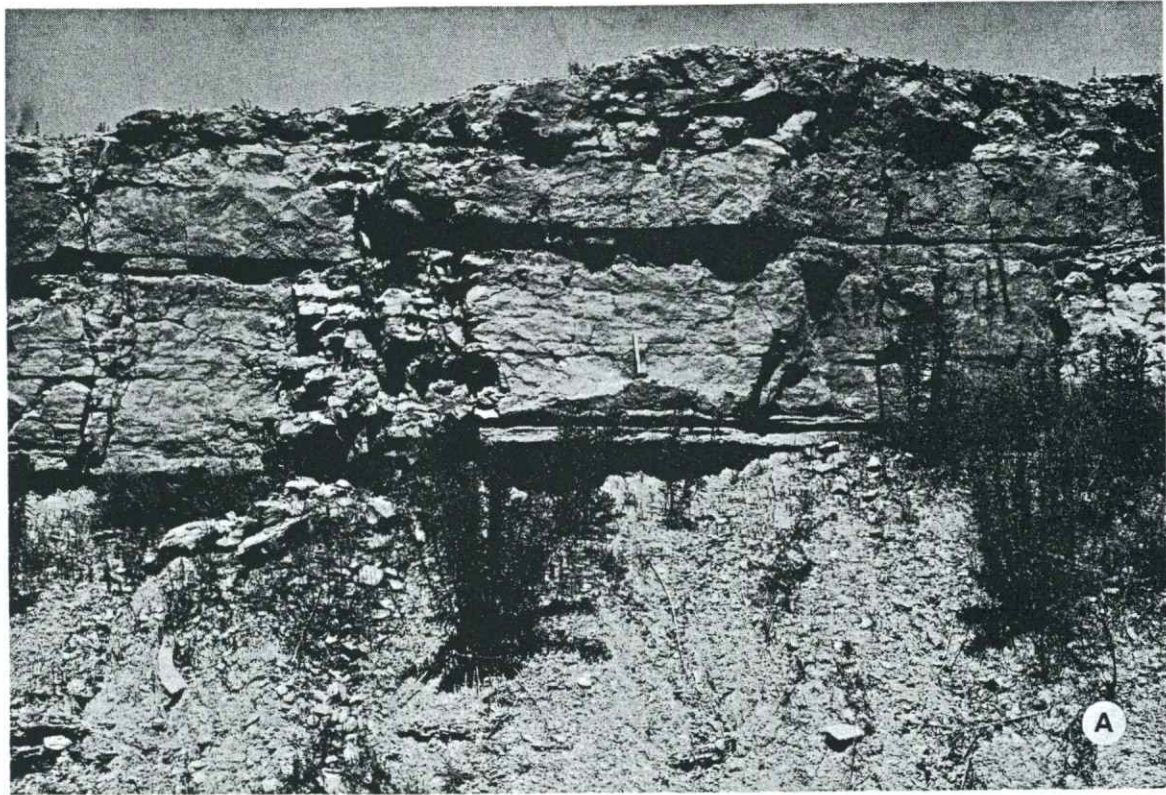
- A. Close-up of Toronto Limestone at Locality 22, near Lawrence, Kansas. Bedding in lower half of unit, mixed biota sub-facies, is even and regular although the bedding surfaces are discontinuous. The echinoderm-fenestrate bryozoan grain facies is the massive bed above the hammer. The mudstone facies, at the top of the photograph, is characterized by uneven, irregular bedding resulting from cut and fill.

- B. Close-up of echinoderm-fenestrate bryozoan grain facies at Locality 22, showing massive character of a bed within the facies which contain "Cryptozoon"-type oncolites (arrows). Geopick resting on datum shaly zone.



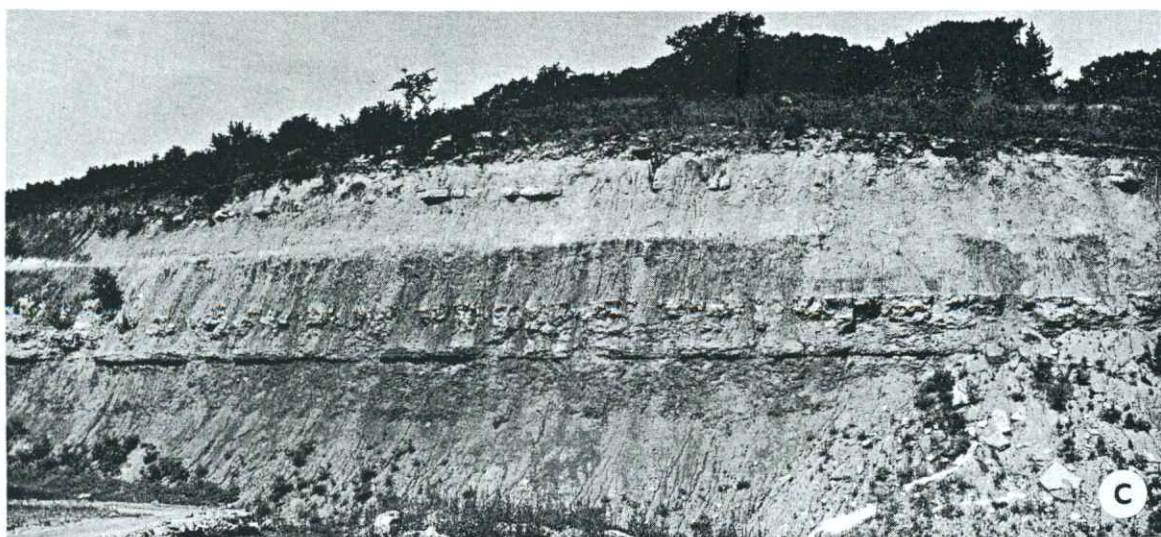
EXPLANATION OF PLATE VIII

- A. Exposure of Toronto Limestone at Locality 11, Lawrence, Kansas. Even, regular, massive bedding in lower two-thirds of the unit. Irregular bedding in upper one-third of the unit is interpreted as due to cut and fill processes.
- B. At Locality 12, Leavenworth County, Kansas, the Toronto Limestone consists of massive beds except for the shaly limestone at the middle (datum) and irregular, uneven bedding at the top.



EXPLANATION OF PLATE IX

- A. Outcrop, Locality 10, at Leavenworth, Kansas. Upper Lawrence Shale, Toronto Limestone, grassy slope of Snyder-ville Shale, Leavenworth Limestone, Heebner Shale, and basal Plattsmouth Limestone.
- B. The Toronto Limestone at Locality 15 near St. Joseph, Missouri. Less than one mile north of this locality the Toronto Limestone is absent, although the Leavenworth Limestone, Heebner Shale, and Plattsmouth Limestones are not abnormal in facies development.
- C. In Johansen's Quarry (Locality 14A), Cass County, Nebraska, the stratigraphic sequence is as follows: Cass Limestone, floor of quarry at lower left; Lawrence Shale, a red mudstone at this locality; Weeping Water (Toronto Limestone); Snyder-ville Shale, lower half is red mudstone and upper half green shale; Leavenworth Limestone, single massive bed; Heebner Shale; and rubbly plates of Plattsmouth Limestone at the line of vegetation.

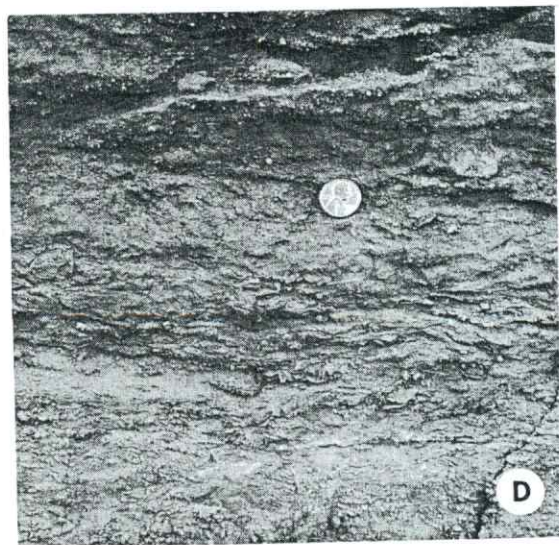
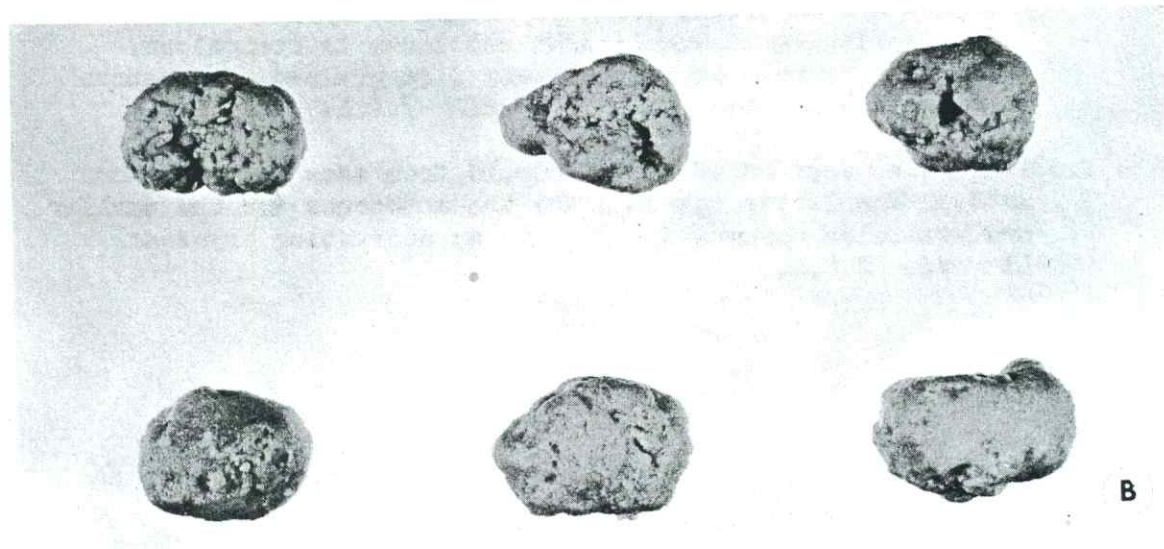
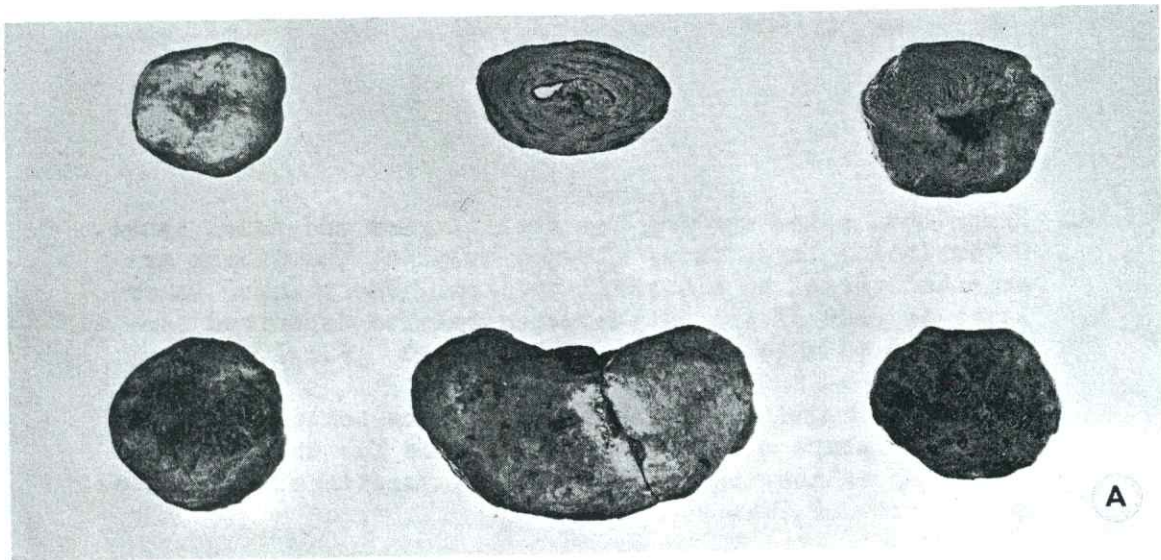


EXPLANATION OF PLATE X

- A. Blue-green algal oncolites from uppermost bed of Toronto Limestone at Locality 20, Coffey County, Kansas. Specimens on upper right and left are bottom views revealing concavities. Cross-sectional view in upper center shows laminations. Bottom row is top view of three specimens. xl
- B. Modern blue-green algal oncolites from lagoon behind Alacran Reef on Yucatan Platform. Bottom views in upper row revealing concavities similar to those described above. Top views in bottom row showing smooth upper surfaces. Specimens provided by Walter C. Pusey, III. xl
- C. Bulbous encrusting bryozoan colony from same locality and bed as oncolites in Fig. A. The colony was attached to the substrate. xl
- D. Potato chip-like particles stratified beneath penny are algal plates (Eugonphyllum). The plates are probably near site where plant grew and were flattened when sediments came to rest over them. 122-5L

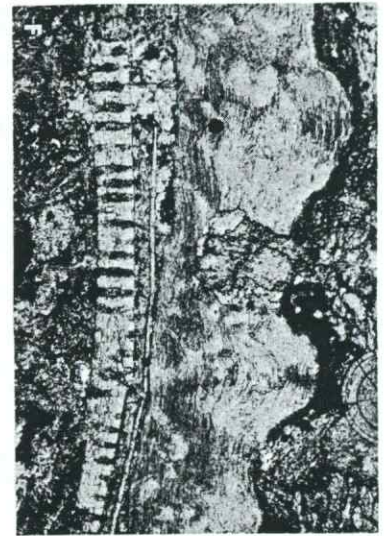
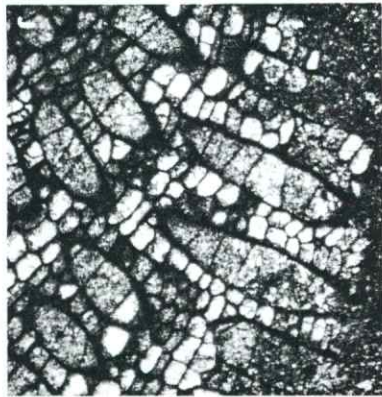
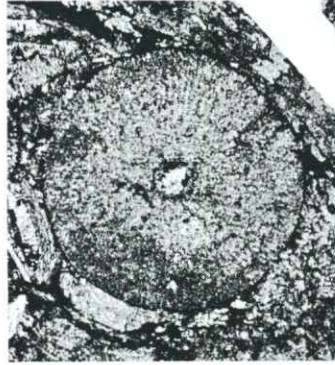
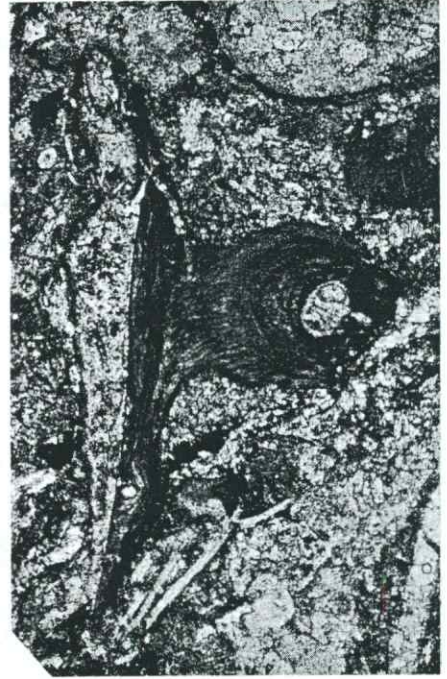
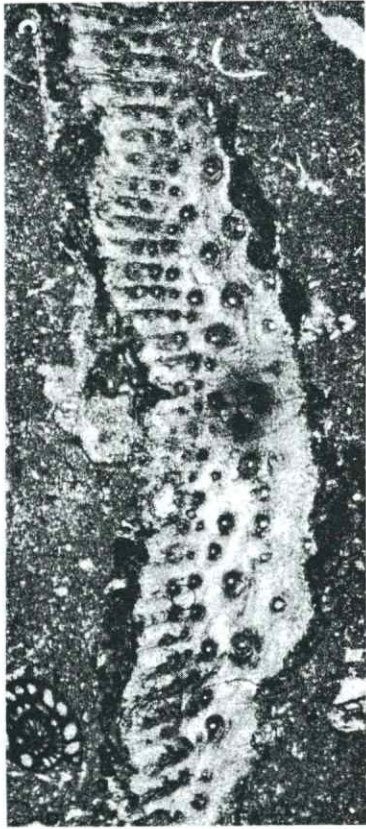
- H. Brachiopod spine showing two shell layers and axial canal. Outer (thin) layer is of fibrous calcite; the fibers are oriented normal to the shell surface. The thicker inner layer is made of thinly laminated calcite deposited tangentially to axial canal. L17-5 x10 P.P.L.*
- I. Trilobite fragment. Note the homogenous texture and irregular shape of the fragment - these features and the traveling extinction property are diagnostic of trilobites. L21-8 x4 P.P.L.
- J. Oblique section of a fistuliporoid bryozoan. The larger chambers are autopores with diaphragms developed within them. Vesicular tissue between autopores is coenosteum. This bryozoan wall is made of very fine-grained, homogenous calcite with no layering. L1 x4 P.P.L.
- K. Tangential section of fistuliporoid from same thin section as J. The larger openings are the autopores and the smaller are vesicular coenosteum. This is an encrusting bryozoan. L1 x4 P.P.L.

*P.P.L. - Plane-polarized light. This abbreviation will be used to distinguish from cross-polarized light which will be abbreviated as C.P.L.



EXPLANATION OF PLATE XI

- A. Basal part of fenestrate bryozoan colony attached to a shell fragment. The successive layers of tissue (sclerenchyma) show the growth stages. A single small chamber is seen at base of the colony and two chambers are present near the top. L17-5 x4 P.P.L.
- B. Three branches of a fenestrate bryozoan frond with up to four chambers (autopores) observable in each. L17-5 x4 P.P.L.
- C. Oblique section of a pseudopunctate brachiopod shell (chonetid). Note the ordered development of the pseudopunctate and "swirled" appearance of the laminae about them. L4-10 x4 P.P.L.
- D. Ostracode shell showing shell structure - single layered wall made of fine-textured prismatic calcite; the prisms are aligned normal to surface of shell. The overlap of the valves, evident in the photograph, is characteristic of ostracodes. C23-46.1 x10 P.P.L.
- E. Crinoid columnal cut parallel to surface revealing axial canal and honeycomb microstructure. The entire columnal is a single calcite crystal. L17-5 x10 P.P.L.
- F. Two brachiopod shells, one above the other. The upper, thicker, shell is a derbyid; the section is oblique, showing two complete costae; note the finely laminated shell structure; the pseudopunctae are not conspicuous in this view. The lower shell with prominent punctae has both calcareous layers; the calcite fibers of the thin outer layer are oriented normal to the shell surface, whereas the fibers of the inner (lower) layer are disposed at a low angle to the shell surface. L17-5 x10 P.P.L.
- G. Algal plate (Eugonophyllum?) showing irregular orientation of small, dark, pellet-like utricles (cells) in near surface areas on both sides of plate. Bilateral symmetry of the plate is indicative of an upright growth habit. L4-10 x4 P.P.L.



EXPLANATION OF PLATE XII

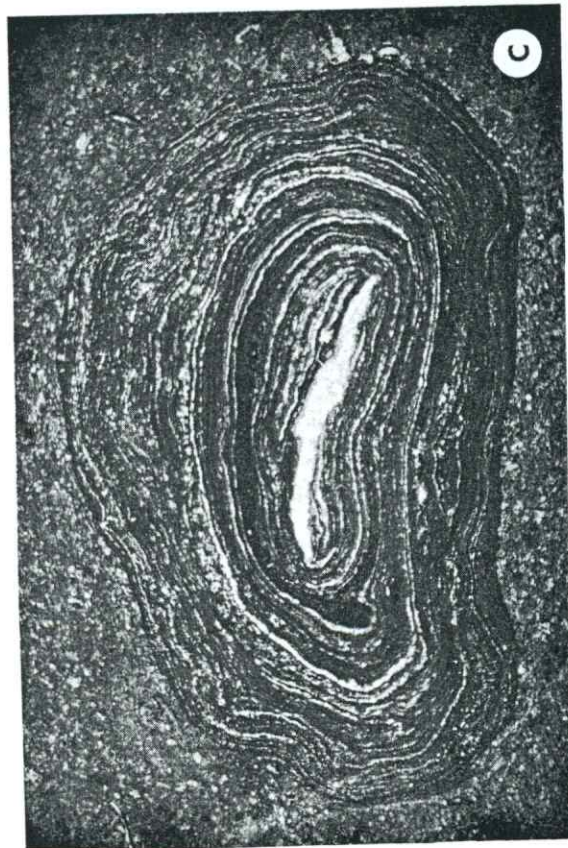
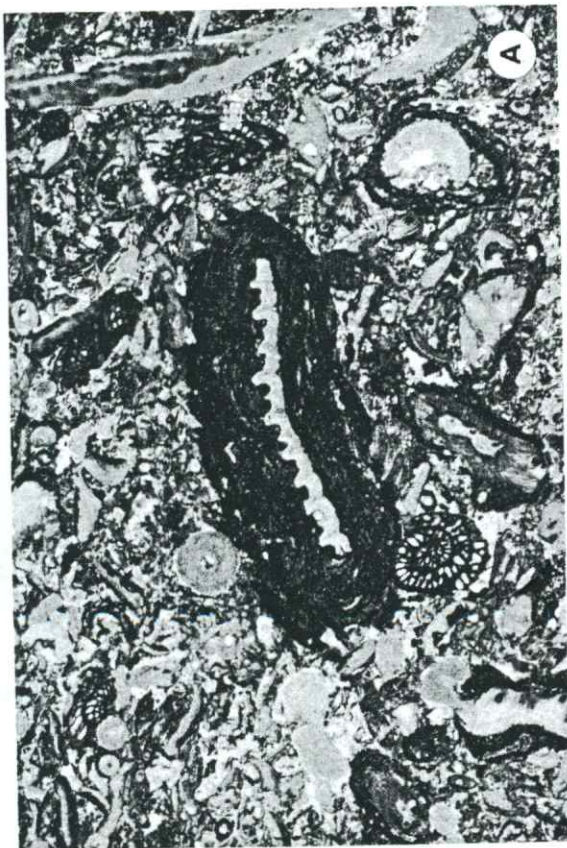
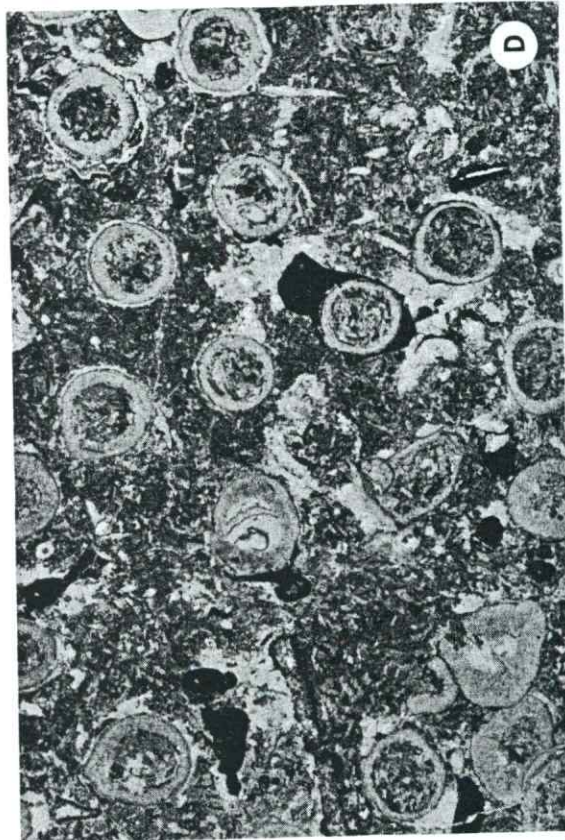
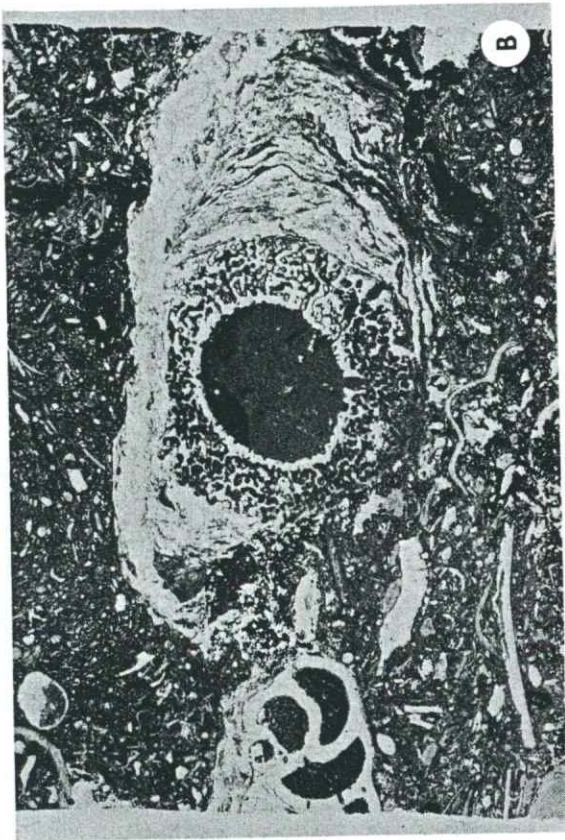
- A. Myalina valves showing relict microstructure. Rhomboporid bryozoan between large shells in right center. Crinoid columnals are conspicuous. Overly close packing of shells and microstylolitic contacts between skeletal grains, as is evident, are characteristic of packstones. L18-9 x4 P.P.L. V.*
- B. Brachiopod grain subfacies. Preponderance of brachiopod debris with matrix of lime mud. Gradation in size from coarse skeletal debris to mud-sized particles. Arrow at left denotes trilobite fragment. Arrow in center refers to pseudopunctate brachiopod shell (chonetid). The dark rinds on brachiopod shell fragments above and to the right of the chonetid are the encrusting cornuspirid foraminifer Apterrinella. Arrow in upper right points out rhomboporid bryozoan. Particle resembling a sieve plate below and to left of bryozoan is a fragment of Epimastopora. Other conspicuous grain types include crinoid segments and fusulinids. L17-2 x4 P.P.L. T.

*V. - vertical section; T. - vertical section with upper position toward top of page.



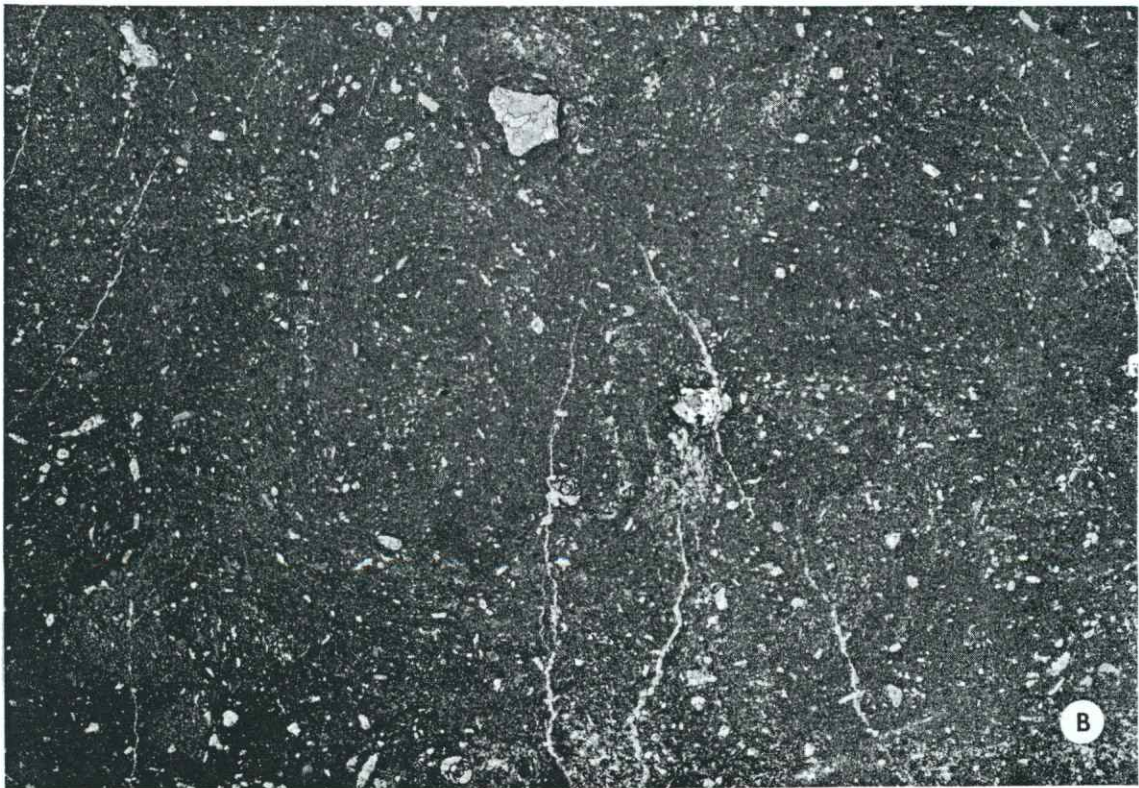
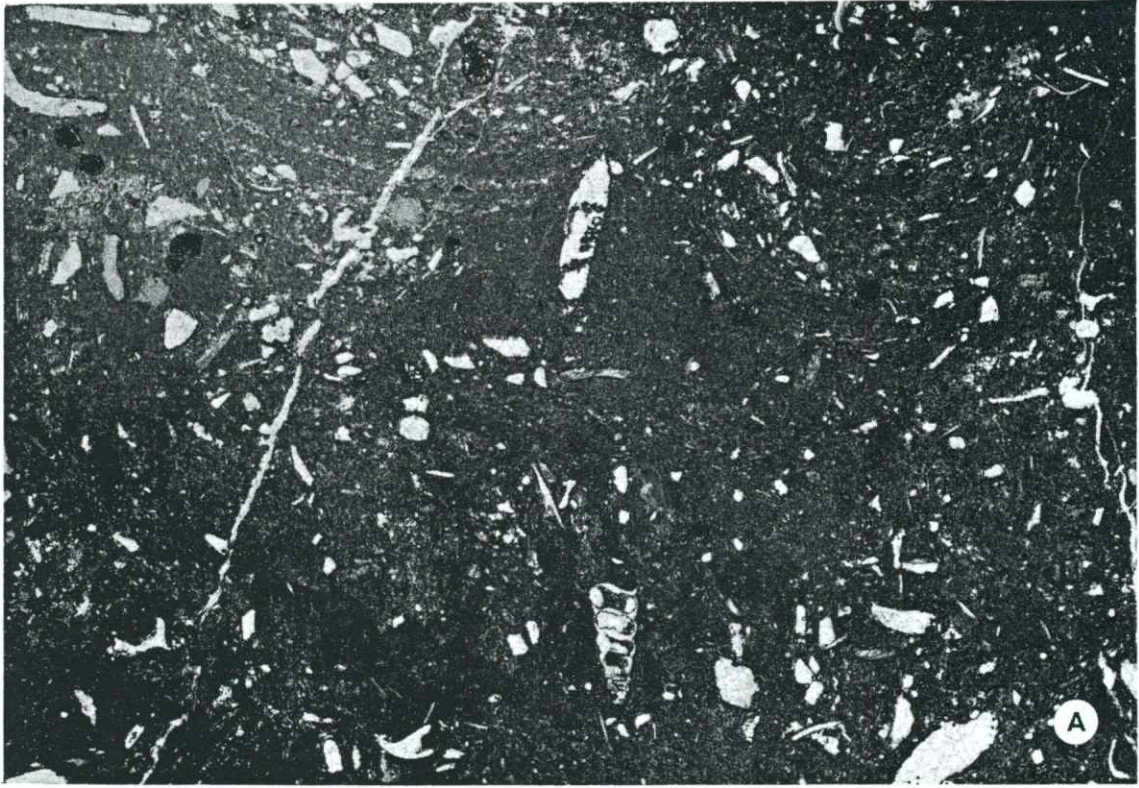
EXPLANATION OF PLATE XIII

- A. Osagia coated grain. Nucleus is Derbyia shell fragment. Poorly developed concentric laminations produce "woven appearance". Osagia coated crinoid columnal, below and to right of larger coated grain, shows irregular periphery of crinoid grain nucleus produced by boring organisms (presumably green algae). L10-3 x7 P.P.L. V.
- B. Coelcladid sponge encrusted by "Cryptozoon"-type material which was subsequently recrystallized or replaced by sparry calcite. Part of sponge on top was removed, perhaps by boring organisms associated with the epibion. L1B-7 x5 P.P.L. T.
- C. Algal biscuit or oncolite showing laminations developed about skeletal grain nucleus. Light colored laminations are sparry calcite which presumably filled space provided by decay of blue-green algae. Darker layers and mud-sized sediment presumably trapped and fixed by the algae. Even concentricity of inner laminae suggests repeated overturning of oncolite in earlier stages of development. Uneven concentricity of outer laminae suggests decrease in frequency of overturning through time. L20-1 x4 C.P.L. T.
- D. Syringoporid coral colony with a dark encrusting organism, Tubiphytes, attached to some of the corallites. L3A-8 x6 P.P.L. T.



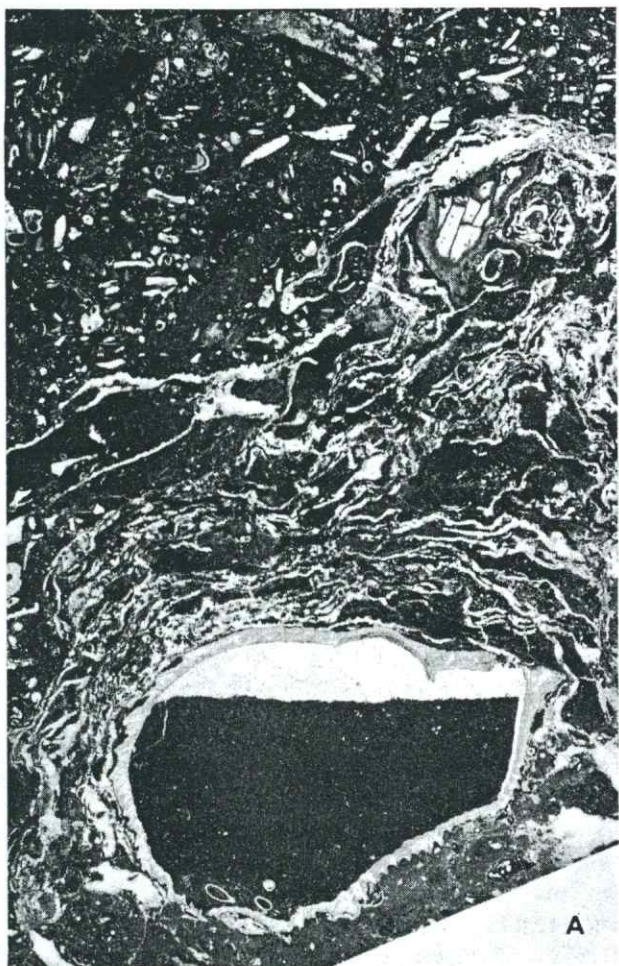
EXPLANATION OF PLATE XIV

- A. Skeletal mud facies - molluscan-"Cryptozoon" subfacies. Fragmental skeletal debris, chiefly molluscs, in framework of lime mud. Broken shell debris suggests activities of scavengers, and swirled fabric was produced by burrowing organisms. High-spired gastropod at bottom center. Fusulinids, some of which are obviously fragments, are scattered through rock. L3-1 x4 P.P.L. T.
- B. Skeletal mud facies - molluscan-"Cryptozoon" subfacies. Finely divided molluscan debris in framework of lime mud. Swirled and mottled fabric was produced by burrowing organisms. Skeletal debris appears to grade in size toward mud-sized particles. Specimen of the foraminifer Bradyina at bottom center. L20-4 P.P.L. V.



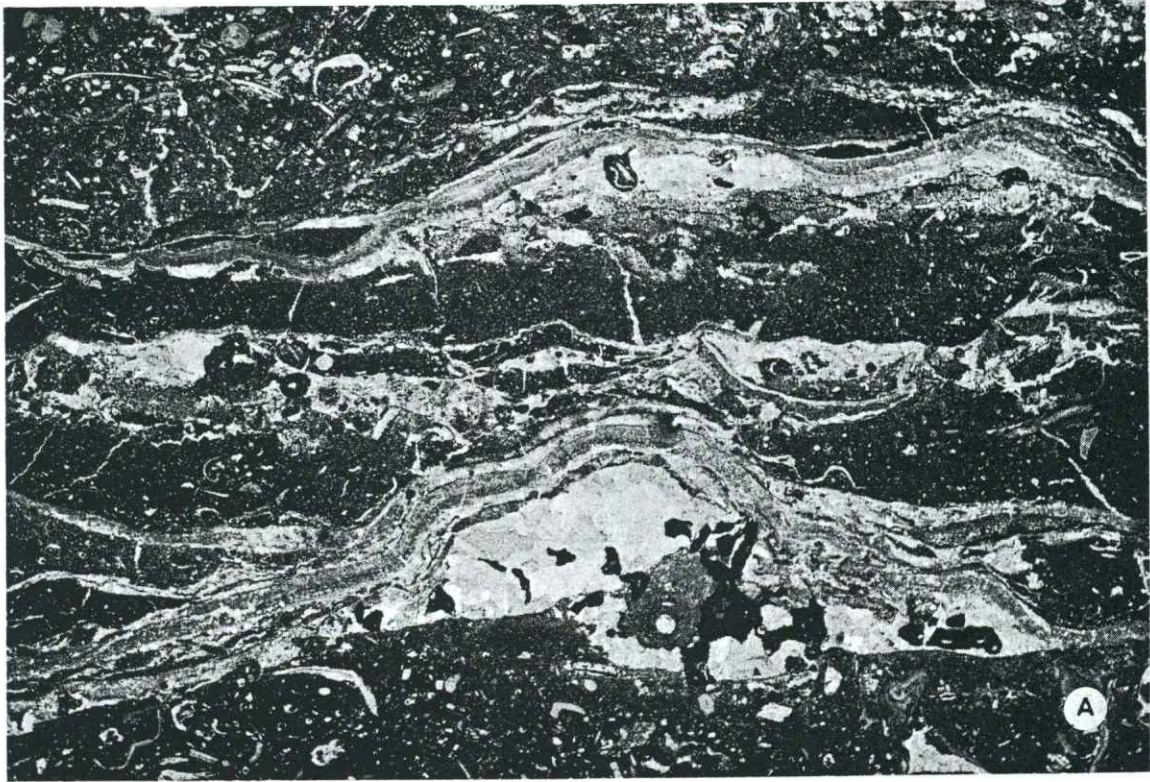
EXPLANATION OF PLATE XV

- A. Skeletal mud facies - mixed biota subfacies. Brachiopod geopetal encrusted by organic entanglement; encrusting complex built up from the brachiopod shell (derbyid) which apparently served as a substrate. Solitary coral near top has been partially destroyed, apparently by boring organisms. Spar filling inside the brachiopod shell extends alongside the mud infill at the right side; this suggests that the internal sediment has contracted due to dehydration prior to deposition of the spar. L3-7 x5 P.P.L. T.
- B. Skeletal mud facies - mixed biota subfacies. Numerous fusulinids present throughout rock in various stages of preservation. The microstructure of the large fusuline at the lower right has been partially destroyed by boring organisms; the wart-like protrusion on the outer surface is a constructional feature produced presumably by blue-green algae (*Osagia*). Large object slightly above and to left of the fusulinid described above is a fusulinid whose microstructure has been completely destroyed by boring algae; additional carbonate has been added to the grain modifying the shape. Other fusulines show various stages of alteration. L20-7 x4 P.P.L. T.
- C. Skeletal mud facies. Molluscan-"Cryptozoon" subfacies. Two large pelecypod shell fragments in upper left and a gastropod at bottom right. Large area of swirled mud in lower part of rock was produced by a burrowing organism. L1B-1C2 x5 P.P.L. T.



EXPLANATION OF PLATE XVI

- A. Organic crusts with cavities developed beneath them. Composition of crusts is carbonate mud; lack of organic microstructure indicates that laminae were probably blue-green algae. Cavities beneath crusts were formed before sediment was deposited over the crusts; this is evident from the growth patterns of the crusts as well as the presence of Tubiphytes in growth position in the lower cavity. The crusty mats occur in discontinuous patches up to several feet in length and a half foot or so in thickness. Ll-9 x3 P.P.L. T.
- B. "Cryptozoon"-type concolite. No skeletal grain nucleus is apparent, however, this is not surprising for the colonies commonly initiate on a skeletal grain and expand outward over surrounding sediments. Clotty mud inside encrusting mass appears to have been coherent, possibly held together by mucoid material. Organism responsible for encrustations has not been positively identified but was probably blue-green algae or sponge. An encrusting bryozoan colony is present within the encrusting mass at the left. A sponge is present above the oncolite at the left. Ll-9 x3 P.P.L. T.



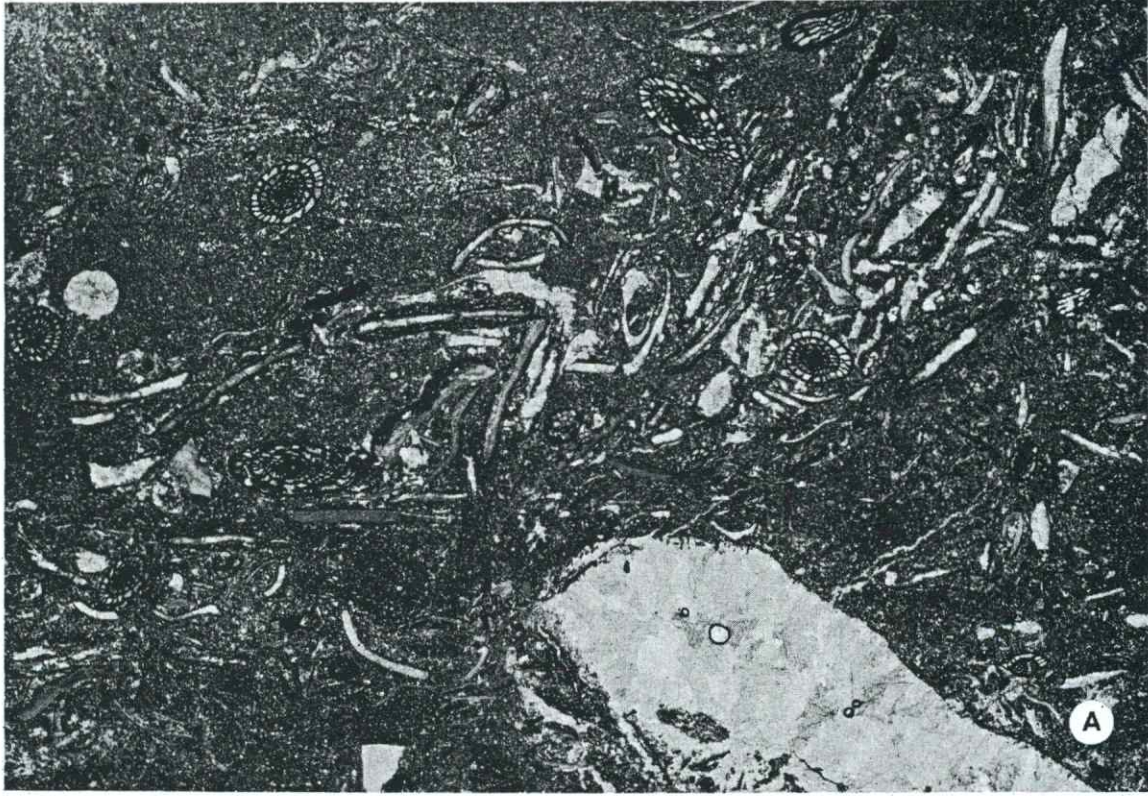
EXPLANATION OF PLATE XVII

- A. Skeletal mud facies - mixed biota subfacies. Pelecypod and gastropod shells and shell fragments suspended in framework of lime mud. Mollusc shell structure is not preserved. Osagia-type organic encrusted debris to the right. Much finely divided shell hash in the mud fraction. L1-9 x5 P.P.L. T.
- B. Skeletal mud facies - mixed biota subfacies. Large complex organic encrusted grains ("Cryptozoon"-type). Crusty mat developed over muddy sediment at top of photomicrograph. Encrusted complex at the right side of the photomicrograph includes two oncolites which were fused together in time. L22-5 x3 T.



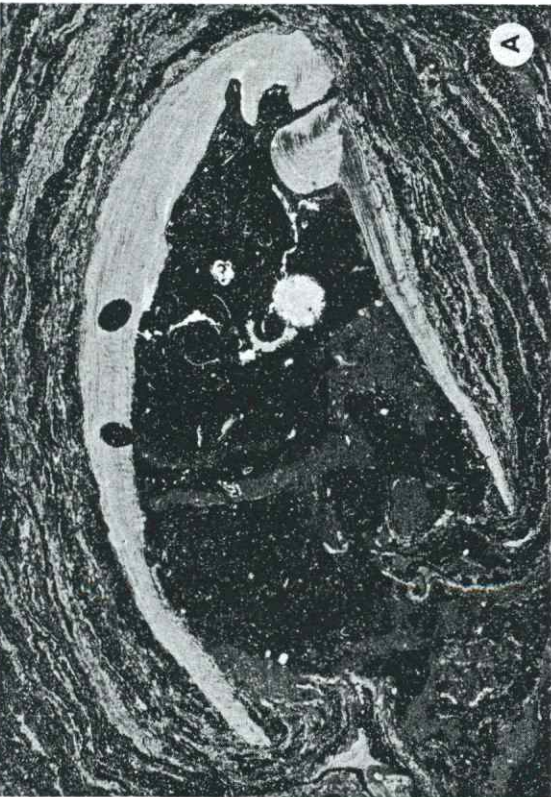
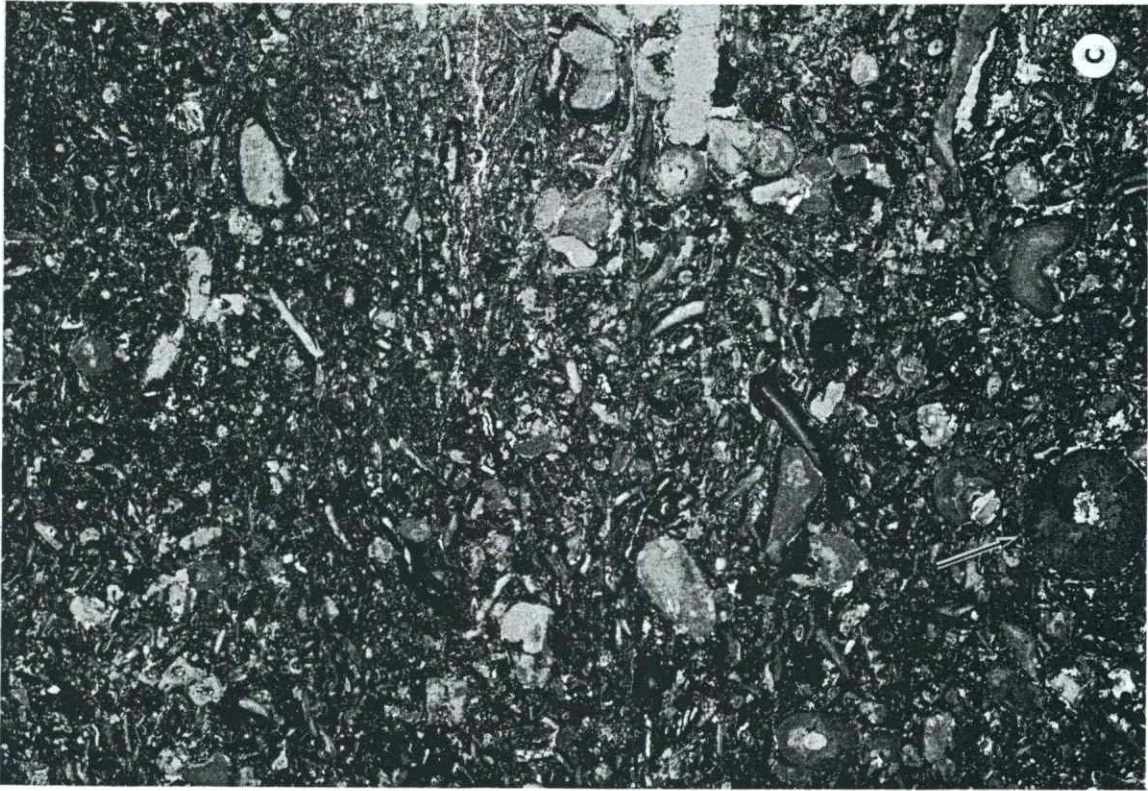
EXPLANATION OF PLATE XVIII

- A. Skeletal mud facies - mixed biota subfacies. Shell fragments, mainly brachiopod and pelecypod, with *Osagia*-type organic encrustations developed about most of them. Fusulines lack coatings. Dark borings, presumably green algae, like those seen on the large altered skeletal grain at the bottom of the photomicrograph, are present beneath the encrustations of the coated grains; this indicates a blue-green algal origin for the organic coating. C7-34.6 x4 P.P.L. T.
- B. Skeletal mud facies - mixed biota subfacies. This is a sample of the thin zone, rich in fusulinids, brachiopods, and *Osagia* coated grains, present at the base of the Toronto Limestone in central Kansas. Terrigenous silt is present in matrix of rock and in coatings. Arrow at left singles out coated grain which contains minute skeletal particle inclusions as well as quartz silt. Central arrow denotes brachiopod spine. Arrow on right refers to a derbyid fragment. Worn fusuline near bottom center. Fenestrate bryozoan fragment (tangential section) in lower left hand corner. lll-8 Bottom x9 C.P.L. T.



EXPLANATION OF PLATE XIX

- A. Productoid brachiopod shell exemplifying well-preserved nature of brachiopod microstructure which consists of laminations of calcite with sharp folds at loci of pseudo-punctae. Holes in pedicle valve were bored into it by acrothoracian barnacles. Organic encrustations ("Cryptozoon"-type) were developed about the brachiopod shell after death of the brachiopod. L9-2 x6 P.P.L. V.
- B. Large planispiral gastropod on right with geopetal fabric developed inside. Original shell structure was apparently replaced by sparry calcite through solution of shell, then introduction of spar. Calcite mosaic inside gastropod coarsens toward its center. Shell on left side of photomicrograph in the center is a pelecypod shell that was replaced by sparry calcite. Much of the fine shell debris elsewhere in the slide is of molluscan derivation. L3-9 x7 P.P.L. T.
- C. Echinoderm-fenestrate bryozoan grain facies. Very abundant crinoid debris throughout slide. Other skeletal particles include fusulinids, fenestrate bryozoans, brachiopod shell fragments and spines and Osagia coatings. Coating on crinoid columnal at bottom of photomicrograph (arrow) penetrates into the shell suggesting the presence of boring green algae; other examples of same phenomena are evident elsewhere in the photomicrograph. Mud-sized fraction of this thin section consists in large part of finely divided skeletal matter. L10-3 x4 P.P.L. T.



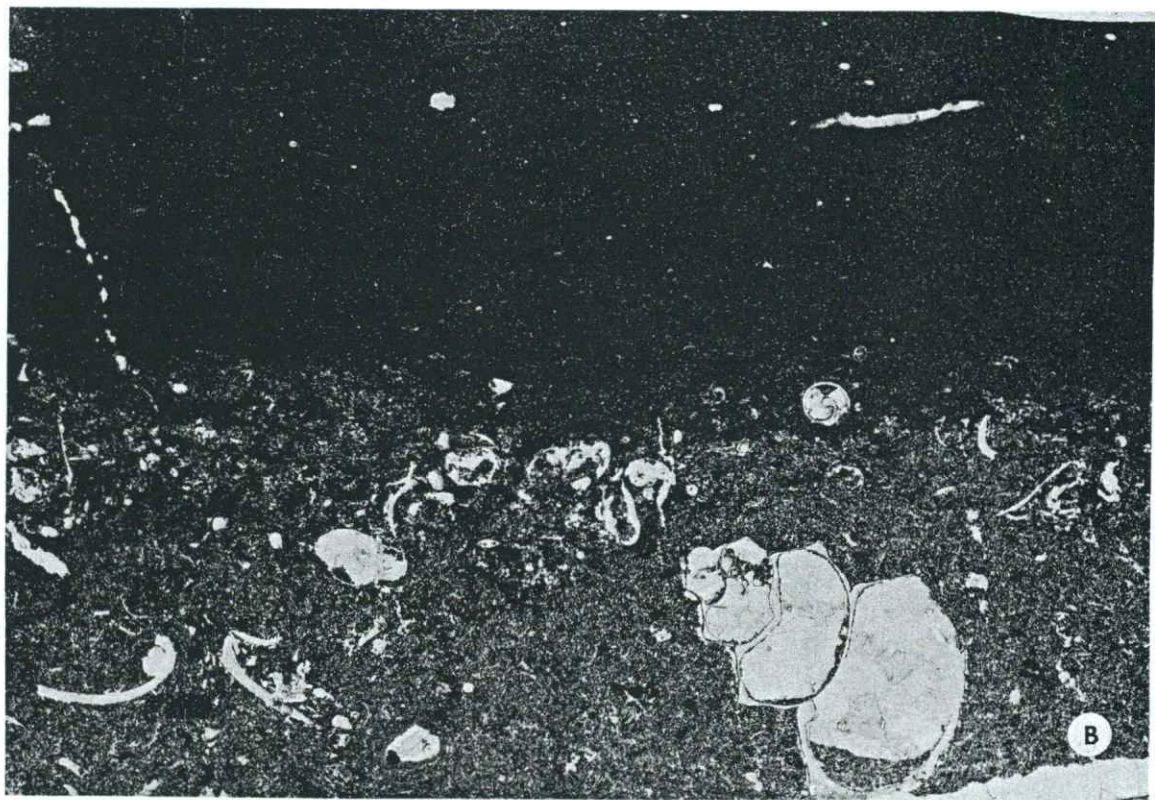
EXPLANATION OF PLATE XX

- A. Echinoderm-fenestrate bryozoan grain facies. Abundant crinoid segments, some partially recrystallized, of various sizes. Other conspicuous skeletal grains are fenestrate and ramose bryozoans, brachiopod shell fragments and spines, and trilobite parts. Osagia-coated grains are conspicuous. C7-27.4 x4.5 P.P.L. T.
- B. Echinoderm-fenestrate bryozoan grain facies. Large flat intraclast extends into photomicrograph from right margin; lithification and erosion to produce intraclast are indicated by beveled shell fragments along edges of clast, notably a fusulinid (arrow) and a brachiopod shell. Encrusting bryozoans are attached to the upper surface of the intraclast to the right of the arrow. L22-3u.p. x4 P.P.L. V.



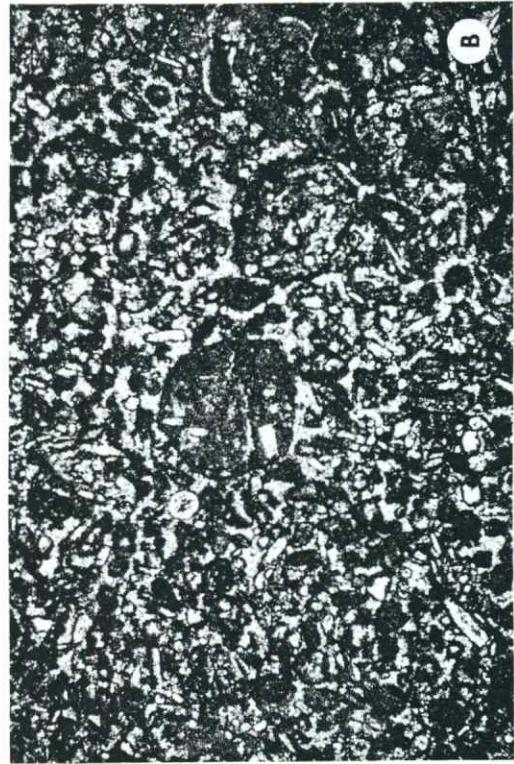
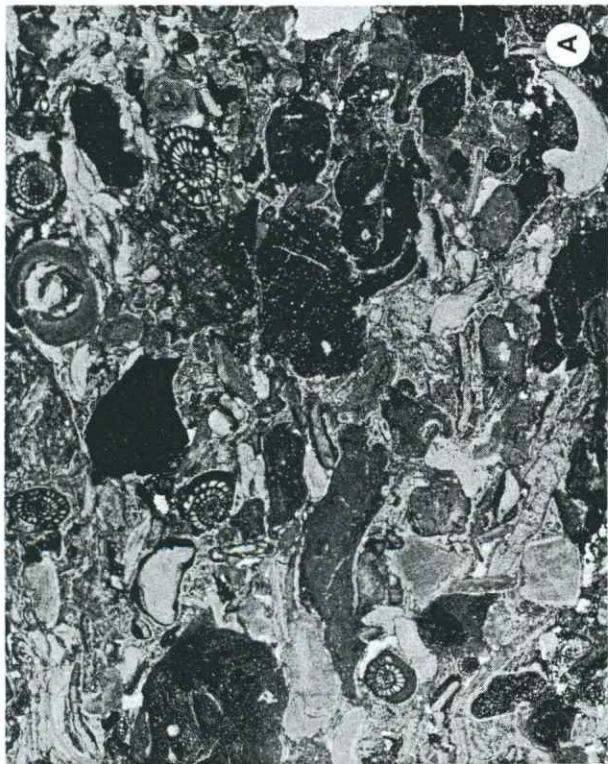
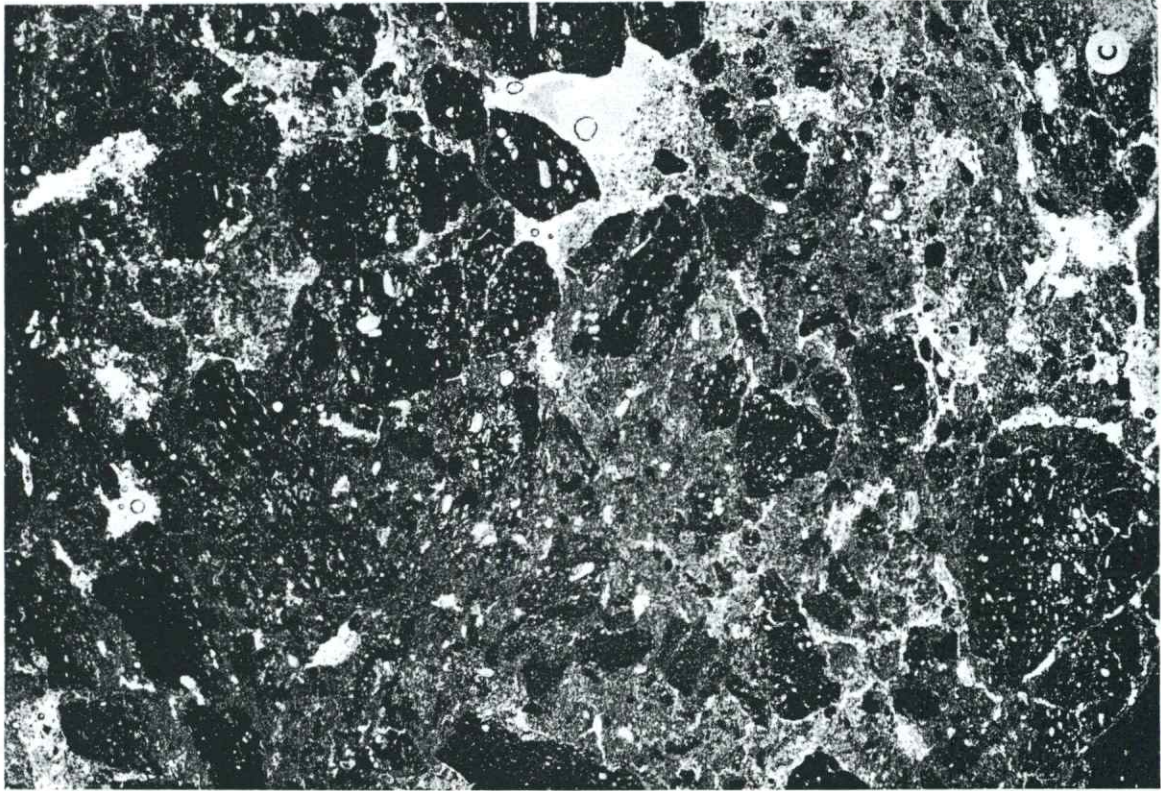
EXPLANATION OF PLATE XXI

- A. Skeletal mud facies - Osagia-rich subfacies. Gastropod shells are abundant in the photomicrograph as are Osagia coatings. Matrix of rock consists of tiny pellets of lime mud. L14A-2 x4 P.P.L. T.
- B. Contact of lime mudstone facies and Osagia-rich subfacies near center of photomicrograph. Lime mudstone contains minute shell fragments. Large gastropod in Osagia-rich subfacies shows geopetal fabric; other shell fragments present are chiefly molluscs, although a few small ostracodes are evident. L14-2 x4 P.P.L. T.



EXPLANATION OF PLATE XXII

- A. Angular to rounded lithoclasts of lime mud rocks admixed with worn fusulinids, crinoid debris, and brachiopod shell fragments and spines to form a packstone. This lithology occurs in the upper bed of the Toronto Limestone at Locality 7A. x5 P.P.L. V.
- B. Well-sorted and worn calcareous sand grains, some of which are pellets, with a sparry calcite cement. Intraclasts, example in center of photomicrograph, of a wackestone containing calcarens identical to those found in the calcaren grainstone are commonplace in this lithology. The gradation of grainstone to wackestone has been observed in thin section. L11-3 x10 P.P.L. V.
- C. Mud pebble conglomerate. Angular intraclasts of ostracode mudstone showing stratification with a matrix of ostracode mud. The fact that many of the pebbles resemble pieces of a jigsaw puzzle, like those at the top of the photomicrograph, suggest subaerial exposure of the ostracode mud to indurate the sediment followed by reworking of mud cracks on a mud flat to produce the conglomerate. L26-7 x4 P.P.L. T.



EXPLANATION OF PLATE XXIII

- A. Skeletal mud facies - mixed biota subfacies. Mottled lime mud above undulatory contact that trends diagonally across the photograph. Homogenous mud below contact. Echinoderm segments, fenestrate bryozoans, gastropod and pelecypod shells, and "Cryptozoon" encrustations are present in the mottled mud. A coelcladid sponge, top of photomicrograph, forms the nucleus of one "Cryptozoon" oncolite. Small cavities between the mottles suggests that the mottles were in some way coagulations of lime mud, possibly due to mucilaginous organic slime or the like or blue-green algae. Echinoderm debris, fenestrate bryozoans, gastropod and pelecypod shells, and broken fusulinid tests are present in the homogenous mud; the lack of parallel arrangement of elongate skeletal grains, the patchy distribution of the skeletal components, and the clastic nature of the same, evidence the activities of scavenging and burrowing organisms. Although the contact between the two sediment types is irregular, there is no evidence to suggest that it is erosional. LLB-1 x7
P.P.L. (Top of section is nearest binding edge.)



EXPLANATION OF PLATE XXIV

Echinoderm-fenestrate bryozoan grain facies. Fusulinid tests, gastropod and pelecypod fragments, fenestrate bryozoans, brachiopod shells, and echinoderm segments in a framework of lime mud. Osagia-type coatings envelop some of the grains. Two large intraclasts at left side of photomicrograph. Lowermost intraclast contains a mollusc shell fragment that appears to have been truncated along edge of clast; this suggests semi-induration of clast prior to erosion of mollusc shell. Large coated crinoid parts at top and bottom of photomicrograph have been bored, suggesting the activities of boring green algae. Large grain in center is an oblique section through a partial crinoid column revealing five separate columnals. LLA-5
x6 P.P.L. T.



EXPLANATION OF PLATE XXV

Skeletal mud facies - mixed biota subfacies. Echinoderm segments, goniocladid bryozoans, brachiopod shells, mollusc fragments, fusulinids, paleotextularids, Tuberitina, and platy alga (Eugonophyllum) with matrix of lime mud. Both Osagia- and "Cryptozoon"-type oncolites with apparent gradations between them. Brachiopod geopetal on lower right side of photomicrograph contains several specimens of the encrusting foraminifer, Tuberitina, attached to the underside of the brachiopod shell testifying to the presence of a cavity beneath the shell. Note how the "Cryptozoon" colony is constructed on top of the brachiopod shell described above. The large partial crinoid column was bored beneath the Osagia coating. LLA-9u x5 P.P.L. (Top of section is nearest binding margin.)

