

# PETROGRAPHY OF SELECTED CHESTERIAN CARBONATES (VISEAN-NAMURIAN) FROM THE TYPE AREA IN SOUTHWESTERN ILLINOIS

ALBERT V. CAROZZI AND JAMES E. ROCHE  
*Department of Geology, University of Illinois, Urbana, Illinois*

**ABSTRACT.**—Six carbonate sections of the upper half of the Chester Series (Glen Dean Formation to Kinkaid Formation) in type area of Southwestern Illinois were sampled at an average interval of 15 centimeters. Nearly four hundred thin sections were analyzed in a statistical petrographic (microfacies) investigation. Frequency indices for crinoid and bryozoan debris, ostracods, calcified monaxonial sponge spicules, arenaceous foraminifers, calcispheres, detrital quartz and oolites were measured. Indices of elasticity were also computed for crinoid debris, detrital quartz and oolites. Curves of the stratigraphic variation of each parameter were plotted and used for the interpretation of the environment of deposition.

The statistical data combined with textural properties and degree of recrystallization revealed an association, at times regularly cyclical, of five distinct and environmentally controlled microfacies. These are in order of increasing energy level or decreasing relative depth: calcisiltite with scattered debris, mud-supported biocalcarenite and three types of grain-supported biocalcarenites with calcisiltite matrix recrystallized to a variable degree.

All these microfacies indicate an environment of general low energy in which moderate winnowing processes were active. In the shallower portions where crinoid and bryozoan colonies thrived, they led to the inflow of transported oolites, the sorting of crinoid debris and the fragmentation of bryozoan fronds almost in place. In the deeper portions of the environment where abundant siliceous sponges and scavengers were associated with small crinoid clumps, the winnowing processes concentrated the silt-size detrital quartz and all the small organic components such as arenaceous foraminifers, ostracods and calcispheres originally distributed throughout the environment.

A detailed petrographic and environmental study of the limestone units of the Upper Chester series was undertaken in the type area of southwestern Illinois. The units chosen for this study ranged stratigraphically upward from the Glen Dean Formation to the Kinkaid Formation. The published sections from a previous paper by Rexroad (1957) on the conodont fauna of the Chester were used as stratigraphic reference.

Nearly four hundred vertically oriented specimens were collected from six sections at a sampling interval of approximately 15 centimeters. Thin sections were then prepared, investigated petrographically, and divided into six distinct microfacies. Variation curves for the organic and mineral parameters measured in thin section were drawn parallel to the stratigraphic column. From these curves the relative energy level and bathymetry of the different microfacies were interpreted and the detailed vertical evolution of the carbonate sediments in Late Chesterian time was reconstructed.

## LOCATION

This investigation was conducted in the vicinity of Chester, Illinois, approximately 60 miles southeast of

St. Louis on the east bank of the Mississippi River. The six sections collected were located in active or abandoned quarries, or in railroad or road cuts (FIGURE 1).

#### STRATIGRAPHY AND PREVIOUS WORK

D. H. Swann (1963) established a detailed stratigraphy of the Chester series (FIGURE 2) and reviewed all previous stratigraphic work and related terminology. Therefore, it is sufficient to point out here that he has only defined additional members in the type area (pp. 10, 40-42).

Although many workers have contributed substantially to the stratigraphy and paleontology of the Chester in the type area, no detailed petrographic work has been done. Rexroad (1957) described eighteen sections in the type area for an investigation of the conodont fauna. Five of his sampling localities from

the Upper Chester were chosen for the present study on the basis of their containing vertically continuous limestone units. They include parts of or all of the Glen Dean, Vienna, Waltersburg, Menard, Clore, and Kinkaid Formations. For comparative purposes Rexroad's original sampling locality numbers were retained in the present study (FIGURE 2), however, locality 10A, Coles Mill South, was chosen as an alternate since the original section has been covered by road construction.

#### METHODS AND TECHNIQUES

The low regional dip to the east of the Mississippian rocks in the vicinity of Chester greatly facilitated the measuring of the selected exposures. The normal procedure was to take a vertically oriented limestone specimen every fifteen centimeters. Wherever bedding was quite massive, this interval was extended up to thirty centimeters; wherever the layers were eight centimeters or less the entire bed was collected. Sandstones and shales were

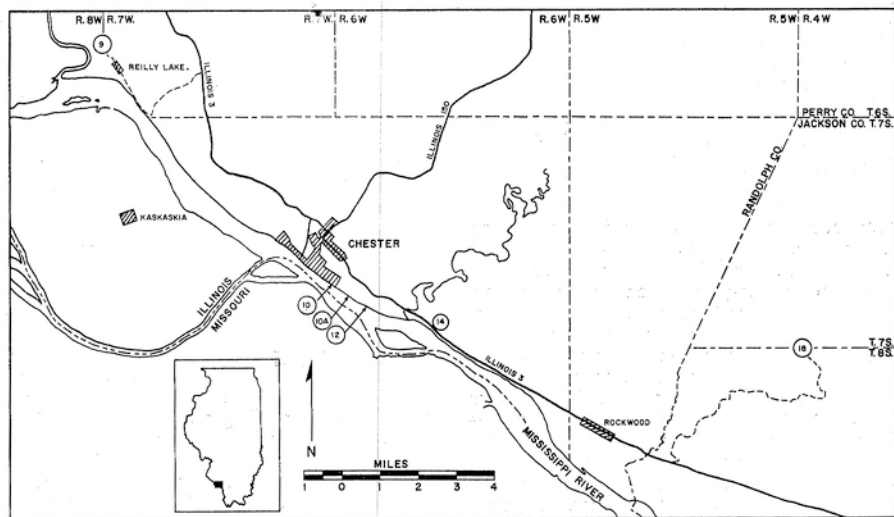
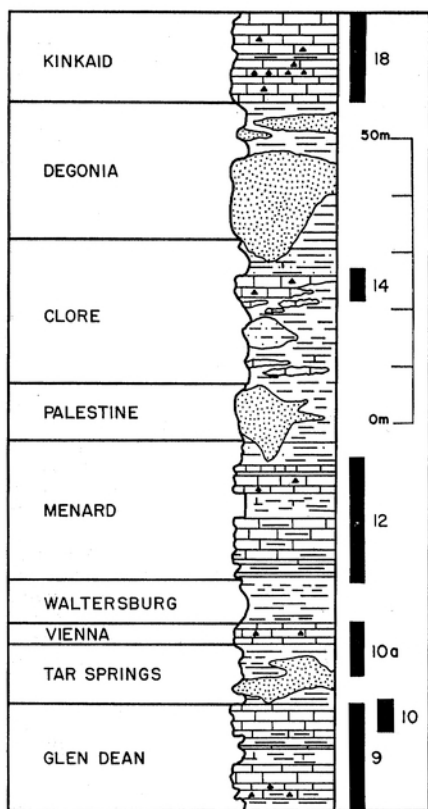


FIGURE 1. — Location map



(MODIFIED AFTER REKROAD, 1957)

GENERALIZED GEOLOGIC COLUMN  
OF THE UPPER CHESTER SERIES  
IN THE TYPE AREA

FIGURE 2.—Generalized geologic column of the Upper Chester Series in the type area.

also routinely sampled, although at an interval of one to two meters, but were not petrographically investigated.

Approximately 380 specimens of carbonates were collected at an average interval of eighteen centimeters. The slabbed and trimmed specimens were placed in a General Electric XRD-4 diffractometer and scanned from 22 to 40 degrees  $2\theta$ . This range includes the major peaks of quartz, calcite, and dolomite. This analysis has shown that nearly all specimens consist of relatively pure limestone with insignificant amounts of dolomite. The thin sections

were prepared in the routine fashion except for the use of an Ingram-Ward thin section machine.

They were then studied following the method proposed by Carozzi (1950, 1958, 1961) which consists of measuring the indices of clasticity and frequency of all the detrital components and the frequency indices of all the organic components of a carbonate rock.

The index of clasticity for any given component in a thin section is defined as its maximum diameter. Since we are dealing with an apparent diameter, except in the particular case where the section is cut through the center of the grain, the index of clasticity is the lowest numerical value of the maximum diameter. In order to attain some degree of constancy in the measuring of the index of clasticity, the ten largest grains from all the grains occurring in a particular thin section were selected and their diameters averaged. The occasional isolated grains noticeably larger than the grains making up the rock were considered to be due to local variations in the agents of deposition, and hence, though their diameters were measured, they were not entered into the tabulation of the index of clasticity.

The final expression of the index of clasticity is a numerical figure, given in millimeters, which represents the largest diameter of a grain that could be set in motion by the general forces acting in the environment of deposition.

The frequency of a given component is defined as the number of its particles present in any given area of a thin section. In practice, this requires counting the number of grains found over a constant area on each thin section. This constant area must be maintained in order to achieve the reproducibility of results necessary for the acquisition of statistical validity. A problem arises with the determination of the frequency index. If the rock was made up predominantly of closely packed grains of a particular clastic component, as the grain size increases the frequency index will decrease, thereby giving a misleading value. In order to overcome this, it was decided to choose an area for each clastic component which had a diameter of at least 10 times the average diameter of that component. For crinoids, bryozoans, ostracods, sponge spicules, arenaceous foraminifers, calcispheres and oolites, the surface area used for frequency index was 110 mm<sup>2</sup>, for detrital quartz, it was 17.9 mm<sup>2</sup>.

The parameters occurring with sufficient frequency to be statistically valid were then plotted, using appropriate arithmetic or logarithmic scales, according to their stratigraphic position in the column. By joining these points, a series of curves were obtained which trace the stratigraphic variation of each particular parameter. The presence of components not abundant enough to allow frequency measurements was indicated by vertical lines in the appropriate column.

On the basis of microscopic textures, presence of a detrital or recrystallized matrix, average values and relationships of organic and inorganic parameters, the thin sections were divided into distinct microfacies. In the last column of each set of variation curves, these microfacies have been arranged from left to right in order of decreasing relative depth of deposition or increasing energy level. The curve resulting from this arrangement is called the relative bathymetric curve. It reflects, in this particular case, both changes in energy level and water depth, and represents the final interpretation of the environmental evolution through time of the carbonates.

## COMPONENTS.

The limit between carbonate skeletal or mineral grains and matrix was set at 60 microns.

Crinoids occur most commonly as columnals and ambulacral fragments. A significant amount of this material displays a characteristic coarse lattice in thin section and while it may belong partly to crinoid calyxes, some of it might be derived from the plates of other echinoderms, such as blastoids and starfish. This assumption is supported by the occurrence of a substantial number of echinoid spines. All plates were entered as part of the frequency counts for crinoids, however, the spines were not.

Fenestrate bryozoans are easily identifiable when directly associated with their zooecia. However, the spiraling stock of the genus *Archimedes*, which contributes a large proportion of the bryozoan debris, occurs as large brown, fibrous fragments.

Arenaceous foraminifers are almost all endothyrids and paleotextularids. Oolites formed mainly around crinoid and fenestrate bryozoan fragments.

They average about one-half millimeter in diameter and usually have multiple concentric rings. A number of oolites show evidence of transportation such as broken or eroded rims, or second-generation rings around the remnants of reworked oolites. Wherever long fronds of bryozoan had become oolitized they were disregarded in the measurements of index of elasticity. Elongate oolites with length: width ratios greater than 2:1 were not measured.

Quartz occurs as subangular to subrounded particles, generally in the coarse silt range, associated occasionally with larger and very elongate grains.

Chert is not very common but does occur in all microfacies. It is most common in the upper portions of the Glen Dean, Vienna, and Kinkaid Formations.

Wherever possible chert specimens were also identified as to microfacies, and in some cases indices of frequency and elasticity on the coarser elements, usually crinoids were obtained.

Phosphate usually occurs as isotropic angular fragments, although a few platy particles display a fibroradiated pattern. The latter are interpreted as fish scales while the other phosphate debris probably represent broken-up conodont remains.

## DESCRIPTION OF MICROFACIES

Petrographic examination disclosed the presence of six distinct microfacies. One of them, a pressure-welded biocalcarenite (microfacies 3d), was found to transgress across the microfacies boundaries of all of the grain-supported rocks regardless of matrix type, and was therefore not used as a potential indicator of environment because of its obvious generation through diagenetic processes.

The remaining five microfacies form a genetically related sequence indicative of variations of conditions of deposition in a relatively quiet environment since they are either mud-supported or grain-supported with a microcrystalline calcite matrix which has recrystallized to a variable degree.

*Microfacies 1.*—Megascopically, microfacies 1 is a light grayish-buff to gray, sub-lithographic to very fine-grained limestone. The lighter colored, less argillaceous variety occasionally displays a slightly conchoidal fracture. Fossils, when present, are large and generally unbroken.

Microscopically, microfacies 1 (FIGURE 3A) is a calcisiltite with scattered fine sand-size organic debris and detrital minerals. The groundmass is a black microcrystalline calcite and the most frequent bioclasts are calcified monaxonic sponge spicules and small crinoid fragments. Ostracods, both as single valves or as complete individuals frequently occur but are by no means omnipresent. Brachiopod and pelecypod shells, and debris of trilobites occasionally appear as large, nontransported fragments, indicating an *in situ* community. Calcispheres, calcareous algae, bryozoans, and arenaceous foraminifers are sparse.

One or two oolites may sometimes be found but invariably they have damaged rims, indicating transportation. Detrital quartz also has a relatively low frequency of occurrence in this microfacies. Chertification occurs only occasionally, preferentially replacing sponge spicules and matrix.

A common feature of microfacies 1 is a laminated structure caused by concentration of the bioclasts along particular zones (FIGURE 3A). Post depositional disturbance, probably due to the burrowing action of scavengers, has rearranged the organic debris into spiral patterns. In one or two samples, pockets of very coarse crinoid debris cemented by cavity-filling calcite, were found to be completely enclosed by a calcisiltite matrix and could represent fillings of burrows.

*Microfacies 2.*—Megascopically, microfacies 2 is a dark gray to grayish-buff, buff weathering, sub-lithographic to finely crystalline limestone. The denser varieties often display a conchoidal fracture, while the more argillaceous units show distinct laminations. This microfacies occurs in thin to massive beds, ranging from 10 cm to 1.3 meters in thickness.

Microfacies 2 is a mud-supported biocalcarenite (FIGURE 3B) and characterized by having more than 50% of the bioclasts larger than 60 microns. These are most commonly crinoid fragments and echinoid plates, calcified monaxonic sponge spicules, and bryozoans. A unique feature of this microfacies is the general presence of echinoid spines. Calcispheres, ostracods, and arenaceous foraminifers are of secondary importance, whereas debris of brachiopods, pelecypods, gastropods, trilobites, and of rodlike calcareous algae make up the remainder of the or-

ganic components. Detrital quartz of fine sand-size is accompanied by a few phosphate fragments and some abraded oolites obviously transported into this environment. Several spiral structures indicating scavenger action were observed.

Partial recrystallization of the matrix into microspar may be seen in several specimens and in a few instances the entire matrix has been changed into an equant mosaic of pseudospar (50-60 microns).

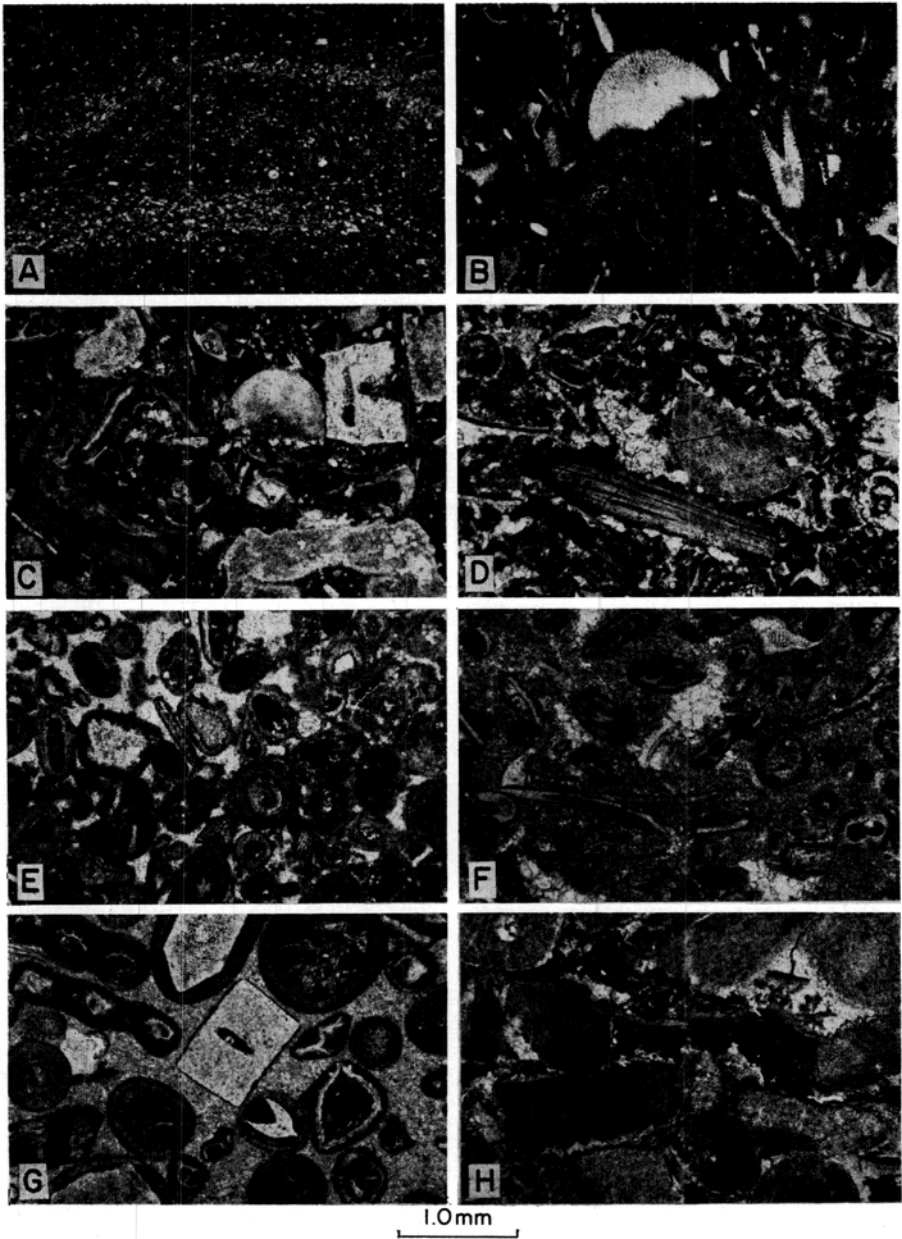
Microspar and pseudospar are types of neomorphic calcite (Folk, 1965) defined as sparry calcite larger than 3.5 microns which results from recrystallization. Microspar ranges from 3.5 microns to an arbitrary upper limit of 30 microns, while pseudospar includes all sparry calcite above this limit. This process of recrystallization will be covered later on in further detail.

*Microfacies 3a.*—In the field, microfacies 3a occurs as a light gray to light grayish-buff, coarsely crinoid limestone. Large fossil fragments are frequent, however, whole shells are rare. Again, the more argillaceous members of this microfacies display a finely laminated structure. The thickness of beds ranges from a few centimeters to a meter.

Microscopically microfacies 3a (FIGURE 3C) is a grain-supported biocalcarenite with a calcisiltite matrix in which recrystallization to microspar or pseudospar does not exceed 20% of the surface. In this study the fabric was termed grain-supported when the bioclastic to matrix ratio was greater than 50%. The predominant bioclasts are crinoids and fenestrate bryozoans. Arenaceous foraminifers, calcispheres, ostracods, and calcified monaxonic sponge spicules are relatively minor constituents. Fragments of brachiopods, pelecypods, gastropods, and calcareous algae are well represented and trilobite debris are more common than in microfacies 1 and 2. Also in this microfacies echinoid spines are present in nearly every slide. Evidence of scavenger action and organic phosphate debris are rare.

Detrital quartz averages slightly more than 0.1 mm in diameter and reaches its peak in frequency in this microfacies.

A few samples contain only detrital quartz grains in a matrix of cryptocrystalline calcite. While some of them should probably be called sandstones



*Typical Microfacies*

FIGURE 3.— A. *Microfacies 1* (Kinkaid Formation, Type Section, Loc. No. 18) Banded calcisiltite with scattered fine sand-sized bioclastic debris, mostly crinoids, ostracods and calcified monaxonic sponge spicules. Nicols not crossed.

- B. *Microfacies 2* (Menard Formation, Chester East, Loc. No. 12)  
Mud-supported biocalcarenite with calcisiltite matrix. "Floating" bioclasts are largely crinoid and echinoid fragments with a few scattered debris of bryozoans and ostracods. Nicols not crossed.
- C. *Microfacies 3a* (Glen Dean Formation, Reilly Lake North, Loc. No. 9)  
Grain-supported biocalcarenite with calcisiltite matrix, consisting mostly of large fragments of crinoids and bryozoans. Arrangement of debris suggests post-depositional disturbance by scavengers. Note fibrous debris of *Archimedes* in lower left corner. Nicols not crossed.
- D. *Microfacies 3b* (Kinkaid Formation, Type Section, Loc. No. 18)  
Grain-supported biocalcarenite with calcisiltite matrix partially recrystallized into pseudospar. Bryozoan debris predominant. Large linear element at lower center is a portion of spiraling stock of *Archimedes*. Nicols not crossed.
- E. *Microfacies 3b* (Menard Formation, Chester East, Loc. No. 12)  
Grain-supported oolitic biocalcarenite with calcisiltite matrix partially recrystallized to pseudospar (particularly in upper left corner). Note poor sorting of transported oolites and intercalations of black microcrystalline calcite between concentric rings. Nicols not crossed.
- F. *Microfacies 3c* (Glen Dean Formation, Reilly Lake North, Loc. No. 9)  
Grain-supported biocalcarenite with secondary cement of dominantly microspar with patches of pseudospar. Predominant bryozoan zooecia filled with and surrounded by dark microcrystalline calcite. Nicols not crossed.
- G. *Microfacies 3c* (Glen Dean Formation, Reilly Lake North, Loc. No. 9)  
Grain-supported oolitic biocalcarenite with secondary cement of pseudospar. Note irregular size distribution of transported oolites and bioclasts with rims of microcrystalline calcite. Nicols not crossed.
- H. *Microfacies 3d* (Menard Formation, Chester East, Loc. No. 12)  
Pressure-welded crinoid-bryozoan calcarenite. Note deep reciprocal interpenetration of all elements which are aligned parallel to bedding, and distortion of more fragile fenestrate bryozoans. Nicols not crossed.

with a calcareous cement they were nevertheless placed in this class.

*Microfacies 3b*.—Megascopically, microfacies 3b differs from 3a only in having a more coarsely crystalline aspect. In some places the fossil fragments are concentrated along definite zones giving a bedded or sometimes even cross-bedded aspect to the rock. When these conditions occur, the individual beds are 0.5 to 1.0 meters thick. However, there is considerable variation in thickness within the units representative of microfacies 3b.

Microfacies 3b (FIGURE 3D) is a grain-supported biocalcarenite with a calcisiltite matrix showing 20 to 80% of its surface recrystallized to microspar or pseudospar. The dominant bioclasts, showing varying degrees of pressure-solution, still consist princi-

pally of crinoids and fenestrate bryozoans with the proportion of crinoids to bryozoans decreasing.

Ostracods, calcified monaxonic sponge spicules, arenaceous foraminifers, and calcispheres are less abundant than in the preceding microfacies. Debris of brachiopods, pelecypods, gastropods, trilobites, calcareous algae, and echinoid spines are minor constituents as are detrital quartz and organic phosphate debris. Worm tubes and disruption by scavengers are rare. Oolites become more important in microfacies 3b, occurring generally in well packed to slightly pressure welded arrangements (FIGURE 3E). The oolite cores are mainly bryozoan fragments, with crinoids and other organic debris being of secondary importance. These oolites are apparently transported, but where the

surrounding microcrystalline matrix has been recrystallized, their edges have become further indented by this process.

*Microfacies 3c.*—Microfacies 3c is the most easily recognizable of the five lithologies in the field. It is usually light gray or light buff in color, sometimes changing to dark gray in the more finely crystalline varieties. The lighter, more common members of this class contain abundant large, well preserved fossils, usually broken, although whole specimens are not uncommon. Microfacies 3c is often oolitic and cross-bedded. Beds are normally 0.5 to 1.5 meters in thickness, although they are somewhat thinner in a few places.

In the most characteristic examples of this class the bioclasts seem to "float" in a glass-like groundmass of pure sparry calcite cement.

Under the microscope, microfacies 3c is a grain-supported biocalcarenite in which more than 80% of the original calcisiltite matrix has recrystallized to microspar and pseudospar. Cavity-filling sparry calcite is absent in this microfacies. The neomorphic calcite displays the following varieties: microspar with scattered patches of pseudospar (FIGURE 3F'); pseudospar with smaller areas of microspar; fine or coarse uniform pseudospar (FIGURE 3G).

Crinoids and fenestrate bryozoan fragments dominate the organic assemblage, with bryozoans occurring with the highest frequency (FIGURE 3F). Oolites of transported nature occur at their highest frequency and elasticity, averaging over 0.6 mm in size. Most are normal oolites, consisting of either bryozoan or crinoidal debris surrounded by multiple concentric rings of fibroradiated calcite. Transportation, which is shown by poor sorting and wide ranges of size, is confirmed by the occurrence of abraded rims, intercalation of calcisiltite between concentric rings, and by excentric rings (Carozzi, 1964).

Ostracods, calcispheres and arenaceous foraminifers are rare. Brachiopod, pelecypod, gastropod, and trilobite fragments, as well as calcareous algae, echinoid spines, and organic phosphate debris make up the remainder of the assemblage.

Quartz averages 0.065 mm and is at its lowest frequency relative to the other microfacies. It is usually sub-angular to sub-rounded.

The grain-supported microfacies 3a, 3b, and 3c have been distinguished on

the basis of an increasing percentage of recrystallization of the original interstitial calcisiltite matrix. In terms of energy level and general environmental interpretation it is of fundamental importance to separate low energy calcarenites with a recrystallized calcisiltite matrix from high energy carbonates with cavity-filling calcite cement. Neomorphic clear calcite resulting from recrystallization of an original calcisiltite matrix displays the following features (Bathurst, 1968; Folk, 1965): grain size ranges continuously from four microns upward; the grain size varies irregularly from place to place within the mosaic; grain boundaries are curved, consertal, and often plicate, as opposed to the straight, planar boundaries of precipitated sparry calcite. The microcrystalline matrix often displays a "nibbled" appearance, often to the point of bearing delicate stringers and patches of the original matrix completely surrounded by coarse calcite (FIGURE 3E).

*Microfacies 3d.*—Megascopically this microfacies appears as a very coarsely crystalline crinoidal limestone of variable color, ranging from light buff to dark gray. In some measured sections its occurrence corresponds to zones of stylolitization.

Microscopically a specimen was termed to be pressure-welded when 50% or more of the bioclastic grains were in reciprocal contact with each other and exhibited mutual interpenetration along their boundaries. All gradations of pressure-welding were noted from incipient grain contact to deep interpenetration accompanied by elimination of the original calcisiltite matrix (FIGURE 3H). Most commonly the bioclasts in these specimens consist of crinoids and bryozoans oriented parallel to bedding by the effects of pressure solution. Most of the other types of organic debris seen in microfacies 3a through 3c, with the exception of brachiopods and pelecypods, have been largely eliminated in the more advanced stages of pressure welding. Fragments of organic phosphate and grains of detrital quartz are also seen occasionally. Oolites are common in this group, although the disruption of their rims due to this process is not to be confused with changes wrought by transportation.

#### COMPOSITE SECTION

The five microfacies 1 through 3c described in the previous section are

gradational vertically into one another (and also horizontally according to Walther's rule) and the variation of their characteristic average parameters (TABLE 1) indicates that such a succession expresses an increase of energy level and at the same time a decrease in the relative depth of deposition. Therefore, it is possible to superpose them in a composite section or statistically most frequent succession which may be used for the interpretation of the investigated sections (FIGURE 4).

The average parameter variations of the composite section may be described as follows:

The frequency curve of crinoid debris has a symmetrical, almost bell-shaped aspect ranging from an average of 56 in microfacies 1 to a peak of 239 in microfacies 3a, then decreases to a value of 97 in microfacies 3c. The elasticity curve of crinoid debris increases lin-

early from 0.797 mm in microfacies 1 to a maximum value of 1.434 mm in microfacies 3c. An abrupt increase in frequency would be expected during the transition from a mud-supported rock (microfacies 1 and 2) into a grain-supported fabric (microfacies 3a). The reduction of the frequency into microfacies 3c may be explained by an increase in the sorting action of the currents or of the agitation of the environment removing smaller fragments, thereby concentrating relatively larger ones in the site of deposition, as shown by the maximum elasticity of the crinoid debris in the same terminal microfacies. Furthermore, many of the bioclastic fragments found in microfacies 3c, especially the crinoids, still display thin, discontinuous coatings of dark calcisiltitic mud indicating moderate intraformational processes of reworking. It may therefore be concluded that the variation of the crinoid parameters ex-

COMPOSITE SECTION

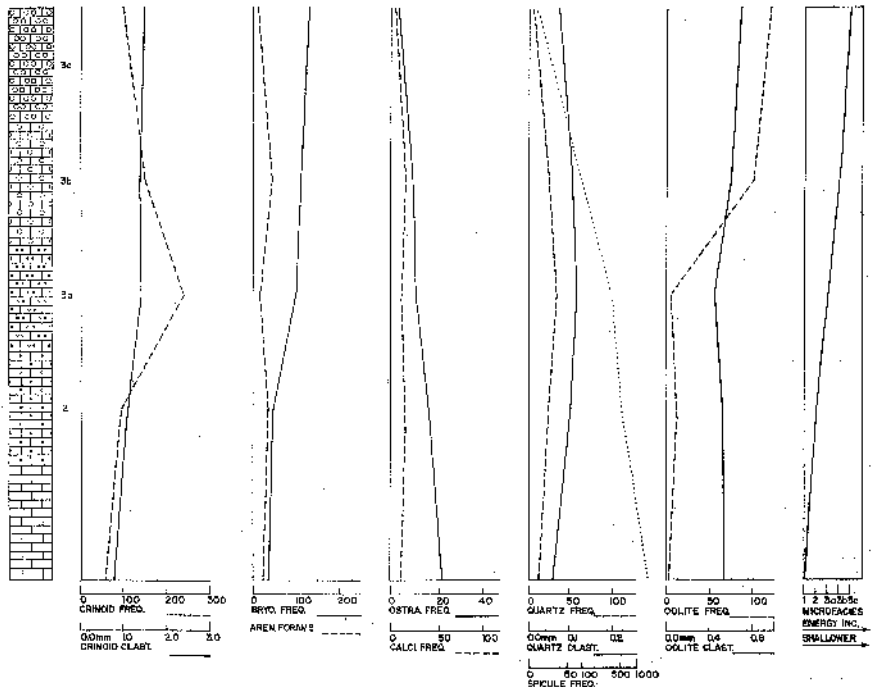


FIGURE 4.— Composite section

TABLE 1. Average Parameter Values by Microfacies.

	Microfacies.				
	1	2	3a	3b	3c
Crinoid Frequency.....	56	97	239	149	97
Crinoid Clasticity (mm).....	0.797	1.109	1.397	1.354	1.434
Bryozoan Frequency.....	33	44	100	109	132
Arenaceous Foraminifer Frequency.....	24	33	14	40	9
Ostracod Frequency.....	24	17	11	10	3
Calcsphere Frequency.....	13	11	12	18	4
Sponge Spicule Frequency.....	1749	517	337	97	13
Detrital Quartz Frequency.....	11	23	31	22	3
Detrital Quartz Clasticity (mm).....	0.053	0.094	0.112	0.099	0.065
Oolite Frequency.....	1	11	3	98	121
Oolite Clasticity (mm).....	0.504	0.504	0.427	0.583	0.660
Percentage of Total Thickness.....	18	10	11	45	16

presses the growth of an almost autochthonous population and the local sorting of its skeletal debris.

The bryozoan frequency increases from microfacies 1, where it has a value of 33, up to 132 in microfacies 3c. There is a sharp change in the slope of this curve in passing from microfacies 2 (mud-supported) to microfacies 3a (grain-supported) which is almost parallel to the rate of crinoid frequency increase in this interval. Beyond microfacies 3a, however, bryozoan frequency increases linearly to a maximum value in microfacies 3c. This is interpreted as being an expression of the increased disintegration of the delicate bryozoan fronds with increasing energy in the environment, whereas resistant crinoid columnals were only sorted according to size but not broken.

The frequency of arenaceous foraminifers exhibits a succession of peaks and lows which do not seem to be of particular significance. The lowest frequency is found in microfacies 3c, where there are but nine foraminifers per unit area. These benthonic and rather small components have been well preserved

in the mud-supported microfacies 1 and 2. Above this, their variable frequency and particularly the minimum in microfacies 3c certainly result from the effect of recrystallization processes.

The ostracod frequency decreases rapidly from a high of 24 in microfacies 1 to a value of 11 in microfacies 3a. From this point there is a more gradual decline to a low value of three counts per section in microfacies 3c. Although no distinction was made between ostracods with both valves intact and those represented by a single valve, the bivalved remains were more prevalent in the lower energy microfacies.

The frequency of calcspheres varies almost as a straight line through the first three microfacies. There is an abrupt increase from 12 to 18 calcspheres per section in passing from microfacies 3a to 3b, and just as abrupt a decrease to a low of four in microfacies 3c.

Sponge spicule frequency decreases in a linear fashion from a high of 1749 in microfacies 1 to a value of 337 in microfacies 3a. Beyond this there is a

sharp change of slope in the curve and the spicule frequency drops off quite rapidly to a value of only 13 spicules per section in microfacies 3c. This curve expresses the liberation in place of sponge spicules and indicates that siliceous sponges reach here their best development in the fine-grained carbonates deposited in quiet and relatively deep conditions.

There is a similarity in behavior between the frequency curve of sponge spicules and that of benthonic arenaceous foraminifers and ostracods and of pseudopelagic calcispheres. All these curves display a general decrease in frequency upwards which may be linear or oscillatory. Actually arenaceous foraminifers, ostracods and calcispheres which should have been present throughout the spectrum of the microfacies have been predominantly preserved only in the low energy conditions of the mud-supported microfacies 1 and 2 and were largely winnowed from the more agitated environment of the grain-supported microfacies 3a, 3b and 3c where only a small number of them could remain caught between larger bioclasts. These somewhat more agitated conditions also explain the higher frequency of single ostracod valves as opposed to the greater abundance of whole individuals in the lower energy microfacies. Similar conditions have been reported from the Rundle Group (Mississippian) of the Front Ranges in Central Alberta, Canada (Walpole and Carozzi, 1961).

Furthermore, the minimum values for the preceding parameters in microfacies 3c may also be ascribed to the additional destructive effect of recrystallization of the matrix.

Detrital quartz shows a symmetrical behavior of both elasticity and frequency, indicating by their parallelism that the supply was regular but never very abundant (Carozzi, 1958). In quartz grains ranging in size from coarse silt to fine sand (0.053 mm to 0.112 mm), it is natural that the larger and more abundant particles settle in microfacies 3a, as an effect of winnowing in the higher energy environments of 3b and 3c. Only smaller and less abundant particles settled in the mud-supported microfacies.

Oolite frequencies begin with low values of 1, 11, and 3 counts per section through microfacies 1, 2, and 3a respectively. The frequency increases abruptly from microfacies 3a to 3b, reaching

a value of 98 at the latter level, thence to a maximum of 121 in microfacies 3c. Oolite elasticity follows the frequency curve quite closely and similarly increases abruptly from 0.427 mm in microfacies 3a to a maximum of 0.660 mm in microfacies 3c. The occurrence of broken oolites and of others displaying internal residual layers of dark calcisilite mud (Carozzi, 1964) indicate that the oolites are essentially transported and originate in environments of relatively high energy adjacent to microfacies 3a-3c. Therefore, they should be interpreted as detrital components distributed from shallow into deep conditions and because of their size, rather unaffected by winnowing.

The final interpretation of the five microfacies in terms of increasing relative energy level or decreasing relative depth is plotted as a smooth curve showing a steady increase in energy from 1 through 3c.

#### ENVIRONMENTAL INTERPRETATION

The horizontal reconstruction of this low energy environment of carbonate deposition submitted to moderate winnowing processes, shows three major subdivisions (FIGURE 5).

The first one consists of microfacies 1 and 2 which are similar except for the ratio of bioclastic debris to matrix being higher in microfacies 2. They represent extremely quiet conditions characterized by the deposition of fine-grained carbonate mud in which siliceous sponges and scavengers were very abundant among scattered clumps of crinoids. As an effect of winnowing processes taking place in higher energy and shallower conditions arenaceous foraminifers, ostracods and calcispheres were finally deposited here associated with a small number of detrital quartz grains, transported oolites and bryozoan debris.

The second subdivision is represented by microfacies 3a, the first

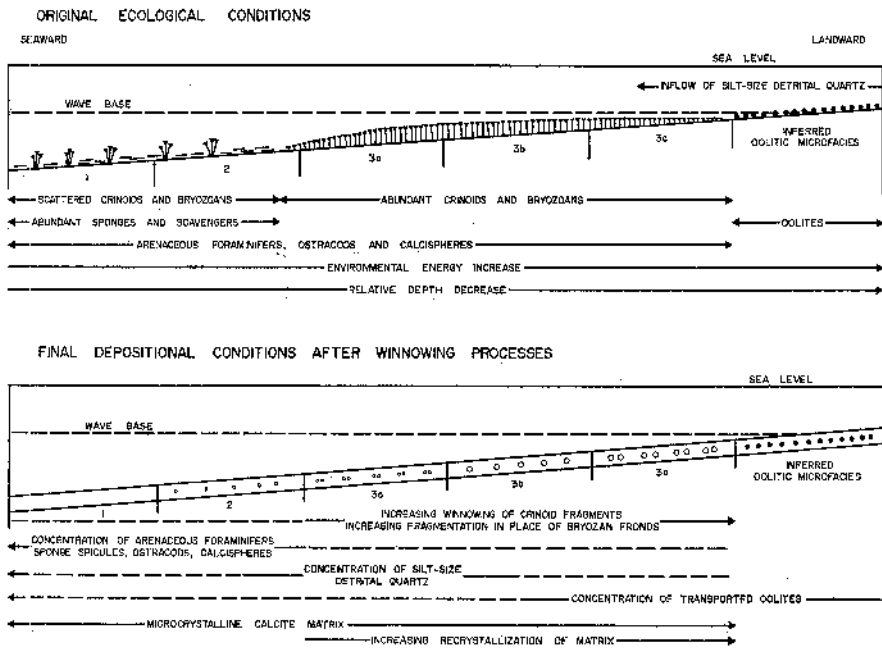


FIGURE 5.— Environmental interpretation

belonging to the grain-supported group characterized by a large development of crinoid and bryozoan colonies. It is in this intermediate position that most of the silt-size detrital quartz of extrabasinal origin, winnowed from higher energy conditions, was finally deposited.

The third subdivision consists of microfacies 3b and 3c and corresponds to higher relative energy and shallower conditions, although an even shallower environment must be inferred from which abundant transported colites originated. The winnowing conditions which characterize these two microfacies have sorted the crinoid debris, fragmented the delicate bryozoan fronds and almost completely eliminated the silt-size detrital quartz and the small-size organic components such as the arena-

ceous foraminifers, ostracods and calcispheres.

Although the group of grain-supported microfacies shows an increase in the degree of diagenetic recrystallization of the original calcisiltite matrix into neomorphic calcite apparently related to an increase in the energy level or a decreasing relative depth, such a relationship may be entirely fortuitous.

#### DESCRIPTION OF SECTIONS

In the following discussion of the individual measured sections reference will be made to the respective sets of variation curves (FIGURES 6-11). Since the microfacies parameters have already been discussed in the composite section in some detail, attention here will be directed to the unusual features of each unit. A

## TABLE OF SYMBOLS

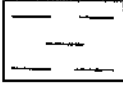

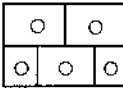
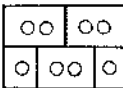
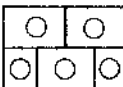
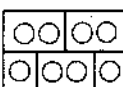
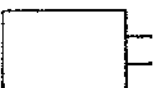
	<b>SHALE</b>
	<b>MICROFACIES 1</b>
	<b>MICROFACIES 2</b>
	<b>MICROFACIES 3a</b>
	<b>MICROFACIES 3b</b>
	<b>MICROFACIES 3c</b>
	<b>THIN SECTION CONTROL</b>

FIGURE 6.—Table of symbols

smooth main trend curve has been superimposed as a dashed line on the relative bathymetric curve in order to show the general evolution of the sedimentation which displays a definite cyclicality within a low energy environment.

*Section No. 9, Reilly Lake North.*  
—Section of Glen Dean Formation exposed in small quarries in Mississippi Valley bluff about 1.1 miles northwest of Reilly Lake, SE $\frac{1}{4}$ ,

SE $\frac{1}{4}$  sec. 24 (extended), T. 6S., R. 8W., Randolph Co., Illinois.

The lower part of this section (FIGURE 7) is characterized by a marked parallelism of crinoid and bryozoan frequencies. The oolite frequency is opposed to the preceding parameters as is to be expected, since an abundance of the former components precludes the presence of the latter. Crinoid and oolite elasticities are also quite similar. Most of this part of the section is in microfacies 3c although it does drop into 3b in a few places.

The upper portion of this section shows considerably more variation, mainly between microfacies 3a and 3b but occasionally reaching microfacies 1. Crinoid and bryozoan frequencies are again parallel with the exception of opposed curves near 14 meters. Benthonic ostracods and pseudopelagic calcispheres exhibit frequency curves which are opposed to those of the crinoids and bryozoans, thereby indicating their susceptibility to winnowing. Associated with the lower energies, detrital quartz appears in this section, with highest frequencies in microfacies 1 and 2.

*Section No. 10, Coles Mill North.*  
—Upper Glen Dean Formation exposed along railroad tracks behind flour mill at south edge of Chester, W. line NW $\frac{1}{4}$  sec. 30. T. 7S., R. 6W., Randolph Co., Illinois.

As in the preceding section the environment is one of relatively high energy with the main trend fluctuating only slightly between microfacies 3b and 3c (FIGURE 7). Parallel trends of crinoid and bryozoan frequency, and of crinoid and

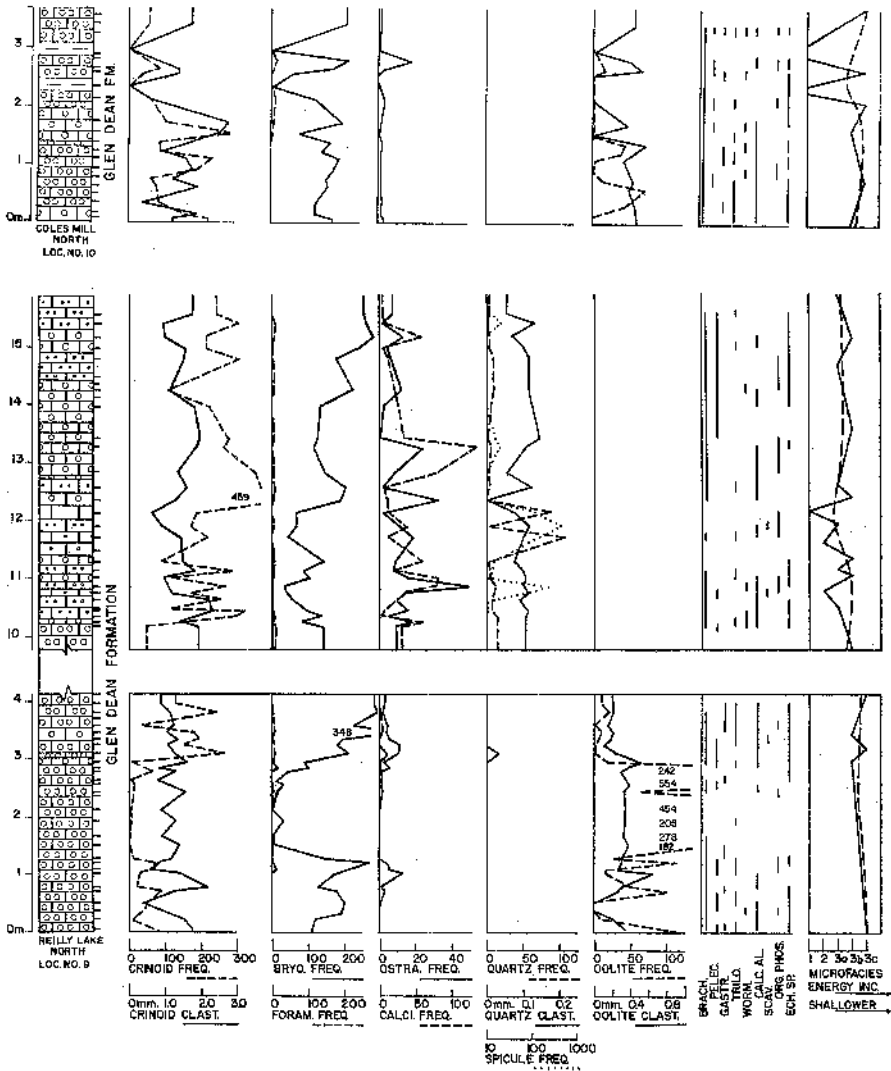


FIGURE 7.—Reilly Lake North, Locality No. 9, and Coles Mill North, Locality No. 10.

oolite elasticity are obvious. Oolite frequency opposes those of the crinoids and bryozoans.

*Section No. 10A, Coles Mill South.*  
—Vienna Formation exposed in road cut about 200 yards south of sec-

tion No. 10, NW $\frac{1}{4}$  NW $\frac{1}{4}$  sec. 30, T. 7S., R. 6W., Randolph Co., Illinois.

The general trend curve (FIGURE 8) shows the upper and lower portions of this section to vary between microfacies 3a and 3b while

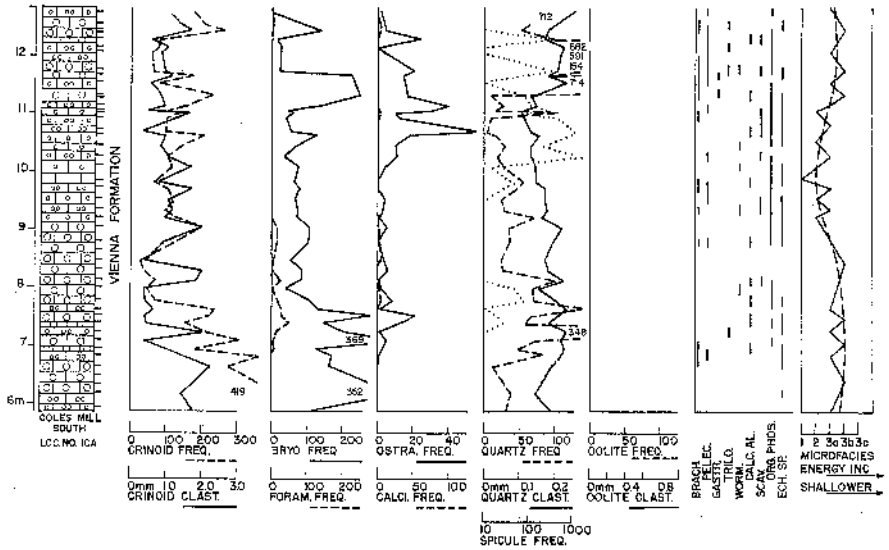


FIGURE 8.—Coles Mill South, Locality No. 10A

in the middle, between 3 and 5 meters, it reflects somewhat lower energy conditions. The frequency curves of crinoids and bryozoans, as well as that of detrital quartz, exhibit the same parallelism noted in the previous two sections. Ostracod frequency runs opposed to the peaks of the crinoid and bryozoan frequencies, again as an expression of the winnowing of small size components from high energy environments. Detrital quartz elasticity closely follows the peaks and lows of its frequency.

*Section No. 12, Chester East.*—Menard Formation exposed in abandoned high level quarry in Mississippi River bluff opposite sand and gravel docks, about 1.4 miles above mouth of Marys River, SW 1/4 SE 1/4 sec. 30, T. 7S., R. 6W., Randolph Co., Illinois.

This section is broken into four parts by three 1.5 to 2.0 meter thick

shales (FIGURES 9, 10). The lowermost portion is characterized by relatively high energy as shown by microfacies 3b and 3c. These conditions are again reflected in the upper portion of the section. The longest uninterrupted part of the section (5 to 14 meters) consists of a series of symmetrical fluctuations ranging from microfacies 1 to 3c. Relatively quiet conditions prevailed after the deposition of the overlying shale, as microfacies 1 is predominant.

Bryozoan and crinoid frequencies parallel each other, although the similarities of their curves are not as striking as in previous sections. The frequency curves of ostracods, arenaceous foraminifers, sponge spicules, and to a certain extent, calcispheres, show some parallelism in their trends, and are generally opposed to those of crinoids, bryozoans, and oolites. This situation again expresses the effects of winnowing.

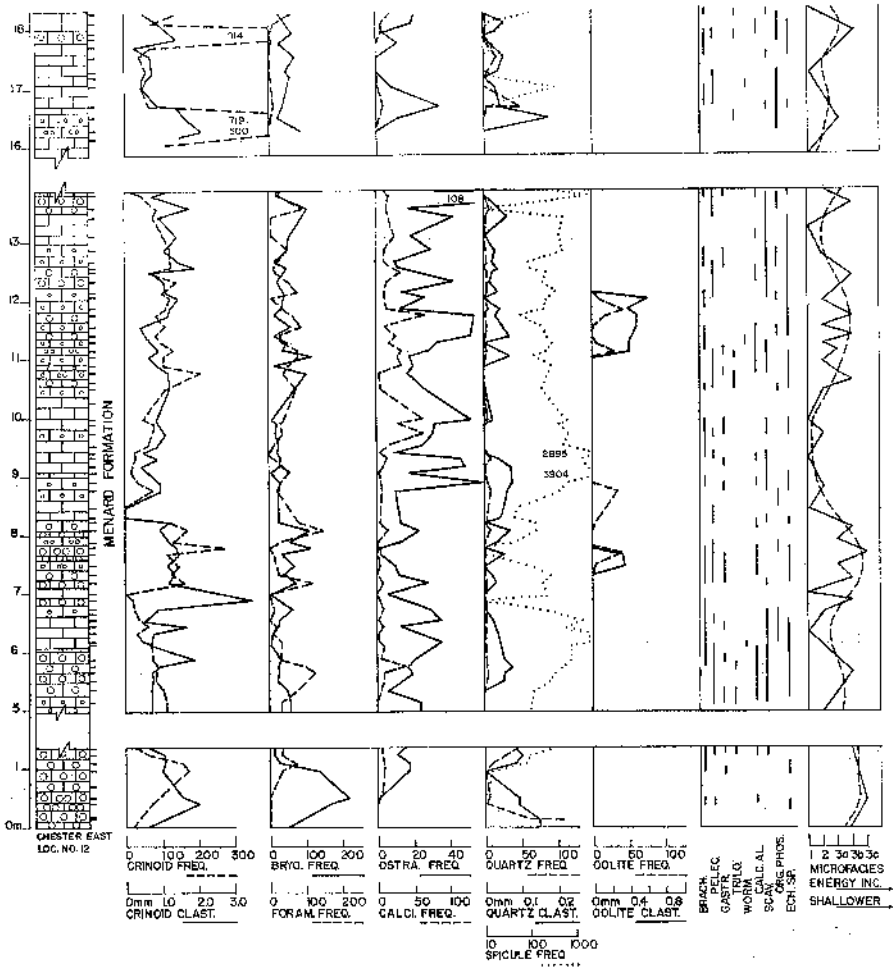


FIGURE 9.—Chester East, Locality No. 12

Section No. 16, Ford W. P. A. Quarry.—Clore Formation in small abandoned quarry in Mississippi River bluff above state highway 3, about 1.3 miles southeast of Marys River bridge, NW¼ SE¼ sec. 33, T. 7S., R. 6W., Randolph Co., Illinois.

This section begins and ends in low energy conditions but rises to a peak in microfacies 3b near its middle (FIGURE 10). Crinoid and

bryozoan frequencies generally parallel each other while the frequencies of arenaceous foraminifers and ostracods are generally opposed to them. Sponge spicules and detrital quartz are quite abundant throughout most of the section.

Section 18, Type Kinkaid.—Type Kinkaid Formation on north bank of Kinkaid Creek in Illinois Stone quar-

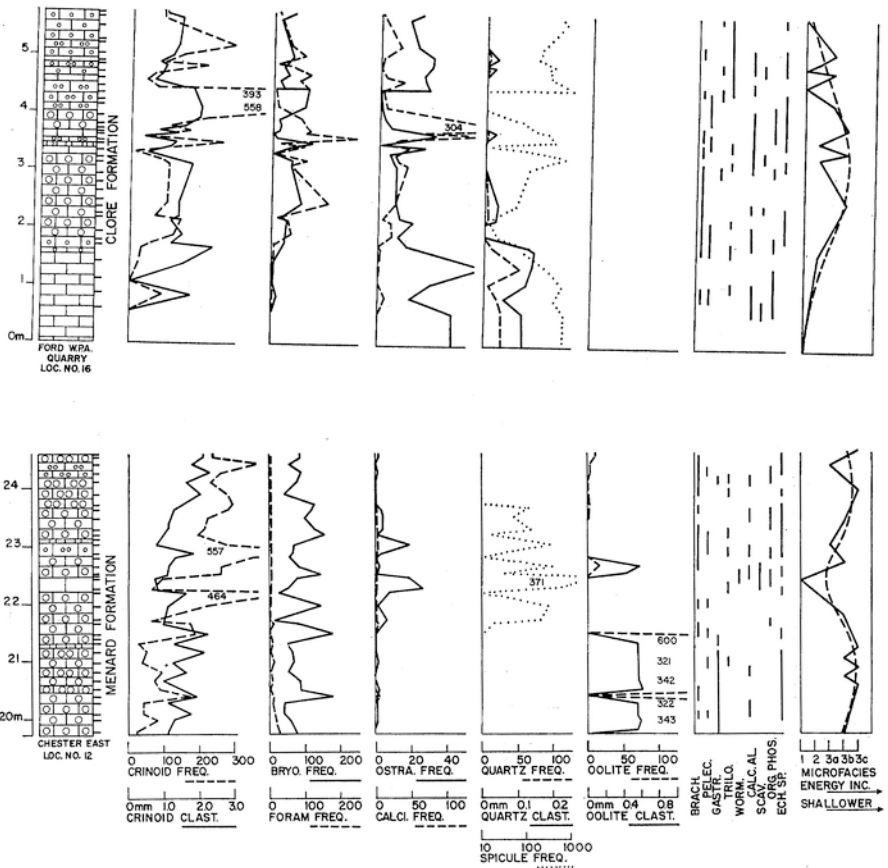


FIGURE 10.—Chester East, Locality No. 12, and Ford W. P. A. Quarry, Locality No. 16.

ry, SE $\frac{1}{4}$  NW $\frac{1}{4}$  NW $\frac{1}{4}$  sec. 6, T. 8S., R. 4W., Jackson Co., Illinois.

The Kinkaid Formation (FIGURE 11) is divided into an upper and a lower unit by a persistent 0.7 to 2.0 meter bed of shale with interbedded limestone stringers. The lower part exhibits the distinctive crinoid-bryozoan parallelism, whereas this frequent relationship disappears in the upper half, mainly due to an almost complete loss of bryozoan debris in the upper 3 or 4 meters. The

lower half of this section, and the lower 5 meters of the upper section are characterized by several long-period, fairly symmetrical fluctuations of the environment, the major portion of the column being represented mainly by microfacies 3a, 3b, and 3c. The upper 3 meters of the Kinkaid are entirely in microfacies 1 and 2 and are particularly marked by an intense development of sponge spicules.

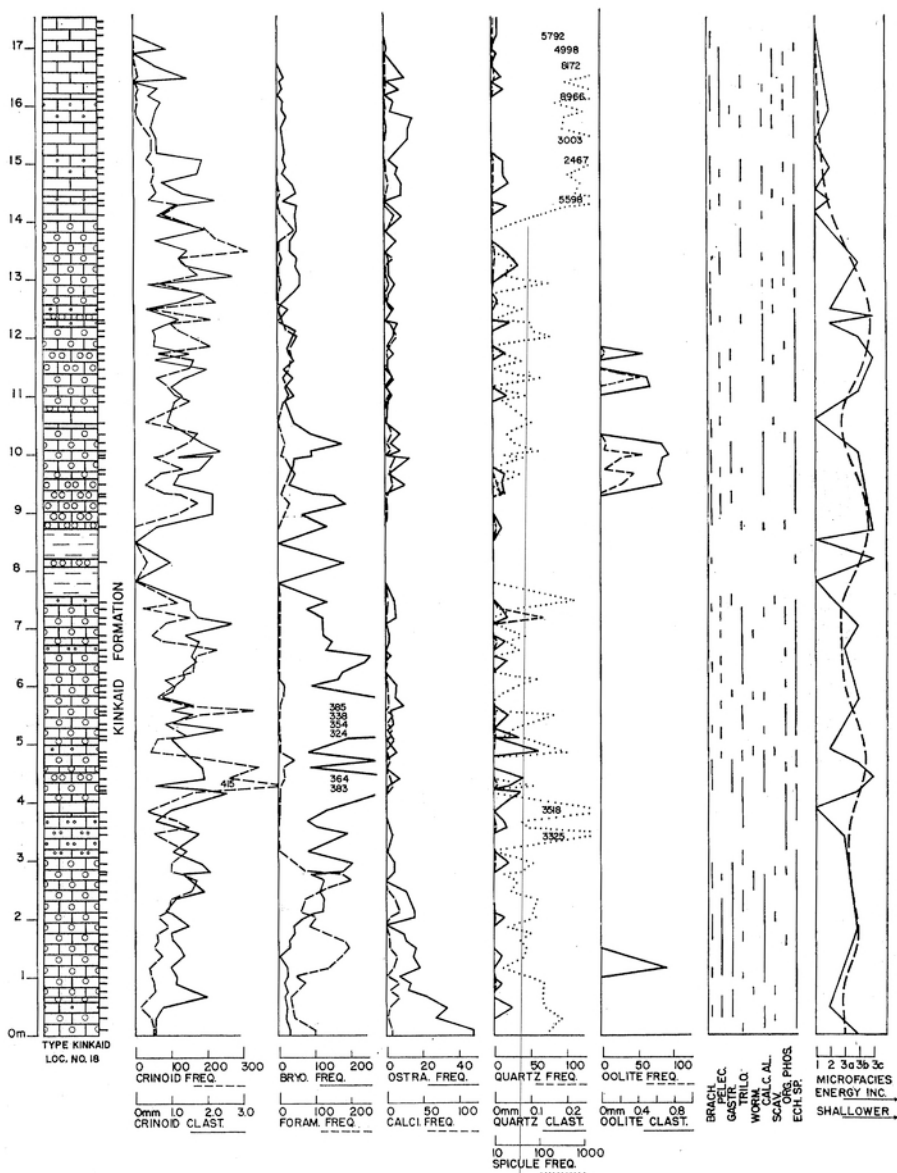


FIGURE 11.—Type Kinkaid, Locality No. 18

CONCLUSIONS

The carbonates of the upper half of the Chester Series in the type area of Southwestern Illinois (Glen Dean

Formation to Kinkaid Formation) consist of an association, at times regularly cyclical, of five distinct and environmentally controlled micro-

facies. These range from calcisiltite through mud-supported bioalcalarenite to grain-supported bioalcalarenite with calcisiltite matrix in order of increasing energy level or decreasing relative depth. All these microfacies indicate an environment of general low energy in which moderate winnowing processes were active. In the shallower portions where crinoid and bryozoan colonies thrived, they led to the inflow of transported oolites, the sorting of the crinoid debris and the fragmentation of the delicate bryozoan fronds almost in place. In the deeper portions of the environment where abundant siliceous sponges and scavengers were associated with small crinoid clumps, the winnowing processes concentrated the silt-size detrital quartz and all the small organic components such as arenaceous foraminifers, ostracods and calcispheres originally distributed throughout the environment.

#### ACKNOWLEDGMENTS

The authors are grateful to Dr. D. H. Swann of the Illinois State Geological Survey for his interest in the investigated problem and stimulating discussions.

#### LITERATURE CITED

- BATHURST, R. G. C. 1958. Diagenetic fabrics in some British Dinantian limestones. *Liverpool and Manchester Geological Journal*. 2:11-36.
- CAROZZI, A. V. 1950. Contribution à l'étude des rythmes de sédimentation. *Archives des Sciences, Genève*. 3:17-40, 95-146.
- \_\_\_\_\_. 1958. Micro-mechanisms of sedimentation in the epicontinental environment. *Jour. Sedimentary Petrology*. 28:133-150.
- \_\_\_\_\_. 1961. Reef petrography in the Beaverhill Lake Formation, Upper Devonian, Swan Hills area, Alberta, Canada. *Jour. Sedimentary Petrology*. 31:497-513.
- \_\_\_\_\_. 1964. Complex ooids from Triassic lake deposit, Virginia. *Amer. Jour. Science*. 262:231-241.
- FOLK, R. L. 1965. Some aspects of recrystallization in ancient limestones, in Dolomitization and limestone diagenesis. *Society of Economic Paleontologists and Mineralogists, Tulsa, Special Publication No. 13:14-48.*
- REXROAD, C. B. 1957. Conodonts from the Chester series in the type area of Southwestern Illinois. *Illinois State Geological Survey Report of Investigations 199: 43 pp.*
- SWANN, D. H. 1963. Classification of Genevievian and Chesterian (Late Mississippian) rocks of Illinois. *Illinois State Geological Survey Report of Investigations 216: 91 pp.*
- WALPOLE, R. L. and CAROZZI, A. V. 1961. Microfacies study of Rundle Group (Mississippian) of Front Ranges, Central Alberta, Canada. *Am. Assoc. Petroleum Geologists Bull.* 45:1810-1846.

*Manuscript received July 17, 1967.*