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*entitled* \_\_\_\_\_ Analysis of Crinoid Communities and their \_\_\_\_\_  
Associated Lithofacies within the Fort Payne Formation \_\_\_\_\_  
(Lower Mississippian) in the Vicinity of Burkesville, Kentucky \_\_\_\_\_  
*be accepted as fulfilling this part of the requirements for the degree of* \_\_\_\_\_ Master of Science \_\_\_\_\_

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**ANALYSIS OF CRINOID COMMUNITIES  
AND THEIR ASSOCIATED LITHOFACIES WITHIN THE FORT PAYNE  
FORMATION (LOWER MISSISSIPPIAN) IN THE VICINITY OF  
BURKESVILLE, KENTUCKY (CUMBERLAND COUNTY)**

A thesis submitted to the  
Division of Graduate Studies and Research  
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requirement for the degree of

**MASTER OF SCIENCE**

in the Department of Geological Sciences  
of the College of Arts and Sciences

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by

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## ABSTRACT

Taphonomic and sedimentologic evidence indicates the presence of locally distributed pelmatozoan-dominated deposits within the Fort Payne Formation (Lower Mississippian) of south-central Kentucky. These deposits intercalate with and are enclosed by argillaceous, dolomitic, and bioturbated siltstone which comprises the major lithology of the Fort Payne. All rock types are interpreted as having been deposited in the sediment-starved Illinois Basin by sediment gravity flows that moved down a ramp developed on top of and roughly parallel to the southwest-dipping Borden delta paleoslope. Facies sequences within Fort Payne exposures along State Highway 61 south of Burkesville, Kentucky, are very similar to those found in carbonate debris aprons that have been described and interpreted from Paleozoic rocks elsewhere. These include sheet-like and channelized debris flow deposits in middle slope and inner facies belt positions and turbidites in both inner and outer facies belt positions. Pelmatozoans generally are found as allochthonous accumulations although autochthonous accumulations are common in green shale and also occur on the upper surfaces of carbonate gravity flow deposits.

Previous studies have used binary cluster analysis to define three distinctive crinoid assemblages occurring at several localities within the Illinois Basin. The

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I am indebted to my grandmother, Dee Brock, who helped cultivate my interest in crinoids during many summer vacations spent on Lake Cumberland. She accompanied me in the field on occasion, working as an assistant as well as providing a base camp. Several other people volunteered (or were subtly manipulated) to assist me in the field including fellow students Ken Loos and John Haynes and my mother, Anne Deuschle. Ken Loos gave

more than six weekends of his time in addition to supplying "words of encouragement" throughout the course of the project. Discussions with him and with other students on the sedimentology of the Fort Payne helped in the interpretation of its depositional environment. My appreciation goes to Jim Beaujon too, for many hours spent perfecting computer programs for the cluster analyses.

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## INTRODUCTION

### Thesis Problem and Objectives

Dark-colored, siliceous carbonates and calcareous siltstones of the Fort Payne Formation are interpreted as having been deposited within the sediment-starved Illinois basin at the close of Borden sedimentation (Lineback, 1966, 1969). These basin-fill sediments enclose and intercalate with pelmatozoan-dominated carbonate deposits and associated fine-grained clastic sediments in areas of south-central Kentucky and northern Tennessee. An interpretation of the overall depositional setting for these sediments is complicated, however, by the unusual combination of textures and sedimentary structures they exhibit and by their localized distribution. Furthermore, the lack of a modern analogue for the entire formation compounds the issue (Lewis and Potter, 1978). Despite these problems, however, many recent studies have contributed to a better understanding of the sedimentology of the Fort Payne Formation, including Sedimentation Seminar (1972), Klein (1974), Hannan (1975), Lewis and Potter (1978), Kuslansky (1981), and MacQuown, (1982).

The paleontology of the Fort Payne Formation in south-central Kentucky has not been as thoroughly researched as the sedimentology, in spite of the wealth of information available in its abundance of well-preserved crinoids. Studies of Lower Mississippian crinoid

communities at localities elsewhere in the Illinois basin have demonstrated the existence of three crinoid assemblages, each of which occupied a different environmental setting (Lane, 1972; Ausich, 1978; Ausich, Kammmer, and Lane, 1979; Ausich and Lane, 1985). The recognition of identical crinoid assemblages within the Fort Payne Formation, therefore, would function as a test of these findings and would more precisely define the physical environments that existed in this part of the Illinois basin.

The main objective of this study is to present a more comprehensive interpretation of the paleoenvironment of the Fort Payne Formation in south-central Kentucky by integrating its paleontologic features more thoroughly with its sedimentology. The basis of this study is a stratigraphic column constructed from a series of Fort Payne exposures along State Highway 61 near Burkesville, Kentucky. Additional insight into depositional environment is provided by taphonomy and by cluster analysis of faunal data for all collecting localities.

## Previous Work

Geological mapping in Kentucky was initiated in 1854 and 1855 during the first "Geological Reconnaissance" of the state by the newly formed state survey (Owen, 1856). Rocks of the Fort Payne Formation, however, were not recognized in Kentucky until 1922 with Butts' publication on the Mississippian series of eastern Kentucky. Stockdale (1939) elaborated further on the Fort Payne in his classic volume on the Lower Mississippian stratigraphy of the east central interior of the United States.

Klepser (1937) was the first to note that limestone buildups within the Fort Payne Formation in southern Kentucky resembled bioherms. A later study by Thaden et al. (1961) redefined the buildups as limestone "reefs" on the basis of their detailed geologic mapping of the area. They referred to these reefs as the "Beaver sand" or "Beaver Creek sand" of the Fort Payne (Thaden et al., 1961, p. B-90). Marcher (1963) described crinoidal bioherms in exposures of the Fort Payne Formation along the Caney Fork River in northern Tennessee and noted that they consisted of three facies: core, and inner and outer flanking beds of a bioherm.

Lineback's studies (1966, 1969) of the deltaic structure of the Borden Siltstone indicated that although Fort Payne sediments were deposited on the foreset slopes of the Borden delta, they did not intergrade or intertongue with the preexisting deltaic sediments. Based

on this evidence, he concluded that the impure, siliceous sediments of the Fort Payne were deposited in deep water marginal to the delta, after cessation of deltaic sedimentation (Fig. 1).

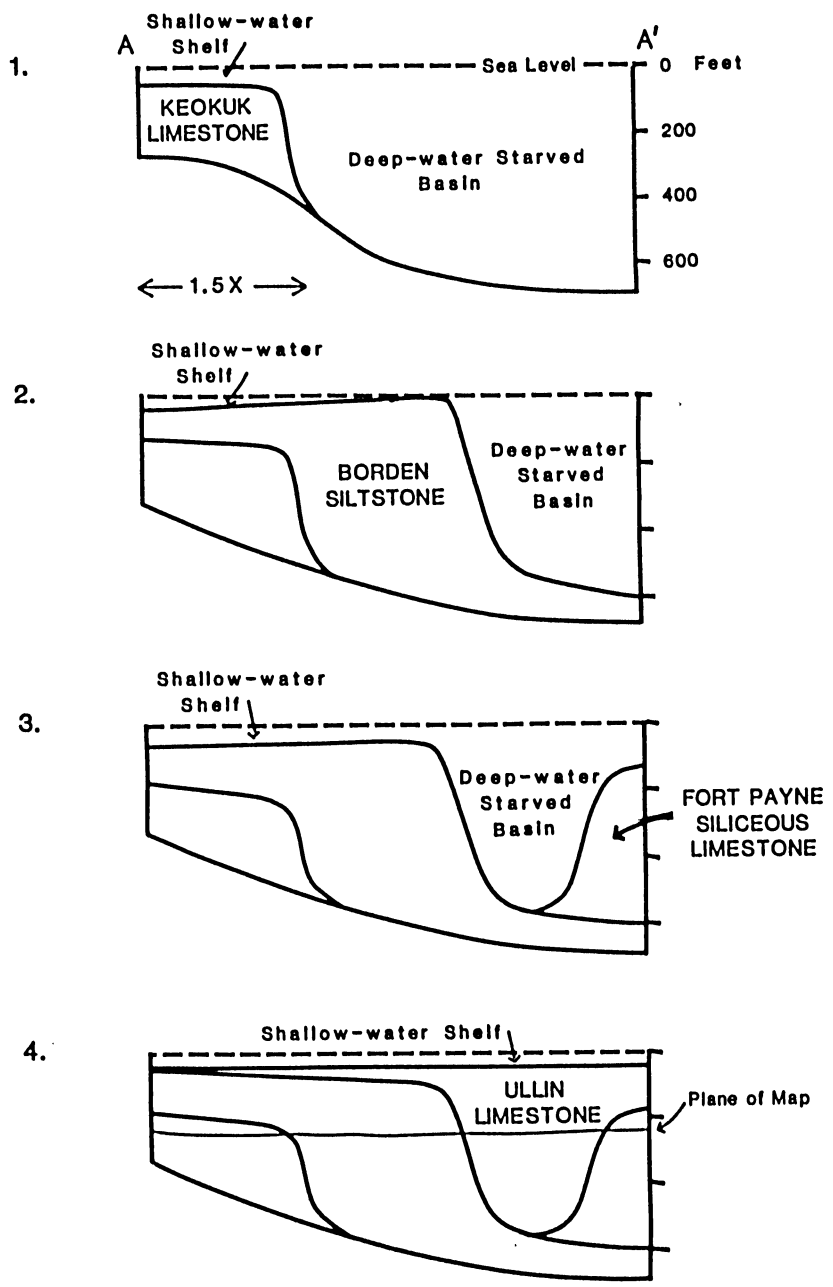
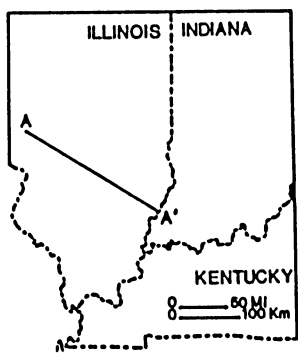
Peterson and Kepferle (1970) noted the presence of a thin, widespread glauconitic zone, the Floyds Knob Member, in central Kentucky, marking the transition from the carbonate-poor Borden Formation to the stratigraphically equivalent, carbonate-rich Fort Payne Formation to the southwest. This zone preserves an ancient deltaic front, referred to by members of the Sedimentation Seminar (p. 2, 1972) as the 'Borden front'.

The Sedimentation Seminar (1972) described and interpreted the Knifley Sandstone and the Cane Valley Limestone, two members of the Fort Payne in central Kentucky, as shallow marine sediments deposited along the Borden front. The Knifley was interpreted as having been deposited as a coastal barrier bar and the Cane Valley as linear shoals along the shelf break of a carbonate platform. Kepferle and Lewis (1974) described a third member of the Fort Payne, the New Providence Shale, and noted it to be continuous with the basal New Providence Shale Member of the Borden Formation. This shale represents the distal edge of the wedge of terrigenous clastics of the Borden Formation (Kepferle, 1971).

Klein (1974) discussed the stratigraphic and petrologic characteristics of the Beaver Creek Limestone

Figure 1. Depositional events leading to the development of a wedge-on-wedge relation between the Borden Formation and the Fort Payne Formation in central Illinois (adapted from Lineback, 1969).

1. End of deposition of Burlington and Keokuk Limestones in western Illinois. These carbonates were deposited in shallow water on the shelf at the northern and western margins while a deep-water sediment starved basin developed in southern Illinois. Carbonate deposition ceased as sediment spread west from the Borden delta in central Illinois.
2. End of deposition of Borden Siltstone. A 6 mile (9.7 km) wide foreset slope up to 1000 feet (305 m) high separated the shelf from the starved basin in southeastern Illinois.
3. End of deposition of Fort Payne Formation. Deep-water areas were not entirely filled by the siliceous sediments of the Fort Payne Formation.
4. Remaining deep-water areas are filled at end of deposition of Ullin Limestone.
5. Deposition of Salem Limestone.



Member of the Fort Payne and interpreted it as sediment gravity flow deposits located downslope from a prograding carbonate platform (Fig. 2). Hannan's (1975) study analyzed the petrographic characteristics of the adjacent dolosiltstones within the same field area.

Lewis and Potter (1978) recognized that the complex facies relationships of the Fort Payne in central Kentucky did not appear to be analogous with any found in modern carbonate environments. They described two carbonate bank facies, both of which are closely associated with fossiliferous green shale: mudstone mounds, composed chiefly of mudstone and/or wackestone; and crinoidal-bryozoan skeletal limestones (p. 8-9). They suggest the Lower Carboniferous or Lower Mississippian Waulsortian facies of western Europe and North America as the best ancient equivalents for the Fort Payne Formation and propose a depositional model identical to that of Gutschick et al. (1976) for the Mississippian Lodgepole Limestone of west-central Montana.

Leiber (1978) described and interpreted a cherty dolomitic unit and a fossiliferous carbonate unit in the subsurface Fort Payne in northern Tennessee. His reconstruction of the Fort Payne includes the colonization of topographic lows on the sea floor by bryozoans and crinoids, which acted as bafflers trapping carbonate mud.

Kepferle et al. (1980) formally recognized and named a fourth member of the Fort Payne, the Jabez Sandstone.

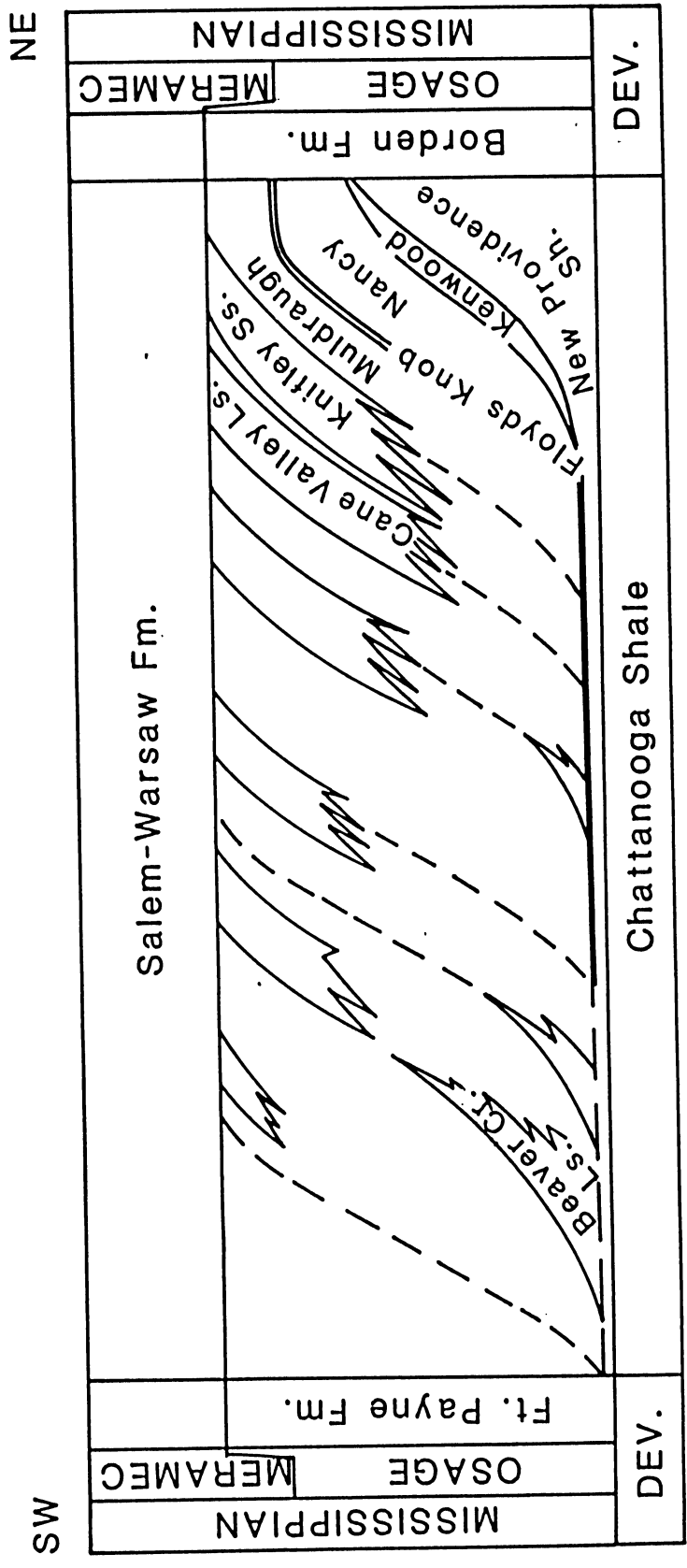


Figure 2. Klein's interpretation of the Cane Valley and Beaver Creek sediment gravity flow deposits (1974, Fig. 4).

Its location on the paleoslope and its sedimentary structures led them to interpret it as having been deposited by a turbidity current.

Kuslansky (1981), MacQuown (1982), MacQuown and Perkins (1982), and Kuslansky and Friedman (1984) all employed the Waulsortian model for their respective interpretations of the Fort Payne Formation in the subsurface of northern Tennessee. Kuslansky (1981) identified the enclosing beds, as well as the core, and inner and outer flanking beds of a Waulsortian mound. MacQuown's (1982) interpretation described the origin of carbonate bodies within the Fort Payne as Waulsortian buildups in intermediate to shallow water environments. He also summarized the similarities and differences between Waulsortian facies, mounds, and lenses occurring in Tennessee versus those in Europe. MacQuown and Perkins (p. 1057, 1982) further stated that the Tennessee mounds were deposited on seafloor 'highs' by a transgressing shelf sea. Kuslansky and Friedman (1984) elaborated on the sedimentological processes that led to the evolution of porosity and reservoir characteristics within the Waulsortian facies of Tennessee.

Gutschick and Sandberg (p. 91, 1983) refer to the depositional site of the Fort Payne Formation as the "Fort Payne Ramp" and place its northernmost edge at approximately the Kentucky-Tennessee boundary. Their interpretation derives from that of MacQuown and Perkins

(1982) wherein Waulsortian-type mounds formed on a shallow slowly subsiding ramp during a eustatic rise of sea-level. Troughward progradation of the Fort Payne mounds ultimately resulted in the formation of banks.

## Localities

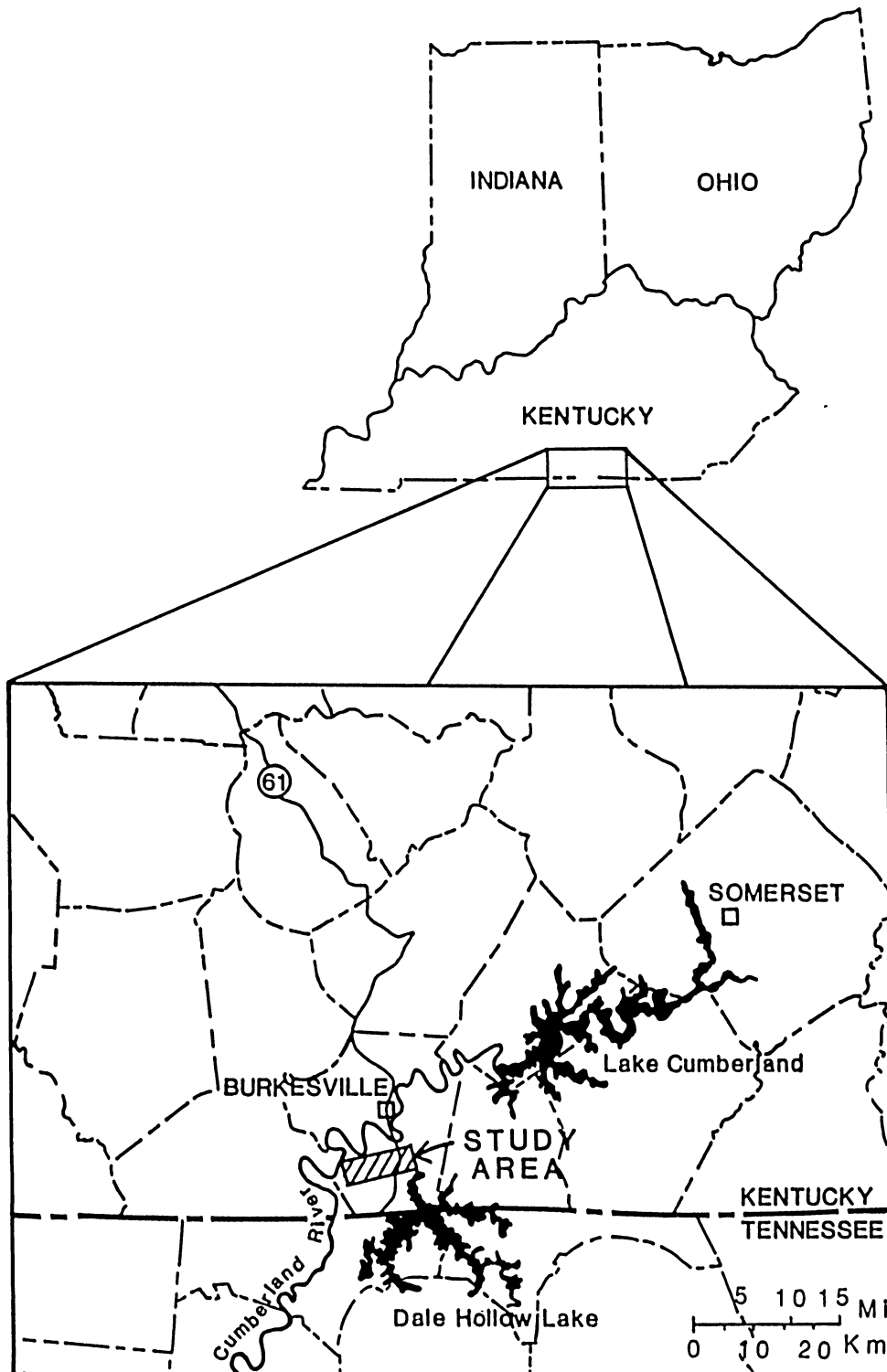
Stratigraphic study of the carbonates of the Fort Payne Formation in south-central Kentucky is considerably hampered by the uneven topography. Roads generally go around rather than through resistant bodies of rock and those that do crop out are extremely weathered and overgrown. The recent rerouting of Kentucky State Highway 61, however, created a relatively continuous series of fresh geologic exposures, 4.6 miles (7.4 km) south of Burkesville, Cumberland County, Kentucky (Froque 7 1/2 minute quadrangle) (Fig. 3). As the highway crosses the Cumberland River and begins its climb out of the river valley, its cuts reveal excellent geologic exposures from the Upper Ordovician up through the Upper Mississippian. Incomplete sections of the Ordovician Cumberland Formation and the Mississippian Salem-Warsaw Limestone, and essentially complete sections of the Devonian Chattanooga Shale and Fort Payne Formation as well, are all exposed here.

## Methods

### Field:

I constructed a vertical section of the Fort Payne Formation based on descriptions of four outcrops found on the east side of State Highway 61 (Fig. 4). Both lower and upper contacts with the Chattanooga Shale and Salem-Warsaw

Figure 3. Location of the study area south of  
Burkesville, Kentucky. Outcrops used for the  
stratigraphic section are located along State Highway  
61; additional collecting sites are found on 61 and  
to the west.



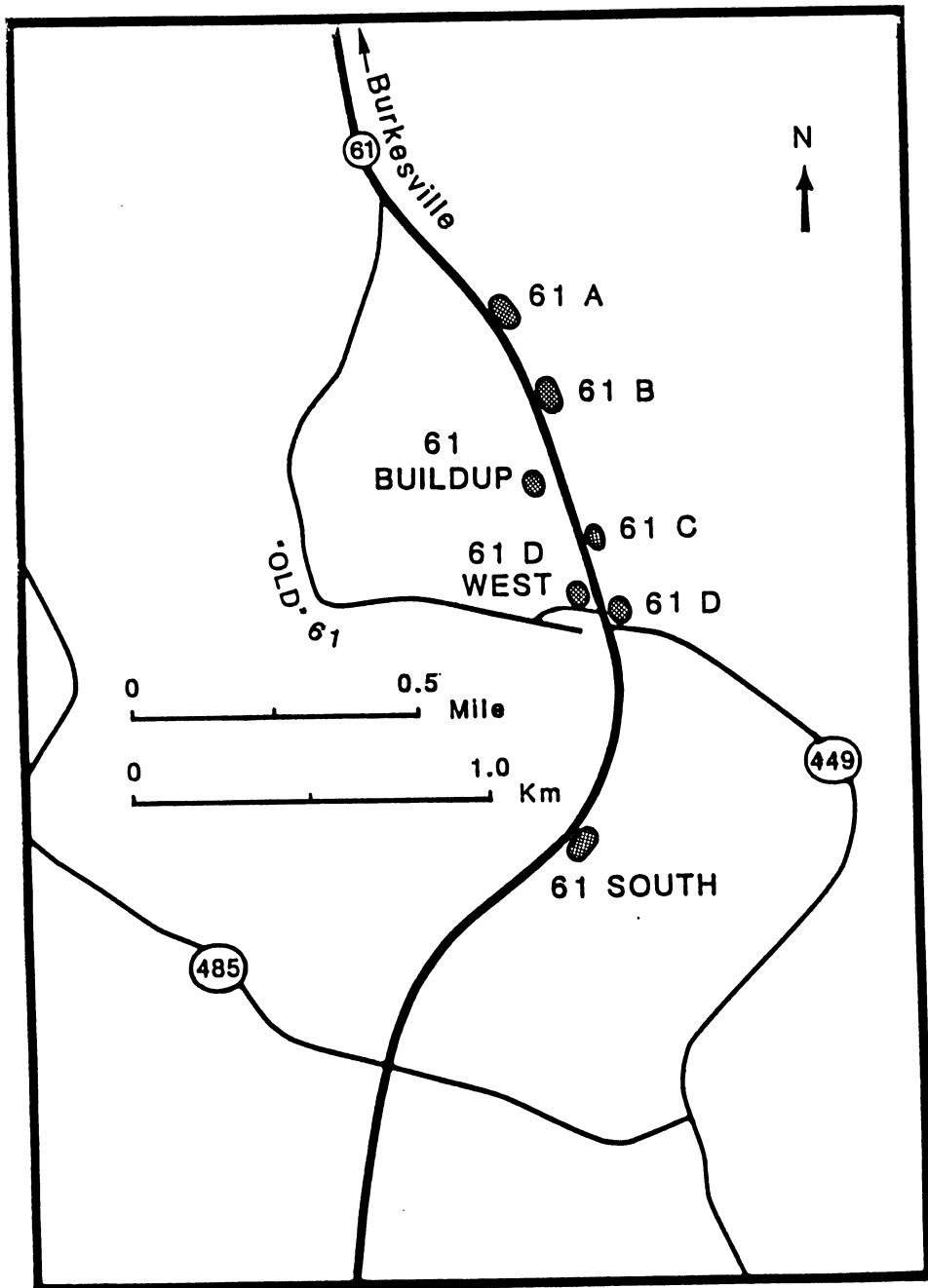


Figure 4. Localities used for the stratigraphic section include 61 A, 61 B, 61 C and 61 D. Additional collecting localities are the 61 Buildup, "Old" 61, 61 D West and 61 South. Burkeville is 4.6 miles (7.4 km) north of the intersection of 61 with the old 61 route.

Limestone respectively, are exposed within this series. I correlated the four separate outcrops, named A, B, C, and D from the base to the top of the section, by sighting from one outcrop to the next using a Brunton compass and a Jacob's staff. These measurements include a 1.5 to 2 degree correction for regional dip. In general, bedding planes could not be used as equivalent stratigraphic horizons across outcrop faces because of the lateral extent of individual outcrops and the tendency for beds to be discordant with regional dip. I also described a massive carbonate body located on the west side of the road between units B and C and correlated it with the measured section using the same sighting methods.

In describing the vertical section I noted lithology, bedding thickness and type, sedimentary structures, grain size and degree of sorting, and paleontology. I collected rock samples at changes in lithology for petrographic study and made a total of 57 thin sections. These were used not only to corroborate field descriptions but also to determine the nature of the matrix material and the identity of fine-grained allochems that could not be seen in hand samples. I also used the thin sections to determine the size ranges of grains, and to estimate what degree of sorting and abrasion had occurred, all of which are clues to the taphonomy.

With regard to paleontologic data, I collected representative fossils, crinoids in particular, throughout

the section and recorded their manner of preservation. These I identified to generic level and if possible, to species. In addition, wherever I found crinoid columnals in abundance I recorded their maximum lengths and diameters.

I augmented the fossils collected from the State Highway 61 exposures with additional specimens collected from three other localities. I did not construct stratigraphic columns for these localities, however, because they were either inaccessible or poorly exposed. The first of these is located along the bypassed section of State Highway 61 and is referred to accordingly as "Old 61". Fossils collected from this rugged exposure were found at the base of vertical rock faces and were labeled, therefore, as float. The turnoff for this road is on the west side of State Highway 61 approximately 4.2 miles south of Burkesville (Fig. 4). The second collecting locality is a shale bedding plane on the east shoulder of County Road 1424, 1.6 miles (2.6 km) north from where it intersects with State Road 953 near Hickory Grove, Kentucky (Fig. 5). It was named and described initially by Klein (1974) as BF 9 (Blacks Ferry 7 1/2 minute quadrangle) and for convenience her usage has been retained here. I measured BF 9 to be 16.9 meters above the Chattanooga Shale using a Brunton and Jacob's staff (the lower contact is exposed in the woods across the road and down the hill). The third collecting locality is on

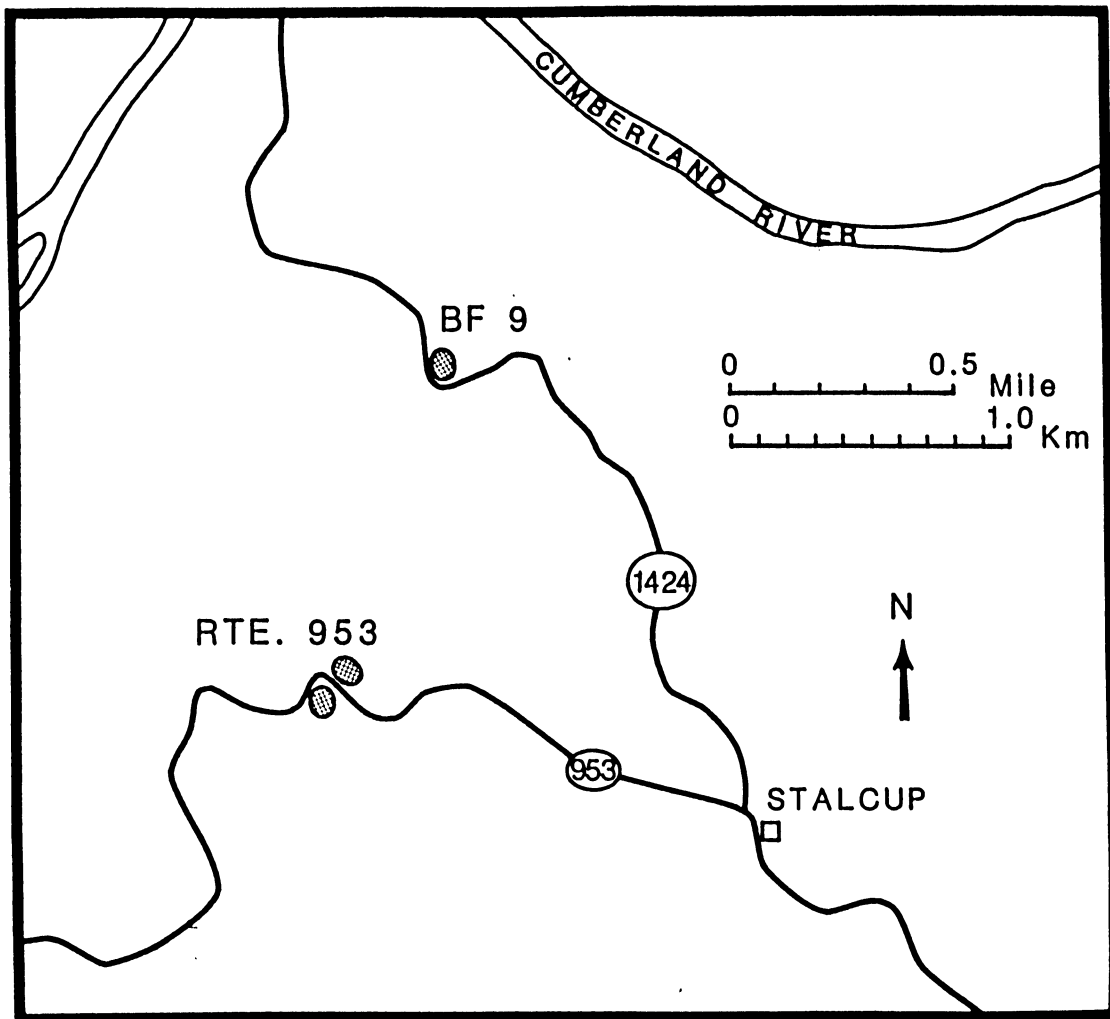


Figure 5. Location of the BF 9 and Route 953 collecting sites (Blacks Ferry Geologic Quadrangle).

State Road 953, 1.1 miles (1.8 km) farther west of its intersection with 1424 (Fig. 5). Although both shoulders of the road here are overgrown they yielded some good crinoid specimens. All of these specimens were collected from float but I estimate the stratigraphic horizon to be approximately 25 meters above the Chattanooga Shale.

#### Laboratory:

The most successful technique for cleaning the fossil specimens consisted of boiling in Quaternary O followed by air abrasive cleaning. Most of the specimens are very well-preserved and silicified and are thus capable of withstanding number 3 or 4 abrasive powder with no damage to fine skeletal details. Because of differences in preservation, however, I found no single cleaning technique to be perfectly suitable for all fossil specimens. For example, a hand-held engraver was necessary to remove more indurated sediment that adhered to some of the specimens, whereas others required no more than a slight blast of air abrasive.

#### Statistical:

I compared the crinoids that were collected in the course of the study with faunal lists from other Osagean localities to determine an age for the fauna. Such a list is found in a cluster analysis of known Mississippian genera that are restricted to the Osagean (Ausich, 1978). I also used cluster analysis to determine the degree of

similarity between the fossil assemblages at each of the localities that I collected in my study area.

### Cluster Analysis

The technique most frequently used in studies of ancient communities is the concept of recurring suites of abundant taxa, usually called biofacies or associations (Scott and West, 1976). This is accomplished by grouping objects (e.g. taxa) together on the basis of shared character states (e.g. occurrences) over several characters (e.g. localities). This ratio may be expressed quantitatively as a coefficient of similarity.

The computation of the coefficient of similarity begins with the organization of paleontological data as in Table 1. Although several different character states (e.g. abundance) may be coded for in this approach, here I am concerned only with the presence or absence of an individual species at each collecting site. Next a matrix containing values for the similarity or resemblance of each item with itself and with all other items is constructed. These values are ratios that express the actual (numerator) out of all potential (denominator) matches. The particular measure of similarity that I used, known as the coefficient of Jaccard, excludes negative matches from being considered as a measure of resemblance between characters. This exclusion is necessary because the absence of a particular species from a collecting locality does not necessarily imply that it

FAUNAL SAMPLES	PELMATOZOAN GENERA	
61 A	Abatorcinus	●
61 B	Actinocrinites	●
61 Buildup	Adinocrinus nodosus	●
61 C	Agaricocrinus	●
61 D	Alloprosallocrinus concius	●
61 D West-top	Barycrinus sp. 1	●
61 D West-mid	Barycrinus sp. 2	●
61 D West-low	Barycrinus cornutus	●
61 South	Barycrinus holdfasts, stems	●
Old 61	Catillocrinus	●
BF 9	Cyathocrinites sp. 1	●
Rte. 953	Cyathocrinites sp. 2	●
	Cyathocrinites sp. 3	●
	Cyathocrinites sp. 4	●
	Cyathocrinites asperimus	●
	Cyathocrinites sp. 6	●
	Dentiblastus	●
	Dichocrinus	●
	Dizygoocrinus	●
	Dorycrinus	●
	Eretmocrinus	●
	Gaulocrinus	●
	Gilbertsocrinus	●
	Granatocrinus	●
	Hadroblastus	●
	Halysioocrinus tunicatus	●
	Macrocrinus	●
	Mespilocrinus	●
	Metichthyocrinus	●
	Onychocrinus	●
	Platycrinites hemisphericus	●
	Synbathocrinus	●
	Uperocrinus	●
	Xenoblastus	●
	New Blastoid Genus A.	●

Table 1. Distribution of pelmatozoan genera within the study area.

is not a member of that ecological association. Rather, its absence may be a natural feature of sampling that should not be regarded as sampling error. Sokal and Sneath (1963) suggest that the absence of a species should be thought of as a reflection of the varying probabilities of occurrence for a particular species within any given assemblage.

Once the similarity values have been calculated, one of several different clustering strategies may be applied. These analyze the patterns of similarity among the characters, in this case collecting sites and species, and then construct a hierarchical classification based on these patterns (Abbott, Bisby, and Rogers; 1985). Most commonly, these patterns are visually illustrated as dendrograms. Differences between clustering strategies are based on the manner in which clusters are linked. Single linkage, according to Sokal and Sneath (1963), links those clusters (each variable initially being considered as a single cluster) with the highest possible similarity coefficient. It allows more members into the cluster by "lowering the criteria of admission", which are those characters with successively lower similarity coefficients (Sokal and Sneath, 1963, p. 180). The problem with this method is that clusters may join on the basis of a single bond between one variable in each cluster even if many or all of the other variables are quite unrelated (Sokal and Sneath, 1963). Average

linkage, on the other hand, links clusters on the basis of the average measure of similarity of all variables within the cluster. The advantage of this method lies in the continual recalculation of the value of the average similarity coefficient for each cluster as it grows (Sokal and Sneath, 1963). The authors found that the average linkage method more effectively distinguishes differences in similarity coefficients (Sokal and Sneath, 1963). Horowitz et al. (1979) note that clusters can be tested to determine their level of confidence, however, such tests are applicable only where single or complete linkage strategies have been employed and the associations have not been averaged.

## Geologic Setting

The siliceous and argillaceous carbonate sediments of the Fort Payne Formation were deposited in the Eastern Interior or Illinois basin during Osage time. This shallow marine basin existed during much of Mississippian time, covering broad areas of Illinois, Indiana, and Kentucky, and smaller areas of Missouri and Tennessee (Sable, 1979). Rocks of the south-central Kentucky study area were deposited at the southern margin of the basin, in a structurally negative area of the Cincinnati arch called the Cumberland saddle (Lewis and Potter, 1978) (Fig. 6). This saddle is bounded by two structurally positive areas to the northeast and the southwest, the Jessamine and Nashville domes respectively. During most if not all of Mississippian time, the Cumberland saddle served as a connection across the axis of the Cincinnati arch to the western margin of the Appalachian basin (Pryor and Sable, 1974).

Rocks at the northern margin of the basin, however, do not grade laterally into the Fort Payne Formation, and exhibit differences in both composition and bedding as well. Known as the Borden Formation in Kentucky and the Borden Group in Indiana, these fine-grained siltstones and sandstones were deposited as a series of delta complexes which prograded into the basin for much of Early and Middle Mississippian time. Their deltaic nature was demonstrated by Lineback (1966), who traced a series of

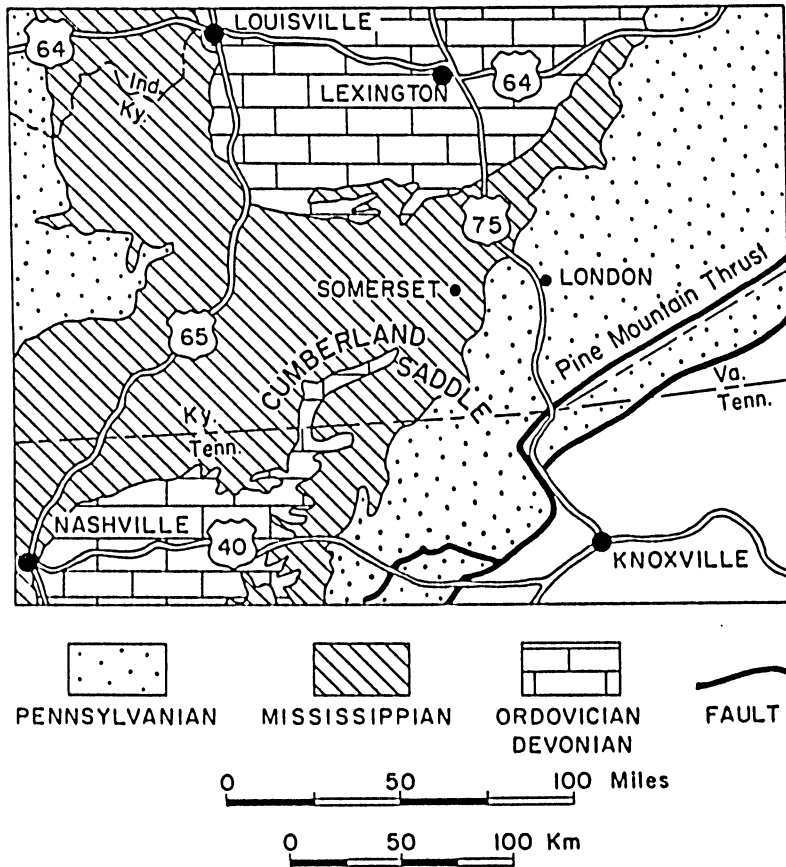


Figure 6. The Cumberland Saddle area of south-central Kentucky (Lewis and Potter, 1978, Fig. 1).

southwesterly-dipping beds down through the top-set, fore-set, and bottom-set portions of a prograding delta sequence. The Borden is considered to be the third and final of a series of westward-prograding Michigan River delta complexes, beginning with the Devonian Catskill delta and followed by the Lower Mississippian Bedford-Berea delta in Ohio (Pepper et al., 1954).

Where the Borden and Fort Payne Formations are adjacent to one another, an abrupt transition from siltstone and sandstone to impure argillaceous carbonate is apparent as a sharp facies change. This zone, called the "Borden Front", is further delineated by a thin, continuous glauconitic zone known as the Floyds Knob bed of the Borden Formation (Sedimentation Seminar, 1972). The Fort Payne thus forms an offlapping relationship with the deltaic deposits of the Borden; where the Borden starts to thin southward, the Fort Payne exhibits a corresponding thickening (Figure 7).

Source areas for the detrital components of the Fort Payne in the study area are suggested to be similar to those of the adjacent Borden Formation (Sable, 1979). These were identified by Potter and Pryor (1961) as being Late and Middle Precambrian sediments and crystalline rocks of the Canadian Shield, and relatively immature Lower Paleozoic clastics and some crystalline rocks from areas east and north of the Appalachian basin. Pryor and Sable (1974) suggest the possibility of an additional

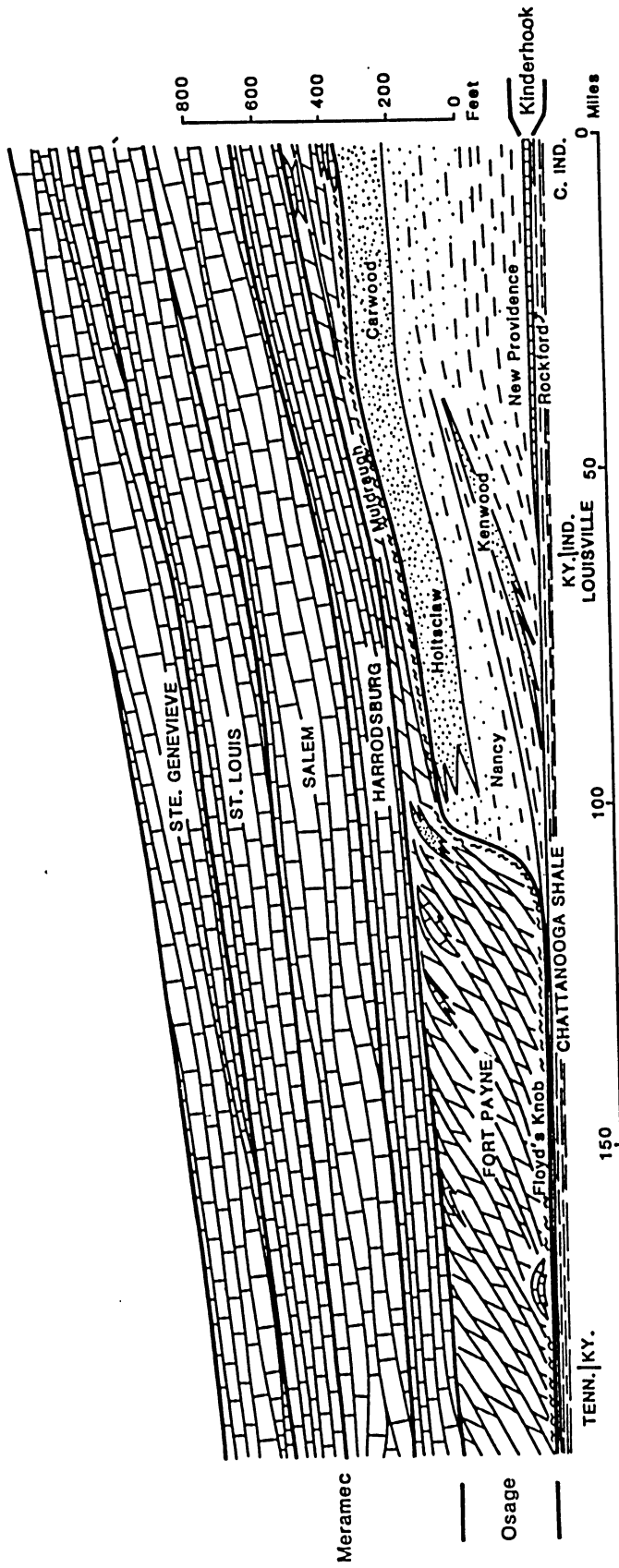


Figure 7. Regional cross section of Kinderhook, Osage, and Meramec Series rocks from southern Indiana to south-central Kentucky (adapted from Pryor and Sable, 1974, Fig. 6).

southeasterly source as well via a connection between the deeper southerly part of the Eastern Interior basin and the Ouachita Trough.

The bedded and massive argillaceous carbonates of the Fort Payne Formation probably were deposited following a marked decline in the amount of terrigenous influx to the Borden delta (Sedimentation Seminar, 1972). The carbonates are considered to be organically derived, representing both the in situ production and accumulation of skeletal material in front of and down dip from the deltaic sediments of the Borden Formation (Sedimentation Seminar, 1972). Depositional dip may have ranged from 0.5 to 1 degree to as great as 4 to 7 degrees (Sedimentation Seminar, 1972, p. 20).

A widespread marine transgression occurred during the Late Mississippian, resulting in the establishment of shallow marine communities over the topography of the Fort Payne and Borden Formations. In the study area, the only rocks that have remained to preserve this late stage in the history of the Eastern Interior basin are those of the Salem and Warsaw Formations.

## Stratigraphy of the Fort Payne Formation

### History of Stratigraphic Nomenclature

Studies of the type Fort Payne Formation or Chert were begun in the late 1800s by the Alabama and Tennessee geological surveys. The name "Fort Payne Chert" was used first in 1890 by Eugene Smith, then Alabama state geologist, for the lower "Siliceous" member of the Sub-carboniferous rocks in a region of Alabama and Tennessee called the 'Barrens' because of its poor, siliceous soil (Smith, 1890, p. 155). Whereas cherty limestone constituted the lower Subcarboniferous, the upper or "Calcareous" member, formed rich soil that made excellent farm land (p. 155). Smith named this member the Mountain Limestone (after similar Subcarboniferous rocks in Europe) and described it as a limestone with interbedded sandstones and shales.

In a subsequent report on the geology of northeastern Alabama and adjacent portions of Tennessee and Georgia, Hayes (1892) described the base of the Fort Payne as composed of massive beds of chert that become less massive and are replaced, more or less, by abundant isolated nodules higher in the formation. He also noted that the lower beds contained few fossils but higher up, they were very abundant such that "the rock frequently consists of a mass of crinoid stems imbedded in a siliceous cement" (1892, p. 46).

In 1922, Butts described the Fort Payne Formation from surface exposures in southern Kentucky and north-central Tennessee, noting that it exhibited a variety of lithologies, similar to those of the type section in Alabama. He described the dominant lithology as shale but emphasized that it commonly changed to limestone within very short lateral distances. Butts in turn subdivided the limestones into two types: one was thick-bedded, coarse-grained, light- or bluish-gray, and highly crinoidal; the second was medium-bedded, fine-grained, bluish-gray and unfossiliferous. He also described a small lenticular body of cavernous thick limestone occurring in southern Kentucky, which was known locally as the Beaver Creek (Butts, 1922). He concluded that the type Fort Payne in Alabama was much chertier than what was exposed in Kentucky and Tennessee, although they were indeed stratigraphic equivalents (Butts, 1922).

The Beaver Creek "sand" was first described by MacLachlan (1928) as part of the New Providence Shale in Wayne, Pulaski, and Russell counties Kentucky. Although these rocks were actually limestones, early drillers referred to them as a "sand" because of their drilling character. MacLachlan described the Beaver Creek lithology as a 'massive, uneven-bedded, very hard, siliceous, pinkish gray ls. containing irregular masses of chert, and 5 to 10 ft. thick, occurring 40 to 45 ft. above the base of the New Providence sh.' Later, however,

Stockdale (1931b) changed the name New Providence to Borden, thereby making the Beaver Creek a member of the Borden of Indiana.<sup>1</sup>

Stockdale's (1939) classic work on Lower Mississippian rocks of the east central interior corrected additional stratigraphic inaccuracies from previous works. He attributed these mistakes to geologists' confusion over the locally variable upper and lower contacts of the Fort Payne. Stockdale concurred with other workers of his time in restricting the term, Fort Payne Formation, to "characteristically cherty strata between the Chattanooga shale (or Maury or New Providence, if present) and the so-called 'Warsaw formation'" (Stockdale, 1939, p. 53).

In his discussion of the Fort Payne Formation, Stockdale (1939) recognized two principal facies also described initially by Klepser (1937). These were the Greasy Creek or northern facies, named from Greasy Creek in Russell County, Kentucky; and the Short Mountain or southern facies, named from Short Mountain in Cannon County, Tennessee. The Greasy Creek facies was characterized by calcareous, massive, gray, siltstone, with many small geodes, abrupt facies changes, and a broad range in lithologic composition, from silty shale to

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<sup>1</sup>Stockdale noted that the town of New Providence had changed its name to Borden, requiring that the like-named lithology be renamed as well. He also remarked that the name probably should never have been assigned in the first place anyway because the town was actually higher than the top of the formation (Stockdale, 1931b).

siltstone to crinoidal limestone (Klepser, 1937, in Stockdale, 1939). Stockdale (1939) attributed these abrupt facies changes to the presence of limestone bioherms enclosed within the shales and siltstones. Although the name Greasy Creek facies is no longer in use, it probably corresponds to the dominant lithology of the Fort Payne in Kentucky, which are the dolosiltstones. These are the so-called "typical" Fort Payne lithology.

Strata of the Short Mountain facies, on the other hand, are made up of 'silty, siliceous limestones, yielding much chert upon weathering' (Stockdale, 1939, p. 54). This facies apparently is restricted to Tennessee and bears a closer resemblance to the cherty strata of the type section in Alabama.

Stockdale (1939, p. 49) also discussed a classification proposed by Klepser in 1937, which documented the Beaver Creek oil 'sand' member of the Forbush Creek Facies of the New Providence Formation in southern Kentucky and Tennessee. Klepser had recognized the New Providence as representing the 'feather-edge' of the formation of the same name in Indiana; he described the phase of the New Providence that occurred in Kentucky as the 'Forbush Creek Facies,' noting that it contained the 'Beaver Creek member' (Stockdale, 1939, p. 51). The New Providence Shale member of the Borden Formation was later recognized as correlative with an identical lithologic unit at the base of the Fort Payne Formation by

Kepferle and Lewis (1974). Several years later, the Beaver Creek 'sand' was again described in Kentucky (Thaden et al., 1961). The authors interpreted the limestone bodies "reefs", noting that they occupied any position within the Fort Payne but possibly were more numerous at the base (Thaden et al., 1961). They equated them with bioherms found on top of the Floyds Knob formation in Indiana by Stockdale (1931a).

The so-called Beaver Creek limestone bodies, therefore, presently are known from the Edwardsville Formation of the Borden Group in Indiana (Ausich, 1978) and the dolosiltstones of the Fort Payne Formation in Kentucky and Tennessee. The Beaver Creek Member occurs within the dolosiltstones above the New Providence Member of the Fort Payne Formation.

Kepferle and Lewis (1974) and the Sedimentation Seminar (1972) mapped and described two limestone bodies and a sandstone body found in the upper part of the Fort Payne near its boundary with the Borden Formation. They interpreted the two units, known respectively as the Cane Valley Limestone and Knifley Sandstone Members, as having developed in response to a shoaling sea. Perhaps the Cane Valley limestone bodies correlate with the Beaver Creek limestone bodies originally described by Klepser (1937).

Klein (1974) studied other limestone bodies in addition to the two studied by the Sedimentation Seminar (1972). She found that the bodies to the northeast were

stratigraphically higher than those to the southwest; she referred to the northeastern bodies as the Cane Valley Limestone Member, and the southwestern bodies as the Beaver Creek Limestone Member.

### Lithologic Character

Dolosiltstone or dolosiltite, is the characteristic lithology of the Fort Payne Formation in south-central Kentucky; as such this lithology is often referred to as the "typical" Fort Payne. Discrete bodies of limestone, sandstone, and shale intercalate with and are enclosed within the dolosiltstone. These lithologies have been formally designated as members of the Fort Payne Formation in Kentucky, and are called the Cane Valley Limestone, the Jabez Sandstone, the Knifley Sandstone, and the New Providence Shale Members. Figure 8 illustrates the stratigraphic positions of these formal lithologic units within the Fort Payne Formation and their relationship to the stratigraphically equivalent but older Borden Formation to the northeast.

The Fort Payne dolosiltstones, and the New Providence Shale, are the only facies of the Fort Payne that are continuous with identical facies of the Borden Formation. The Muldraugh Member of the Borden Formation, an argillaceous, dolomitic unit, intercalates with and grades into the dolosiltstone of the Fort Payne. The dolosiltstones of the Fort Payne and the Borden are in

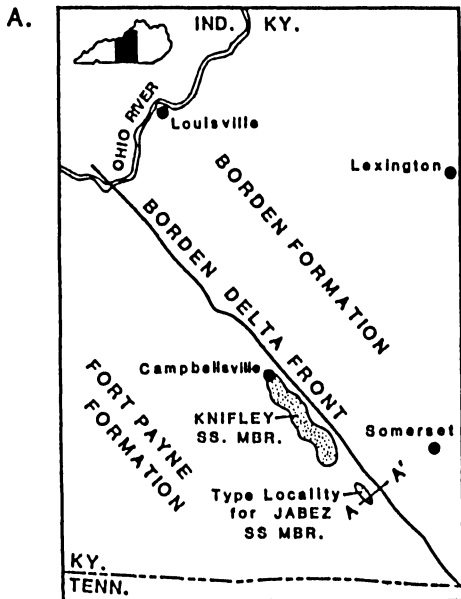
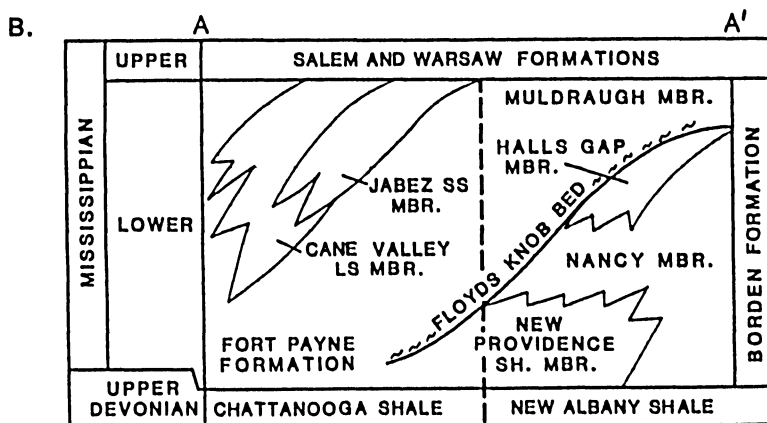
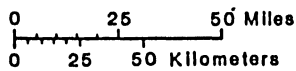


Figure 8. Stratigraphic relationships between the Fort Payne Formation and the Borden Formation across the Borden Delta Front. A. Index map of south-central Kentucky showing outcrop of the Jabez and Knifley Sandstones of the Fort Payne Formation and their position in relation to the Borden Delta Front. B. Diagrammatic cross section of line A-A' across the type locality of the Jabez Sandstone illustrating stratigraphic relationships and nomenclature (adapted from Kepferle et al, 1980, Figs. 4 and 5).



turn underlain by the New Providence Shale, a lithologic unit that is likewise continuous between both formations.

#### Distribution and Thickness

The Fort Payne Formation or Chert crops out in surface exposures in several states including Alabama, Illinois<sup>2</sup>, Georgia, Kentucky, Mississippi, Tennessee, and Virginia . For the most part, the lithology is extremely resistant to weathering, forming ridges and often supporting overlying formations. In addition, it has lithologic correlatives in the subsurface of several states, including Missouri and Arkansas. Its thickness is variable, from 49 meters at the type locality in Alabama (Swanson et al., 1981) to 186 meters at its northernmost extent in southern Illinois (Lineback, 1966).

The stratigraphic section that I measured is approximately 96 meters or 315 feet thick, although locally the Fort Payne Formation varies in thickness from 190 to 330 feet (Lewis, 1967; Van Horn and Griffitts, 1969). Some authors have attributed the variations in thickness to variations in the thickness of the underlying Chattanooga Shale. Hannan (1975) and Kuslansky (1981) suggest thickening above structural lows whereas Kuslansky (1981), and Kuslansky and Friedman (1984) suggest thickening above structural highs. The presence of

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<sup>2</sup>It generally is found in the subsurface of Illinois, however, faulting associated with Hicks Dome has caused it to be exposed at the surface in southern Illinois (Lineback, 1966).

limestone "reefs" within the Fort Payne, on the other hand, is reported to have no effect on the total thickness of the formation in the study area (Lewis, 1967; Van Horn and Griffiths, 1969).

#### Type of Contacts

In the study area, the Fort Payne Formation is overlain by the Salem and Warsaw Limestones and the contact varies from gradational to abrupt. Where carbonates occur at the top of the Fort Payne, they grade into the overlying limestones. This type of contact is marked by a gradual change from planar- to wavy-bedded, argillaceous packstones to well-washed, cross-bedded, and oolitic grainstones within a 1 to 2 meter thick interval. The contact is abrupt, however, where Salem-Warsaw Limestones overlie clastic sediments of the Fort Payne. Here the lithologic change from dolosiltstone to cross-bedded grainstone is very pronounced in appearance.

The contact with the underlying New Providence Shale and the Floyds Knob Glauconite is evident as a fairly sharp transition from black, well-bedded shales to dark green, bioturbated shales of the New Providence Member of the Fort Payne. The base of the New Providence Shale contains abundant phosphate nodules and its thickness ranges from less than one foot in the study area to nearly one hundred feet to the north. It is abruptly overlain by wavy-and thick-bedded carbonates of the Fort Payne Formation in the study area.

## Sedimentology of the Fort Payne Formation

### New Providence Shale Member

#### Description:

The New Providence Shale Member of the Fort Payne Formation, is a greenish-gray clay shale continuous with the like-named shale member of the Borden Formation. In both formations, the New Providence persists over a wide geographic area, and forms the lowermost lithologic unit (Kepferle and Lewis, 1974). It is underlain by the Chattanooga Shale and is generally overlain by the Floyds Knob glauconitic zone. Its thickness ranges from nearly 100 feet to the northeast, steadily decreasing to less than 1 foot to the southwest where it wedges beneath the argillaceous carbonates of the Fort Payne Formation (Kepferle and Lewis, 1974). The New Providence Shale locally may be absent within the study area.

#### Interpretation:

The clays of the New Providence Shale were deposited as the distal prodeltaic and basinal portions of the Borden delta complex (Lineback, 1966). Deposition of Borden clastics was followed by a period of erosion and/or nondeposition, during which the Floyds Knob bed formed. This interval was thus preserved as an unconformity at the base of the Fort Payne Formation.

### Beaver Creek Limestone Member

#### Description:

Klein (1974) describes the Beaver Creek limestone bodies as "wedge-fan-shaped bodies that occur as a swarm of coarse, poorly-sorted, crinoidal-bryozoan grainstones, packstones, wackestones, and mudstones at the base of the Fort Payne Formation. The bodies are as small as 0.5 miles in diameter and exhibit variable thicknesses, up to 160 feet in their centers, but taper distally and down dip from the Cane Valley limestone bodies (Klein, 1974). Bedding likewise changes from the center to the distal edges of the bodies: beds are thicker, more massive, truncated or wedged and usually have uneven bases in the center as opposed to beds at distal edges (Klein, 1974). Primary dip decreases systematically toward the edges of bodies and their directions radiate out from the centers to the distal edges (Klein, 1974).

Petrographically, Klein (1974, p. 38) describes the Beaver Creek as "clay to gravel-sized, very poorly sorted, disarticulated crinoidal-bryozoan grainstones, packstones, wackestones, and mudstones." Major faunal components are crinoid, bryozoa, and brachiopod fragments with minor amounts of sponges and molluscs whereas the matrix is composed of quartz grains, intraclasts, two types of dolomite rhombs (4 to 60 microns), argillaceous clay and trace amounts of glauconite (Klein, 1974). Cements include sparry calcite and sparry ferroan dolomite (Klein, 1974).

Mudstones generally occur at the base, distal parts, and tops of the Beaver Creek limestone bodies, and also as lenses within the packstones and wackestones (Klein, 1974). Wackestones occur throughout the bodies but like the mudstones are generally more abundant at the base, distal, and top parts of limestone bodies. Packstones occur throughout the bodies and exhibit a variety of compositions and textures. Those at the base contain more clay matrix than dolomite rhomb matrix; those in the center are often graded (fining upward) whereas more distal packstones have no internal organization (Klein, 1974). In general, grainstones are restricted to the thickest, central portions of the bodies, but may be found as thin beds associated with packstones in the distal edges as well (Klein, 1974). The chief cement is sparry calcite and only minor amounts of dolomite rhombs are present (Klein, 1974).

#### Interpretation:

There are two models that attempt to explain the origin of the Beaver Creek Limestone bodies. The first model interprets them as Waulsortian-type bioherms with associated flanking beds (Lewis and Potter, 1978) whereas the second interprets them as sediment gravity flow deposits (Klein, 1974; and Hannan, 1975). The bioherms presumably grew as in situ accumulations of fine-grained carbonate that were stabilized by the baffling action of crinoids and bryozoans. The carbonate sediment in turn

was derived from the physical breakdown of the skeletons of crinoids, bryozoans, and other organisms that colonized the tops of these mounds. Also associated with these are channel fills of cross-bedded, well-washed carbonate sands. According to Lewis and Potter (1978), these skeletal sand banks may form large composite banks, many thousands of feet in length. They modeled their interpretation after that of Gutschick et al. (1976), wherein deposition took place along a basin margin with Waulsortian banks accumulating in shallow water on the slope. The skeletal sands, on the other hand, were deposited as channel fill sediments and in some cases, may have travelled as isolated sand waves (Lewis and Potter, 1978).

Klein (1974) interpreted the Beaver Creek limestone bodies as sediments transported and deposited by three different types of subaqueous gravity flow processes: turbidity currents, grain flows, and debris flows. The source of the carbonate sediment was the shallow water platform to the northeast developed on the clinoform topography of the Borden delta complex. The skeletal debris in this case was transported beyond the slope deposits that constitute the Cane Valley limestone bodies. The end product was fan-shaped deposits in relatively deep water at the base of the slope (Klein, 1974). With time, the carbonate platform and its associated slope deposits prograded to the southwest (Klein, 1974).

## Cane Valley Limestone Member

### Description:

The two limestone bodies of the Cane Valley Limestone share many affinities with the Knifley Sandstone. Both display similarities in geometry and orientation, as well as in their relationships to associated lithologies. The type section is also located in Adair County, Kentucky, and takes its name from the town of the same name (Kepferle and Lewis, 1974). The limestone bodies lie west of and parallel to the Knifley Sandstone, are approximately 30 miles long with an average width of 6 miles, and reach a maximum thickness of 200 feet (Sedimentation Seminar, 1972). The Cane Valley limestone bodies descend stratigraphically in the section westward, just as the Knifley does, ultimately pinching out or grading into the adjacent dolostiltstone (Kepferle and Lewis, 1974).

The dominant lithology of the Cane Valley is grainstone, consisting of well to poorly sorted skeletal grains derived from crinoid and bryozoan debris. Fragments of brachiopods, gastropods, pelecypods, ostracodes, corals, and algae are preserved as well. Bryozoan and crinoid grains range in size from silt to coarse sand, and are usually cemented by sparry calcite, although finely comminuted fossil debris, dolomite, and quartzose sand and silt grains may be present in some beds too (Kepferle and Lewis, 1974). Dolomitic siltstone and

silty, dolomitic shale are commonly interbedded with the limestones (Kepferle and Lewis, 1974). Sedimentary structures are common; coarser skeletal limestones often are crossbedded with foresets dipping to the southwest from 5 to 28 degrees, whereas finer grained limestones are planar and ripple bedded (Sedimentation Seminar, 1972; Kepferle and Lewis, 1974). Measurements also reveal a persistent depositional dip of 4 to 7 degrees to the southwest (Sedimentation Seminar, 1972).

#### Interpretation:

The Cane Valley limestones were deposited whenever the influx of argillaceous sediments decreased or stopped altogether (Sedimentation Seminar, 1972). They are thought to have developed as linear, carbonate shoals in shallow-water at the platform margin and on the slope (Sedimentation Seminar, 1972; Klein, 1974). In addition, dip measurements suggest that some of the bodies might have been deposited as small sand waves that migrated downslope (Sedimentation Seminar, 1972).

#### Knifley Sandstone Member

##### Description:

The Knifley Sandstone Member is a variably thick, northwest-southeast trending prism of sandstone named for exposures near Knifley in Adair County, Kentucky (Kepferle and Lewis, 1974). It is overlain by the Salem and Warsaw Formations but the contact is obscure. At its northeast limit it occurs within the upper part of the Fort Payne

descending lower into the formation toward the southwest, exhibiting a depositional dip of 0.5 degrees (Sedimentation Seminar, 1972). At its southwest terminus it grades into and interfingers with the dolosiltstones. It is 25 miles in length, with its long axis trending parallel to the Borden front, whereas its average width is 6 miles, and its maximum thickness is 250 feet, although it commonly is much thinner (Sedimentation Seminar, 1972).

The Sedimentation Seminar (1972) describes the Knifley as "a very fine-grained to silty, argillaceous and dolomitic subgraywacke." Sedimentary structures include poorly defined horizontal bedding and obscure ripple marks (Sedimentation Seminar, 1972). The absence of conspicuous sedimentary structures is attributed to intensive bioturbation, verifiable in X-radiographs and microscopic study (Sedimentation Seminar, 1972). Preserved fossils include crinoid debris, gastropods, and brachiopods along with the trace fossils Zoophycus and one that resembles Scalarituba (Kepferle and Lewis, 1974).

#### Interpretation:

The Sedimentation Seminar (1972) suggests the origin of the Knifley Sandstone as a submarine, infralittoral barrier system below the zone of intense wave and current action. They based their interpretation on the fine-grained nature of the sands, the clay and silt matrix, and the lack of well-developed cross-bedding.

Jabez Sandstone Member

### Description:

The Jabez Sandstone, a northwest-trending prism of sandstone similar to the Knifley Sandstone, is located in Wayne County, Kentucky near the town of Jabez (Kepferle et al., 1980). The Jabez resembles the Knifley in being overlain by the Salem and Warsaw Formations, and by occurring stratigraphically high in the Fort Payne to the northeast but lower to the southwest where it intercalates with the enclosing dolosiltstones. Its dimensions, somewhat less than those of the Knifley, are 6 miles long, 4 miles wide, and 140 feet thick, whereas its location is 7.5 miles to the southeast of the Knifley (Kepferle et al., 1980). The Jabez differs from the Knifley in being coarser grained and more extensively intercalated with limestone tongues projecting from the Cane Valley Member (Kepferle et al., 1980).

### Interpretation:

The Jabez sandstone body originated in a similar depositional setting as did the Knifley, in an infralittoral barrier bar system (Kepferle et al., 1980). The authors also point out that despite the similarities in their composition, geometry, and location, the Knifley and the Jabez sandstone bodies are distinctly separate bodies.

### Dolosiltstone/Dolosiltite

### Description:

The dolosiltstones that enclose and intercalate with the carbonates and shales are the most commonly occurring rock type in the Fort Payne Formation. In the stratigraphic section that I measured and described, however, dolosiltstones and dolosiltites constitute a much smaller fraction of the rock column because of the enclosed limestones.

In fresh outcrop exposures, the dolosiltstones are dark gray to black, as opposed to weathered surfaces, which more typically are light- to olive-gray. Uniformity in both grain size and composition combined with poorly developed or nonexistent bedding, lends a monotonous appearance to this lithology. Sedimentation Seminar (1972) does note, however, the presence in many large outcrops of "master bedding planes". These conspicuous beds are spaced 5 to 10 feet apart, may extend across (and perhaps between) outcrops, and may display depositional dips of up to 5 degrees to the southwest (p. 4). They also report the destruction of most small-scale bedding structures by either deformation or, more commonly, by extensive bioturbation (Sedimentation Seminar, 1972). Rock surfaces are characterized by spalling, which produces rock chips with rounded surfaces and sharp edges. Silicified geodes and patches of fossil debris may occur interbedded within the dolosiltstones.

A precise term defining the lithologic composition of this rock type is difficult to specify because this rock

may occur as a dolomitic argillaceous siltstone at one locality and an argillaceous dolosiltite at another. This lithology rests in the center of a compositional triangle with clay, siltstone, and dolomite as the apices, therefore, any description is somewhat subjective.

Sedimentation Seminar ( 1972, p. 4) describes the petrography of the Fort Payne dolosiltstones as "a groundmass of dolomite rhombs (40 microns average diameter) with varying, but small, amounts of detrital argillaceous minerals (illite, chlorite, and kaolinite), glauconite pellets, and detrital quartz silt and sand grains". They also note the replacement of dolomite rhombs by chert, ranging from small isolated patches to nearly complete silicification with only scattered surviving dolomite rhombs. The sparse fossil fauna includes spiriferid brachiopods, disarticulated crinoidal debris, and bryozoan fragments. Despite intensive bioturbation, many identifiable trace fossils are preserved, including vertical tubes, horizontal curly worm tracks, spreite-filled burrows, and Zoophycus (Sedimentation Seminar, 1972).

Klein (1974) describes several changes in lithostratigraphic features of the dolosiltstones from the base to the top of the section, a distance of approximately 300 feet (92 m). The following information is taken from her discussion. The lithology changes from dolomitic, argillaceous mudstones at the base to

dolosiltstones in the central and upper parts of the section. The mudstones are characteristically thin-bedded (10 to 15 cm thick beds) and graded, with some ripple laminae preserved. The dolosiltstones, in contrast, are thicker bedded, show an overall coarsening upward in grain size, display persistent primary bedding dips of 4 to 6 degrees to the southwest, and are increasingly bioturbated toward the top of the section. They also contain abundant gypsum nodules and quartz geodes.

To the northeast, the dolosiltite intertongues with the Muldraugh Member of the Borden Formation. Kepferle et al. (1980) describe the dolosiltite as "granular dolomite in silt-size rhombs" (1980, p. A104).

#### Interpretation:

Lineback (1966) stated the Fort Payne Formation to be dark-colored, cherty, impure limestone that partially filled the deep-water starved basin in front of the Borden at the end of deltaic deposition. The Fort Payne sediments ultimately filled in the basin to the degree that a shallow-water platform developed on top of the basin fill sediments (Lineback, 1969). He suggests that the "foresetlike" beds within the Fort Payne are the result of sediment movement on a slope primarily by slumps and turbidity currents analogous to what occurs on the present continental slopes (Lineback, 1969). The Sedimentation Seminar (1972, p. 20), interpreted the argillaceous sediments to have been deposited during

intervals characterized by the influx of carbonate mud, skeletal debris, and terrigenous mud and silt, which "prograded seaward and basinward toward the southwest", and "the sediments were deposited on the southwestward dipping slope." Hannan (1975) suggests deposition via sediment gravity flows. His interpretation is based on the parallel orientation of master bedding planes in the dolosiltstones with the depositional topography of the limestone bodies.

Lewis and Potter (1978, p. 11) note the Fort Payne to be "the silty, dolomitic, muddy, bioturbated fill deposited in front of, and mostly after, the deposits of the Borden." They add that it "is a shelf margin fill, one that existed at the end of the Borden deposition." Their study includes photographs of large-scale slide and slump structures developed within the dolosiltstones.

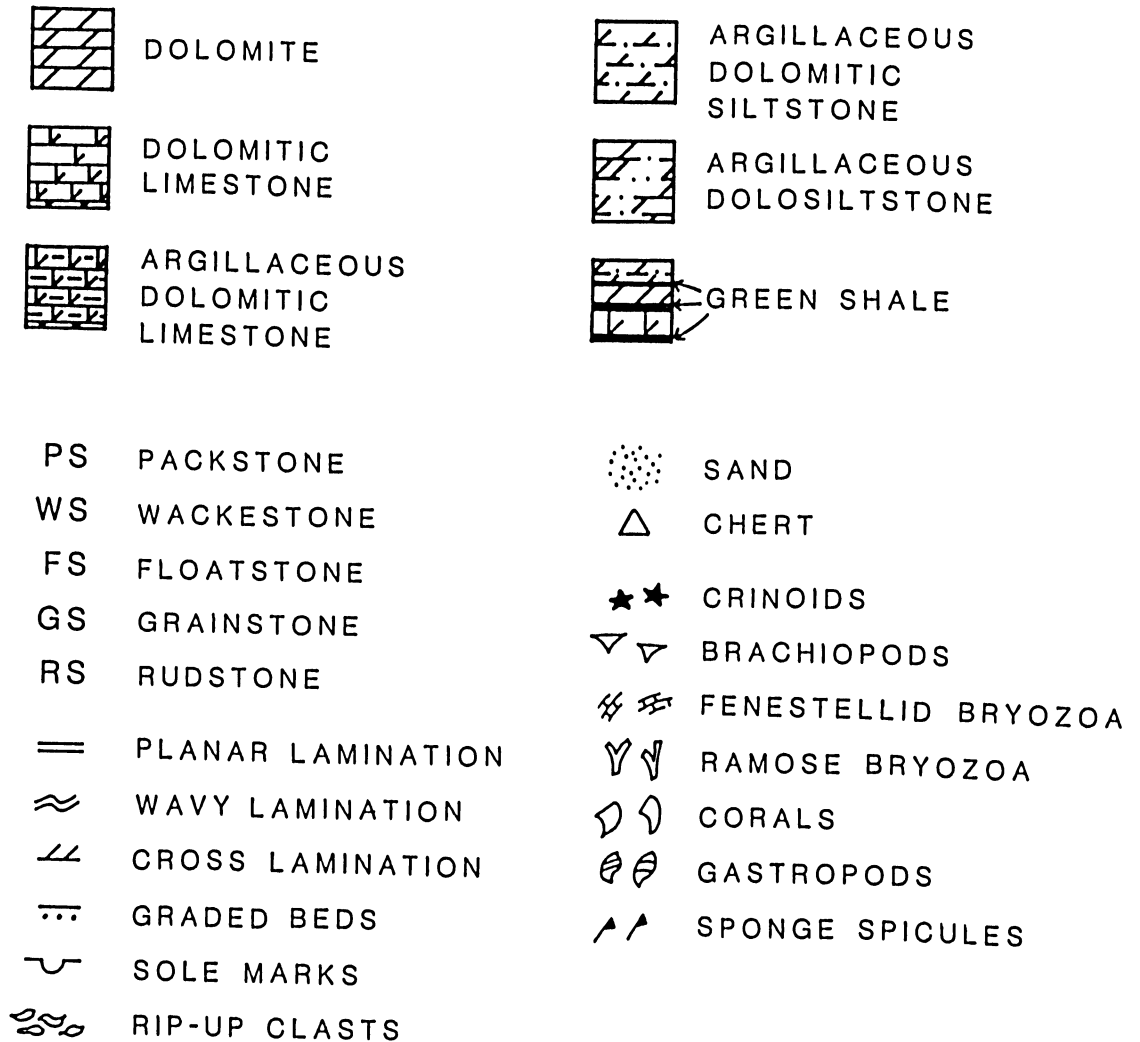
## RESULTS

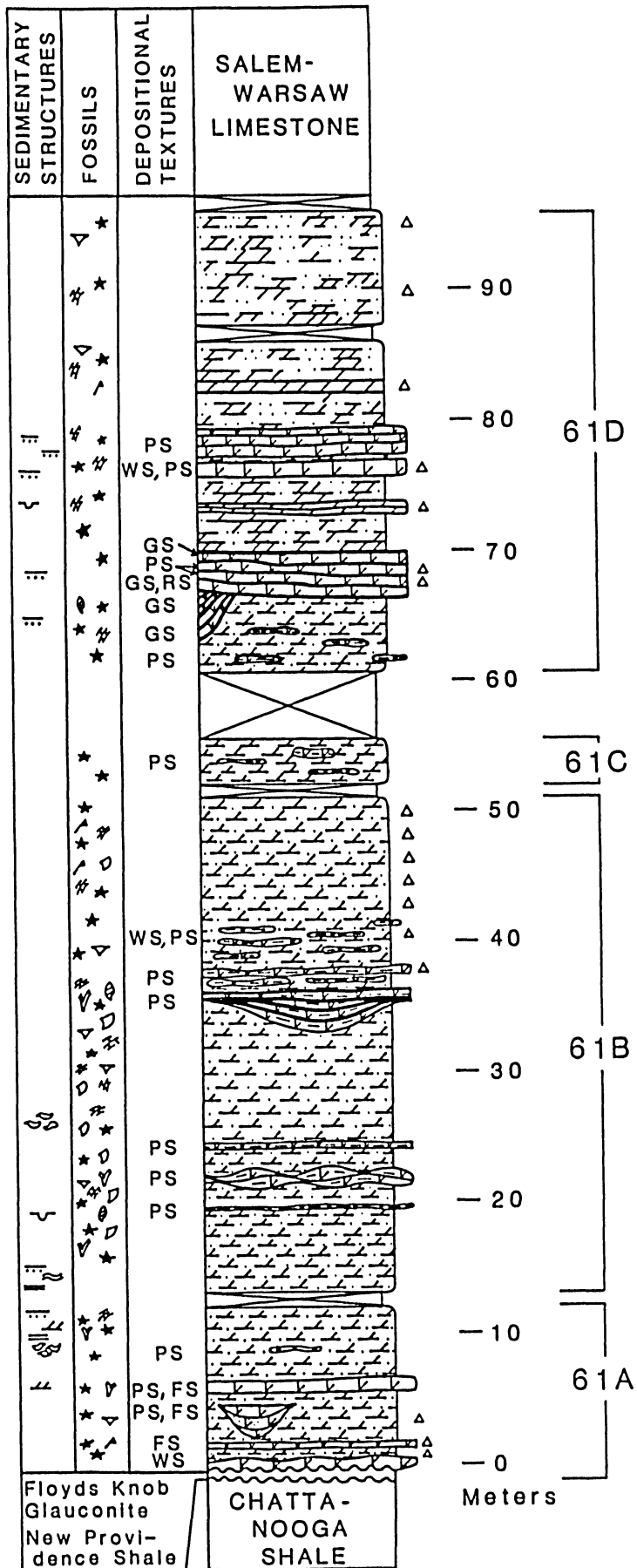
### Lithofacies of the Stratigraphic Section

The Fort Payne Formation consists of several complexly interbedded lithologies within the study area. These include carbonate rocks such as dolosiltstones, argillaceous dolomitic limestones, grainstones and dolomites, and clastic rocks such as green shales and argillaceous dolomitic siltstones. Replacement rock types include dolomites and cherts. Figure 9 is a stratigraphic section compiled from field and laboratory descriptions of rocks from four outcrops along State Highway 61 (locality map: Fig. 4). This study concentrates on the lithologies which are the most crinoid-rich, hence although six of the above seven lithologies are described and interpreted in this section, closest attention is paid to the argillaceous limestones and the green shales. The dolosiltstones have been described and discussed in the Stratigraphy section. A description of the massive carbonate body that is located on the west side of Highway 61 follows that of the stratigraphic section.

Petrographic work began with the field documentation and description of each lithology and was later augmented by polished slab and thin section analyses. Both carbonate and clastic classification schemes were necessary to define individual rock types: carbonates are those rocks which contain 50% or greater carbonate, whereas clastic rocks contain greater than 50% terrigenous

Figure 9. Stratigraphic section of the Fort Payne Formation along Highway 61 south of Burkesville, Kentucky. Figure 4 shows the location of the outcrops used in compiling the section.





material. The procedure I used for naming the rock types is included in Appendix 3.

### Argillaceous Limestone

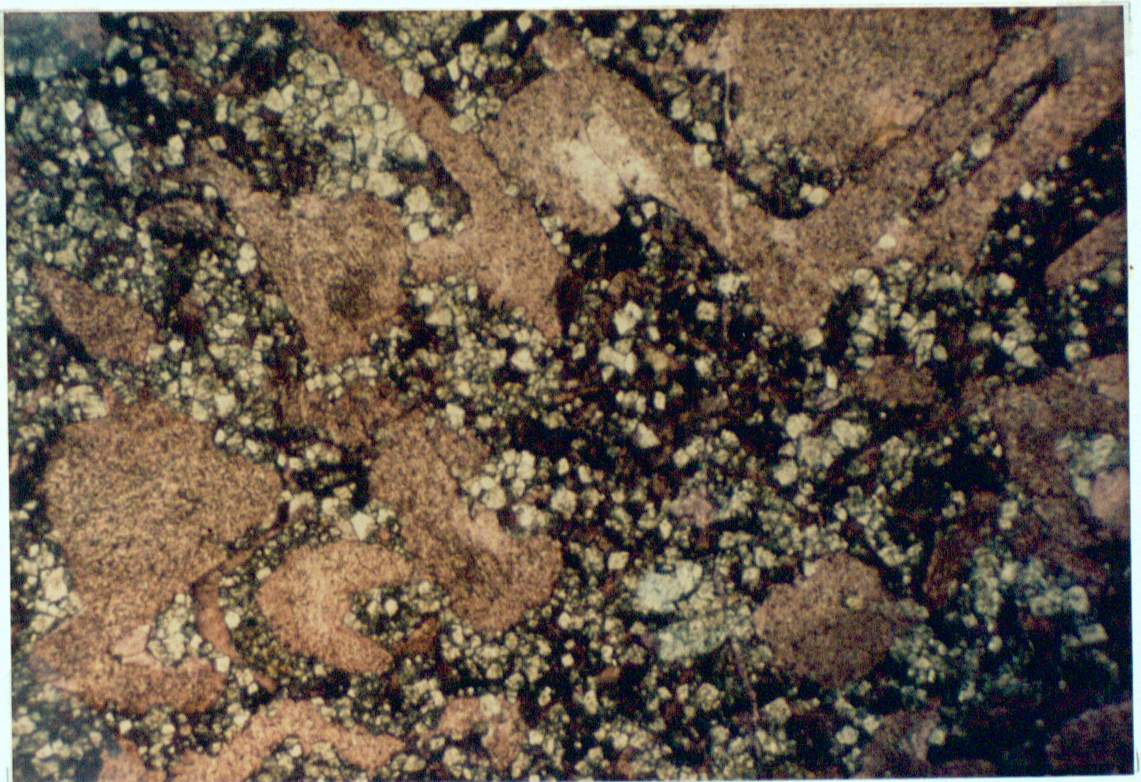
#### Description:

All carbonate rocks in the study area, with the exception of a few local grainstones, contain significant quantities of argillaceous material. Petrographically, these carbonates consist of admixtures of skeletal fragments, clay minerals, dolomite rhombs, ferroan dolomite, sparry calcite, microspar and authigenic minerals (Pls. 1 and 2). Bioclasts exhibit a broad range of grain sizes and the rocks vary from mud-rich to mud-poor. Texture is gradational from wackestone to packstone, with local patches of micstone.

Framework grains generally consist of variable quantities of disarticulated echinodermal and bryozoan fragments. Overall, crinoid fragments (ossicles) are the most abundant type of fossil debris. Several unique features, such as their unit extinction, their many distinctive shapes, and the common presence of syntaxial rim cement overgrowths, make them easily recognizable in thin section. Fenestrate bryozoans are the second most abundant bioclast in thin section. They are easily recognizable in thin section because of their zooecia and their dark brown, fibrous wall structure. The zooecia often are infilled with matrix, carbonate cement, or phosphatic material, probably collophane.

Plate 1. Thin section of an argillaceous packstone (53.7 m) stained with alizarin red S and potassium ferricyanide. Adjacent crinoid fragments show dissolution where they are in contact; margins of the ossicles have undergone slight silicification as well. The matrix consists of argillaceous material, some dolomite and bryozoan fragments. Area of slide shown is approximately 3 mm in width.

Plate 2. Stained thin section of a dolomitic packstone (74.7 m). Framework grains predominantly consist of crinoid debris. Dolomite rhombs (unstained) comprise a large part of the matrix along with argillaceous material. Area of slide shown is approximately 3 mm in width.



Bioclasts present in minor amounts include molluscs, corals, sponges, and arthropods. Whole and fragmented gastropods are relatively common at outcrops but are much less so in thin section. The relative abundance of Platyceras sp. shells often parallels that of crinoid debris within individual beds. Corals, sponges, and arthropods comprise lesser quantities of the fossil debris. Although uncommon in thin section, corals are relatively common in outcrops. Whole rugose corals as well as fragments of the tabulate, Cladochonus crassus, are chief among these. Sponge spicules are locally common but for the most part are visible only in thin section. Sponge root tufts were found at a few localities. Trilobite fragments are recognizable in a few thin sections but are extremely rare, as are ostracod tests.

Thin sections reveal the matrix to be composed primarily of clay minerals and dolomite rhombs. Its overall color often is reddish-brown because of the abundance of clay minerals. Sericite and muscovite are both recognizable although other clay minerals are impossible to identify without X-ray analysis. Dolomite rhombs generally are idiotopic, and fall within two size ranges: a fine-grained assemblage ranging from less than 10 to approximately 25 microns in diameter, and a coarser-grained assemblage ranging from 25 to greater than 70 microns in diameter. The fine-grained rhombs generally are distributed throughout the argillaceous matrix and

also may be found filling bryozoa zooecia and pores within echinoderm stereom. The coarser rhombs are randomly distributed within the matrix but often are concentrated at the centers and around the edges of echinoderm fragments. In some instances, fine-grained rhombs may comprise most of the matrix, surrounding clusters of coarser rhombs. Where dolomite has completely replaced the matrix, an interlocking crystalline mosaic of anhedral rhombs is the result, so-called xenotopic-A texture (see Appendix 3). Dolomite rhombs in some rocks commonly are zoned, made apparent by the staining of crystal faces by iron oxide. Ferroan or saddle dolomite is distinguishable by its light blue to turquoise color when stained and its sweeping extinction in polarized light. These crystals are not rhombic, rather they have curved geometric outlines and are much coarser grained, a texture known as xenotopic-C. This type of dolomite occurs as discrete aggregates within argillaceous matrix that is moderately to extremely dolomitized. Commonly, it comprises the center of crinoid ossicles, with only a rim of the original calcite bioclast remaining.

Sparry calcite and microspar (1 to 5 micron-sized crystals) generally are rare in the argillaceous limestones, occurring as occasional patches filling in both intra- and intergranular voids. Hematite, present only in trace amounts, is probably the most abundant authigenic mineral. It generally occurs as very small

spheres, that often are strung together like a "string of pearls". Chert replacement is common; it tends to occur in carbonate beds that are mud-poor. Chert usually takes the form of nodules although in some cases these may coalesce to form nodular beds.

The argillaceous limestones may be subdivided further on the basis of field properties such as bedding and sedimentary structures. Basically, three types of deposits characterize these limestones, each of which is exhibited in the stratigraphic section (Fig. 9). The first type consists of predominantly massive-bedded carbonate beds that exhibit a pinch and swell morphology (Pl. 3). Some beds can be traced by following stringers of coarse skeletal debris, usually crinoidal, that have weathered out in relief. A few of these deposits show a fining upward trend in bioclast grain size (Pl. 4). This type of bedding comprises limestones near the base and at about the 21 to 22 meter interval within the stratigraphic section (Fig. 9). Beds attain a thickness of 1.5 meters or greater while their length may extend 20 meters or more. An identical but larger scale bed comprises the thickest portion of the carbonate buildup that is located on the west side of State Highway 61. Texturally, the pinch and swell limestones are transitional from packstone to wackestone, and less commonly, to micstone. In addition, the beds at the 21 to 22 meter interval of the stratigraphic section along with

Plate 3. Massive-bedded carbonates at the base (21-22 m) of the 61 B outcrop are characterized by their pinch and swell morphology.



Plate 4. Coarse, siliceous bioclastic debris weathered out in relief at the 61 A outcrop. The lower left portion of the photograph shows the transition from the upper, finer-grained portion of one bed to the lower, coarser-grained base of a second bed.



the lower beds in the buildup exhibit a distinctively weathered zone with friable or rubbly texture (Pl. 5, Fig. 10).

Medium- to thick-bedded, planar to slightly wavy, laterally continuous beds are a second type of bedding manifested by the argillaceous limestones. These are found at several horizons within the stratigraphic section and are especially well-developed from about 36 meters up to 41 meters and from about 65.5 meters on up to about 80 meters. Where they occur near the base of the section (5.5 to 6.5 m), they are horizontal, thick-bedded, coarse-grained, and bioclasts are very poorly-sorted. Approximately 20 meters higher in the section, individual beds become thinner and more wavy-bedded, and often are traceable along their entire length. In addition, moderately thick shale or dolosiltstone sequences separate each bed (Pl. 6). Toward the top of the section, the beds are more clinoform with depositional dips of from 3 to 10 degrees. Overall there is a slight decrease in average grain size of bioclasts although sorting remains poor.

Channel-fill deposits comprise the third type of deposit. One type of channel-fill deposit is narrow but deep compared to its width whereas the other type is several meters in breadth but relatively shallow in comparison to its width. An example of the first type occurs near the base of the section in the interval from 2 to 4.5 meters (Pl. 7). It is 2.5 meters thick, 30

Plate 5. A close-up of the carbonate beds of Plate 3 reveals several distinctively weathered zones that exhibit a friable or rubbly texture. The diagram in Figure 10 shows the distribution of these so-called rubbly zones within this outcrop.

Plate 6. The second type of bedding characteristic of the argillaceous carbonates is exhibited by the two laterally continuous, planar to slightly wavy beds near the center of the photo (61 B). Both occur interbedded within a relatively thick sequence of dolosiltstone. This type of bedding is also evident in the upper left corner of the photograph, just above the large-scale channel-fill deposit (arrows; 36-41 m).



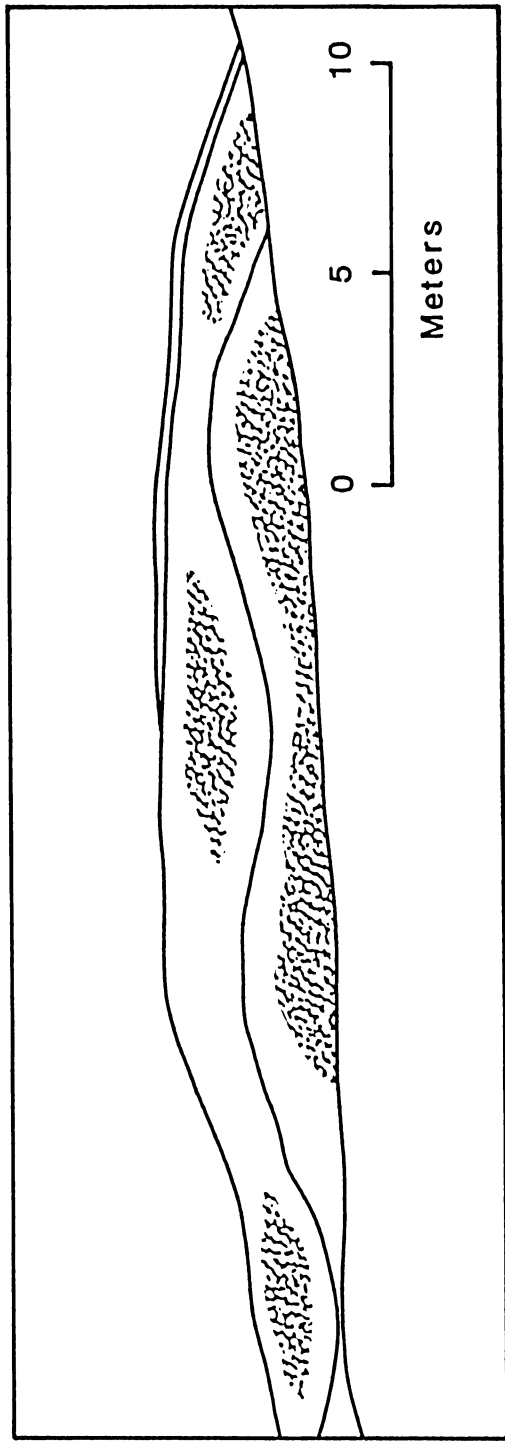


Figure 10. Map of the pinch and swell carbonate beds of Plates 3 and 5. Stippled areas mark the distribution of rubbly-textured zones within the beds.

Plate 7. One type of channel-fill deposit within the study area (61 A) is narrow but deep compared to its width. Bedding planes are indicated by lighter-colored zones of silicification.

Plate 8. The second type of channel-fill deposit within the study area (61 B) is several meters wide and is relatively shallow in comparison to its width. Beds filling the channel are thinner, more laterally continuous and finer-grained than those of the first type. Individual beds also are separated by thin shale sequences.



meters across, and is filled with 30 to 60 centimeter thick, quartz silt-rich floatstones and packstones. A much larger channel-fill deposit, an example of the second type, is found at the 33.7 to 36.6 meter interval (Pl. 8). The width of this channel extends nearly the entire outcrop, a distance of several tens of meters. Unlike the previously described example, the carbonate beds filling in this channel are thinner, more laterally continuous, and consist of finer-grained carbonate debris. They also are separated by shale sequences whereas the lower channel-fill deposit contains only carbonate rock. The base of another channel very similar to this one is found at about the 65 to 67 meter interval (Pl. 9). Lithologically, the beds filling this channel are virtually identical to those of the channel-fill deposit in Plate 8, with the exception of a localized series of lensatic beds.

Taphonomy:

Much of the skeletal debris in the argillaceous limestones is preserved as calcite with chert and dolomite common as replacement minerals. A few thin sections that exhibit zones of complete chert replacement contain abundant sponge spicules in non-silicified areas of the slide.

Within individual limestone beds, most crinoids are disarticulated and bryozoans are extremely fragmented. Large pieces of articulated crinoid columnals are extremely common at certain horizons within the

Plate 9. Assistant is standing at the center and thickest part of this channel-fill deposit (61 D) located at about the 65 to 67 meter interval of the stratigraphic section. The lensatic beds are to his right.

Plate 10. A bedding plane exposure (61 B) showing a variety of disarticulated crinoid ossicles as well as a partial calyx of the monobathrid camerate Uperocrinus sp. Breakage of the central portion of the calyx occurred as the result of weathering whereas disarticulation of the arms, stem and part of the anal chimney occurred prior to or in the process of deposition. This is the typical mode of preservation of camerate calyxes within carbonate rocks of the study area. Scale is in centimeters.



stratigraphic section, whereas whole articulated cups, usually without the stem attached, are somewhat less common. Generally, articulated columnals are oriented parallel to bedding and cups are randomly oriented (Pl. 10). In thin section, whole crinoid ossicles are commonly preserved, although they often are abraded or broken; generally they range from a few microns up to and greater than two millimeters in diameter. Columnals often are still articulated, ranging up to ten millimeters or more in length. The more fragile nature of bryozoan zooaria usually prohibits the preservation of fragments larger than a few millimeters both in outcrop and in thin section.

Localized accumulations of the disarticulated cup plates and fragments of stem from single crinoid individuals are found in situ on the upper surfaces of some argillaceous limestone deposits, particularly the buildup on Highway 61. These bioclastic deposits might have provided a fairly coarse-grained, carbonate substrate for the living crinoids.

### Grainstone

#### Description:

Grainstone deposits are restricted to the upper third of the stratigraphic section. They occur both as planar beds and as channel-fill deposits and are typically composed of poorly-sorted, coarse-grained crinoid debris (1000 to 2000 microns) with some bryozoan debris. Crinoid

bioclasts usually are deformed by compaction and often have embayed contacts with adjacent grains. The interstices are filled by syntaxial rim cement, dolomite rhombs, and very minor amounts of argillaceous material.

The approximately three meter thick grainstone deposit filling in the channel at the 63.5 to 66.5 meter interval (Pl. 11) is composed of 40 to 60 centimeter thick beds, separated by shale partings that individually are less than 1 centimeter thick. The 3 meter deep channel is approximately 10 meters in width and depositional dip of the beds ranges from 3 to 7 degrees. The lowermost beds are somewhat finer grained than those at the top. At its base, the channel cuts into fossiliferous green shale, which was designated as the 61 D collecting locality. The channel-fill unit eventually is truncated by thin argillaceous packstone beds interbedded with green shale; these were described in the argillaceous limestone section above as the broad channel-fill deposits. These are in turn overlain by a laterally continuous, planar-bedded grainstone deposit. The texture of this grainstone resembles that of the channel-fill grainstones: it is poorly-sorted, coarse-grained, and grains exhibit evidence of considerable compaction. Faintly perceptible bedding results where bands of coarse crinoid debris (average 2 mm diameter) alternate with bands of predominantly finer debris (less than 1 mm diameter). Less than two meters above this planar grainstone are two additional grainstone

Plate 11. A grainstone channel-fill deposit exposed at the 61 D outcrop. A green shale bedding plane at the base of this channel was designated as the 61 D collecting locality. Abundant crinoid columnals are visible in the rock.



beds, each about 25 to 30 centimeters thick and both resembling the first one. These two beds differ, however, in being somewhat finer grained (medium to coarse sand-sized crinoids and fine sand-sized bryozoans) and in the absence of any apparent bedding.

#### Taphonomy:

Taphonomic features exhibited by grainstone beds are analogous to those of the previously discussed argillaceous limestones. Although crinoid remains overall are much more abundant in the grainstones, there is no evidence that they are in situ.

### Green Shale

#### Description:

These shales are greenish-gray to olive-gray in color, are moderately silty, and contain lenses and stringers of bioclastic debris. They are poorly indurated and lack any distinctive lamination. Typically they are interbedded with argillaceous wackestones and packstones and are found throughout the stratigraphic section. In addition, Lewis and Potter (1978) note the common association of this green clay shale with carbonate mudstone buildups on the shores of nearby Lake Cumberland.

Thicknesses of the green shale sequences range from a few centimeters to several meters. This is also the most fossiliferous rock type; the lithology at the 61 D, 61 D West, 61 South, and BF 9 collecting localities is green

shale (see Appendix 1 for faunal lists). Well-preserved fossils are found in green shale interbeds between medium- to coarse-grained, argillaceous packstone and wackestone beds. The green shales commonly drape over clinoform carbonate beds (Pl. 12). They are also associated with the massive buildup on State Highway 61 as overlying beds; whether or not the green shale is associated with the lateral edges of the buildup is unclear, however, because of overgrowth. Thin, planar bedded wackestones adjacent to the BF 9 exposure are a few meters higher stratigraphically. These carbonates are thinner-bedded, finer-grained, and somewhat more planar and laterally continuous than those associated with the 61 South, 61 D, and 61 D West localities.

#### Taphonomy:

Fossil material within the green shale is abundant and well-preserved and consists chiefly of echinoderms (Pl. 13). Calcite is the dominant replacement mineral; subordinate replacement minerals in order of abundance from greatest to least are silica, pyrite and siderite.

With regard to the study area as a whole, this lithology is the one most likely to yield intact, unabraded crinoid calyxes. Moreover, accumulations of disarticulated cup plates on bedding planes often contain the full complement of plates necessary to reconstruct a whole cup. Complete crinoid specimens, with stems and arms still attached, however, are lacking although

Plate 12. The 61 South collecting locality: green shale draped over clinoform carbonate beds.

Plate 13. Close-up of the green shale bedding plane at 61 D. Disarticulated crinoid stems comprise the dominant portion of skeletal debris.



articulated sections of columnals and arm segments are relatively common. Columnals 10 to 20 centimeters in length are typical; one notable specimen, although broken in several places, measured over 24 centimeters. Articulated sections of arm segments more commonly are biserial rather than uniserial; the majority of the former belong to either Agaricocrinus sp. or Eretmocrinus sp. Uniformly-sized biserial, uniserial and flexible arm ossicles, along with disarticulated cup plates and anal tubes are abundant in bulk shale samples. Presumably, identical cup plates and arm ossicles of similar size came from either one animal or from several different animals of the same age.

Blastoid calyxes are preserved in more or less the same manner as crinoids, although the blastoids more frequently are crushed, very likely a consequence of their more globose (and perhaps less rigid) theca. Preservation of granulose and nodose surface ornamentation on the cup plates of both blastoids and crinoids is common.

At least two types of holdfasts are characteristic of the green shales: radix holdfasts of Barycrinus sp. (Pl. 14) and unidentified complete juvenile radix holdfasts attached to crinoid stems (Pl. 15).

Taphonomic evidence from other invertebrate groups correlates well with that derived from the echinoderms. Brachiopods generally are articulated and unabraded although thin-shelled strophomenids such as Rhipodomella

Plate 14. Barycrinus sp. holdfast. Scale is in centimeters.

Plate 15. Unidentified juvenile radix holdfast attached to a crinoid stem. Scale is in millimeters.



oweni typically exhibit post-depositional dorso-ventral compaction. Bryozoans show a wide range of preservational styles depending upon zoarial form. Cystodictya lineata, a relatively thick-walled, bilaminate bryozoan comprises virtual mats at some horizons. Zoaria of more delicate ramose forms usually are fragmented although the lacy fronds of fenestrate bryozoans are preserved almost exclusively as molds ranging from a few to several square centimeters in area. In general, specimens of Platyceras sp. are fragmented and the apical region crushed, thereby complicating species identification. Rugose corals typically are slightly crushed. Cladochonus crassus, a tabulate, commonly is found still encircling the crinoid stem on which it attached itself in life and as individual corallites broken from colonies.

#### Dolosiltstone/Dolosiltite

##### Description:

Lithologic features of this rock type are described in the stratigraphy section. This is the dominant lithology of the Fort Payne Formation in south-central Kentucky wherever the interbedded carbonates characteristic of the study area are absent. Within the stratigraphic section, however, dolosiltstone is restricted to the uppermost 16 meters; above it is well-washed, coarse-grained, grainstone of the Salem-Warsaw Limestone. Underlying the dolosiltstone is an orange-brown, approximately 10 centimeter thick weathered zone

with abundant lathes of secondary gypsum precipitated along bedding planes. Below this are graded beds of coarse-grained, silty grainstone.

### Argillaceous Dolomitic Siltstone

#### Description:

Argillaceous dolomitic siltstone is gradational in composition with the dolosiltstone lithology, the latter being more indurated (more dolomite-rich), darker in color, and much less fossiliferous. Both lithologies are extensively bioturbated and contain varying amounts of argillaceous material, silt- to sand-sized quartz grains, and fossils.

Argillaceous dolomitic siltstone occurs as interbeds throughout the section and exhibits a range of color and composition. Typically it is light blue-gray on fresh surfaces and dark blue-gray to olive-gray on weathered surfaces. At some exposures, however, it weathers yellowish-tan to yellowish-brown and exhibits a mottled appearance with irregular-shaped, dark-stained patches. Analysis of thin sections reveals that the matrix is composed of 40 to 50 per cent micaceous material with rounded quartz grains (less than 62 microns) and dolomite rhombs; laminations often result from solution seams filled with clay minerals. Microscopic features also include micritic intraclasts containing extremely fine-grained skeletal material and siliceous sponge spicules. X-ray analysis by Hannan (1975) indicates it to be less

dolomitic at the base of the section (approximately 10 per cent) than it is higher up (50 per cent or greater). Overall this lithology is slightly to moderately fossiliferous; the most abundant faunal elements are moderate- to well-sorted, fine to coarse sand-sized bioclasts of bryozoans, crinoids, and brachiopods. Elongate fragments generally are oriented parallel to bedding. Thin lenses and stringers of partially silicified coarse-grained crinoid material are present at some horizons. At the 61 B locality, the interval from approximately 19.5 to 34 meters is especially fossiliferous. The first 1.7 meters of a nine meter thick interval (42 to 51 meters; Fig. 9) of yellowish-tan argillaceous dolomitic siltstone exhibits an increase in average grain size upward from shale to silt to sand. The rock then varies from a siltstone to a silty shale for the rest of the interval. In addition, there is a four centimeter thick zone of rugose coral from 46.5 to 46.9 meters and some beds have molds of bryozoans preserved along bedding planes. Scattered lenses of partially silicified crinoid material, geodes from 0.5 to 6 centimeters or more in diameter and bedded chert zones are also common. Where green shale and argillaceous dolomitic siltstone both occur, the contact between the two is gradational.

Taphonomy:

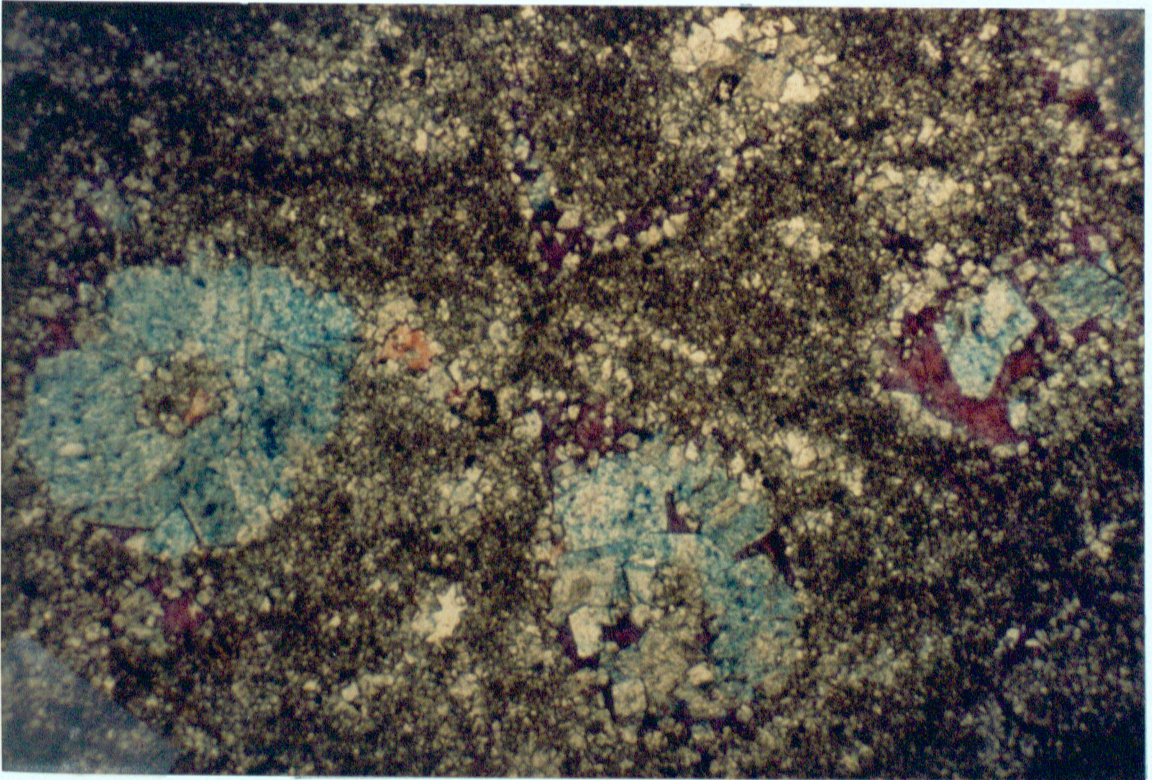
Fossils are preserved as calcite with chert a common replacement mineral. Skeletal material within the stringers is disarticulated and often abraded as well; accumulations of related crinoid cup plates are not uncommon where it is locally fossiliferous. Where it is not, crinoid material consists only of the finest grained skeletal debris. The small range of grain size in addition to the high degree of sorting, breakage, and abrasion of bioclasts indicates that these fossils were transported some distance from where they lived.

#### Replacement Rock Types: Dolomite

The definition used here for dolomite is a rock composed of ninety per cent or more dolomite. Partial to nearly complete replacement of carbonate by dolomite and ferroan dolomite occurs in all Fort Payne rock types. Thin section petrography reveals that dolomite rhombs may be grouped into two types based on size. The first type consists of very fine-grained rhombs (20 microns and less) that usually form an interlocking mosaic. The second type is coarser-grained (30 to 80 microns) and occurs randomly distributed within the matrix, which usually is argillaceous. Ghost textures of original allochems, especially crinoids and relict bedding, commonly are discernible even where dolomitization is nearly complete.

There are two isolated planar beds of dolomite within the stratigraphic section, one at 24.5 meters (Pl. 16) and the other at 74.8 meters. Complete dolomitization,

Plate 16. Thin section of a calcareous dolomite from 24.5 meters. Ferroan dolomite is stained blue, calcite is pink and dolomite rhombs are unstained. Skeletal grains have been replaced by coarse-grained dolomite rhombs whereas the matrix has been replaced by finer-grained rhombs. Skeletal grains are still recognizable as crinoidal. Area shown is approximately 3 mm in width.



although it is patchy in distribution, also occurs within the massive-bedded carbonate buildup on State Highway 61.

#### Replacement Rock Types: Chert

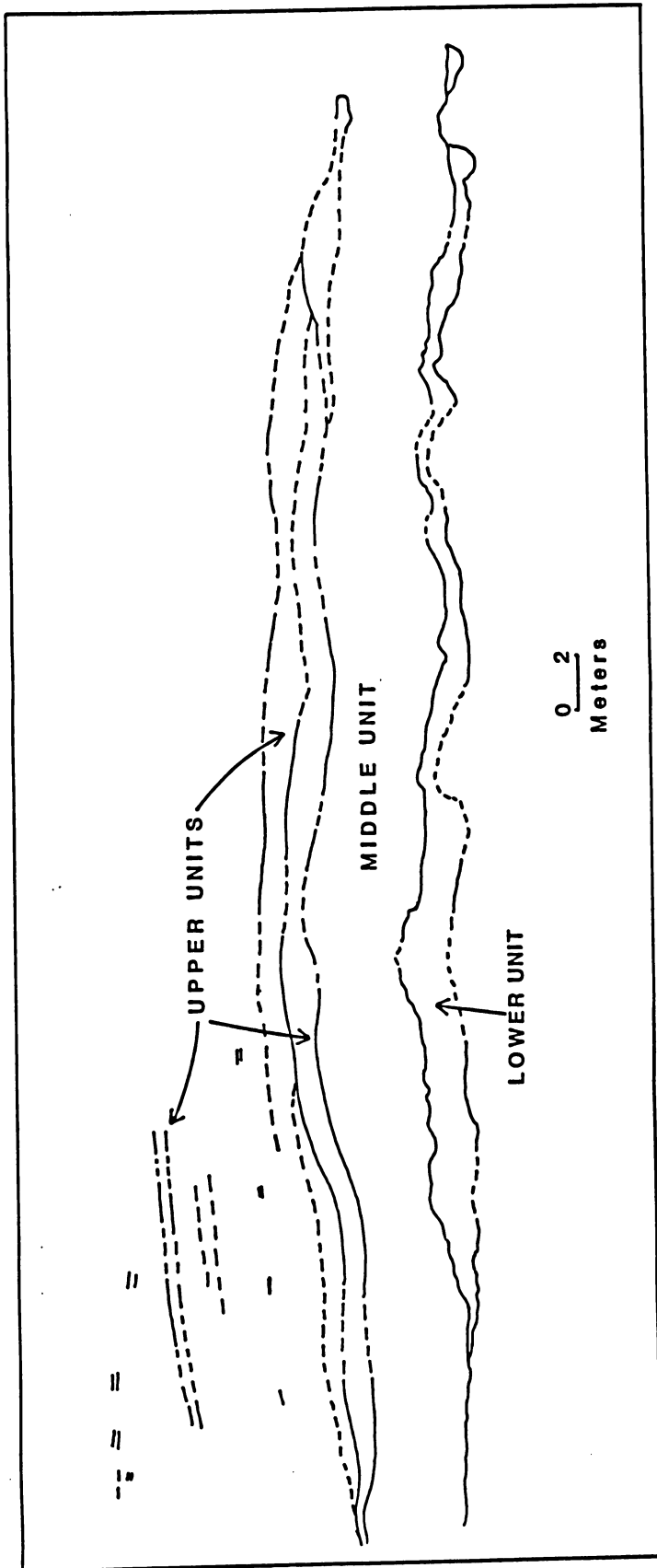
According to the classification scheme in Appendix 3, cherts are those rocks with greater than eighty per cent silica composition. Most thin sections of both carbonate and clastic rock types reveal silicification of bioclasts to some degree, especially crinoids. Where silicification is extensive, chert may occur either bedded or as nodules. Laterally continuous chert beds may be interbedded with shales, siltstones, and carbonates. Chert nodules or lenses are found interbedded with both siltstones and dolosiltstones and within discrete carbonate beds. In the case of nodules and lenses, the borders of the chert zone in thin section are very sharp and cut across grains and grain boundaries. Small patches of either dolomite or the original calcite may remain but are usually of insignificant quantities.

Chert usually occurs as microcrystalline quartz, recognizable as tiny (less than ten microns), randomly oriented interlocking crystals, which have a black and white speckled appearance in polarized light. It is typically found replacing the interiors of calcareous bioclasts, especially crinoids. Also present but in smaller quantities is megaquartz, randomly oriented as well but with larger crystals. Chalcedony, easily distinguished by its radial fibrous nature, is most common

Plate 17. The carbonate buildup on the west side of State Highway 61. Two figures in the middle foreground provide scale.



Figure 11. Map of the carbonate buildup pictured in Plate 17. I divided the buildup into a lower, middle and upper unit for descriptive purposes. The lowermost unit, which extends from the creek to the base of the thick, massive-bedded middle unit, consists of rubbly-textured, dolomitic wackestone. The thickest unit within the mound, the massive-bedded middle unit, consists of dolomitic wackestone and packstone. Its exposed upper surface is smooth and undulate. The upper unit consists of a sequence of wavy, sheet-like carbonate beds, separated by thin shale breaks. It includes the wavy bed just above the massive-bedded middle unit as well as at least two beds that outcrop in the hillside above the main body of the buildup. Texturally the upper unit consists of packstones and wackestones that are somewhat coarser-grained than the middle unit. Of the three units, the upper unit contains the greatest percentage overall of crinoid debris.



originated in three stages or that it consists of three distinct facies. Petrographic descriptions are keyed to the diagram in Figure 11 and are included in Appendix 2.

#### Lower Unit: Rubbly Dolomitic Wackestone

The exact geometry of this facies is unknown because it is bounded at its base and sides by talus and ground cover. Its upper boundary is marked by an abrupt transition from rubbly, weathered rock to the massively bedded middle facies. Near the base of the exposure is a one to two centimeter thick green shale break but the actual lower boundary is not exposed.

Sedimentary textures and structures are obscured by the extremely weathered and friable nature of this facies (rubbly texture). At the base of this unit, however, fresh rock samples could be obtained by clearing away some of the weathered exterior. Here the rock is light tan with pale green elongate splotches of color; these appear to be irregularly-shaped rip-up clasts composed of dolomite. The rock is sparsely fossiliferous and lacks any apparent bedding. Thin section analysis reveals the texture to be that of a wackestone. The matrix has been partially to completely dolomitized, with rhombs averaging 30 to 40 microns in diameter. Patches of finer grained rhombs (10 microns and less) occur interspersed within the matrix whereas coarser-grained rhombs (50 microns and greater) occur adjacent to and within calcitic crinoid bioclasts. Large crystals of saddle or ferroan dolomite,

some up to one or two millimeters in diameter, also may partially replace crinoid bioclasts. Argillaceous material and sparry calcite typically are found within intercrystalline areas. Skeletal debris mainly consists of crinoids with rare, if any, bryozoans. Crinoid fragments are very fine-grained and well-sorted although scattered pockets of poorly-sorted, sand-sized to two millimeter in diameter fragments occasionally are found. In some cases, the more elongate crinoid fragments are oriented parallel to inferred bedding planes, producing faint stratification. Burrows and pellets are common in some thin sections, especially those with coarser-grained crinoid fragments.

#### Middle Unit: Massive Dolomitic Wackestone and Packstone

The thickest unit within the mound, the middle unit, is composed of massively-bedded dolomitic wackestone and packstone. Its lowest extent is marked by the rubbly zone whereas its clearly defined upper surface is smooth and undulate. Its thickness ranges from three to five meters, with the greatest thickness occurring near its center. The middle unit measures approximately sixty meters in length but may actually be greater because its southern flank is covered by vegetation and its northern flank is extremely weathered.

The middle unit does not appear to be bedded and its color ranges from dark gray to tan. Thin sections reveal the rock to be extremely burrow-mottled and pelletal in

places yet vaguely laminated in others. Pellets have round to oval outlines and are darker in color than the surrounding matrix. They are composed of argillaceous material and very fine-grained calcite (1 to 5 microns) and are distributed throughout the middle unit although their abundance may be quite variable.

Texturally, the middle unit is gradational from pelletal micstone (rare) to crinoidal wackestone to tightly packed, bryozoan packstone. Much of the rock has undergone selective dolomitization as well. In general, micstone is only slightly dolomitized in comparison to other textural types. In some instances, however, its original micritic matrix has been recrystallized to very fine-grained calcite or microspar. Skeletal debris is poorly-sorted, some bioclasts are as large as 0.6 centimeter in diameter, and is composed of crinoids, fenestrate bryozoans, and brachiopods. The crinoidal wackestone, on the other hand, contains much less of the fine-grained calcite that characterizes the micstone. Its matrix consists chiefly of euhedral dolomite rhombs that range in diameter from 10 or less to 25 or greater microns. Ferroan dolomite and sparry calcite commonly fill the porosity within solution seams and skeletal fragments. Skeletal debris consists mostly of crinoids and bryozoans with overall excellent preservation of fine detail. One hand sample actually contained a nearly whole calyx of Actinocrinites sp. on its upper surface.

Preservation is not as good where dolomite or ferroan dolomite has partially to completely replaced some bioclasts, usually crinoids. The bryozoan packstone also contains a small amount of microspar although dolomite is much more abundant. Skeletal debris typically is composed of large fragments of articulated (although many are broken because of compaction), unabraded bryozoans, many of which have sparry calcite filling their zoecia.

#### Upper Unit: Sheet-like Dolomitic Wackestone

The middle and upper units are separated by a two to three centimeter thick shale break (Fig. 11). The lowermost bed of the upper unit exhibits a pinch and swell morphology over corresponding highs and lows developed on the upper surface of the middle unit. Each of the successively deposited beds exhibits an identical morphology, and all are separated as well by a thin shale break. The result is a sequence of wavy, sheet-like carbonate bodies pinching out against one another. Petrographically, these are dolomitic wackestones and packstones virtually identical in composition to those of the middle unit, although they generally are somewhat coarser grained.

## Paleontology of the Fort Payne Formation

Twenty crinoid genera and a minimum of twenty-eight species are reported herein from all the combined collecting localities. Blastoid identifications are tentative but suggest up to five genera and species. The existence of additional crinoid genera and species is highly probable because I was unable to identify several cups, basal circlets, and cup plates. Unfortunately, time constraints prevented detailed systematic study of most other members of the fauna. I have attempted to identify as many of the fossil specimens as possible, nevertheless, in many cases I can only estimate their variety and number.

### Taxonomic Composition

Crinoids--A compilation<sup>4</sup> of the crinoid and blastoid fauna found at each collecting locality is presented in Appendix 1. Patterns of abundance and diversity are discernible where sufficiently large numbers of specimens have been collected, most notably the BF 9, 61 South, and 61 D West localities. For the study area as a whole, the most abundant and diverse group of crinoids are the monobathrid camerates. The two most common genera are Actinocrinites spp. (Pl. 18) and Agaricocrinus spp. (Pl. 19); at least two species of each probably are present.

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<sup>4</sup>This list will be augmented at the completion of taxonomic studies in progress by D.L. Meyer and W.I. Ausich.

Plate 18. Actinocrinites sp., a common monobathrid  
camerate; basal circlet; 61 D West, upper-middle  
ramp; scale is in millimeters.

Plate 19. Agaricocrinus sp., a common monobathrid  
camerate; dorsal view of calyx showing anus; found at  
intersection of Hwy. 61 and 441 (north of 61 D West);  
scale is in centimeters.



Alloprosallocrinus conicus, Eretmocrinus spp., Macrocrinus spp?. (Pl. 20), Platycrinites hemisphericus, and Uperocrinus spp. (Pl. 21) likewise are all common in the study area. Less commonly found are Abatocrinus sp., Dichocrinus?, Dizygocrinus sp., and Dorycrinus sp. Diplobathrid camerates are very rare as indicated by the presence of only two partial specimens of Gilbertsocrinus sp.

Disparid inadunates include abundant Halysiocrinus tunicatus (Pl. 22) and Synbathocrinus spp. Cladid inadunates, on the other hand, are not as abundant but are considerably more diverse in numbers of species. Disarticulated cup plates have been used to identify at least three species of Barycrinus (Pl. 23) and six, possibly seven species of Cyathocrinites (Pls. 24 and 25). Flexibles are somewhat diverse but are not at all abundant with five species represented by seven specimens.

Blastoids--An as yet unidentified spiraculate blastoid<sup>5</sup> predominates over all other blastoids. Two other species of spiraculate, Granatocrinus sp. and Dentiblastus sp., are much less common. Fissiculates are rare, as exemplified by only one specimen each of Hadroblastus n. sp. (Pl. 26) and Monadoblastus? n.sp. (Pls. 27 and 28).

Brachiopods--Brachiopods belonging to each of the following orders are present: Strophomenida, Orthida, and

---

<sup>5</sup>It has been identified by D.L. Meyer as a new genus and is yet to be named.

Plate 20. Macrocrinus sp., a common monobathrid camerate;  
lateral view of calyx; 61 D West, upper-middle ramp;  
scale is in centimeters.

Plate 21. Uperocrinus nashvillae (Troost, 1849), a common  
monobathrid camerate; dorsal view of calyx; 61 D  
West; diameter is approximately 4 centimeters.

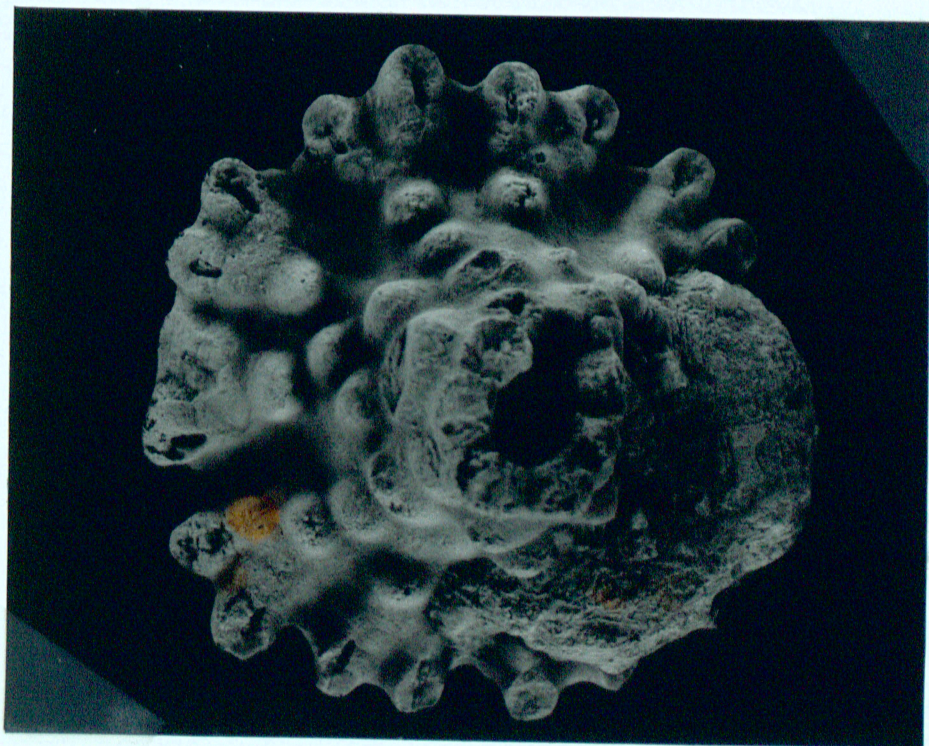


Plate 22. Halysiocrinus tunicatus (Hall, 1860), a disparid inadunate; fused A, D and E radials and inferradial; 61 South, 68-69 m; scale is in millimeters.

Plate 23. Barycrinus sp., a cladid inadunate; radial; BF 9; scale is in millimeters.



Plate 24. Cyathocrinites sp. 4, a cladid inadunate;  
radial; 61 South, 69-71 m; scale is in millimeters.

Plate 25. Cyathocrinites sp. 2; calyx and radial; 61  
South, 69-71 m and 68-69 m respectively; scale is in  
centimeters.

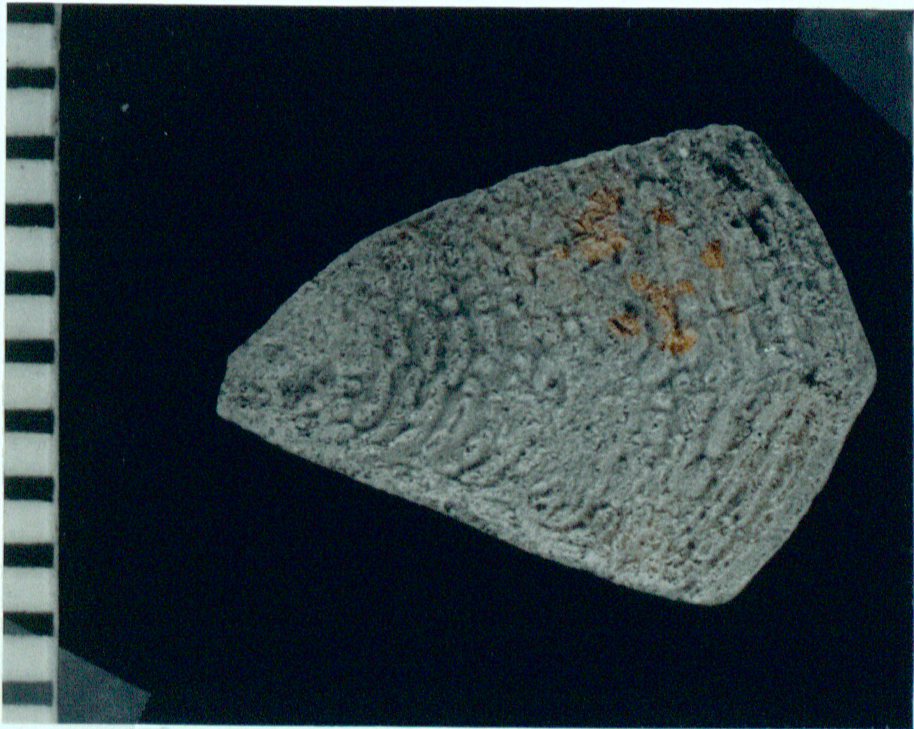


Plate 26. Hadroblastus n. sp., a fissiculate blastoid;  
calyx; BF 9; cup is approximately 2 centimeters in  
diameter.



Plate 27. Monadoblastus? sp.; radial prong; BF 9; scale  
is in millimeters.

Plate 28. Monadoblastus? sp.; radial?; BF 9; scale is in  
millimeters.



Spiriferida. I have tentatively identified several specimens as Rhipidomella oweni.

Bryozoans--One bryozoan that is abundant and easily recognizable as well is Cystodictya lineata (Pl. 29). Unfortunately, most other bryozoans are extremely fragmented, thereby complicating taxonomic identification. The documentation of zoarial forms, nonetheless, is very relevant in terms of paleoecology. All four zoarial forms that typify Lower Mississippian bryozoans, delicate ramose (vinculariform), bilaminate (adeoniform), fenestrate (reteporiform), and encrusting (membraniporiform) (Kammer, 1982), are found within the study area. I identified only one of several genera of bryozoans within the study area that exhibit a ramose zoarial form, this being Saffordotaxis incrassata. Bilaminate bryozoans include Cystodictya lineata and at least two other genera that I could not identify. Fenestrate bryozoans include at least one species of Fenestella sp. and conceivably additional genera as well. There are several species of encrusting bryozoans, one of which bears a strong resemblance to Kammer's (1982) photograph of Leioclema sp.

Molluscs--The only fossil specimens that I collected from this phylum were those of Platyceras sp., a coprophagous gastropod. Identification is hampered because most specimens are fragmented and preservation of the apical region is necessary to distinguish between the two known subgenera. These two subgenera, Platyceras (Platyceras)

Plate 29. The bilaminate bryozoan Cystodictya lineata is extremely common within the study area. Scale is in centimeters.



sp. and Platyceras (Orthonychia) sp., are the longest-ranging and most ubiquitous platycerids known (Knight, et al., 1960). It is likely, therefore, that both species are found within the study area.

Corals--Both rugose and tabulate corals are found in the study area, with the rugosan being the dominant group. Of the latter group, most specimens belong to the order Streptolesmatida. The wide variety of shapes and sizes displayed by these corals suggests the existence of several species. The tabulates consist primarily of Cladochonus crassus, an encrusting coral that encircled the stem of living crinoids. Many specimens are found still attached to stem ossicles although free corallites are also common. Plate 30 shows a crinoid columnal encrusted by Cladochonus c.

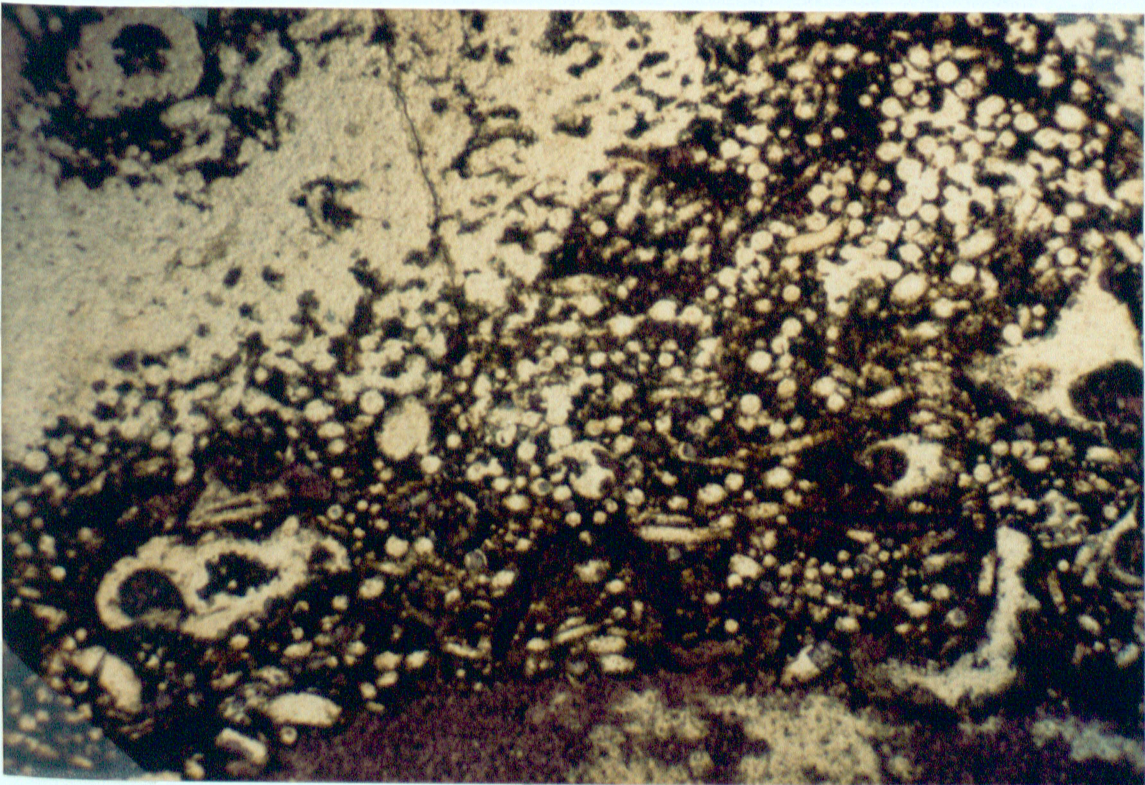
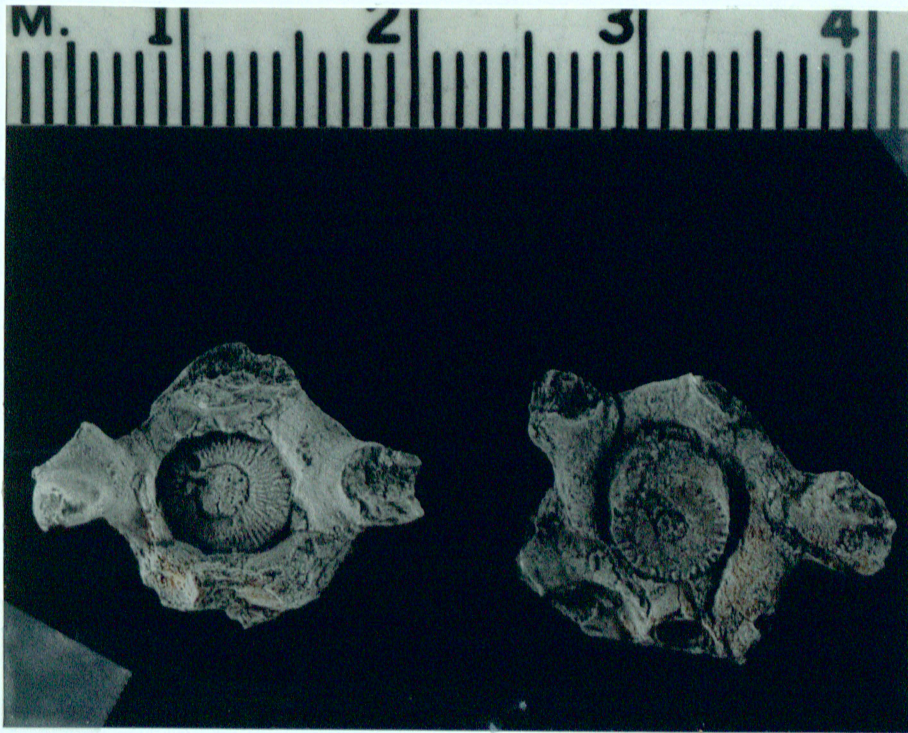
Sponges--With the exception of one dubious specimen, whole body fossils of sponges were not found in the study area. Their root tufts and spicules, however, are present. I observed the spicules on rock slabs and in thin section; all appear to be siliceous monaxons (Pl. 31).

#### Age

Van Sant and Lane (1964) report that crinoids from the Edwardsville Formation (Borden Group) at Crawfordsville, Indiana share more common species with those of the Fort Payne Chert of Kentucky and Tennessee than with Burlington or Meramec forms. In addition, they note that some of these crinoids have an extremely wide

Plate 30. Crinoid columnals encrusted by the tabulate coral, Cladochonus crassus. Scale is in centimeters.

Plate 31. A sponge spicule-rich thin section of an argillaceous, siliceous packstone from the stratigraphic section (52.3 m). Spicules are recognizable in cross section by their centrally located lumen. Area of view is approximately 3 mm wide.



geographic distribution, ranging from the type Keokuk locality in Iowa, east to Crawfordsville, to as far south as Kentucky and Tennessee (Van Sant and Lane, 1964).

Many Keokuk crinoids are noticeably specialized and as such, are excellent for biostratigraphic studies. One important group, the batocrinids, are very unique in appearance and typically occur in large numbers (Van Sant and Lane, 1964). Some of the features that make them distinct from geologically older members of their group include increased robustness, stronger ornamentation of nodes and radial ridges, and often, an increase in the number of arms (Van Sant and Lane, 1964). Dizygocrinus sp. and Alloprosallocrinus conicus, two batocrinids that are restricted to the Keokuk, are both found in the study area (Van Sant and Lane, 1964). Table 2 lists genera and several species of pelmatozoans found within the study area that are known from the Edwardsville Formation (Borden Group) of Indiana, another Keokuk-aged locality. This data corroborates a Keokuk age for the Fort Payne crinoids of south-central Kentucky.

There is evidence to suggest, however, that the Fort Payne Formation within the study area becomes younger downdip and to the southwest away from the Borden Front. In her study of the Beaver Creek and Cane Valley limestone bodies Klein (1974) collected crinoids from several field localities and gave them to N. Gary Lane for biostratigraphic analysis. He found the Beaver Creek

Table 2. Crinoid genera common to the Edwardsville Formation (Borden Group), Indiana and the Fort Payne Formation, south-central Kentucky (data for Indiana crinoids is taken from Ausich, 1978). Species names are included where known.

Diplobathrid Camerates  
Gilbertsocrinus sp.

Monobathrid Camerates  
Actinocrinites sp.  
Agaricocrinus sp.  
Alloprosallocrinus conicus  
Dizygocrinus sp.  
Eretmocrinus sp.  
Macrocrinus sp.  
Platycrinites hemisphericus  
Uperocrinus sp.

Disparid Inadunates  
Catillocrinus sp.  
Halysiocrinus tunicatus  
Synbathocrinus sp.

Cladid Inadunates  
Adinocrinus nodosus  
Barycrinus asperrimus  
Barycrinus cornutus  
Barycrinus spp.  
Cyathocrinites spp.

Flexibles  
Onychocrinus sp.

fossils (actually collected from BF 9) to be comparable to fossils found in the New Providence Shale in northern Kentucky and southern Indiana, especially with those known as the Button Mold Knob fauna. The Cane Valley fossils, on the other hand, did not appear to be directly related to any known crinoid faunas from other localities. Several typical Keokuk genera were absent from the Cane Valley, including Dorycrinus sp., Eretmocrinus sp., Uperocrinus sp., Alloprosallocrinus conicus, and large, ornate specimens of Agaricocrinus sp. He concluded that the differences in faunal composition between the Cane Valley and Beaver Creek facies had an equal chance of being either because of different time frames for each or because of differences in community structure and physical environment from one facies to the other (Klein, 1974). He cautioned that more thorough collecting was necessary before stronger conclusions could be made (Klein, 1974).

#### Faunal Composition of Localities

Table 3 shows the number of genera and number of individuals for each of the eight collecting localities with five or more genera present. Of these eight localities, BF 9 and 61 South were the most extensively collected, therefore, the data for each of these probably are the most reliable. The three 61 D West intervals and 61 D were also very thoroughly collected, however, each of these exposures was more limited in terms of area compared to either BF 9 or 61 South. As Table 3 indicates, 61

Table 3. Pelmatozoan data for the eight collecting localities in the study area with five or more genera represented.

	DIP	MON	DIS	CLA	POT	FLE	BLA
BF 9							
species	0	5	3	8	1?	3	4
individuals	0	9	41	33	1?	4	9-10
61 South							
species	0	9	2	13+	2	3	1
individuals	0	66+	12	21	2	3	2
61 D West (mid)							
species	0	8	3	5	1	0	1
individuals	0	39+	4	7	1	0	10
61 D West (top)							
species	0	5	1	0	0	0	1
individuals	0	9	2	0	0	0	3
61 D West (low)							
species	0	5	1	0	0	0	1
individuals	0	8	1	0	0	0	8
61 D							
species	1	5	2	4	0	0	1
individuals	1	15-16	2	7-8	0	0	2
61 B							
species	0	6	0	4	0	0	1
individuals	0	19	0	7	0	0	3
Route 953							
species	1	2	1	1	0	0	0
individuals	1	3	1	1	0	0	0

DIP: Diplobathrid Camerates  
 MON: Monobathrid Camerates  
 DIS: Disparid Inadunates  
 CLA: Cladid Inadunates  
 POT: Poteriocrine Inadunates  
 FLE: Flexibles  
 BLA: Blastoids

South contains the highest number by far of monobathrids, both in terms of species and in individuals. Actinocrinites, Agaricocrinus, Alloprosallocrinus conicus, and Uperocrinus comprise the bulk of these numbers. The disparids are represented by abundant Halysiocrinus tunicatus and Synbathocrinus whereas cladids are composed of a number of species each of Barycrinus and Cyathocrinites. 61 D West (middle) also is dominated by high numbers of monobathrids, including Actinocrinites, Agaricocrinus, Alloprosallocrinus conicus, Macrocrinus, and Platycrinites. Disparids are less abundant here though, but again they consist of Halysiocrinus tunicatus and Synbathocrinus. The cladids are the only other group present in any significant number. 61 D West (top) and 61 D West (lower) reflect more or less the same numbers as 61 D West (middle), however, the top and lower intervals contain no cladids. Data for 61 D indicate it to be very similar in composition to 61 D West (middle), with numbers falling somewhere in between those of the middle and the top and lower intervals.

Data for BF 9, however, show its faunal composition to be somewhat different from the above localities, especially 61 South. Although a number of monobathrids are present, they are quite fewer in number than those of 61 South, both in species and individuals. Disparids consist almost entirely of Halysiocrinus tunicatus and Synbathocrinus just as does 61 South and 61 D West but

they are much more abundant at BF 9. Cladids are diverse and moderately abundant, with a few species common only to BF 9, including Barycrinus sp. 2 and Cyathocrinites asperimus. Where BF 9 really differs from the Highway 61 localities is in the composition of its blastoid fauna. At least three (Dentiblastus, Granatocrinus and Hadroblastus) and possibly four (?Monadoblastus) species of blastoids are confined to BF 9. The Highway 61 localities, on the other hand, contain abundant specimens of a new spiraculate blastoid (currently being described by D.L. Meyer) a taxon unknown from BF 9. With regard to flexibles, both Gaulocrinus and Metichthyocrinus are restricted to BF 9.

#### Results of Cluster Analysis

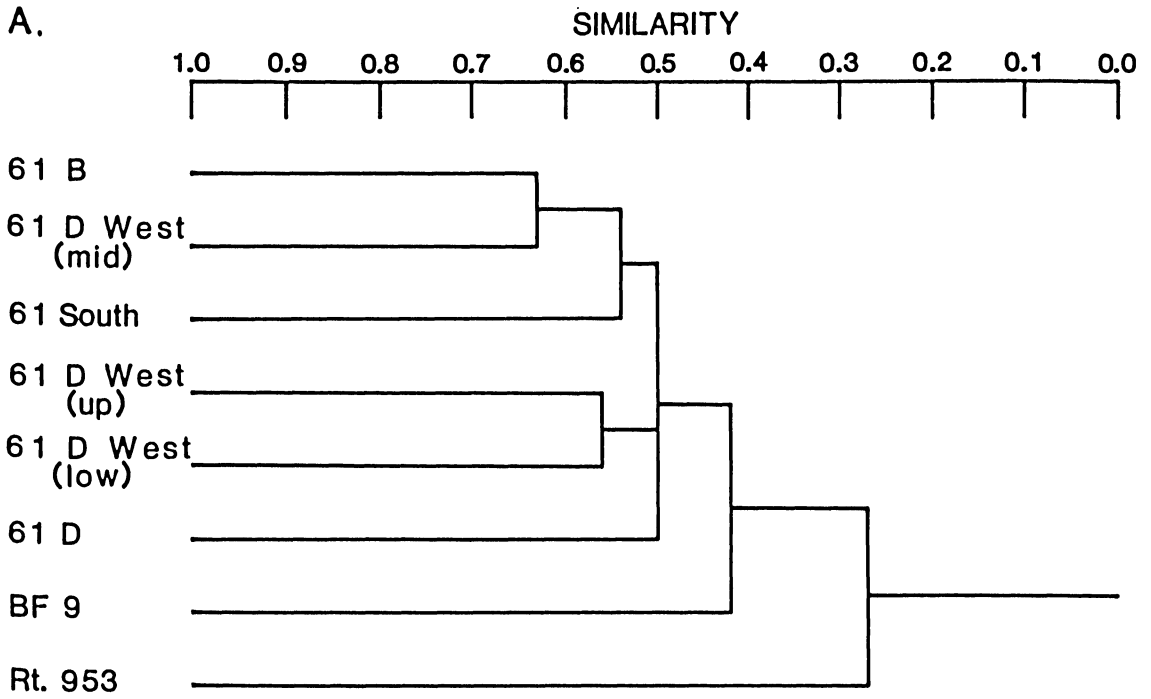
Interpretation of dendrograms:

I performed a cluster analysis using data from localities containing five or more genera, these being eight of the twelve collecting localities. Dendrograms of the results are illustrated in Figure 12. Localities that crop out along Highway 61 form a distinct cluster in Figure 12A whereas the BF 9 and Route 953 localities each form a single cluster respectively. In figure 12B, results for the average linkage clustering strategy are almost identical, the difference being in the slightly lower similarity values for the clusters.

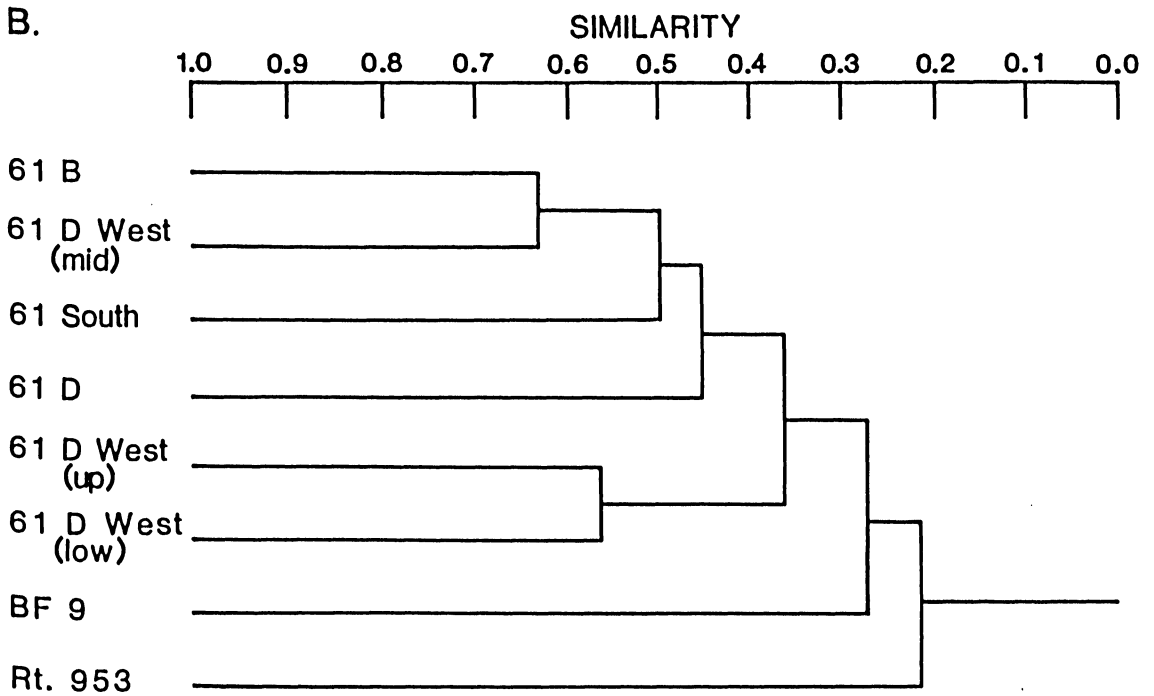
I also performed a cluster analysis of faunal data from a number of previously studied Keokuk localities and

Figure 12. Dendrograms for cluster analyses of collecting localities with five or more genera. The Jaccard coefficient was used as the measure of similarity. A. Single linkage. B. Average linkage.

A.



B.



from this study. Table 4 is a compilation of the presence/absence data that were used in this analysis and Figure 13 shows the dendrograms that were generated. In Figure 13B, the BF 9 and Button Mold Knob localities cluster together. The largest cluster includes the 61 South, 61 D West, Whites Creek Springs (Fort Payne Chert), 61 D, Allens Creek bank (Edwardsville Formation, Borden Group, Indiana), and Boy Scout Camp (Edwardsville Formation) localities. This large cluster then joins with the BF 9 and Button Mold Knob cluster. The three remaining localities, Whites Creek Springs (New Providence Shale), Cane Valley, and Beaver Creek, join with this main cluster at relatively insignificant similarity values.

Table 4. Presence/absence data of crinoid genera for selected Keokuk localities around the Illinois basin and within the study area. Button Mold Knob data is from Kammer (1982), Allens Creek bank, Boy Scout Camp and White's Creek Springs data is from Ausich (1978), and Beaver Creek and Cane Valley data is from Klein (1974).

1: present  
0: absent  
?: identification not confirmed

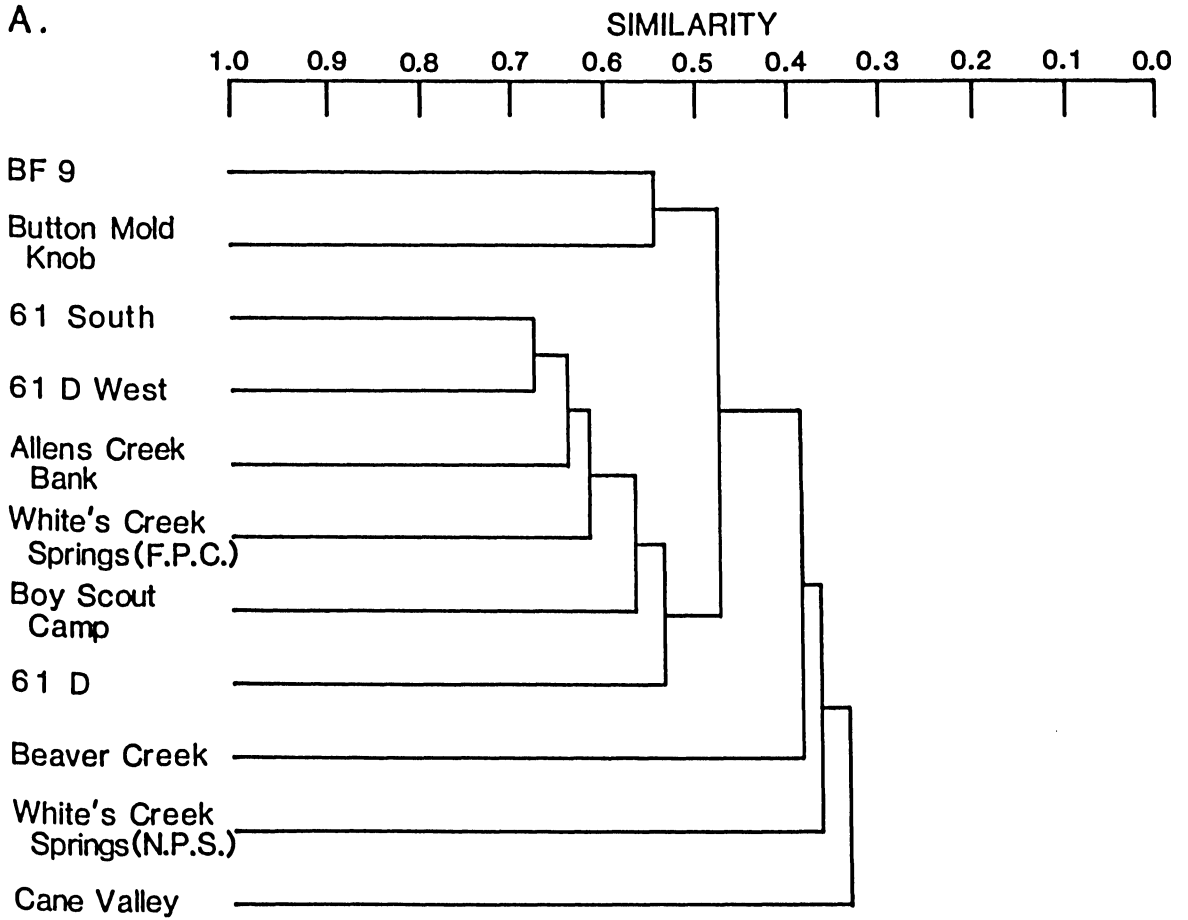
A=BF 9	H=Beaver Creek
B=61 South	I=White's Creek Springs (Ft. Payne Chert)
C=61 D	J=White's Creek Springs (New Providence Shale)
D=61 D West	K=Boy Scout Camp
E=Button Mold Knob	L=Total Monroe Reservoir
F=Allens Creek Bank	M=Total Crawfordsville
G=Cane Valley	

(Table 4 continued)

	A	B	C	D	E	F	G	H	I	J	K	L	M
Abatocrinus	0	1?	0	0	0	1	0	0	1	0	0	1	1
Abrotocrinus	0	0	0	0	0	1	0	0	0	0	1	1	1
Actinocrinites	1	1	1	1	1	1	1	0	1	0	1	1	1
Adinocrinus	0	1	0	0	0	1	0	0	1	0	0	1	0
Agaricocrinus	1	1	1	1	0	1	1	1	1	0	1	1	1
Alloprosallocrinus	0	1	1	1	0	1	0	1	1	0	0	1	1
Amphoracrinus	0	0	0	0	1	1	0	0	0	0	0	1	0
Atelestocrinus	0	0	0	0	0	0	0	0	1	0	0	1	0
Barycrinus	1	1	1	1	1	1	0	1	1	1	1	1	1
Cactocrinus	0	0	0	0	1	0	0	0	0	0	0	0	0
Catillocrinus	1	0	1	0	1	1	0	0	0	1	1	1	0
Cyathocrinites	1	1	1	1	1	1	1	1	1	0	1	1	1
Dichocrinus	1?	0	0	0	0	0	0	1	0	0	1	1	1
Dizygocrinus	0	0	0	1?	0	0	0	0	0	0	0	1	1
Dorycrinus	0	1?	0	0	0	1	0	0	1	0	1	1	0
Eretmocrinus	1	1	1	1	1	1	0	0	1	1	1	1	1
Forbesiocrinus	0	0	0	0	1	0	0	1	0	0	0	0	1
Gaulocrinus	1	0	0	0	1	0	0	0	0	0	0	0	0
Gilbertsocrinus	0	0	1	0	1	1	0	0	0	0	1	1	1
Halysiocrinus	1	1	1	1	1	1	1?	1?	0	1	1	1	0
Hypselocrinus	0	0	0	0	0	1	0	0	0	0	0	1	1
Macrocrinus	0	1	0	1	0	1	0	0	0	0	1	1	1
Mespilocrinus	1	1	0	0	1	0	0	0	0	0	0	0	0
Metichthyocrinus	1	0	0	0	1	0	0	0	0	0	0	0	0
Nipterocrinus	0	0	0	0	0	0	1	0	0	0	1	1	0
Onychocrinus	0	1	0	0	0	1	0	0	0	0	1	1	1
Paradichocrinus	0	0	0	0	1	1	1	0	0	0	1	1	1
Parichthyocrinus	0	0	0	0	0	0	0	1	0	0	1	1	1
Platyocrinites	1	1	1	1	1	1	0	0	0	0	1	1	1
Scytalocrinus	0	0	0	0	0	0	1	0	0	0	0	1	1
Springericrinus	0	0	0	0	1	1	0	0	0	0	1	1	1
Stinocrinus	0	0	0	0	1	0	0	0	0	0	0	0	0
Synbathocrinus	1	1	0	1	1	1	1	0	1	1	1	1	1
Taxocrinus	0	0	0	0	1	0	0	0	0	0	1	1	1
Uperocrinus	0	1	0	1	0	0	0	0	1	0	0	1	1

Figure 13. Dendrograms for cluster analyses of the study area and the previously studied Keokuk localities listed in Table 4. The coefficient of Jaccard was used as the measure of similarity. A. Single linkage. B. Average linkage.

A.





## DISCUSSION

### Transport and Deposition by Sediment Gravity Flows

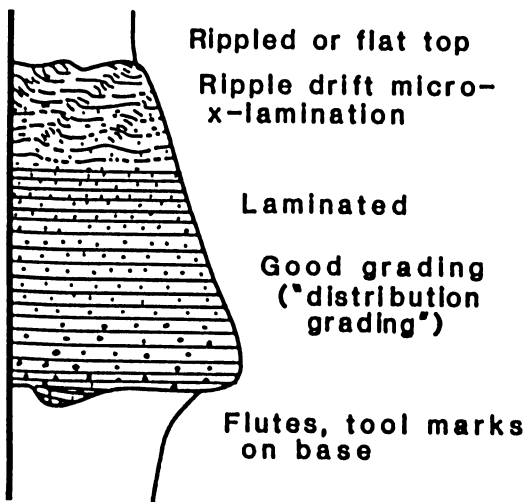
Middleton and Hampton (1976) discuss four sediment gravity flow types, each capable of transporting large volumes of coarse debris into ocean basins. Each of the following four types is characterized by the manner in which grains are supported within the flow: (1) turbidity currents, (2) grain flows, (3) fluidized sediment flows, and (4) debris flows. The authors hasten to add that these are only conceptual end members of a broad spectrum, and that in real flows, more than one type of grain support mechanism is generally in operation. Two of these flow types in particular, turbidity currents and debris flows, can transport significant quantities of sediment over long distances (Nardin et al., 1979). The following discussion is taken from Middleton and Hampton (1976) unless otherwise noted.

High concentrations of sediment are held in suspension in turbidity currents by the upward component of fluid turbulence. The flow may be divided into three main parts, the head, body, and tail. Processes in operation at any given time in a turbidity current might include erosion of the slope at the head of the current, incorporation of finer sediment into a dilute cloud that is swept along with the flow, concentration of coarsest sediment into the head with the loss of fines, dilution of the flow with water mixed in from above the flow, and

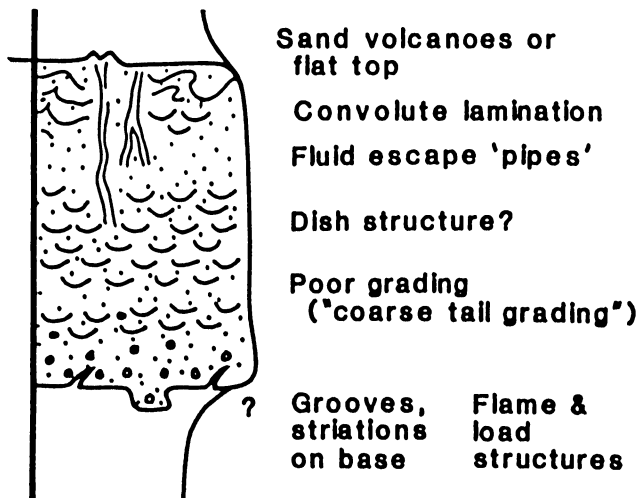
rapid deposition of sediment from the body and tail. Such deposits display a variety of diagnostic sedimentary structures the most characteristic of which are sole marks and graded beds. The idealized turbidite bed in Figure 14 known as a Bouma sequence reflects the progressive deposition from the head to the tail of a turbidity current from its base to the top.

Sediment within a grain flow is cohesionless and is supported by dispersive pressure, that is, individual grains "bounce off" one another. Relatively large angle slopes (18-37 degrees) (p. 206, 1976) are required for uniform grain flow and deposition of the entire flow results by "freezing". Deposits generally are five centimeters or less in thickness (Lowe, 1976) and are presumed to be of small importance in nature except on avalanche slopes (Nardin et al., 1979). There exists, however, a continuum between grain flows and turbidity currents with some flows being a combination of the two types: an upper turbidity current with grains supported by turbulence and a lower grain flow with grains supported by dispersive pressure (p. 204). Successive grain flow layers deposited at the base of large turbidity currents could, therefore, coalesce as thick grain flow deposits (Nardin et al., 1979). Grain flow deposits are difficult to recognize but may be characterized by beds with sharp upper and lower contacts, inverse graded bedding, and by an absence of erosional features (Fig. 14).

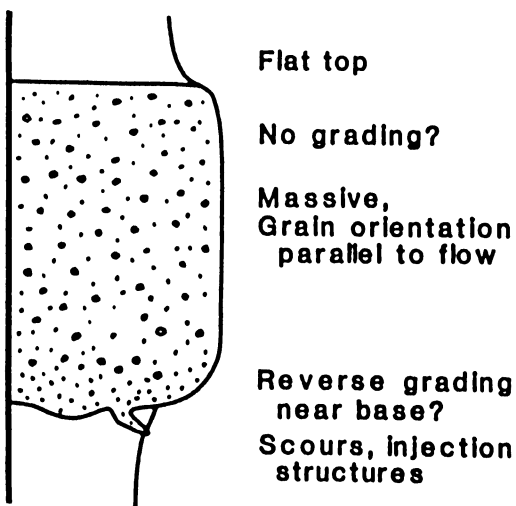
## Turbidity Current



## Fluidized Flow



## Grain Flow



## Debris Flow

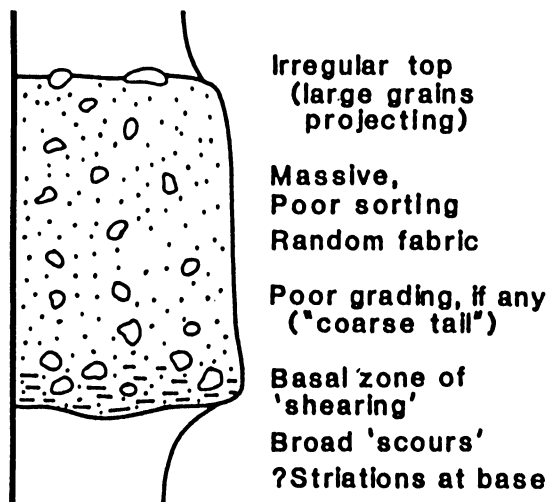


Figure 14. Sequence of structures associated with each of the four hypothetical sediment gravity flow deposits described by Middleton and Hampton (1976, Fig. 9).

Grains subject to liquified flow are loosely packed and are supported in part by pore fluids. Once a fluidized flow is initiated, grains are supported by pore fluid at pressures which rise above normal hydrostatic pressures. Such flows may be one thousand times as viscous as water, allowing them to flow rapidly down relatively gentle slopes. Fluidized flows typically are short-lived, however, because the excess pore pressures rapidly decrease as fluid is lost upward through the pores. The flow loses its ability to support the grains and consolidation occurs. Recognizable features include dish structures, load structures, and convolute lamination (Fig. 14).

In a debris flow, grains are usually supported by a fluid matrix composed of clay minerals and water; together these materials act as a single fluid. The grains, in essence, are rafted along by the cohesive strength of the fluid phase and if the fluid matrix is strong and dense enough, debris flows may move on any slope. Grains too large to be supported by the fluid, however, would be left behind at the source thus resulting in a specific size distribution of grains within the flow. Deposition occurs when the driving stress of gravity decreases below the strength of the debris, and the flow "freezes". Middleton and Hampton emphasize that although strength and buoyancy are the main support mechanisms, dispersive pressure and turbulence may also play a role in debris flows. Debris

flow deposits generally are matrix-supported with poorly developed grading and fabric (Nardin et al., 1979). They are also massive and unstratified, although internal flow structures may occur within the deposit (Nardin et al., 1979), with poorly developed sole marks and an irregular upper surface. Large clasts, if present, are randomly distributed within the deposit and may project above the upper surface as well.

#### Characteristics of Carbonate Gravity Flow Deposits

Cook et al. (1972) describe allochthonous carbonate debris flow deposits containing large blocks from basin strata adjacent to three Devonian reef complexes in Alberta, Canada. These coarse-textured, shoal-derived, debris-bearing units occur as tongues and channels that extend from the shallow water buildups into the basin facies (Fig. 15). They are located in a transitional area between shoal water and more distal parts of the basin, a geologic setting of little relief and with gentle depositional slopes. Sheets of megabreccia and conglomerate up to ten meters thick and extending several kilometers or more into the basin comprise the most conspicuous facies. Finer-grained and thinner sheets with planar bases and irregular hummocky upper surfaces and channel deposits are less common. The authors suggest a variety of transport and depositional processes as being responsible for the origin of these allochthonous deposits, the most significant being subaqueous debris

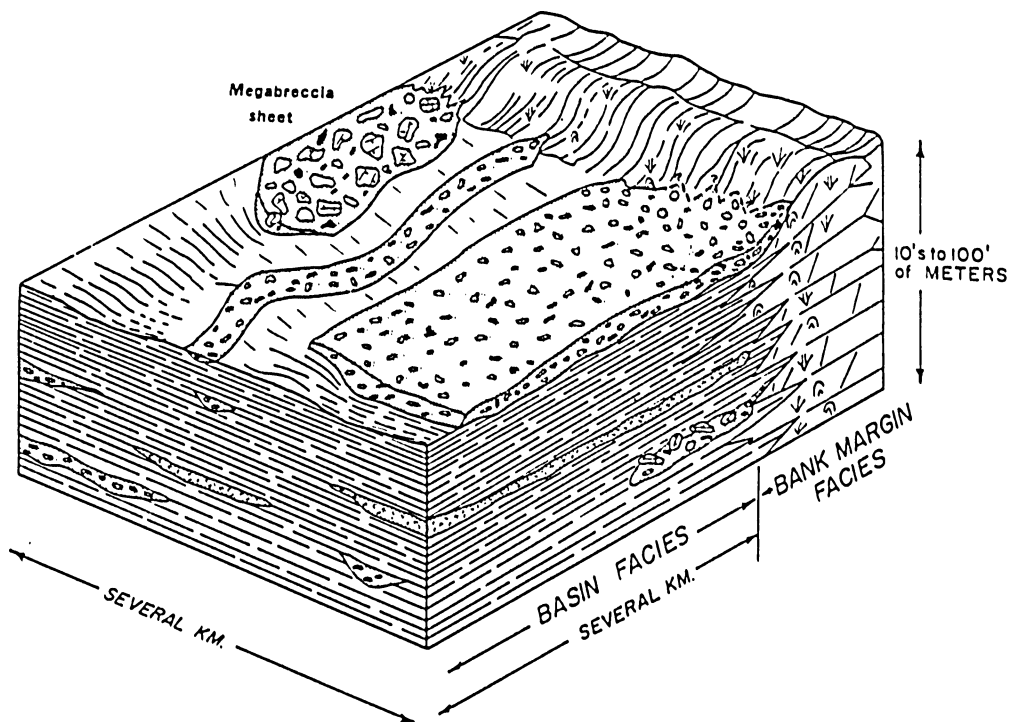


Figure 15. Generalized representation of allochthonous carbonate debris flow deposits at bank and reef margins (Cook et al., 1972, Fig. 5). These mass-transported carbonate deposits typically occur as randomly distributed thin-bedded turbidites in channel and sheet form and as large debris flow sheets, aprons or wedges.

flows. Locally graded sand- and silt-size deposits may represent transport and deposition from turbidity currents whereas subaqueous sliding and slumping were evidently minor. Although the carbonate deposits of the study area do not contain large blocks and are not conglomeratic, some of the planar bedded argillaceous limestones appear to resemble the thin-bedded sheets described above. In addition, the graded deposits Cook et al. describe may be analogous to those of the study area as well (see Pl. 4). There is a difference in scale, however, between the Devonian gravity flow deposits and those of the Fort Payne Formation, the latter being mappable over distances of a few hundred meters rather than tens of kilometers. The largest mappable deposit within the study area is the carbonate buildup on Highway 61. Even when taking into consideration that the pinch and swell beds at the base of 61 B are continuous with the 61 Buildup, its greatest dimension is still only a few hundred meters at most (see Fig. 4 for distance from 61 B to the buildup).

Davies (1977) describes two types of gravity-displaced rocks in the Hare Fiord Formation (Pennsylvanian to Lower Permian), both of which strongly resemble carbonates of the study area. First are well-bedded, internally size-graded crinoidal limestones that attain a maximum thickness of about 30 centimeters. They consist up to 95% by volume of crinoidal debris, their basal contact is planar whereas upper contacts are gradational

into argillaceous and calcareous fine-grained clastic rocks, and they lack recognizable Bouma cycles. He interprets these as being deposited from turbidity currents. The second type are massive-bedded, carbonate debris sheets, which exhibit planar to undulose basal contacts and irregular upper surfaces. Large-scale variations in thickness of these deposits imparts to them a lenticular or mound-like profile whereas a few of the deposits possibly are channelized (Davies, 1977). These he interprets as having been deposited from debris flows. The depositional environment for the Hare Fiord carbonates, the slope adjacent to a carbonate shelf in the Sverdrup basin, is analogous to that of the study area as well. Well-bedded crinoidal limestones resembling those described by Davies are found within the study area at the 61 B outcrop (Fig. 9). Moreover, the 61 Buildup is correspondingly analogous to the Hare Fiord massive-bedded carbonate sheets that display a mound-like profile.

Cook (1982) notes that mass-transported carbonate sediment deposits typically form randomly distributed debris aprons as opposed to the more orderly facies sequences such as are found in clastic submarine fans. Furthermore, carbonate submarine fan systems are exceedingly rare in the geologic record. In central Nevada, however, the predominantly carbonate lithofacies of an exposed Paleozoic continental margin sequence exhibit orderly facies patterns analogous to those of

clastic turbidite fan deposits. Cook (1983) suggests at least three possible origins for these deposits: one being as single, episodic debris sheets; the second as debris sheets punctuated by random sheet flows of calcarenites; and the third as submarine fans. His conclusion is that they represent a combination of processes, these being debris sheet and submarine fan deposition. His interpretation includes channelized deposits in both inner- and mid-fan positions near the basin margin; thin-bedded turbidites in basin plain, outer-fan fringe and interchannel settings; and unchannelized outer-fan sheet-like lobes. Once again, however, there are great differences in scale between the carbonate deposits of the study area and those described by Cook. In addition, rocks of the study area do not exhibit orderly facies patterns although the variety of lithofacies present does suggest a combination of depositional processes such as the above example.

#### Submarine Fans Versus Carbonate Aprons

The random distribution of debris within ancient carbonate mass-transported deposits as opposed to the more orderly facies sequences of terrigenous submarine fan deposits has led to the proposal of alternative models for the origin of carbonate sediment gravity flow deposits by Mullins and Cook (1986). They note the major difference between submarine fans and carbonate aprons to be a point source with channelized sedimentation on fans versus a

line source with sheet-flow sedimentation on aprons. Other significant differences are summarized in Table 5. Mullins and Cook also present two carbonate apron models drawn from the original debris sheet model of Cook et al. (1972) (Fig. 15). The first apron type, referred to as a carbonate slope apron, is found along relatively gentle ( $<4^\circ$ ) platform-margin slopes. The second type, called a carbonate base-of-slope apron, is found where there are relatively steep ( $4-15^\circ$ ) platform margin slopes. Here gravity flows bypass the upper slope via multitudes of small submarine canyons, depositing their sediment load at the base of the slope instead. Both apron types are further subdivided into inner and outer facies belts. Table 6 lists additional features of the two carbonate apron types.

#### Characteristics of Carbonate Mud Mounds

Massive carbonate mud mounds and associated lithofacies referred to as the Waulsortian facies are known from Lower Mississippian (Kinderhookian to Osagean) deposits in North America, Europe and North Africa. At least two types have been distinguished on the basis of their paleoenvironmental setting: one occurred at shelf margins whereas the second occurred in a basinal setting. All other features such as shape, lithology, sedimentary textures and structures, and fauna are virtually identical; these are listed in Table 7. Several features of the 61 Buildup offer compelling evidence for its

## CARBONATE DEBRIS-SHEET MODEL

1. Redeposited facies result from unchanneled sheet-flow events that originate parallel to and along adjacent platform margins.
2. Carbonate debris-flow deposits form a major facies type.
3. Apron sediments are segregated laterally into inner and outer facies belts.

Geologic occurrence: virtually throughout geologic column in a diversity of tectonic and stratigraphic settings; carbonate slope, base-of-slope, and basin-plain sequences.

Geometry: large, mud-rich fans that tend to be elongate.

## SUBMARINE-FAN MODEL

1. Fan facies are characterized by channeled flow along inner- and middle-fan regions and sheet flow only on outer portions of fans.
2. Debris-flow deposits play a lesser role; fan facies are dominated by turbidity-current processes with debris-flow deposits largely confined to inner parts of fans.
3. Orderly sequences of thickening- and thinning-upward fan facies.

Geologic occurrence: wide variety of geologic settings throughout the geologic record, however, exposures of carbonate submarine fan systems are RARE as opposed to clastic submarine fans.

Geometry: sand-rich fans are characterized by radially-shaped geometries in map view and mounds in cross-section.

Table 5. Comparison of carbonate mass transport models (compiled from Mullins and Cook, 1986).

CARBONATE SLOPE APRON

CARBONATE BASE-OF-SLOPE APRON

Type of Slope:	Relatively gentle ( $<4^\circ$ )	Relatively steep (4-15°)
Where Deposited:	Immediately adjacent to shallow-water platform.	Upper slope is bypassed; deposits found at base-of-slope.
Facies	Inner Facies Belt:	
Characteristics:	-thick, mud-supported conglomerates and megabreccias -thick, coarse-grained turbidites interbedded with subordinate amounts of fine-grained, peri-platform ooze.	
	Outer Facies Belt:	
	-thinner, grain-supported conglomerates and turbidites -classical turbidites with recognizable Bouma divisions, interbedded with approximately equal proportions of peri-platform ooze.	
Facies	Seaward:	
Relationships:	Aprons grade laterally into basinal facies of thin, base-cut-out carbonate turbidites that are subordinate to peri-platform ooze.	
	Shelfward:	Shelfward:
	Apron grades immediately into shoal-water, platform-margin facies without an intervening bypass slope.	Apron grades into an upper slope facies of fine-grained peri-platform ooze cut by numerous small canyons that are filled with coarse debris as well as intraformational truncation surfaces which result from submarine sliding.

Table 6. Characteristics of carbonate apron deposits (compiled from Mullins and Cook, 1986).

Table 7. Characteristics of Lower Mississippian carbonate mud mounds. Two types have been identified on the basis of their paleoenvironmental setting (compiled from Pratt, 1982).

## SHELF MARGINAL

## BASINAL

Geometry	Massive, unchannelized sheets of limestone (restricted to Ireland).	Large, individual micrite mounds that are lensatic or smooth, rounded, and almost perfectly conical; diameters and thicknesses range from less than ten to several hundreds of meters.
Mound Lithofacies	Four basic types: 1) lime mudstone or wackestone core (50 to 80% of rock volume); 2) sparry calcite and <u>Stromatactis</u> (10 to 15%); 3) fenestrate bryozoan fronds and <u>crinoid ossicles</u> (4 to 20%); and 4) flanking grainstones of winnowed crinoid debris, often forming "halos" around mound.	
Associated Lithofacies	1) Flanking bioclastic grainstones grade laterally into intermound rock of sparsely fossiliferous, argillaceous, often cherty, thin- or nodular-bedded lime mudstones, wackestones and shales.	
Depositional and Early Postdepositional Features	1) Dips both within mounds and of flanking beds generally range from greater than ten up to fifty degrees; 2) where present, layering is parallel to the convex upper surface; 3) some mounds have shed a talus of lithified blocks; 4) mounds often exhibit early, submarine dilatational fracturing, producing dike-like fissures that are infilled with crinoidal debris; 5) no evidence for soft sediment compaction.	
Fossils	1) Framebuilding organisms are conspicuously absent; 2) fenestrate bryozoans and pelmatozoans dominate the fauna; 3) brachiopods, gastropods, ostracodes, trilobites, cephalopods, sponge spicules, conodonts and forams are less common; 4) burrows are rare and evidence for extensive bioturbation is lacking.	
Taphonomy	1) Fossils are both articulated and disarticulated, but not broken or abraded; 2) many occur concentrated in pockets ("nests") or as thin discontinuous grainstone beds.	

interpretation as a Waulsortian mud mound. These include its lensatic profile, the local abundance of crinoids and bryozoans, the presence of in situ crinoids on its upper surface, and the nature and distribution of its various lithologies. More specifically, the Waulsortian-type lithologies of the 61 Buildup include overlying coarse-grained, bioclastic packstone and wackestone sheets and less commonly, burrow mottled wackestones and pelletal micstones (rare) within the massive middle unit. Less compelling, however, is the presence of dolomitic rip-up clasts near the base of the buildup, the absence of steep depositional dips within flanking beds, the lack of a positive identification of Stromatactis, and the lack of any significant core facies.

#### Lower Mississippian Crinoid Community Types

Three suspension-feeding community types, each defined on the basis of their crinoid faunas, have been recognized in Keokuk-aged rocks of the eastern continental interior (Ausich, 1978; Ausich, Kammer and Lane, 1979). Binary cluster analysis clearly defines only one of them, this being the poteriocrine inadunate community, which contains an extremely high diversity of poteriocrines. The other two, although not as well defined, are the monobathrid-disparid and the equitable diversity communities. The monobathrid-disparid community is dominated in terms of abundance and diversity by monobathrid camerate and disparid crinoids whereas the

equitable diversity community has all groups, except perhaps for the poteriocrines, more equally represented.

The distribution of these three community types is strongly controlled by physical environment as indicated by the consistent recurrence of each type in similar depositional settings (Kammer, Ausich and Lane, 1983). Ausich's (1978) study at Monroe Reservoir in Indiana determined that the poteriocrine inadunate community lived on a substratum of fine-grained quartz sand or silt, such as found within distributary sandstone channels and sheet sandstones developed on the Borden delta platform. The monobathrid-disparid community flourished on a bioclastic carbonate substratum, such as commonly found on carbonate banks or bioherms. The most widespread community type, the equitable diversity community, is primarily confined to fine-grained terrigenous facies such as are found in both interdistributary siltstones and mudstones on the delta platform and in mudstones at the base of the delta slope. During the Keokuk, all three crinoid communities occurred along the western, eastern, and southern margins of the Illinois basin (Ausich and Lane, 1985). In addition, there are small scale taxonomic differences between the respective localities, which are attributable to geographic endemism (Ausich and Lane, 1985).

Crinoid Communities and Their Associated Lithofacies  
in South-central Kentucky

Two of the three crinoid community types discussed above are present within the study area, the monobathrid-disparid and the equitable diversity communities. Crinoids from the BF 9 locality are interpreted as belonging to the equitable diversity community type for several reasons. First of all, although it can be argued that most crinoid groups are as equally well represented at the 61 South and 61 D West localities as they are at BF 9, the number and variety of monobathrids at BF 9 are few in comparison with numbers for 61 South and 61 D West (Table 4). Secondly, when compared to other Keokuk localities, BF 9 clusters not with Highway 61 localities but with the Button Mold Knob locality (Fig. 19), the fauna of which belongs to the equitable diversity community type. Lastly, the lower stratigraphic position of BF 9 combined with its distance from the Highway 61 localities, are reasons to suggest that its depositional environment might possibly differ from that of the other localities, despite the fact that all occur in predominantly fine-grained terrigenous rocks. The shale bedding planes at 61 South and 61 D West are interbedded with carbonates that are somewhat different in character than those found at BF 9 (those at BF 9 being comparatively thinner- and more planar-bedded and finer-grained). Furthermore, if indeed all rocks within the study area were deposited on a clinoform slope with foresetlike beds as suggested by Klein (1974), the

environment of the BF 9 locality consequently would have been more basinward than the Highway 61 localities.

Faunal assemblages at the 61 South and 61 D West localities, therefore, are interpreted as belonging to the monobathrid-disparid community type. The high degree of similarity between these two localities is illustrated by the dendrograms in Figure 13, both of which show that 61 South and 61 D West join as a single cluster prior to their linking with other localities.

Defining community types for the other faunal assemblages found within the study area is somewhat problematic. Employing the same reasoning as above, the faunal assemblages of 61 D and 61 B are suggested to constitute the monobathrid-disparid community type. Unfortunately, data for the 61 A, 61 C, Old 61, Route 953 and 61 Buildup localities are too incomplete to warrant strong conclusions.

#### Taphonomy

Further details of community structure may be gleaned from an analysis of taphonomic processes. The abundance of preserved crinoid material at green shale localities within the study area provides a perfect opportunity for such an analysis. Although the taphonomy of each of the green shale localities (61 D, 61 D West, 61 South and BF 9) is similar, there are degrees of difference, with BF 9 reflecting a less turbulent environment.

Fossils at BF 9 generally are articulated with excellent preservation of minute details. Abundant articulated arm segments and cup plates are indicative of little, if any, transport away from original life positions. Indeed, the degree of disarticulation at BF 9 is strikingly similar to what Meyer (1971) reported in a study of the disarticulation rates of dead comatulid crinoids under natural low energy conditions. He found that the centrodorsal, radials and some proximal brachials of the calyx plus arm fragments consisting of several brachials remained articulated for at least six days after death whereas the major parts of the arms and cirri break after only two to three days. In contrast, Liddell (1975) found that complete disarticulation of a comatulid skeleton takes place in only two days in agitated natural environments. The skeletal remains of crinoids at the BF 9 locality, therefore, may have persisted on the sea floor for a few days prior to burial. If death had occurred rapidly as the result of a sudden influx of a significant volume of sediment, preservation of more completely articulated specimens would be expected. In this case, however, burial may not have been deep and subsequent bioturbation of the upper few centimeters of sediment could have disturbed the remains of any organisms buried just beneath the sediment surface. Another scenario might entail the sudden influx of a thin blanket of sediment sufficient to cause death but insufficient for complete

burial of many larger organisms. Settlement of the finer sediment fraction for a period of time afterward would subsequently bury remaining skeletal material.

Preservation of the pelmatozoan fauna at the three remaining green shale localities, 61 D, 61 D West and 61 South, reflects more turbulent environmental conditions. Stem fragments are the dominant skeletal element, with dissociated cup and arm plates much less common than at BF 9. This suggests that current winnowing may have played a significant taphonomic role at these localities. In addition, bryozoans typically are more fragmented here than at BF 9.

Where crinoid material is preserved in abundance in other lithofacies, taphonomic evidence indicates a predominantly allochthonous origin. Within the argillaceous carbonates and the grainstones, skeletal material is broken and abraded and consists chiefly of relatively robust stem fragments. Smaller, more fragile skeletal fragments such as cup and brachial plates are much less common. Nonetheless, long articulated lengths of crinoid stems are quite common within some carbonate beds. This is because ligamentary articulations joining the columnals are more resistant to breakage as opposed to the muscular articulations that typically join other plates. In addition, whole camerate cups sans arms and stem are not uncommon in some of the argillaceous carbonate beds. This manner of preservation is

attributable to the more rigid nature of the camerate theca in comparison to other crinoid groups.

Taphonomic analysis of crinoid material within the dolosiltstones suggests the greatest transport distances of all the lithofacies. Skeletal fragments are almost without exception disarticulated, are very low in abundance, and overall are fine- to very fine-grained. Small, disarticulated crinoid columnals comprise the dominant portion of the skeletal material.

## SUMMARY

Sedimentologic evidence indicates that most carbonate and clastic rocks within the study area have an allochthonous origin. In addition, a large part of the crinoid debris contained within these rocks is interpreted to be allochthonous although certain occurrences are deemed to be in situ assemblages. Sediment gravity flows previously have been identified by Klein (1974) as the means by which both bioclastic and terrigenous sediment were transported in Fort Payne time. The dominant types of carbonate deposits within the study area are interpreted to be turbidites and debris flow deposits located at or near the base of the paleoslope.

Rocks exposed at both the 61 A and 61 B outcrops are illustrative of the facies and facies relationships that characterize the base-of-slope carbonate apron model described by Mullins and Cook (1986) (Pls. 7 and 8, Table 6). The pinch and swell carbonate deposit at the base of 61 B is exemplary of a sheet-like debris flow deposit whereas the debris flow deposit of Plate 7 is more channelized. The latter deposit consists of an erosional channel filled with relatively coarse-grained and poorly sorted debris. It is comparable to the upper slope facies of the base-of-slope apron model, which typically is cut by numerous erosional channels filled with coarse debris. The planar carbonate beds continuous across the 61 B outcrop face and the overlying broad channel deposit, on

the other hand, were deposited by turbidity currents. These along with the sheet-like debris flow deposits and the broad channelized turbidite of Plate 8 are more characteristic of the inner facies belt of the apron itself. The thinner-bedded, unchannelized turbidites exposed near BF 9 in turn belong to the outer facies belt.

Taphonomic evidence suggests that most of the crinoid debris comprising these deposits is allochthonous. A platform margin source is certainly possible considering the ability of debris flows to transport large volumes of sediment with very little turbulent motion. Much of the crinoid debris, however, also came from within the study area where pelmatozoans colonized the surfaces of debris flow deposits. Successive flows would incorporate the bodies of crinoids that had colonized the bioclastic surfaces of earlier flows. The remains of whole albeit disarticulated crinoid skeletons on the uppermost surface of the 61 Buildup attests to this type of colonization.

The in situ remains at the green shale localities, however, are indicative of a more stable paleoenvironment. Here benthic communities were able to flourish for significant periods of time and differentiation of two community types occurred. Although the finer grained substrate might indicate a relatively quiescent environment, interbedded argillaceous carbonate turbidites suggest periodic influxes of allochthonous material. Furthermore, the green shales are always associated with

either debris flow deposits and/or turbidites suggesting that their depositional environments are somehow related. The green shales might possibly comprise a distinct facies within the apron model, however, more sedimentologic information is necessary to warrant stronger conclusions.

The occurrence of two different crinoid community types within the green shales is significant because although each type has been described from a number of Illinois basin localities, each has been interpreted as having occupied distinct paleoenvironmental settings. The presence of the monobathrid-disparid community at the Highway 61 localities suggests a fairly uniform depositional environment with moderate current velocities. In contrast, the equitable diversity community at BF 9 is known to have prevailed at much lower energy conditions.

On the basis of the distribution of crinoid communities BF 9 is interpreted to fall within the outer facies belt and the Highway 61 localities within the inner facies belt of the base-of-slope carbonate apron model. Figure 16 is a schematic representation showing the distribution of the facies belts of the carbonate apron and the relative positions of the crinoid communities.

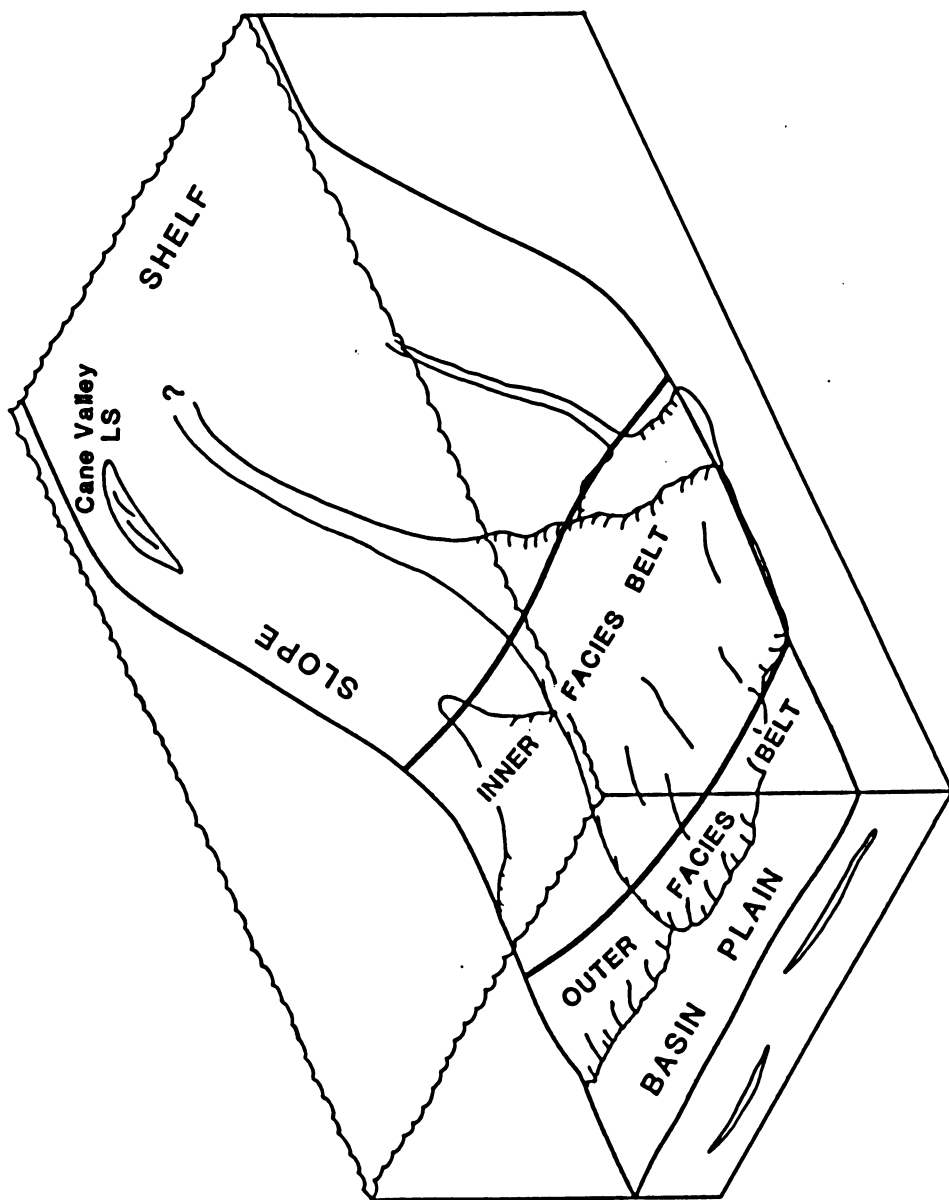


Figure 16. Schematic representation of the carbonate apron facies belts and the relative positions of Ft. Payne crinoid occurrences. Highway 61 localities are within the inner facies belt whereas BF 9 is in the outer facies belt. Adapted from Fig. 124, p. 611 in Cook and Mullins, 1983.

## CONCLUSIONS

1. The heterogeneous lithofacies of the Fort Payne Formation in south-central Kentucky near Burkesville were deposited by sediment gravity flows moving down a clinoform slope that was developed roughly parallel to the Borden delta paleoslope. Debris flow deposits and turbidites are the dominant types of deposits within the study area.
2. These lithofacies exhibit a variety of sedimentary textures and structures resembling the nonorderly facies described in base-of-slope carbonate aprons, including sheet-like and channelized debris flow deposits in middle slope and inner facies belt positions and turbidites in both inner and outer facies belt positions.
3. Carbonate facies consist chiefly of abundant allochthonous crinoid debris; occasionally the upper surfaces of these deposits were colonized by crinoids. Crinoid material within carbonate facies, therefore, was derived from the platform as well as from previous gravity flow deposits.
4. Clastic facies typically are unfossiliferous although one lithology in particular, green shale, contains abundant well-preserved pelmatozoans; on the basis of taphonomic evidence these are determined to be largely autochthonous accumulations.
5. Taphonomic evidence indicates that crinoid material within the dolosiltstones was transported the greatest

distance from its source, and that crinoid material within the green shales is in situ. Furthermore, a greater degree of disarticulation and abrasion of crinoid debris at the Highway 61 localities than at BF 9 suggests an environment subject to higher current velocities at those localities.

6. Cluster analysis of crinoids from green shale localities reveals the presence of two crinoid community types: the monobathrid-disparid community, which is dominated in terms of abundance and diversity by monobathrid and disparid crinoids; and the equitable diversity community, which has all groups, except for the poteriocrines, more equally represented.

7. Comparison of the faunal composition of the study area with that of other localities from the Illinois basin indicates a Keokuk age.

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APPENDIX 1. Faunal register and lists of fauna by locality.

Grand Total

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates <u>Gilbertsocrinus</u> sp.	2
2. Monobathrid Camerates	
<u>Abatocrinus?</u>	1
<u>Actinocrinites</u> sp.	38-41+
<u>Agaricocrinus</u> sp.	37+
<u>Alloprosallocrinus conicus</u>	27
<u>Dichocrinus?</u>	1
<u>Dizygocrinus?</u>	1
<u>Dorycrinus?</u>	1
<u>Eretmocrinus</u> sp.	12+
<u>Macrocrinus</u> sp.	27
<u>Platycrinites hemisphericus</u>	17+
<u>Uperocrinus</u> sp.	17
3. Disparid Inadunates	
<u>Catillocrinus</u> sp.	2
<u>Halysiocrinus tunicatus</u>	29
<u>Synbathocrinus</u> sp.	32
Unidentified basal circlet	1
4. Cladid Inadunates	
<u>Adinocrinus nodosus</u>	1
<u>Barycrinus</u> sp. 1	9-10
<u>Barycrinus</u> sp. 2	2
<u>Barycrinus cornutus</u>	8
<u>Barycrinus</u> sp.?	5
<u>Barycrinus</u> holdfasts, stems	9
<u>Cyathocrinites</u> sp. 1	11
<u>Cyathocrinites</u> sp. 2	15
<u>Cyathocrinites</u> sp. 3	5
<u>Cyathocrinites</u> sp. 4	3
<u>Cyathocrinites asperrimus</u>	3
<u>Cyathocrinites</u> sp. 6	2
<u>Cyathocrinites</u> sp.?	2
5. Flexibles	
<u>Gaulocrinus</u> sp.	2
<u>Mespilocrinus</u> sp.	2
<u>Metichthyocrinus</u> sp.	1
<u>Onychocrinus?</u>	1
Unidentified cup	1
6. Blastoids	

N. Genus A.	28
<u>Dentiblastus</u> n. sp.	3
<u>Granatocrinus granulatus</u>	4-5
<u>Hadroblastus</u> n. sp.	1
<u>Monadoblastus?</u> n. sp.	1

61 A

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates	
<u>Actinocrinites</u> sp. (15 radials, basal, 4 cup plates, partial cup)	4-5
<u>Platycrinites hemisphericus</u> (radial)	1
3. Disparid Inadunates	0
4. Cladid Inadunates	
<u>Barycrinus cornutus</u> (2 radials)	1
<u>Cyathocrinites</u> sp. 3? (1 radial)	1
5. Flexibles	0
6. Blastoids	0
Anal chimney, geodized stem	
Corals: rugose; tabulate ( <u>Cladochonus c.</u> )	
Brachiopods	
Molluscs: <u>Platyceras</u> sp.	

61 B

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates	
<u>Actinocrinites</u> sp. (cup: 37-41 m; *cup: 37.5-38.2 m; partial cup: 38.7 m; basal: 39.5 m; basal circlet: 40.5 m)	5
<u>Agaricocrinus</u> sp. (cup: 37.5-38.2 m; *cup: 37.5-38.2 m; cup: 38.8 m; 2 partial cups: 37.5 m; partial cup: 35 m)	6
<u>Alloprosallocrinus conicus</u> (partial cup: 37.5; partial cup: 38 m)	2
<u>Eretmocrinus</u> sp. (arm segments: 36-39 m, 40 m)	2
<u>Platycrinites hemisphericus</u> (basal circlet: 26 m; stem: 32 m)	2
<u>Uperocrinus</u> sp. (*cup: 37.5-38.2 m; partial cup: 37.5 m)	2
3. Disparid Inadunates	0
4. Cladid Inadunates	
<u>Barycrinus</u> sp. 1 (radial: 26 m; radial: 35 m; cup: 38.2 m)	3
<u>Barycrinus</u> sp. 2 (cup: 39.5 m)	1
<u>Barycrinus cornutus</u> (2 radials: 26 m)	1
<u>Barycrinus</u> sp. ? (stem)	1
<u>Cyathocrinites</u> sp. 2 (2 radials: 36 m)	1
5. Flexibles	0
6. Blastoids	
N. Genus A. (large cup: 32-36 m; cup: 39.2 m; cup: float)	3

\*Specimen not collected; identified from photo.

Brachiopods

Corals: tabulates (Cladochonus c.); rugose

Crinoids: miscellaneous plates, dendritic holdfast

Bryozoans

One ? cup

61 Build-up

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates	
<u>Actinocrinites</u> sp. (cup)	1
<u>Agaricocrinus</u> sp. (*cup)	1
<u>Alloprosallocrinus conicus</u> (cup)	1
<u>Eretmocrinus</u> sp. (partial cup: 33-34 m)	1
<u>Macrocrinus</u> sp. (cup: 33-34 m)	1
3. Disparid Inadunates	0
4. Cladid Inadunates	0
5. Flexibles	0
6. Blastoids	0

\*Specimen not collected; identified from photo.

61 C

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates <u>Eretmocrinus</u> sp. (cup: 53 m)	1
3. Disparid Inadunates	0
4. Cladid Inadunates	0
5. Flexibles	0
6. Blastoids	0

## 61 D

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates <u>Gilbertsocrinus</u> sp. (partial cup)	1
2. Monobathrid Camerates <u>Actinocrinites</u> sp. (basal circlet: 61 m; basal circlet: 62.8-63 m; basal circlet: 60-64 m; basal: 62.8-63 m; cup plate: 61 m; cup plate: 67 m; 3 cup plates: 60-64 m; 2 cup plates: 62.8-63 m)	7-8
<u>Agaricocrinus</u> sp. (partial cup: 69.8 m; cup: 70.1 m)	2
<u>Alloprosallocrinus conicus</u> (2 basal circlets: 61 m)	2
<u>Eretmocrinus</u> sp. (cup: 67.5 m; cup?: 60-64 m)	2
<u>Platycrinites hemisphericus</u> (radial: 67.5 m; basal circlet: 61 m)	2
3. Disparid Inadunates <u>Catillocrinus</u> sp. (cup: 60-64 m)	1
<u>Halysiocrinus tunicatus</u> (cup: 67 m)	1
4. Cladid Inadunates <u>Barycrinus</u> sp.1 (3 radials: 60-64 m; 3 radials: 61 m; cup plate: 61 m)	2-3
<u>Barycrinus</u> sp. ? (holdfast: 62.8-63 m; holdfast: 60-64 m; holdfast: 69.4 m)	3
<u>Cyathocrinites</u> sp. 1 (radial: 61 m)	1
Unidentified cup (60-65 m)	1
5. Flexibles	0
6. Blastoids N. Genus A. (cup: 62.8-63 m; several fragments: 60-64 m)	2
Unidentified cup (order?) 2 radix holdfasts (61, 60-64 m) Molluscs: scaphopod (75.1 m) Miscellaneous crinoid plates, abnormal stem Brachiopod	

61 D West: Top (77-78 m)

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates	
<u>Actinocrinites</u> sp. (2 cups)	2
<u>Agaricocrinus</u> sp. (cup, 3 articulated brachials)	2
<u>Alloprosallocrinus conicus</u> (cup)	1
<u>Macrocrinus</u> sp. (cup)	1
<u>Uperocrinus</u> sp. (3 cups)	3
3. Disparid Inadunates	
<u>Synbathocrinus</u> sp. (2 cups)	2
4. Cladid Inadunates	0
5. Flexibles	0
6. Blastoids	
N. Genus A. (2 cups, radial)	3

61 D West: Middle (72-76 m)

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates	
<u>Actinocrinites</u> sp. (6 basals, 2 basal circlets, 6 cup plates, 5 arm segments)	4+
<u>Agaricocrinus</u> sp. (2 cups, 3 partial cups, 13 arm segments)	5+
<u>Alloprosallocrinus conicus</u> (3 cups, partial cup)	4
<u>Dizygocrinus?</u> (cup)	1
<u>Eretmocrinus</u> sp. (partial cup, 8 arm segments)	1
<u>Macrocrinus</u> sp. (18 cups)	18
<u>Platycrinites hemisphericus</u> (3 basal circlets, radial)	4
<u>Uperocrinus</u> sp. (2 cups)	2
3. Disparid Inadunates	
<u>Halysiocrinus tunicatus</u> (2 partial cups)	2
<u>Synbathocrinus</u> sp. (cup)	1
Unidentified basal circlet	1
4. Cladid Inadunates	
<u>Barycrinus</u> sp. 1 (radial)	1
<u>Barycrinus cornutus</u> (7 radials)	2
<u>Barycrinus</u> sp. ? (cup)	1
<u>Cyathocrinites</u> sp. 2 (radial)	1
<u>Cyathocrinites</u> sp. ? (radial)	1
Unidentified poteriocrine? (radial)	1
5. Flexibles	0
6. Blastoids	
N. Genus A. (7 cups, 3 radials, deltoid with attached radials)	10
4 unidentified basal circlets	
Unidentified basal	
Miscellaneous cup plates, arm segments, spines, anal chimneys	
4 holdfasts, radix holdfast	
Brachiopods: spiriferid	
Corals: tabulate ( <u>Cladochonus c.</u> ); rugose	

61 D West: Lower (66.5-70 m)

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates	
<u>Alloprosallocrinus conicus</u> (3 cups)	3
<u>Eretmocrinus</u> sp. (cup)	1
<u>Macrocrinus</u> sp. (2 cups)	2
<u>Platycrinites hemisphericus</u> (basal)	1
<u>Uperocrinus</u> sp. (cup)	1
3. Disparid Inadunates	
<u>Synbathocrinus</u> sp. (cup)	1
4. Cladid Inadunates	0
5. Flexibles	0
6. Blastoids	
N. Genus A. (3 cups, 3 partial cups, radial, 2 radials)	8
Miscellaneous cup plates, stems	

61 South: Combined (68-71 m)

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates	
<u>Abatocrinus?</u> (cup)	1
<u>Actinocrinites</u> sp. (5 cups, 5 basal circlets, partial cup, 4 basals, 2 cup plates)	14-15
<u>Agaricocrinus</u> sp. (8 cups, 10 partial cups, articulated radials and brachials)	19
<u>Alloprosallocrinus conicus</u> (11 cups, cup?, basal circlet)	13
<u>Dorycrinus?</u> (spines)	1
<u>Eretmocrinus</u> sp. (cup, arm segments)	1+
<u>Macrocrinus</u> sp. (5 cups)	5
<u>Platycrinites hemisphericus</u> (cup, basal circlet, radials, 2 cup plates, several stems)	33+
<u>Uperocrinus</u> sp. (8 cups, partial cup)	9
3. Disparid Inadunates	
<u>Halysiocrinus tunicatus</u> (3 cups, partial cup, basal)	5
<u>Synbathocrinus</u> sp. (6 cups, cup?)	7
4. Cladid Inadunates	
<u>Adinocrinus nodosus</u> (partial cup)	1
<u>Barycrinus</u> sp. 1 (2 radials)	1
<u>Barycrinus cornutus</u> (2 radials)	1
<u>Barycrinus</u> sp. ? (cup, 2 radials, cup plate, stem)	4
<u>Cyathocrinites</u> sp. 1 (6 radials)	2
<u>Cyathocrinites</u> sp. 2 (cup, 7 radials)	3
<u>Cyathocrinites</u> sp. 3 (2 radials)	1
<u>Cyathocrinites</u> sp. 4 (radial)	1
<u>Cyathocrinites</u> sp. 6 (2 cups)	2
<u>Cyathocrinites</u> sp. ? (infrabasal circlet)	1
Unidentified poteriocrine? (3 radials)	2
Unidentified cup	1
Unidentified infrabasal circlet	1
5. Flexibles	
<u>Mespilocrinus</u> sp. (cup)	1
<u>Onychocrinus?</u> (articulated brachials)	1
Unidentified cup	1
6. Blastoids	
N. Genus A. (2 cups)	2
11 unidentified cups (order?)	

Miscellaneous crinoid plates, anal chimney, spines,  
holdfasts  
Brachiopods; fenestrate bryozoans; corals: tabulate  
(Cladochonus c.), rugose; molluscs: Platyceras sp.;  
sponges

Old 61

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates	
<u>Agaricocrinus</u> sp. (cup)	1
<u>Alloprosallocrinus conicus</u> (cup)	1
3. Disparid Inadunates	
<u>Synbathocrinus</u> sp. (cup)	1
4. Cladid Inadunates	
<u>Cyathocrinites</u> sp. 2 (cup)	1
5. Flexibles	0
6. Blastoids	0

BF 9

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates	0
2. Monobathrid Camerates	
<u>Actinocrinites</u> sp. (basal circlet)	1
<u>Agaricocrinus</u> sp. (cup, 5 arm segments)	2
<u>Dichocrinus?</u> (radial)	1
<u>Eretmocrinus</u> sp. (arm segments)	1
<u>Platycrinites hemisphericus</u> (16 radials, columnals)	4
3. Disparid Inadunates	
<u>Catillocrinus</u> sp. (cup)	1
<u>Halysiocrinus tunicatus</u> (6 cups, 11 radials, 8 basal circlets, fragments of 4 cups)	21
<u>Synbathocrinus</u> sp. (19 cups)	19
4. Cladid Inadunates	
<u>Barycrinus</u> sp. 1 (3 radials)	1
<u>Barycrinus</u> sp. 2 (3 radials)	1
<u>Barycrinus cornutus</u> (12 radials)	3
<u>Barycrinus</u> sp. ? (holdfasts)	4
<u>Cyathocrinites</u> sp. 1 (37 radials)	8
<u>Cyathocrinites</u> sp. 2 (45 radials)	9
<u>Cyathocrinites</u> sp. 3 (11 radials)	3
<u>Cyathocrinites</u> sp. 4 (4 radials)	1
<u>Cyathocrinites asperrimus</u> (14 radials)	3
5. Flexibles	
<u>Gaulocrinus</u> sp. (10 radials)	2
<u>Mespilocrinus</u> sp. (cup)	1
<u>Metichthyocrinus</u> sp. (cup)	1
6. Blastoids	
<u>Dentiblastus</u> n. sp. (radial prong, 13 radials)	3
<u>Granatocrinus granulatus</u> (3 cups, 4 deltoids, 5 radials)	4-5
<u>Hadroblastus</u> n. sp. (cup)	1
<u>Monadoblastus?</u> n. sp.	1
2 unidentified basal circlets	
Brachiopods: orthid, strophomenid, spiriferid	
Molluscs: <u>Platyceras</u> sp.	
Corals: rugose (Streptolesmatid); tabulate ( <u>Cladochonus</u> c.)	
Bryozoa: <u>Cystodictya lineata</u>	

Route 953

<u>Taxa:</u>	<u>Number of Individuals:</u>
1. Diplobathrid Camerates <u>Gilbertsocrinus</u> sp. (partial cup)	1
2. Monobathrid Camerates <u>Actinocrinites</u> sp. (radial) <u>Eretmocrinus</u> sp. (2 cups)	1 2
3. Disparid Inadunates <u>Synbathocrinus</u> sp. (cup)	1
4. Cladid Inadunates <u>Barycrinus</u> sp. 1 (radial)	1
5. Flexibles	0
6. Blastoids	0
1 unidentified cup	
Miscellaneous stems and plates	

APPENDIX 2. Petrographic descriptions. All descriptions are from thin sections unless otherwise specified.

Stratigraphic section:

24.5

Calcareous dolomite. Fine to very fine silt-sized, euhedral dolomite rhombs and large crystals of baroque dolomite have almost completely replaced the original limestone. Outlines of original allochems (crinoids and gastropods) have been preserved as ghost textures. Other allochems are preserved as patches of euhedral rhombs coarser-grained than those making up the matrix. Other bioclasts are silicified, including large numbers of sponge spicules. Relict bedding is visible as alternating bands of uniformly sized rhombs. Small, rounded to angular, heavy mineral grains are sprinkled within the matrix. Staining reveals patches of ferroan dolomite, iron-rich calcite, and calcite in the matrix.

32.6

Dolomitic, fine- to medium-grained wackestone to coarse packstone. Matrix is stained blue, indicating ferroan-dolomite. Skeletal grains include crinoids, bryozoans, brachiopods, siliceous sponge spicules, corals, trilobites, and ostracodes. Most are calcitic, but some have been replaced by ferroan-dolomite. Bryozoan fragments are poorly sorted, ranging up to 8 mm in length. Zooecia are often in-filled with brownish-yellow phosphatic material that is isotropic with crossed nicols. Dolomite rhombs occur within the zooecia too. Small opaque grains of hematite are common at the centers and edges of crinoid fragments. Not much compaction or distortion of allochems has occurred. Preservation of fine details, such as stoma, is common. In hand sample, thin laminations of dark green, fine-grained material can be seen that are not visible in thin section. These are composed of dolomite.

34.8

Dolomitic, argillaceous, medium- to coarse-grained packstone. Euhedral dolomite rhombs and clay minerals fill spaces between poorly-sorted, disarticulated and closely packed crinoid and bryozoan debris. Grain boundaries are indistinct as the result of extensive dissolution. Crinoid fragments have syntaxial overgrowths and/or silicified interiors. One bryozoa fragment is 12.4 mm long and is oriented with its long axis parallel to bedding. In hand sample, this blueish-gray wackestone is unbedded, with moderately- to well-sorted bioclasts. Solution seams are dark blue to greenish-gray.

36.6

Dolomitic, argillaceous, medium- to coarse-grained packstone. The lower portion of the slide is chert. Interstices are filled by euhedral dolomite rhombs, averaging 20 to 40 microns in diameter. Bioclasts are mostly echinoderms and bryozoans, and are poorly-sorted. Some crinoid fragments have syntaxial rim cement. Iron-zoned dolomite rhombs (average 35 to 40 microns) are common within bryozoa zooecia. Silicification of grains has nearly obliterated textures in the lower part of the slide, although ghosts of crinoids and bryozoans are visible with crossed nicols. A small amount of calcite may remain in the centers of some crinoid fragments. Staining reveals the presence of small amounts (<5% each) of ferroan dolomite and iron-rich calcite. One cm thick and greater beds are obvious in hand sample. Chert near base is blue-gray with white crinoid fragments; chert grades upward into stringers of dark gray, medium-grained packstone. This in turn grades into a reddish to yellowish brown, dolomitic wackestone to packstone.

#### 38.0

Dolomitic, argillaceous packstone. Echinoderm and bryozoan fragments, exhibiting an average grain size of medium sand, are densely packed, and have sutured contacts. Some grains have undergone micritization. Similar to 36.6 but somewhat finer-grained and better sorted. Hand sample: bedded (average one cm), greenish-gray, moderately-sorted wackestone to packstone. Individual beds display moderate sorting.

#### 38.6

Dolomitic, argillaceous packstone. Original matrix is almost completely replaced by euhedral dolomite rhombs, some of which exhibit iron-zoning. Skeletal debris includes crinoids, bryozoans, and one foram. Contacts between adjacent crinoid fragments are sutured. Crinoid fragments may be replaced by ferroan dolomite, or have syntaxial overgrowths. Some columnals are still articulated. Bryozoan fragments are broken up but often retain delicate features. Faint laminations are formed by the concentration of dark-colored clay minerals along solution seams. Hand sample exhibits graded bedding, each about 5 to 6 cm thick. Very coarse at base with moderate silicification, grading up into a layer with 1 to 2 mm sized fragments, this in turn grading up into a fine-grained (<1 mm), matrix-rich top layer. Matrix is tan and considerably dolomitic.

#### 40.5

Dolomitic, argillaceous packstone very similar to 38.6 above. Hand sample: moderately sorted wackestone. Solution seams are somewhat wavy laminated; rock tends to break along these zones of weakness. Geodes are common.

#### 41.6

Dolomitic, argillaceous packstone. Allochems are mostly fragmented pieces of bryozoa with little crinoid debris; interstices are filled with iron-zoned dolomite rhombs (average 15, range from <5 to >45 microns), argillaceous material, and a trace of framboidal siderite. Crinoid fragments are poorly sorted; one articulated section of arm ossicles is 10.5 mm long. Long axes of fossil fragments are generally oriented parallel to argillaceous-rich laminations. Edges of fossil fragments have undergone dissolution. Zooecia have iron-poor bladed calcite crystals lining their interior and exterior walls, and are filled in with matrix material. Some crinoid ossicles have microcrystalline quartz at their centers. Hand sample shows extreme development of parallel orientation of crinoid fragments, probably the result of compaction. Fragments also are "sugary" looking. A small geode (< 1 cm in diameter), a green, micritic intraclast, and lots of solution seams along which the rock tends to split also are exhibited in hand sample.

#### 41.8

Argillaceous, dolomitic wackestone. Bryozoa fragments comprise the dominant allochem in this rock; one piece is 3.7 mm in length. Fragments generally are oriented parallel to bedding. Solution seams are common. Hand sample shows beds that are 2 cm thick and greater; not apparent in thin section. Rock also exhibits moldic porosity.

#### 43.5

Calcareous chert. Rock has been almost completely replaced by microcrystalline and chalcedonic quartz, and lesser amounts of dolomite (<10%) and megaquartz (<1%). Relict textures reveal bryozoan zooecia, sponge spicules, and crinoid ossicles all of which were disarticulated and poorly sorted. Small patches of argillaceous material and iron dolomite are preserved within zooecia. Small grains of hematite and possibly some pyrite are interspersed throughout. Hand sample reveals beds that are from 1 to 2 cm thick. Chert is translucent with a blueish-gray color.

#### 43.8

Dolomitic, fossiliferous, silty shale, with parallel to wavy lamination. Matrix is 40 to 50% micaceous material (probably sericite), with rounded quartz grains (<62 u), scattered iron mineral grains, and lots of dolomite rhombs, some of which are iron-zoned. Moderate- to well-sorted bioclasts include mostly bryozoans, crinoids, and some brachiopods. The interiors of some crinoid fragments are silicified. A single micritic intraclast contains fine-grained skeletal fragments, including some siliceous sponge spicules. Solution seams filled with clay minerals

form laminations. Some bioclasts have their long axes oriented parallel to bedding.

#### 46.2

Argillaceous, dolomitic wackestone with an interbedded packstone layer. Packstone is rich in silicified sponge spicules; otherwise it is identical in composition to the wackestone. Spicules are monaxons and generally are oriented parallel to bedding. Matrix is composed of argillaceous material and euhedral dolomite rhombs, some zoned, that range from about 10 to 20 microns. Bioclasts are moderately sorted and have undergone quite a bit of dissolution at their edges. Some matrix-infilled burrows have been preserved. Textural differences seen in this thin section are not apparent in hand sample.

#### 52.3

Argillaceous, siliceous packstone. Matrix is composed mostly of randomly oriented clay minerals and some detrital quartz grains. Bioclasts (crinoids and bryozoans) are poorly sorted and many have been replaced by microcrystalline quartz. Their rims have undergone considerable dissolution, although less than 5% of the total composition is dolomite. Patches of iron-rich calcite and framboidal siderite (crystals <1 micron) are interspersed within the matrix.

#### 53.7

Dolomitic, fossiliferous, silty shale very similar to 43.8. Matrix is composed of clay minerals and dolomite rhombs with thin coats of iron minerals. Some layers are a jumble of poorly-sorted, medium to very coarse sand-sized, crinoid debris with only small amounts of bryozoan fragments, whereas other layers are composed of uniformly sized bryozoan fragments (medium to coarse sand-sized) with only small amounts of crinoid debris. Some bioclasts have been partly silicified. Dark bands that represent accumulations of clay minerals along thin solution zones or microstylolites form thin laminations. Thin quartz-filled veins are generally associated with these zones as well. Dissolution of calcite is common where adjacent crinoid grains touch one another. The resultant suture line usually contains concentrations of micaceous material.

#### 55.0

Dolomitic, siliceous, argillaceous packstone. Bioclasts (mostly crinoids with bryozoans secondary) are coarse to very coarse sand-sized, and are poorly sorted. Calcite in the lower portion of the slide has been partially or completely replaced by microcrystalline chert. Euhedral dolomite rhombs are interspersed within the chert, along with patches of iron-rich calcite. Laminations are formed by solution seams filled with oriented clay minerals and

crinoid fragments with their long axes oriented parallel to bedding. Hand sample: matrix is light green and contains pods of coarse-grained fossil debris. An unbroken crinoid cup plate exhibits little to no abrasion; fine details are well preserved. Some compaction has occurred as indicated by the "squeezing out" of matrix from in between grains.

#### 65.0

Dolomitic grainstone. Skeletal grains are mostly echinoderm fragments; followed in abundance by bryozoans and encrusting corals. These range in size from medium to very coarse sand and are poorly sorted. Syntaxial overgrowths on echinoderm fragments fill interstices, occluding euhedral dolomite rhombs and argillaceous material. Coral fragments often are replaced by ferroan (baroque) dolomite. The interiors of some echinoderm fragments are replaced by microcrystalline quartz. Some crinoid fragments are oriented with their long axes parallel to bedding. Hand sample: a tan- to green-gray, very poorly sorted grainstone. Articulated columnals are not uncommon; one measures 2 cm in length and 1.5 cm wide. Matrix appears somewhat argillaceous and dolomitic. Embayed contacts are common. No bedding is apparent.

#### 65.4

Siliceous, rudstone. Many echinoderm and bryozoan fragments have been replaced by microcrystalline quartz and by chalcedony but some have retained their original composition. There is some zebraic chalcedony as well. Others have been replaced by iron-poor calcite. Bioclasts are poorly sorted, for example, one articulated columnal (4 ossicles) is 9 mm in length and 16 mm wide. Echinoderm fragments often have embayed contacts. Euhedral dolomite rhombs are interspersed within the matrix but comprise less than 5% of the total composition, and clay minerals are present in a few per cent abundance. Hand sample: allochems are moderately sorted; articulated columnals are common. Thin, wavy, greenish layers composed of dolomitic mud and argillaceous material drape over the fossil debris.

#### 65.8

Dolomitic rudstone. This rock is composed mostly of very coarse-grained, poorly sorted, echinoderm fragments that look extremely compacted. Crinoid ossicles exhibit calcite twinning. Interstices are filled with syntaxial rim cement, euhedral dolomite rhombs, and bryozoan fragments. Grain borders have undergone dissolution. Echinoderm fragments have syntaxial overgrowths, and some are partially silicified at their centers. Hand sample: matrix is dark green and fine-grained. Allochems are very coarse-grained, ranging from 2 to several mm in diameter. Most have undergone dissolution along their boundaries

with adjacent grains; many of the larger grains are partially silicified.

### 67.3

Dolomitic, medium- to coarse-grained grainstone. The interstices are filled with calcite cement, which precipitated as syntaxial overgrowths on crinoid ossicles. Dolomite rhombs as well as a small amount of clay minerals have been caught up in the cement too. Skeletal grains (ranging in order of abundance from greatest to least) are crinoids, bryozoans, and brachiopods. They all show evidence of compaction and distortion. Crinoid grain outlines are indistinct as a result of dissolution and some grains have silicified interiors. Some of the original matrix has been preserved inside bryozoa zooecia, and consists of argillaceous material and detrital, silt-sized, quartz grains. Bedding is evident as bands of coarse crinoid debris (ave. 2 mm) alternating with bands of predominantly finer debris (< 1 mm).

### 68.4

Siliceous packstone grading upward into a calcareous chert. The slide is divided into zones as follows:

- upper: nearly complete silicification; original textures almost obliterated
- upper middle: silicification of matrix, bryozoa fragments, and rims of crinoid grains
- middle: thin zone of non-silicified material, including bryozoan and crinoidal fragments plus argillaceous material; also some authigenic hematite
- lower middle: same as upper middle
- base: not silicified

Bryozoan-rich layers cap crinoid-rich ones, forming beds on a scale of 15 to 20 mm. Staining reveals iron-rich calcite as patches in the matrix and lining a vein. Chert is mostly microcrystalline quartz, with some coarse-grained, mosaic quartz filling voids within crinoid grains, such as the centers of columnals. Euhedral dolomite rhombs make up less than 10% of the total composition and are more common in non-silicified areas. Opaque, fine to very fine silt-sized spherules of hematite form clumps and stringers that are concentrated in non-silicified areas. Detrital quartz grains are present in trace amounts. Solution seams lined with argillaceous material form thin laminations.

### 69.1

Dolomitic, medium- to coarse-grained, grainstone. Allochems are a well-sorted mixture of uniformly-sized crinoid fragments (medium to coarse sand-sized) and uniformly-sized bryozoan fragments (fine sand). Euhedral

dolomite rhombs are interspersed between crinoid grains and within bryozoan zooecia. Some bryozoa zooecia are filled with phosphatic material, probably collophane. Very similar to 67.3 but this is more homogeneous-looking because it lacks bedding structures.

#### 69.5

Calcareous chert, grading upward into a medium- to coarse-grained grainstone. Uniformly-sized crinoid fragments (medium to coarse sand) are tightly packed in with uniformly-sized bryozoan fragments (fine sand). Syntaxial overgrowths on crinoid fragments comprise the cement; euhedral dolomite rhombs are preserved within the cement but are less than 10% of the total composition. Some crinoid grains have been partially silicified. Some bryozoan zooecia are in-filled with phosphatic material. Similar to 69.1 except for the chert at the base of this slide. Hand sample: chert is nodular-looking. Matrix is dark gray and fragments are off-white; the borders of the fragments often "blend" into the matrix. Solution seams contain dark gray, fine-grained material.

#### 71.0

Dolomitic, coarse- to very coarse-grained, well-sorted, grainstone. Cementation has occurred as syntaxial overgrowths on crinoid ossicles. Bryozoans are tightly compacted between crinoid grains. There is some equant calcite spar filling zooecia and interparticle voids. Euhedral dolomite rhombs are dispersed within the cement and within zooecia.

#### 72.7

Dolomitic, coarse- to very coarse-grained, poorly sorted, packstone. Euhedral dolomite rhombs ranging in size from <5 to >60 microns (average about 30 microns) have almost completely replaced the original matrix. Crinoid fragments may or may not have syntaxial overgrowths and some are partially replaced by microcrystalline quartz. Others are replaced by baroque dolomite or equant calcite. Many grains are oriented with their long axis parallel to bedding. Bryozoan fragments are second in abundance as usual and have phosphatic material preserved within their zooecia. Brachiopod fragments are present in small amounts. Graded beds are apparent in hand sample. Coarse sand-sized bioclastic material at the base grading up into fine sand-sized layer. Solution seams are filled with very fine-grained greenish material.

#### 73.1

Dolomitic, siliceous packstone. Crinoid fragments, the dominant allochem, are fairly well-sorted, and are coarse to coarse sand-sized. They have sutured contacts, syntaxial overgrowths, and their edges are partially replaced by euhedral dolomite rhombs. Bryozoan fragments

are well-sorted and have undergone partial dissolution. Zoecia may contain phosphatic material, baroque dolomite, or original matrix material. Euhedral dolomite rhombs and some argillaceous material are interspersed with the bryozoan fragments. Microcrystalline quartz has selectively replaced the interiors of some crinoid grains. Coarser-grained, mosaic quartz occurs where several crinoid grains have been dissolved. Dolomite is barely 10% in abundance, and rhombs average about 15 microns in diameter. Hand sample reveals a gradation from a coarse sand-sized, well-sorted packstone at the base to a more matrix-rich and somewhat finer-grained layer at the top. Total thickness of graded bed is about 2.8 to 3 cm. A second graded bed overlies this,; its bottom bed is coarser, more closely packed, and completely silicified. Cherty areas exhibit moldic porosity.

#### 74.7

Dolomitic packstone. Dissolution has obliterated most allochems except for crinoid grains which are medium to coarse sand-sized and well-sorted. Grain borders are indistinct (from dissolution), and some have syntaxial overgrowths. Only very small fragments of bryozoans remain. Euhedral dolomite rhombs form the matrix and range in size from <10 to >65 microns, averaging about 40 microns. Spherules of hematite are interspersed within the dolomite rhombs.

#### 74.8

Siliceous dolomite. The original limestone fabric has been replaced by tightly interlocking euhedral and anhedral dolomite rhombs (<6 to >30 microns; averaging about 10 to 15 microns), with hardly any calcite remaining. Relict textures of very fine to medium sand-sized crinoid ossicles are preserved as both microcrystalline and coarsely crystalline quartz, and ferroan dolomite. The relict crinoid debris forms thin (0.5 cm) beds and laminations. Rhombs may be occluded within the quartz.

#### 75.1

Dolomitic wackestone to packstone. Matrix is composed of euhedral dolomite rhombs ranging from 20 to 80 microns. Edges of echinoderm fragments are corroded as result of dissolution and subsequent replacement by dolomite. Some crinoid grains are partially replaced by microcrystalline quartz. Overall this looks poorly sorted but coarse debris does seem to be restricted to particular bands. The base of the slide is a partially dolomitized wackestone; euhedral rhombs are smaller too, averaging from 10 to 20 microns in diameter.

#### 76.9

Dolomitic, siliceous packstone. Deeply embayed contacts

where crinoid fragments adjoin one another. Mostly crinoidal debris with abundant bryozoan fragments. Many bryozoan fragments are fairly long; one measures 4.9 mm. They generally are aligned parallel to bedding. Rhombs within the matrix are euhedral and fairly coarse (20 to 70 microns). Replacement of calcite by chalcedony and microcrystalline quartz is common. Grain sizes fine upward from an average of 2 to 3 mm at the base up to .35 to .5 mm at the top within a zone of a few centimeters; a graded bed.

#### 78.5

Hand sample: Dolomitic, siliceous packstone. Graded beds.

#### 83.8

Siliceous dolomite. Interlocking dolomite rhombs (range from 2 to 40 microns; average about 15 to 20 microns) comprise the fabric of this rock. Siliceous, monaxial sponge spicules oriented parallel to bedding are the dominant allochem. Crinoid grains have been replaced by ferroan dolomite, and more rarely, by equant calcite. Aggregates of larger sized dolomite rhombs may have once been bioclasts. Faint laminations are formed by horizontal orientation of allochems and hematite spherules and clumps. Glauconite is present in trace amounts.

#### 85.7

Chert. Skeletal fragments have been replaced almost completely by microcrystalline quartz, with only small amounts of the original calcite remaining. In polarized light, relict grain outlines are visible, mostly crinoids. Other bioclasts include brachiopods and a large coral fragment. Euhedral dolomite rhombs, hematite, and fibroidal siderite are interspersed within the chert.

#### 94.0

Silty dolomite to dolosiltstone. Interlocking, euhedral dolomite rhombs comprise the matrix. Silt-sized (62 to 88 microns and less) angular quartz grains make up 20 to 30 per cent of this rock. Clay minerals, including muscovite flakes, are present in smaller amounts. Small rounded opaque grains, probably hematite and pyrite, are interspersed within the matrix. Faint parallel laminae are formed as the result of concentration of clay minerals along solution seams. Glauconite is present in trace amounts.

#### 94.6

Silty, argillaceous dolomite. Silt comprises about 10% of composition. Texture is idiotopic-E with lots of clay and some quartz silt filling intercrystalline areas. Dolomite is somewhat fine-grained, ranging from less than 10 to generally no greater than 20 microns. Quartz ranges from 12 to 75+ microns; grains are rounded to subrounded. Rock

is faintly laminated with some porosity. Clay material is particularly concentrated within solution seams.

#### 97.0

Chert. Chert has completely replaced the matrix material but bioclasts show excellent preservation of fine details such as the stroma of crinoid fragments. A thin rim of chalcedony is present on nearly all bioclasts. Dolomite rhombs are replaced too as indicated by chalcedony rimmed, hollow rhombs. A fair amount of argillaceous material can be found within intercrystalline spaces. This originally may have been a very well-sorted coarse sand-sized crinoidal packstone or grainstone, that was somewhat graded. As in nearly all other thin sections from the study area, there are lots of reddish, fibroidal spheres peppered throughout; these seem to be hematitic. Solution seams are present too.

#### FPD-20.9

Argillaceous siltstone. Faint, discontinuous laminations are the result of alternating quartz silt-rich and argillaceous-rich (silt-poor) layers. Quartz grains are poorly sorted and range from very fine to coarse (<5 to >40 microns) silt size. Rhombs of iron-rich dolomite, crinoid fragments, dark grains of hematite and siderite, and trace amounts of glauconite are interspersed within the matrix. Many grains are oriented parallel to the laminations.

#### Massive Carbonate Buildup:

##### M2

Dolomitic wackestone. Matrix is composed of relatively fine-grained (average <10 u in diameter), euhedral dolomite rhombs. Fossil fragments are poorly-sorted (ranging from <0.5 mm to >5.0 mm in size), and are composed mostly of crinoid fragments. Calcite of the outer rims and centers of some crinoid fragments has been dissolved and replaced by large dolomite rhombs (average of 20-50 u) and by ferroan (baroque) dolomite; the interiors may be replaced by microcrystalline chert.

##### M3a

Dolomitic wackestone. Matrix is identical to that of M2. Patches of euhedral dolomite rhombs larger than those comprising the matrix, are shaped like the outlines of crinoid fragments, that seem to have been well-sorted. Many bioclasts have probably been obliterated by dolomitization. Some crinoid fragments are silicified (microcrystalline and megaquartz) with little or no calcite remaining. Small amounts of at least two varieties of clay minerals are interspersed within the matrix, along with scattered dark heavy mineral grains,

and small amounts of detrital quartz grains.

M3b

Same as 3a. Some crinoid fragments have retained calcareous cores, however.

M4

Dolomite. Matrix is composed of fine-grained, euhedral dolomite rhombs. The only remaining bioclasts are silicified (microcrystalline quartz) remnants of crinoid fragments. Patches of coarsely crystalline calcite within the matrix are not recognizable as relict skeletal grains. Also interspersed within the matrix are clay minerals and small grains of heavy minerals.

M5

Calcareous dolomite. Relict grain textures are preserved as aggregates of coarse dolomite rhombs and as patches of equant (recrystallized) calcite. Areas of predominantly small rhombs that are interbedded with areas of predominantly medium to large rhombs resemble laminations. Skeletal fragments do not appear to be particularly well-sorted.

M6

Dolomitic wackestone. Matrix is largely dolomitized, with idiotopic-E texture; rhombs average about 5 to 20 microns in diameter. Remnants of large crinoid fragments remain but are almost completely dolomitized. Large euhedral rhombs (45 to 70 microns) and baroque dolomite crystals have formed in the interiors of these originally calcitic fragments. One very large silicified crinoid fragment is greater than 3 mm in diameter. Fragments are not well-sorted. No stratification is apparent although the faint outlines of pellets can be discerned.

M7

Dolomite. Matrix is completely dolomitized. Vaguely recognizable crinoid grains are preserved as patches of dolomite rhombs that are coarser grained than those comprising the matrix. Otherwise, bioclasts have been obliterated by dolomitization. Small black grains interspersed within the matrix are pyrite or heavy minerals.

M9

Dolomite. The original matrix has been replaced almost completely by interlocking euhedral to anhedral dolomite rhombs, 7 to 25 microns in size. Patches of larger-sized rhombs (average 40 microns) are common; some are shaped vaguely like rounded crinoid ossicles. A few large crinoid fragments that escaped dolomitization are partially silicified. Small amounts of iron-rich dolomite and siderite are present. No bedding is apparent.

#### M14

Dolomitic packstone. Bryozoan-rich with sparry calcite infilling some zoecia. Euhedral rhombs are 30 to 50 microns in diameter. Pellets of very fine-grained calcite (< 3 microns) and argillaceous material are found within the matrix. Similar to M13.

#### M15

Dolomite. Texture is idiotopic-E with patches of baroque dolomite. Dolomite rhombs average 25 to 95 microns in diameter; some are greater than 120 microns. Identity of original fragments is very difficult to determine (relict textures are absent). Sparry calcite occurs within interstices in some areas. Parts of the slide are pelletal-looking with very fine-grained dolomite (10 microns or less); some areas are very pelleted.

#### M16

Dolomitized wackestone. Texture is xenotopic-A near base, idiotopic-E toward top. Base: crystal boundaries are very abraded. This along with porosity suggests much dissolution has occurred. Overall: a small amount of sparry calcite occurs within intercrystalline areas along with some baroque dolomite. Crinoidal bioclasts are very fine-grained and well-sorted; individual grains do not exhibit unit extinction because of fracturing. Some stratification is apparent.

#### M17

Dolomitized wackestone. Lots of baroque dolomite within a medium-grained (25 to 50 microns) dolomite matrix displaying idiotopic-E texture. Some calcite remains but not much; it occurs as spar within intercrystalline areas. There are some layers of finer-grained dolomite as well (5 to 25 microns). In general, bioclasts are fine-grained and well-sorted; some stratification is apparent.

#### M18

Wackestone. Pseudospar comprises the matrix, which is burrow-mottled and pelletal. Bioclasts include large crinoid fragments (>2.3 mm) and lots of small, broken bryozoan fragments. Slide is almost completely pink but there is little if any sparry calcite which leads me to call it pseudospar. There are some large patches of mauve too. Greenish clay minerals are concentrated at the centers of the pellets.

#### M19

Micstone. Very similar to M18 above. Slide is burrow-mottled and pelleted and matrix is composed of pseudospar, alas bioclasts are less abundant. Hand sample: dark gray to tan, partially dolomitized wackestone. Fossil debris ranges in size from less than 500 micron to 0.6 cm, and

consists of crinoids, brachiopods, and fenestrate bryozoans. Small areas of the rock are completely dolomitized whereas other areas are unaffected (pseudospar). Stylolites are common with reprecipitation of calcite within cavities. A nearly whole cup of Actinocrinites eight-plus centimeters in diameter was found on the upper surface of this sample upon examination in the laboratory. Recrystallization has obliterated most of its finer details.

#### M20

Dolomitized wackestone. Texture is idiotopic-E. Crinoid fragments are replaced by ferroan dolomite; one particularly large fragment has extremely large (1400 microns=longest axis) euhedral dolomite rhombs occluded within it. There are large aggregates of hematite here as well.

#### M21

Extremely dolomitized micstone. There is one large patch of sparry calcite, probably a geode, and also some pseudospar. This is similar to M11 and M12. Dolomite texture is idiotopic-E. Some small patches of microspar look pelletal.

#### M22

Dolomitized wackestone. Matrix is composed of fine-grained dolomite (5 to 15 microns). Large euhedral dolomite rhombs (25 to 75 microns) have partially replaced the calcite of many crinoid fragments. Bedding is apparent where a finer-grained bed is sandwiched in between two coarser-grained beds. Bioclasts range up to 1.5 mm and greater in diameter in the latter beds. The middle bed is much finer-grained; hardly any grains are visible at all in the hand sample. Matrix contains some pellets and some ferroan calcite. Cleavage planes within many of the calcareous grains are lined with dark to reddish-brown, fine-grained material. Some ?forams may be present.

#### M26

Dolomitized wackestone. Matrix is composed of fine-grained dolomite rhombs (15 to 25 microns) that exhibit idiotopic-E texture. Larger dolomite rhombs usually are found within patches of calcite that are remnant crinoid ossicles. Many crinoid fragments are part ferroan dolomite, part calcite, and/or part ferroan calcite. Silicified sponge spicules are preserved: central canals are replaced with quartz that is light brown in plane polarized light whereas quartz comprising exterior of spicules is microcrystalline with radial fibrous crystals perpendicular to the central canals. Many spicules are flattened somewhat. Some quartz is chalcedonic. Layers

rich in coarser-grained fossil fragments produce  
lamination.

### APPENDIX 3. Procedure for naming rock types.

#### Carbonates

Carbonate rocks are fairly consistent in composition throughout the stratigraphic section, making texture a more useful parameter for classification. Texture is also an important tool in reconstructing the depositional environment of carbonate rocks. Figure 3-1 illustrates the classification system used for limestones in this study. The fact that the mud-sized fraction consists mostly of terrigenous material and recrystallized lime mud as opposed to pure lime mud or micrite, however, must be considered when using this system. In this case, all mud-sized material is simply treated as lime mud. Dolomite-containing rocks have been named using the compositional triangles in Figure 3-2. The limestone classification system remains applicable where dolomite crystals are present but are less than fifty percent in abundance; however, the modifying term "dolomitic" is prefixed to the rock name. Dolomites are rocks with 50% or more of that mineral present; a "pure" dolomite contains 90% or more dolomite, whereas rocks containing from 50 to 90% dolomite are "impure". The term "impure" may be substituted for the appropriate compositional term that describes the next most abundant mineral in the rock. Dolomite crystal textures are described using the system in Figure 3-3 developed by Gregg and Sibley (1984).

Allochthonous limestones original components not organically bound during deposition				Autochthonous limestones original components organically bound during deposition				
Less than 10% > 2 mm components			Greater than 10% > 2 mm components		By organ- isms which act as baffles	By organ- isms which encrust and bind	By organ- isms which build a rigid frame- work	
Contains lime mud ( < .03 mm)		No lime mud	Matrix sup- ported	> 2 mm com- ponent sup- ported				
Mud supported		Grain supported						
Less than 10% grains ( > 0.3 mm < 2 mm)	Greater than 10% grains							
Mud- stone	Wacke- stone	Pack- stone	Grain- stone	Float- stone	Rud- stone	Baffle- stone	Bind- stone	Frame- stone

Figure 3-1. Dunham (1962) classification of limestones according to depositional texture by Embry and Klovan (1971)(Wilson, 1974, Fig. 1-6).

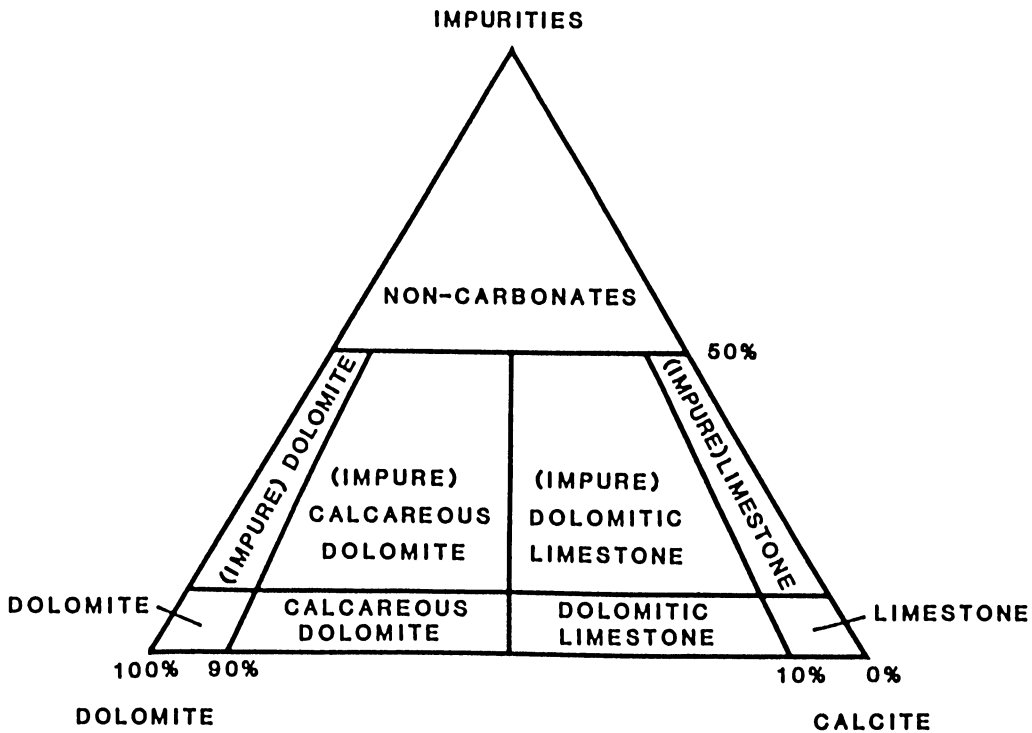
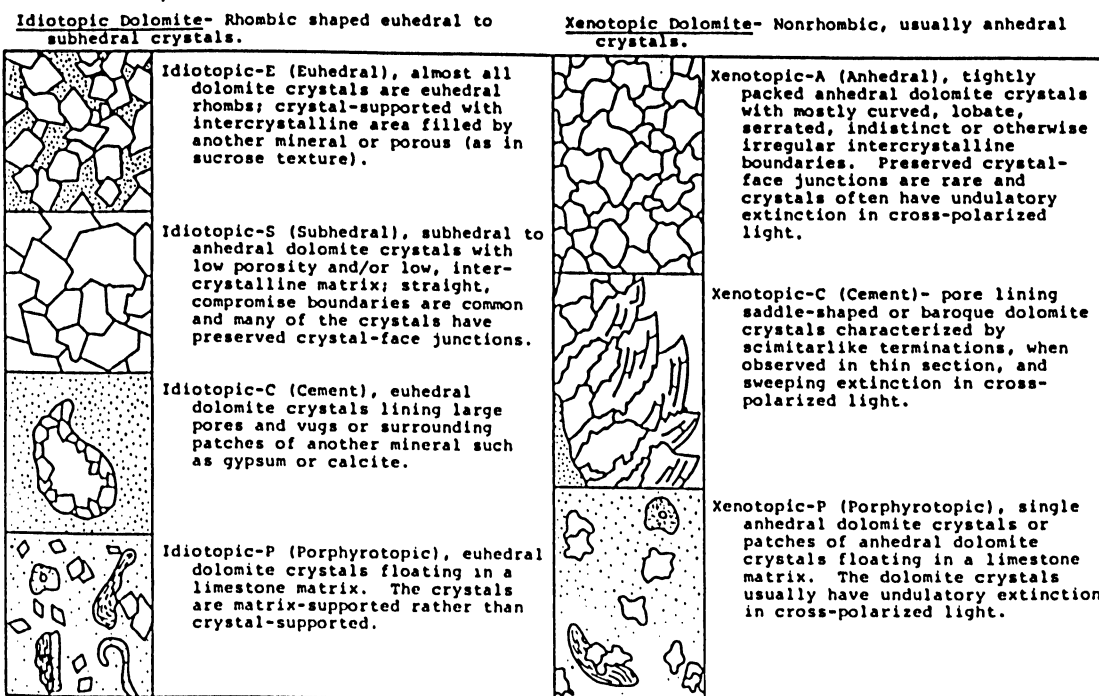


Figure 3-2. Compositional terminology for carbonate rocks (Leighton and Pendexter, 1962, Fig. 2).

Figure 3-3. Dolomite textural classification system  
(Gregg and Sibley, 1984, Fig. 6).



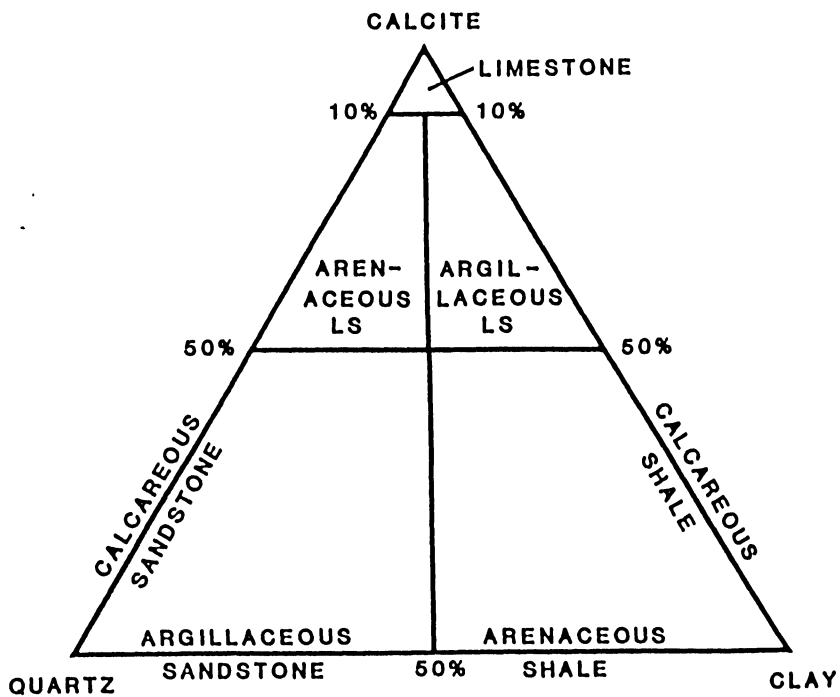


Figure 3-4. Compositional terminology for quartz- or clay-rich carbonate rocks (Krumbein and Sloss, 1963, Fig.

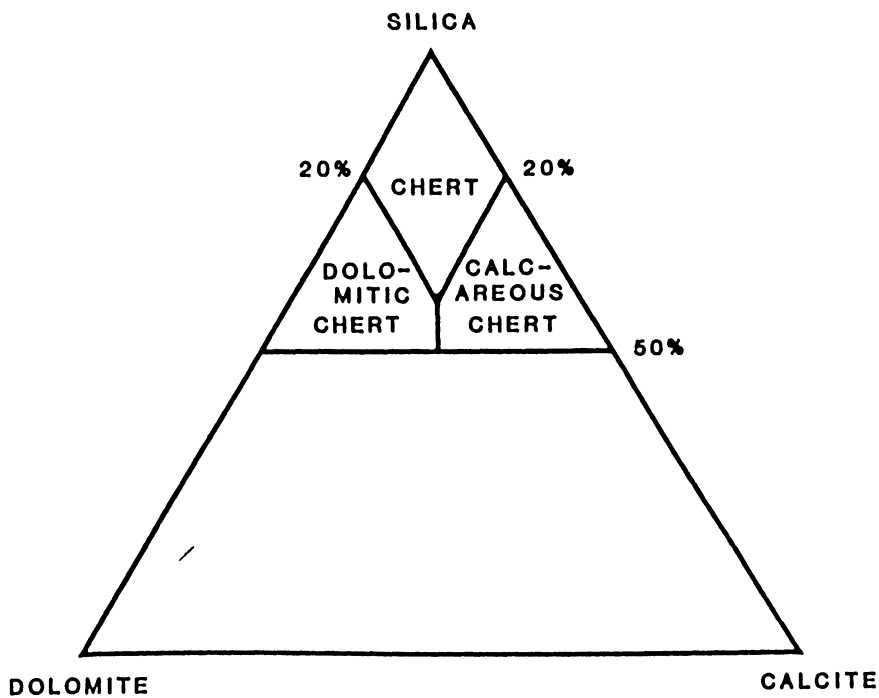


Figure 3-5. Compositional terminology for silica-rich carbonate rocks (adapted from Krumbein and Sloss, 1963,

#### APPENDIX 4. Procedure for staining thin sections.

Petrographic work required that thin sections be stained to identify the different carbonate minerals. I prepared a solution of alizarine red S and potassium ferricyanide following the procedure by Dickson (1978). One liter of dilute hydrochloric acid (0.5%) is prepared by mixing 5 ml of concentrated HCl with 995 ml of distilled water. This is split into 500, 300 and 200 ml portions respectively. 4 grams of potassium ferricyanide are dissolved in the 200 ml volume and 0.6 grams of alizarin red S are dissolved in the 300 ml volume of acid. Once all solids have dissolved the two staining solutions are combined (filtering may be necessary if any solids remain).

Prior to staining the thin section is etched in the 0.5% HCl solution for 10 seconds. Following this it is immersed in the stain solution for 1 to 1.5 minutes, then rinsed in distilled water.

The stained slide is interpreted as follows:

Calcite: pink to orange

Ferroan calcite: mauve-purple-royal blue

Dolomite: not stained

Ferroan dolomite: pale to deep turquoise or green

Aragonite: pink to orange