KGS
OF
91-11

PALEOECOLOGY AND SEDIMENTOLOGY
OF THE LATE CARBONIFEROUS (PENNSYLVANIAN)
HAMILTON LAGERSTATTE, GREENWOOD COUNTY, KANSAS

A Thesis Presented to

The Graduate Faculty of

The College of Arts and Sciences of Ohio University

In Partial Fullfillment

of the Requirements for the Degree

Master of Science

Timothy R. Fahrer

August 1991

This thesis has been approved

for the Department of Geology

and the College of Arts and Sciences by

Dr. Royal H. Mapes
Professor of Geology

Dr. F. Donald Eckelmann
Dean, College of Arts and Sciences

Kansas Geological Survey
Open-file Report

Disclaimer

ACKNOWLEDGEMENTS

I would like to express my thanks and appreciation to the individuals whose supervision, help and encouragement made this project possible:

Dr. Royal H. Mapes who proposed, supervised and edited my thesis project and Dr. Gene Mapes who along with Dr. Royal Mapes inspired my interest in this project. (Financial support was also provided by Dr. Royal H. Mapes through grants received from the American Chemical Society of the Petroleum Research Fund).

The Kansas Geological Survey, which supported this project in the field, provided core sample information and topographic maps. Chris Maples and Lynn Watney of the Kansas Survey were responsible for the administrative actions that led to my support and also provided guidance while I was in the field.

Dr. Damian Nance and Dr. David Kidder for editing the manuscript and Brent Miller for aid in thin section preparation.

Tom Satter, a resident and geologist in Hamilton, Kansas, provided friendship and assisted in field mapping.

Last but certainly not least a special thanks to my wife Debra, who did photography, editing and provided suggestions, but more importantly provided the love and friendship needed to make this project possible.

ABSTRACT

The Hamilton Lagerstatte in Greenwood County, Kansas, is a fining upward carbonate sequence which differs lithologically from the established stratigraphic sequence in this area. An admixture of exquisitely preserved marine and terrestrial biota are preserved within the Lagerstatte beds. Age estimates for the Lagerstatte range from Upper Pennsylvanian to Lower Permian but are based primarily on paleontological information rather than stratigraphic position. The overall geometry of the deposit and its relationship to the contemporary coastline are unknown.

The areal distribution of the Lagerstatte beds were mapped using a plane table and alidade. Also by utilization of core information provided by the Kansas Geological Survey the three dimensional configuration of the deposit and stratigraphic relationships were determined. Hand samples were obtained for thin sections. Based on thin section analysis and paleontological information the overall depositional environments of the deposit were determined.

The Hamilton deposit is a north to south trending, paleochannel deposit of Upper Pennsylvanian age. This paleochannel was at times a very low energy environment that was tidally influenced. The Lagerstatte preservation is restricted to tidally influenced layers. The Hamilton paleochannel deposit reflects a fluctuating base level fall and subsequent rise resulting from either glacio-eustatic contols or local structural events.

LIST OF FIGURES cont.

Figure | Page

TABLE OF CONTENTS

TABLE OF CONTENTS cont.

LIST OF FIGURES

INTRODUCTION

The term "fossil Lagerstatte", as introduced by Seilacher et al., (1985), is defined as a rock body unusually rich in paleontological information either in the quantitative or the qualitative sense. These deposits provide unique insights into past communities and serve as major sources of evolutionary and paleoecological information. Most Lagerstatten are the result of unusual sedimentological processes that preserve instantaneous or nearly instantaneous events such as storms, turbidity flows, and ash falls (Seilacher et al., 1985).

In the vicinity of the town of Hamilton located in Greenwood County, southeastern Kansas (Figs.1,2), the Late Paleozoic Hamilton Lagerstatte contains a unique and diverse assemblage of exceptionally preserved invertebrate, vertebrate and plant remains in a north-south trending fining-upward sequence of beds. The Lagerstatte is a laminated carbonate mudstone which overly carbonate conglomerates. Carbonaceous shales are interbedded with carbonate mudstones and conglomerates. The fossil biota from these units are indicative of a wide range of paleoenvironments ranging from marine to transitional-marine to terrestrial.

Fossil specimens from the Lagerstatte beds include articulated vertebrates (fish, amphibians, reptiles), articulated invertebrates (insects, bivalves, cockroaches) and plant remains (conifers, cordaites, and ferns). Although the fossils have been the focus of the majority of the research

Figure 1. Geologic map of eastern Kansas showing the location of Greenwood County and the location of the study area. The study area is near the Pennsylvanian-Permian boundary.

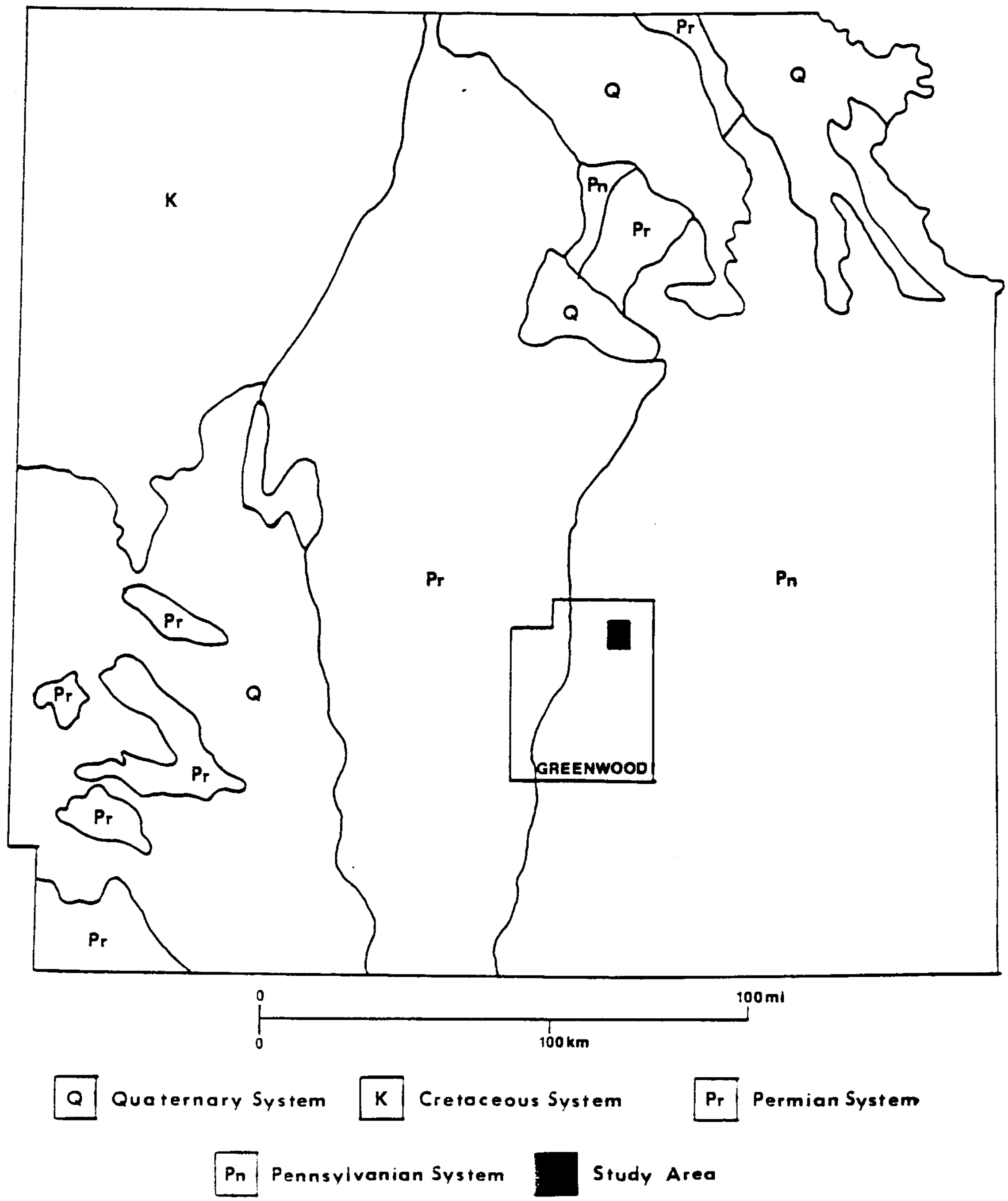
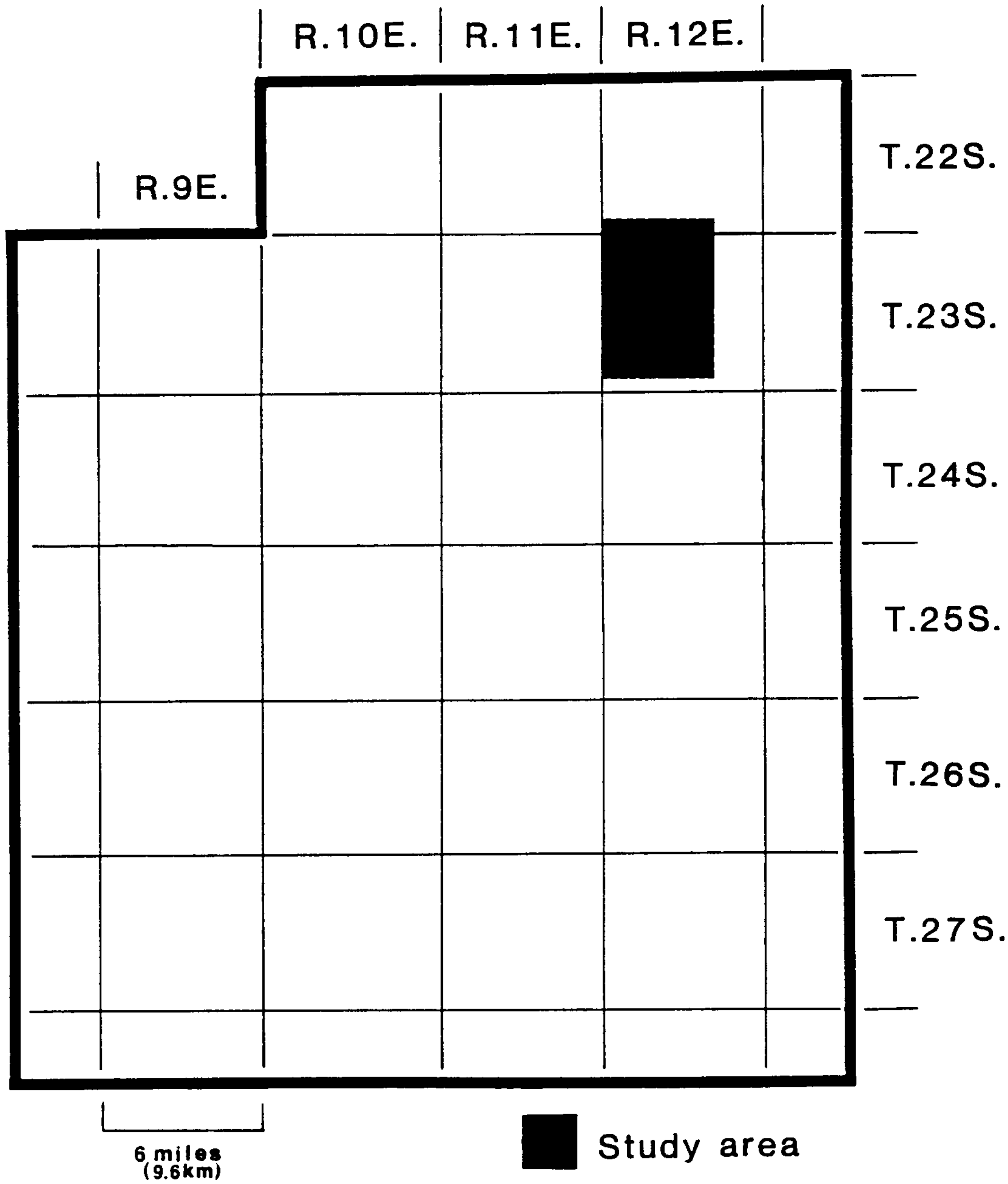

Pr
Q
Q
K
Pn
Pr
Q
Pr
Pn
Pr
Q
Pr
Pr
Pr
GREENWOOD
Pr
0
100 mi
0
100 km
Q Quaternary System
K Cretaceous System
Pr Permian System
Pn Pennsylvanian System
Study Area

Figure 2. Map of Greenwood County showing study area covering approximately 62 sq. km. (24 sq. mi.).



Greenwood County

(especially those recovered from the finer grained carbonates), little work has been done on the sedimentology, petrology, and distribution of all the Hamilton beds. Regardless, there are at least two published depositional interpretations (French et al., 1988; Busch, 1988).

There are also two conflicting interpretations pertaining to the salinity gradient of the paleoenvironment of the carbonate mudstone beds containing the Lagerstatte. One interpretation favors freshwater deposition, (Bridge 1988; Kues 1988; Kaesler 1988; Maisey 1988; and Taggert and Ghavidel-Syooki 1988) whereas (Busch et al. 1988; French et al. 1988; Mapes and Maples 1988; Maples and Mapes 1988; Schultze and Chorn 1988; and Leisman et al. 1988) argue for fluctuating salinity in a marine environment. Storm surge transport of marine organisms into nonmarine setting has been suggested by French et al., (1988) and Kaesler, (1988), whereas Busch et al. (1988) suggest that relatively short-lived sea level changes were responsible for the admixture of marine and nonmarine biota.

Numerous ages have been assigned to the Hamilton Lagerstatte ranging from Upper Pennsylvanian to Lower Permian. Palynological information interpreted by Taggert and Ghavidel-Syooki (1988), suggest that the carbonate mudstone beds of the Lagerstatte are Lower Permian, however the presence of Pennsylvanian age fusulinids (Douglass, 1988) disputes this age assignment. Additionally, the Hamilton deposit is interpreted to have formed during the formation of the Topeka (Bridge, 1988) and more specifically to have formed either during or after the deposition of the Calhoun Shale, the Iowa Point Shale or the Severy Shale (French, 1988).

HISTORY OF INVESTIGATIONS

Over the past 25 years, interest in the Hamilton Lagerstatte increased resulting in several significant investigations (Bridge and Mapes, 1988). The fossiliferous content of the Hamilton quarry was discovered by the amateur paleontologist, Walter Lockard in 1964 who brought it to the attention of Gil Leisman, a paleobotonist at Emporia State University in Kansas. Since then there have been at least 65 published abstracts and reports which have dealt with various aspects of this unique locality.

Earlier studies were limited to gross paleontologic, sedimentologic and stratigraphic aspects of the locality, and a preliminary report on these findings was presented (Bridge et al., 1972) at the 1972 South Central Sectional meeting of the Geological Society of America. Additional paleontological details were presented at the 108th annual meeting of the Kansas Academy of Science which included a special session devoted to the Hamilton area with several of the reports subsequently published in the Kansas Academy of Science Transactions (1976). From 1971 to 1988 only four reports on the Hamilton biota were made. Three of these reports were made on the paleobotany of the deposit (Leisman, 1971; G. Mapes, 1981; Rothwell, 1982). An abstract presented as a poster session at the International Botanical Congress at Edmonton, Alberta (Mapes and Mapes, 1984) provided a preliminary interpretation of the depositional environment of the main Lagerstatte bed in the Hamilton quarry. In 1986, efforts to revitalize study of the Hamilton geology included a symposium session at 1988 South-Central Sectional meeting of the Geological Society of America which included the publication of a guidebook published in 1988 [sic Feb. 1989] (edited by G. Mapes and R.H. Mapes) that contains 32 reports on various aspects of the geology and paleontology.

Current research within the last decade has been supported by the National Science Foundation, American Chemical Society, The Kansas Geological Survey and Ohio University. An abstract was presented at the South Central G.S.A. on the age and geometry of the Hamilton Lagerstatte (Fahrer et. al., 1990). Additionally a guidebook on Upper Paleozoic Vertebrate Paleontology included a section on the geology of the Hamilton Lagerstatte (Feldman et. al., 1990).

PURPOSE OF STUDY

The carbonate mudstones of the Hamilton deposit have yielded numerous exquisitely preserved fossils. Consequently the paleontological aspects of predominantly the mudstones have received the majority of the research attention. Relatively little attention has been given to the stratigraphic and depositional relationships that exist including the boundaries of the deposit, the geometric features represented, and the facies change relationships. Additionally, the age of the deposit and the depositional circumstances which yield this mixture of exquisitely preserved marine and nonmarine biotas are disputed.

The purpose of this study is to:

1. Determine the boundaries both laterally and vertically of the Hamilton deposit.
2. Assign an age to the Hamilton deposit.
3. Propose a model for the deposition of the Hamilton Lagerstatte deposit.

REGIONAL GEOLOGY

REGIONAL DEPOSITIONAL SETTING

Throughout Late Pennsylvanian time, Kansas was periodically covered by shallow, subequatorial, epeiric seas (Heckel, 1972). These epeiric seas produced marine limestone sequences alternating with terrestrial units resulting in distinct formations that were deposited across Kansas in a cyclic manner. The marine limestone units were periodically disrupted by deltaic clastic influx from the Ouachita region (Heckel, 1972). Sediment was deposited in broad north to south synclinal structures (Cubitt, 1975) where major structural highs such as the Ozark Dome and the Wichita Mountains did not exist.

The Ozark Dome of east-central Missouri is a complex uplifted block of Precambrian crystalline igneous and Paleozoic sedimentary rocks (Cubitt, 1975) and served as a source area for clastic sediments found in this region (Schultz, 1989). The existence of this source area in eastern Kansas is supported by the presence of Late Pennsylvanian channel sandstone deposits that reflect the mineralogy of the Ozark region (Cubitt, 1975).

In Kansas, rhythmic (or cyclic) sedimentation comprising both major repetitive transgressive/regressive events and minor sea level fluctuations are interpreted by Heckel (1986) to reflect patterns consistent with the Milankovitch insolation theory. These cyclic sediments are best preserved toward the center of the Late Paleozoic epicontinental sea and are most variable along the margins (Watney, 1980). The rapid facies changes associated with the margins can be attributed to the basin's overall broad, flat topography; the margins would be sensitive to even minor fluctuations in sea level and would reflect any significant change in depositional setting. The Hamilton beds were deposited near the marginal edge of an epicontinental sea (Fig. 3), therefore local depositional complexity should be expected (Merriam 1986).

The Hamilton deposit developed either within the Shawnee or the Wabnausee group megacyclothem, on the edge of an epicontinental sea. These megacyclothems contain several repetitive nonmarine-marine cycles (Fig 4). Based on the "Kansas cyclothem" model of Heckel (1977)(Fig.8), a generalized cyclothem sequence (in stratigraphic order) includes a nearshore (outside) shale, transgressive limestone, offshore core shale, and regressive limestone that is overlain by the nearshore shale of the next cycle. The Hamilton deposit has disrupted the cyclic pattern.

Figure 3. Map of the Midcontinent region showing the general position of the epicontinental seas which existed at that time (from Heckel, 1977).

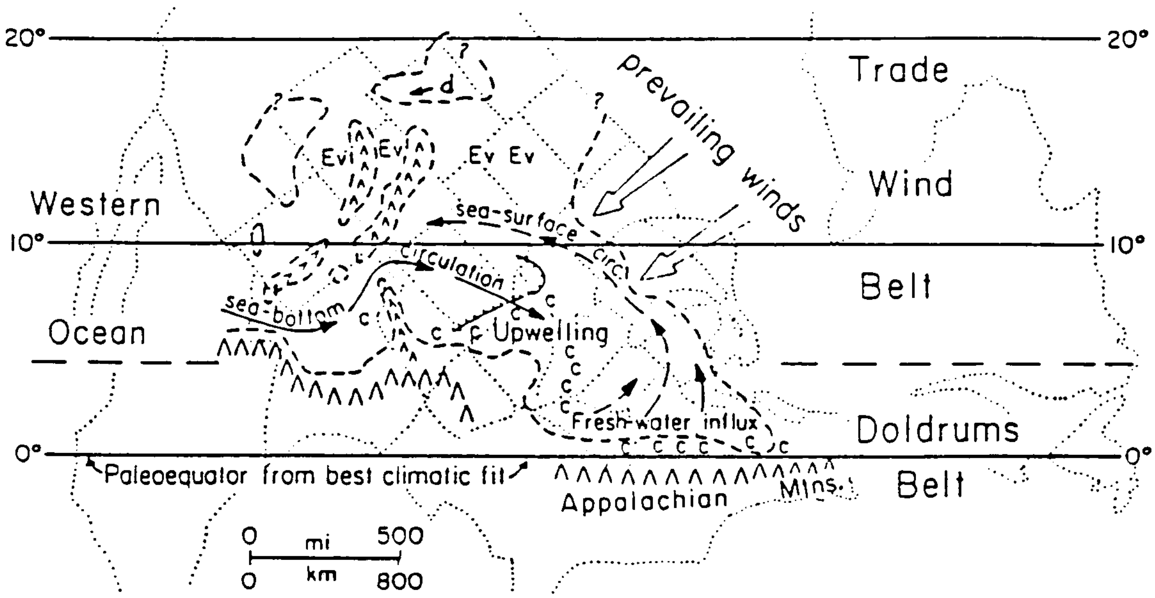

20°
20°
Trade
prevailing winds
Wind
Western
Ev Ev
Ev Ev
d
sea-surface
circulation
10°
10°
Belt
sea-bottom
circulation
Upwelling
Ocean
Fresh-water influx
Doldrums
0°
0°
Paleoequator from best climatic fit
Appalachian Mtns.
Belt
0 mi 500
0 km 800

Figure 4. An Upper Pennsylvanian stratigraphic sequence which exhibits several repetitive dominantly marine limestone bundles (Howard, Topeka and Deer Creek Formations) which are interrupted periodically by terrestrial shale deposits (Severy, Calhoun and Tecumseh Formations). The significant units of the study area are the Howard Limestone Formation, Severy Shale Formation, Topeka Limestone Formation, Calhoun Shale Formation, and the Deer Creek Limestone Formation (modified from Zeller, 1968).

Utopia Ls. Mbr. Winzeler Shale Mbr. Church Ls. Mbr. Aarde Shale Mbr. Bachelor Ck. Ls. Mbr.	Howard Lime-stone	Sacfox Subgroup	Wabanausee Group	VIRGILIAN STAGE	PENNSYLVANIAN SYSTEM
	Severy Shale	Sacfox Subgroup	Wabanausee Group		
Coal Creek Ls Mbr. Holt Shale Mbr. Du Bois Ls. Mbr. Turner Creek Sh. Mbr. Sheldon Ls. Mbr. Jones Pt. Shale Mbr. Curzon Ls. Mbr. Iowa Pt. Shale Mbr. Hartford Ls. Mbr.	Topeka Limestone		Shawnee Group		
	Calhoun Shale		Shawnee Group		
Ervine Creek Ls. Mbr. Larsh–Burroak Sh. Mbr. Rock Bluff Ls. Mbr Oskaloosa Sh. Mbr. Ozawkie Ls. Mbr.	Deer Creek Limestone		Shawnee Group		
	Tecumseh Shale		Shawnee Group		

REGIONAL STRUCTURAL SETTING

Major structures (post-Mississippian to pre-Desmoinesian, Merriam, 1963) associated with the Hamilton deposit include the Bourbon Arch to the north and the Nemaha Anticline to the west (Fig. 5). Located within the Cherokee basin, the Hamilton deposit is bordered by the Sedgewick Basin to the west and the Forest City Basin to the north. Numerous minor flexures are present in the southeast Kansas, the most prominent being the Beaumont, Longton and Virgil Anticlines.

Surface geomorphic features often reflect the regional structure. An especially good example are the joint patterns which often become stream valleys, this pattern is relatively consistent and can be easily recognized on topographic maps in this area (Merriam and Sovenson, 1982). Additionally these surface features are relatively consistent with subsurface fault block structures that are interpreted by Rich (1935) to exist in southeastern Chase and northwestern Greenwood Counties (Merriam, 1986).

The study area lies within the Osage Cuesta physiographic province (Schoewe, 1949) (Fig. 6). These "cuestas" are controlled by the gentle westward tilt of the beds (1 degree or less) along with the differential erosional characteristics of the underlying units. These "cuestas" have relatively low topographic relief and produces a slightly rolling topography.

Figure 5. Structure map of eastern Kansas adapted from Merriam, (1963) with the study area in Greenwood County included.

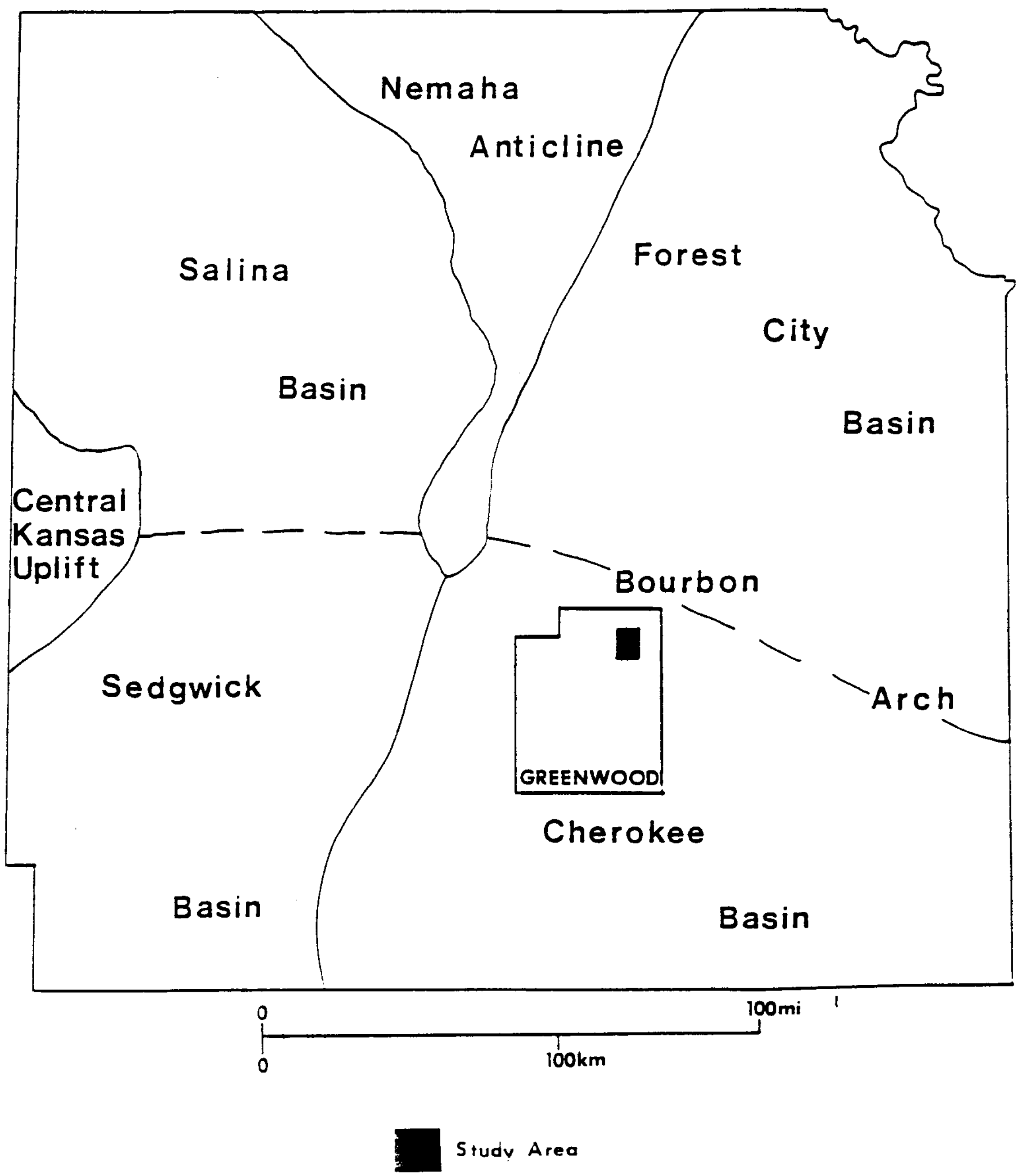
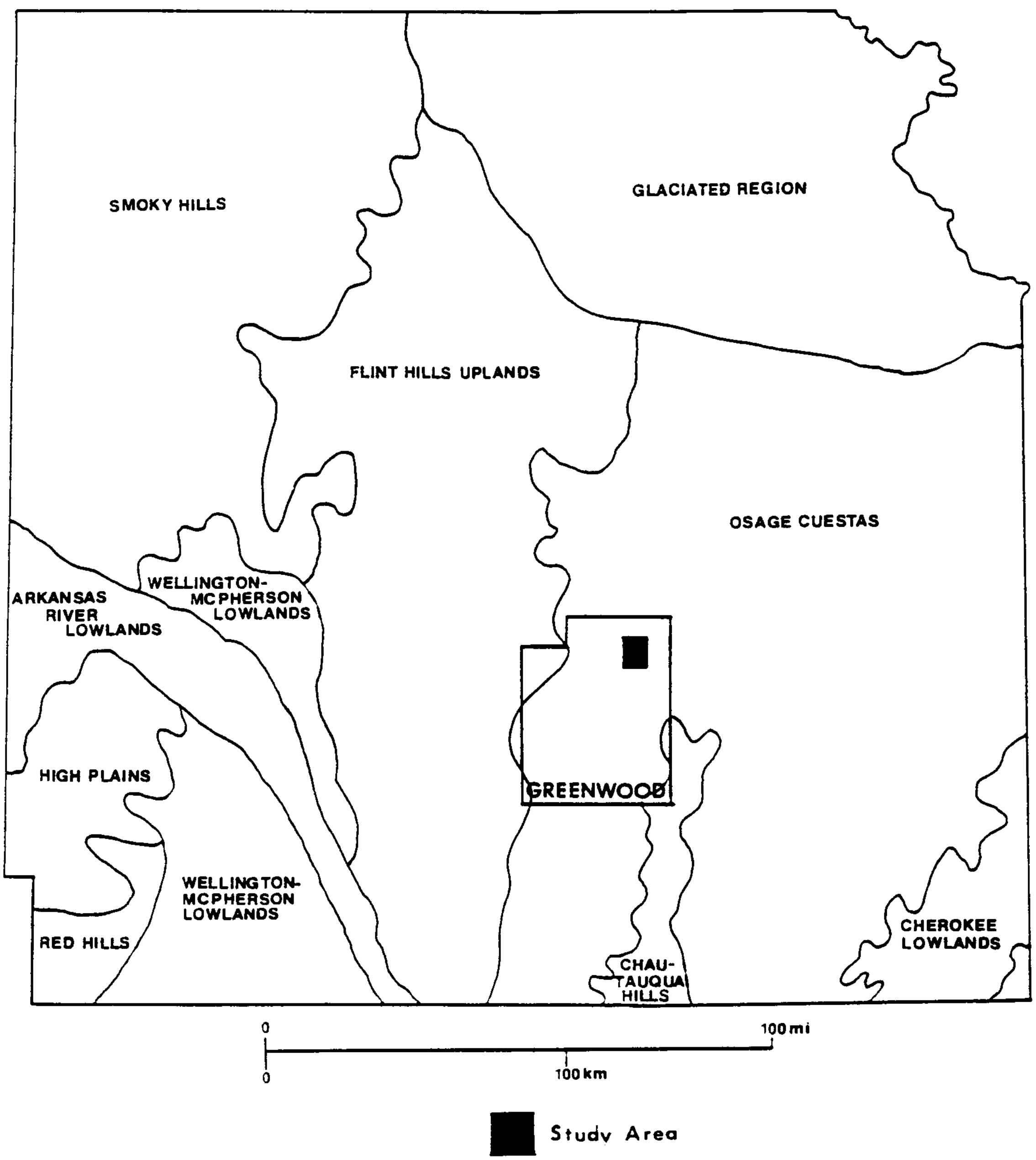

Nemaha
Anticline
Salina
Basin
Forest
City
Basin
Central
Kansas
Uplift
Bourbon
Arch
Sedgwick
Basin
GREENWOOD
Cherokee
Basin
0
100mi
0
100km
Study Area

Figure 6. Physiographic map of eastern Kansas modified from Schoewe (1949).


SMOKY HILLS
GLACIATED REGION
FLINT HILLS UPLANDS
OSAGE CUESTAS
WELLINGTON-
MCPHERSON
LOWLANDS
ARKANSAS
RIVER
LOWLANDS
GREENWOOD
HIGH PLAINS
WELLINGTON-
MCPHERSON
LOWLANDS
RED HILLS
CHAU-
TAUQUA
HILLS
CHEROKEE
LOWLANDS
0
100 mi
0
100 km
Study Area

METHODS

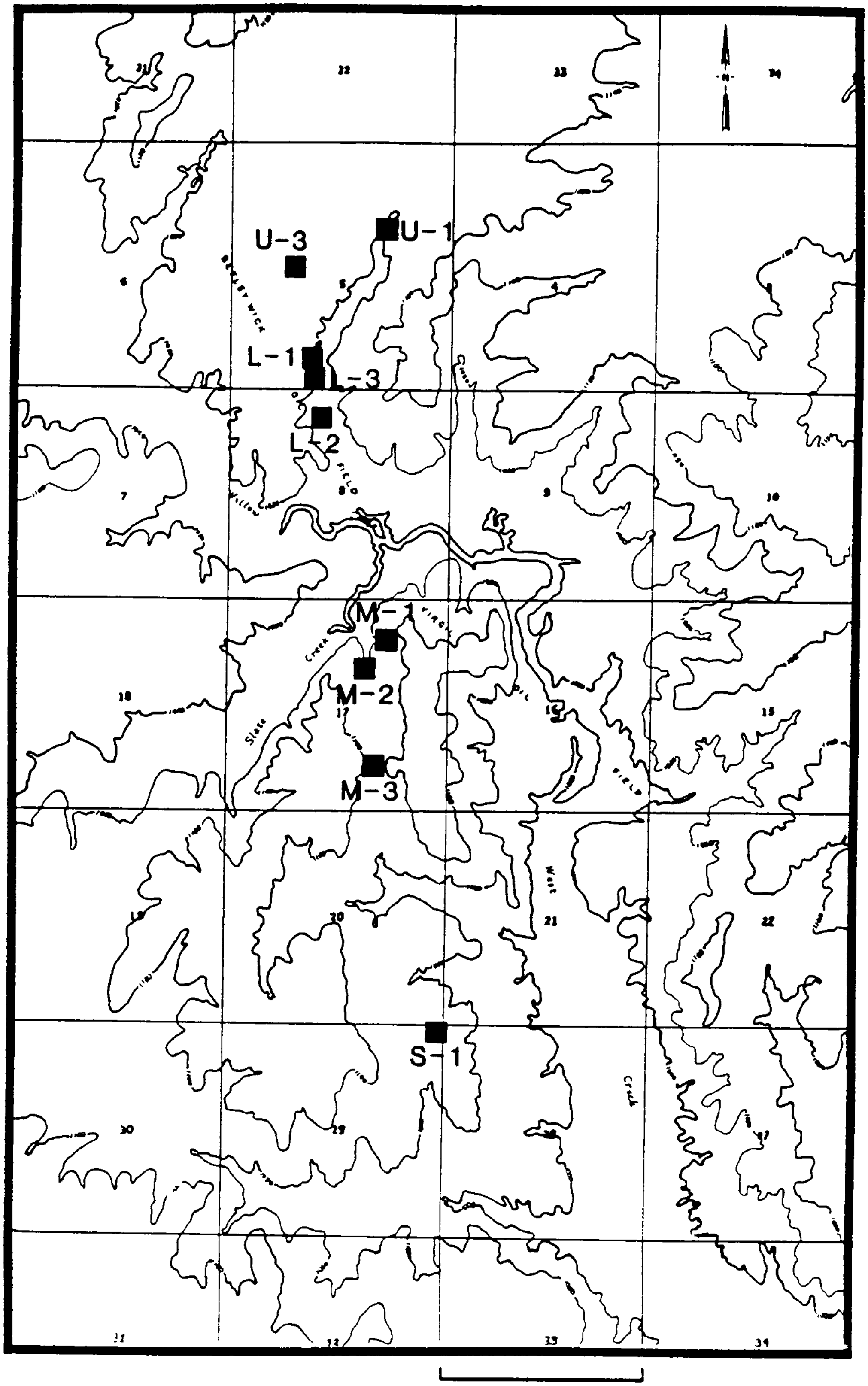
In order to resolve some of the problems associated with the Hamilton deposit, a detailed field mapping project accompanied by the collection of in situ rock samples for later laboratory based observations was undertaken. The field mapping would aid in resolving the boundary and stratigraphic relationships of the entire deposit while the laboratory study would provide a more detailed analysis of the existing microfabric and paleontologic relationships that exist. From this information an interpretation can be made explaining the admixture of nonmarine and marine biota, and an overall depositional model can be constructed to explain the lateral and vertical distribution and succession of paleoenvironments.

FIELD

Field mapping was initiated by walking out the area to locate outcrops. Topographic maps, aerial photographs, a Brunton compass, a steel tape and a hand level were used as an aid to mapping. Recorded information included photographs, bedding orientations, joints, fossil occurences, measured stratigraphic sections etc. Additionally in the summers of 1988 and 1989 the Kansas Geological Survey undertook an extensive core sampling program (Fig. 7) which was available for study. The core sample localities which were generally located at the time of the drilling program were more precisely located with a plane table and alidade during the study.

The collecting of samples was accomplished by extracting in situ slabs of the fossiliferous layers throughout the entire Hamilton sequence both laterally and vertically, noting orientations and then bringing them back to Ohio University for special individual study. In situ rock slabs with faunal and floral assemblages were collected from different areas of the carbonate mudstone of the Hamilton deposit to establish the lateral distribution of the biota.

Figure 7. Location of the core samples taken by the Kansas Survey in the summers of 1988 and 1989.



■ Core localities

1 Mile
(1.6km)

LABORATORY

Once the field mapping and sample collecting was accomplished the samples were studied in the laboratory. Laboratory based investigations included hand sample and thin section identification, microfossil analysis and with bedding plane analysis. This laboratory phase allowed for the analysis of microfabrics not visible in the field and the recovery and analysis of micropaleontological specimens from acid residues. Additionally, bedding planes of the carbonate mudstone could be observed for plant orientations that provided current direction information.

The laboratory process started with the measurement of the plant debris orientations on collected slab faces of the lime mudstone from various areas of the deposit. A 1.0 m square sheet of acetate was placed upon the rock surface which had previously been oriented. This enabled plant directions to be easily recorded for later use. Once the slab faces were documented they were processed like the rest of the hand samples taken from the remaining vertical succession of the deposit.

Following collection of the plant direction data on the bedding plane surfaces, the samples were cut and polished on two sides. This enabled hand sample investigation and aided in the selection of pertinent fabrics to use for thin section preparation. Thin sections were then prepared for later petrographic study. The unused portions of the samples that were trimmed in thin section preparation were saved (approximately 2 kg)

The 2 kg samples were individually dissolved in formic acid until all of the sample had dissolved. The sample was then washed through a 240 mesh sieve screen and dried in a laboratory oven for several hours. The sample was then picked for vertebrate remains and especially for conodonts since none had yet been recovered from any of the Hamilton Lagerstatte beds.

STRATIGRAPHY

The Normal Stratigraphic Sequence

The general stratigraphy in the area of Hamilton, Kansas includes the Shawnee Group (Virgilian Stage, Upper Pennsylvanian); however, to the north, the overlying Wabnausee Group (Virgilian) crops out and may have played an important role in the formation of the Hamilton deposit. Both of these groups have similar sequences of predominantly marine limestone alternating with predominatly nonmarine shale recognized as formations. Each limestone formation contains several members which alternate between marine limestones and mostly marine shales. The shale formations are nonmarine. In general all units thicken to the south and become more sandy until, near the Oklahoma border, they either pinch out or are no longer recognizable (Merriam, 1986).

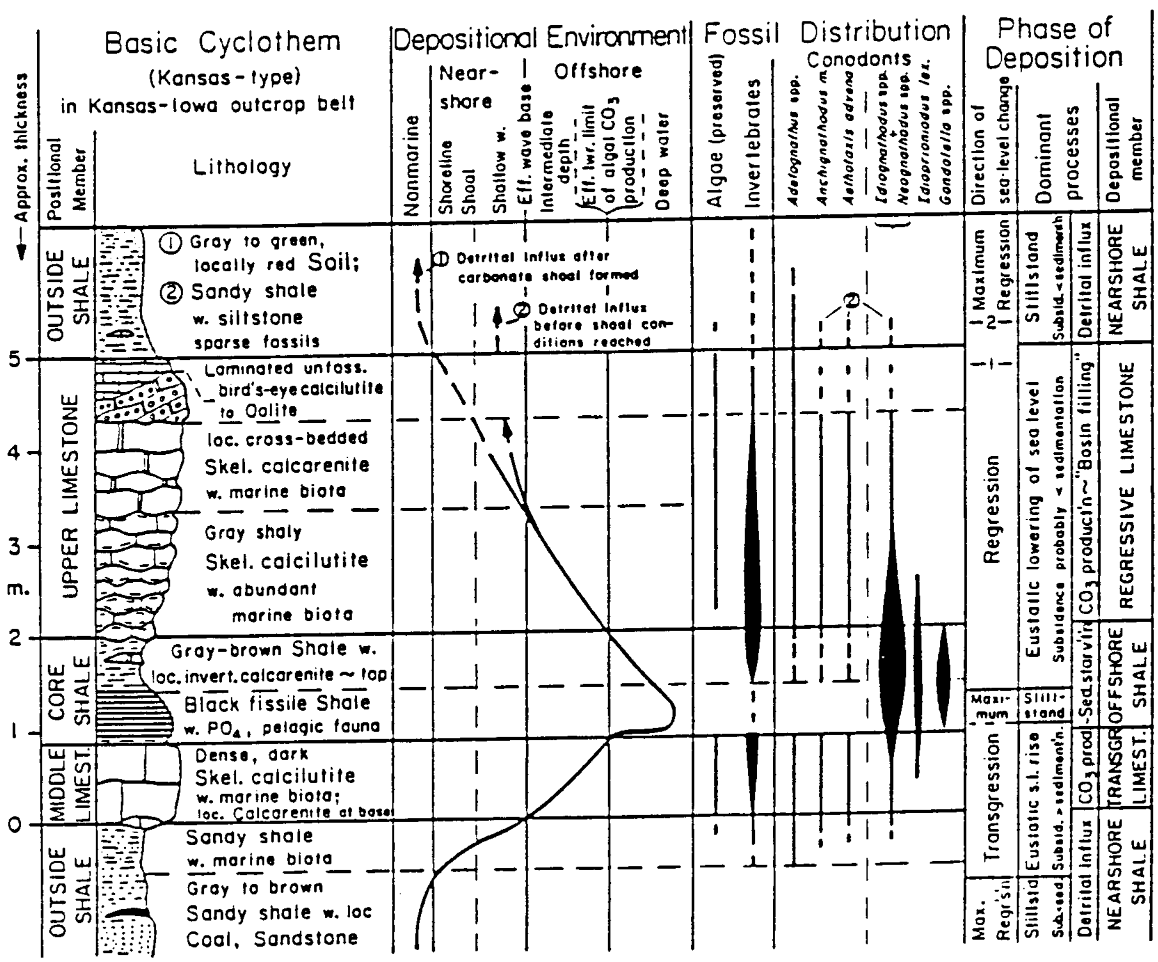
The limestone and shale formations contained within the Shawnee and Wabnausee Groups represent cyclothems (Heckel, 1989). The cyclothem model (Fig. 8) consists of the following in ascending order: 1. Transgressive limestone, deposited in deepening water. 2. Offshore ("core") shale formed at maximum transgression. 3. Regressive limestone deposited in shallowing water and, 4. The nearshore ("outside") shales which lie outside the limestone formations and represent a lower sea level stand where nearshore and terrestrial deposits dominate.

The cyclothem then repeats itself starting with a transgressive limestone.

Figure 8. Basic Kansas cyclothem illustrating the transgressive/regressive sequence which occurs within the limestone bundles throughout Kansas (from Heckel, 1989).

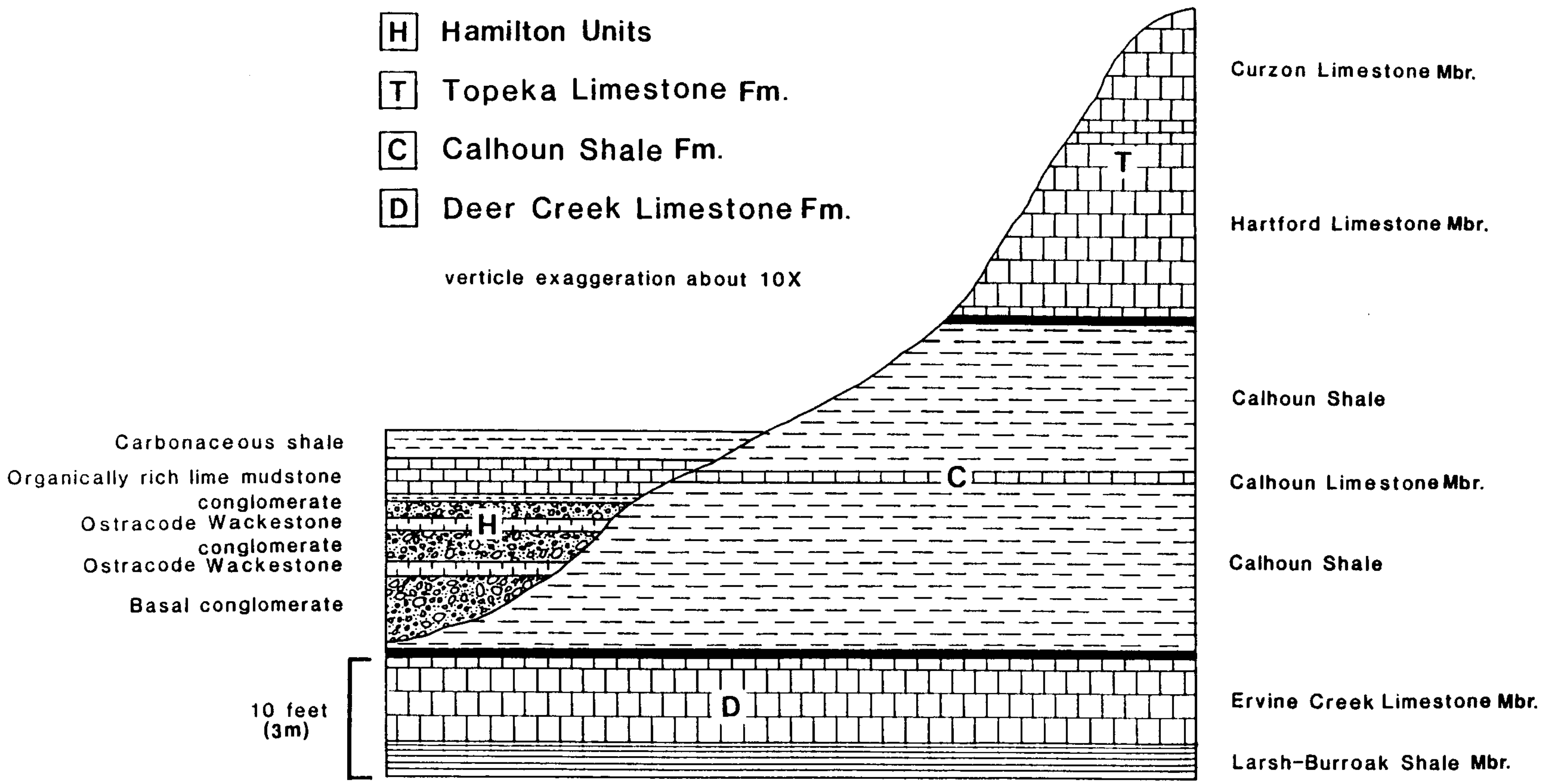
The Hamilton deposit formed at the boundary between a terrestrial, nearshore shale and either a regressive or transgressive marine limestone. The Hamilton Lagerstatte deposit unconformably truncates the stratigraphic interval that includes the Ervine Creek Limestone Member of the Deer Creek Formation, the Calhoun Shale Formation, and the Hartford Limestone, Iowa Point Shale and Curzon Limestone Members of the Topeka Formation (fig. 9). The Hamilton deposit cuts completely through the Curzon Limestone Member, Iowa Point Shale Member, Hartford Limestone Member and almost the entire sequence of the Calhoun Shale, but does not truncate the Ervine Creek Limestone Member.

The Topeka Formation of the Shawnee Group is not complete in the Hamilton Lagerstatte area with only the transgressive phases (Hartford Limestone, and Curzon Limestone Members) represented. The Iowa Point Shale which is absent between the Hartford and the Curzon Limestones is considered to be locally controlled in eastern Kansas where it is often absent between these two members (Skelton, 1988). In the Hamilton deposit area the Curzon is the youngest exposed member; however, to the northeast, the Severy Shale Formation of the Wabnausee Group overlies the Curzon limestone and apparently the rest of the Topeka Formation has been eroded away.



Basic Cyclothem
(Kansas-type)
in Kansas-Iowa outcrop belt
Approx. thickness
Positional Member
Lithology
Depositional Environment
Nonmarine
Near-shore
Offshore
Shoreline
Shoal
Shallow w.
Eff. wave base
Intermediate depth
Eff. lwr. limit of algal CO_3 production
Deep water
Fossil Distribution
Algae (preserved)
Invertebrates
Conodonts
Adetognathus spp.
Anchignathodus m.
Aethotaxis advena
Idiognathodus spp. + Neognathodus spp.
Idioprioniodus lax.
Gondolella spp.
Phase of Deposition
Direction of sea-level change
Dominant processes
Depositional member
OUTSIDE SHALE
① Gray to green, locally red Soil;
② Sandy shale w. siltstone sparse fossils
① Detrital influx after carbonate shoal formed
② Detrital influx before shoal conditions reached
UPPER LIMESTONE
Laminated unfoss. bird's-eye calcilutite to Oolite
loc. cross-bedded Skel. calcarenite w. marine biota
Gray shaly Skel. calcilutite w. abundant marine biota
CORE SHALE
Gray-brown Shale w. loc. invert. calcarenite ~ top
Black fissile Shale w. PO_4, pelagic fauna
MIDDLE LIMEST.
Dense, dark Skel. calcilutite w. marine biota; loc. Calcarenite at base
OUTSIDE SHALE
Sandy shale w. marine biota
Gray to brown Sandy shale w. loc Coal, Sandstone
5
4
3
m.
2
1
0
1 Maximum 2 Regression
Stillstand
Subsid. < sedimentn
Detrital influx
NEARSHORE SHALE
Regression
Eustatic lowering of sea level
Subsidence probably < sedimentation
CO_3 producti'n ~ "Basin filling"
REGRESSIVE LIMESTONE
Maximum
Stillstand
Sed. starvin
OFFSHORE SHALE
Transgression
Eustatic s.l. rise
Subsid. > sedimentn.
CO_3 prod.
TRANSGR. LIMEST.
Max. Regr'sn
Stillstd
Sub.<sed.
Detrital influx
NEARSHORE SHALE

Figure 9. Generalized stratigraphic sequence of the Hamilton beds on the left and lithologies of the cyclothem beds on the right as exposed in the Hamilton quarries an cores.



Generalized east to west cross-section showing relationship between channel units and associated lithologies.

Deer Creek Formation

Ervine Creek Limestone Member

The Ervine Creek limestone of the Deer Creek Formation is an upper, or regressive, limestone, conformably overlying the Larsh/Burroak core shale. Regionally ranging in thickness from 1 to 10 m, the Ervine Creek limestone in the Hamilton area is from 1 to 2 m thick and consists entirely of wavy bedded limestone. Elsewhere this limestone is overlain by 0.3 to 0.6 m of yellowish-gray clayey shale (Zeller, 1968) and an upper, massive limestone that is generally less persistent.

The lower, wavy bedded limestone of the Ervine Creek is light- to blue-gray, fine-grained, and locally contains chert nodules. A variety of fossils including corals, phylloid algae fragments, fusulinids, echinoderm fragments, bryozoans, mollusks and brachiopods were observed from this unit in the Hamilton area.

The upper limestone, which is found outside the Hamilton area, ranges up to 2 m in thickness. It has a variable lithology and is very fine-grained, sandy, nodular, oolitic or coquinoidal and contains the algae Osagia (Zeller, 1968)

Calhoun Shale

The Calhoun shale which is an outside or nearshore shale within the cyclothem model, generally consists of 10 to 12 m of brown, micaceous and silty shale, locally containing micaceous lenticular sandstones and thinly-bedded limestones in the upper portion of the unit. From a maximum thickness of approximately 15 m in Shawnee County, the Calhoun shale progressively thins southward toward Central Elk County where it is no longer present (Lamoreaux, 1986). In northeastern Kansas, there is a thin coal bed toward the top and plant remains occur in the sandier lithologies (Zeller, 1968).

Heckel (1979) interpreted outside shales to reflect deltas that prograded into shallow seas. In Kansas, the outside shales are variable in thickness and locally can attain a thickness up to 40 m. Some of the nearshore shales display evidence of subaerial exposure (Skelton 1986).

In the Hamilton area the Calhoun Shale is similar to the regional descriptions throughout eastern Kansas; however, there were no plant remains or fossils recovered from the Hamilton area. The Calhoun Shale is approximately 10 m thick, consists of almost entirely of a brown micaceous shale and in the upper portions contained micaceous sandstone lenses. Additionally, the Calhoun Shale does not contain coal beds as in northeastern Kansas but has a thin (30 cm) limestone sequence representing minor transgressions of a nearby sea.

Topeka Formation

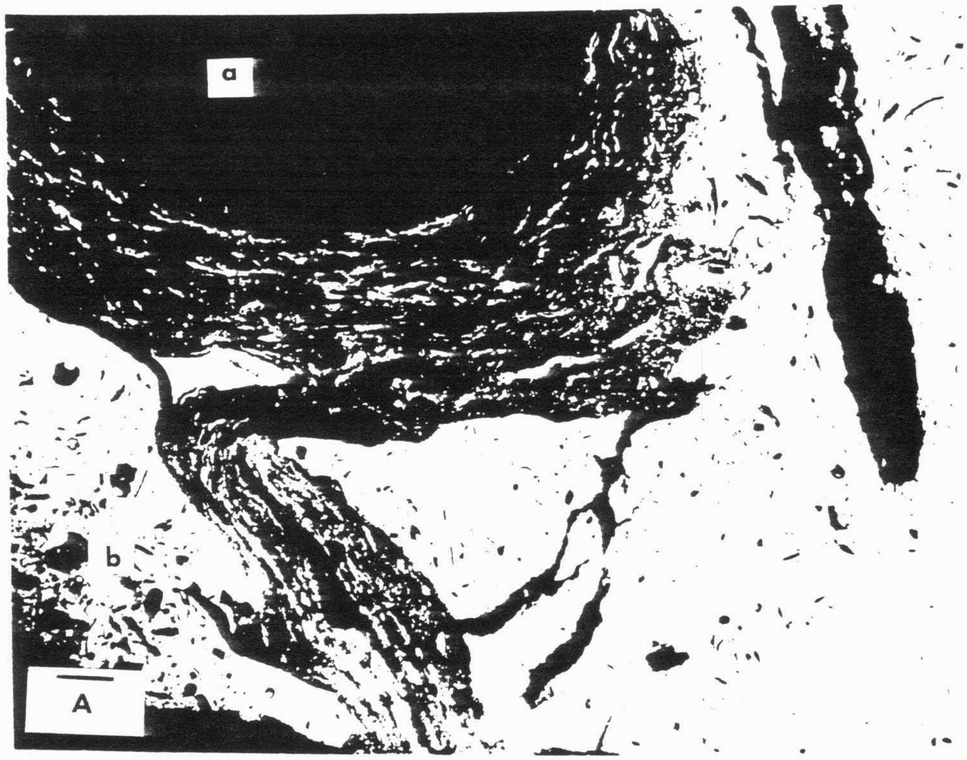
Hartford Limestone Member

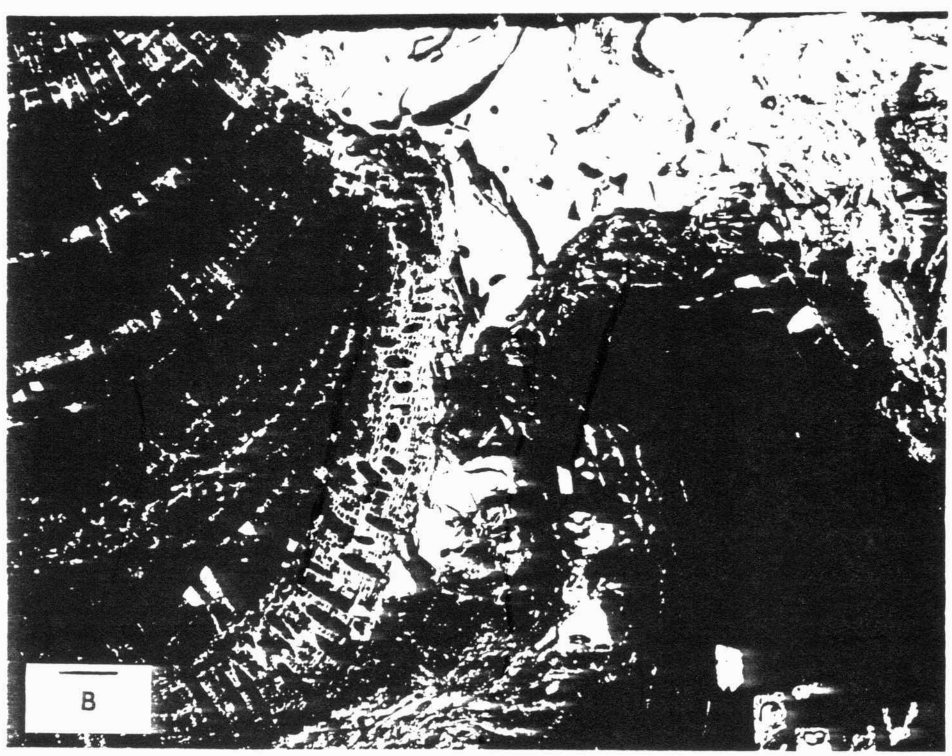
Facies relationships and depositional interpretations from lithologic and paleontologic characteristics of the Hartford Limestone suggest that a minor transgressive-regressive event took place during its deposition (Silfer, 1986). Following deposition of the Calhoun Shale (maximum regression), the skeletal and algal-bank facies of the Hartford limestone represent a time of transgression. This transgressive phase of the Hartford Limestone is overlain by a regressive oncolite limestone facies characteristic of a more turbulent environment, which is in turn overlain by a fusulinid limestone facies reflecting a nearshore marine environment. Maximum regression is then represented by the deposition of the terrestrial Iowa Point Shale Member of the Topeka Formation (Silfer, 1986).

In the vicinity of the Hamilton Lagerstatte the Hartford Limestone Member of the Topeka Formation, comprises two limestone units; each is 4 to 5 m thick. The lower unit, consists of wavy bedded, bioclastic, oncolitic packestone and wackestone that is dark gray on fresh surfaces but weathers to orange. This lower unit also contains the chambered sponge Amblysiphonella (Fig. 10) which provides a conspicuous marker fossil for the area. This unit is overlain by the upper unit of the Hartford Limestone comprising light tan to brown peloid and phylloid algal wackestone (Fig. 10). Approximately 8 km to the northeast of the Hamilton

Lagerstatte, the upper portion of the Hartford contains abundant fusulinids, which occur above a restricted-marine, phylloid-algal bank facies (Silfer, 1986).

Figure 10. Photonegatives of thin sections taken from the Hartford Limestone Member. (A) Two chambers of the spongue Amblysiphonella. One chamber was not filled in (a) while the other chamber (b) was filled in with the mud supported matrix. (B) Other unidentified sponges from the Hartford Limestone. (Bar scale = 1 mm)


a
b
A


B

Iowa Point Shale Member

Regionally the Iowa Point Shale Member of the Topeka Formation is a yellow to blue-gray calcareous shale characterized by a basal thin, soft micaceous sand containing plant fossils (Jeffords, 1940) overlain by a gray blocky marine fossiliferous shale (Moore,1935). Ranging in thickness from a few centimeters to a couple of meters (Moore, 1935), the Iowa Point Shale thins southwestward from northeastern Kansas and eventually disappears south of Topeka, Kansas where the Curzon Limestone lies directly upon the Hartford Limestone Member (Zeller, 1968). Because in much of Kansas the Curzon Limestone lies directly upon the Hartford Limestone, the Iowa Point shale may be strictly a local facies (Moore ,1935). In fact, Moore (1935) considered the Hartford Limestone, Iowa Point Shale, and the Curzon Limestone as a single member; however, from a depositional point of view, each of these units are important since they represent distinct transgressions and regressions.

The nonmarine Iowa Point shale reflects maximum regression that completes the transgression-regression cycle of the Hartford limestone. During this time, the decline of sea level induced progradation of delta lobes into the area resulting in deposition of lower Iowa Point sediments. In areas outside the Hamilton Lagerstatte, a thin coal seam in the Iowa Point Shale represents sedimentation in a swampy, alluvial-deltaic plain environment; the coal marks maximum regression and the conclusion of the Hartford Limestone depositional cycle (Silfer, 1986).

In the Hamilton deposit area the Iowa Point Shale is very thin (5 cm) and in almost all localities is completely absent. In the few exposures the only part of the Iowa Point Shale that was present was a thin micaceous shale layer thought to represent the basal portion of this unit. No fossils were recovered from the Iowa Point Shale in the Hamilton area.

Curzon Limestone Member

The Curzon is a transgressive limestone representing the reestablishment of normal marine conditions following the deposition of the Iowa Point Shale. The Curzon Limestone which ranges in thickness from 1.6 to 4.0 m, was described by Zeller (1968) as consisting of two or more massive, blue-gray limestone units that weather brown (Fig. 11). The lower and middle sections of this member are characterized by abundant chert nodules and abundant to sparse fusulinids while Brachiopods, bryozoans and echinoid remains are common in the upper layers.

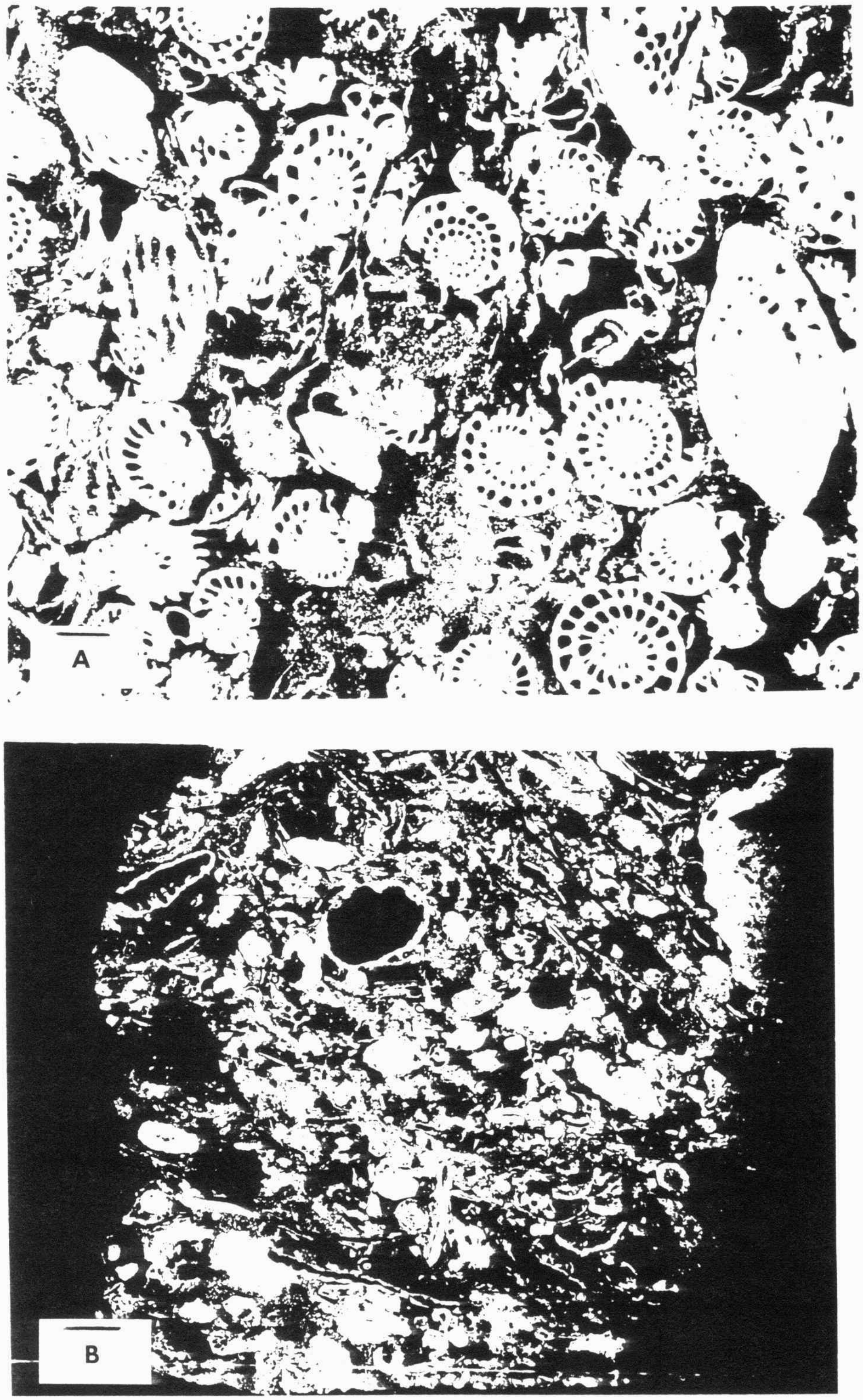
In the Hamilton area the Curzon Limestone was separated into two distinguishable parts; a lower portion that weathered brown and contained abundant fusulinids, and an upper portion that remained white and contained abundant shell debris consisting of fusulinids, echinoids, brachiopods and gastropods (fig. 11). At several localities in the Hamilton area the Curzon Limestone appeared to lie directly upon the Hartford Limestone.

Severy Shale Formation

Although the Severy Shale is not present in the study area it is present approximately 4 km to the northeast where it unconformable overlies the Curzon Limestone of the Topeka Formation. The rest of the Topeka Formation was removed by erosion during the deposition of the Severy Shale. Absent members of the Topeka Formation include from youngest to oldest: Coal Creek Limestone Member, Holt Shale Member, Dubois Limestone Member, Turner Creek Shale Member, Sheldon Limestone Member, and the Jones Point Shale Member. The Severy Shale was described by White (1986) as a formation that consists of approximately 50 to 75 feet (15-23m) of clay and mudstone overlain by siltstone.

The basal claystone contains broad, shallow channel sandstones that contain soft sediment deformation (White,1986) and erode deep into the Topeka Limestone (Zeller,1963). Additionally several outcrops of the Severy Shale containing these channel sandstones which lie unconformably upon the Curzon Limestone Member (Johnson and Adkinson, 1967). This basal claystone is overlain by a gray, sparsely fossiliferous mudstone which contains plant fragments, brachiopods, bivalves, bryozoans and gastropods. This unit additionally contains limestone stringers which contain mainly crinoidal fragments. The overlying siltstone contains rippled laminations, climbing ripples and cross laminations. Plant fossils are the most abundant fossil.

Fig. 11 Photonegatives of thin sections from the Curzon Limestone Member. (A) Lower portion of the Curzon Limestone which contains abundant fusulinids. (B) Upper portion of the Curzon Limestone which contains fossil debris such as fusulinids and bivalves. (Bar scale = 1 mm)


A
B

Deposition of the Severy Shale Formation results from several factors that include the lowering of sea level, and increased influx of sediment into the basin (White, 1986). The Severy Shale is considered by White (1986) to be a nearshore or nonmarine deposit. The Severy was deposited in a dynamic environment where high energy channel sandstones with soft sediment deformation were interbedded with low energy fossiliferous clay and mudstones containing abundant plant debris. Additionally the presence of limestone stringers within the Severy Shale is evidence of encroachment of the sea to levels which would sustain marine organisms and carbonate production (White,1986).

Howard Limestone Formation

Aarde Shale Member

Marine fossils present in the upper portion of the Severy Shale record a marine incursion of short duration, but these were soon replaced by widespread swamp conditions favorable for the accumulation of carbonaceous materials, notable the Nodaway coal bed at the base of the Howard Limestone Formation. The brown to black Nodaway coal bed of the Aarde Shale Member was then overlain by the other beds of the member which consist of claystone or siltstone (Johnson and Adkinson, 1967).

Most of the Aarde Shale is light olive to dark gray olive, laminated to platy claystone. Locally the claystone in the upper part of the member contains small nodules and lenses of light olive gray to brown fossiliferous limestone. Fossils present in the Aarde Shale include plants, foraminifera, bryozoans, corals, brachiopods and crinoid pieces. (Johnson and Adkinson, 1967).

Stratigraphy of the Hamilton deposit

Stratigraphic relationships are complex throughout the entire Hamilton deposit. Changes within the Hamilton facies occur not only north to south along the linear extent of the deposit, but also east to west as the deposit thickens or thins. There is also an increase in marine influence in the Hamilton sequence toward the south.

In the northern area of the Hamilton deposit, nonmarine sediments predominate (Fig. 13,14 A). Thinly bedded, marine influenced conglomerates, that range in thickness from 15 - 20 cm and contain abundant 1 -3 cm pink carbonate clasts, are overlain by nonmarine carbonaceous shales and lime mudstone that range in thickness from 60 - 80 cm. The light brown carbonaceous shales contain abundant mica flakes, and the brown to gray lime mudstones are blocky, generally featureless and contain abundant ostracodes and poorly preserved plant remains

In the Main quarry (Fig. 13, 14 B) at the upper midsection of the Hamilton deposit there is a more equal distribution of marine influenced conglomerates overlain by nonmarine carbonaceous shales (lithologically similar to those in the north) and carbonate mudstones (Fig. 15). The carbonate mudstones however, are quite different with their cryptalgal laminations, soft sediment deformation and well preserved fossils (Fig. 17). These tan to gray laminated carbonate mudstones contain the majority of the exquisitely preserved vertebrates, invertebrates and plants which give this deposit its Lagerstatte classification.

Figure 12. Location of cross-sections taken from the linear extent of the Hamilton deposit demonstrating channel-like tendancies and illustrating the geologic exposures in the study area.

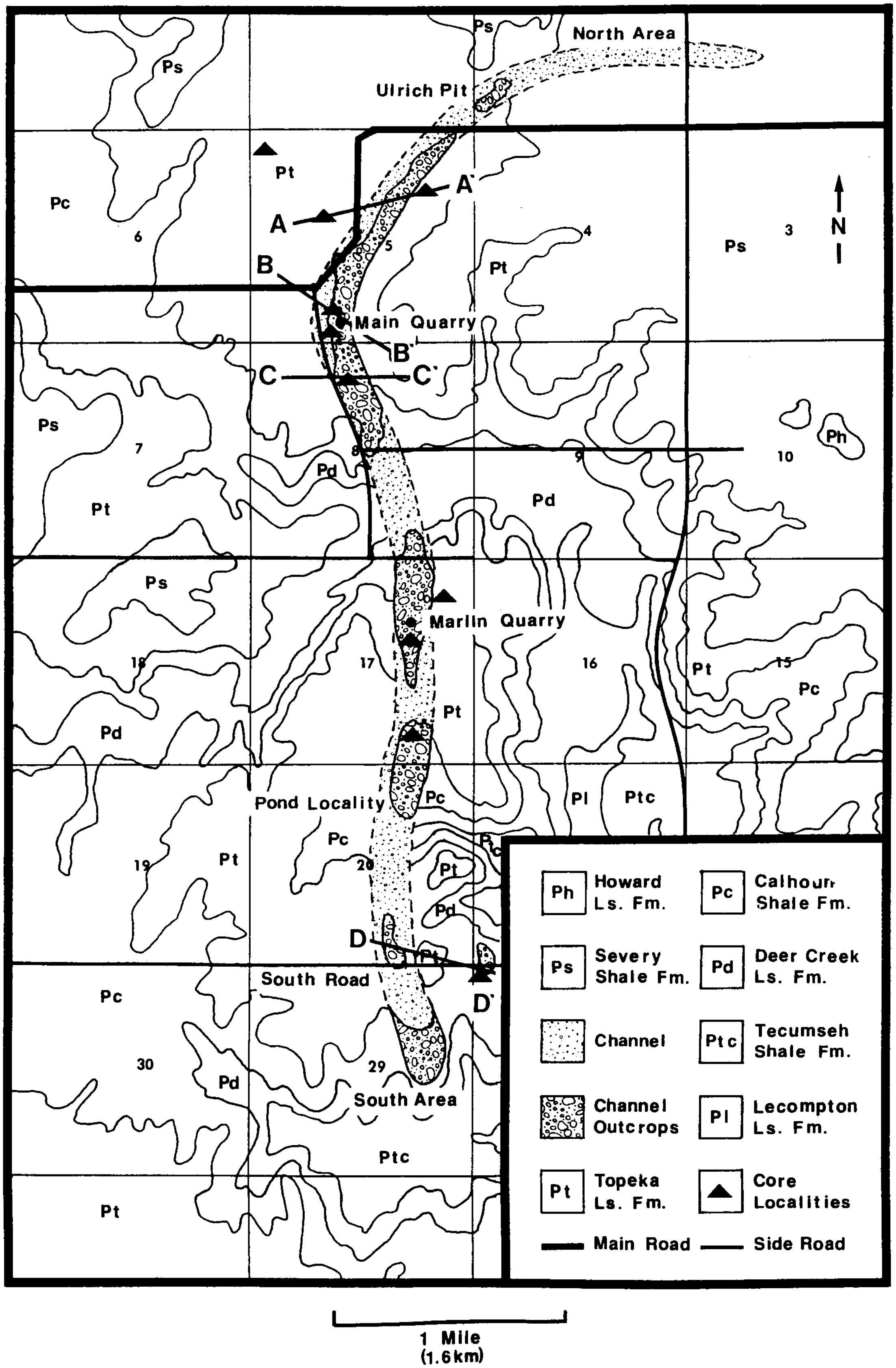
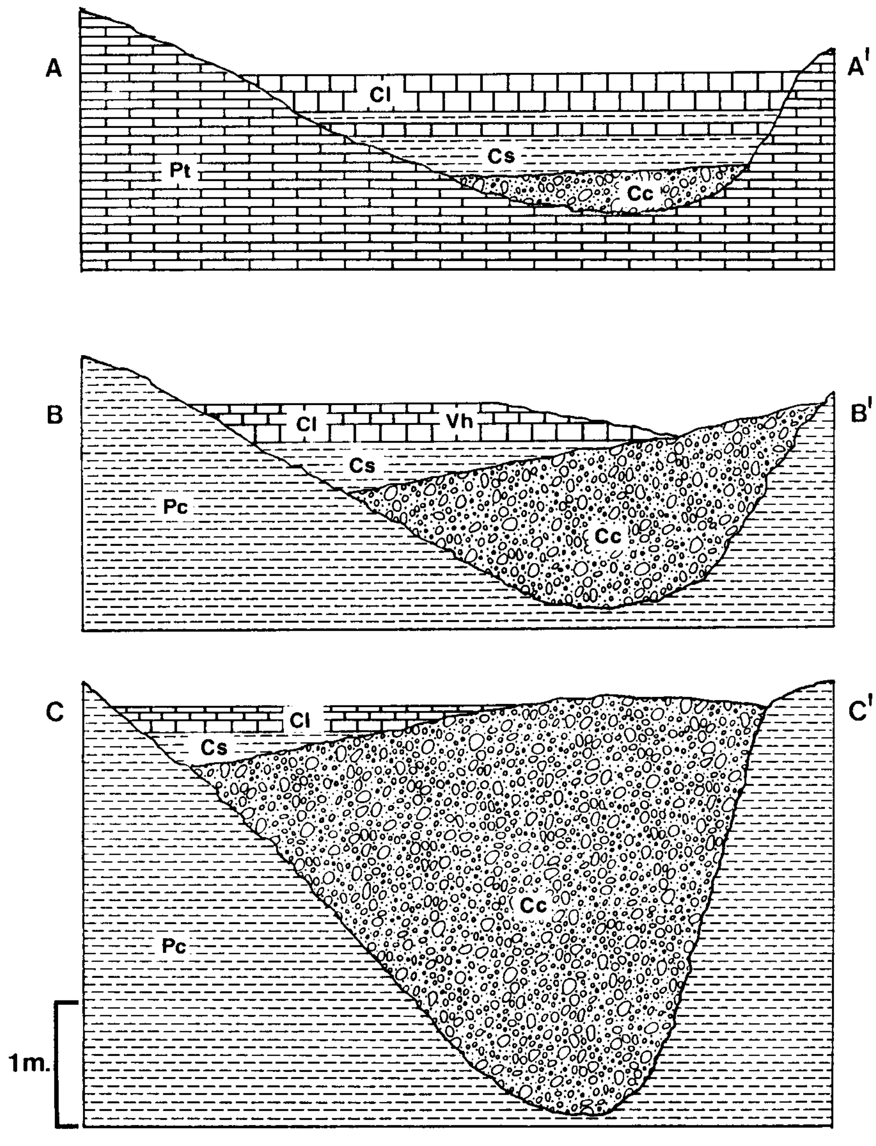

North Area
Ulrich Pit
Ps
Pt
Pc
A
A'
B
B'
C
C'
D
D'
N
Main Quarry
Marlin Quarry
Pond Locality
South Road
South Area
Pd
Ph
Pl
Ptc
Ph Howard Ls. Fm.
Pc Calhoun Shale Fm.
Ps Severy Shale Fm.
Pd Deer Creek Ls. Fm.
Channel
Ptc Tecumseh Shale Fm.
Channel Outcrops
Pl Lecompton Ls. Fm.
Pt Topeka Ls. Fm.
Core Localities
Main Road
Side Road
1 Mile
(1.6km)

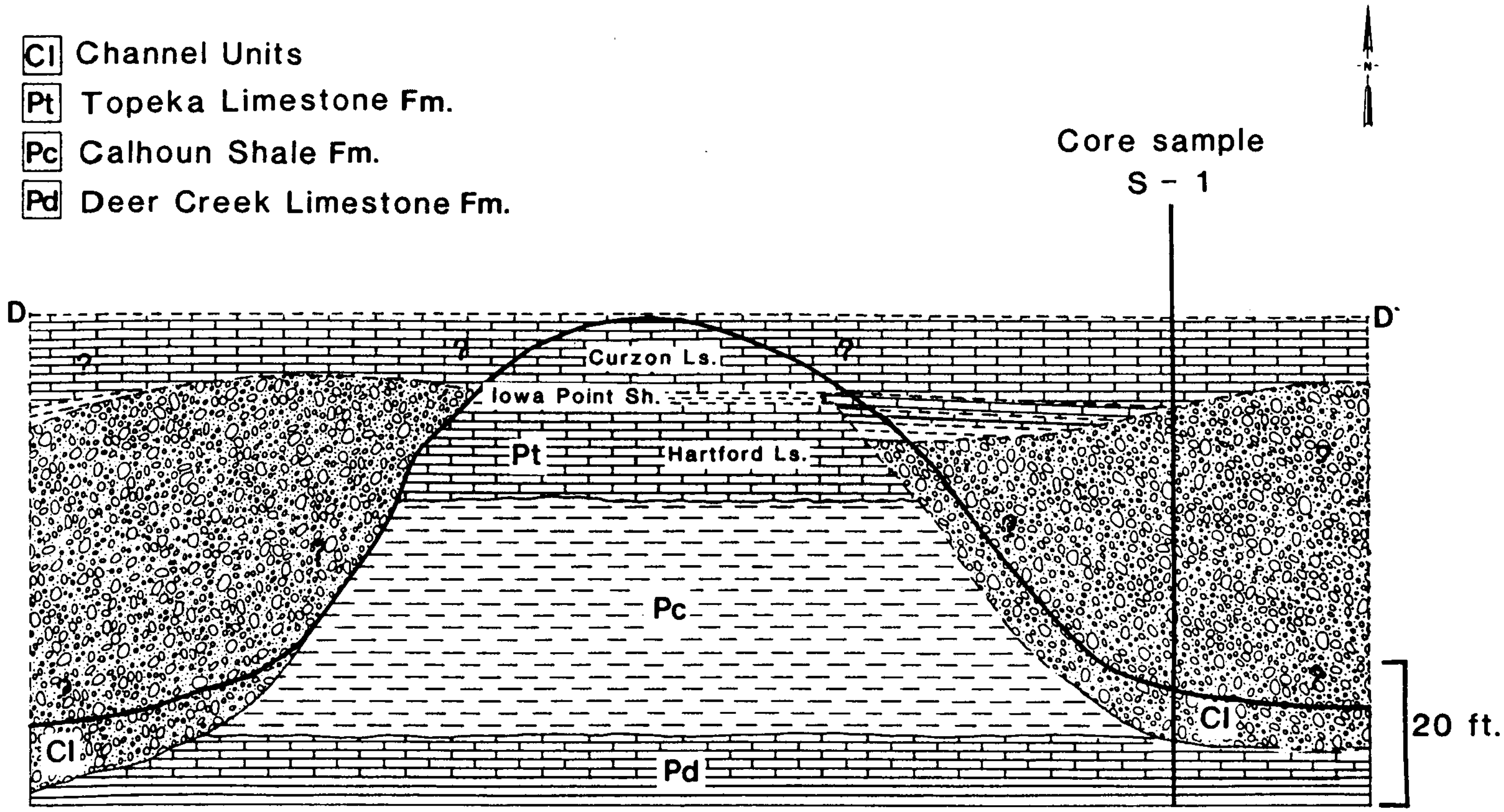
Figure 13. Generalized cross sections of the Hamilton deposit through its linear extent. Note the southward deepening and asymmetrical shape.



Cl	Channel Lime mudstones	Pt	Topeka Ls. Fm.
Cs	Channel Shales	Pc	Calhoun Shale Fm.
Cc	Channel Conglomerates	Vh	Vertebrate Horizon

Vertical exaggeration about 30x

Figure 14. Generalized cross-section D-D′ of the southernmost extent of the channel. One possible scenario is that the Hamilton Lagerstatte beds formed during Iowa Point time which was then overlain by the Curzon limestone. However actual overlying units or interfingering was not noted.



Vertical exaggeration about 5X

In the south-central portion of the Hamilton deposit, (Figs. 13,14c) marine influenced conglomerates predominate with little to no accumulation of nonmarine deposits. The carbonaceous shales and lime mudstones are either replaced by one or more ostracode wackestones that contains eurypterid remains or they could have been eroded away. The latter seems more plausible since there are carbonate mudstones directly to the south. Several complex lithologic sequences exist within this area, and they change drastically from outcrop to outcrop in different areas. These relationships are well exhibited in the Marlin quarry area (Fig. 19) where a relatively thick, cross stratified basal conglomerate sequence approximately 3 meters thick, is overlain by an alternating sequence of cream colored ostracode wackestone and conglomeratic grainstones (Fig. 19).

The southern extent of the Hamilton deposit (Fig. 13) generally lacks outcrops except for the southern most exposure which crops out in a large lobe shape (Fig. 23). This lobe consists of stacked conglomerates approximately 5 m in thickness that are lithologically similar to the basal units exposed in the Marlin Quarry. Outcrops north of the lobe are scarce; however, there is an outcrop at the South Road locality that indicates that the conglomerates which formed the lobe are overlain by shales and thin bedded carbonate mudstones. The carbonate mudstones recovered from this area are generally featureless and contain poorly preserved plant fossils. There is only one other outcrop that contains the carbonate mudstone between this locality and the Marlin Quarry and that is near the Pond Locality. Shrimp fossils were described by Schram (1988) from this locality. The carbonate mudstone at this locality contains plant debris and abundant annelid worms (Fig. 24) and in some places the mudstone is deformed by soft sediment deformation.

Figure 15. The main pit where the majority of the Lagerstatte recoveries have been located. Vertical successions of the carbonate mudstone beds which in the Main Pit consisted of three distinct layers. About 1 m of carbonaceous shale is dug out with the conglomerate at the bottom of the hole.

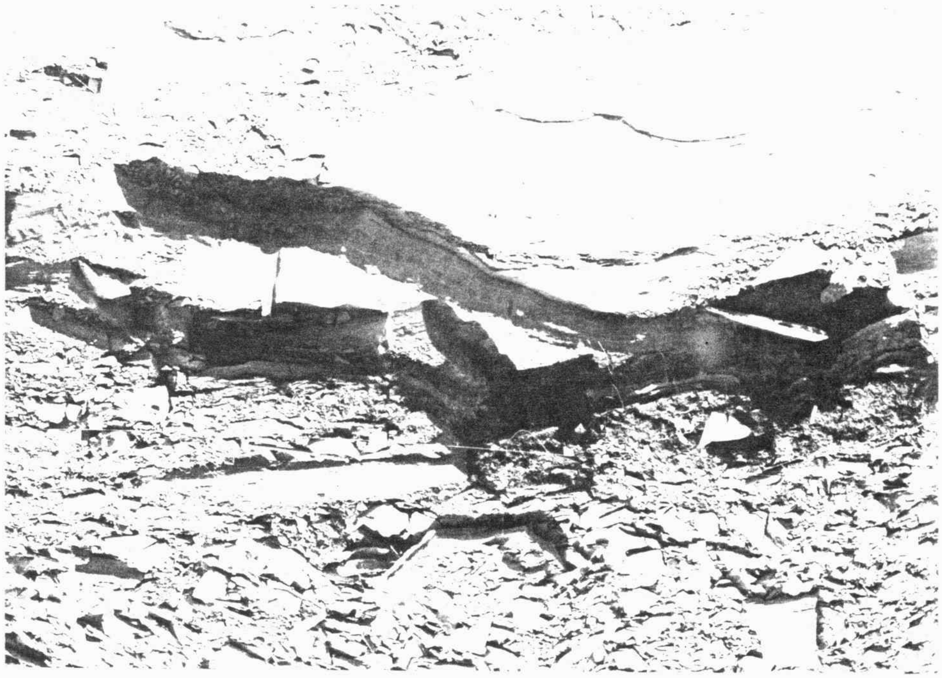
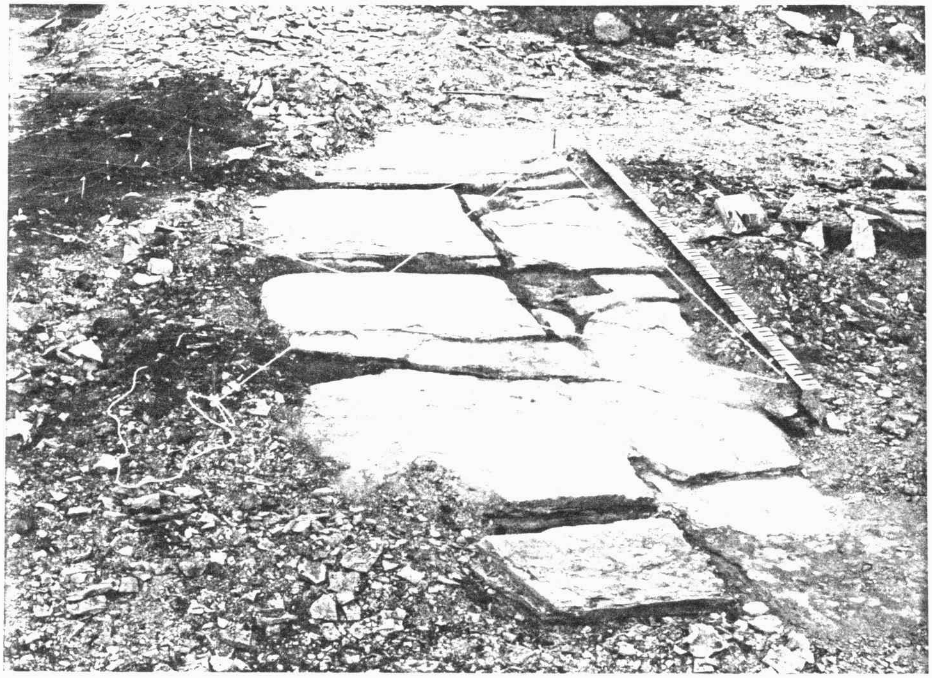


Figure 16. Other areas of the main pit containing the Lagerstatte beds. (A) Lateral distribution of the calcarenite layers illustrating the perpendicular jointing pattern which exists. These jointing patterns are oriented in the same manner as the joints found in the Topeka Formation. (Bar scale = 30 cm) (B) Sample of the type of fossils recovered from the calcarenite beds in the Main Pit. This sample contains two adult acanthodians lying upon each other. (Bar scale = 3 cm)



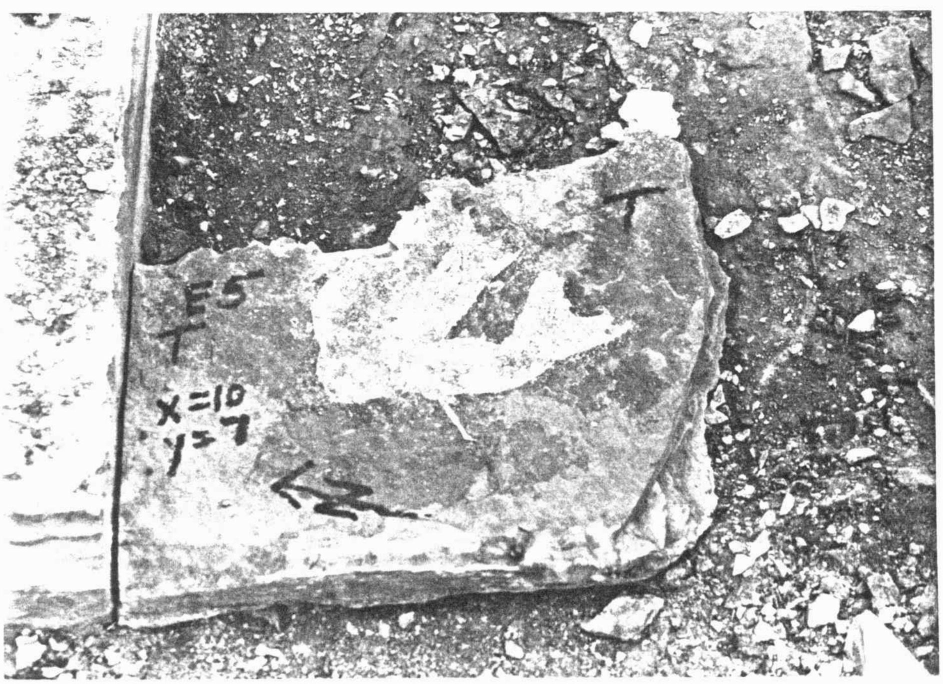
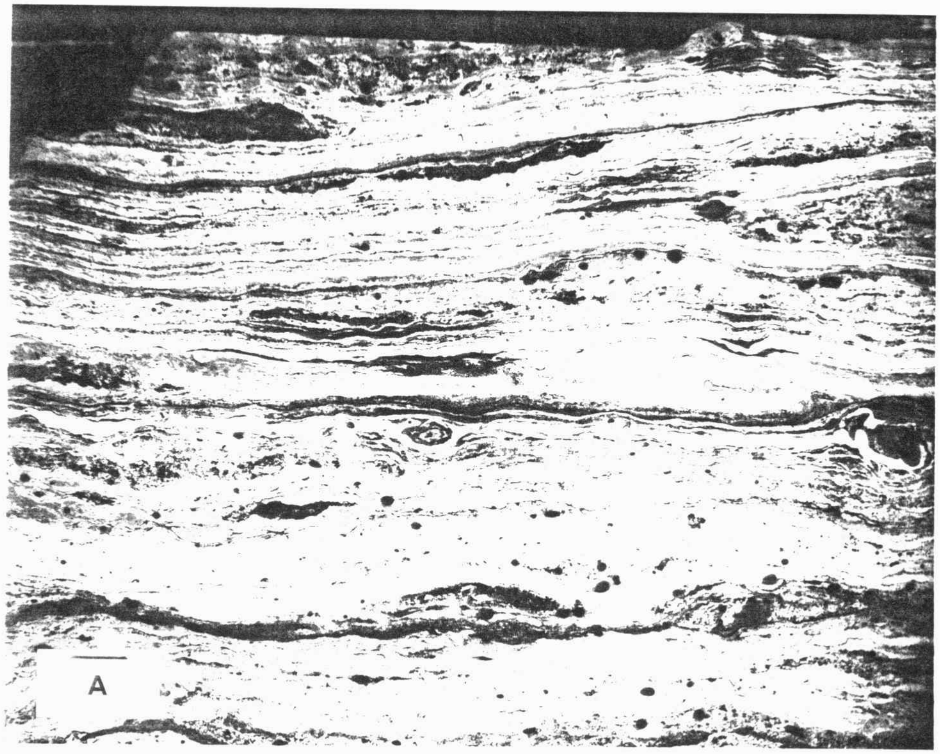

E5
X=10
Y=7

Figure 17. Photonegatives of the tan to gray fossiliferous lime mudstone from the main quarry area. (A,B) Cryptalgal laminated ostracode lime mudstones with the ostracodes confined to certain layers.


A

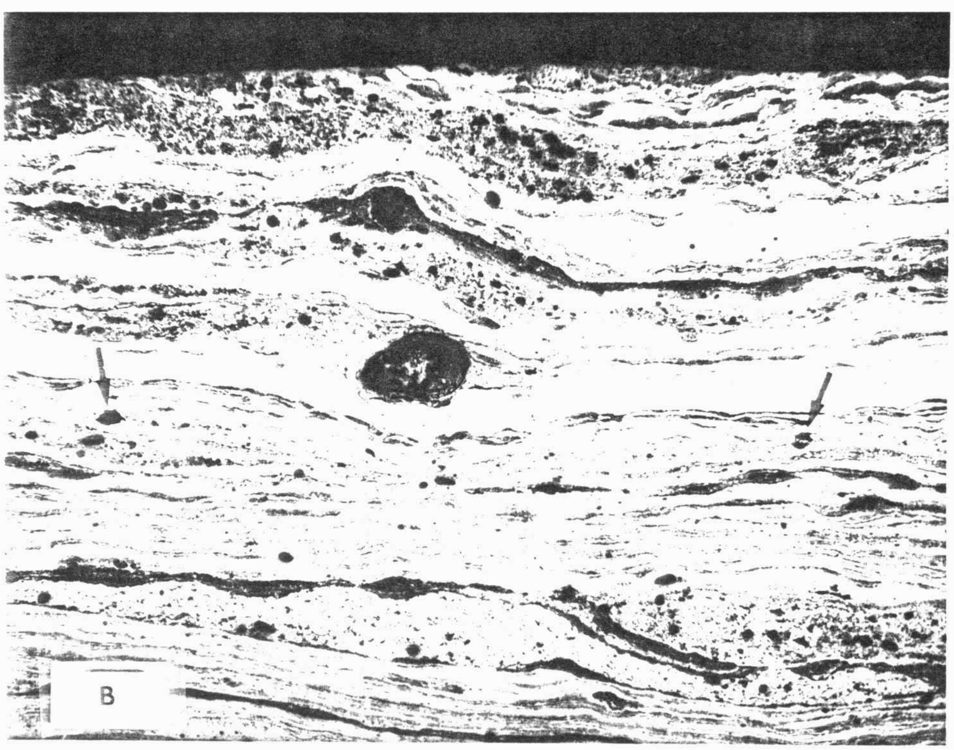
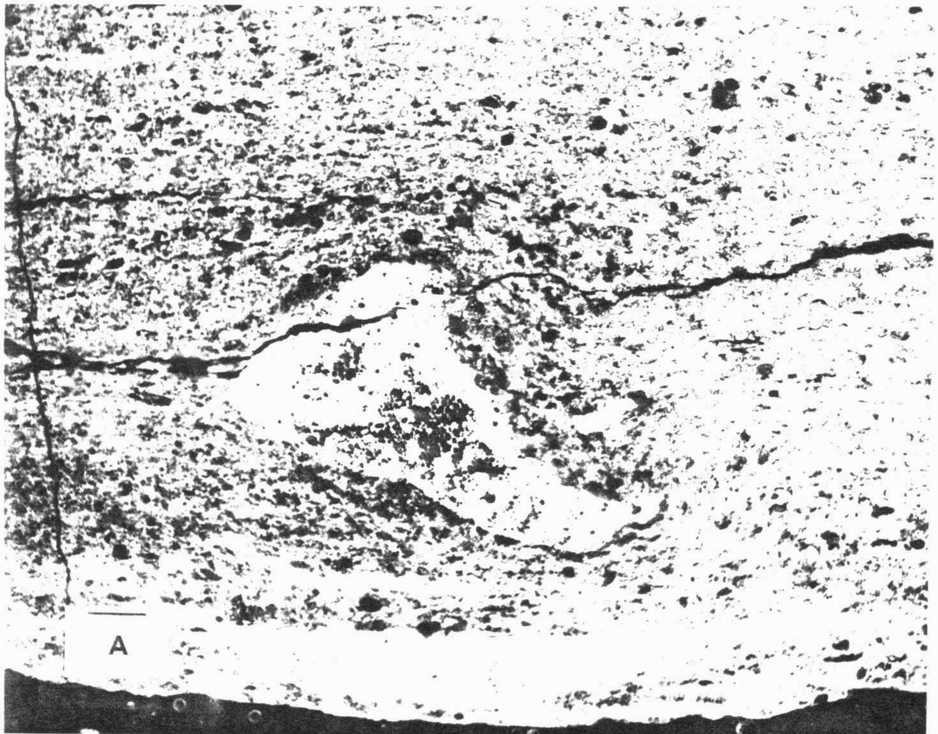

B

Figure 18. (A) A sample of less laminated ostracode lime mudstone which contains plant debris. (B) Another sample of the cryptalgal laminated ostracode calcarenite. Note the alternating sequences of light and dark bands possibly recording tidal influence.


A

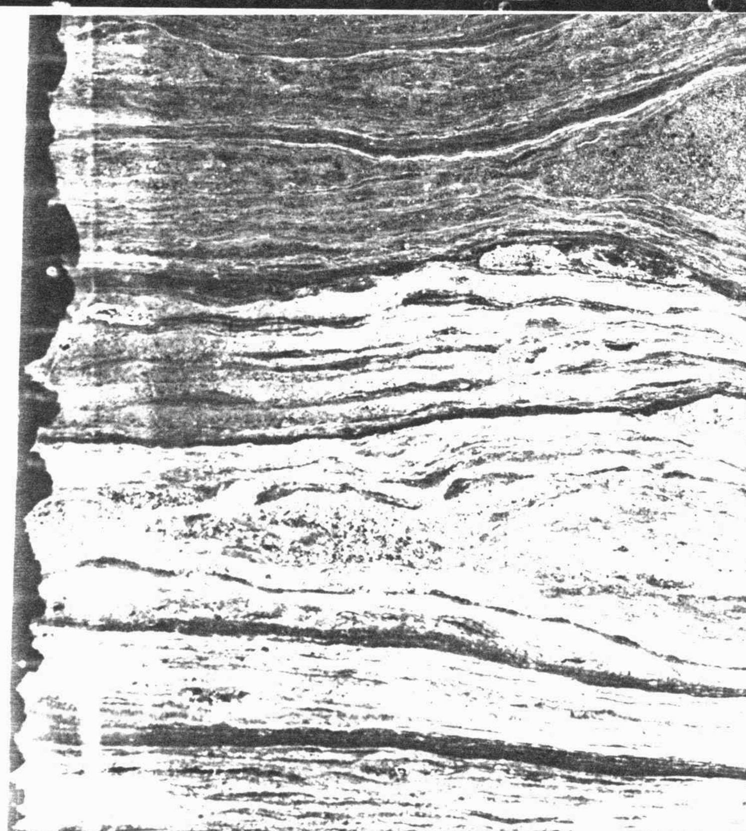

B

Figure 19. The Marlin Quarry area with its well exposed conglomeratic sequence. (A) East wall of the Marlin Quarry. The basal conglomerate unconformably overlies the Calhoun Shale and foreset bed dipping directions suggest a southward prograding channel sequence. The basal conglomerate is overlain by alternating sequences of fine grained conglomerate and ostracode wackestone. (B) South wall of the Marlin Quarry which crops out perpendicular to the foreset bed dip direction. (Each E = .5 ft (.8 m))

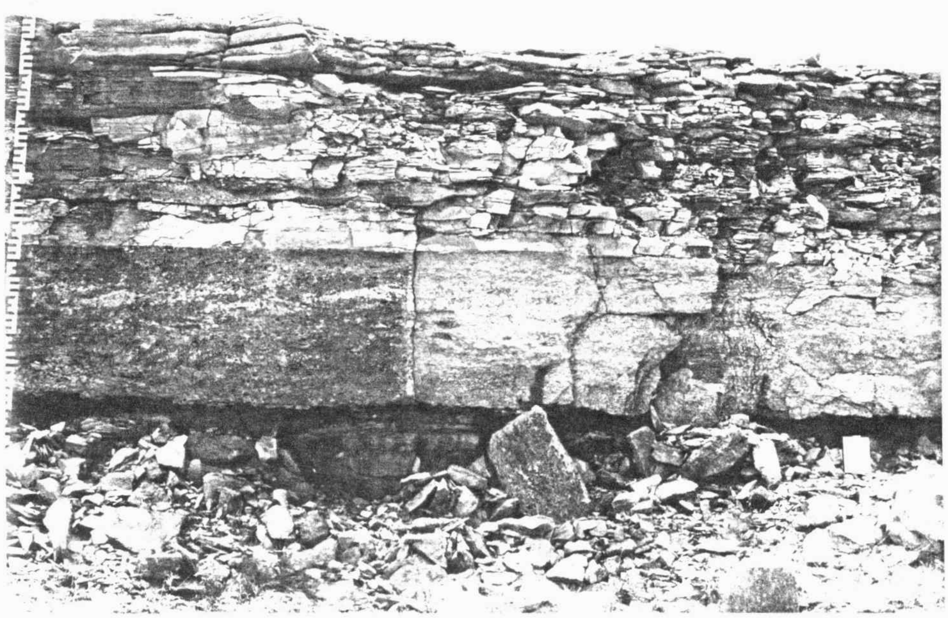


Figure 20. Photonegatives of thin sections from samples of the Marlin Quarry area illustrating the different fabrics contained within the different lithologies. (A,B) Basal conglomerate which contains pebbles of an unknown origin supported by a grain dominated matrix. Note the fracturing of the pebbles. (Bar scale = 1 mm)


A
B

Figure 21. The middle conglomerate from the Marlin Quarry which contains abundant fusulinids, echinoid, brachiopod, and trilobite pieces. Some of the fossils are fractured and some of the fusulinids show some abrasion. (Bar scale = 1 mm)


A

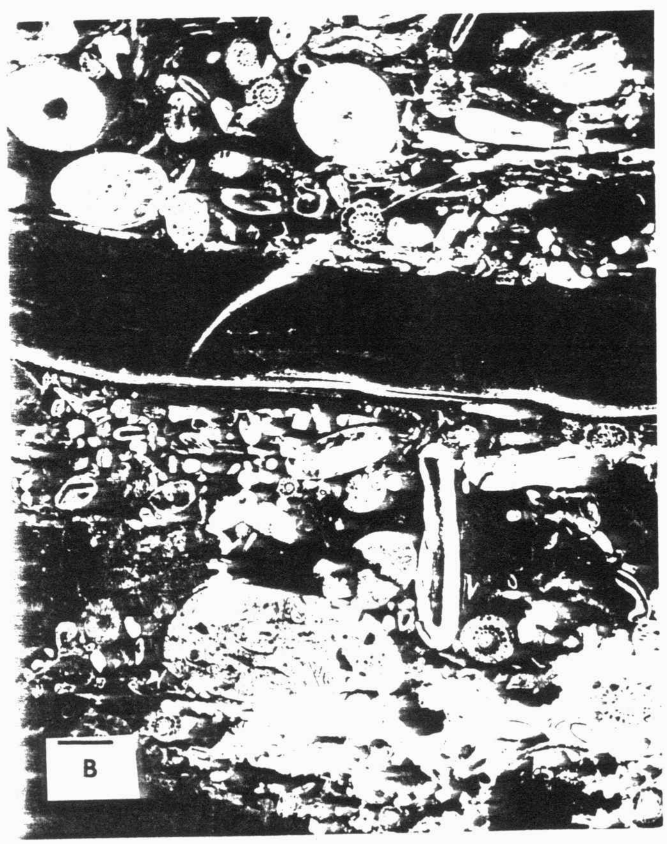

B

Figure 22. Upper portions of the Marlin Quarry which contain finer grained sediments and ostracode rich sequences.

A

B

Figure 23. The southernmost exposure of the Hamilton deposit where conglomerates similar to those in the Marlin Quarry crop out in a large lobe shape approximately .5 km wide.

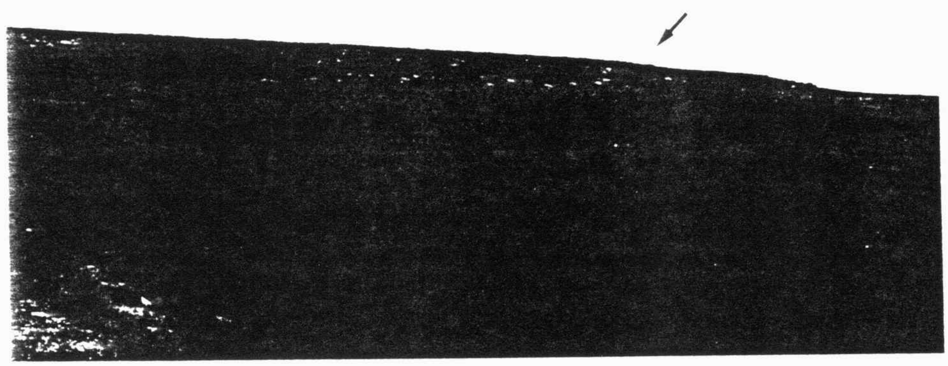
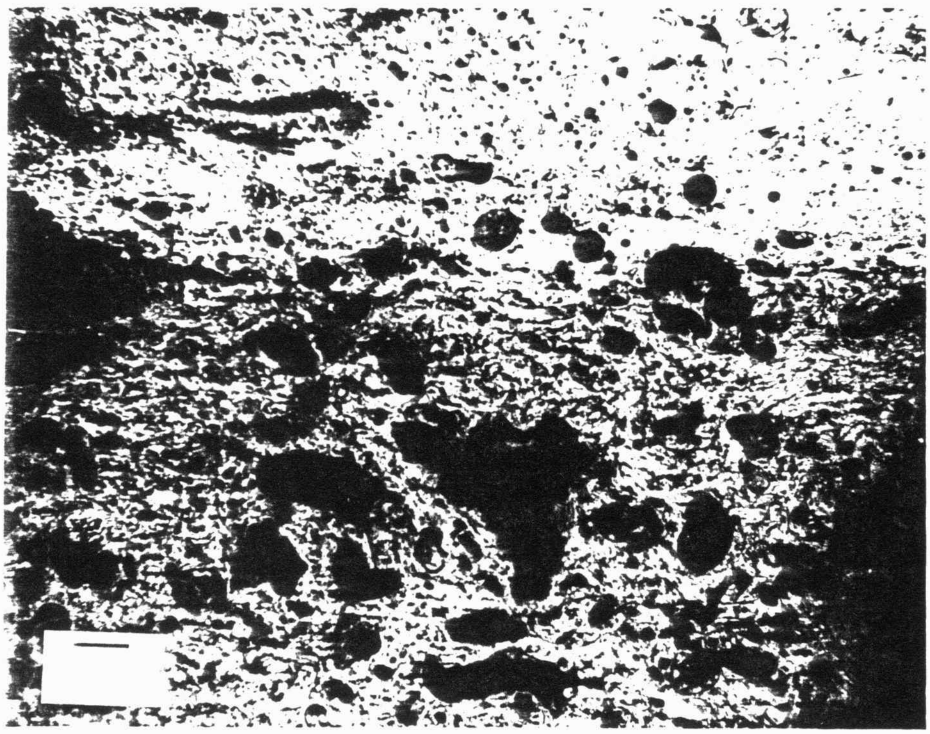


Fig 24. Photonegative of a thin section of the lime mudstone that contains serpulid worms from the Pond locality. (Bar scale = 1 mm)

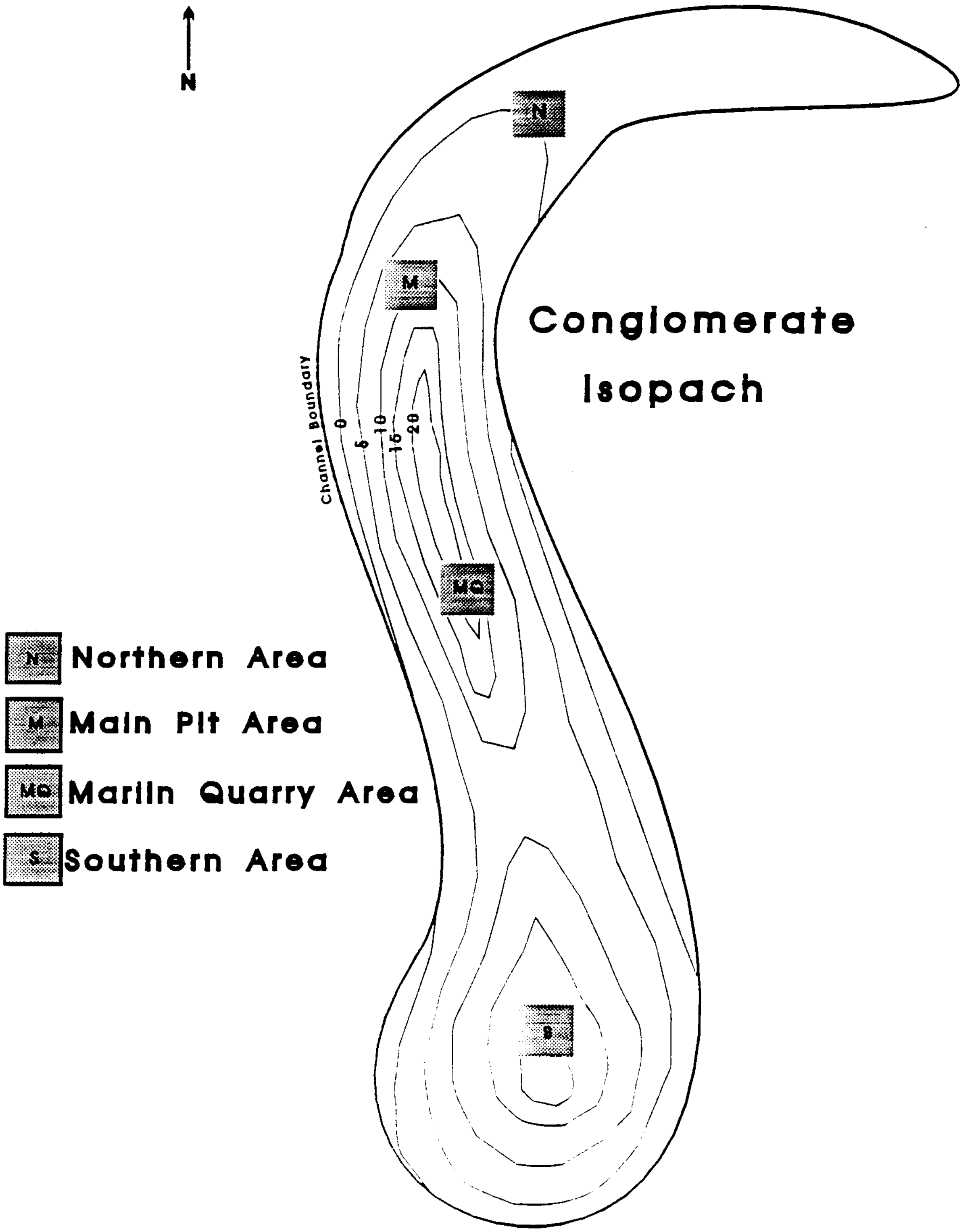


Geometry and Age Relationships

The Lagerstatte beds lie in a linear belt with an asymmetrical cross section and exhibit a general fining upward sequence (Figs. 13, 14). The Hamilton deposit is approximately 9 kilometers long and has a maximum width of 300 meters. The relationship between the Hamilton beds and the cyclothemic lithologies changes from north to south. Also, the Hamilton deposit thickens southward where there are thicker conglomerates and thinner carbonate mudstones (Fig. 25,26). These geometric relationships suggest that this deposit is a north to south prograding channel sequence.

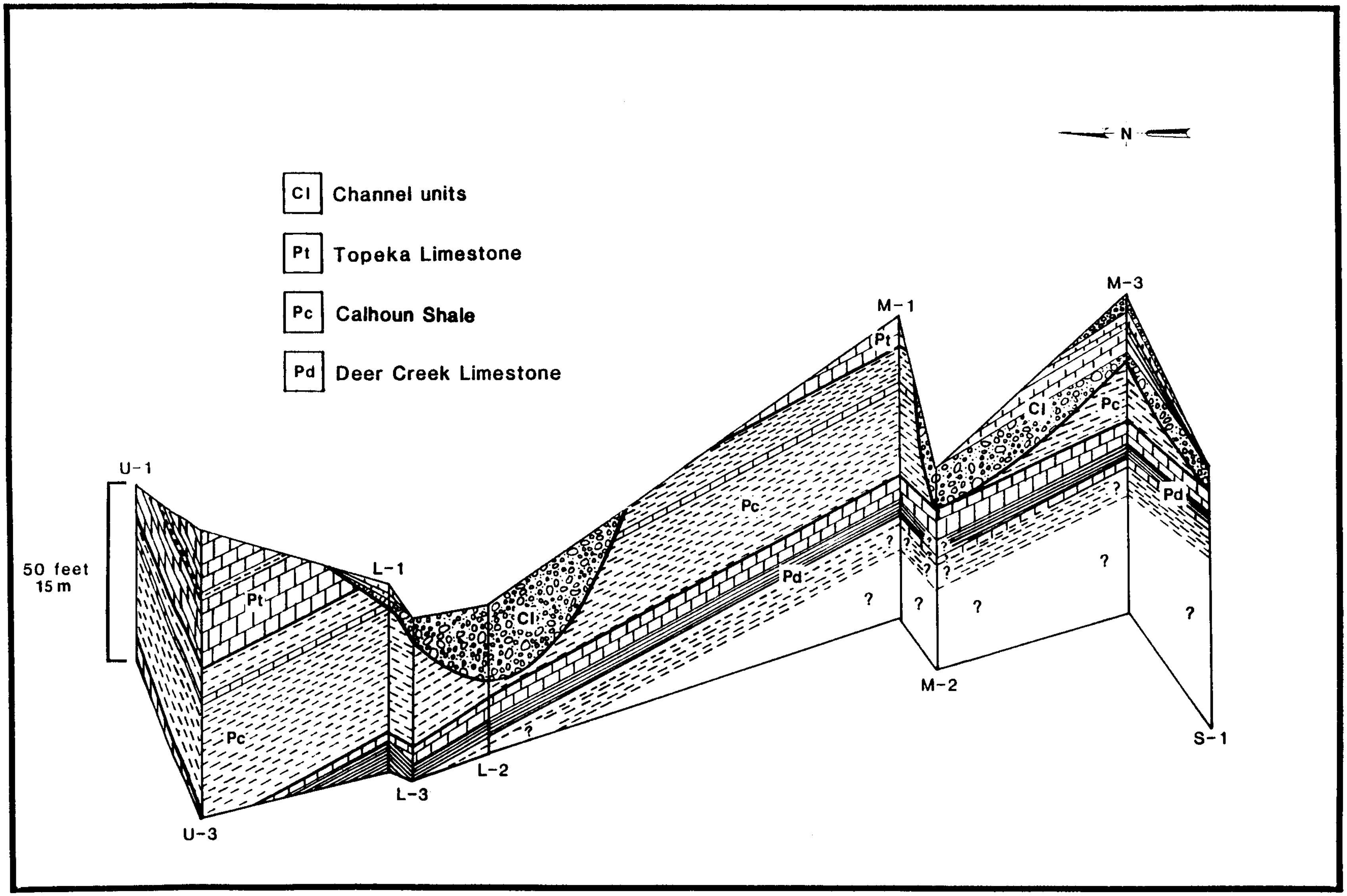
The channel deposit cuts through a portion of the Topeka Formation (the Hartford Limestone Member, the Iowa Point Shale Member and the Curzon Limestone Member) and in places cuts almost entirely through the Calhoun Formation making the deposit at least younger than these units (Virgilian). To date there are no known deposits overlying; however, north of the channel deposit the forces that formed the Severy Shale Formation have completely eroded all members of the Topeka Formation above the Curzon Limestone Member. Therefore it appears that the channel in which the Hamilton beds formed was produced as a part of the erosional event which occurred during the deposition of the Severy Shale. The deposition of the Hamilton beds probably took place following the deposition of the Severy Shale, possibly during the formation of the Howard Limestone. Bridge (1988) states that the Hamilton sequence interfingers with the Topeka Formation but does not give a precise locality where this relationship can be observed. Interfingering was not observed during field mapping of the Hamilton beds in 1989.

Figure 25. Isopach map of the conglomerate thickness throughout the Hamilton deposit (width is exaggerated 5x, contour interval = 5 ft.).



N
Conglomerate
Isopach
Channel Boundary
0
5
10
15
20
N
M
MQ
S
Northern Area
Main Pit Area
Marlin Quarry Area
Southern Area

Figure 26. Three dimensional fence diagram constructed from the Kansas survey core descriptions illustrating the geometric shape of the Hamilton deposit.



N
Cl Channel units
Pt Topeka Limestone
Pc Calhoun Shale
Pd Deer Creek Limestone
U-1
50 feet
15 m
Pt
Pc
U-3
L-1
L-3
L-2
Cl
Pc
Pd
M-1
Pt
M-2
M-3
Cl
Pc
Pd
S-1

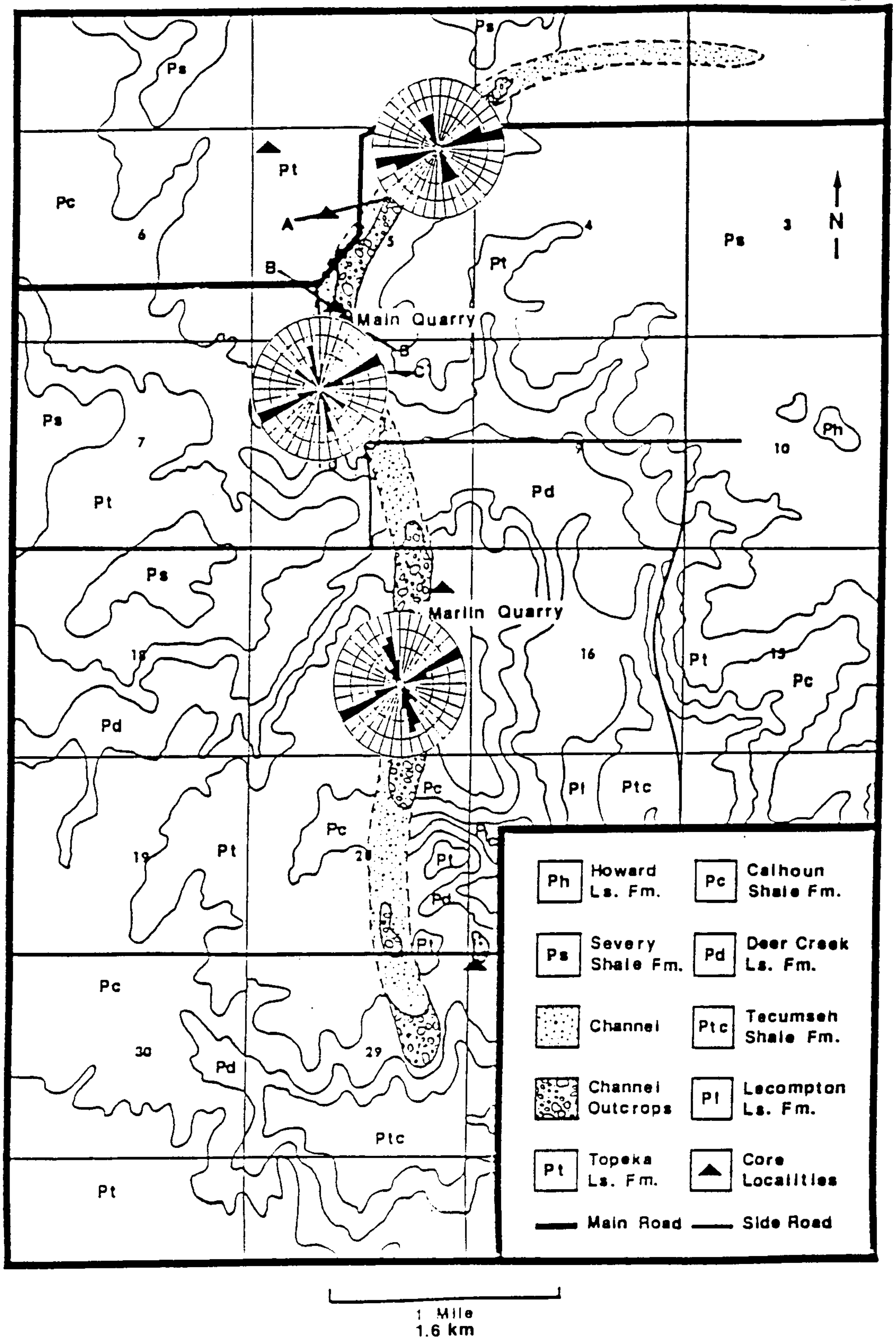
STRUCTURAL CHARACTERISTICS

Local structure is significant; the Hamilton deposit crops out across the southwest flank of the N. 40 degrees E. trending Virgil Anticline and is located 3 Km west of the Virgil Oil Field. The Virgil Oil Field produces from Mississippian limestone at depths of about 570 m. The field is a structural trap with oil accumulation controlled by the 20 m of anticlinal closure (Beekly, 1929). Structure is also present in the younger (Upper Pennsylvanian) Lecompton Limestone. The top of the Ervine Creek Limestone Member at the site of the Hamilton quarries conforms to the Lecompton, with dips of 12.5 m/km (60 ft./mi.) (to the northwest (French, 1988).

Joint patterns exist throughout the Hamilton deposit which are similar to jointing patterns in adjacent areas and throughout south-central Kansas. The joint faces are perpendicluar to bedding in both the cyclothemic units and the Hamilton beds. Two mutually perpendicular sets are prominant; one strikes N 61 degrees E and the other strikes N 30 degrees W (Fig. 15), (Appendix C). Similar jointing patterns (N 61 degrees E and N 30 degrees W) were measured by Ward (1969) in south-central Kansas.

Joint patterns, consisting of at least two separate but inter-related systems, are believed (Ward, 1968) to have formed prior to the development of the anticlinal folds in the area, but may have developed simultaneously with the later readjustment of folds. The age of the joints was determined by Ward (1968) to be post-Lower Permian and pre-Lower Cretaceous. A northwest-directed horizontal, compressive force generated by wrench-fault tectonics during initial Ouachita Mountain uplift may have formed the joints.

Figure 27. Rose diagram showing the dominate joint patterns which occur within the Hamilton deposits throughout the study area.



Ps
Pc
Pt
A
B
6
5
4
3
N
Main Quarry
B
C
Ph
7
9
10
Pd
Marlin Quarry
16
15
Pc
Pi
Ptc
19
28
30
29
Ptc
Ph Howard Ls. Fm.
Pc Calhoun Shale Fm.
Ps Severy Shale Fm.
Pd Deer Creek Ls. Fm.
Channel
Ptc Tecumseh Shale Fm.
Channel Outcrops
Pl Lecompton Ls. Fm.
Pt Topeka Ls. Fm.
Core Localities
Main Road
Side Road
1 Mile
1.6 km

Figure 28. Regional joint patterns in south-central Kansas as described by Ward (1968).

Kansas Geol. Survey Bull. 191, Pt. 2, 1968

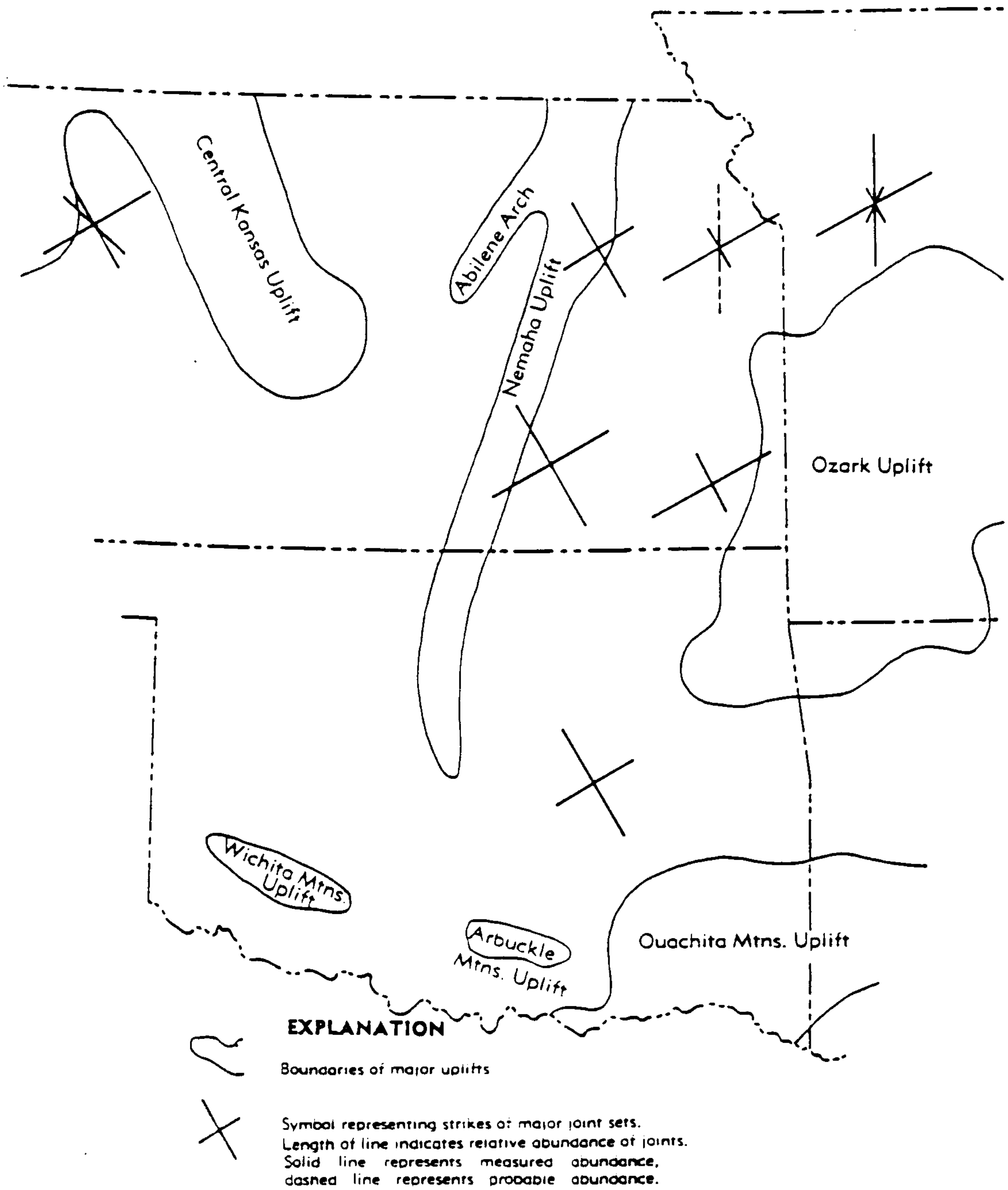


FIGURE 14.—Midcontinent joint systems (modified from Geological Highway Map Committee, 1966).

PALEONTOLOGY

A diverse assemblage of biota has been recovered from the Hamilton deposit, including marine, nonmarine and terrestrial fossils (Tables I,II Appendix D,E). The marine organisms are concentrated in the basal conglomerate and increase in abundance in the southern region were the conglomerate also thickens. The upper lime mudstones and wackestones contain the exquisitely preserved primarily terrestrial and nonmarine biota and are classified as the Lagerstatte deposit. However, there are also marine organisms in the lime mudstones as would be expected in a marginal marine environment were faunal mixing is the norm rather than the exception (Moore, 1964). This would suggest that the marine biota was transported into the nonmarine environment.

The basal conglomerate which is continuous throughout the channel sequence contains marine biota that suggest a nearshore environment. Vertebrate teeth, bone fragments and plant charcoal are common throughout the extent of the unit. Additionally, several invertebrates are present, most of which are entirely marine. These include: brachiopods, gastropods, bivalves, crinoids, trilobites, fusulinids and bryozoans. Microsamples recovered from acid residue techniques contained abundant (around 100 per kilogram sample) isolated vertebrate teeth and out of all the samples of the conglomerate that were processed only two conodonts of the Genus Streptognathodus (Virgilian) were recovered. However the origin of these conodonts is not known. They could have been from the matrix or from the pebbles of the conglomerate. Since conodonts are not normally found in a nearshore environment the latter is suspected. Nonetheless it does aid in an age assessment.

Interbedded with the upper portions of the conglomerate sequence, the laminated white to cream calcarenite beds of the Hamilton deposit contain freshwater to brackish water fauna. Highly degraded carbon impressions of ferns and seed fern foliage and conifer remains are present in association with freshwater bivalves (Maples and Mapes, 1988). Additionally articulated eumalacostracan crustaceans (Schram, 1988) and both articulated and disarticulated eurypterids (Kues, 1988) have been recovered. Neither vertebrate teeth nor conodonts were present in the microsample of this unit.

The tan to gray lime mudstone layers which are best developed in the main pit area contain the majority of the fossils that have been studied in the past 25 years. These fossils are extremely well preserved and this permits the classification of the Hamilton deposit as a Lagerstatte deposit. Disarticulated and articulated vertebrate remains include paleoniscoid fish (Gottfried, 1988), juvenile and adult acanthodians (Zidek, 1988), chondrichthyans (Zidek, 1988b; Maisey, 1988), lungfish (Chorn and Schultze, 1988), osteolepidid rhipidistian fish (Schultze, 1988), dissorophoid amphibians (Daly, 1988), reptiles (Reisz, 1988) and coprolites

(McAllister, 1988). Invertebrate remains include "freshwater" bivalves, brachiopods, gastropods, crinoid fragments and annelid worms (Spirorbis and Serpula) (Mapes and Maples, 1988). Abundant vertebrate teeth (300 per kilogram) along with seven conodonts were recovered from all of the processed samples. The conodonts were of the genus Streptognathodus (Virgilian) and an explanation for this occurence is difficult. The only possible hypothesis is that the conodonts were brought in by the same means that the other marine remnants were brought in. This would suggest that the Hamilton deposit was deposited vertically within a short range of time.

Plant remains are abundant throughout the tan to gray lime mudstone with the best preservation occuring in the main pit area. Some of the most significant plant material includes permineralized primitive walchian conifers (Mapes and Rothwell, 1984,1988) that were at times so well preserved that the seed cones contain cotyledonary embryos (Mapes, et al, 1989). Other plant remains include cordaites and seed ferns (Mapes and Gastaldo 1986; Rothwell and Mapes, 1988) and spores and pollen (Taggert and Ghavidel-Syoohi, 1988). Additionally charcoalized plant remains are also present.

Significant Depositional Characteristics and Interpretations

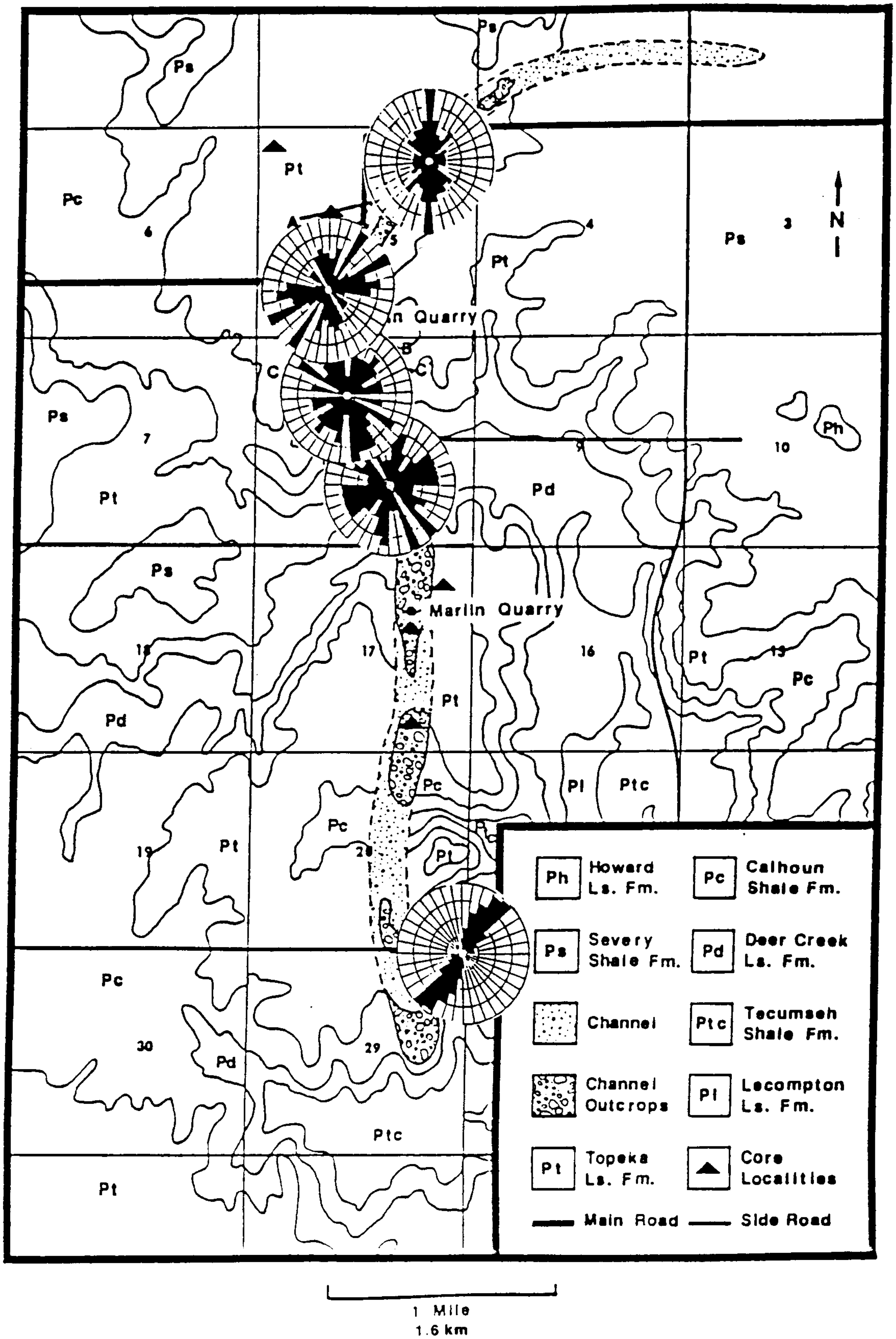
The geometric shape of the Hamilton deposit indicates that it is a southward prograding channel sequence. Stratigraphic relationships from field observations additionally support the hypothesis that the Lagerstatte is contained within a north to south trending channel deposit. That the channel was at times probably tidally influenced is suggested by the presence of light and dark banding in the carbonate mudstones (Fig. 17). Foreset bed dip directions (Figure 42), the southward deepening of the channel sequence, and paleocurrent information obtained from plant orientation data support a predominantely north to south current direction (Fig. 34, Appendix B).

The nearby marine source was south of the southern margin of the channel. The direction of this source is determined by the southward increase in the thickness of conglomerates which contain predominantly marine fossils. In the Main Pit area there is a more equal distribution (Fig. 16) of marine influenced conglomerates and the predominantly terrestrial deposits that overlie them. The northern extent of the channel deposit appears to be almost entirely nonmarine with the conglomerates thinning and the terrestrial shales thickening.

In the mid section of the channel, there is a thick pod of conglomerate which is immediately south of the Lagerstatte deposit (Fig. 14). This thick accumulation may have acted as a barrier to water circulation and perhaps caused the stagnation that has permitted the Lagerstatte preservation characteristic of the mid section of the channel directly to the north. The carbonate mudstone which contains the majority of the Lagerstatte fauna and flora was probably tidally influenced when this barricade was either breached by daily or seasonal tides and perhaps by minor storm events. However this breaching of the barricade must have been relatively quiescent allowing the delicate Lagerstatte to remain undisturbed. Additionally, the plant orientation data shows a dominant north to south current direction in the north and south areas indicated by a preferred north-south alignment of plant debris. In the Main Pit area howevever there is a random orientation of plant debris which could possibly indicate that this was a stagnated area. Storm washover deposits are present in the Marlin quarry area where thin sheets of marine carbonates are interbedded with the channel units. These washover deposits are thought to be responsible for the freshwater and marine faunal mixture in a dominantly nonmarine environment (French, 1988).

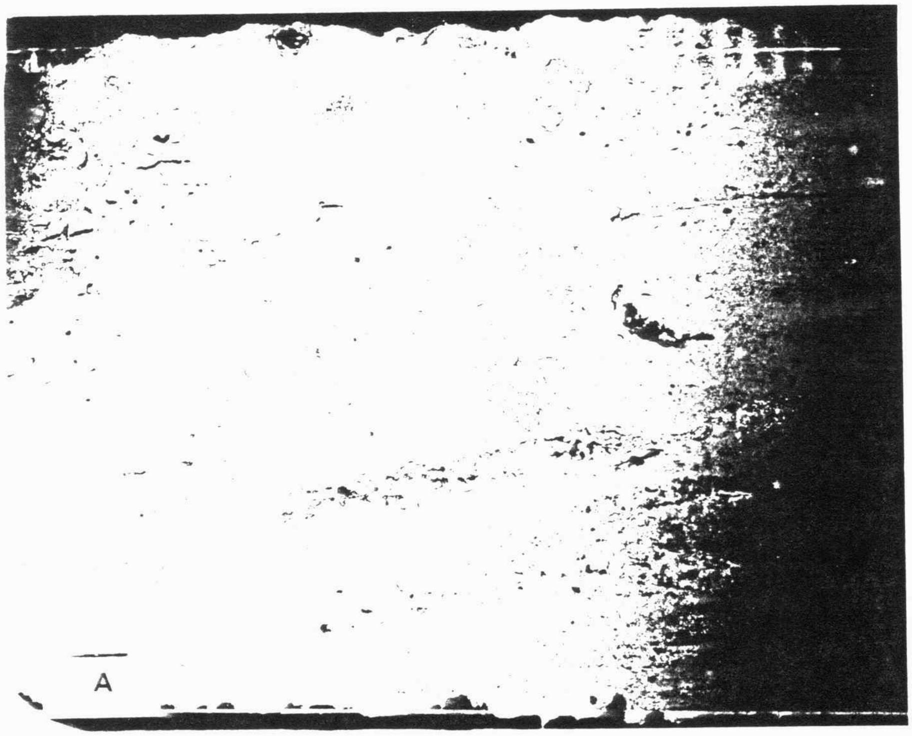
Fossil wood such as that which exists in the lime mudstone layers of the Hamilton deposit has been used as paleocurrent indicators in the past (MacDonald and Jefferson, 1985). Current flow is suggested to be either parallel to or perpendicular to plant axis orientation. However there are many factors controlling orientations of wood fragments such as current velocity, fragment shape and fragment size and caution must be exercised.

Figure 29. Rose diagrams of the plant data collected from the bedding planes of the lime mudstone indicating a more prominant current direction in the northern and southern areas of the Hamilton deposit and a more random current direction in the Main Pit area suggesting stagnation in the Lagerstatte area.


N
Ps
Pc
Pt
Pd
Ph
Ptc
Pl
n Quarry
Marlin Quarry
Howard Ls. Fm.
Calhoun Shale Fm.
Severy Shale Fm.
Deer Creek Ls. Fm.
Channel
Tecumseh Shale Fm.
Channel Outcrops
Lecompton Ls. Fm.
Topeka Ls. Fm.
Core Localities
Main Road
Side Road
1 Mile
1.6 km

Soft sediment deformation occured in the carbonate mudstone in the Main Pit area, the Pond Locality, and in some of the fine grained carbonates of the Marlin Quarry area. These soft sediment deformation features would suggest that the sediments within the Hamilton deposit were deposited rapidly. Several hand samples of the carbonate mudstone contained small scale (1-3 mm) slump features. Additionally larger scale slump features were also present throughout the channel sequence. The axes of all the slump features parallel the channel strike. This suggests that unconsolidated sediment slid into the mid section of the channel. Additionally, soft sediment features exist in the Marlin Quarry intrusive type dewatering features whereby the conglomeratic matrix intruded up into ostracode wackestones.

Figure 30. Samples from the Hamilton sequence illustrating soft sediment deformation: (A) small scale slump features and (B) dewatering features.


A


B

DEPOSITIONAL ENVIRONMENTS

The carbonate conglomerates, carbonaceous shales and carbonate mudstones which comprise the Hamilton channel have been interpreted as being deposited in a system of relatively high energy barriers and tidal inlets that fronted a low energy, restricted, mainly nonmarine estuarine complex (French et al.,1988). The grain supported basal conglomerates represent the high energy phase of the deposit while the carbonaceous shales and carbonate mudstones represent decreases in energy with an increase in mud content. Plant debris orientations suggest that the carbonate mudstones in the Main Pit area formed in a stagnated and therefore low oxygen environment. These low energy anoxic settings permitted the preservation of the delicate, primarily terrestrial Hamilton biota.

The geometry of the Hamilton deposit suggests a north to south prograding channel sequence with an increase in marine influence to the south. This is determined by the overall thickening of carbonate conglomerate (entirely marine) to the south along with a thinning of the carbonate mudstones and shales (mostly non-marine). Although there is no question that the carbonate conglomerate is marine, the carbonate mudstone does contain some marine fossils. Some of these appear to have been transported while others would appear indigenous. The delicate nonmarine biota of the Hamilton Lagerstatte (dragonflies, fish with skin preserved) must have been indigenous since it would be unlikely to be preserved if transported.

This mixing of nonmarine and marine biota could have been accomplished in several ways. One possibilty is that salinity tolerances were different during this time permitting the movement of marine fauna into the nonmarine environment. Another possibility would be from storm washover deposits which are recorded in the Marlin quarry area and possibly washed the marine fauna into the nonmarine environment. A third possibilty is that the marine fauna was transported into the nonmarine biota by fish and deposited as coprolitic matter.

The Hamilton channel deposit may be the result of a single marine incursion (e.g. glacioeustatic rise) as suggested by French et al.,(1988) during which time the sequence of events developed in the valley and prograded seaward. However, the Hamilton sequence may also be the result of a number of small-scale base-level fluctuations or wholly a record of local (autogenic) events. The soft sediment deformation which occurs in the carbonate mudstones and the preservation of the Lagerstatte fosssils in the carbonate mudstone would require rapid deposition indicating that this was a rapidly formed sequence and therefore small-scale base level fluctuations would be the best explanation.

The presence of Severy shale to the north of the deposit which unconformably overlies the Curzon Limestone Member of the Topeka

Formation suggests that the Severy may have had a major influence on the development of the Hamilton deposit. The Severy contains channel sequences throughout eastern Kansas although they are primarily sandstone (Zeller, 1968). The Severy Shale was a nearshore tidally influenced (Bridge, 1988) micaceous, sandy shale which, in the area just north (1 km) of the Hamilton deposit, is overlain by the Aarde Shale Member of the Howard Limestone Formation. The Aarde Shale Member contains claystone, siltstone and mudstone which are layered in a similar fashion to the Lagerstate carbonate mudstones. The Aarde Shale Member additionally contains a coal bed (Nodaway), and plants are quite abundant in certain areas of this deposit. Additionally, a sample of what is believed to be the Aarde Shale member contained abundant ostracodes.

CONCLUSIONS

The three-dimensional geometry and areal distribution of the deposits associated with the Lagerstatte strongly supports the concept that the Hamilton beds were deposited in a channel that was at times tidally influenced. The channel contains a shallowing up sequence similar to a point bar depositional facies pattern which would be expected on a topographically low relief surface that presumbably existed when the channel was filled.

Many different ages have been assigned to the Hamilton channel deposit ranging from Upper Pennsylvanian to Lower Permian. Palynological information interpreted by Taggert and Ghavidel-Syooki (1988), indicates that the channel is Lower Permian, however the presence of Pennsylvanian age fusulinids (Douglass, 1988) disputed this age assignment. Additionally, the channel has been determined to have formed during Topeka time (Bridge, 1988) or during the time that either the Calhoun, Iowa Point, or the Severy were deposited (French, 1988). The channel cuts through the Curzon Limestone Member, the Iowa Point Shale Member and the Hartford Limestone Member of the Topeka Formation, and almost the entire sequence of the Calhoun Shale Formation. Thus the channel is at least younger than the Curzon Limestone Member.

The Hamilton Deposit was formed by two depositional events;

a down cutting phase followed by a depositional phase. During the time when the Severy Shale was deposited, an erosional event downcut the valley which controlled the general geometry of the Hamilton deposit. This erosional event removed the upper portion of the Topeka Formation from the area and possibly left remnants of its former existance in the basal conglomerate of the Hamilton channel deposit. The deposition of the Severy Shale was followed by the deposition of the Aarde Shale Member, a dominantly nonmarine muddy shale which contains isolated limestone pods with marine fossils indicating its nearby marine source. The similarity of the Aarde Shale and the carbonate mudstones both in their lithology and fossil content would suggest that this member of the Howard Limestone Formation is time equivelant to the Hamilton lime mudstone Lagerstatte. If so, then the Hamilton Lagerstatte is Middle Virgilian (Upper Pennsylvanian) in age.

APPENDIX A

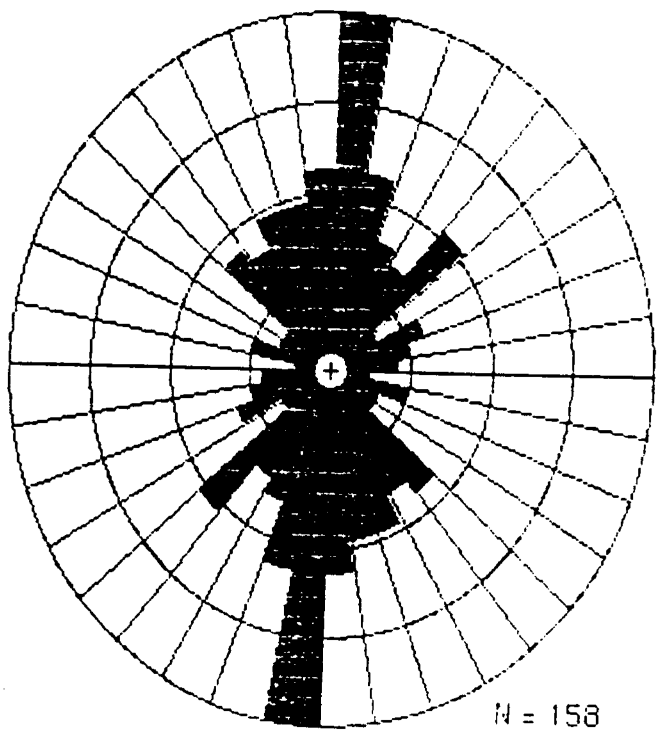
Plant Orientation Data

Northernmost area at Ulrich pit

1:	72.0000
2:	63.0000
3:	70.0000
4:	73.0000
5:	60.0000
6:	12.0000
7:	11.0000
8:	170.0000
9:	168.0000
10:	0.0000
11:	23.0000
12:	170.0000
13:	2.0000
14:	100.0000
15:	85.0000
16:	10.0000
17:	165.0000
18:	80.0000
19:	160.0000
20:	145.0000
21:	134.0000
22:	132.0000
23:	43.0000
24:	45.0000
25:	50.0000
26:	5.0000
27:	90.0000
28:	50.0000
29:	156.0000
30:	70.0000
31:	150.0000
32:	65.0000
33:	30.0000
34:	120.0000
35:	50.0000
36:	43.0000
37:	44.0000
38:	175.0000
39:	20.0000
40:	120.0000
41:	145.0000
42:	5.0000
43:	170.0000
44:	20.0000
45:	20.0000
46:	5.0000
47:	15.0000
48:	0.0000
49:	35.0000
50:	25.0000
51:	105.0000
52:	57.0000
53:	45.0000
54:	155.0000
55:	125.0000
56:	108.0000
57:	178.0000
58:	170.0000
59:	110.0000
60:	155.0000
61:	160.0000
62:	40.0000
63:	0.0000
64:	0.0000
65:	60.0000
66:	60.0000
67:	10.0000
68:	7.0000
69:	45.0000
70:	25.0000
71:	88.0000
72:	75.0000
73:	155.0000
74:	104.0000
75:	110.0000
76:	112.0000
77:	155.0000
78:	160.0000
79:	170.0000
80:	160.0000
81:	170.0000
82:	160.0000
83:	140.0000
84:	155.0000
85:	130.0000
86:	140.0000
87:	150.0000
88:	150.0000
89:	170.0000
90:	140.0000
91:	143.0000
92:	115.0000
93:	105.0000
94:	120.0000
95:	165.0000
96:	165.0000
97:	40.0000
98:	35.0000
99:	20.0000
100:	45.0000
101:	20.0000
102:	15.0000
103:	40.0000
104:	12.0000
105:	30.0000
106:	32.0000
107:	70.0000
108:	80.0000
109:	100.0000
110:	35.0000
111:	0.0000
112:	40.0000
113:	160.0000
114:	130.0000
115:	5.0000
116:	85.0000
117:	0.0000
118:	175.0000
119:	150.0000
120:	135.0000
121:	150.0000
122:	145.0000
123:	130.0000
124:	140.0000
125:	15.0000
126:	0.0000
127:	65.0000
128:	140.0000
129:	130.0000
130:	0.0000
131:	1.0000
132:	6.0000
133:	5.0000
134:	13.0000
135:	18.0000
136:	4.0000
137:	135.0000
138:	65.0000
139:	130.0000

Northernmost area at Ulrich pit cont.

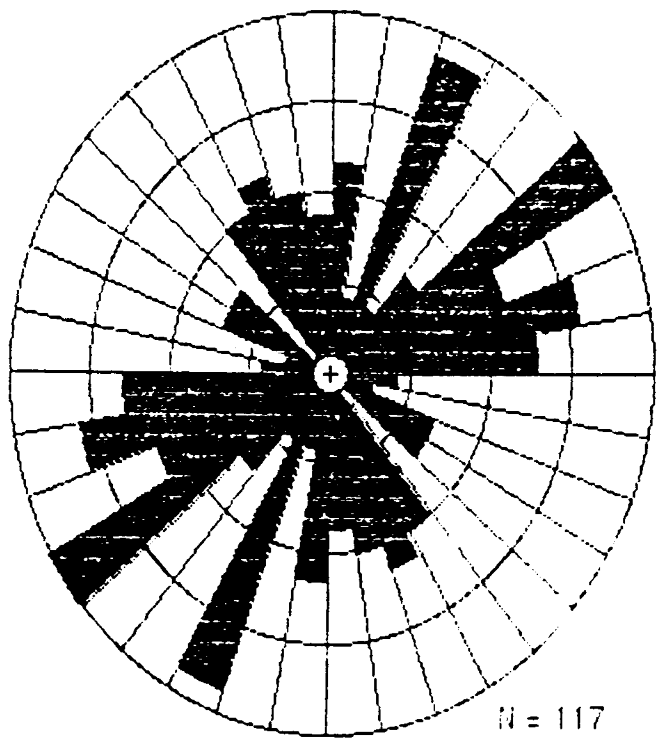
140:	93.0000
141:	17.0000
142:	15.0000
143:	6.0000
144:	7.0000
145:	10.0000
146:	35.0000
147:	90.0000
148:	175.0000
149:	170.0000
150:	175.0000
151:	160.0000
152:	130.0000
153:	35.0000
154:	20.0000
155:	170.0000
156:	0.0000
157:	1.0000
158:	0.0000



Main Quarry pit area

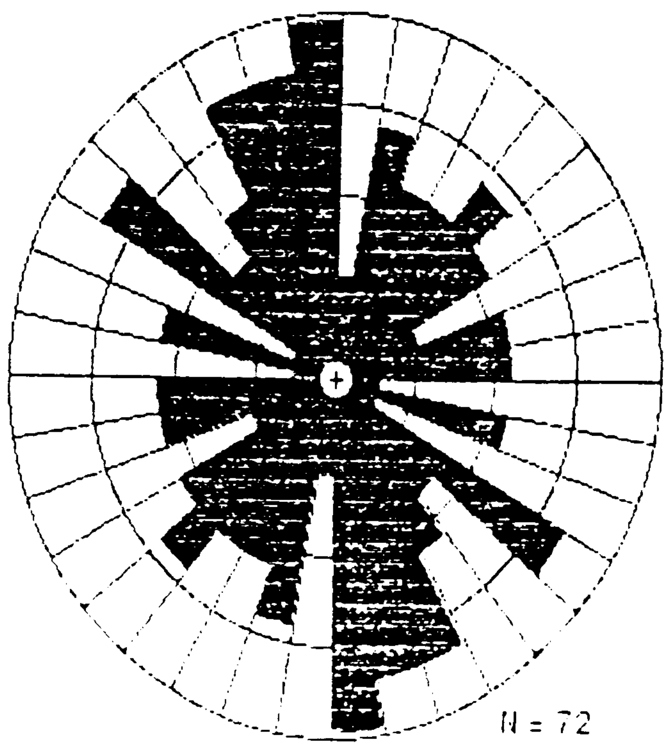
1:	50.0000	48:	26.0000	94:	355.0000
2:	60.0000	49:	65.0000	95:	70.0000
3:	52.0000	50:	24.0000	96:	70.0000
4:	320.0000	51:	28.0000	97:	75.0000
5:	55.0000	52:	57.0000	98:	78.0000
6:	338.0000	53:	52.0000	99:	25.0000
7:	325.0000	54:	52.0000	100:	340.0000
8:	50.0000	55:	20.0000	101:	35.0000
9:	333.0000	56:	43.0000	102:	342.0000
10:	85.0000	57:	293.0000	103:	323.0000
11:	27.0000	58:	58.0000	104:	322.0000
12:	62.0000	59:	56.0000	105:	63.0000
13:	332.0000	60:	47.0000	106:	82.0000
14:	45.0000	61:	357.0000	107:	88.0000
15:	50.0000	62:	303.0000	108:	42.0000
16:	55.0000	63:	257.0000	109:	90.0000
17:	302.0000	64:	253.0000	110:	73.0000
18:	303.0000	65:	334.0000	111:	25.0000
19:	325.0000	66:	294.0000	112:	6.0000
20:	80.0000	67:	2.0000	113:	35.0000
21:	58.0000	68:	14.0000	114:	15.0000
22:	62.0000	69:	85.0000	115:	65.0000
23:	320.0000	70:	20.0000	116:	7.0000
24:	340.0000	71:	27.0000	117:	70.0000
25:	275.0000	72:	335.0000		
26:	280.0000	73:	30.0000		
27:	295.0000	74:	335.0000		
28:	352.0000	75:	88.0000		
29:	352.0000	76:	52.0000		
30:	302.0000	77:	25.0000		
31:	85.0000	78:	294.0000		
32:	5.0000	79:	65.0000		
33:	60.0000	80:	9.0000		
34:	90.0000	81:	307.0000		
35:	340.0000	82:	282.0000		
36:	82.0000	83:	293.0000		
37:	70.0000	84:	342.0000		
38:	350.0000	85:	78.0000		
39:	346.0000	86:	82.0000		
40:	355.0000	87:	58.0000		
41:	40.0000	88:	330.0000		
42:	320.0000	89:	29.0000		
43:	340.0000	90:	22.0000		
44:	25.0000	91:	334.0000		
45:	8.0000	92:	72.0000		
46:	4.0000	93:	6.0000		
47:	10.0000				

Main Quarry pit area cont.



South Pit Area

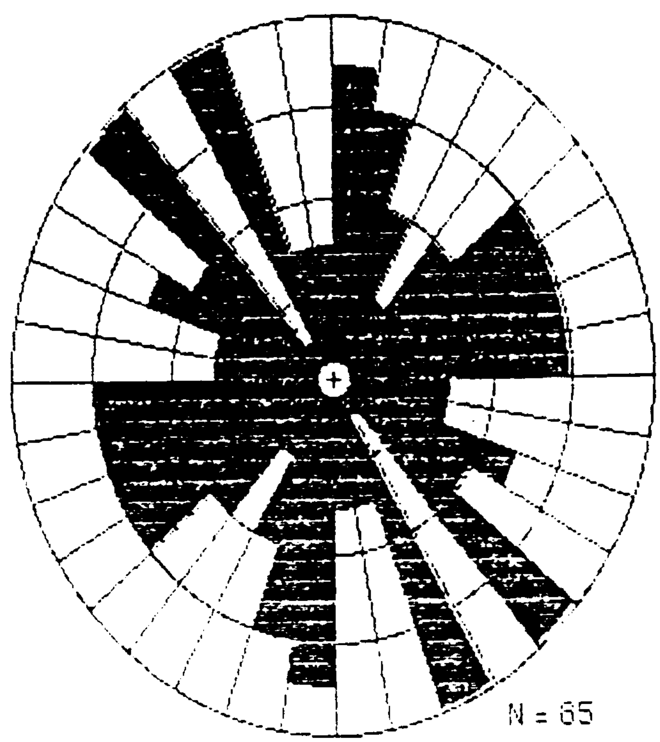
1:	125.0000
2:	85.0000
3:	120.0000
4:	50.0000
5:	110.0000
6:	30.0000
7:	45.0000
8:	170.0000
9:	90.0000
10:	60.0000
11:	30.0000
12:	80.0000
13:	150.0000
14:	174.0000
15:	170.0000
16:	140.0000
17:	40.0000
18:	120.0000
19:	150.0000
20:	105.0000
21:	160.0000
22:	30.0000
23:	160.0000
24:	105.0000
25:	0.0000
26:	140.0000
27:	150.0000
28:	70.0000
29:	160.0000
30:	10.0000
31:	15.0000
32:	150.0000
33:	170.0000
34:	10.0000
35:	20.0000
36:	40.0000
37:	150.0000
38:	120.0000
39:	30.0000
40:	170.0000
41:	45.0000
42:	20.0000
43:	120.0000
44:	130.0000
45:	80.0000
46:	60.0000
47:	10.0000
48:	40.0000
49:	170.0000
50:	160.0000
51:	70.0000
52:	140.0000
53:	50.0000
54:	130.0000
55:	130.0000
56:	100.0000
57:	50.0000
58:	70.0000
59:	55.0000
60:	170.0000
61:	125.0000
62:	0.0000
63:	120.0000
64:	150.0000
65:	70.0000
66:	100.0000
67:	160.0000
68:	10.0000
69:	20.0000
70:	165.0000
71:	140.0000
72:	80.0000
73:	20.0000



N = 72

South Pit area cont.

1:	94.0000
2:	10.0000
3:	90.0000
4:	150.0000
5:	15.0000
6:	0.0000
7:	30.0000
8:	100.0000
9:	0.0000
10:	55.0000
11:	135.0000
12:	110.0000
13:	80.0000
14:	5.0000
15:	10.0000
16:	150.0000
17:	60.0000
18:	170.0000
19:	170.0000
20:	40.0000
21:	130.0000
22:	150.0000
23:	70.0000
24:	150.0000
25:	20.0000
26:	20.0000
27:	110.0000
28:	150.0000
29:	70.0000
30:	15.0000
31:	120.0000
32:	110.0000
33:	60.0000
34:	60.0000
35:	5.0000
36:	170.0000
37:	120.0000
38:	130.0000
39:	40.0000
40:	130.0000
41:	60.0000
42:	135.0000
43:	10.0000
44:	60.0000
45:	5.0000
46:	160.0000
47:	30.0000
48:	20.0000
49:	120.0000
50:	70.0000
51:	175.0000
52:	130.0000
53:	90.0000
54:	80.0000
55:	10.0000
56:	80.0000
57:	130.0000
58:	125.0000
59:	150.0000
60:	75.0000
61:	150.0000
62:	60.0000
63:	70.0000
64:	50.0000
65:	110.0000
66:	100.0000
67:	80.0000
68:	50.0000
69:	165.0000
70:	100.0000
71:	135.0000
72:	75.0000
73:	55.0000
74:	50.0000
75:	20.0000
76:	40.0000
77:	80.0000
78:	5.0000
79:	50.0000
80:	160.0000
81:	40.0000
82:	110.0000
83:	145.0000
84:	80.0000
85:	155.0000
86:	5.0000



N = 65

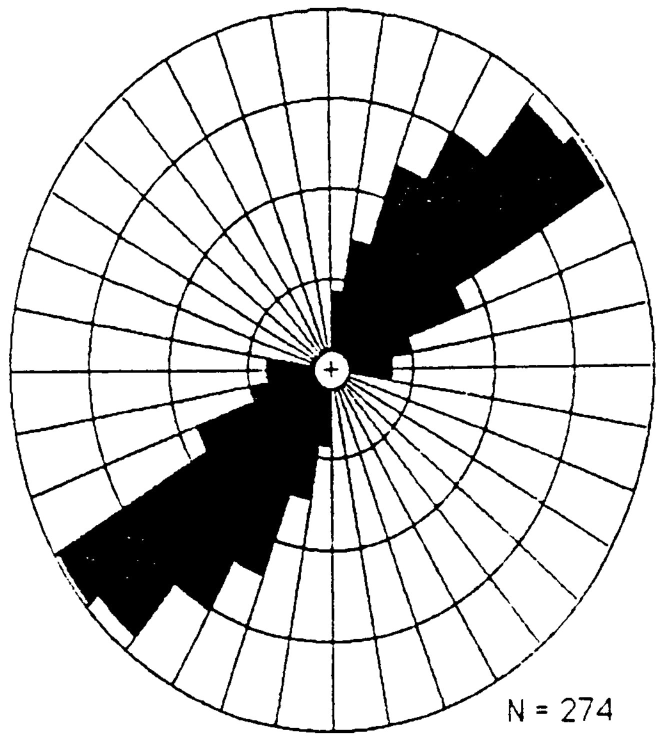
Southernmost road outcrop

1:	85.0000	49:	95.0000	97:	60.0000
2:	35.0000	50:	96.0000	98:	170.0000
3:	70.0000	51:	130.0000	99:	35.0000
4:	50.0000	52:	76.0000	100:	5.0000
5:	75.0000	53:	18.0000	101:	15.0000
6:	15.0000	54:	130.0000	102:	30.0000
7:	15.0000	55:	47.0000	103:	31.0000
8:	0.0000	56:	70.0000	104:	45.0000
9:	3.0000	57:	55.0000	105:	60.0000
10:	16.0000	58:	30.0000	106:	60.0000
11:	38.0000	59:	30.0000	107:	160.0000
12:	45.0000	60:	40.0000	108:	90.0000
13:	45.0000	61:	42.0000	109:	25.0000
14:	43.0000	62:	44.0000	110:	25.0000
15:	142.0000	63:	30.0000	111:	20.0000
16:	95.0000	64:	50.0000	112:	40.0000
17:	40.0000	65:	24.0000	113:	20.0000
18:	120.0000	66:	43.0000	114:	25.0000
19:	6.0000	67:	52.0000	115:	30.0000
20:	7.0000	68:	15.0000	116:	35.0000
21:	0.0000	69:	12.0000	117:	80.0000
22:	115.0000	70:	12.0000	118:	70.0000
23:	30.0000	71:	18.0000	119:	40.0000
24:	30.0000	72:	55.0000	120:	15.0000
25:	50.0000	73:	49.0000	121:	50.0000
26:	58.0000	74:	40.0000	122:	40.0000
27:	54.0000	75:	85.0000	123:	20.0000
28:	25.0000	76:	62.0000	124:	100.0000
29:	177.0000	77:	40.0000	125:	100.0000
30:	73.0000	78:	50.0000	126:	70.0000
31:	25.0000	79:	30.0000	127:	15.0000
32:	27.0000	80:	40.0000	128:	0.0000
33:	15.0000	81:	19.0000	129:	30.0000
34:	10.0000	82:	37.0000	130:	50.0000
35:	58.0000	83:	39.0000	131:	55.0000
36:	56.0000	84:	25.0000	132:	80.0000
37:	80.0000	85:	35.0000	133:	80.0000
38:	28.0000	86:	33.0000	134:	60.0000
39:	23.0000	87:	20.0000	135:	50.0000
40:	50.0000	88:	20.0000	136:	45.0000
41:	41.0000	89:	20.0000	137:	20.0000
42:	35.0000	90:	70.0000	138:	55.0000
43:	50.0000	91:	30.0000	139:	48.0000
44:	52.0000	92:	60.0000	140:	22.0000
45:	64.0000	93:	30.0000	141:	10.0000
46:	52.0000	94:	70.0000	142:	13.0000
47:	30.0000	95:	45.0000	143:	30.0000
48:	26.0000	96:	45.0000	144:	39.0000

Southernmost road outcrop cont.

145:	64.0000	193:	42.0000	241:	60.0000
146:	69.0000	194:	54.0000	242:	40.0000
147:	155.0000	195:	95.0000	243:	30.0000
148:	46.0000	196:	53.0000	244:	110.0000
149:	53.0000	197:	40.0000	245:	50.0000
150:	40.0000	198:	85.0000	246:	80.0000
151:	41.0000	199:	65.0000	247:	40.0000
152:	13.0000	200:	50.0000	248:	73.0000
153:	113.0000	201:	30.0000	249:	80.0000
154:	97.0000	202:	40.0000	250:	160.0000
155:	15.0000	203:	44.0000	251:	155.0000
156:	25.0000	204:	40.0000	252:	105.0000
157:	34.0000	205:	40.0000	253:	20.0000
158:	35.0000	206:	55.0000	254:	37.0000
159:	32.0000	207:	40.0000	255:	80.0000
160:	0.0000	208:	65.0000	256:	60.0000
161:	65.0000	209:	40.0000	257:	57.0000
162:	35.0000	210:	25.0000	258:	50.0000
163:	34.0000	211:	47.0000	259:	55.0000
164:	30.0000	212:	25.0000	260:	53.0000
165:	27.0000	213:	47.0000	261:	53.0000
166:	50.0000	214:	30.0000	262:	50.0000
167:	34.0000	215:	40.0000	263:	52.0000
168:	60.0000	216:	45.0000	264:	44.0000
169:	35.0000	217:	50.0000	265:	75.0000
170:	39.0000	218:	70.0000	266:	78.0000
171:	50.0000	219:	68.0000	267:	90.0000
172:	60.0000	220:	50.0000	268:	20.0000
173:	20.0000	221:	45.0000	269:	50.0000
174:	52.0000	222:	57.0000	270:	52.0000
175:	40.0000	223:	35.0000	271:	90.0000
176:	55.0000	224:	55.0000	272:	53.0000
177:	50.0000	225:	24.0000	273:	67.0000
178:	170.0000	226:	20.0000	274:	15.0000
179:	160.0000	227:	90.0000		
180:	30.0000	228:	94.0000		
181:	45.0000	229:	15.0000		
182:	57.0000	230:	55.0000		
183:	67.0000	231:	50.0000		
184:	0.0000	232:	45.0000		
185:	47.0000	233:	60.0000		
186:	42.0000	234:	60.0000		
187:	25.0000	235:	45.0000		
188:	25.0000	236:	60.0000		
189:	50.0000	237:	20.0000		
190:	47.0000	238:	50.0000		
191:	5.0000	239:	0.0000		
192:	65.0000	240:	45.0000		

Southernmost road outcrop cont.

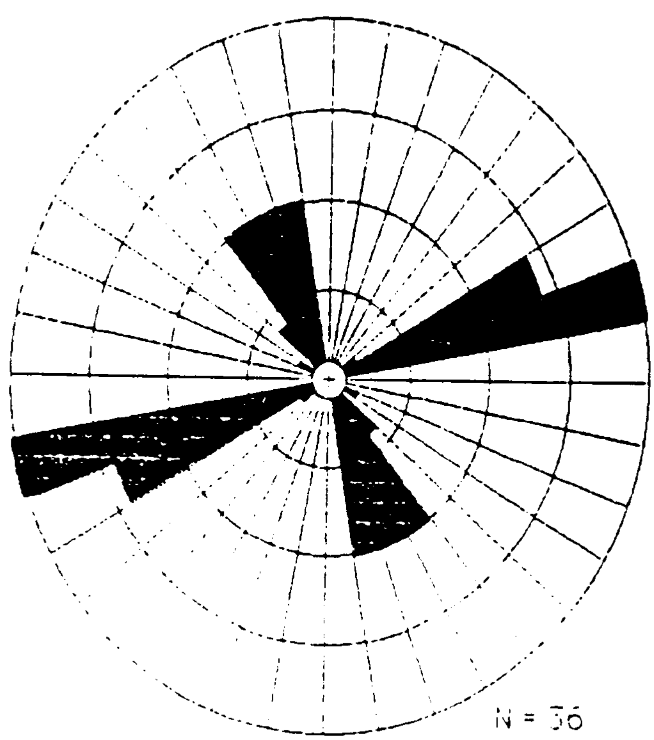


APPENDIX B

Joint Patterns

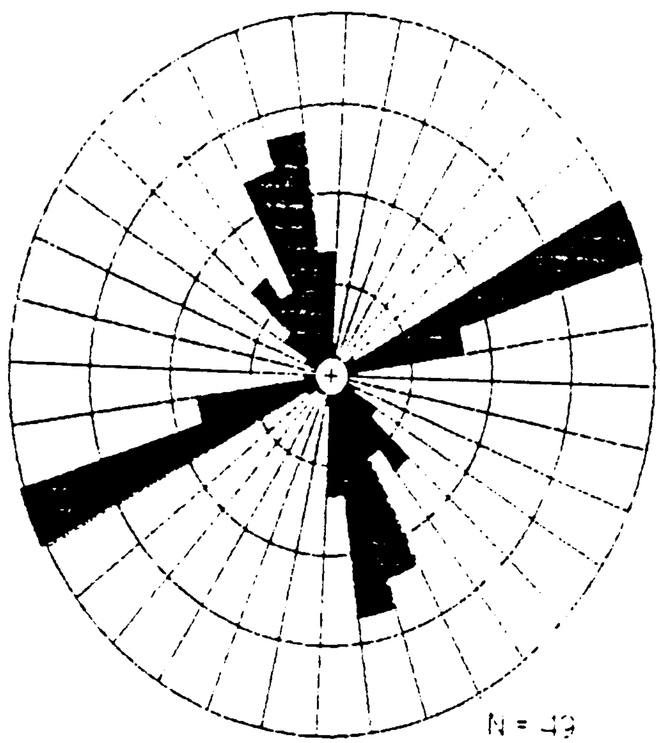
North area near Walter's house

1:	65.0000	19:	320.0000
2:	70.0000	20:	322.0000
3:	75.0000	21:	60.0000
4:	70.0000	22:	64.0000
5:	73.0000	23:	58.0000
6:	340.0000	24:	335.0000
7:	335.0000	25:	335.0000
8:	345.0000	26:	325.0000
9:	340.0000	27:	70.0000
10:	337.0000	28:	60.0000
11:	75.0000	29:	315.0000
12:	65.0000	30:	70.0000
13:	70.0000	31:	60.0000
14:	75.0000	32:	315.0000
15:	60.0000	33:	295.0000
16:	325.0000	34:	344.0000
17:	315.0000	35:	70.0000
18:	325.0000	36:	73.0000



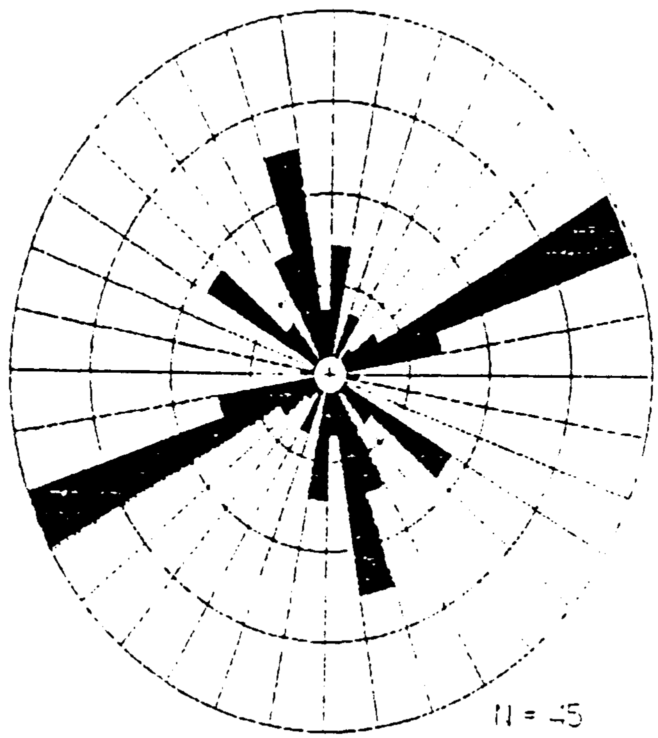
Main Quarry pit area

1:	298.0000
2:	355.0000
3:	331.0000
4:	333.0000
5:	340.0000
6:	64.0000
7:	67.0000
8:	62.0000
9:	63.0000
10:	313.0000
11:	326.0000
12:	72.0000
13:	64.0000
14:	336.0000
15:	65.0000
16:	330.0000
17:	323.0000
18:	333.0000
19:	320.0000
20:	340.0000
21:	83.0000
22:	316.0000
23:	343.0000
24:	314.0000
25:	341.0000
26:	342.0000
27:	308.0000
28:	72.0000
29:	75.0000
30:	307.0000
31:	60.0000
32:	347.0000
33:	334.0000
34:	316.0000
35:	57.0000
36:	73.0000
37:	342.0000
38:	345.0000
39:	353.0000
40:	337.0000
41:	67.0000
42:	67.0000
43:	63.0000
44:	352.0000
45:	355.0000
46:	322.0000
47:	67.0000
48:	72.0000
49:	5.0000



Marlin Quarry area

1:	42.0000
2:	50.0000
3:	304.0000
4:	0.0000
5:	67.0000
6:	307.0000
7:	305.0000
8:	308.0000
9:	65.0000
10:	65.0000
11:	342.0000
12:	9.0000
13:	312.0000
14:	334.0000
15:	353.0000
16:	274.0000
17:	336.0000
18:	69.0000
19:	27.0000
20:	53.0000
21:	350.0000
22:	75.0000
23:	72.0000
24:	70.0000
25:	21.0000
26:	341.0000
27:	2.0000
28:	345.0000
29:	347.0000
30:	319.0000
31:	65.0000
32:	63.0000
33:	73.0000
34:	330.0000
35:	70.0000
36:	348.0000
37:	348.0000
38:	62.0000
39:	65.0000
40:	0.0000
41:	63.0000
42:	336.0000
43:	69.0000
44:	68.0000
45:	302.0000



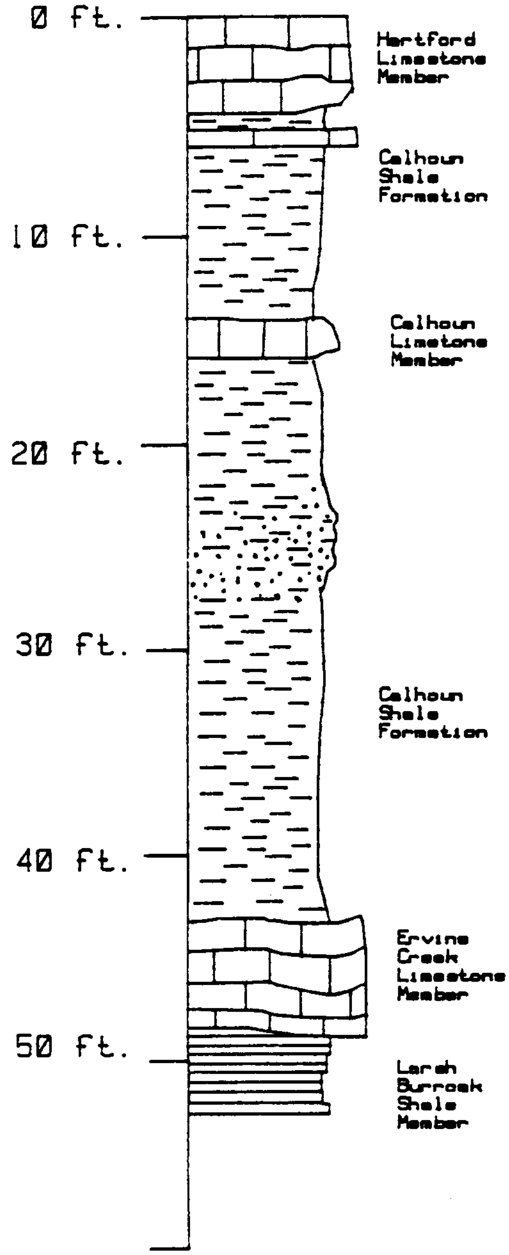
APPENDIX C

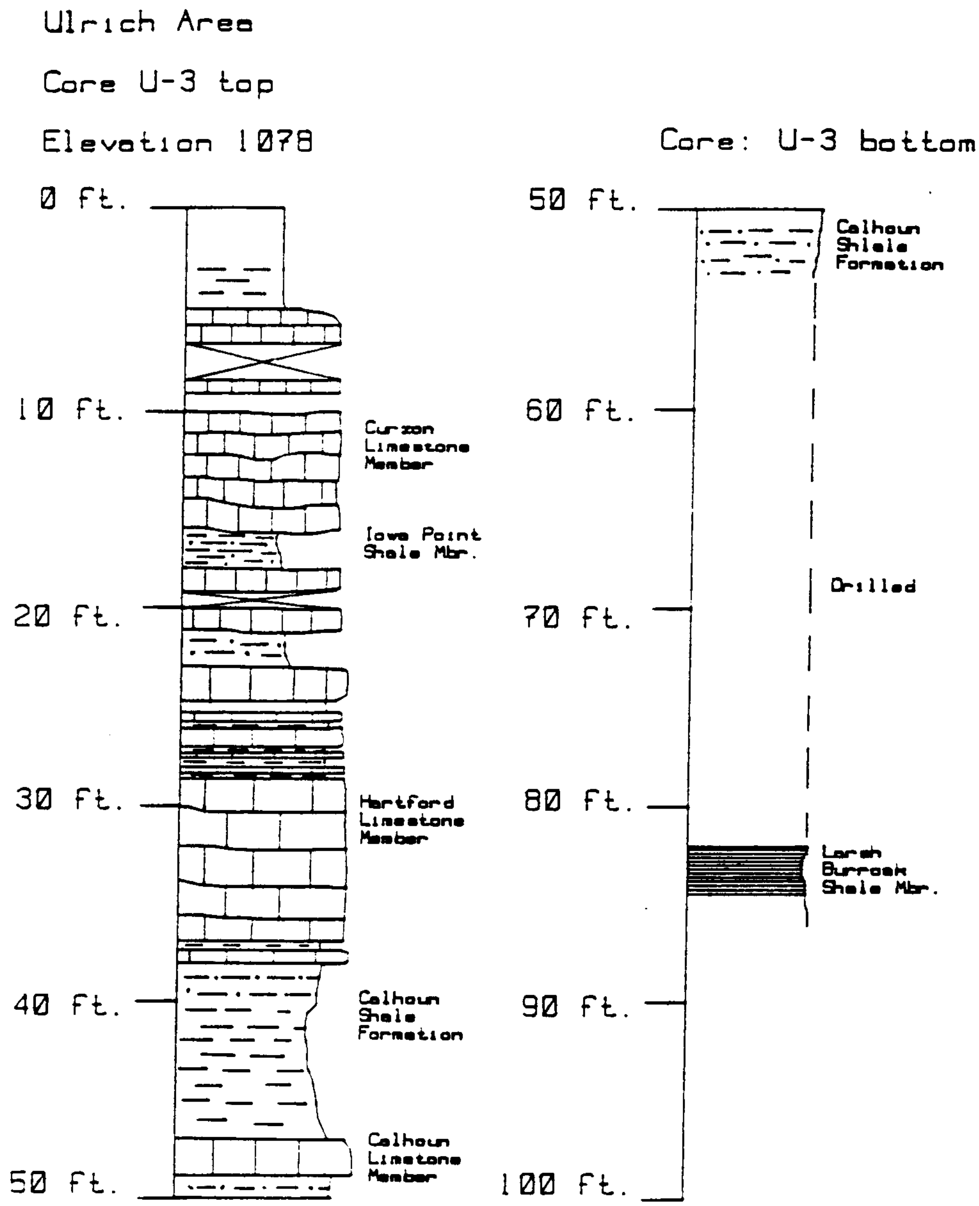
Core Descriptions

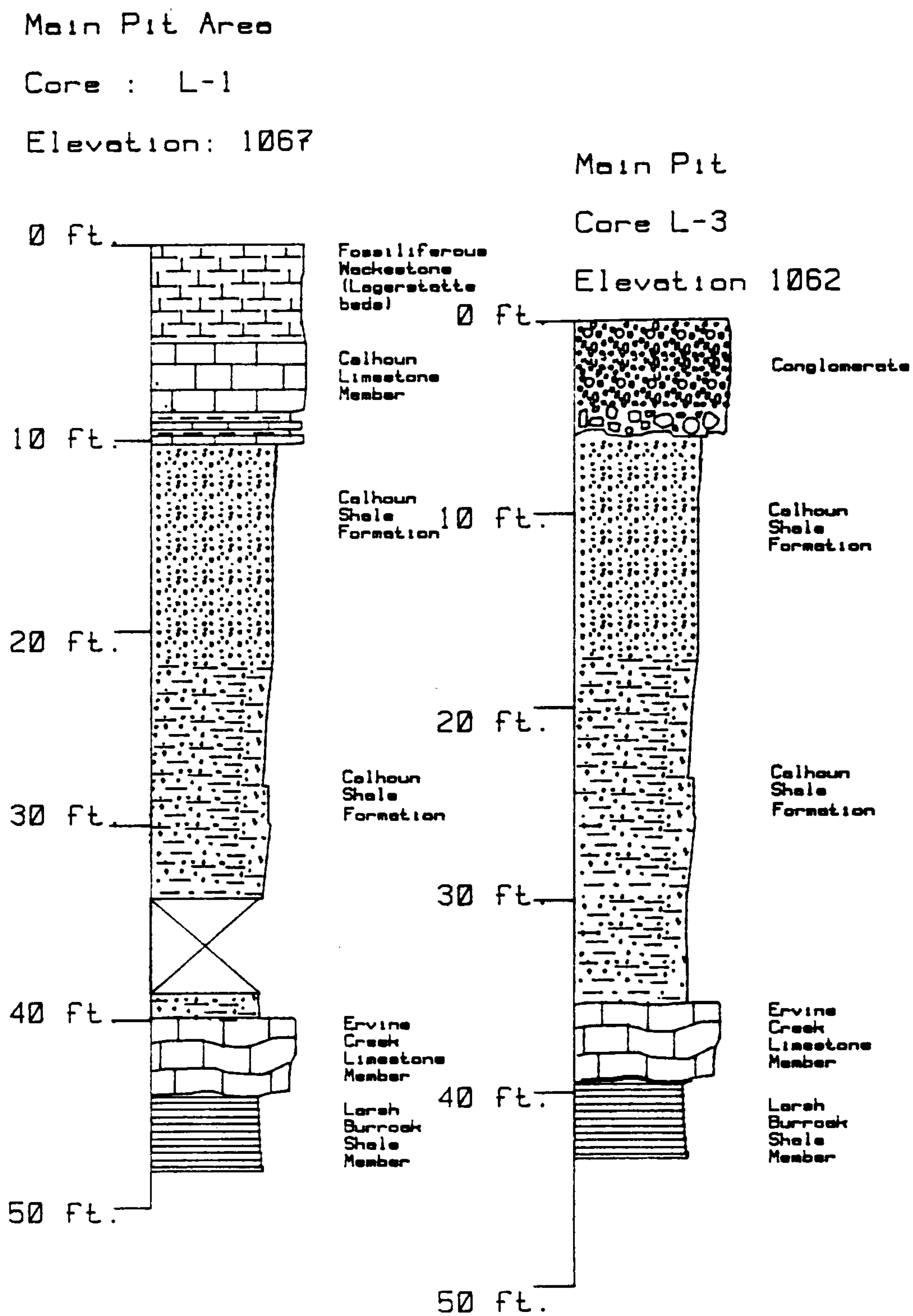
Ulrich Area

Core U-1

Elevation 1049



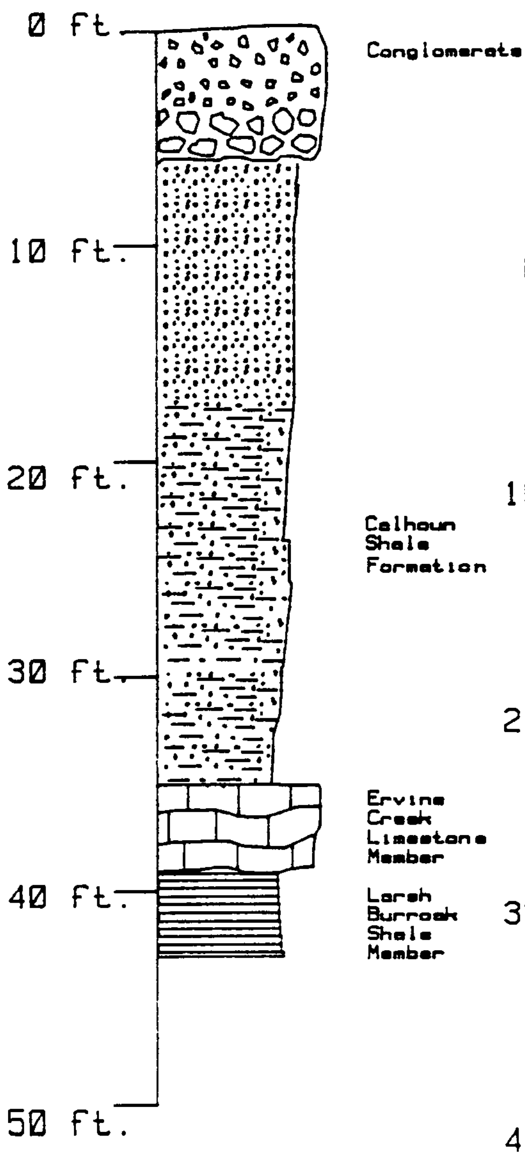

Ulrich Area
Core U-3 top
Elevation 1078
Core: U-3 bottom
0 ft.
10 ft.
20 ft.
30 ft.
40 ft.
50 ft.
Curzon Limestone Member
Iowa Point Shale Mbr.
Hartford Limestone Member
Calhoun Shale Formation
Calhoun Limestone Member
50 ft.
60 ft.
70 ft.
80 ft.
90 ft.
100 ft.
Calhoun Shlale Formation
Drilled
Larsh Burroak Shale Mbr.


Main Pit Area
Core : L-1
Elevation: 1067
0 ft.
10 ft.
20 ft.
30 ft.
40 ft.
50 ft.
Fossiliferous Wackestone (Lagerstatte beds)
Calhoun Limestone Member
Calhoun Shale Formation
Calhoun Shale Formation
Ervine Creek Limestone Member
Larsh Burroak Shale Member
Main Pit
Core L-3
Elevation 1062
0 ft.
10 ft.
20 ft.
30 ft.
40 ft.
50 ft.
Conglomerate
Calhoun Shale Formation
Calhoun Shale Formation
Ervine Creek Limestone Member
Larsh Burroak Shale Member

Main Pit Area

Core : L- 3

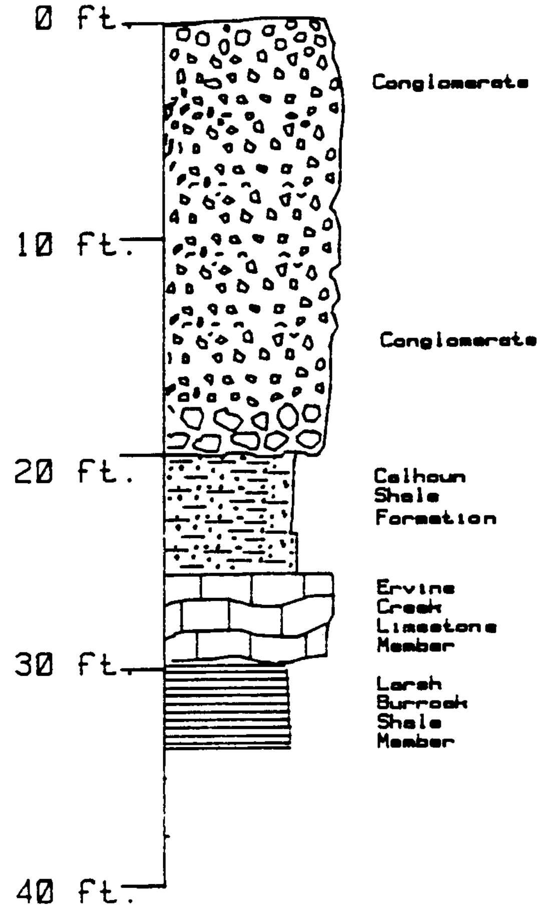
Elevation: 1062



Main Pit Area

Core : L- 2

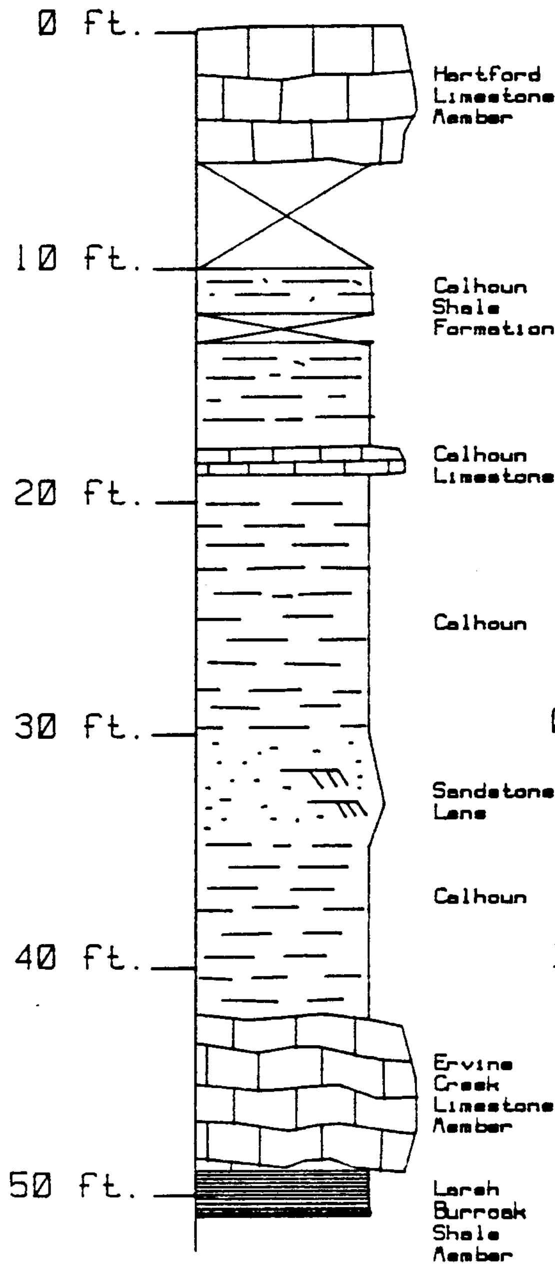
Elevation: 1050



Marlin Quarry

Core : M-1

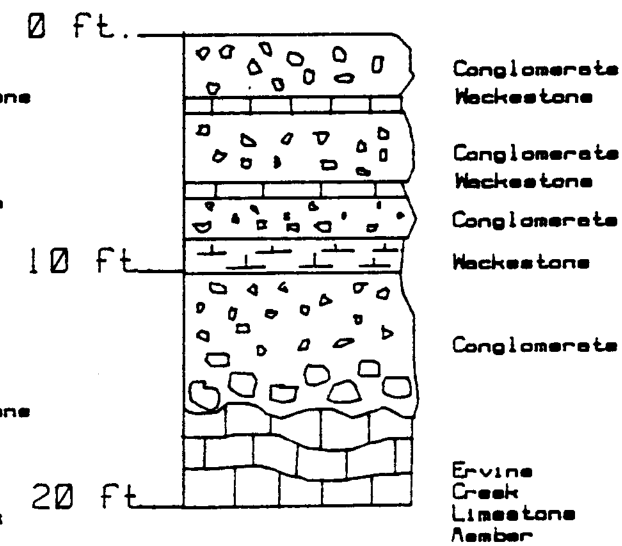
Elevation 1084 ft.



Marlin Quarry

Core M-2

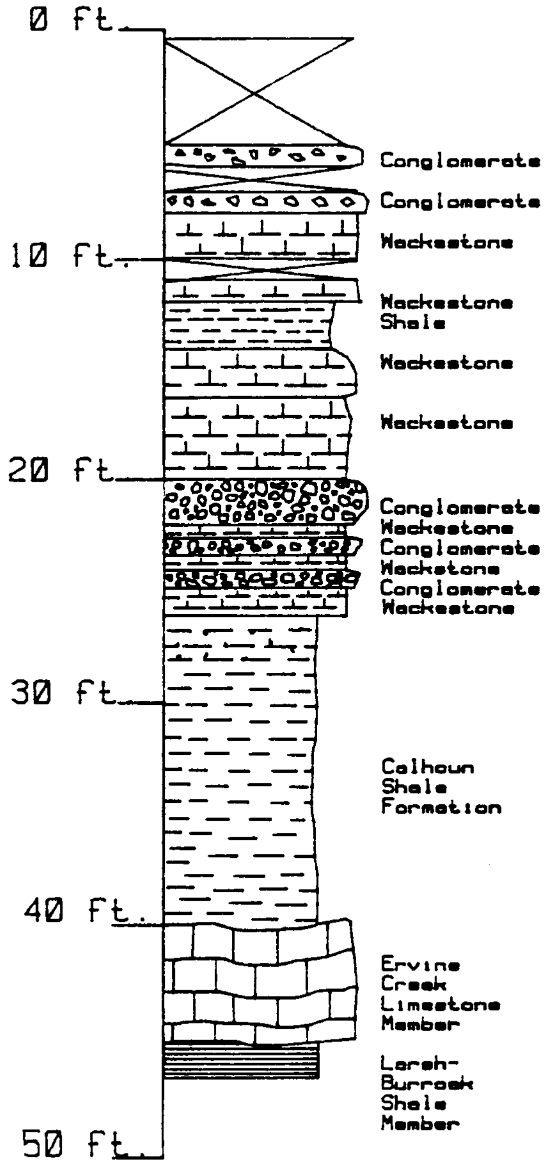
Elevation 1055 ft.



Marlin Quarry

Core: M-3

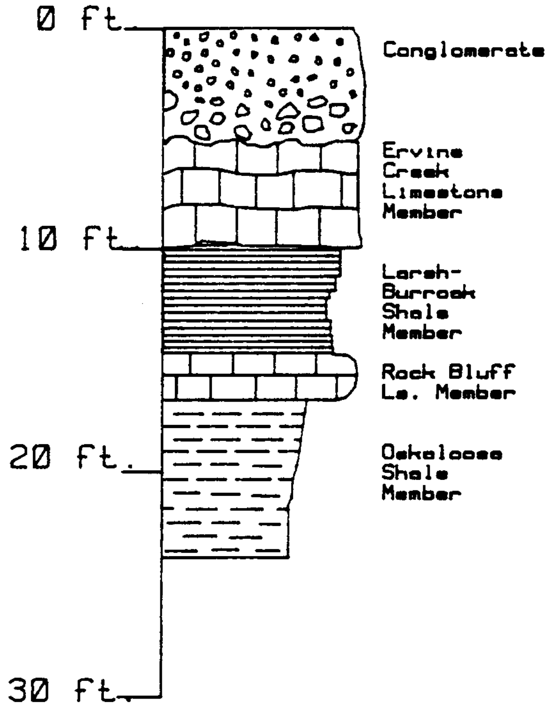
Elevation 1088 ft.



South Road

Core: S-1

Elevation 1073 ft.



APPENDIX D

Table 1

Invertebrates from the Hamilton deposit

- FORAMINIFERA
  - *Tricites*
- BRYOZOA
  - Fenestrate *incertae sedis*
  - Ramose *incertae sedis*
- BRACHIOPODA
  - ARTICULATA
    - *Juresania*
    - *Kozlowskia*
    - *Neochonetes*
    - *Neospirifirer*
    - *Productid*
- MOLLUSCA
  - BIVALVIA
    - *Anthraconaia*
    - *Myalinella*
    - *Permaphorus*
    - *Phestia*
    - *Scizodus*
  - GASTROPODA
    - *?Bellerophon*
    - *Euphemites*
    - *Incertae sedis*
- ANNELIDA
  - POLYCHAETA
    - *Serpula*
    - *Spirorbis*
- ARTHROPODA
  - ARACHNIDA
    - THELYPHONIDA
  - CRUSTACEA
    - OSTRACODA
      - *Bairdia*
      - *Carbonita*
      - *Darwinula*
    - PERACARIDA
      - Spelaeogriphacean
    - SYNCARIDA
      - Palaeocaridid
  - EURYPTERIDA
    - *Adelopthalmus*
  - SCORPIONIDA
    - *?Archaeoctonous*
- UNIRAMIA
  - MYRIAPODA
    - DIPLODA
      - Euphoberiid
      - ?Juliform Milliped
  - INSECTA
    - BLATTARIA
    - ODONATA
    - PALAEODICTYOPTERA
    - PROTORTHOPTERA
  - TRILOBITOMORPHA
    - TRILOBITA
- ECHINODERMATA
  - CRINOIDEA
  - ECHINOIDEA

APPENDIX E

Table 2

Vertebrates from the Hamilton deposit

GNATHOSTOMATA
CHONDRICHTHYES
- ELASMOBRANCHII
  - XENACANTHIDA
    - *Expleuracanthus*
    - *Orthacanthus*
  - EUSELACHII
    - hybodont indet.

ACANTHODII
- ACANTHODIDA
  - *Acanthodes*

OSTEICHTHYES
- ACTINOPTERYGII
  - PALEONISCIFORMES
    - indeterminant
- ACTINISTIA
  - indeterminant
- RHIPIDISTIA
  - OSTEOLEPIDIDA
    - megalichthyid
- DIPNOI
  - *Sagenodus*

TETRAPODA
- TEMNOSPONDYLI
  - dissorophoid
  - eryopoid
  - trimerorhachoid
- REPTILIA
  - CAPTORHINOMORPHA
    - protorothyrid sp.
  - INDETERMINANT
  - DIAPSIDA
    - n.g.n. sp.
- PELYCOSAURIA
  - edaphosaur
  - ophiacodont

References

Beekly, A.L., 1929, Virgil pool, Greenwood County, Kansas: in Structure of Typical American Oil Fields: American Association of Petroleum Geologists: v. 2, p. 142-149.

Bridge, T.E., Leisman, G.A., and Lockard, W., 1972, Vertebrate, invertebrate, and plant fossils of the Hamilton quarry: Geological Society of America, South Central Section, Abstracts with Program, v.4, no. 4, p.275.

Bridge, T.E., and Mapes R.H., 1988, Background history of the discovery and development of the Hamilton quarry site; in, Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G. and Mapes, R.H., comps. and eds.: Kansas Geological Survey Guidebook Series 6, p. 21-25.

Bridge, T.E., 1989, Geology and Stratigraphy of the Hamilton quarry area. in, Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 11-14.

Busch, R.M., Bogina, M.A., and Clark, M.H., 1988, Preliminary report on the genetic stratigraphy of the Hamilton, Kansas, fossil localities--Deer Creek fifth-order T-R unit; in, Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G. and Mapes, R.H., comps. and eds.: Kansas Geological Survey Guidebook Series 6, p. 59-65.

Chorn, J., and Schultze, H.-P., 1988, A complete specimen of Sagenodus (Dipnoi) from the Upper Pennsylvanian of the Hamilton quarry, Kansas, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G. and Mapes, R.H., comps. and eds.: Kansas Geological Survey Guidebook Series 6, p. 173-176.

Cubitt, J.M., 1975, A computer analysis of the geochemistry and mineralogy together with the petrology of the Upper Pennsylvanian and Lower Permian Shales of Kansas, U.S.A.: unpubl. doctoral dissertation, Univ. Leicester (U.K.), 366 p.

Douglass, R.C., 1988, Fusulinids at the Hamiton quarry. in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 85-87.

Durden,C.J., 1988, Hamilton insect fauna, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G. and Mapes, R.H., comps. and eds.: Kansas Geological Survey Guidebook Series 6, p. 117-124.

Fahrer, T.R., Mapes, R.H., and Maples, C.G., 1990. The Age and Geometry of the Late Carboniferous Hamilton Lagerstatte, Greenwood County, Kansas. GSA Abstracts with Programs vol. 22, no.1, Feb. 1990.

Feldman, R.H., Franseen, E.K., Fahrer, T.R., and Maples. C.G., Geology and sedimentology of the Hamilton Lagerstatte in 1990 Society of Vertebrate Paleontology Upper Paleozoic of Eastern Kansas Excursion Guidebook: Kansas Geological Survey Open file Report 90-24, p. 36-41.

French, J.A., Watney, L.W., And Anderson, J.E., 1988, Stratigraphic and sedimentologic considerations relating to the fossiliferous limestones (Upper Pennsylvanian?) at Hamilton quarry, Greenwood County, Kansas. in, Regional Geology and Paleontology of Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 37-58.

Gottfried, M.D., 1988, Paleoniscoid fishes from the Upper Pennsylvanian Hamilton quarry, Greenwood County, Kansas, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 161-166.

Heckel, P.H., 1972, Pennsylvanian stratigraphic reefs in Kansas, some modern comparisons and implications: Geol. Rundsch., v. 61, no. 2, p. 584-598.

Heckel, P.H., 1977, Origin of phoSphatic black shale facies in Pennsylvanian cyclothems of Midcontinent North America: American Association of Petroleum Geologists, Bulletin, v.61, p. 1,045-1,068.

Heckel, P.H., and Baeseman, J.F., 1975, Environmental interpretation of conodont distribution in Upper Pennsylvanian (Missourian) megacyclothems in eastern Kansas: American Association of Petroleum Geologists, Bulletin, v.59, p. 486-509.

Jeffords, R.M., 1940, Stratigraphic relations of the Topeka Limestone in Kansas: Kansas Geological Survey, Openfile Report 40-5, 22 p.

Johnson, W.D., and Adkinson, W.L., 1967. Geology of eastern Shawnee County, Kansas and vicinity: U.S. Geol. Survey Bull. 169, p. 275-281.

Kaesler, R.L., 1988, Ostracoda from the hamilton quarry, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey Guidebook Series 16, p. 109-112.

Kues, B.S., 1988, Observations on the Late Pennsylvanian eurypterid of the Hamilton quarries, Kansas, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 95-104

Lamoreaux, S.B., 1986, Stratigraphic development of the marine algal bank occuring in the Ervine Creek Limestone in Elk and Chautauqua Counties, Kansas: Kansas Geological Society, 38th Annual Field Conference Guidebook, p. 98-119.

MacDonald, D.I.M., and Jefferson, T.H., 1985, Orientation studies of waterlogged wood: A paleocurrent indicator?: Journal of Sed. Petrology v. 55 p. 235-239.

Maisey, J.G., 1988, The hybodont shark from the Hamilton quarry, in Regional Geology and PaleonTology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G. and Mapes, R.H., comps. and eds.: Kansas Geological Survey Guidebook Series 6, p. 177-180.

Mapes, G., and Gastaldo, R.A., 1986 Late Paleozoic non-peat accumulating floras,in Broadhead, T.W., ed., Land Plants : University of Tennessee, Department of Geological Sciences Studies in Geology, no. 15, p. 115-127.

Mapes, G., and Rothwell, G. W., 1984, Permineralized ovulate cones of Lebachia from Late Paleozoic limestones in Kansas: Paleontology, v. 27, p. 69-94.

Mapes, G., and Rothwell, G.W., 1988, Diversity among Hamilton conifers, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G. and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 225-244.

Mapes, G., Rothwell, G.W., and Haworth, M.T., 1989, Evolution of seed dormancy: Nature, v. 337, no. 16, p. 645-646.

Mapes, R.H., and Maples, C.G., 1988, "Marine" macroinvertebrates, Hamilton quarry, Kansas, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 67-75.

Maples, C. G., and Schultze, H.-P., 1988, A prelimianry comparison of the Pennsylvanian faunaL assemblages of Hamilton, Kansas, with marine and nonmarine contemporaneous assemblages: in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 235-273.

McAllister, J., 1988, Prelimianry description of the coprolitic remains from Hamilton quarry, Kansas, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes C.G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 195-202.

Merriam, D.F., 1963, The geologic history of Kansas: Kansas Geol. Survey Bull. 162, 317 p.

Merriam, D.F., 1986, Geology of the Shawnee Group (Virgilian Stage, Upper Pennsylvanian) in eastern Kansas and its relation to the cyclothem theory; in Stratigraphic, Sedimentologic, and Cyclic Relationships of Shawnee Group (Virgilian, Pennsylvanian) in Eastern Kansas: Kansas Geological Society, 38th Field Conference Guidebook, p. 1-51.

Moore, R.C., 1935, Stratigraphic classification of the Pennsylvanian rocks of Kansas: Kansas Geological Survey Bulletin 22, 256 p.

Rich, T., 1935, Fault-block nature of Kansas structures suggested by elimination of regional dip. Am. Assoc. Petroleum Geologists Bull., v. 19, p. 1540-1543.

Rothwell, G.W., and Mapes, G., 1988, Vegetatlon of a Paleozoic conifer community, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 213-223.

Schoewe, W.H., 1949, The geography of Kansas, pt. 2, physical geography: Kansas Acad. Sci. Trans., v. 52, no. 3, p. 261-333.

Schram, 1988, Eumalacostracan crustaceans from the quarries at Hamilton, Kansas; in Regional Geology and Paleontology ofUpper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes C.G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 105-107.

Schultz R. B., 1989, Geochemical charateristics and inferred depositional environments of Upper Pennsylvanian (Virgilian) black shales in eastern Kansas, The Compass of Sigma Gamma Epsilon, Vol. 67, no. 1, p. 47-54.

Schultze, H.-P., 1988, An Osteolepidid rhipidistian in Upper Pennsylvanian deposits of Hamilton, Kansas, in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas, Mapes, G., and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16,p. 181-183.

Silfer, J.A., 1986, Facies and depositional history of the Hartford Limestone (Topeka Limestone Formation, Upper Pennsylvanian Series) algal-mound complex in east-central Kansas: in Stratigraphic, Sedimentologic, and Cyclic Relationships of Shawnee Group (Virgilian, Pennsylvanian) in Eastern Kansas : Kansas Geological Society, 38th Field Conference Guidebook, p. 136-158.

Skelton, L.H., 1986, The Topeka Formation of Kansas - the study of a megacyclothem: in Stratigraphic, Sedimentologic, and Cyclic Relationships of Shawnee Group (Virgilian, Pennsylvanian) in Eastern Kansas: Kansas Geological Society, 38th Field Conference Guidebook, p. 120-135.

Taggert, R.E., and Ghavidel-Syooki, M., 1988, Palynology of the conifer macrofossil horizon from the Hamilton quarry, Kansas. in Regional Geology and Paleontology of Upper Paleozoic Hamilton Quarry Area in Southeastern Kansas., Mapes, G. and Mapes, R.H., comps. and eds.: Kansas Geological Survey, Guidebook Series 16, p. 245-253.

Ward, J.R., 1968, A study of the joint patterns in gently dipping sedimentary rocks in south-central Kansas: Kans. Geol. Survey, Bull. 191, pt. 2, 23 p.

White, L.H., 1986, The Severy Shale - stratigraphy and depositional processes: in, Stratigraphic, Sedimentologic, and Cyclic Relationships of Shawnee Group (Virgilian, Pennsylvanian) in Eastern Kansas: Kans. Geol. Society, 38th Field Conference Guidebook, p. 159-166.

Watney, W.L., 1980, Cyclic sedimentation of the Lansing-Kansas City Groups in northwestern Kansas and southwestern Nebraska: Kansas Geological Survey, Bulletin 220, 72 p.

Zeller, D.G., 1968, The stratigraphic succession in Kansas: Kansas Geol. Survey Bull. 189, 81 p.