

165  
2F  
9-13

STRATIGRAPHY AND DEPOSITIONAL HISTORY OF THE BOURBON FLAGS  
(UPPER PENNSYLVANIAN), AN ENIGMATIC UNIT  
IN LINN AND BOURBON COUNTIES IN  
EAST-CENTRAL KANSAS

by

Mark Roland Underwood

A thesis submitted in partial fulfillment  
of the requirements for the degree of  
Master of Science in Geology  
in the Graduate College of  
the University of Iowa

August, 1984

Thesis supervisor: Professor Philip H. Heckel

Graduate College  
The University of Iowa  
Iowa City, Iowa

CERTIFICATE OF APPROVAL

-----

M.S. THESIS

-----

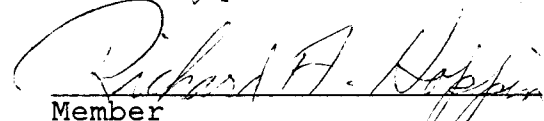
This is to certify that the M.S. thesis of

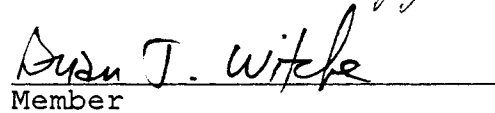
Mark Roland Underwood

has been approved by the Examining Committee  
for the thesis requirement for the Master of  
Science degree in Geology at the August,  
1984 graduation

Thesis committee

  
Thesis supervisor

  
Member

  
Member

## AKNOWLEDGMENTS

I would like to thank the Petroleum Research Fund administered by the American Chemical Society for funding the assistantship that supported me through graduate school; and the State Geological Survey of Kansas for providing field support.

I would also like to thank the members of my graduate committee for their relevant input: Dr. Brian Witzke, and Dr. Richard A. Hoppin.

The following people inspired wisdoms and insights into this research: Mary Edson, Kim Knight, Peter Hudelson, and Helene Greenberg. A special thanks to Allan P. Bennison for his insights into Midcontinent field geology.

I would like to acknowledge Susan Hough, whose devoted companionship has given me hope, inspiration, and emotional support through this last year; and my parents, Mr. and Mrs. Roland Underwood, who have faithfully encouraged me in this endeavor.

Lastly, I would like to express my appreciation to Dr. Philip H. Heckel for serving as advisor to this study. His knowledge and insights were invaluable to this thesis; his steady enthusiasm, constructive advice, and steadfast encouragement transcend the scope of geology.

## ABSTRACT

The Bourbon flags constitute an enigmatic unit of repetitive thin dark-grey silty micaceous shales and dark-grey argillaceous, sublithographic, unfossiliferous limestones in a sequence up to 10.5 m thick. The unit occurs along a narrow outcrop belt averaging 5 to 6 km wide and nearly 40 km long trending southwest-northeast from northwestern Bourbon County to southeastern Linn County. The unit lies between the shales of the Pleasanton Group, below, and the limestone-dominated Hertha Formation, above. There are three distinct facies zones in the thesis area: 1) the northwestern zone, where upper Pleasanton calcareous silty shales grade up into the basal Critzer (lower Hertha) argillaceous calcilutite, overlain by upper Critzer calcarenite and thin Mound City Shale (middle Hertha); 2) the Bourbon flags zone, where Bourbon flags grade up into algal Critzer, overlain by Mound City Shale thickening to the southeast; and 3) the southeastern zone, where extremely thick Mound City shales directly overlie Pleasanton shales with no intervening carbonates. These facies changes may be explained by a transect from a shallow shelf environment in the northwest, to a deeper basinal environment in the southeast.

The deposition of the Bourbon flags occurred along the slope of a Pleasanton prodeltaic front during stillstand and early regression after minor marine transgression. The limestones represent the background sedimentation mode of either authigenic or allochthonous carbonate muds under turbid and/or dysoxic bottom conditions. The shales represent event-mode pulses of coarser terrigenous detrital sedimentation. The overlying Critzer was deposited over the same slope during later regression. Diagenesis of the carbonates shows that the Critzer in the northwestern zone underwent early lithification and exposure to meteoric dissolution followed by void-filling of molds; in the Bourbon flags zone, both the flags and the Critzer show neomorphism of grains, compaction before lithification, and no evidence of exposure to meteoric waters. Mound City Shale deposition effectively covered and filled most of the basin in the study area leading to uniform deposition of the Sniabar Limestone (upper Hertha) above the Mound City. These interpretations suggest the need for revision of the stratigraphic and nomenclatural classification of these units in the area.

## TABLE OF CONTENTS

	Page
LIST OF FIGURES . . . . .	vii
INTRODUCTION . . . . .	1
Objectives . . . . .	10
Approach . . . . .	10
STRATIGRAPHY . . . . .	11
Introduction . . . . .	11
Northwest Lithofacies Zone (XNW) . . . . .	16
Bourbon Flags Lithofacies Zone (HID, MNW) . . . . .	20
Southeastern Lithofacies Zone (LORB) . . . . .	31
Stratigraphic Interpretations . . . . .	34
PETROGRAPHY . . . . .	46
Introduction . . . . .	46
Petrography of the Northwest Lithofacies Zone . . . . .	47
Petrographic Interpretations for the Northwest Lithofacies Zone . . . . .	52
Petrography of the Bourbon Flags Lithofacies Zone . . . . .	53
Petrographic Interpretations of the Bourbon Flags Lithofacies Zone . . . . .	59
Petrographic Conclusions . . . . .	63
CONODONTS . . . . .	66
DEPOSITIONAL ENVIRONMENTS . . . . .	68
Introduction . . . . .	68
Interpretation of Lithologies . . . . .	69
Origin of Slope . . . . .	74
Source of Terrigenous Muds . . . . .	81
Source of Carbonate Muds . . . . .	82
Dearth of Fossils . . . . .	84
Depositional Mode With Respect to Cyclothem Model . . . . .	86
Summary of Bourbon Flags Deposition . . . . .	87



	Page
Deposition of the Critzer Limestone and the Mound City Shale . . . . .	89
SUMMARY AND CONCLUSIONS . . . . .	96
APPENDIX 1 . . . . .	99
REFERENCES CITED . . . . .	109

## LIST OF FIGURES

Figure	Page
1. Generalized stratigraphic nomenclature . . . . .	2
2. Vertical sequence of basic "Kansas" cyclothem. . . . .	5
3. Map showing outcrop area of upper Pleasanton Group in east-central Kansas. . . . .	7
4. Map location of thesis area in Kansas. . . . .	12
5. Lithofacies zones superimposed over map of thesis area. . . . .	14
6. Locality XNW: Representative of northwestern lithofacies zone. . . . .	17
7. Locality HID: Representative of Bourbon flags lithofacies zone. . . . .	21
8. Outcrop photograph of the Bourbon flags at HID roadcut. . . . .	23
9. Close-up photograph of Bourbon flags outcrop at HID roadcut. . . . .	24
10. Locality MNW. . . . .	29
11. Locality LORB: Representative of southeastern lithofacies zone. . . . .	32
12. Location of lines of cross-section superimposed over facies zones. . . . .	36
13. Cross-section X-X'. . . . .	38
14. Cross-section X-Z. . . . .	40
15. Isopach map of Bourbon flags. . . . .	42
16. Isopach map of Mound City Shale. . . . .	44

17.	Thin section photomicrograph of skeletal packstone in upper Critzer at XNW. . . . .	49
18.	Thin section photomicrograph of interbedded skeletal wackestone in Critzer at XNW. . . . .	50
19.	Thin section photomicrograph of skeletal wackestone in upper Critzer at XNW. . . . .	51
20.	Photograph of well preserved plant fossil in Bourbon flags at HID. . . . .	55
21.	Photograph of worm-burrows on top of bedding surface of Bourbon flags at HID. . . . .	56
22.	Photograph of large burrows found on top of bedding surface in Bourbon flags at HID. . . . .	57
23.	Photonegative print of bioturbated limestone in upper Bourbon flags at HID. . . . .	58
24.	Thin section micrograph of skeletal wackestone showing relict neomorphosed red algal blade in middle Critzer at HID. . . . .	60
25.	Thin section micrograph of dasyclad green algae in top of Critzer at HID. . . . .	61
26.	Cross-section X-X using absolute elevations as datum. . . . .	70
27.	Cross-section X-X corrected for regional dip. . . . .	72
28.	Idealized model for deposition of the Bourbon flags. . . . .	75
29.	Map delineating the 38th parallel structural lineament. . . . .	79
30.	Idealized model for deposition of Critzer limestone. . . . .	91
31.	Idealized model for deposition of Mound City Shale. . . . .	93
32.	Insoluble residue analysis. . . . .	100
33.	Locality XN. . . . .	101
34.	Locality XS. . . . .	102

35.	Locality GH.	103
36.	Locality WWH.	104
37.	Locality HP.	105
38.	Locality MN.	106
39.	Locality NQ.	107
40.	Locality MW.	108

## INTRODUCTION

Upper Pennsylvanian (Missourian) rocks of Midcontinent North America (figure 1) usually exhibit widespread lateral continuity and repetitive cyclic sequences. Limestone formations containing thin, often dark, phosphatic shale members represent marine inundations, whereas the intervening sandy shale formations represent the nearshore to terrestrial regime. The alternation of these shale and limestone formations reflects periodic transgression and regression of the sea. Occasionally, a particular rock unit does not fit these somewhat predictable features. The subject of this study, a unit known as the "Bourbon flags" at the top of the Pleasanton Group (figure 1), is an example of one such unit that is anomalous with respect to the more typical and predictable cyclic or "cyclothem" nature of Upper Pennsylvanian strata.

The currently recognized basic eustatic "Kansas cyclothem," described by Heckel (1980, p. 200), consists of the following ascending sequence (figure. 2): 1) thick, sandy nearshore-marine to nonmarine shale formation; 2) thin, transgressive limestone member, typically skeletal calcilutite; 3) thin, nonsandy offshore ("core") shale

Figure 1. Generalized stratigraphic nomenclature and relationships of Upper Middle and Lower Upper Pennsylvanian stratigraphic units in east-central Kansas. Approximate location of Bourbon flags in sequence is noted. From Heckel, 1984.

MIDDLE PENN.	UPPER PENN.		South Bend STANTON
DESMOINESIAN	KANSAS CITY	LAN- SING	PLATTSBURG
			WYANDOTTE
			IOLA
			DRUM-Quivira-DEWEY lower CHERRYVALE
			DENNIS
			SWOPE
	MARMATON	PLEAS- ANTON	HERTHA-CHECKERB'D
			Exline
			"LOST BRANCH"
			LENAPAH - Upr
			ALTAMONT
			PAWNEE
CHEROKEE		upper FT. SCOTT lower FT. SCOTT-Excello	
		Breezy Hill Verdigris-Mecca Qy.	

← "Bourbon flags"

member, typically with black phosphatic facies; 4) thick, regressive limestone member, typically a skeletal calcilutite grading upward to a skeletal calcarenite and shoreline facies; 5) thick, sandy nearshore shale formation (unit 1) again.

The Bourbon flags constitutes an enigmatic unit of repetitive thin layers of dark-blue sublithographic limestones 0.1-0.5 m thick, and dark-grey silty shales 0.1-0.5 m thick. The unit occurs in a narrow outcrop belt, 4 km to 7 km wide, and 40 km long, from northwestern Bourbon County, Kansas, through southeastern Linn County, Kansas (figure 3). Within this outcrop belt, the Bourbon flags show variable thicknesses, attaining a maximum of 10.5 meters with roughly thirty alternations of shales and limestones, at the Hidden Valley Lake spillway section. In all directions from this section, the Bourbon flags are reduced in both thickness and number of alternations.

Moore (1936) was the first to describe the unit, calling it a "dark-blue flaggy limestone" with alternating dark-grey shales. At that time, Moore placed the unit into the "Bourbon Formation", which encompassed the predominantly clastic (shaley) rocks from the basal Missourian disconformity to the base of the Hertha Limestone. In 1949, Moore proposed replacing the name "Bourbon Formation" with the "Pleasanton Group". Apparently, the flaggy limestone

Figure 2. Vertical sequence of basic "Kansas" cyclothem. Curved line represents progression of depositional environments through one eustatic rise and fall of sea level. Diagram after Heckel (1984).

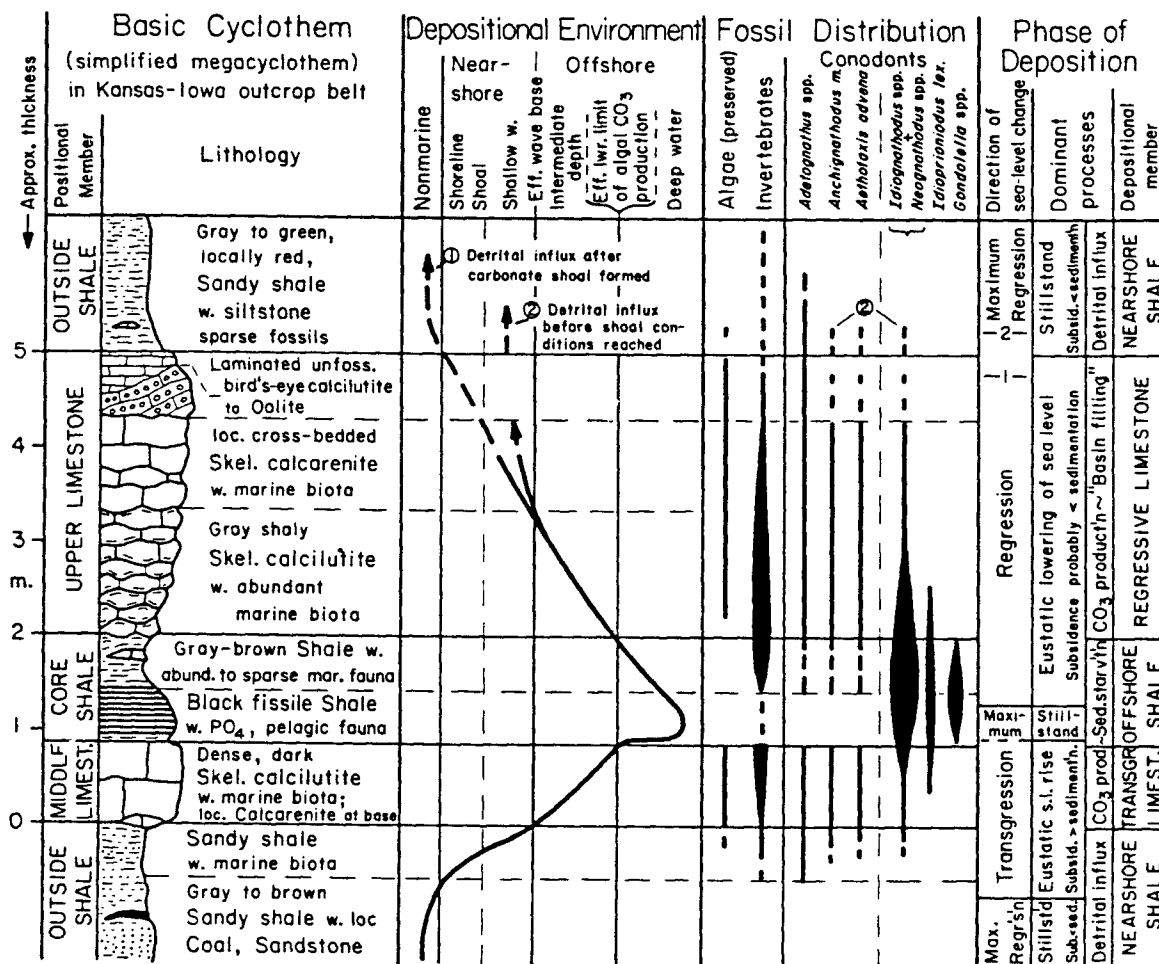
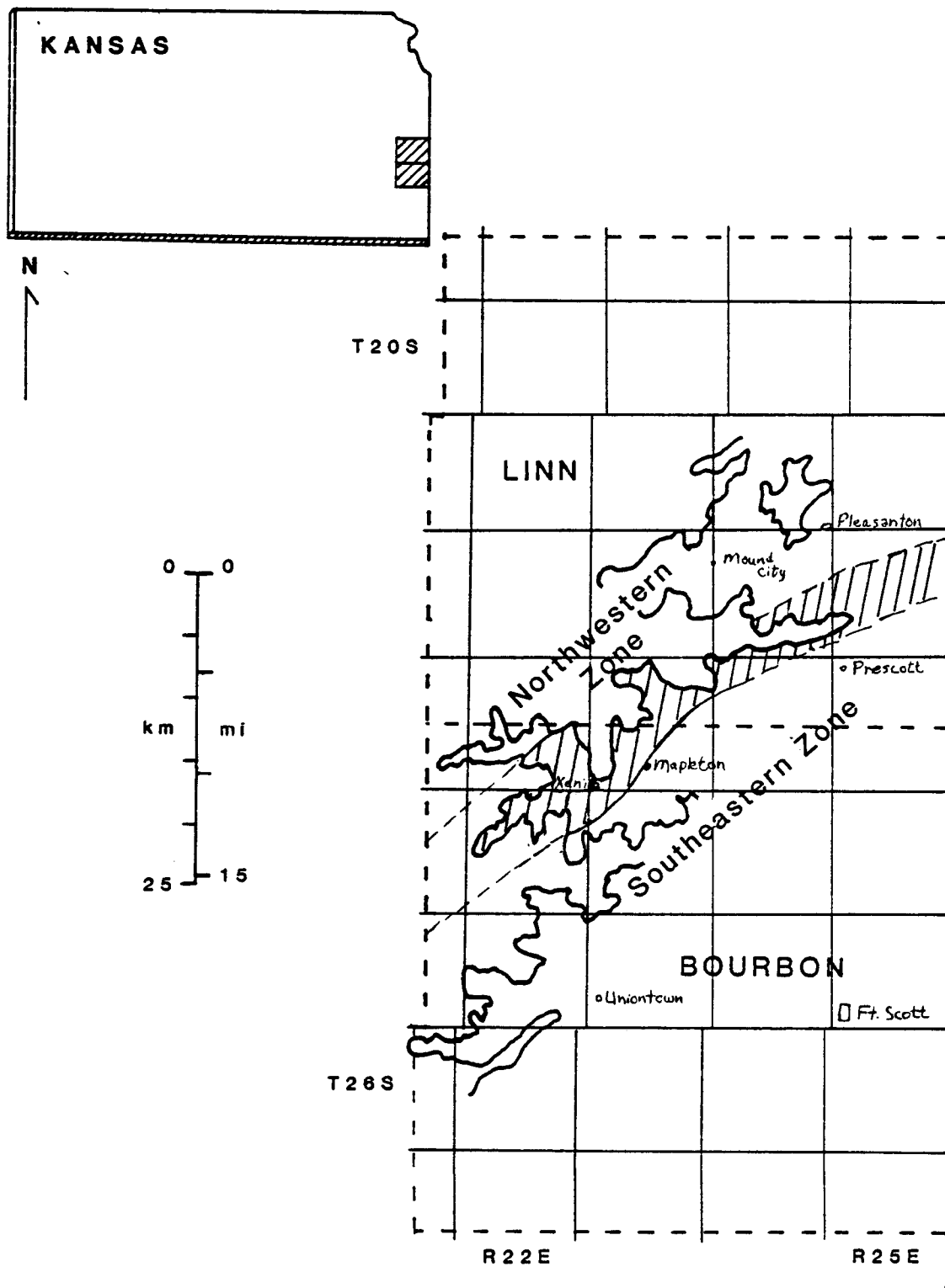


Figure 3. Map showing outcrop area of upper Pleasanton Group in east-central Kansas. Hatched area shows approximate thesis study area. From Geological Map of Kansas, 1964.



unit in the upper Pleasanton had been tagged with the name "Bourbon flags" because of its prominent occurrence in northern Bourbon County. Zeller (1968) and Seevers (1969) were the first to use the informal term "Bourbon flags" in print.

The unit overlying the Bourbon flags is the Hertha Limestone. The Hertha can be subdivided into three members in central Linn County, north of Bourbon flags occurrences. These three members, in ascending order, are: Critzer Limestone, Mound City Shale, and Sniabar Limestone. These have been interpreted by Ravn (1981), to be a transgressive limestone, an offshore shale, and a regressive limestone, respectively.

The unit underlying the Bourbon flags is the lower part of the Pleasanton. The Pleasanton farther south in Kansas is divided into the following formations in ascending order: Seminole Formation (grey shales and sandstones), Checkerboard Limestone, and black Tacket Shale. The Pleasanton found in the Bourbon flags outcrop area is composed of predominantly grey silty micaceous shales, which have not yet been correlated with the named formations. These silty shales are virtually indistinguishable from the shale layers within the Bourbon flags.

More recent investigations (Ravn, 1981; Heckel, 1984) have noted several peculiarities with the stratigraphy in

the Bourbon flags outcrop area: nowhere could definite three-member Hertha be found overlying the Bourbon flags; nor could the offshore shale horizon be found in the Hertha that was identified above the Bourbon flags.

#### Objectives

In view of these peculiarities, the objectives of this study are: 1) to determine how the Bourbon flags fit into the stratigraphic framework of southeastern Kansas; and 2) to interpret the environment of deposition of the Bourbon flags. Particular problems of the Bourbon flags involve its enigmatic nature and the sedimentologic relationship between the shales and the limestones of the unit.

#### Approach

With the stratigraphic ties between the Bourbon flags and the overlying Hertha Formation, it becomes apparent that a study of the Bourbon flags involves also looking also at the Hertha. Many of the stratigraphic problems were approached in the field: finding outcrops, tracing beds, describing and assessing lithologies and lithofacies changes, mapping thicknesses and elevations of rock units, in order to comprehend the present stratigraphy. Rock samples were collected for petrographic study, insoluble residue analysis, and conodont studies.

## STRATIGRAPHY

### Introduction

The Bourbon flags crop out along a belt across the southeastern part of Linn County, into the northwestern part of Bourbon County, in east-central Kansas (figure 3, 4). Coincidentally, the stratigraphy of both the underlying Pleasanton and the overlying Hertha, are different on either side of the Bourbon flags outcrop belt. For clarity in reference, three facies zones (figure 5) will be referred to as 1) "northwestern lithofacies zone", found northwest of the Bourbon flags belt, primarily in Linn County; 2) "Bourbon flags lithofacies zone", coincident with the Bourbon flags outcrop belt; and 3) "southeastern lithofacies zone", found southeast of the Bourbon flags belt, primarily in Bourbon County. The stratigraphic and lithofacies relationships of these zones shall be discussed in the remainder of this section. Their depositional significance will be the focus of the chapter on depositional environments.

Figure 4. Map location of thesis area in Kansas. The study area is roughly 8 km north-south, by 12 km east-west. Outcrop locations are noted by letter abbreviations.

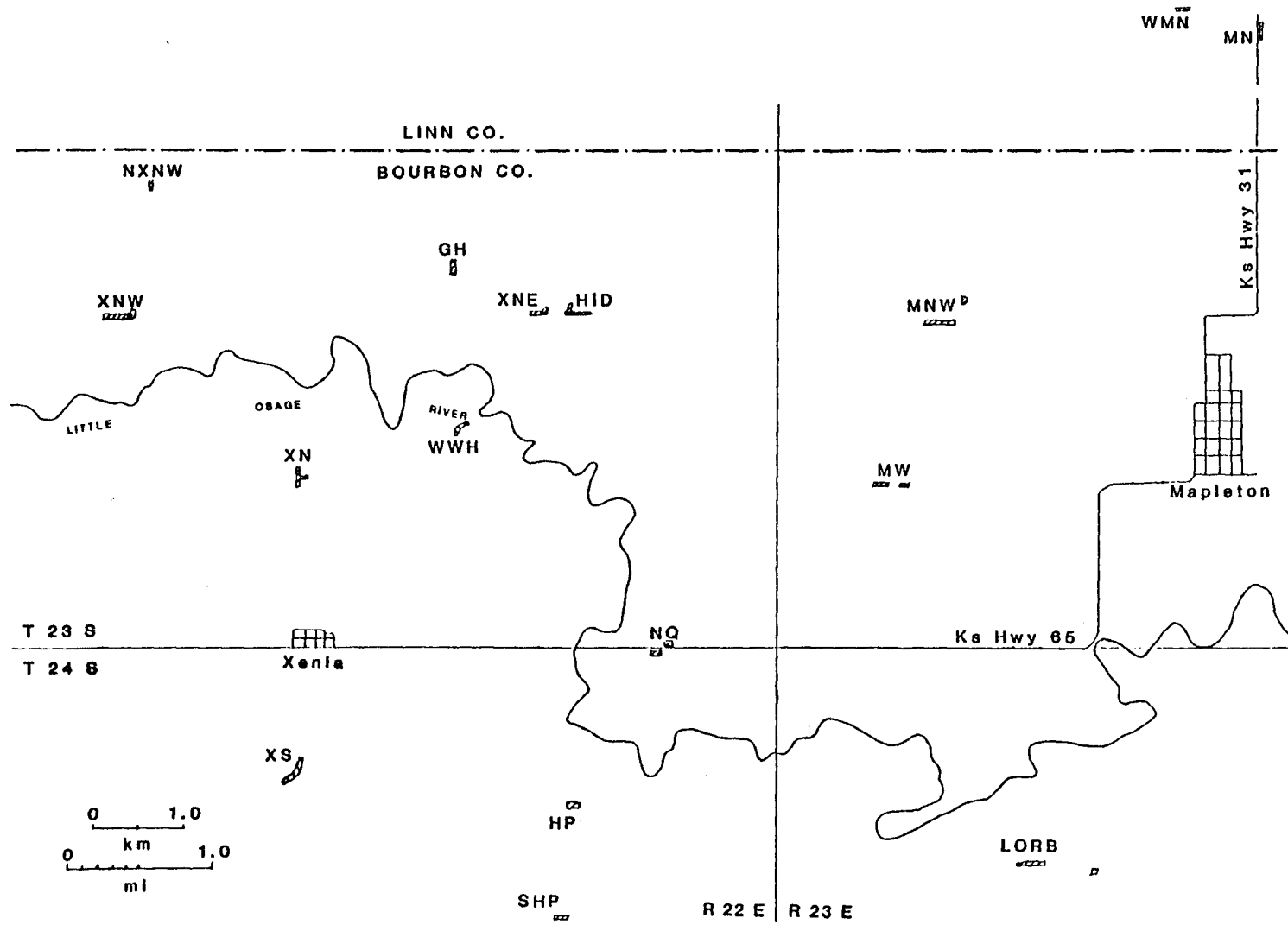
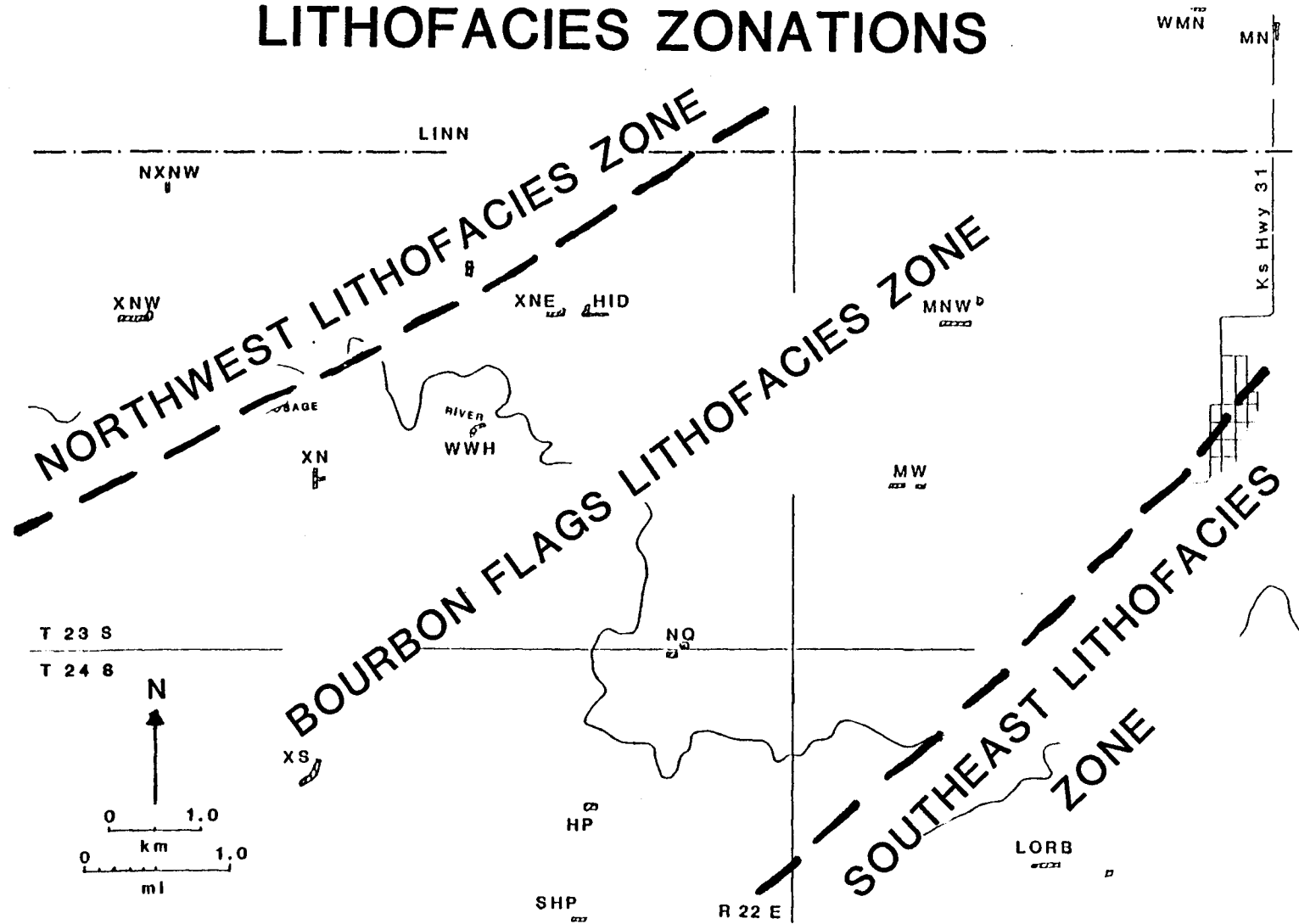


Figure 5. Lithofacies zones superimposed over map of thesis area. Central area, labelled Bourbon flags lithofacies zone, represents known lateral extent of Bourbon flags outcrop.

# LITHOFACIES ZONATIONS



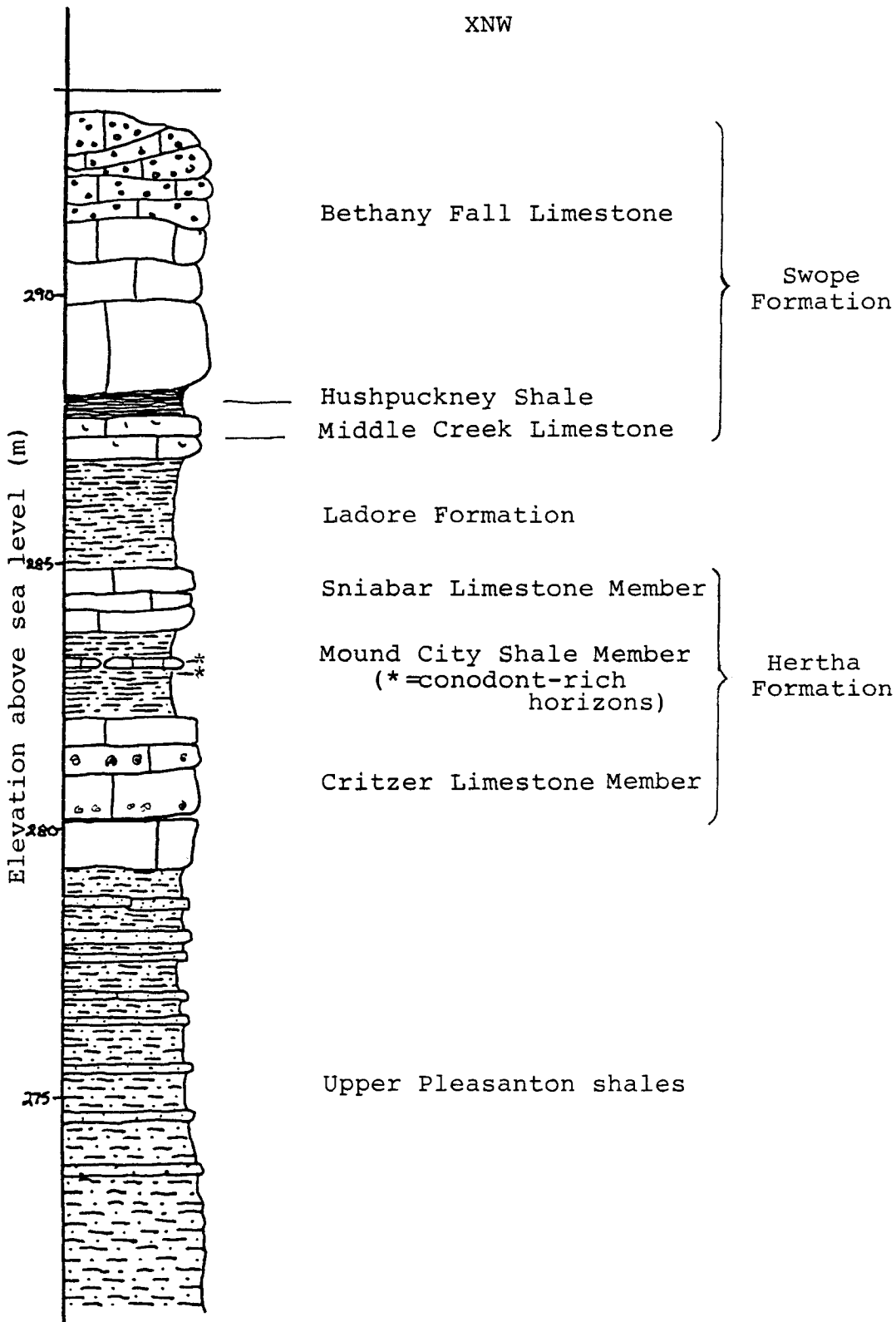
Northwest Lithofacies Zone (XNW)

A roadcut section 3 km northwest of the town of Xenia (XNW) exhibits the lithofacies typical of the northwest lithofacies zone (figure 6). The units will be described in ascending order.

About 6 meters of brown silty and sandy shales of the upper Pleasanton are exposed in the hillside northeast of the roadcut. The lower 3 meters are a brown, predominantly silty shale. The upper 3 meters exhibit distinct very-fine grained sandy horizons up to 10 cm thick, and weather like flagstones. Outside the thesis area, at a roadcut section along Kansas Hwy. 7, 1 km south of Mound City, the sandy horizon is around 6 meters thick, and the sand lenses are thicker and slightly coarser grained.

The unit above the Pleasanton is the Critzer Limestone Member, lower limestone of the Hertha Formation. The contact between the two units appears to be abrupt, yet on a somewhat irregular surface. The Critzer is a 2.8-meter-thick, earthy brown, skeletal calcilutite, medium bedded with several calcarenitic horizons. The lower 0.7 meters is a massive earthy calcilutite, with no distinct fossils. Above this lies interbedded skeletal calcarenites and skeletal calcilutites, with minor shale partings. Several distinct horizons containing large bellerophontid gastropods can be found in the upper two-thirds of the unit.

Figure 6. Locality XNW: Representative of northwestern lithofacies zone. SE 1/4, SE 1/4, section 20, T. 23 S, R. 22 E, Bourbon County, Kansas. Roadcut along east-west county road approximately 3 km northwest of Xenia.



Lying above the Critzer is the 2-meter-thick Mound City Shale Member, medial shale of the Hertha Formation. The Mound City is a grey-brown silty shale with a single 10 cm thick nodular crinoidal calcarenite, which contains abundant conodonts. This crinoidal limestone horizon is diagnostic of the Mound City throughout central Linn County, and was used by J. M. Jewett when mapping the local geology (Stratigraphic sections on file with Kansas Geological Survey). It was also discovered (by Heckel, pers. commun., 1984) that the grey shale horizon immediately below the crinoidal limestone at XNW contained conodonts in greater abundance than the crinoidal limestone.

Above the Mound City Shale lies the 1.5-meter-thick Sniabar Limestone Member, upper limestone of the Hertha Formation. The Sniabar is a tan, massive skeletal calcilutite grading upward to a medium-bedded skeletal calcarenite. Throughout the thesis area, the Sniabar does not change appreciably, although, it is noted to change into an algal facies farther to the south (Heckel, pers. comm., 1984).

Above the Sniabar lies the Ladore and the Swope Formations. The Ladore at XNW is a 2-meter-thick grey silty shale. The Swope, above the Ladore, is considered to be a classic Kansas cyclothem with three members: Middle Creek Limestone, lower limestone member; Hushpuckney Shale,

middle shale member; and Bethany Falls Limestone, upper limestone member. The Middle Creek Limestone is a distinctive dense, grey skeletal algal calcilutite, approximately 1.7 meters thick. The Hushpuckney Shale is a fissile black phosphatic shale, approximately 0.5 meter thick. The Bethany Falls Limestone is a 6-meter-thick limestone which grades from a massive skeletal calcilutite, in the lower part of the unit, to a wavy-bedded oolitic calcarenite, in the upper part of the unit.

Bourbon Flags Lithofacies  
Zone (HID, MNW)

The section best representing the lithofacies of the Bourbon flags outcrop belt can be seen at a spillway excavation overlooking the lake outlet for Hidden Valley Resort (HID), 6 km northeast of Xenia and 6 km directly east of XNW (figures 7, 8, and 9). Approximately 20 meters of section are exposed along the spillway excavation, with an additional 10-12 meters poorly exposed on the hilltop east of the spillway. The lower 8 meters of the section is the grey, silty, micaceous shale of the upper Pleasanton. Two meters up in the unit, a 10-cm-thick conodont-rich horizon was discovered, which contained mostly Adetognathus.

Above this shale unit lie around 10.5 meters of alternating limestones and shales, known as the Bourbon flags. The interbedded shales of the Bourbon flags are

Figure 7. Locality HID: Representative of Bourbon flags lithofacies zone. SW 1/4, SE 1/4, section 23, T. 23 S, R. 22 E, Bourbon County, Kansas. Spillway excavation of private lake development known as Hidden Valley Resort. Shows complete exposure of Bourbon flags (10.5 meters thick) and Critzer Limestone ( 2.8 m) forming top of excavation cut. Mound City and Sniabar are poorly exposed on hillside just east of the spillway cut.

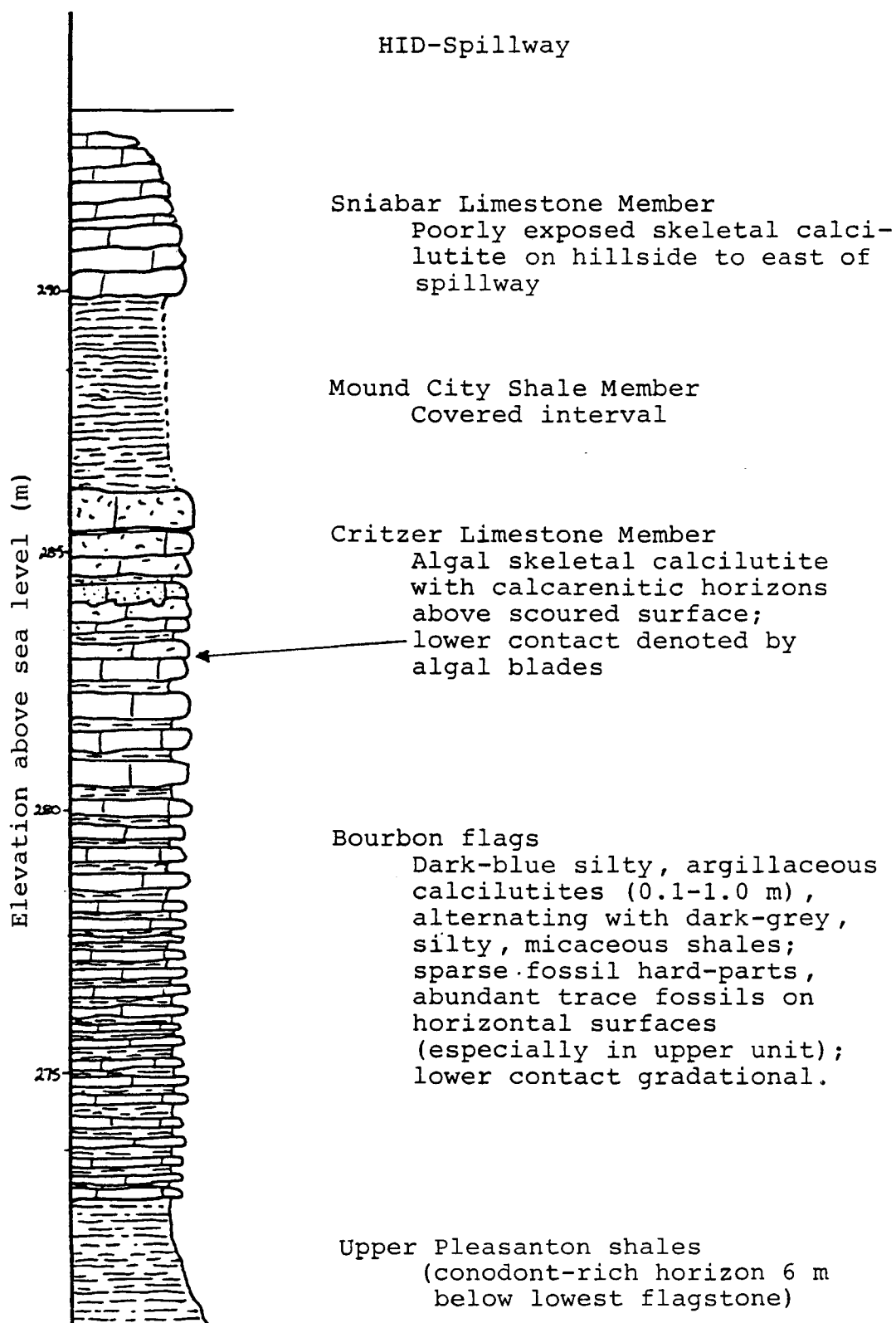




Figure 8. Outcrop photograph of the Bourbon flags at HID roadcut. Exhibits upper 7 meters of Bourbon flags with overlying Critzer Limestone (arrow).



Figure 9. Close-up photograph of Bourbon flags outcrop at HID roadcut. Shows alternating layers of shales and limestones, average  $1/4$  to  $1/3$  m thick.

virtually indistinguishable from the shales of the Pleasanton. They are grey, silty and micaceous, and often contain finely disseminated coaly fragments, generally less than 5 mm in length. The limestones are dark-grey or bluish, sublithographic calcilutites or lime mudstones. There are around 30 shale/limestone alternations, in which the shales range in thickness from 8 to 70 centimeters, and the limestones range from 10 to 100 centimeters thick. Within the Bourbon flags, the limestones become more dominant upward as the shales become less prominent and thinner, especially in the upper few meters. In all directions from the HID section, the lithic alternations in the Bourbon flags are reduced in both thickness and number. Contrary to the westerly regional dip, established to be around 2-4 m/km (Miller 1966, 1969) in most Pennsylvanian units in this part of Kansas, the Bourbon flags can be seen in the east-west roadcut near HID to be dipping anomalously to the east at around 10-12 m/km.

An unusual aspect of this unit is the dearth of fossilized skeletal remains. A few scattered fossil grains can be found, including small brachiopods (less than 2 cm in length), crinoidal fragments (up to 5 mm), and molluscan shell fragments (up to 5 mm). There is, however, an abundance of ichnofossils occurring along the surface of horizontal bedding planes. In general, the bioturbation

consists mostly of worm burrows and can be seen to increase upward. A few small peloidal structures were found in specimens of float. A single well preserved plant fossil, a drachis from a seed fern (J. T. Schabillion, pers. commun., 1984), was found in one of the pieces of limestone float.

The upper few flagstones layers begin to exhibit conspicuous fossil grains, mostly brachiopod shells and echinoderm plates. The first appearance of phylloid algal blades was used as criterion for distinguishing the base of the Critzer Limestone. The lower Critzer Limestone is a 0.7 meter medium bedded, brown-grey skeletal calcarenite, containing grains from echinoderms, molluscs, brachiopods, and red algae. Syringoporid corals are also found, apparently in growth position. The upper surface of the calcarenite is extremely burrowed and/or scoured. Above the scoured interval lies a 0.7-meter-thick interbedded algal-skeletal calcarenite and algal-skeletal calcilutite. The calcarenites are grey, dense and weather to a rusty color. They are composed of medium to very-coarse grained abraded shell fragments of echinoderms, brachiopods, molluscs, bryozoans, and phylloid algae (termed marklets in the old descriptive literature). The calcilutites are mostly carbonate muds with floating fine-to-medium grained skeletal fragments, and conspicuous relict red-algal structures in the blades. The top of the Critzer, forming

the top of the spillway excavation, is a 1.2-meter interval of abundantly algal calcilutite. The algal blades weather to relief from the background muds.

Above the top of the Critzer is a 4-meter-covered interval, apparently shale, and originally considered Ladore by Ravn (1981). Above this, however, lies a 2-meter-thick poorly exposed brown skeletal calcilutite, which turns out to be the Sniabar, because a dense algal calcilutite, the Middle Creek Member of the Swope, was found around 4 meters above yet another covered interval, which turns out to be the Ladore. Thus the 4-meter-covered interval immediately above the Critzer is the Mound City Shale. Efforts to uncover the conodont-rich horizon of the slumped and overgrown Mound City, however, were fruitless.

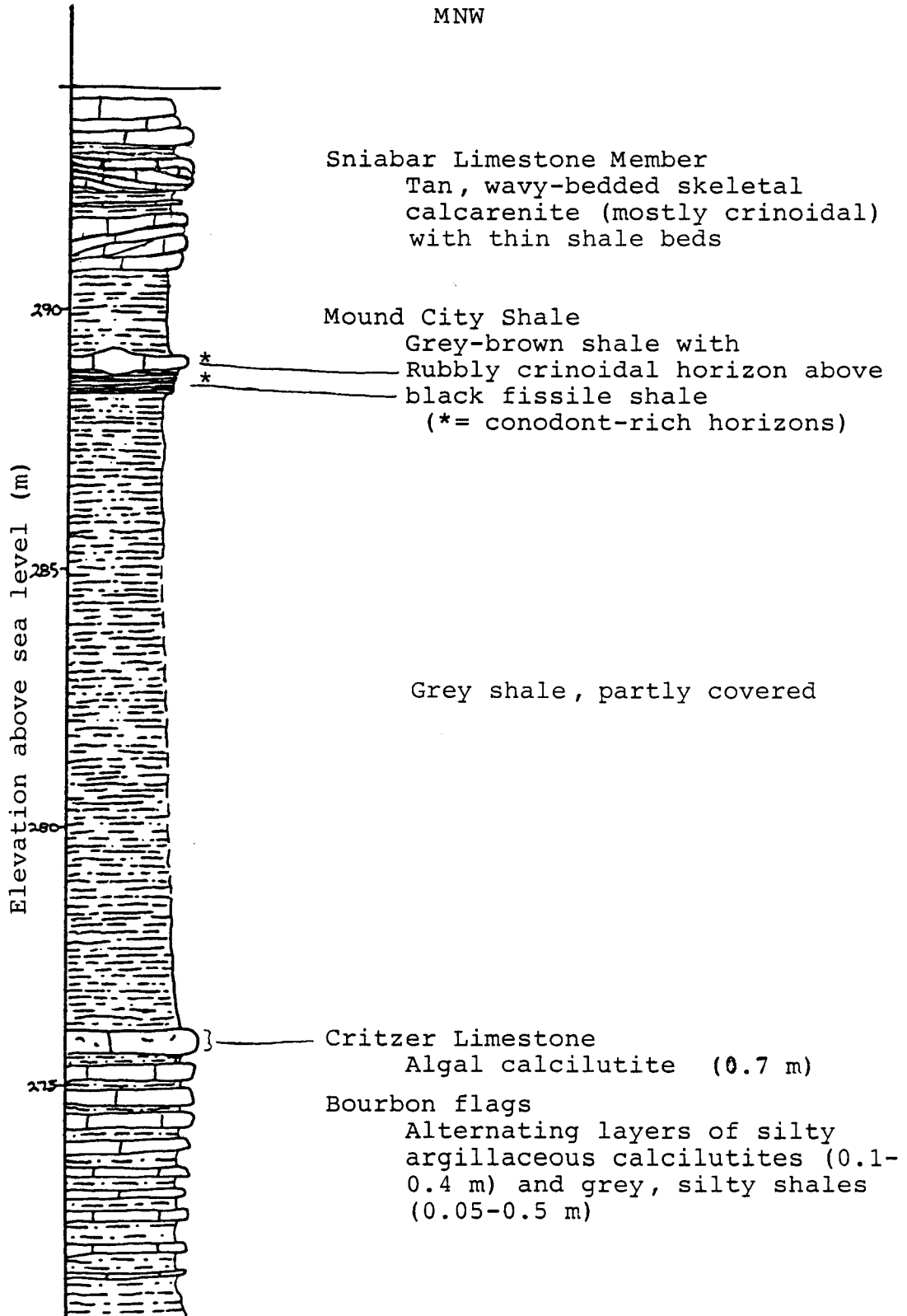
Confirmation of the stratigraphic interpretations at the HID section came from the discovery of a section approximately 5 km east of HID and 3.5 km northwest of Mapleton (figure 10). This section shows the complete exposure of the Bourbon flags and algal Critzer facies, approximately 3 meters and 1 meter thick, respectively. Above the Critzer is 15 meters of fairly well exposed grey shale, capped by 2.5 meters of tan wavy-bedded skeletal calcarenite. About 11 meters up into the shale is a black-fissile shale, 30 cm thick, overlain by a rubbly crinoidal calcarenite, from 30-40 cm thick, both of which

contain abundant conodonts. The conodonts from these two thin units represent the same fauna as found in the grey shale and crinoidal limestone in the 2-meter-thick Mound City Shale at XNW, 11 km to the west (Heckel, pers. commun., 1984). Thus the 15-meter-shale at MNW is the dramatically thickened Mound City Shale, with a thin black fissile facies. The 2.5-meter wavy-bedded limestone at the top, then, is the Sniabar Limestone.

It should be mentioned that previous studies (e.g., Ravn, 1981) had correlated the entire Hertha to the 2.5 meters of algal dominated limestone above the Bourbon flags at HID. According to Ravn (1981), the Critzer included only the calcarenite above the scoured and burrowed surface approximately 2 meters below the top of the HID spillway cut, the Mound City Shale was missing, and the Sniabar comprised the upper algal facies now known to be the upper Critzer. Apparently, the Sniabar, back up on the hillside, has been generally overlooked, leading to miscorrelations throughout the area.

Due to the uncommonly good exposure and development of the Bourbon flags at the HID spillway, it is recommended that this section be considered informally as the type section for the Bourbon flags. No previous mention of a type section for the unit is known.

Figure 10. Locality MNW. NW 1/4, NW 1/4, section 29, T. 23 S, R. 23 E, Bourbon County, Kansas. Long roadcut along east-west county road 3 km northwest of Mapleton. Bourbon flags poorly exposed in driveway of abandoned farmhouse on south side of road, but well exposed across road in stream embankment (SW 1/4, SW 1/4, section 20). Mound City Shale and Sniabar Limestone best seen 0.3 km west of abandoned farmhouse.

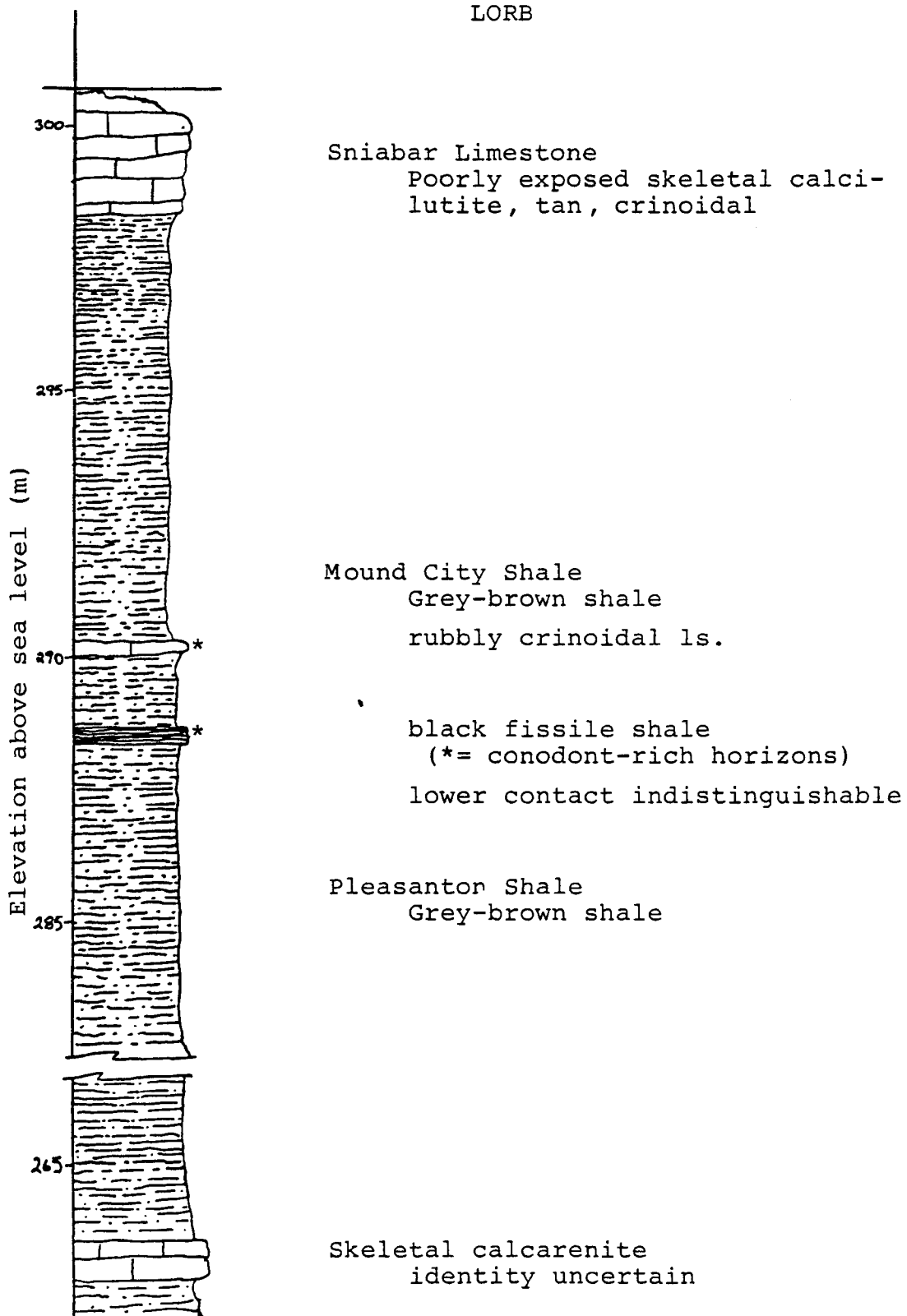


Southeastern Lithofacies Zone (LORB)

A section (LORB) located on a west-facing hill 1.5 km south of the Little Osage River bridge, 6 km southwest of Mapleton, best represents the stratigraphy of the southeastern lithofacies zone (figure 11). At this location, there is in excess of 20 meters of exposed shales below the poorly exposed Sniabar Limestone, which acts as a caprock. The Sniabar is a 2-meter-thick brown, skeletal calcilutite. Approximately 7 meters below the Sniabar lies a 15 cm thick rubbly crinoidal limestone, which is about 1 meter above a 25 cm black fissile shale. Both the rubbly limestone and the black shale carry an abundant conodont fauna (confirmed by Heckel, 1984), which is similar to that found in the corresponding beds in the thickened Mound City Shale at MNW, 4 km to the north. On the eastern flank of the same hill, approximately 28 meters stratigraphically below the black fissile shale (with allowance for regional dip), is a 0.6 meter skeletal oolitic calcarenite. This thin limestone is still under investigation, but it does not resemble the Critzer or the Bourbon flags at MNW, and so it must be stratigraphically lower, possibly the Lenapah (P. H. Heckel and H. Greenberg, pers. commun., 1984). It is believed, therefore, that this section illustrates that both the Bourbon flags and the Critzer are missing, and the Mound City Shale, therefore, must lie indistinguishably on top of the Pleasanton.

Figure 11. Locality LORB: Representative of southeastern lithofacies zone. Center of NW 1/4, section 8, T. 24 S, R. 23 E, Bourbon County, Kansas. Outcrop along north side of roadcut and associated gulley, 6 km southwest of Mapleton and 1 km southeast of the Little Osage River bridge. Black fissile facies forms top of knoll to west as well as crops out in brush-covered part of gulley approximately 8 m below Sniabar.

## LORB



### Stratigraphic Interpretations

Stratigraphic correlations are illustrated using two cross-section lines across the thesis area (figure 12). Cross-section X-X' (figure 13) shows the trend of the stratigraphy going from west to east; while cross-section X-Z (figure 14) illustrates the stratigraphy heading south then east, showing the progression from the northwest facies zone, across the Bourbon flags facies zone, to the southeastern facies zone, going from left to right on the cross-section.

The Pleasanton changes from a tan sandy silty shale in the northwestern facies zone, to a darker grey silty shale, in the southeastern facies zone. Over the Bourbon flags belt, or middle zone, the Bourbon flags unit thickens then pinches out abruptly (figure 15). As this unit thins, the number of shale/limestone alternations is reduced, while the individual horizons tend to be thinner. The Critzer changes from an earthy, punky skeletal calcarenite to calcilutite, in the northwestern facies zone, to a dark, dense, algal calcilutite with one calcarenitic horizon in the Bourbon flags belt. The Critzer appears to be missing, along with the Bourbon flags, in the southeastern facies zone. The Mound City Shale exhibits dramatic thickening over the Bourbon flags belt (figure 16), and is indistinguishable from the Pleasanton in the southeastern facies zone (at

LORB). The Mound City also develops the distinctive black shale horizon over the Bourbon flags belt, which continues into the southeastern facies zone, from which it has been traced throughout Bourbon County (Heckel, 1984). The Sniabar shows changes from earthy calcarenite in the northwest zone, to a bedded calcarenite in the southeast zone.

Cross-section X-X' shows the same trends as cross-section X-Z, except that the Bourbon flags and the Critzer are still present at the eastern edge of the cross-section, which is still in the Bourbon flags facies zone, though presumably approaching the southeast lithofacies zone, as the unit has thinned to around 3 meters from 10.5 meters at HID.

Figure 12. Location of lines of cross-section superimposed over facies zones.

# CROSS-SECTION LOCATIONS

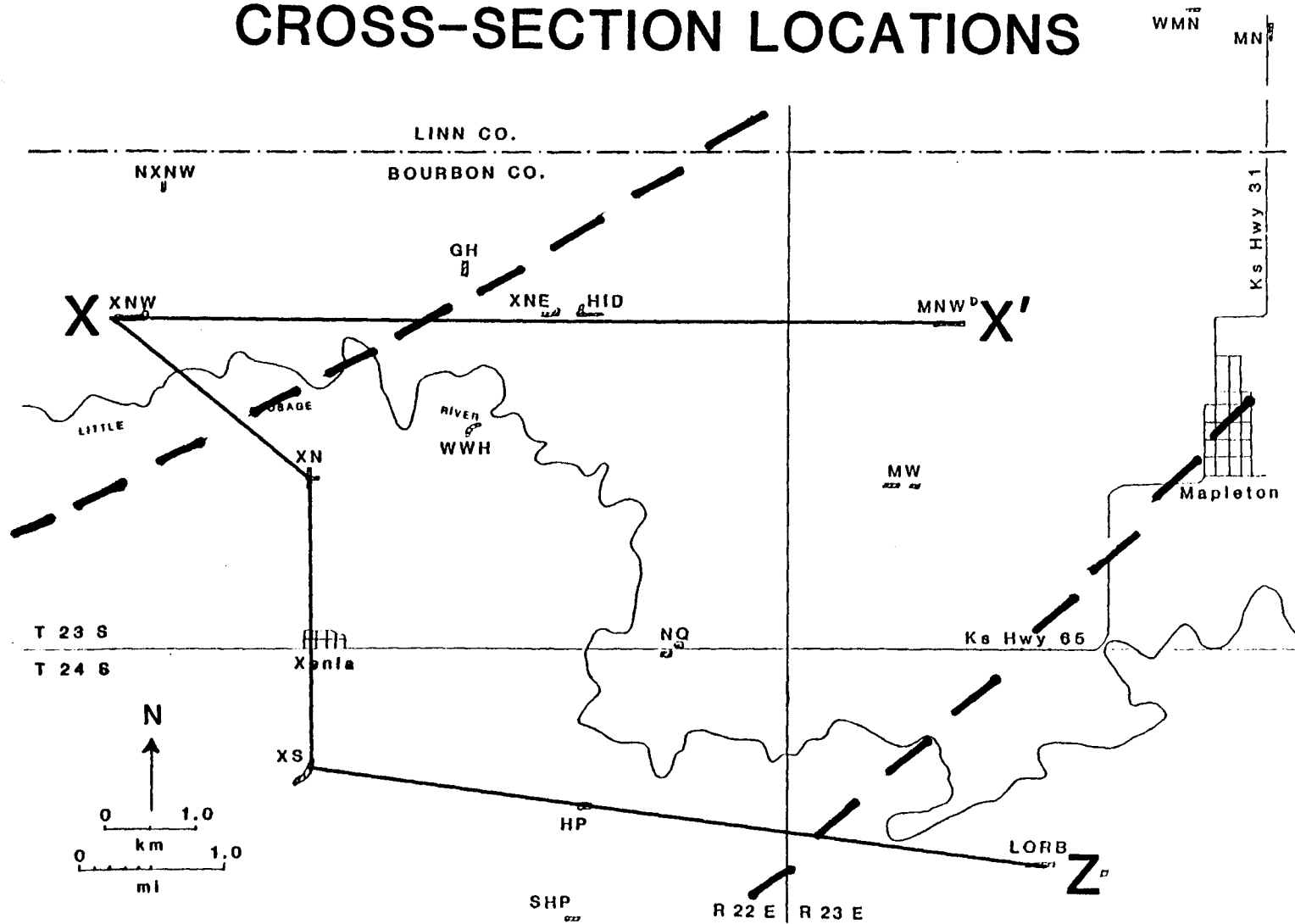


Figure 13. Cross-section X-X'. Shows traverse from northwestern lithofacies zone to Bourbon flags lithofacies zone, using Mound City/Sniabar contact as datum. Bourbon flags are seen to thicken and begin to pinch out. Critzer develops algal facies over Bourbon flags locations, while Mound City Shale thickens and develops black fissile facies toward the east.

# CROSS-SECTION X-X'

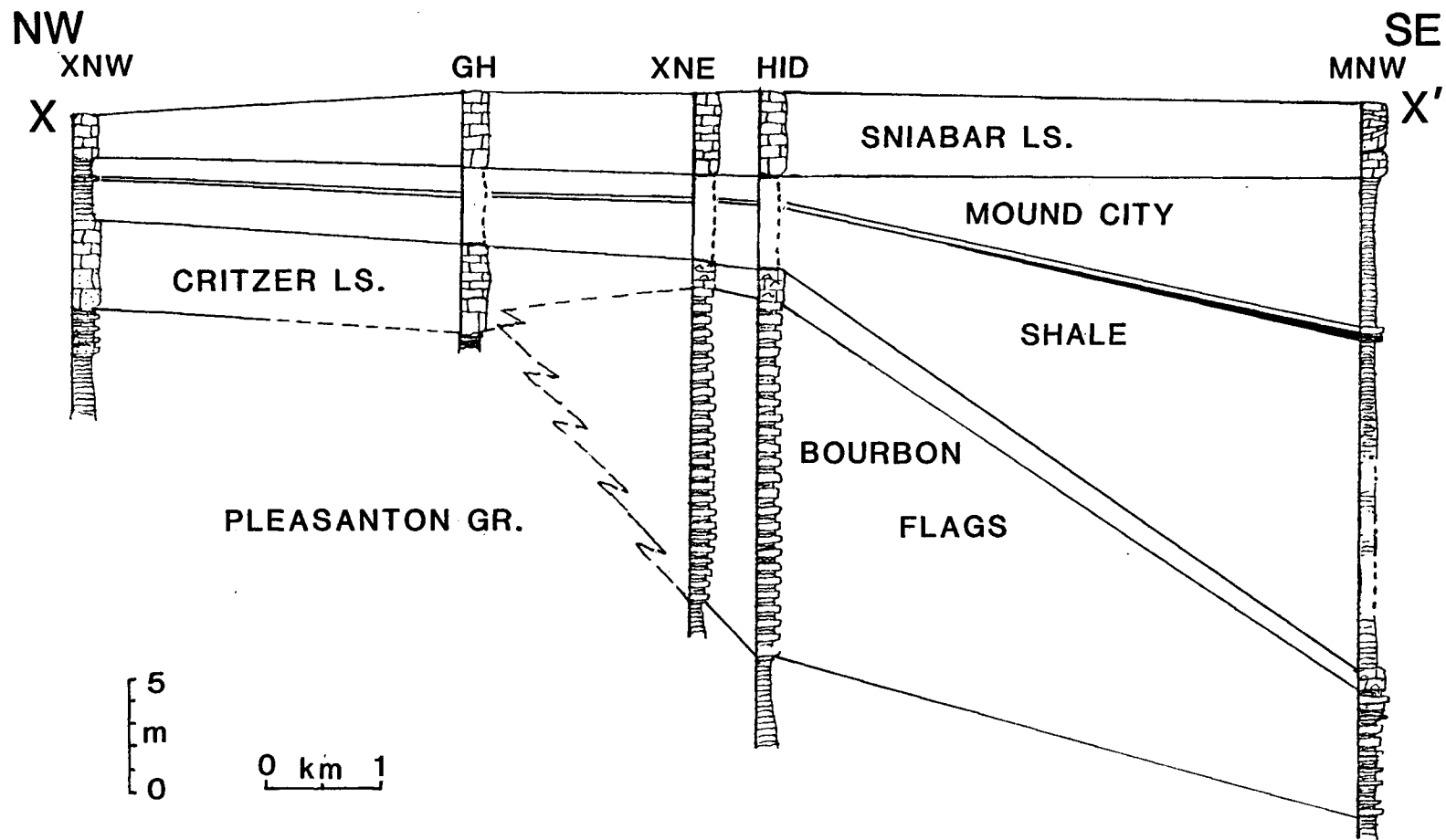


Figure 14. Cross-section X-Z. Shows traverse from west to east through Bourbon flags lithofacies zone into the southeast lithofacies zone, where Bourbon flags and Critzer units pinch out, and Mound City lies indistinguishably over the Pleasanton.

# CROSS-SECTION X-Z

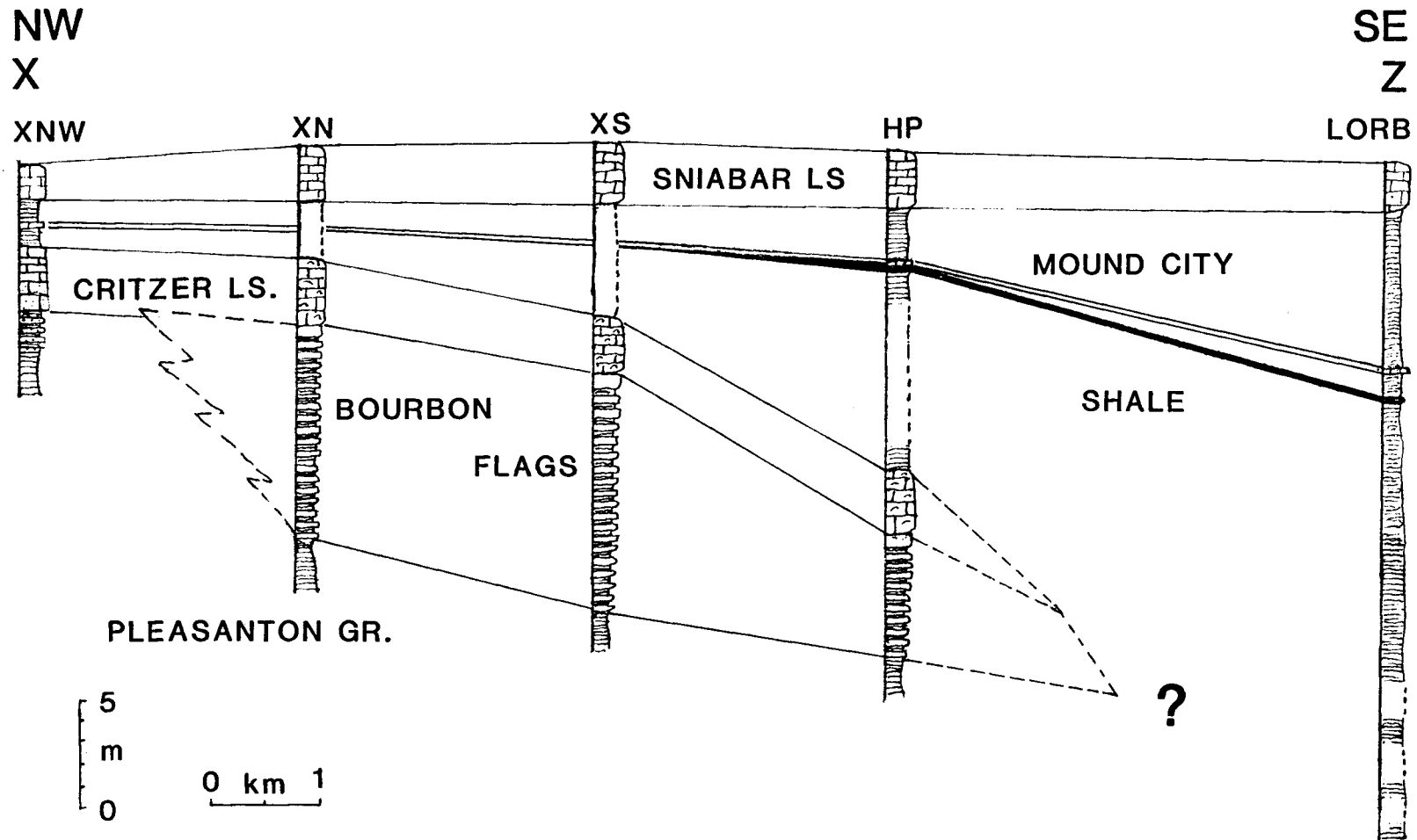


Figure 15. Isopach map of Bourbon flags. Illustrates abrupt thickening and thinning, with axis of thickening running northeast-southwest.



Figure 16. Isopach map of Mound City Shale. Illustrates dramatic thickening of unit toward the southeast. North and northwest of the thesis area, the Mound City is generally around 2 meters thick.



## PETROGRAPHY

Introduction

Samples for petrographic analysis were collected with an emphasis on the XNW and HID sections as representative sections of the northwestern and Bourbon flags lithofacies zones, respectively. All samples were collected at approximately 40 cm intervals and across lithologic breaks. The samples were cut and polished; some were thin-sectioned and stained. Additionally, representative limestone samples and supplementary shaley and sandy samples were placed in 1:5 formic acid solution for insoluble residue analysis. (The data table for insoluble residue analysis can be found in the appendix section). Samples from other stratigraphic sections were collected and treated in similar manner. The information from these supplemental collections were found to support the information found in detailed analysis of the XNW and HID sections; therefore, only the XNW and HID sections will be discussed.

Field terms used in this text are after Grabau (1913). Petrographic terms are after Dunham (1962), where more precise classification is possible.

Petrography of the  
Northwest Lithofacies Zone

The XNW section was used as the representative for the northwest lithofacies zone because of its complete exposure of the Upper Pleasanton sandy shale sequence and the overlying Critzer Limestone.

Insoluble residue analysis of a sample of an upper Pleasanton "sandy" (flaggy) bed reveals 69.2 weight percent insolubles, with no detrital grains greater than 63 microns in size. Thin-section study shows the 10-20 cm thick sandy lenses in the upper Pleasanton to be a homogeneous mixture of fine silt and very fine sand-sized carbonate crystals in a matrix of clay and carbonate mud. There is an abrupt field contact between the Pleasanton shales and the massive ledge of the lower Critzer.

The Critzer can be divided into two major petrographic facies. The lower facies ranges upward to 0.7 meters from the base and is dominated by argillaceous lime mud. The upper petrographic facies consists of the upper 2 meters of Critzer Limestone, and is dominated by carbonate grains and lime mud.

The lower petrographic facies is an argillaceous lime mudstone. Thin-sections reveal a homogeneous mixture of iron-oxide-rich clays and carbonate muds, with floating silt-sized grains of quartz. The base of the facies contains more than 77 weight percent insoluble material

(mostly clays), which is greater than that of the underlying Pleasanton "sandy" lenses, while near the 0.6 meter mark, there is only 23.7 weight percent insoluble material. The visible carbonate crystals from thin-section analysis appear to be mostly ferroan calcite.

The upper petrographic facies has interbedded skeletal wackestones and skeletal packstones (figure 17). Carbonate grains are abundant, mostly rounded very-fine to medium sized fragments. Several distinctive horizons containing large (up to 4 cm) bellerophontid gastropods may be found. Other grain types include echinoderms, brachiopods, gastropods, pelecypods, and ostracodes. The wackestones (figure 18) have grains floating in a matrix of clayey and micritic muds. The muds are high in iron-oxides, and the carbonates appear to be mostly composed of ferroan calcite. Voids in fossils and a few interstitial spaces are filled by large blocky calcite crystals.

The packstone horizons display grain-to-grain contact as well as interstitial muds. Intragranular and available intergranular voids are filled with large blocky ferroan calcite crystals, which exhibit increasing crystal size toward the centers of voids. For both wackestone and packstone horizons, original unstable grains such as gastropods and molluscs are often dissolved and filled with large crystals of blocky calcite. Gastropod shells often show translocation of internal shell molds prior to final



Figure 17. Thin section photomicrograph of skeletal packstone in upper Critzer at XNW. Shows rounded grains in local area of sparry void-filling cement. Plane polarized light. Scale bar is 0.1 mm.

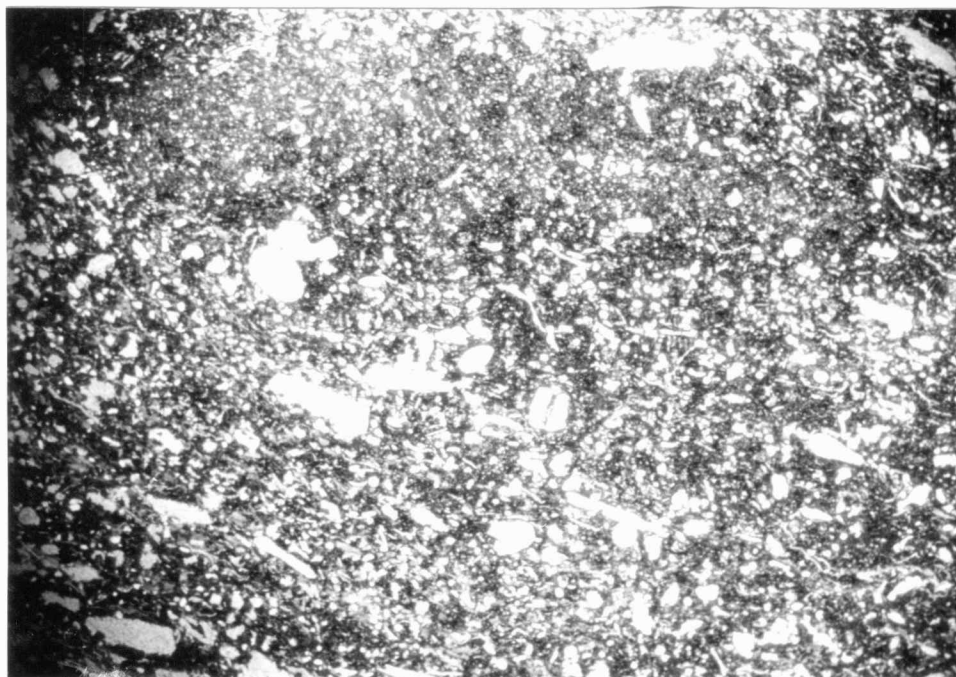


Figure 18. Thin section photomicrograph of interbedded skeletal wackestone in Critzer at XNW. Darkness of mud due to opaque limonitic muds. Plane polarized light. Scale bar is 0.1 mm.



Figure 19. Thin section photomicrograph of skeletal wackestone in upper Critzer at XNW. Shows gastropod with dropped internal mold over geopetal muds indicating that shell material was leached after early induration of matrix and later filled with drusy calcite. Suggests dissolution by exposure to undersaturated meteoric waters prior to void-filling. Plane polarized light. Scale bar is 0.1 mm.

void-filling (figure 19). There are also overgrowths on echinoderm plates. Upward in the unit, nonferroan calcite void-filling can be seen. In general, insoluble residues decrease upward in this upper unit from 20% near the base to 8.7% near the top.

Petrographic Interpretations for  
the Northwest Lithofacies Zone

Petrographic similarities of the upper Pleasanton "sandy" beds and the basal Critzer "limestone" indicate that the Pleasanton/Critzer contact, which seems sharp in the field, is actually transitional. The main changes seen are a loss of shale beds and a general decrease in sediment size, from the "sandy" beds to the basal limestone bed. This could have occurred as the result of a decrease in wave or water energy, or as a result of a shift in sediment supply. The somewhat limited fauna suggests restricted marine conditions, during formation of the sediment. (Both of these issues will be discussed further in the Depositional Environments section).

Translocated gastropod shells suggest that the unit underwent some early induration then was exposed to unsaturated waters prior to complete lithification. Partial dissolution of the original shell led to collapse of the internal mold into the void. Later precipitation of sparry calcite into the void preserved the mold and left relict

shell structure (figure 21). This suggests that this unit was exposed to unsaturated meteoric waters for partial dissolution of the original shell material, followed by exposure to saturated meteoric waters during final void-filling. This is a common diagenetic sequence occurring during late regression (Heckel, 1983). The prevalence of ferroan calcite suggests a possible influence from the ubiquitous iron-rich clays in the Critzer in a low oxygen environment.

#### Petrography of the Bourbon Flags Lithofacies Zone

The section at HID, with the best representation of the Bourbon flags and Critzer units in the Bourbon flags lithofacies zone, displays three petrographic facies: 1) the lower unit is a thick argillaceous lime mudstone, which includes the Bourbon flags and the lower 0.6 meter of the Critzer, up to the scoured surface; 2) the middle lithofacies is about 1.2 meters thick of interbedded skeletal and algal packstones and wackestones; 3) the upper petrographic unit is an algal wackestone 0.7 meters thick.

The lower petrographic unit is distinguished by repetitive intervals of monotonous argillaceous mudstones of the Bourbon flags and lower Critzer. Thin-sections reveal a uniform groundmass of clayey and silty carbonate muds. The carbonate appears to be ferroan calcite, mostly micritic and

silt-sized grains. Occasional fossil grains include echinoderm plates, brachiopod shell fragments and ostracode shells. A well preserved plant fossil was uncovered in one limestone interval (figure 20). There are also considerable numbers of trace fossils on the top of bedding surfaces (figures 21 and 22), which increase upward in abundance in the unit. Thin-sections through some flagstones show laminations with extremely flattened burrows (figure 23). The identity of the organism that made these tracks is unknown, though it was probably a worm-like creature. Insoluble analysis of the limestone beds in this unit shows residues decreasing upward from 48% to 22%. As mentioned in the stratigraphy section, the arbitrary break between the Bourbon flags and the Critzer is based on fossil content, especially phylloid red algal blades. Petrographic analysis show this break to be somewhat subjective, as the rock composition changes very little across the boundary.

Immediately above the scoured surface at HID, the skeletal packstones are composed of medium-to-very coarse rounded and abraded skeletal grains with interstitial carbonate mud. The grains include echinoderms, brachiopods, ostracodes, red algae, gastropods, bryozoans, and molluscs. Syringoporid coral heads are found in growth position, apparently buried by the carbonate sands. The surrounding mud forms geopetal surfaces in some voids. The skeletal



Figure 20. Photograph of well preserved plant fossil in Bourbon flags at HID. According to J. T. Schabillion (pers. commun., 1984), this is a rachis of a seed fern not normally preserved in marine sediments because of rapid decomposition. It suggests rapid deposition of Bourbon flags.

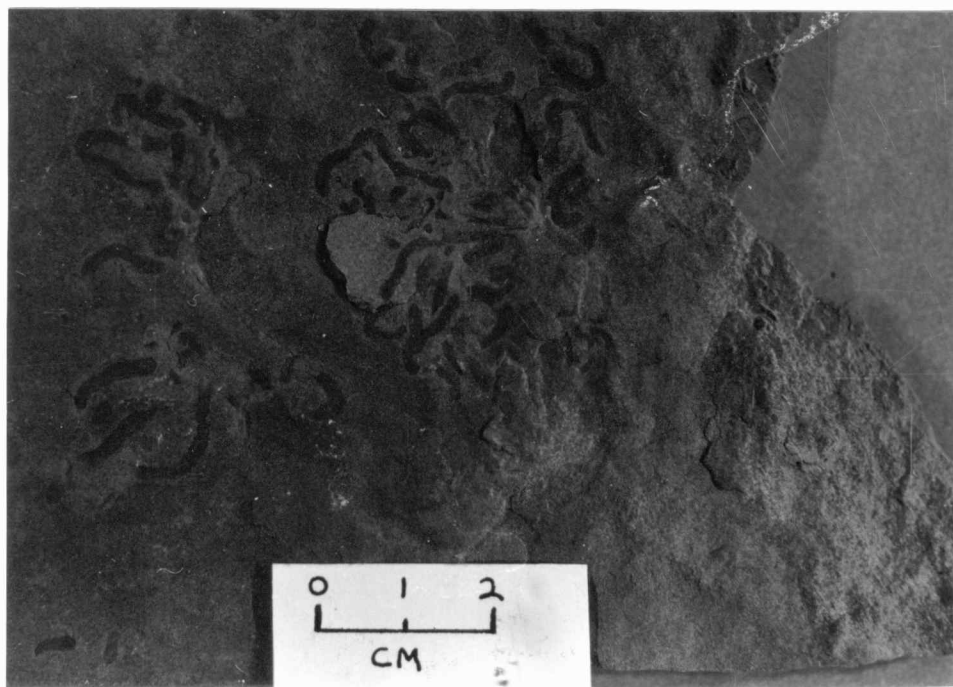


Figure 21. Photograph of worm-burrows on top of bedding surface of Bourbon flags at HID. Similar burrows occur on both shales and limestones throughout Bourbon flags unit, but are more prevalent upwards.



Figure 22. Photograph of large burrows found on top of bedding surface in Bourbon flags at HID. Note smaller burrows on either side of large burrow.



Figure 23. Photonegative print of bioturbated limestone in upper Bourbon flags at HID. Lighter colored disk-shaped blebs in upper part are cross-sections of worm burrows. Their flattened shape suggests compaction before lithification. Scale bar is 1.0 mm.

wackestones of the middle petrographic unit differ mainly in having fewer fossil grains, which are also not as well rounded, and having considerably more carbonate mud (figure 24).

The upper petrographic unit is an algal wackestone, dominated by both red and dasyclad green algae in a carbonate mud matrix (figure 25). Scattered invertebrate grains include the following groups: echinoderms, brachiopods, molluscs, ostracodes, and bryozoans.

The upper two petrographic units of the Critzer exhibit similar diagenetic features and trends. There is considerable fracturing of algal blades and grains, and some fractures are offset and filled with micritic muds. There is neomorphism of algae, indicated by skeletal ghost structures and recrystallization across grain boundaries (figure 24). Void-filling in both grains and interstitial spaces occurs as blocky ferroan calcite spar and microspar. Other unstable grains are neomorphosed, but do not exhibit translocation of original shell material.

#### Petrographic Interpretations of the Bourbon Flags Lithofacies Zone

The lower petrographic unit, consisting of the Bourbon flags and the lower Critzer, appears to have formed in a restricted marine environment. The dearth of fossils indicates a hostile environment for the growth of

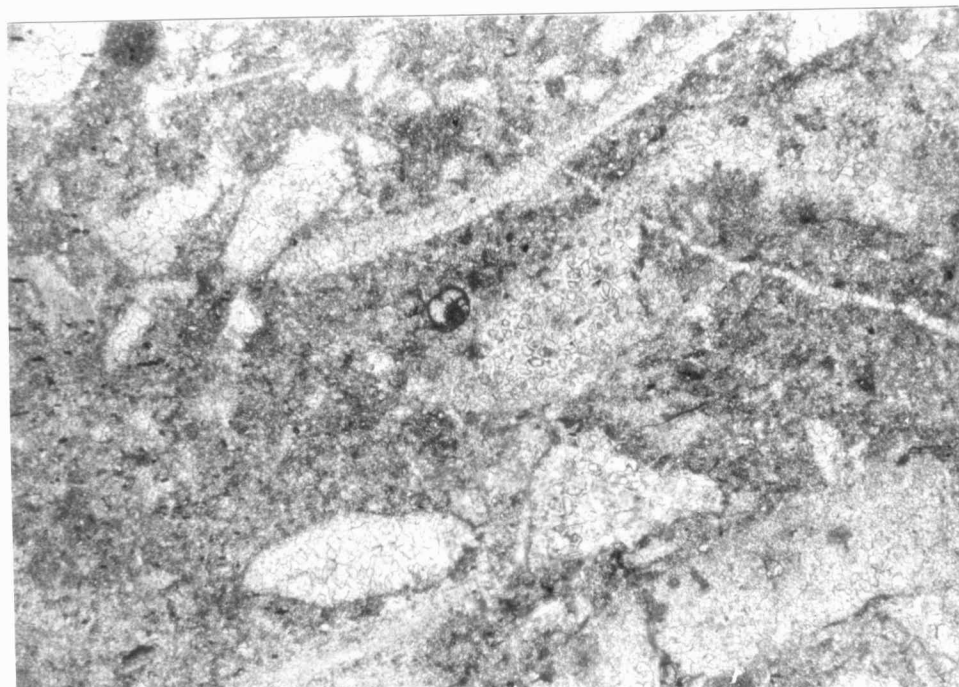


Figure 24. Thin section micrograph of skeletal wackestone showing relict neomorphosed red algal blade in middle Critzer at HID. Occurs through entire vertical extent of unit. Plane polarized light. Scale bar is 0.1 mm.

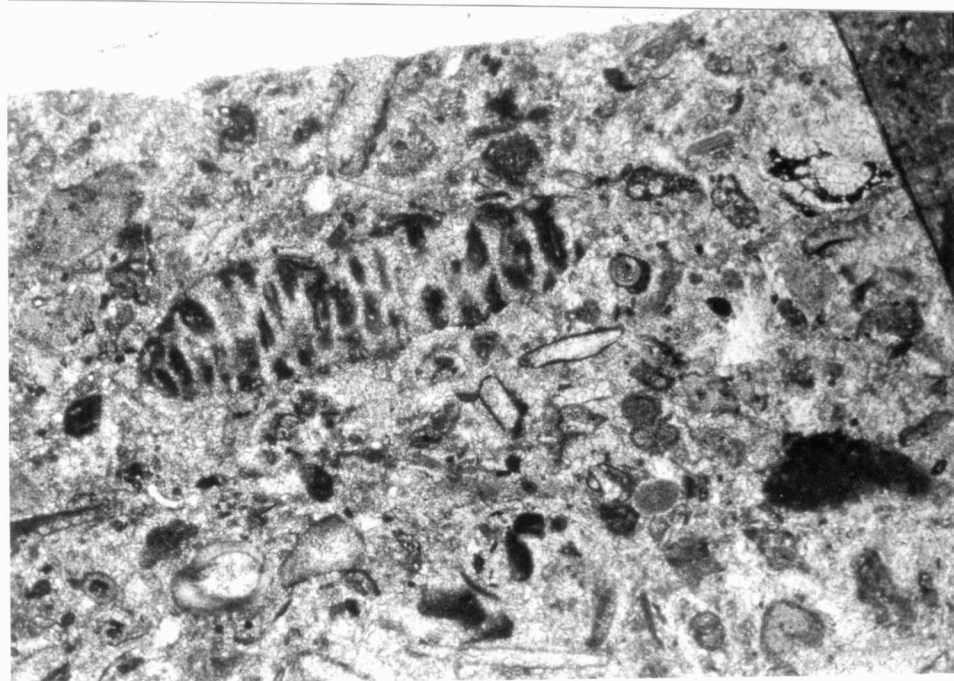


Figure 25. Thin section micrograph of dasyclad green algae in top of Critzer at HID. Occurs only in upper part of unit. Plane polarized light. Scale bar is 0.1 mm.

carbonate-producing organisms. The abundance of argillaceous material in the unit suggests a strong terrigenous detrital influence, which may have created turbid conditions causing the restriction of organic growth. Density of the rock along with flattened burrows suggests that there was considerable compaction before lithification. The thick, highly compacted sequence, with laminated structures and a well-preserved plant fossil of the type not normally preserved in a marine sequence suggests rapid deposition for the unit.

Above the scoured surface, the middle Critzer exhibits a drastic change in petrography. The unit becomes considerably more calcareous, having considerably higher fossil content, including red algae, and a very low insoluble residue content. This indicates that the sediments formed in a shallow, open marine setting, within the photic zone without appreciable terrigenous detrital influx. Rounding of grains generally occurs in waters above effective wave base, whereas carbonate muds collect in quieter, undisturbed waters. Thus, the packstones of the Critzer at HID probably formed either in a variable environment, or the sediments were transported in, as discussed further in the Depositional Environments section. The presence of dasyclad green algae in the upper Critzer also suggests a further shallowing of water, possibly due to

regression, as they are found mainly in shallowest waters today.

Diagenetic features such as fractured and offset grains suggest burial and compaction prior to complete lithification. Neomorphism without translocation of unstable grain boundaries, on the other hand, suggests that there was no exposure to undersaturated meteoric waters prior to complete lithification.

#### Petrographic Conclusions

In general, it is possible to correlate the lithologies between the XNW and HID sections. The petrography of the lower Critzer facies at XNW, which is gradational from the upper Pleasanton, is similar to the petrography of the Bourbon flags and lower Critzer at HID. Both are lime mudstones with considerable argillaceous materials and both become more calcareous upward. The main differences lie in their thickness, density, color, and diagenetic histories. In contrast, it appears that the Bourbon flags formed in an environment with higher sedimentation rates and greater compaction, and in which iron was stable in its reduced state. The upper petrographic facies of the Critzer at XNW and the middle petrographic facies at HID appear also to be very similar. Both exhibit interbedded packstones and wackestones with rounded grains, ferroan cements and

void-filling. The unit at HID, however, is denser, darker, and contains a somewhat more diverse fauna, noted especially in the presence of red algae. According to Heckel (1984, pers. commun.), red algae are the first algae to appear upward in a regressive cycle, and may reflect formation in deeper parts of the photic zone.

The upper Critzer unit at HID has no apparent correlative in the northwest lithofacies zone. It may be considered a later stage development of the middle petrographic unit. The presence of dasyclad green algae indicates a shallow-water environment of deposition.

There is a contrast in the interpretation of the diagenesis for these two sections. The section at XNW appears to have undergone early induration, then at least partial dissolution before final lithification, whereas the units at HID were strongly compacted prior to any lithification and exhibit extensive neomorphism rather than dissolution. These differences may reflect a difference in water depth during deposition. If the facies at XNW were deposited in shallower water, then it probably was exposed to undersaturated water which dissolved unstable aragonite prior to final lithification. This probably occurred in a meteoric environment that developed during the regression prior to Mound City deposition. The facies at HID, on the other hand, may have formed in deeper waters and were

exposed only to stagnant diagenetic environments, therefore undergoing neomorphism and much compaction prior to lithification. Further discussion follows in the Depositional Environments section.

## CONODONTS

Conodonts were utilized in this study mainly to support the stratigraphic interpretations. Two conodont-rich horizons were discovered at four localities within the study area and at two localities north and south of the study area. The lower horizon was found approximately 6 meters below the lowest limestone horizon in the Bourbon flags at HID, and the upper horizon was found in the black fissile shale in the thick Mound City Shale at MNW and Horse Pond (HP), in black fissile shale in the thicker sequence of shales at LORB, and also in a grey shale below the crinoidal limestone in the thin Mound City Shale at XNW.

The conodonts of the lower interval at HID were mostly the shallow-water form Adetognathus, but included some specimens of Idiognathodus more like those of the Pleasanton conodont horizons than those of the Mound City (Heckel, pers. commun., 1984).

All the grey-to-black fissile horizons in the Mound City Shale at MNW, Horse Pond, and LORB exhibited Idioprioniodus, Gondolella, and a distinctive species of Idiognathodus typical of Mound City Shale intervals in northern Linn County and northward (Heckel, pers. commun.,

1984). The associated thin rubbly crinoidal limestone layer directly above these grey and black shales yielded similar conodonts, but without Gondolella.

The distinctive Mound City fauna was found also in black shale in thick sections of Mound City Shale, both at the US 69 roadcut northwest of Prescott above the purer facies of the Bourbon flags, and at Bourbon County State Lake above the limestone erroneously thought to be the entire Hertha by Hatcher (1962) and Ravn (1981). A "Pleasanton-like" Idiognathodus-dominated fauna was found in dark shales below the Bourbon flags northwest of Prescott and at the base of the lower limestone at Bourbon County State Lake, which is a position similar to that of the Adetognathus-dominated fauna found below the Bourbon flags at HID.

## DEPOSITIONAL ENVIRONMENTS

Introduction

Consideration of the deposition of the Bourbon flags must also include that of the Critzer, as the two units appear to be intimately related, both stratigraphically and petrographically. As seen at the HID section, the appearance of red algal blades in the upper flaggy limestones suggests that the change from typical Bourbon flags to Critzer is gradational. The coincidence of algal facies of the Critzer over the Bourbon flags region also suggests their genetic relationship. Because of this close relationship, the Bourbon flags and the Critzer may be considered separate facies of the same depositional unit or cycle. It is also possible, that the Critzer of southern Linn and northern Bourbon counties, Kansas, may not be the same unit that is reported as Critzer farther to the north (Heckel, 1978, p. 25) and east (Howe, 1982) of the study area (Heckel, pers. commun., 1984). Furthermore, the relationship between the Critzer of this study, and the Sniabar may not be as close as previously interpreted by Ravn (1981) as developed in forthcoming arguments. For the sake of clarity, the terms Bourbon flags and Critzer will be

used to represent separate facies, though possibly of the same cycle.

#### Interpretation of Lithologies

Differentiation between the facies zones to the northwest and southeast of the Bourbon flags suggests the presence of a shelf regime to the northwest and a basin regime to the southeast. The Pleasanton in the northwestern facies zone exhibits coarser facies than the Pleasanton in the southeast facies zone. Overlying the Pleasanton in the northwest is a mostly calcareous Critzer, with no apparent correlative in the southeast. The Mound City Shale, then, presents the real key to this interpretation, as it can be seen to thicken dramatically toward the southeast while developing a black fissile facies, thought to be a deeper water facies than its grey equivalent at XNW (Heckel, 1977).

Figures 26 and 27 are cross-section figures showing present elevations of the units (figure 26) and relative elevations of the units corrected for regional dip (figure 27). These cross-sections illustrate the anomalous eastwardly dip of the Bourbon flags and the overlying Critzer. They strongly show the continuing presence of a small basin in the east.

Thus, the deposition of the Bourbon flags must have occurred along the transitional slope between these two

Figure 26. Cross-section X-X using absolute elevations as datum. Shows eastward dip where Critzer and Bourbon flags are together, contrary to regional westward dip. Elevation in meters above sea level.

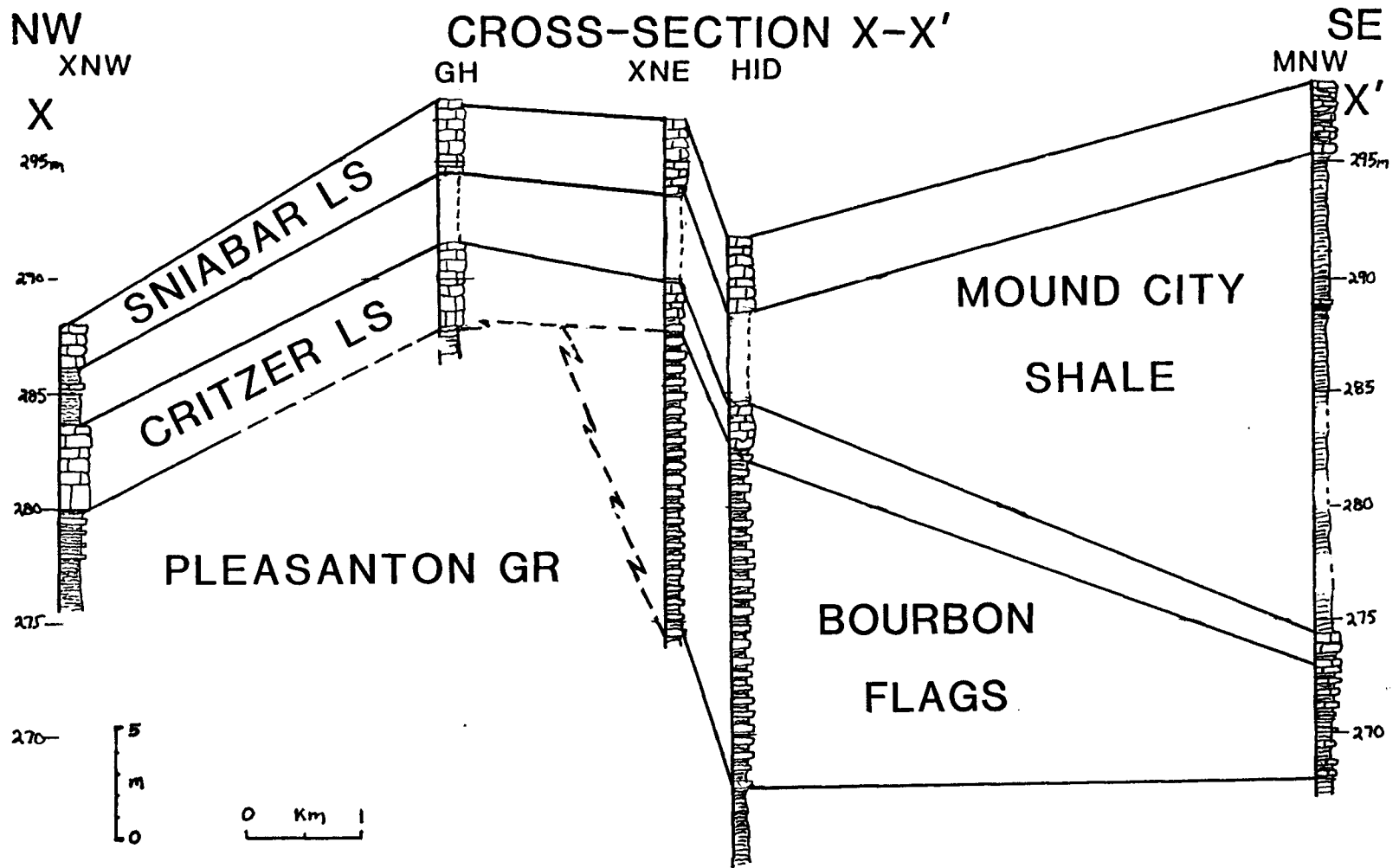
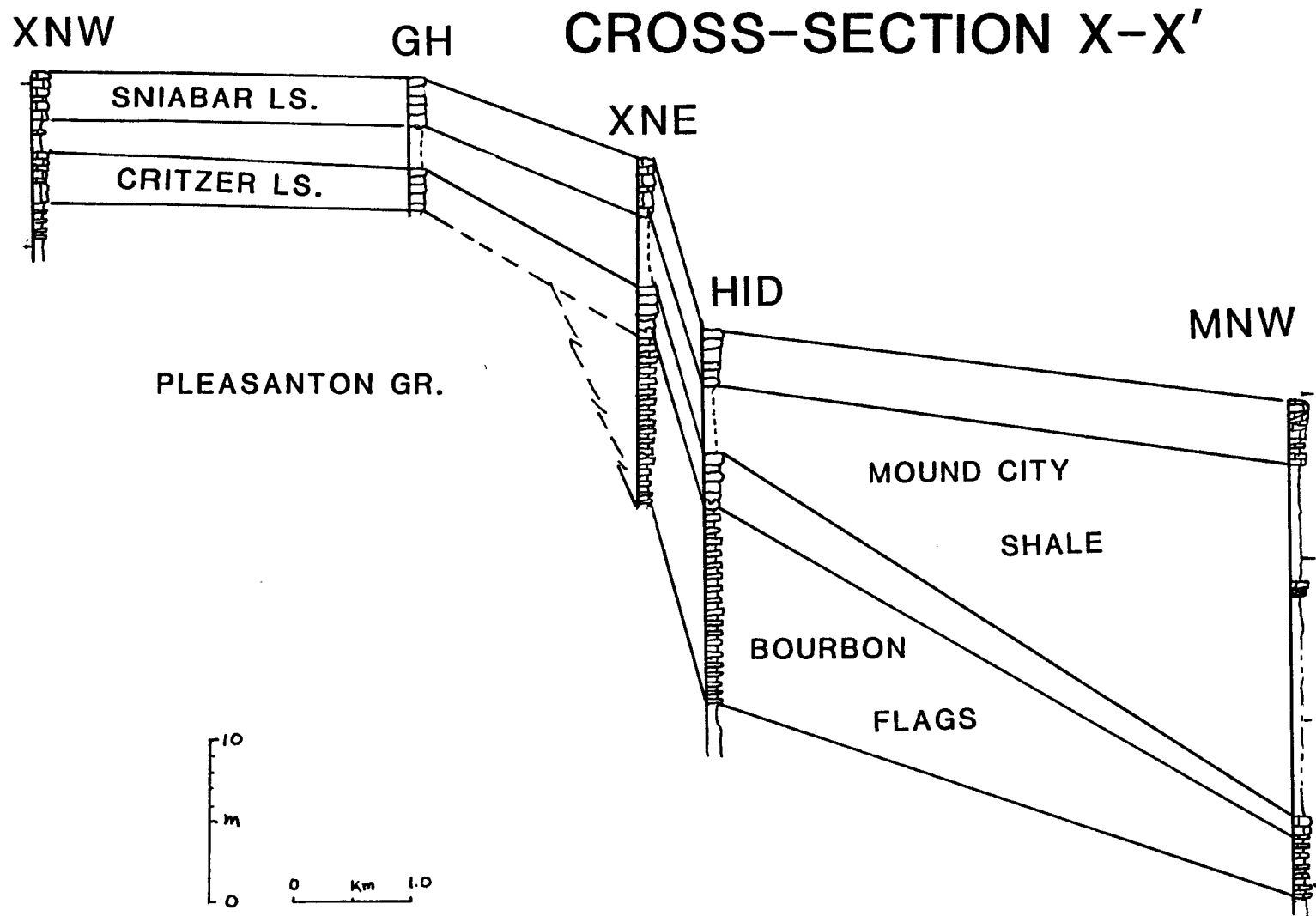


Figure 27. Cross-section X-X corrected for regional dip. Regional dip for most units in this part of eastern Kansas is westward from 2-4 m/km (Miller, 1966, 1969). Correction dip used was 3 m/km.



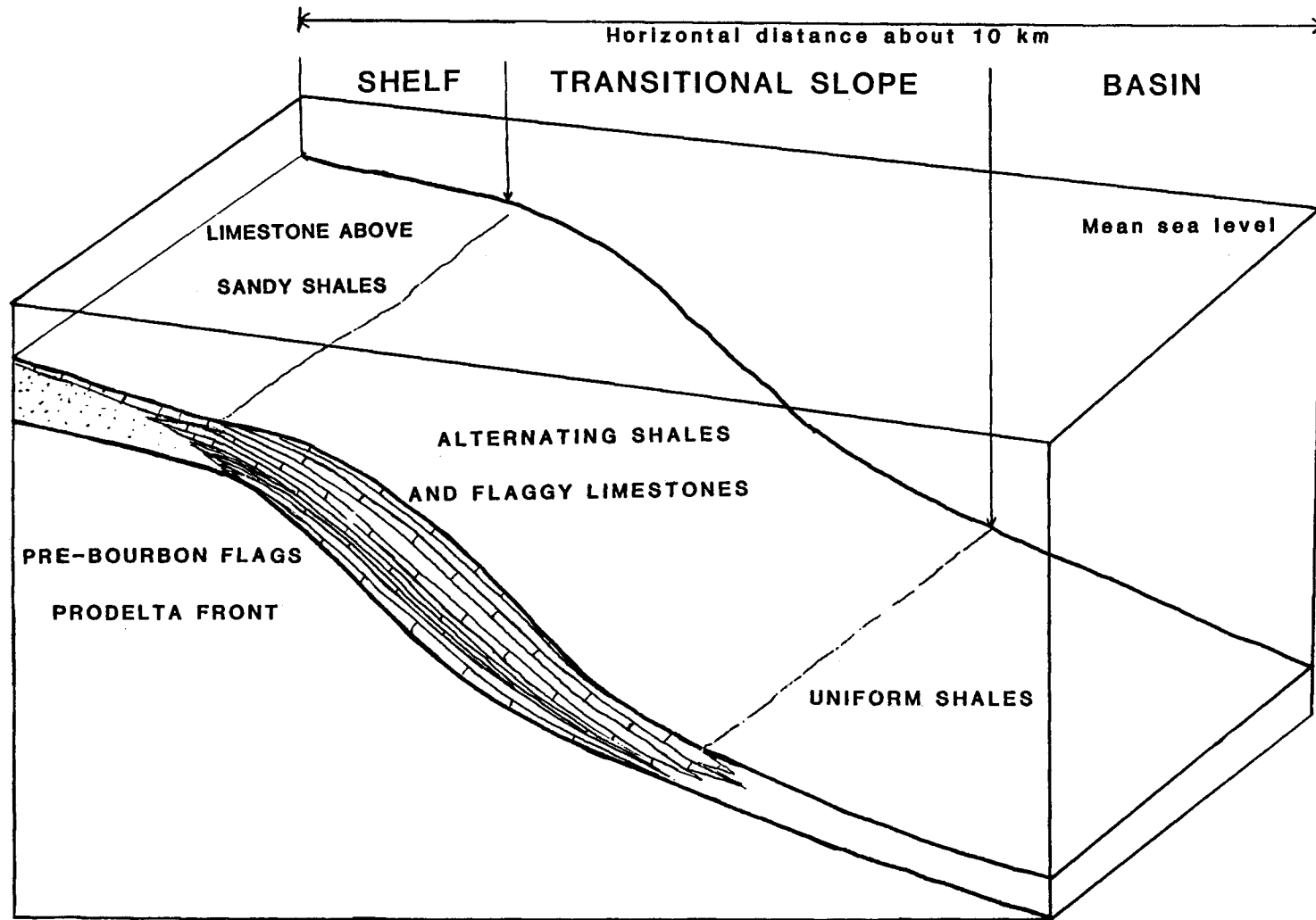
environments, and the northwest to southeast facies trends form a transect from a shallow-water shelf into a deeper water basin (figure 28). Given the narrow width of this slope (about 5 km average), it seems that the slope was great enough to create the rather drastic changes in environment that are seen in the lithofacies zonation.

#### Origin of Slope

There are several possibilities for the origin of this transitional slope: 1) aggradation of a depositional front; 2) structural upwarping or downwarping of the depositional surface; 3) differential rates of compaction on either side of the transitional slope. In any case, the bottom topography initiated during Pleasanton deposition appears to have affected sedimentation through deposition of at least the Mound City Shale.

Evidence for a depositional origin of the slope may be found in analysis of Pleasanton rocks. The Pleasanton is considered a deltaic sequence with proximal nonmarine sandy facies in northwestern Missouri (Howe, 1982), and distal finer-grained marine facies toward the south. Both Hatcher's (1962) study and field observations from this study noted the Pleasanton to change significantly from brown, sandy facies, in the northern two-thirds of Linn County, Kansas, to darker grey, silty shale facies southward

Figure 28. Idealized model for deposition of the Bourbon flags. Shows development of Bourbon flags along transitional slope between shelf environment, where possible Bourbon flags correlative sediments are the lower Critzer as well as upper Pleasanton, and the basin, where depths were too great for limestone to form.



ENVIRONMENT OF DEPOSITION FOR THE BOURBON FLAGS

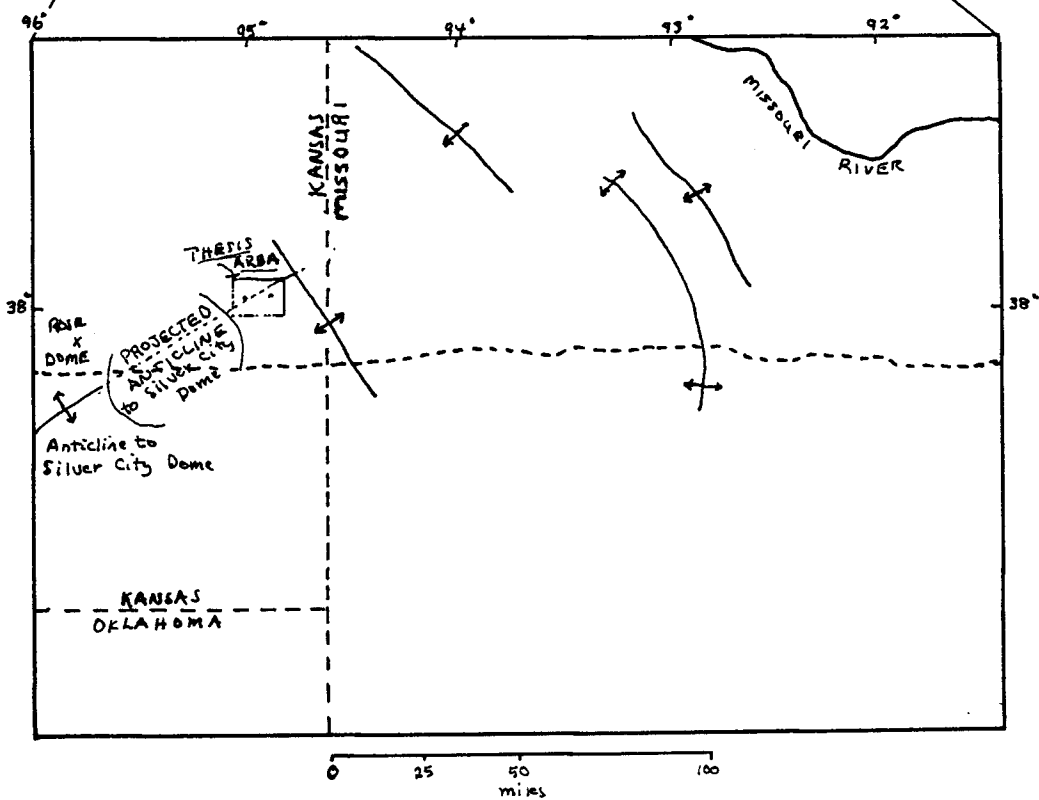
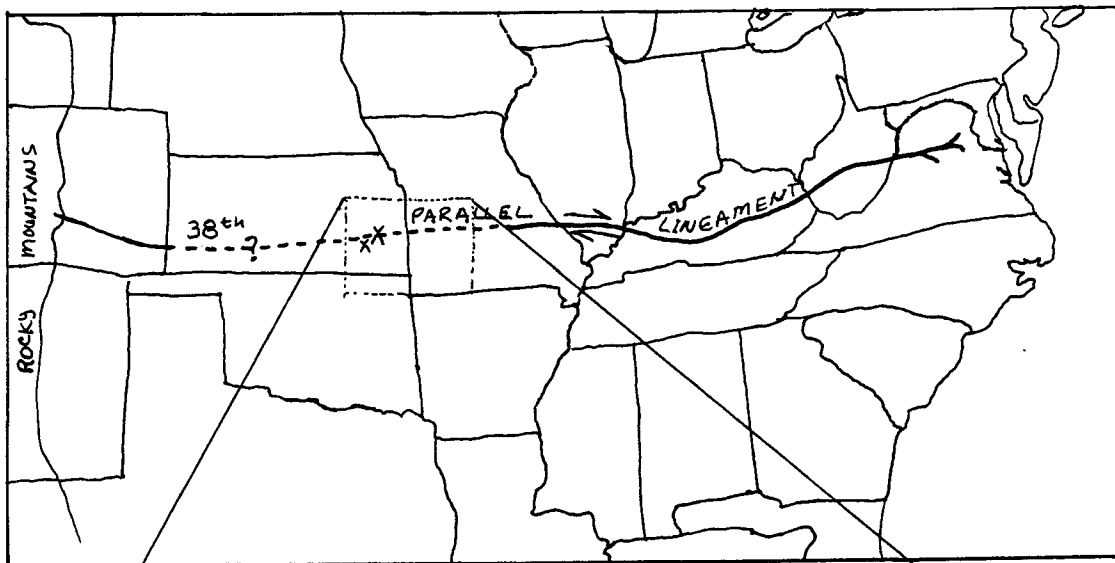
in Bourbon County. With a marine stillstand, it is possible for prodeltaic sediments to build out lobes or fronts into deeper, basinal regimes (Miall, 1979). The effective result would be to create shelf environments on top of the fronts, and transitional environments on the slopes of fronts. This kind of lateral depositional accretion may account for the lithofacies changes seen in the upper Pleasanton through Mound City units.

Evidence for possible structural development of the upper Pleasanton topography may be found in a structural feature known as the 38th parallel lineament, which is a well-developed zone of faults and structural features extending for more than 800 miles, roughly along the 38th parallel (Heyl, 1972). This structural zone is marked by nearly continuous segments of surface faults, intrusives, breccias, and by stratigraphic changes in sedimentary facies across the structural zone (Heyl, 1972). Most structural movement along the feature is believed to have occurred during the Precambrian, with some movement occurring along different segments at different times since the Precambrian. Near-surface features can be seen from eastern Virginia to south-central Missouri, and structural features believed to be associated with the 38th parallel lineament can be seen in eastern Kansas in the occurrence of the Rose dome and the Silver City dome (Heyl, 1972), (figure 29). Both Kansas

features are associated with mid-Cretaceous radiogenically dated intrusives. Nevertheless the Silver City dome has an associated anticline, which, if extended in its N 60 E trend, would intersect the thesis area along roughly the same trend as the observed facies zonations. It is possible, given the coincidence of the 38th parallel running through the thesis area, that the upper Pleasanton topographic surface, and subsequent sedimentation, could have been structurally influenced. Since there is little field evidence to support this possibility, however, the depositional topography of the upper Pleasanton seems better explained as originating from a depositional build up of sediments, as described in the previous paragraph.

Differential compaction that occurred in the different sediment types of the northwestern and southeastern lithofacies zones may have contributed to the topography of the Pleasanton surface prior to Bourbon flags deposition. According to Rieke and Chilingarian (1974), differential compaction has been observed where facies change from sandy to shaley. The sands, which were deposited with a lower initial porosity than the shales, compact less and therefore remain thicker upon compaction. With the upper Pleasanton showing facies fining to the southeast, it is possible for differential compaction to account for some of the bottom topography inferred to have existed. It is doubtful,

Figure 29. Map delineating the 38th parallel structural lineament. Shows also trend of Silver City anticline feature, which, if extended (hatched line) would intersect thesis area (shaded). This possibility remains speculative, as there is little support from field evidence. Modified from Heyl, 1972.



however, that differential compaction alone could have accounted for the transitional slope on which the Bourbon flags were deposited. Hatcher (1962) determined the entire Pleasanton at several outcrops in central Linn County to be about 100 feet thick, of which most (more than 60%) of the net thickness is not sandy. Furthermore, the southeastern lithofacies zone exhibits fairly uniform shales little different from those present with the sands to the northwest. There does not, therefore, appear to be enough sandy sediments in the northwest lithofacies zone, nor enough purer shales in the southeast lithofacies zone to create two distinct compactional regimes, as may be deduced from the observed stratigraphy.

#### Source of Terrigenous Muds

The similarity between the Pleasanton shales and the shales of the Bourbon flags suggests a common genesis. Howe (1982) considered the Pleasanton in Missouri to be a sequence of deltaic and prodeltaic sandstones and shales. Hatcher (1962) recognized facies zonations in the Pleasanton similar to those found in this study, and interpreted the Pleasanton of Linn and Bourbon counties to be deltaic in origin. The lines of evidence presented here suggest that the shales of the Bourbon flags also are deltaic in origin, specifically prodeltaic or distal facies of the Pleasanton

deltaic episode. As they are somewhat coarser grained than the intercalated carbonate muds, the silty shales of the Bourbon flags must represent the event mode of sedimentation.

The cyclicity of the shale deposition may be the result of periodic shifting of minor prodelta lobe or washouts of suspended mud during periodic floods.

#### Source of Carbonate Muds

The source of carbonate muds must have been either authigenic or allochthonous. Either source represents the normal or background mode of sedimentation. Both possibilities will be discussed.

If the carbonate muds were authigenic, then the organisms that formed them left no visible trace of their identity. They must have been able to inhabit the muddy substrate left by events of shaley deposition, and also must have been able to withstand the remaining high turbidity, since even the carbonates of the Bourbon flags appear to contain considerable terrigenous detrital influx. The shale layers may represent events in which terrigenous detrital influx simply overwhelmed carbonate production. The progressive reduction in thickness of carbonates toward the southeast, then, would suggest that conditions became increasingly adverse toward the southeast, possibly as a result of greater water depth.

If the carbonate muds were allochthonous, then there must have been a nearby carbonate regime that was periodically swept of its muds, which were then transported and deposited over the narrow range of the depositional environment. The very fine-grained carbonate muds may actually have been transported over some distance, existing as the winnowed fine-fraction of periodic events. Being very fine grained, the muds must have settled in a quiet water environment, below effective storm wave base. The dearth of fossilized hard parts within the Bourbon flags unit suggests that either there was too much turbidity in the environment to allow for the growth of organisms, or that bottom conditions were otherwise inhospitable for organic growth (discussed later). The progressive thinning of the carbonate layers away from the shelf would suggest that the muds settled very soon after reaching the quieter waters over the slope. The relatively high insoluble residue content in the carbonates suggests that there may have been a mixing of terrigenous detrital sediments with the carbonate muds, probably during transportation.

For all practical purposes, the carbonate muds of the Bourbon flags may have had a combination of authigenic and allochthonous origins. The likely source for the allochthonous muds may have been the Critzer or Critzer equivalent farther to the north or northwest. Then during

periods of relative quiescence of the deltaic terrigenous detrital source, nonskeletal carbonate-producing organisms (probably green algae like the modern Penicillus) may have invaded the depositional area to form authigenic muds.

The interbedded shaley layers, being coarser grained sediments, probably were transported into the depositional region during higher than normal energy events. Trace fossils and laminations found through some of the individual shale intervals suggests that a single event probably could not account for the whole shale thickness. Instead, shale deposition may have been the result of pulses of shaley sedimentation as a result of a shifting sediment source, such as the shifting of a minor prodelta lobe or several frequent flood events. The time lag of noncarbonate deposition may also represent the recovery time from a particularly devastating event that wiped out the carbonate-producing organisms (in the case of authigenic sedimentation).

#### Dearth of Fossils

The dearth of fossils in the Bourbon flags, may be either from hostile bottom conditions, or from high turbidity. In his model of carbonate facies within an anoxic basin, Byers (1977) predicts the formation of dark, organic rich mudstones without skeletal parts, yet with

abundant bioturbation in dysoxic (low oxygen) bottom conditions. Rhoads and Morse (1971) found the modern pycnocline that caused dysoxic bottom conditions in the Gulf of California to be between 50 and 150 meters in depth. The limestones of the Bourbon flags may, then, have formed in dysoxic bottom conditions in deeper water. It is possible also that dysoxic bottom conditions may have been the result of the slow upwelling of deeper, low-oxygen water into the environment of deposition. The presence of a sill along a stagnant basin could have forced deeper, low-oxygen waters upward, thereby effectively raising the pycnocline (Byers, 1977). An advancing or prograding Pleasanton prodeltaic lobe could have formed an effective sill to create this upwelling, as well as the slope environment of deposition. Greater bioturbation in the upper Bourbon flags, and the appearance of phylloid algal blades in the lower Critzer suggests that bottom oxygen content increased upward during Bourbon flags deposition, and became noticeably increased during Critzer deposition.

The lack of fossils may also been a result of excessive turbidity. The presence of insoluble residues from 22% to 48% bulk weight in the Bourbon flags, suggests that steady influx of terrigenous detritus may have plagued the area throughout deposition of the unit. This would have effectively prevented the development of the hard-shelled

organisms that are filter-feeders, or photosynthetic carbonate-producing organisms. The most common fossil found in the unit is the brachiopod Crurithyris, considered to be an opportunist dweller, or a "first comer" to a stress environment (Malinky, 1984). It appears that the conditions were never stable enough for a more complex community to get started.

Depositional Mode With  
Respect to Cyclothem Model

According to Heckel (1984), formation of flaggy carbonates would be expected to occur in water close enough to a terrigenous detrital source for periodic influx to occur, yet shallow enough for carbonate production or accumulation to occur during episodes of terrigenous detrital cessation. This model of formation of flaggy limestones would apply primarily to the accumulation of authigenic muds. If there were an allocthonous source for carbonate muds, on the other hand, periods of terrigenous detrital influx would be broken by periods of influx of carbonate muds, or vice versa. The influx of allocthonous carbonate muds suggests a nearby source for the muds, and an accompanying development in current or wave climate to transport the carbonate sediments into the region. The overall finer texture of the limestones suggests that they are background-mode sediments occurring during more normal depositional events. The coarser-grained shaley sediments,

on the other hand, suggest an event-mode of deposition occurring during higher-energy depositional events, such as flood or storm events. The general reduction in terrigenous shaley sediment found with Bourbon flags deposition implies that there must have been a minor marine transgression between the main part of Pleasanton shale deposition and Bourbon flags deposition. Conodont-rich horizons found below the Bourbon flags at HID and northwest of Prescott (outside the thesis area) suggest that the maximum transgression occurred before the Bourbon flags were deposited. The deposition of the Bourbon flags, therefore, may have been during a marine stillstand as aggregation of alternating sediment types on a transitional slope. Critzer deposition (as discussed later) may have been during the following minor regression.

#### Summary of Bourbon Flags Deposition

In order to view the deposition of the Bourbon flags in its proper perspective, it is necessary to discuss the Bourbon flags deposition with respect to eustatic changes in sea level, involved in Heckel's (1977; 1980) model for a basic Kansas cyclothem (figure 3). Since the upper Pleasanton Group and the Hertha Formation considered together were used to interpret the stratigraphy and depositional history of the Bourbon flags, these units will

also be viewed together with respect to Heckel's cyclothemic model (1977; 1980).

The Pleasanton displays delta plain deposits in north-central Missouri, and delta-front and prodelta deposits in west-central Missouri (Howe, 1982) not far from the thesis area in east-central Kansas. Deposition of the Bourbon flags on top of the Pleasanton suggests the development of a bottom topography that later developed shelf-to-basinal facies (figure 28). Since there are progressively more sandy facies upward in the Pleasanton sequence in the northern part of the studied area, it may be deduced that the Pleasanton delta was prograding south to southeastward. As discussed earlier the resulting topography on which the Bourbon flags was deposited was probably a lobe of an advancing prodelta front.

The initiation of Bourbon flags deposition probably occurred during a marine stillstand following a marine transgression. The transgression inhibited deltaic influx enough to allow accumulation of authigenic or allochthonous carbonate. The accumulated carbonated muds, in turn, were periodically buried by subdued pulses of prodeltaic muds. The alternation of deposition between terrigenous detrital sediments and carbonate sediments apparently happened at least 30 times. The pulses of shale that buried the intercalated carbonates were either the waning stages of the

Pleasanton prodeltaic advances, which probably occurred during flood events, or the periodic shifting of minor lobes on the delta. The Bourbon flags deposition apparently occurred in a hostile environment, that was either very turbid or dysoxic or both. Eventually the main delta lobe became completely abandoned and there was a return to clear, shallow, aerobic water conditions represented by the deposition of the algal and locally calcarenitic Critzer. This illustrates how the Bourbon flags and Critzer may be related to the same transgressive/regressive cycle.

Deposition of the Critzer  
Limestone and the Mound City  
Shale

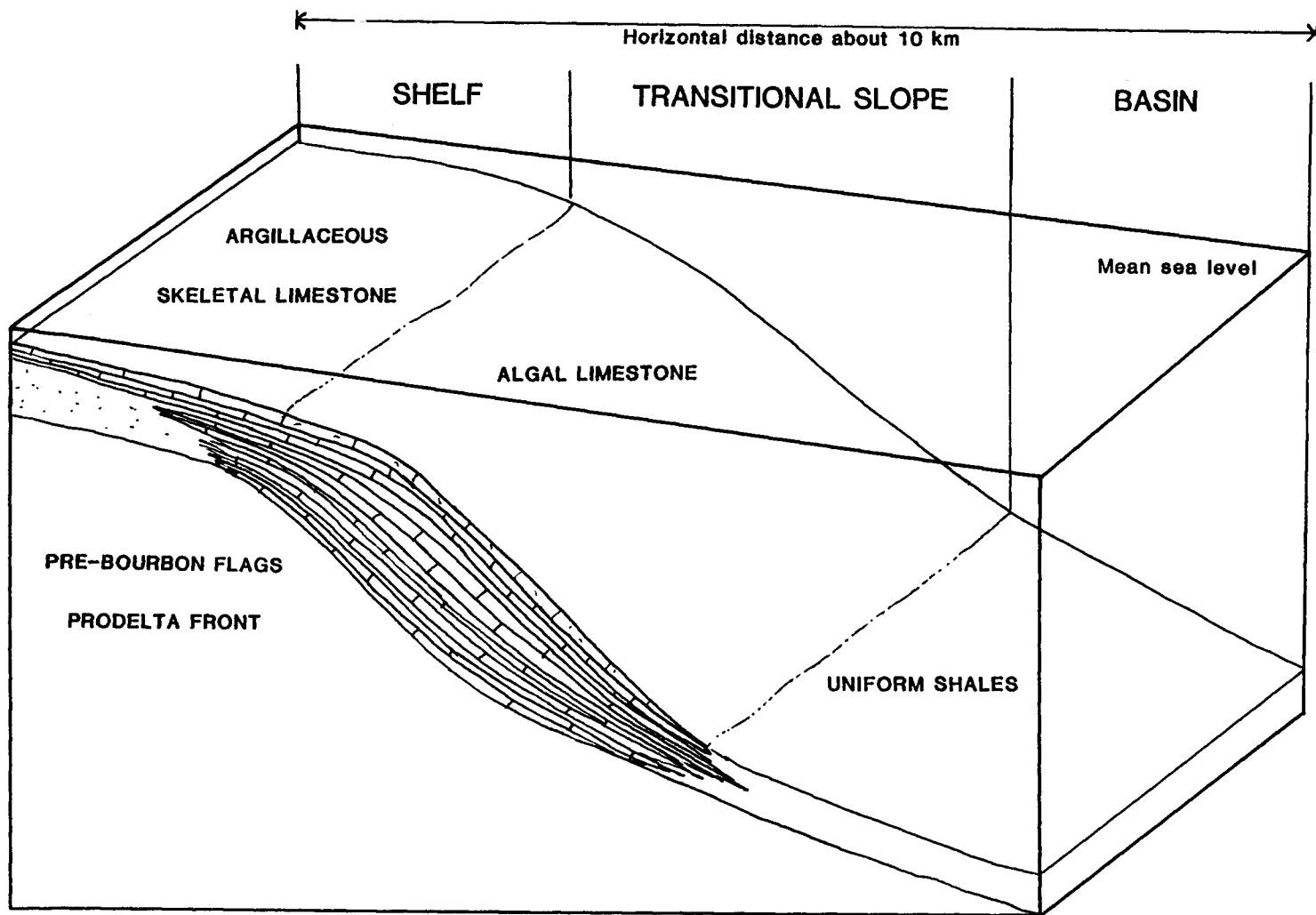
The Critzer, as discussed earlier, reflects the Pleasanton topography affecting Bourbon flags deposition. Furthermore, the two units are closely related and probably were part of the same depositional cycle. Compared to the Bourbon flags, the Critzer is less dense, lighter in color, and exhibits the shallow-water dasyclad green algae in the upper part of the unit (at HID). These features suggest formation during shallowing seas. The presence of dissolved and collapsed shell material with later void-filling in the northwestern facies suggests that sea-level had regressed to the point of exposure to meteoric waters. The Critzer over HID, however, appears to have been compacted before exposure

to meteoric waters. It is the opinion of the author that the Critzer mainly was deposited during the regressive part of a cycle (figure 30), but the sediments over the Bourbon flags area did not receive as much (if any) exposure to meteoric waters as did the Critzer over the northwest zone.

The Mound City Shale continued the dual facies development, with a thin (2-meter) facies over the shelf in the northwestern lithofacies zone, and a dramatically thickening facies over the slope and into the basin in the southeastern lithofacies zone (figure 31). In view of the thickening Mound City and the trend of regression postulated for Critzer deposition, it would seem that regression continued into lower Mound City deposition, with an influx of terrigenous detrital sediments into the area as a major delta lobe shifted back into the area.

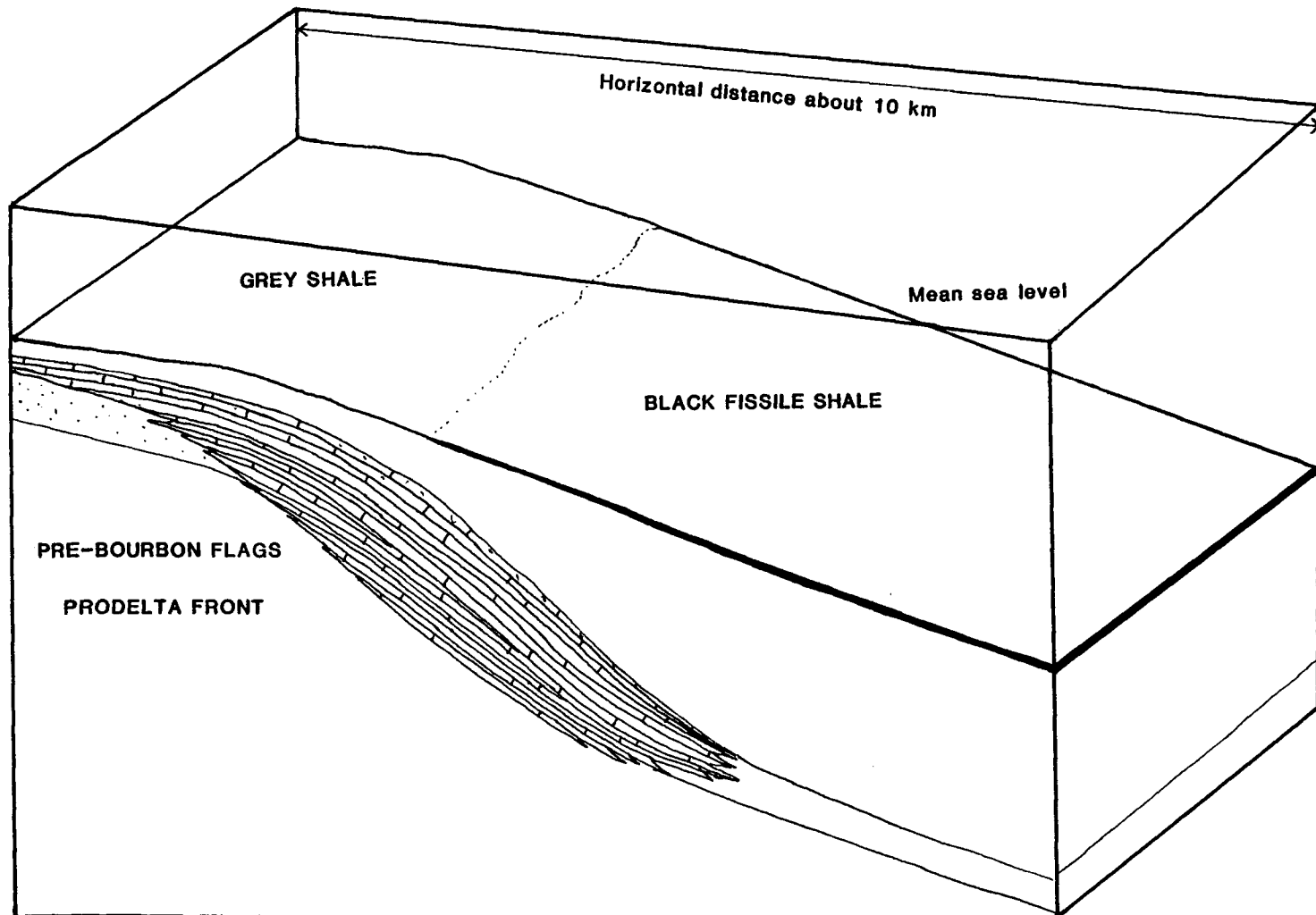
The sudden appearance within the Mound City of a conodont-rich shale over the whole study area with a black fissile facies confined to the slope and basin to the southeast, strongly suggests that a rapid transgression occurred and caused sediment starvation for a while allowing conodonts to accumulate without sediment dilution. This shale, with the deep-water conodont, Condolella (Heckel and Baesemann, 1975), and the deep-water gastropod Trepostira (Boardman, et al, 1984), would appear to be the maximum transgressive lithofacies. The rubbly crinoidal limestone

Figure 30. Idealized model for deposition of Critzer limestone. Sea level is lowered from Bourbon flags deposition, suggesting deposition during regression.



ENVIRONMENT OF DEPOSITION FOR THE CRITZER LIMESTONE

Figure 31. Idealized model for deposition of Mound City Shale. Shows time when black fissile and grey conodont-rich shales were deposited during maximum transgression. Notice that thickening of lower Mound City sediments had effect of partly filling the basin, but left enough topography that black facies still formed in lower area to southeast.



ENVIRONMENT OF DEPOSITION FOR THE MOUND CITY SHALE

above both the black and grey facies of the conodont-rich shale probably represents the return to hospitable bottom conditions for invertebrate (though not algal) growth. Another pulse of shale deposition, probably from the east, interrupted this carbonate deposition before development of the Sniabar Limestone, which is the final regressive limestone of the Mound City transgression.

Later Mound City deposition over the southeastern lithofacies zone may be thought of as a basin fill (figures 27 and 31). The topography established during Pleasanton deposition, and built upon during Bourbon flags and Critzer deposition, was, in effect, blanketed and filled such that the deposition of the Sniabar did not register any obvious lithofacies changes in this study area. According to Heckel (pers. commun., 1984), the Sniabar farther to the south of the study area may exhibit similar facies trends seen in the Critzer of this study, as the basin-filling Mound City Shale thins southward into the thinner Tackett black shale sequence in southeasternmost Kansas.

## SUMMARY AND CONCLUSIONS

The enigmatic Bourbon flags are a sequence of up to 10.5 meters of alternating argillaceous limestone and silty shale cropping out in a belt 4-7 km wide, northeastward from northwestern Bourbon County into south-central Linn County; they appear to extend as less shaley limestones 40 km into southeastern Linn County. Petrographically they appear to be gradational between the predominantly shaley deposits of the underlying Pleasanton, and the purer limestone of the overlying Critzer. The Bourbon flags consist of highly compacted, argillaceous, carbonate mudstone with interbedded silty, micaceous shales, and seem to represent transitional submarine slope deposits during a marine stillstand on a delta or prodelta lobe of the Pleasanton in the process of abandonment. The limestone layers appear to represent background sedimentation forming either as authigenically precipitated carbonate muds from unpreserved organisms, or from allochthonous aggregation of both transported carbonate and terrigenous detrital muds. The shale intervals, then, represent the event-mode of sedimentation, as they are coarser and more purely terrigenous detrital. The dark-grey color and dearth of fossil shells suggests that deposition

occurred both in slightly deeper, dysoxic waters, and under turbid conditions. Diagenetically, the Bourbon flags appear to have been buried prior to any cementation.

Even though having only a narrow range of known geographic distribution, the unit expresses rather significant stratigraphic changes that facilitate the understanding of the complex stratigraphy of the upper Pleasanton-Hertha interval of east-central and southeastern Kansas. The apparent southeastward disappearance of the Bourbon flags and associated Critzer limestone in conjunction with the thickening of the overlying Mound City Shale suggests that shales of the Mound City lie indistinguishably upon similar shales of the Pleasanton in much of Bourbon County. This accounts for the apparent inability of Ravn (1981) to find the typical Mound City conodont-rich horizon in the limestone with thin shales that lie above some previously mapped Pleasanton intervals, because this limestone is entirely the overlying Sniabar Member. The Mound City conodont-rich horizon is 6 or more meters below this limestone-shale contact in the black shale considered to have been lower in the Pleasanton by both Hatcher (1962) and Ravn (1981).

There remains a need to straighten out the stratigraphic nomenclature in the area. By present definition, the Bourbon flags unit is placed in the

Pleasanton Group separate from the Critzer, which is part of the Hertha Formation. The Tacket, a formation in the Pleasanton Group of southern Bourbon County, exhibits at least two conodont-rich horizons, the upper of which contains a conodont fauna resembling that of the Mound City (Heckel, personal communication from J. Pavlicek, 1984). Thus, the Mound City appears to merge into the upper Pleasanton (Tacket) from northcentral Bourbon County (LORB) southward. A similar problem exists in regard to the Bourbon flags and Critzer units as members of separate formations. It is the recommendation of this study that the Bourbon flags and the Critzer be considered members of the same formational unit, on the basis of their close petrographic and stratigraphic relationships. Possible nomenclatural changes shall be left for future studies.

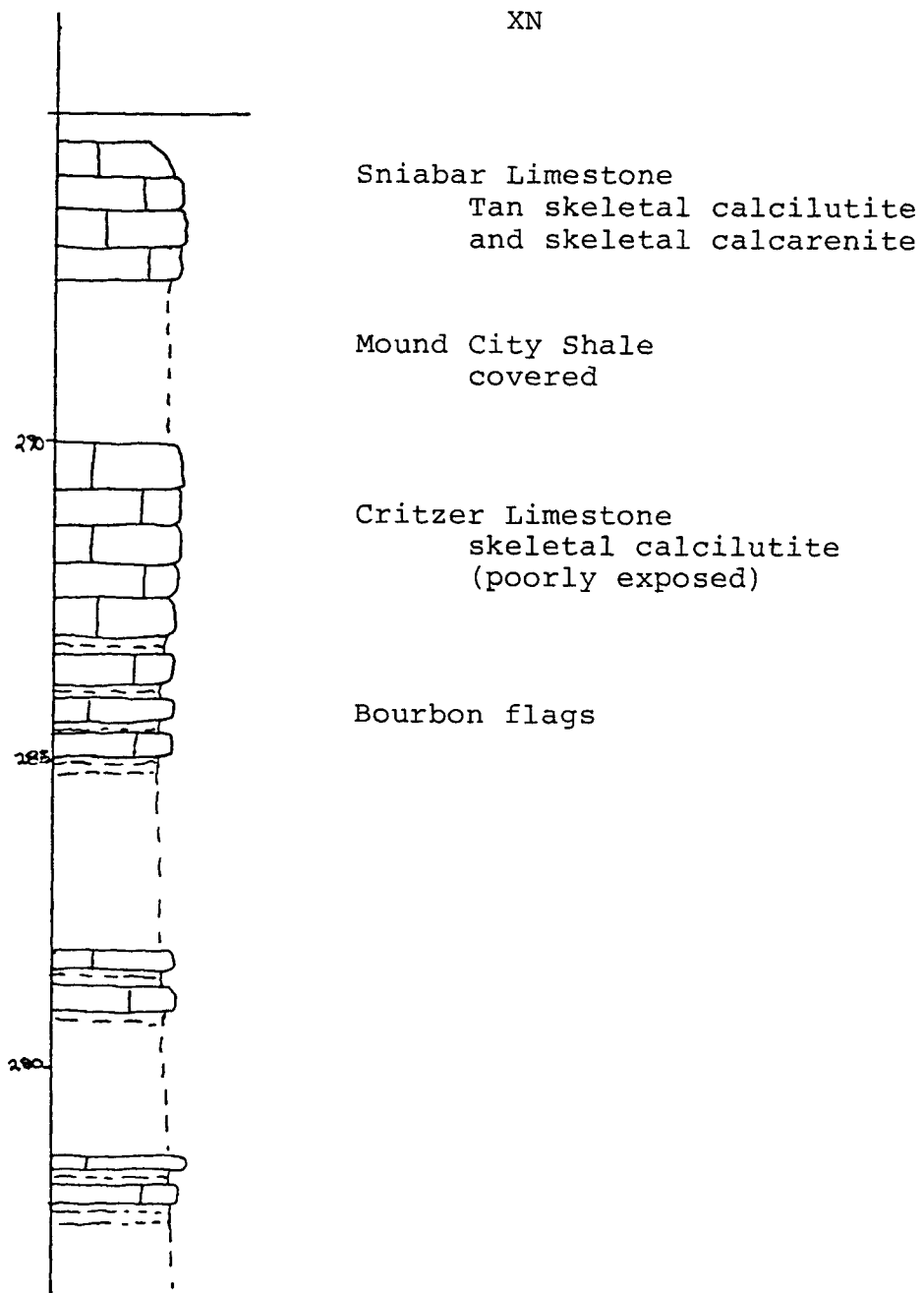
APPENDIX 1

## INSOLUBLE RESIDUE ANALYSIS

Section	Unit	Location	Sample Wt.	Insol. Wt.	Insol. Pct.	Insoluble Description
NWX	Critz.	top	32.0 gm	1.5 gm	4.3 %	clays
NWX	Critz.	1.4 m	32.5	4.7	14.5	clays
NWX	Critz.	0.7	29.0	5.2	17.9	clays
NWX	Critz.	0.6	30.0	7.1	23.7	clays, f.silt
NWX	Critz.	base	22.5	17.5	77.9	clays, f.silt
NWX	Plton.	upr lens	32.5	22.5	66.9	clays, silt
HID	Critz.	top	30.5	2.4	7.9	clays
HID	Critz.	mid	26.5	1.2	4.5	clays
HID	Critz.	base	28.5	8.7	30.5	clays, f.silt
HID	Bb flgs	top flag	30.0	11.0	36.7	clays, f.silt
HID	Bb flgs	upr mid	34.0	7.7	22.7	clays, f.silt
HID	Bb flgs	mid	28.5	9.5	33.3	clays, f.silt
HID	Bb flgs	lwr mid	30.0	14.5	48.5	clays, silt
HID	Plton.	lwst exp	21.0	19.5	92.8	silt, clays
NWP	Bb flgs	upr mid	25.5	2.7	10.6	clays

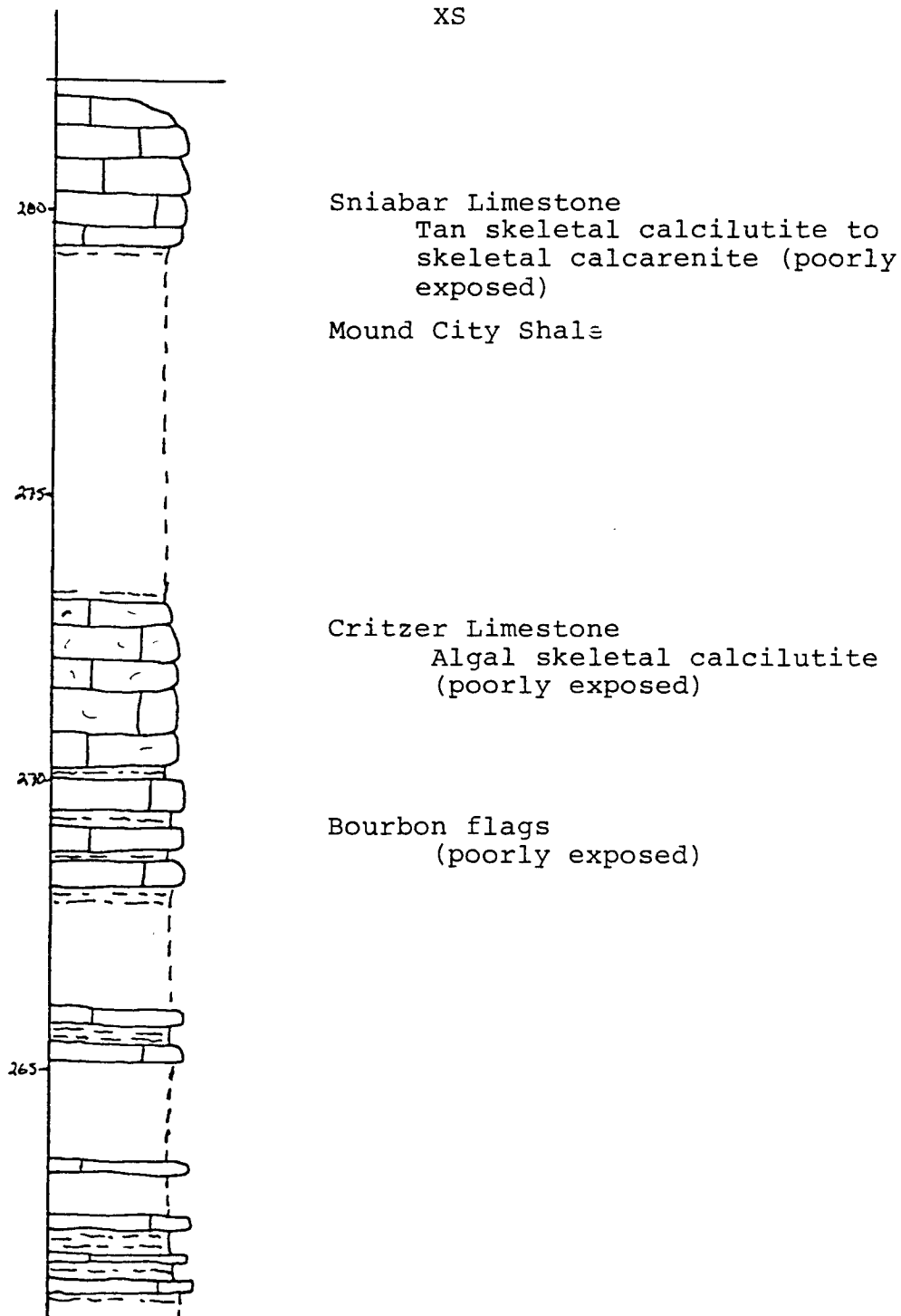
Solution: 1 part formic acid concentrate to 5 part water (1:5).

Approximately 30 grams of sample in 300 ml solution.

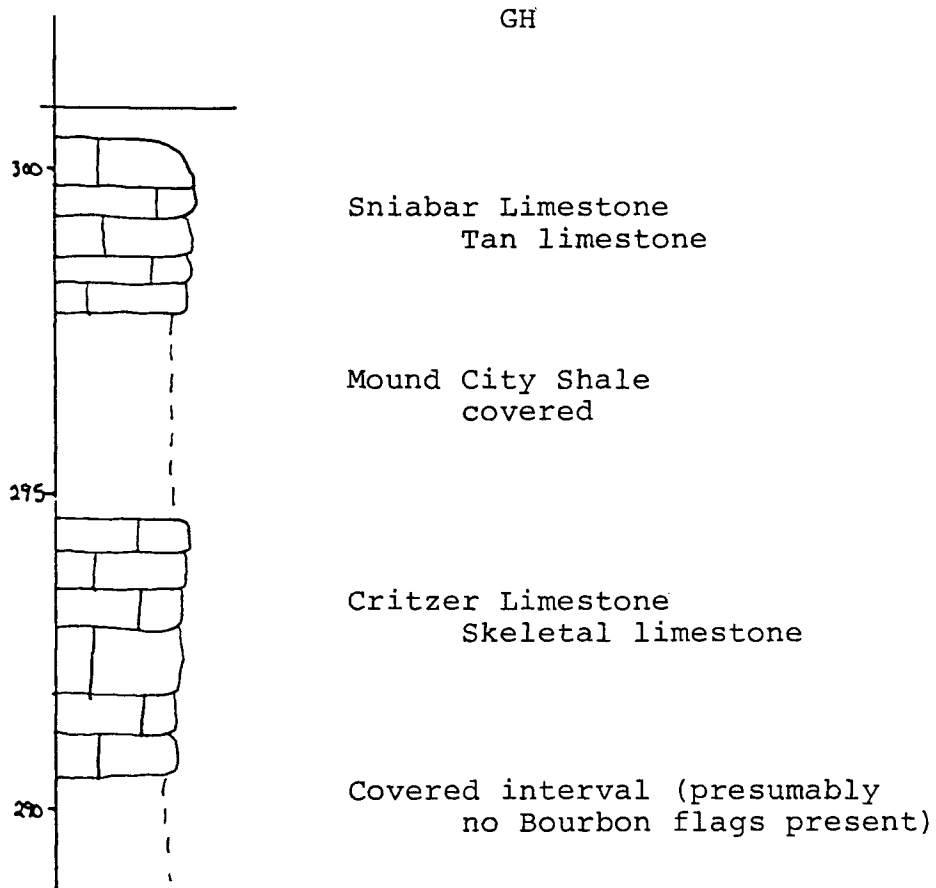


Locality XN: SW 1/4, SW 1/4, Section 27, T 23 S, R 22 E,  
Bourbon County, Kansas. Roadcut and gulley on east  
side of road, 2 km north of Xenia.

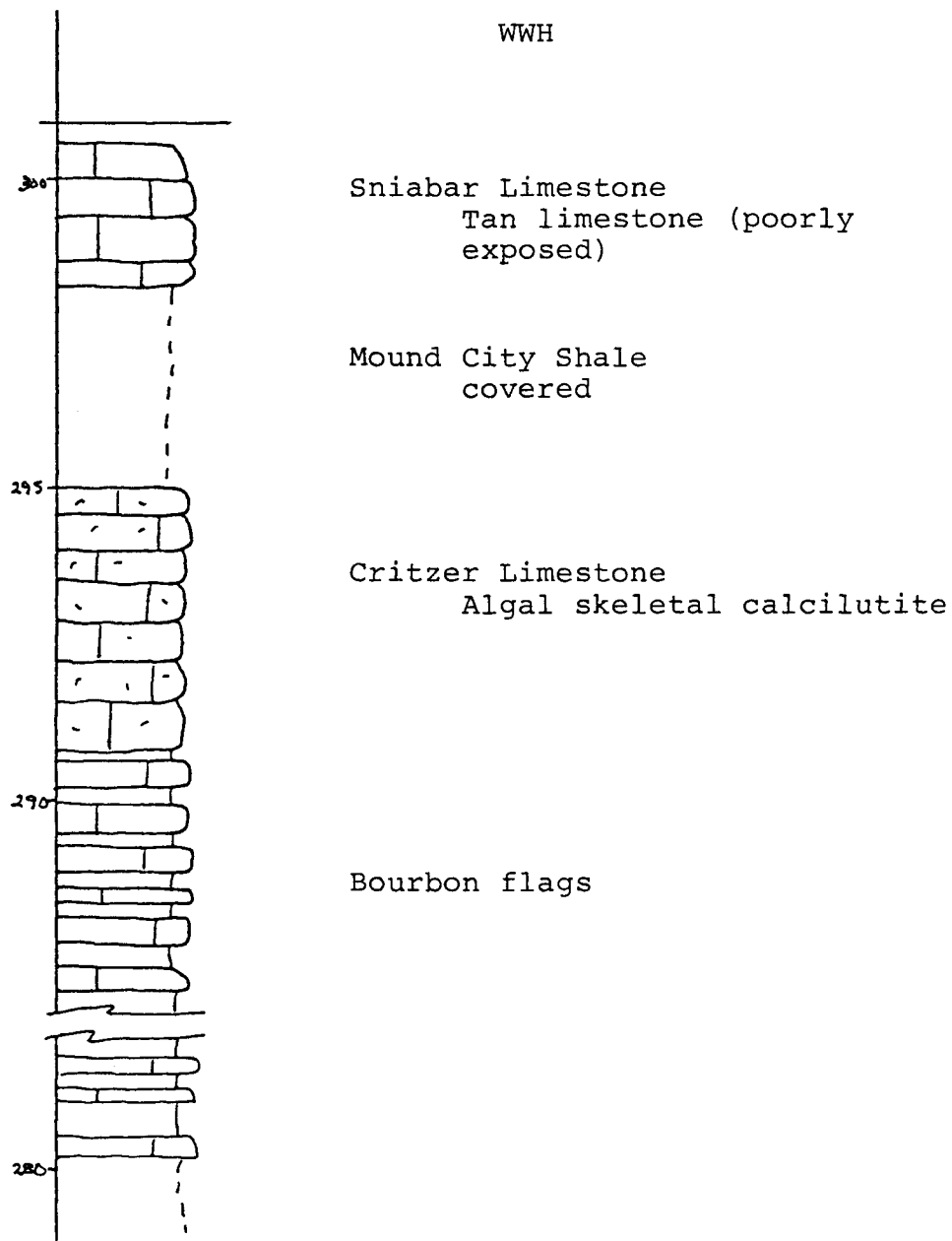
XS



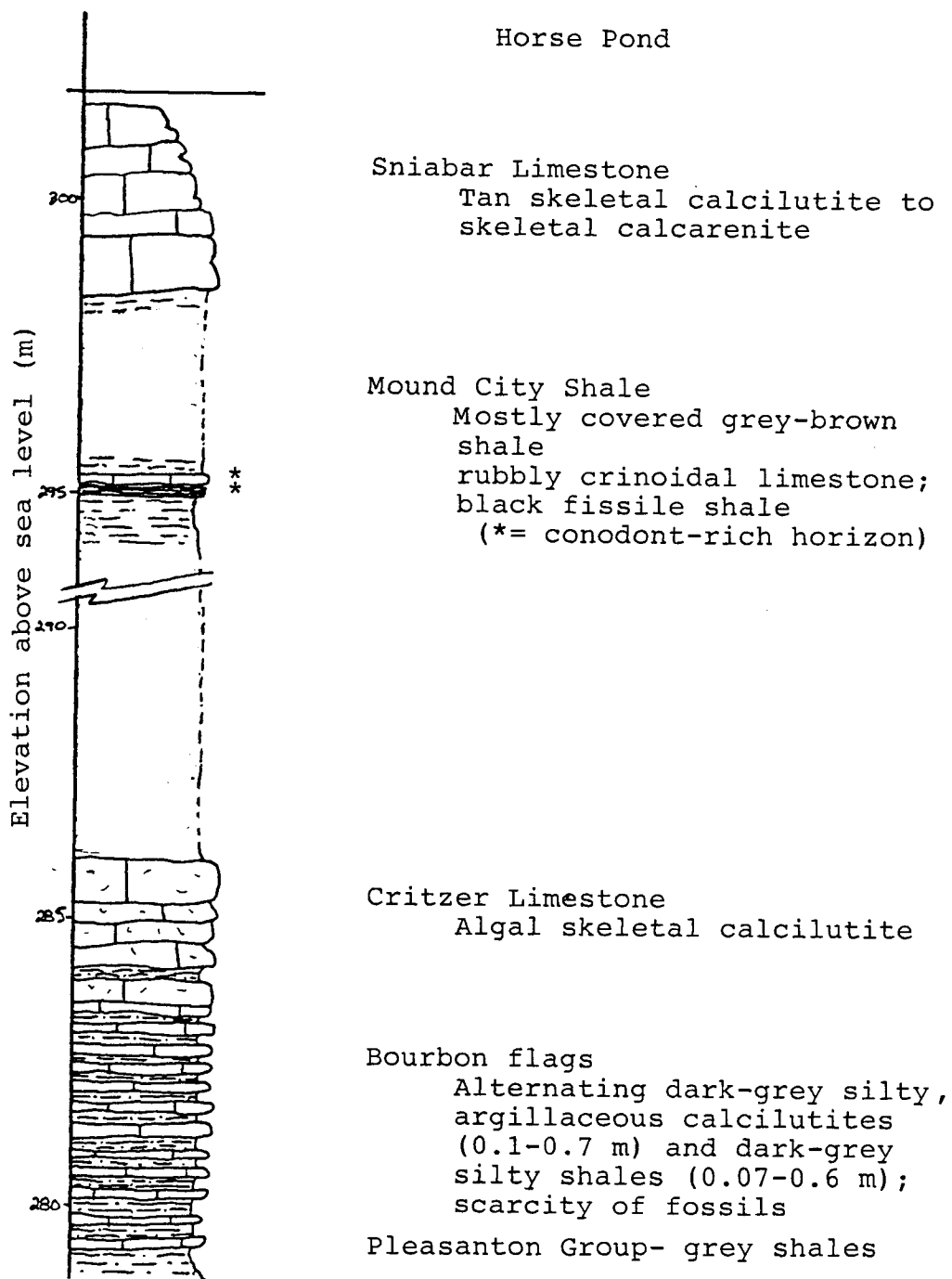
Locality XS: SE 1/4, SE 1/4, Section 4, T 24 S, R 22 E,  
Bourbon County, Kansas. Long roadcut 1.5 km south of  
Xenia.



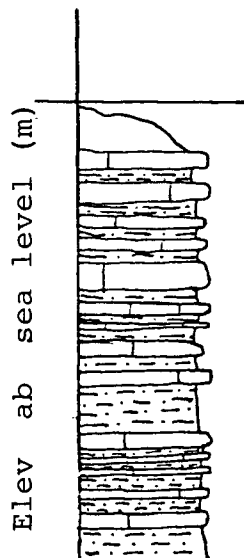
Locality GH: SE 1/4, SE 1/4, Section 17, T 23 S, R 22 E,  
Bourbon County, Kansas. Overgrown roadcut 5.5 km  
northeast of Xenia.



Locality WWH: NE 1/4, SE 1/4, Section 27, T 23 S, R 22 E  
Bourbon County, Kansas. Roadcut of abandoned road 2.5  
km northeast of Xenia.



Locality HP: NE 1/4, NE 1/4, Section 11, T 24 S, R 22 E, Bourbon County, Kansas. Pond excavation (for horses) and overgrown natural exposure to west.



### Mapleton North

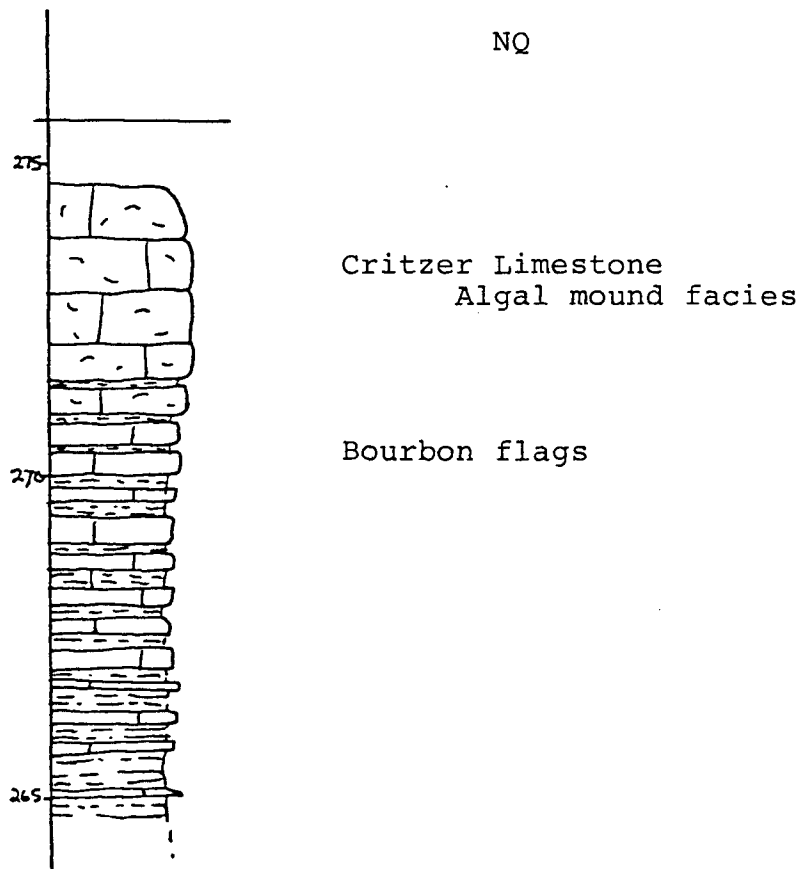
#### Critzer Limestone

Poorly expose algal calcilutite

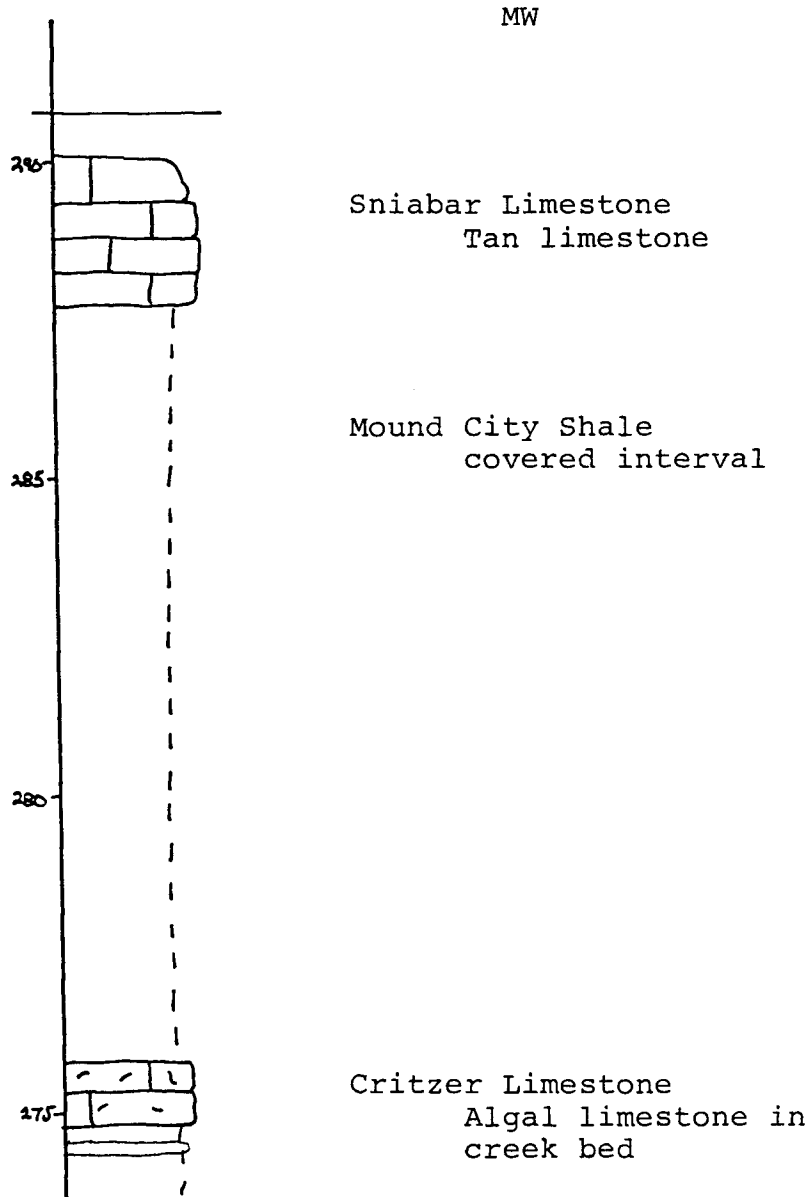
#### Bourbon flags

Alternating shales and flagstone  
limestones; scarcity of fossils

Locality MN: SW 1/4, NE 1/4, Section 17, T 23 S, R 23 E,  
Linn County, Kansas. Roadcut on east side of road,  
3.5 km north of Mapleton.



Locality NQ: SE 1/4, SW 1/4, Section 36, T 23 S, R 22 E  
Bourbon County, Kansas. Abandoned Northway Quarry,  
4 km east of Xenia.



Locality MW: SE 1/4, SW 1/4, Section 30, T 23 S, R 23 E,  
Bourbon County, Kansas. Hillside roadcut and creek  
bed 2.5-3 km west of Mapleton.

## REFERENCES CITED

- Bennison, A. P., 1983 Shelf to trough correlations of late Desmoinesian and early Missourian carbonate banks and related strata, northeast Oklahoma, p. 1-57.
- Boardman, D. R. II, Mapes, R. H., Yancey, T. E., Malinky, J. M., 1984. A new model for the depth-related allogenic community succession within North American Pennsylvanian cyclothems and implications on the black shale problem: in Hynes, N. J. (editor), Limestones of the Mid-Continent, Tulsa Geol. Soc. Spec. Publ. No. 2, p. 141-182.
- Byers, C. W., 1977. Biofacies patterns in euxinic basins: a general model; in Enos, P. E. and Cook, H. E., Deep-Water Carbonate Environments, p. 5-18.
- Hatcher, D. A., 1962. Stratigraphy of the Pleasanton Group in Miami, Linn, and Bourbon Counties, Kansas: M. S. Thesis, West Texas State College, 65 pp.
- Heckel, P. H., 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothems of Mid-Continent North America: Am. Assoc. Petrol. Geol. Bull., v. 61, pp. 1045-1068.
- Heckel, P. H., 1978. Field guide to Upper Pennsylvanian cyclothem limestone facies in eastern Kansas: Kansas Geol. Surv. Guidebook Ser. 2, 79 pp.
- Heckel, P. H., 1980. Paleogeography of eustatic model for deposition of Midcontinent Upper Pennsylvanian cyclothems, Rocky Mtn. sec. SEPM Paleozoic Paleogeography of west-central United States Paleogeography Symposium 1, p. 197-215.
- Heckel, P. H., 1983. Diagenetic model for carbonate rocks in Midcontinent Pennsylvanian eustatic cyclothems: Journ. Sed. Petrol., v. 53, pp. 733-759.
- Heckel, P. H., 1984. Factors in Mid-Continent Pennsylvanian limestone deposition: in Hyne, N. J. (editor), Limestones of the Mid-Continent, Tulsa Geol. Soc. Spec. Publ. No. 2, p. 25-50.

- Heyl, A. V., 1972. The 38th parallel lineament and its relationship to ore deposits: *Econ. Geol.*, v. 67, p. 879-894.
- Howe, W. B., 1982. Stratigraphy of the Pleasanton Group, Pennsylvanian System in Missouri (preliminary draft version): Open file report series-Missouri Dept. of Nat. Resour., Geol. and Land Sur. Div., 84+ pp.
- Jewett, J. M., Emery, P. A., and Hatcher, D. A., 1965. The Pleasanton Group (Upper Pennsylvanian) in Kansas: *Kansas Geol. Sur. Bull.*, v. 64, p. 461-487.
- Longman, M. W., 1980. Carbonate diagenetic environments: *Am. Assoc. Petrol. Geol. Bull.*, v. 64, p. 461-487.
- Malinky, J. M., 1984. Paleontology and paleoenvironment of "core" shales (Middle and Upper Pennsylvanian) Mid-Continent North America: Ph. D. Dissertation, University of Iowa, 322 p.
- Miall, A. D., 1979. Facies model No. 5-Deltas; in *Geoscience Canada, Reprint Series 1, Facies Models*, ed. Walker, R. G., p. 43-56.
- Miller, D. E., 1966. Geology and ground-water resources of Miami County, Kansas: *State Geol. Surv. of Kansas, Bull.* 181, 66 pp.
- Miller, D. E., 1969. Geology and ground-water resources of Allen County, Kansas: *State Geol. Surv. of Kansas, Bull.* 195, 50 pp.
- Moore, R. C., 1936. Stratigraphic classification of the Pennsylvanian rocks of Kansas: *Kansas Geol. Sur. Bull.* 22, 256 pp.
- Moore, R. C., 1949. Divisions of the Pennsylvanian system in Kansas: *State Geol. Sur. of Kans., Bull.* 83, p. 66-74.
- Ravn, R. L., 1981. Stratigraphy, petrography, and depositional history of the Hertha Formation (Upper Pennsylvanian), Midcontinent North America: Ph. D. Dissertation, University of Iowa, 284 pp.
- Rhoads, D. C. and Morse, J. W., 1971. Evolutionary and ecologic significance of oxygen-deficient marine basins, *Lethia*, v. 4, p. 413-428.

- Rieke, H. H. III, and Chillingarian, G. V., 1974.  
Compaction of argillaceous sediments, v. 16 of  
Developments In Sedimentology, Elsevier Publ., p. 1-122.
- Seevers, W. J., 1969. Geology and ground-water resources of  
Linn County, Kansas: State Geol. Sur. of Kans., Bull.  
193, p. 12-13.
- Swade, J. W., 1982. Conodont distribution, paleoecology,  
and preliminary biostratigraphy of the Upper Cherokee and  
Marmaton Groups (Upper Desmoinesian, Middle  
Pennsylvanian) from two cores in south-central Iowa: M.  
S. Thesis, University of Iowa, 127 pp.
- Zeller, D. E., 1968. The stratigraphic succession in  
Kansas: State Geol. Sur. of Kans., Bull. 189, p. 27-28.